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EDITED BY PAMELA BUXTON

METRIC HANDBOOK

PLANNING AND DESIGN DATA

FIFTH EDITION

ROUTLEDGE

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METRIC HANDBOOK

- Significantly updated in reference to the latest construction standards and evolving building types
- Many chapters revised including housing, transport, offices, libraries and hotels
- New chapter on flood-aware design
- Sustainable design integrated into chapters throughout
- Over 100,000 copies sold to successive generations of architects and designers – this book belongs in every design studio and architecture school library

The *Metric Handbook* is the major handbook of planning and design information for architects and architecture students. Covering basic design data for all the major building types, it is the ideal starting point for any project. For each building type, the book gives the basic design requirements and all the principal dimensional data, and succinct guidance on how to use the information and what regulations the designer needs to be aware of.

As well as building types, the *Metric Handbook* deals with specific aspects of design such as materials, acoustics and lighting, and general design data on human dimensions and space requirements. The *Metric Handbook* provides an invaluable resource for solving everyday design and planning problems.

Pamela Buxton is a freelance architecture and design journalist. She has contributed to many national newspapers, consumer magazines and trade publications, including the architecture publications *Building Design* and *RIBA Journal.*

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METRIC HANDBOOK

Planning and Design Data

Fifth Edition

Edited by Pamela Buxton

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

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Contents

Preface
Acknowledgements

DESIGN BASICS

1 **Design information and dimensional coordination**
Terry Nichols with David King

2 **People and space**
Updated by Professor Norman Wienand

3 **People and movement**
Updated by Professor Norman Wienand

4 **Access and inclusion**
Neil Smith and David Dropkin

5 **Capital and whole life costs of buildings**
David Holmes, Chris Bicknell and John Davies

ESSENTIALS

6 **Structure**
David Adler and Norman Seward
Revised by Andrew Peters

7 **Materials**
Arthur Lyons with AHR Architects

8 **Thermal environment**
Phil Jones

9 **Light**
Joe Lynes

10 **Sound**
Chris Steel

11 **Fire**
Beryl Menzies

12 **Flood-aware design**
Robert Barker and Richard Coutts

13 **Crime prevention design**
Nick Hughes

BUILDING TYPES

14 **Agricultural buildings**
John Weller, Rod Sheard, Frank Bradbeer and others

15 **Auditoria**
Ian Appleton and Stefanie Fischer

16 **Civic buildings**
Updated by David Selby (town halls) and
Martin Sutcliffe and Neil Sansum of BDP (law courts)

17 **Community centres**
Jim Tanner

18 **Emergency services**
Including Fire stations by Michael Bowman

19 **Hospitals**
David Clarke

20 **Hotels**
Fred Lawson

21 **Houses and flats**
John Chapman

22 **Homes for older people**
Ian Smith (updated by David Littlefield)

23 **Student housing and housing for young people**
Liz Pride

24 **Industrial facilities**
Jolyon Drury and Ian Brebner

25 **Industrial storage buildings**
Jolyon Drury, updated with advice from Stephen George & Partners

26 **Laboratories**
Catherine Nikolaou and Neville Surti

27 **Libraries**
Brian Edwards with Ayub Khan

28 **Masterplanning and landscaping**
David Simister with Guy Walters, with contributions by Sarah Burgess, Hugh Barton and Marcus Grant

29 **Museums, art galleries and temporary exhibition spaces**
Geoffrey Mathews

30 **Offices**
Frank Duffy with Jack Pringle, Angela Mullarkey and Richard Finnemore of Pringle Brandon Perkins+Will

31 **Payment and counselling offices**
Richard Napier

32 **Places of worship**
Leslie Fairweather, Ian Brewerton, Atba Al-Samarraie, David Adler and Derek Kemp. Revised by Maurice Walton

33 **Primary health care**
Geoffrey Purves

34 **Restaurants and foodservice facilities**
Fred Lawson

35 **Retail shops and stores**
Fred Lawson

36 **Schools**
Anthony Langan

37 **Security and counter-terrorism**
Mark Whyte and Chris Johnson

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38 Sports facilities: indoor and outdoor
Philip Johnson and Tom Jones

39 Streets and spaces for people and vehicles
Updated by Ben Hamilton-Baillie (introduction, shared space and place-making) and Sustrans (cycling routes and parking)

40 Studios for sound and vision
David Binns

41 Transport terminals and interchanges
Airports updated by Andrew Perez with additional contributions by Richard Chapman. Railways by Declan McCafferty

42 Tropical design
Patricia Tutt

43 Universities
Mike Hart and Rod McAllister

Appendix A – SI system

Appendix B – Conversion factors and tables

Index

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Preface

Welcome to the fifth edition of *Metric Handbook*. As well as updating and rewriting more than a quarter of the chapters, this latest edition has a new structure to enable the reader to navigate more easily through the volume. Chapters are grouped into design basics, universal themes and then building types, the latter arranged alphabetically. We hope this will provide a more reader-friendly way to access the vast array of information within this resource.

As society changes, building design must adapt to suit changing behaviours and needs. Nowhere is this more clear than in the design of the office, which has undergone a revolution since the development of computer technology and in particular wireless, mobile working. Our new Offices chapter, written by Frank Duffy with Pringle Brandon Perkins + Will, reflects these changes and gives architects the information they need to rise to the challenge of designing the new workplace.

We have also extensively updated chapters on other fast-evolving building types such as libraries, transport terminals, schools, housing and civic architecture, and also reflected changing attitudes to street design in our chapter on Streets and Spaces for People and Vehicles. Basic information on space requirements for people and movement through buildings has been extensively overhauled in Chapters 2 and 3 respectively, and the Materials section has been updated. But perhaps one of the most significant additions to this edition of *Metric Handbook* is the new chapter on Flood-aware Design, introduced in response to the increased risk of flooding as a result of climate change.

But while much of the content has changed, the ambition of the *Metric Handbook* remains the same. By bringing together best practice and regulatory requirements from sizes to volumes, materials to standards, this book gives readers a thorough grounding and an essential headstart when tackling a new building type.

Pamela Buxton
December 2014

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Acknowledgements

This fifth edition of Metric Handbook is greatly indebted to the time and efforts of its many contributors in updating and writing anew the large number of updated chapters within this new edition. Their generosity and expertise is much appreciated.

Thanks too are due to commissioning editors Fran Ford and Jennifer Schmidt at Routledge, and also to their editorial, design and production colleagues who all played such important roles in the Herculean task of updating such a substantial volume.

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1 Design information and dimensional coordination

Terry Nichols with David King

Terry Nichols, Director, ELE and David King, HOK London, Director for Project Delivery

KEY POINT:
- *For clear understanding the conventions must be followed*

Contents
1 Design information standards
2 Metric annotation
3 Drawings
4 Drawing content
5 Dimensional coordination
6 Reprographics and paper sizes
7 Ordnance survey maps
8 References
9 Case study

1 DESIGN INFORMATION STANDARDS

1.1 Production methods

Several methods for the production and sharing of project information are available to the AEC industry. Though some firms continue to use traditional manual drafting techniques, many have adopted 2D CAD systems and an increasing number have progressed onto 3D parametric object-based design systems and Building Information Modelling. Whichever of these methods is selected, the adoption of standards is important for clarity in communication between the members of the design team. This section summarises standards as they relate to visual output whether that be on paper or screen display.

1.2 Traditional drafting

In traditional drafting, paper is the main information exchange mechanism. Though individual drawing styles can be accommodated, it is only by the inclusion of standard drawing conventions and symbols that the content can be correctly interpreted.

1.3 2D CAD systems

2D CAD tools provide easier ways of editing and copying drawing content. Information sharing can be achieved by the transfer of drawing files and this has led to improved levels of collaboration between members of the design team. In some cases the data transfer is supported by web-based collaboration services. For this data exchange to be effective, standards have been introduced for file naming conventions, drawing layering structures. When different CAD systems are employed, translation processes are also needed to overcome any system incompatibilities.

The AEC (UK) CAD Standards Initiative was formed in 2000 to improve the process of design information production, management and data exchange. The initiative addressed CAD layering conventions as the primary concern for users of design data. As design needs and technology have developed, the scope has expanded to cover other aspects of design data production and information exchange. The AEC (UK) CAD Standard Basic Layer Code was released in 2001, with an Advanced Code released in 2002.

1.4 3D parametric object based systems

The introduction of 3D parametric object-based modelling systems offers further advantages in terms of the automatic co-ordination of 3D views, plans, sections, elevations and component schedules, the ability to carry out clash detection plus structural and environmental analysis.

1.5 BIM

Building Information Modelling (BIM) involves more than the adoption of a 2D CAD or 3D object based tool. It is founded on the development of a Common Data Environment for sharing information between the members of the design, manufacturing and construction teams. The technicalities involved are set out in BS 29481-1:2010 *Building information modelling. Information delivery manual – methodology and format.* Typically many different software applications will access and interrogate the common data set to generate information that is appropriate for a specific purpose. Ultimately the aim is for a fully integrated set of data incorporating 4D (construction timing) and 5D (costing) elements plus any other data necessary for the life-cycle management of the facility. These features are becoming increasingly important as a part of the drive for Integrated Project Delivery (IPD).

With the increased use of computer methods for electronic transfer and the combining of models from different members of the design team, the use of common standards is essential. For BIM much of the work on standards originated with organisations such as BuildingSmart who have developed and promoted the adoption of Industry Foundation Class (IFC). This open system is designed to enable interoperability between different proprietary systems. It is registered as the international standard ISO 16739.

The AEC (UK) BIM Standards build on the guidelines defined by world-wide standards initiatives, including BS1192:2007, the US National BIM Standard (NBIMS) and existing, proven internal company procedures. It is aimed at providing a base starting point for a unified BIM standard that can easily be adopted ‘as is’ or developed and adapted for implementation within projects that have specific requirements for the structuring of their BIM data. In 2011 the UK government published its Building Information Modelling (BIM) Working Party Strategy and announced the intention to require collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on its projects by 2016. The standard recommended for non-graphical information is COBie: Construction Operations Building information exchange. This was developed by a number of US public agencies to improve the handover process to building owner-operators. A growing number of software packages now support the import and export of data in this format.

2 METRIC ANNOTATION

2.1 Units

The main units should be used as shown in Table I.

Table I Summary of symbols and notation

Quantity	Description	Correct unit symbol	Acceptable alternatives	Incorrect use	Notes
Numerical values		0.1 0.01 0.001		.1 .01 .001	When the value is *less* than unity, the decimal point should be preceded by zero
Length	metre millimetre	m mm		m. M meter m.m. mm. MM M.M. milli-metre	
Area	square metre	m^2	sqm	m.sq sm sq.m sqm.	
Volume	cubic metre cubic millimetre litre (liquid volume)	m^3 mm^3 1, ltr	cu m cumm	cu.m m.cu cu.mm. mm.cub. mm.cu. l. lit	Preferably write *litre* in full to avoid 'l' being taken for figure 'one'
Mass (weight)	tonne kilogram gram	t kg g		ton Kg kG kg. kilogramme g. G.	Preferably write *tonne* in full to avoid being mistaken for imperial ton
Force	newton	N		N. n	Note that when used in written text, the unit of newton is spelled out in full and begins with a lower-case letter 'n'. When used as unit symbol, in calculation or in a formula it is then expressed as capital letter 'N'

On a drawing, either metres or millimetres should be used: these units should not be mixed. If this rule is followed, ambiguity is avoided – it is not possible to confuse which units are intended. Common practice is to use mm without a decimal, so 2 m is shown simply as 2000.

2.2 Decimal marker

The decimal marker (full stop) on the baseline is the standard decimal point in the UK; but the marker at the halfway position is also acceptable. It should be noted that Continental practice is to use the comma on the baseline. The appropriate number of decimal places should be chosen depending on the circumstances in which the resulting value is to be used.

2.3 Thousand marker

To avoid confusion with the Continental decimal marker, no thousand marker should be used. Where legibility needs to be improved a space can be left in large groups of digits at every thousand point. Where there are only four digits, a space between the first digit and the others is not desirable (e.g. 15000, 1500). (However, the comma is used in currency, e.g. £115,000.)

2.4 Notation

As a rule the sizes of components should be expressed in consistent and not mixed units, e.g. 1500 mm × 600 mm × 25 mm thick and not 1.5 m × 600 mm × 25 mm thick. However, for long thin components such as timbers, it is preferable to mix the units, e.g. 100 mm × 75 mm × 10 m long.

It is important to distinguish clearly between the metric tonne and the imperial ton. The tonne is equivalent to 2204.6 lb while the ton is equal to 2240 lb – a difference of 1.6 per cent.

The interval of temperature should be referred to as degree Celsius (°C) and not as centigrade. The word centigrade is used by the Continental metric countries as a measure of plane angle and equals 1/10000th part of a right angle.

Examples

Correct use	Incorrect use
33m	3cm 3mm
10.100m	10m 100mm*
50.750kg	50kg 750g

Note. Some metric values are expressed differently in certain countries. The value of 10.100m, for example, could mean ten thousand one hundred metres and not ten metres one hundred millimetres, as in the UK.

3 DRAWINGS

3.1 Information required

Table II indicates the typical drawings required during the design phases of a project. The work stage summary is taken from the RIBA Outline Plan of Work 2007 (amended November 2008). This organises the process of managing and designing projects into a number of key work stages. The sequence or content of these stages may vary and/or overlap dependent on the procurement method selected – and the RIBA Outline Plan of Work provides guidance on their applicability to the principal procurement routes.

3.2 Graphic techniques

Graphic techniques should follow the recommendations in BS EN ISO 9431, and in particular:

(a) line thickness should be not less than 0.25 mm on drawings to be reproduced without reduction, or to be microfilmed;
(b) if different line thicknesses are used, each thickness should be at least twice the next thinner line;
(c) the space between lines should be not less than 0.7 mm;
(d) inclined lines should be at an angle of 15 or a multiple of 15;
(e) lettering (including numbers) should have a capital height of:
  (1) not less than 2.5 mm for drawings as in (a) above;
  (2) not less than 3.5 mm for drawings as in (b) above.

While these guidelines originally refer to manual drafting the same principles should ensure clarity when applied to plotted output from 2D CAD and 3D modelling systems.

3.3 Drawing scales

The internationally agreed and recommended range of scales for use in the construction industry is given in Table III.

Where two or more scales are used on the same sheet, these should be clearly indicated.

3.4 Traditional types of drawings

Types of drawings at the most suitable scales are shown in Figures 1.1 to 1.7. Note that in Figures 1.5 and 1.6 alternative dimensional units are shown for comparison. The method of expressing dimensions as shown in the shaded drawings is not recommended. 2D CAD systems provide the capability for creating similar output but with the advantage of being able to edit, copy and rescale portions of the drawing set.

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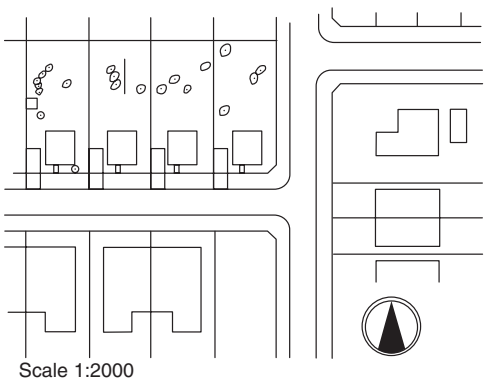
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Table II RIBA work stages – outline plan of work (design phase)

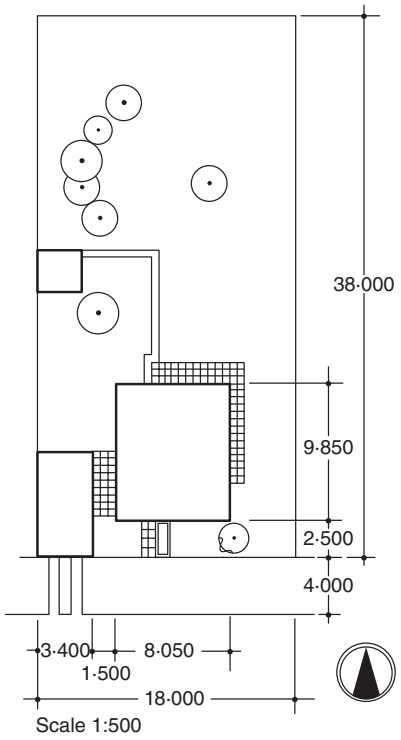
Work stage	Information required	Typical drawings
C: Concept design *(previously called Outline Proposals)*	Prepare concept design, including outline proposals for structure and building systems, outline specifications and preliminary cost plan. *Submit for outline planning if required.*	*Drawings will typically illustrate the outline proposals for each building element. This may include diagrammatic analyses of requirements, use of site, functional and circulation criteria, massing, construction and environmental strategies; the design sufficiently developed for the client to approve as a basis for proceeding to Stage D.*
D: Design development *(previously called Detailed Proposals, and often still referred to as 'Scheme Design')*	Develop concept design with fully coordinated structural and services systems; update outline specification and cost plan. *Submit detailed planning application as required.*	*Drawings will typically illustrate the design for each building element and the size and character of the project in sufficient detail for the client to agree planning and spatial arrangements, elevational treatment, environmental systems, buildability, materials and internal/external appearance. Drawings should be at a scale suitable for planning application, and the design sufficiently developed for the client to approve as a basis for proceeding to Stage E.*
E: Technical design *(previously called Final Proposals, and before that 'Detail Design')*	Prepare technical design(s) and specifications, sufficient to complete the co-ordination of all project components and elements; *information for statutory approvals/ construction safety.*	*Drawings will typically illustrate the finalised proposals for each building element and the details of all principal construction materials, components, junctions, interfaces, interior and exterior finishes. Drawings should be at a scale suitable for building regulations application. This stage essentially completes the design phase, except for those elements subject to design development by specialist sub-contractors in later stages.*
F: Production information	**F1** Prepare production information in sufficient detail for tenders to be obtained; with performance specifications where appropriate. *Apply for statutory approvals.* **F2** Prepare further information for construction as required under building contract. Review buildability and construction safety.	*The RIBA Outline Plan of Work includes diagrams illustrating different sequences for the completion of tender information (F1) and construction information (F2) for various procurement methods.*

Table III Preferred scales

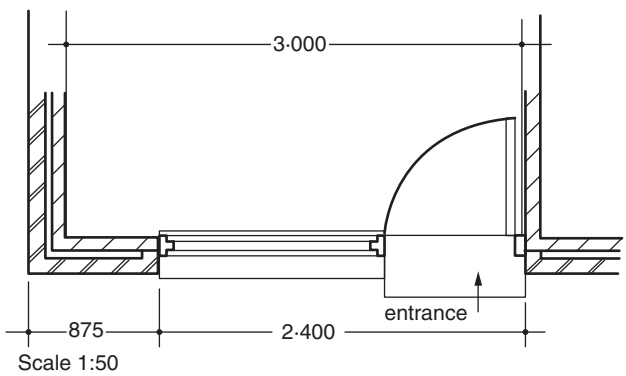
Use	Scale
Maps	1:1000000 1:500000 1:200000 1:100000
Town surveys	1:50000 1:20000 1:10000 1:5000 1:2500 1:2000 1:1250 1:1000
Location drawings	
Site plan	1:500 1:200
General location	1:200 1:100 1:50
Ranges	1:100 1:50 1:20
Component drawings	
Assembly	1:20 1:10 1:5
Details	1:10 1:5 1:1



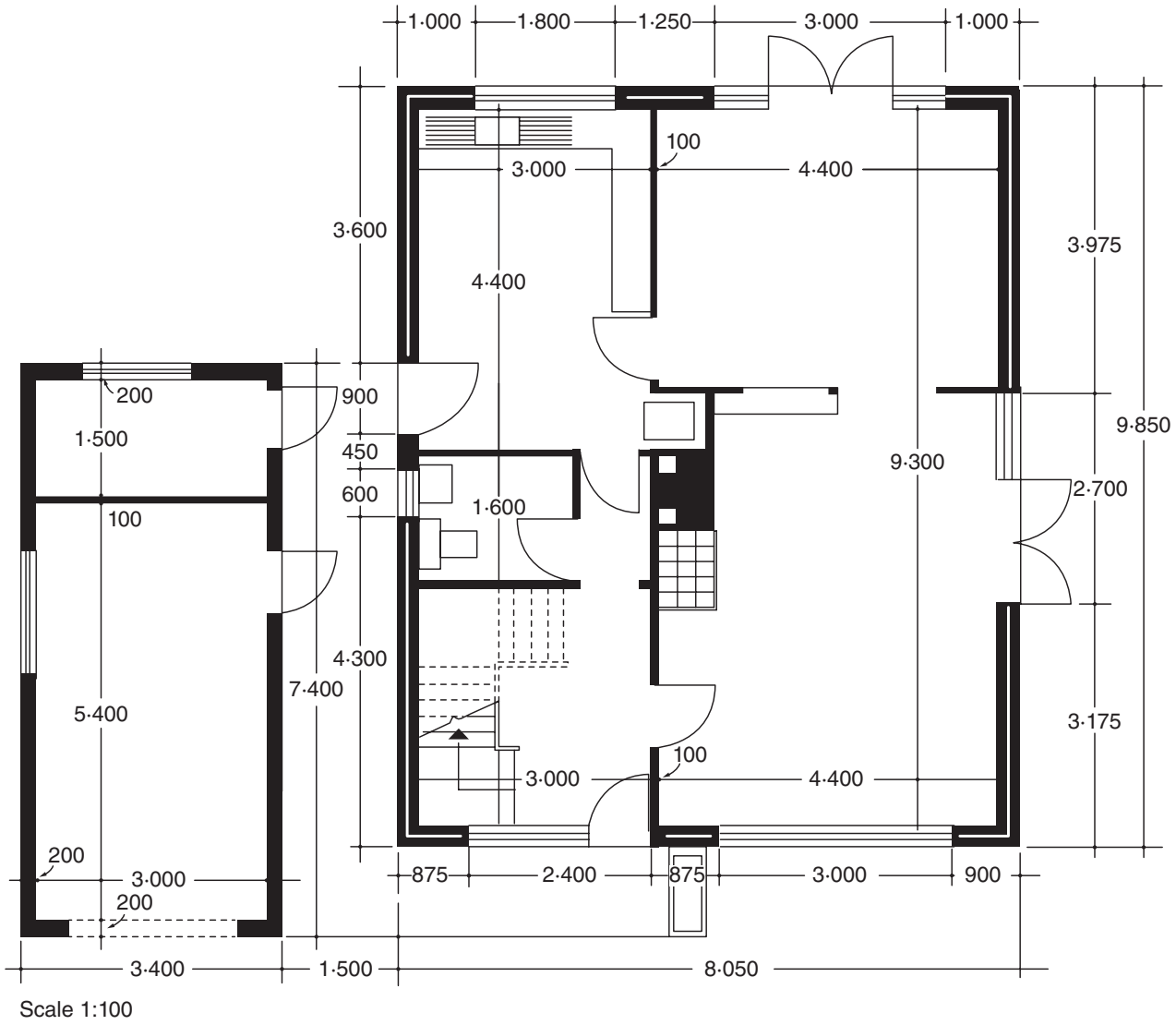
1.1 *Layout plan (note that the Ordnance Survey continue to use the 1:2500 scale)*



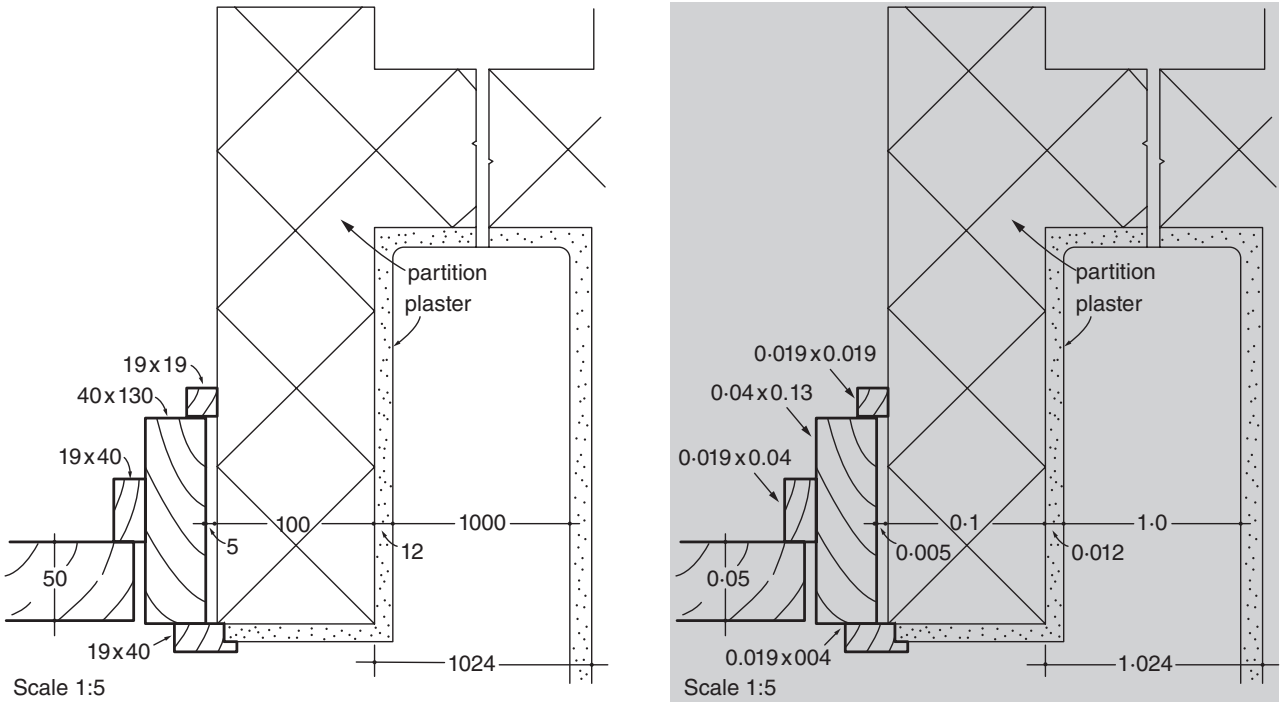
1.2 *Site plan*



1.3 *Location drawing*

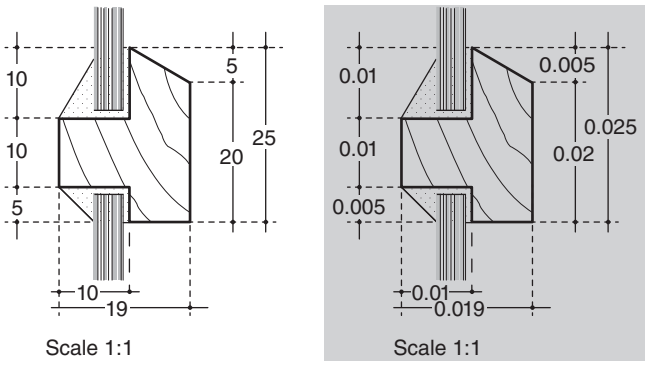


1.4 *Location drawing (sketch plan)*



1.5 *Assembly detail drawing (shaded version not recommended)*

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1.6 *Full size detail (shaded version not recommended)*

3.5 Drawings from 3D systems and BIM

Similar 2D building plans, sections, and elevations can be created using a 3D modelling system. Being derived from a single model these have the added benefit of being automatically coordinated. The scale, location and cut planes of any particular view can be adjusted dynamically making the production of a drawing set extremely flexible. Of course, not everything needs to be modelled in 3D and it is common practice to include conventional 2D details within the drawing set. Using callouts, these can be cross-referenced to their location on the model. Overall this approach simplifies management of the drawing set helping to ensure that the information provided remains consistent.

A typical system will allow for the project model to commence with simple massing diagrams and evolve to fully detailed construction drawings. In particular the concept of the single data model allows for additional software to be employed for specific applications such as:

1 Providing photo-realistic perspective still images and animated views of the project.
2 Studying environmental planning issues such as sun paths, daylighting, acoustics and escape simulations.
3 Checking for clashes between structure, components and services. This may be carried out visually and in certain instances automatically at an early stage in the project to help avoid costly mistakes occurring on-site.
4 Using the data as a basis for component manufacture.

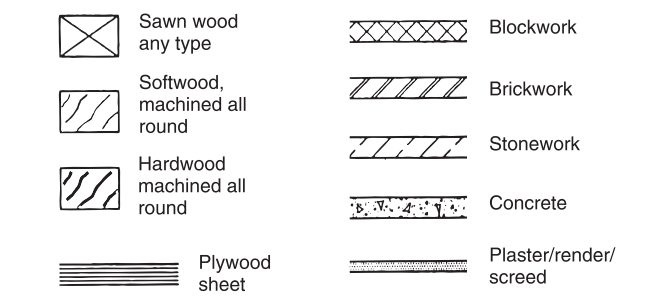
The case study at the end of this chapter illustrates some of the practical benefits of this approach.

4 DRAWING CONTENT

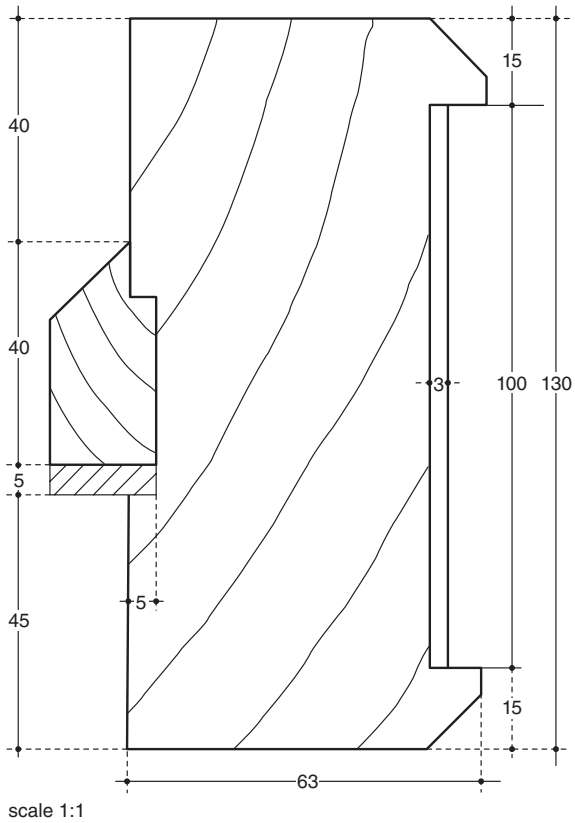
4.1 Standard elements

In manual drafting, repeated standard elements and symbols are often introduced in the form of printed transfers. In 2D CAD, blocks are used for this purpose and can be scaled. With 3D CAD, parametric objects are employed for almost all of the drawing content and can be created to automatically generate different representations of elements and components that show a level of detail relevant to the chosen scale of a view.

BS 8541-2 provides guidance and recommendations for 2D symbols and other graphic conventions for use on drawings for the



1.8 *Conventional shadings for various materials in section*



1.7 *Full size detail*

construction industry. The symbols covered by this BS are restricted to the architectural and land registry symbols as the base for architecture drawing, modelling and planning activities. The more specific symbols for mechanical, electrical and plumbing along with the structural steel sections and welding are deferred to those institutes that have a greater understanding of the needs of their members in a fast changing world. BSRIA has a large symbol library for the MEP and Building Services engineers and the Institution of Engineering and Technology (IET) covers both electronic and electrical symbols.

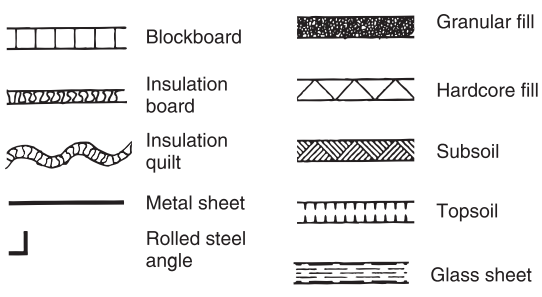
The BS stresses that:

The amount of detail in a simplified representation should be limited to the essential attributes of the object.
A geometric shape should not be used if its meaning is not determined by context and experience.
Over-complexity of building elements components and symbols should be avoided by one of the following methods:

(a) omitting unnecessary information (for example, if all the items in a project are of the same type);
(b) annotating differences between one item and another;
(c) referring differences to a schedule or other document.

4.2 Conventions

BS 1153 specifies certain traditional symbols for use on drawings. A selection of these are shown in Figure 1.8.

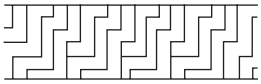
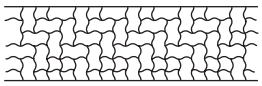
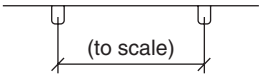
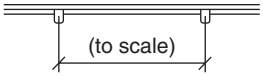
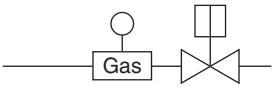
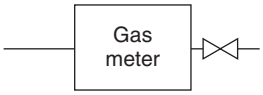
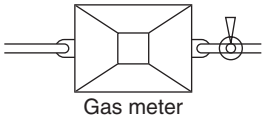


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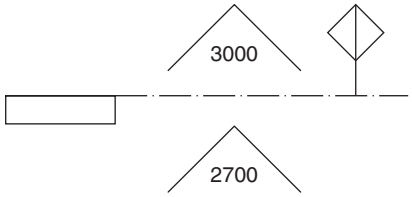
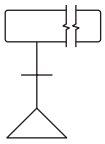
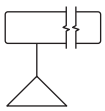
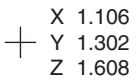
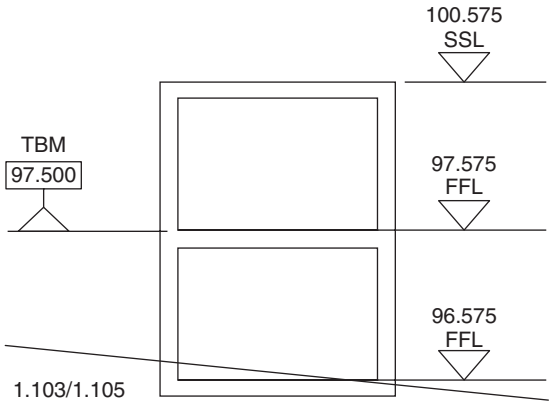
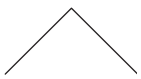
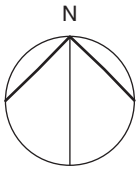
4.3 Symbol representations

In object modelling systems, the representation of a symbol may be created so that it changes automatically depending on the scale of the output. BS 8541-2 includes a comprehensive set of tables showing standards for typical symbols, elements and components.

Item	Symbol	Simplified representation	Representation
Interlocking concrete block paving			
Fence			
Gas meter and shut-off valve			

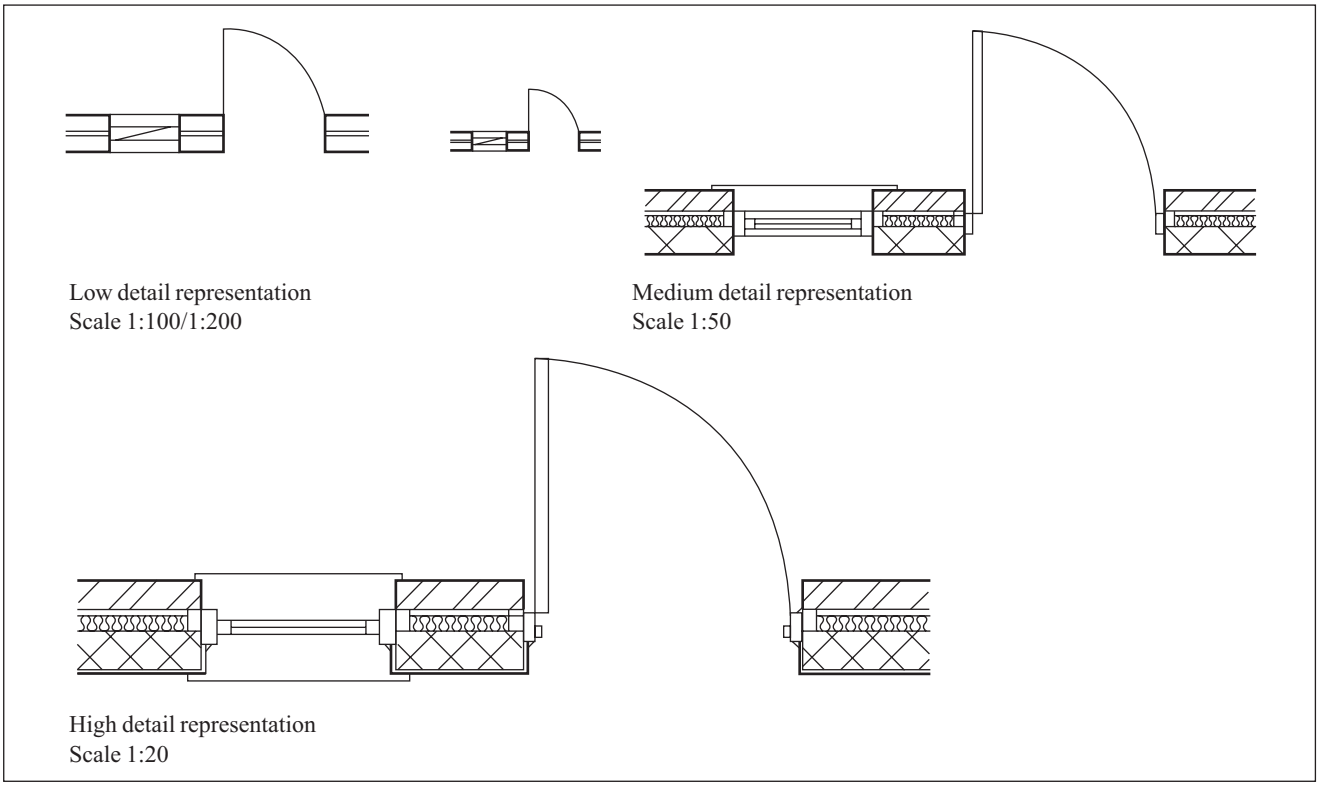
4.4 Levels on plan section and elevation

The standards shown are from BS 8541-2.

Symbols		Applications
bench mark		Change of suspended ceiling level at bulkhead 
datum on plans		
datum on cuts, sections, elevation		
level on plans		Datum and levels on section
level on cuts, sections, elevations		
Ceiling height above ffl on plans		
North point		

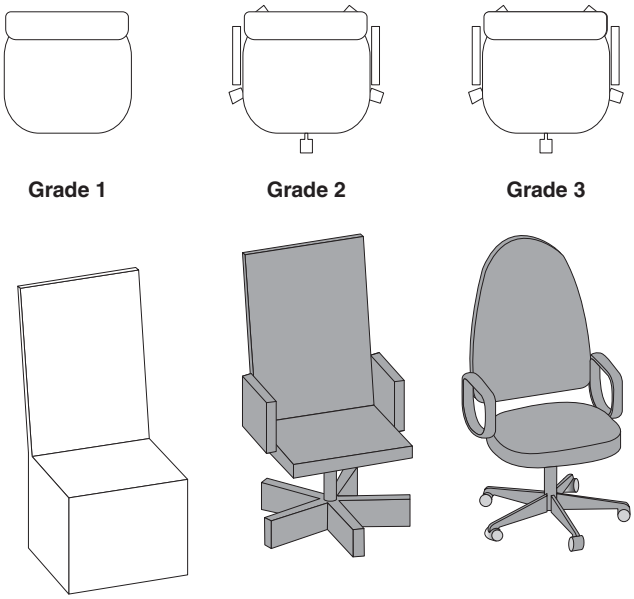
4.5 Scales and representations of elements

The level of detail shown to represent a building element varies depending on the representative scale: if the detail is too complex it may not be possible to reproduce clearly on the plotted output. In 3D modelling systems this process may be automated.



4.6 Graded components

With 3D modelling systems it is possible to replace an object with another showing more detail as the design progresses. To facilitate this, the AEC BIM Standards recommend that all components created, or otherwise obtained should be graded, named and stored accordingly in the project structure as follows.



Component Grade 1 – Concept

- Simple place-holder with absolute minimum level detail to be identifiable, e.g. as any type of chair.
- Superficial dimensional representation.
- Generic in terms of manufacturer information and technical data.

Component Grade 2 – Defined

- Contains all relevant meta-data and technical information, and is sufficiently modelled to identify type of chair and component materials.
- Typically contains level of 2D detail suitable for the ‘Preferred’ scale.
- Sufficient for most projects.

Component Grade 3 – Rendered

- Identical to the Grade 2 version if scheduled or interrogated by annotation. Differs only in 3D representation.
- Used only when a 3D view at a sufficient scale deems the detail necessary due to the object’s proximity to the camera.

In addition to the grading, a component may make use of Low, Medium and High levels of detail to control its graphical representation in relation to the chosen scale as indicated in Section 4.3.

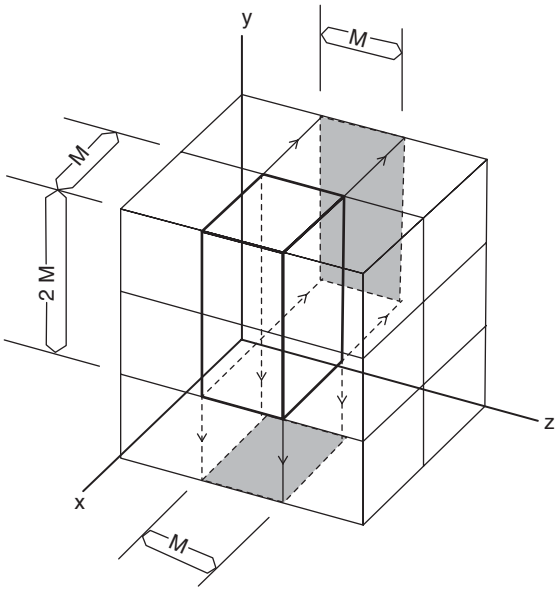
5 DIMENSIONAL COORDINATION

5.1 General

Current building practice involves the assembly of many factory-made components: in some cases the whole project consists of such components slotted together like a child’s construction kit. Dimensional coordination (DC) is essential to ensure the success of the system, and consists of a range of dimensions relating to the sizing of building components and assemblies, and to the buildings incorporating them. DC enables the coordination of the many parts that go to make up the total construction which are supplied from widely separated sources. At an international level, 100 mm is accepted as the basic module (often referred to by the letter ‘M’).

Dimensional coordination relies on establishment of rectangular three-dimensional grids of basic modules into which components can be introduced in an interrelated pattern of sizes, Figure 1.9. The

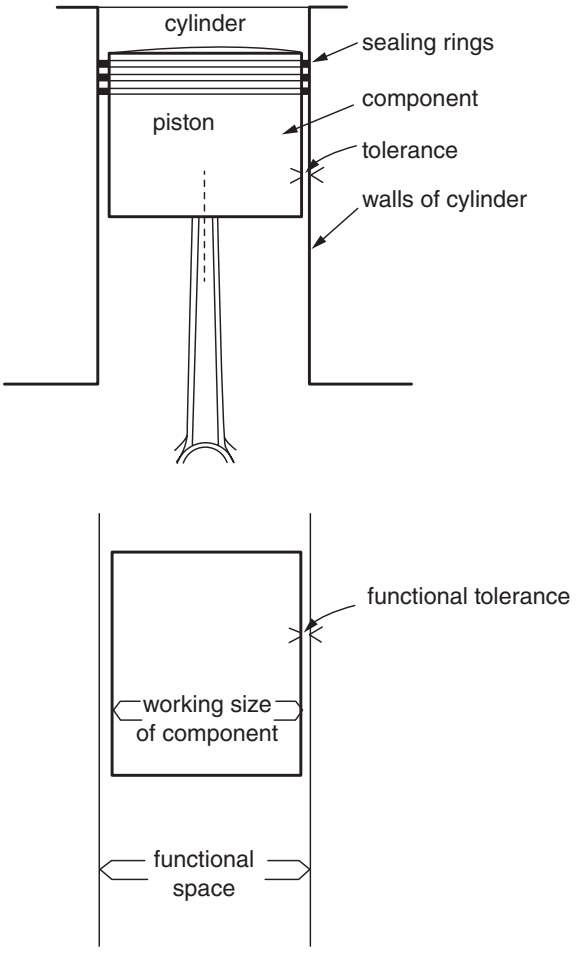
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1.9 *Three-dimensional grid of basic modules*

modular grid network delineates the space into which each component fits. The most important factor of dimensional coordination is that the component must always be undersized in relation to the space grid into which it has to fit (but not to too great an extent).

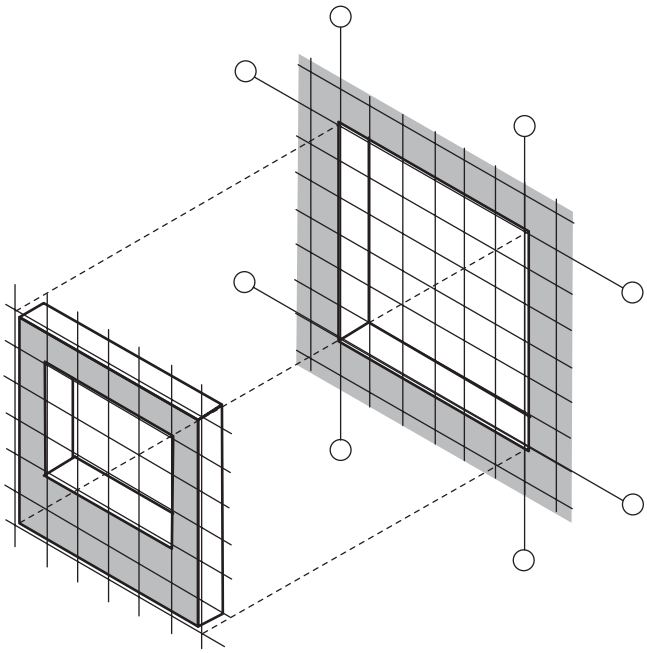
In the engineering world the piston and cylinder principle establishes the size relationship between dimensional space grid and component, Figure 1.10. The size of the cylinder must allow for the right degree of accuracy and tolerance to enable the piston to move up and down.



1.10 *The piston and cylinder principle*

The degree of inaccuracy to be allowed for in the building process is related to the economics of jointing. Adequate space must be allowed for size of component plus joint. Transgressing the rules of locating components within the allotted space contained by grid lines will cause considerable difficulty in site assembly.

The basic arrangement of components within the grid layout shows them fitting into the spaces allocated to them: dimensionally they are coordinated, thus allowing the designer maximum use of standard components, Figure 1.11.



1.11 *Fitting a component into a dimensionally coordinated grid*

Advantages to designers may include:

- reduction in design labour
- reduced production of working drawings by the use of standard details
- choice of interrelated standard components at the various price levels.

5.2 Basic aims of DC

The basic aims of DC (as defined in BS 4011:1966) were:

- to obtain maximum economy in the production of components
- to reduce the manufacture of non-standard units
- to avoid wasteful cutting on-site.

Potential advantages to manufacturers include:

- more effective use of labour in producing standard lines
- reduction in the stocking, invoicing and other operations connected with numerous differently sized products. there should also be advantages to contractors, not only through better design of components for fit but also through increasing familiarity with standard components.

BS 4011 was superseded by BS 6750:1986.

5.3 Basic elements of DC

Preference for size

The preferred increments are:

- First preference (multimodule) multiples of 300 mm
- Second preference (basic module) multiples of 100 mm
- Third preference (submodule) multiples of 50 mm up to 300 mm
- Fourth preference (submodule) multiples of 25 mm up to 300 mm.

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Reference systems
Grid and line: the DC reference system identifies controlling dimensions by the use of a grid on plans and a series of horizontal lines on elevations and sections. The terminology is precise:

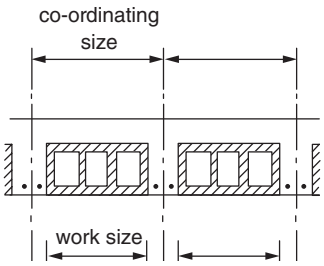
- Controlling dimensions lie between key reference planes (e.g. floor-to-floor height). They provide a framework within which to design and to which components and assemblies may be related.
- Key reference planes define the boundaries of controlling zones or structural axes.
- Controlling lines on a drawing represent a key reference plane.
- Axial controlling lines are shown on drawings by a chain dotted line with a circle at the end, in which the grid reference is given.
- Face controlling lines are shown by a continuous line with a circle at the end in which the grid reference is given.
- Zones between vertical or horizontal reference planes provide spaces for one or more components which do not necessarily fill the space. Provided that use of associated components is not inhibited, a building component (or group of components) may extend beyond the zone boundary, as may trims and finishes.

5.4 Drawings

The representation of the dimensional coordination framework should be consistent on all drawings. On general location drawings a grid representing 300 mm (or a multiple of 300 mm) may be used. Assembly details may use grids of 300 or 100 mm.

Reference lines
Reference lines or grids should be thin, to distinguish them from other, particularly constructional, lines.

Dimension lines
Different types of dimensions should be distinguished by the type of arrowhead, Figure 1.12.



1.12 *Coordinating and work sizes*

Running dimensions should be set off from a datum, Figure 1.13.



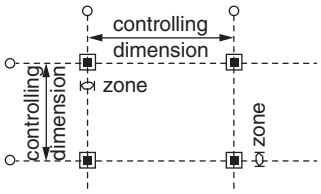
1.13 *Running dimensions. The symbol at the datum should be as shown. An arrowhead is sometimes used, but is not the preferred alternative*

Assembly details
Assembly details should show components in their context, that is, in relation to the adjoining element, with details of the joint.

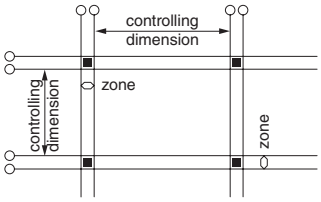
5.5 Locating components by grid

Types of grid
The structural grid of axial controlling lines, Figure 1.14, is established physically by the contractor on-site; it serves as the main reference in construction. It is subject to setting-out deviations which affect the spaces required for assemblies of components; but this should have been allowed for in the design stage. A planning grid of face controlling lines, Figure 1.15, locates non-structural elements.

- A neutral zone is a zone that does not conform to the recommended dimensions given in Table IV.



1.14 *Axial control*



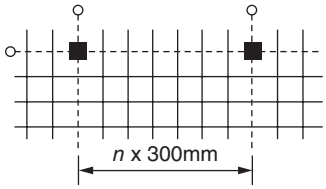
1.15 *Facial control*

Table IV Sizing of zones and heights

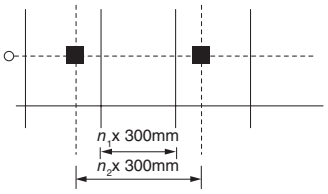
Range (mm)	Multiples of size (mm)
Horizontal controlling dimensions	
Widths of zones for columns and loadbearing walls	
100 to 600	300 (first preference)
	100 (second preference)
Spacing of zones for columns and loadbearing walls	
From 900[1]	300
Vertical controlling dimensions	
Floor to ceiling heights	
2300[2] to 3000	100
3000 to 6600	300
over 6600	600
Heights of zones for floors and roofs	
100 to 600[3]	100
over 600	300
Floor to floor (and roof) heights	
2700[4] to 8400	300
over 8400	600
Changes in level	
300 to 2400	300
above 2400	600

[1] Housing may use 800
[2] Farm buildings may use 1500 and 1800
Domestic garages may use 2100
Housing may use 2350
[3] Housing may use 250
[4] Housing may use 2600

Relation between structural and planning grids
Structural and planning grids may coincide but do not necessarily do so. The controlling dimensions for spacing structural elements on plan on axial lines are in multiples of 300 mm (Table IV). If a 300 mm square grid is used then axial controlling lines will coincide with the grid, Figure 1.16, but if the grid is a multiple of 300 mm then the controlling lines will be offset from the axial grid by 300 mm or by a multiple of 300 mm, Figure 1.17.

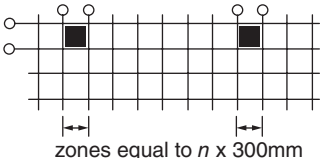


1.16 *Uninterrupted grid*

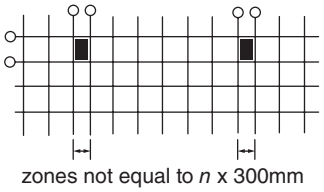


1.17 *Controlling lines offset from grid*

Relating zones to a 300 mm grid
If widths of structural zones are multiples of 300 mm, the grid is continuous, Figure 1.18. If the zone is not a multiple of 300 mm, however, the grid is interrupted by the dimension of that zone, Figure 1.19. This is referred to as a neutral zone.



1.18 *Continuous grid*

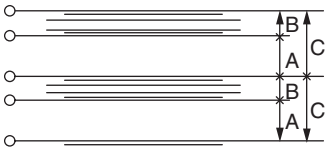


1.19 *Interrupted grid and neutral zones (tartan)*

Key reference planes
Key reference planes, Figure 1.20, should generally occur at:

- finished floor level
- finished suspended ceiling level
- finished wall surface.

Sizes of zones indicated by key reference planes should be selected from Table IV. Where controlling or reference lines bound floor or roof soffits, deflection should be allowed for in the zone.



1.20 *Vertical control: A being floor-to-ceiling height controlling dimension; B floor and roof zone; C floor-to-floor and floor-to-roof controlling dimension*

5.6 Size of components

Coordinating and work sizes
Controlling dimensions are coordinating sizes:

- Coordinating sizes, **1.12**, make allowance for fitting and jointing. They represent the overlaid grid which does not usually coincide with actual junction lines on the face of the building. They are indicated by open arrowheads.
- Work sizes are the specified manufactured sizes (within permissible deviations). They are indicated by closed arrowheads.

Tolerance and fit
Joint sizes are critical. There are graphical aids (see References) to help reconcile all the factors affecting tolerance, such as

- expansion and contraction
- variability in manufactured size
- satisfactory joint clearance range
- variations in setting out dimensions, adjacent components, etc.
- number of components in an assembly
- variations in interpretation of work size from a given coordinating size.

Degree of accuracy
Designers should identify where fit is critical and where not, or they must assess:

- where standard sizes are appropriate and readily available
- if some components can be made to order without a significant cost penalty
- whether cutting is acceptable (and the effect on performance)
- the likely order of assembly.

5.7 Boundary conditions
Some assembly and support conditions may necessitate variations in elements to allow for:

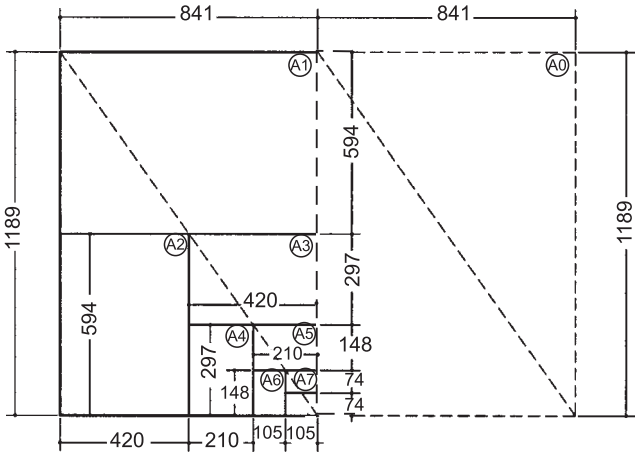
- an extended floor slab beyond the clear span to gain a bearing on a wall
- reduction in size to permit the application of a finish
- an increased height of positioning to allow for building directly off the floor slab or extending through a suspended ceiling to reach the soffit of the floor slab.

These allowances (termed ‘boundary conditions’) should be in multiples of 25 mm. They may be uneconomic to produce, limiting the applications of the product to which they apply.

6 REPROGRAPHICS AND PAPER SIZES

6.1 Paper
Traditionally paper was the main means of information transfer. The use of CAD and BIM systems coupled with various forms of electronic transfer now means that team collaboration can be supported by using interactive screen displays. But for many purposes paper is still the preferred medium and the International A-series of paper sizes is used for all plotted drawings and printed material.

6.2 Sizes in the A-series
The A range is derived from a rectangle AO of area 1 m^2 with sides x and y such that x:y = 1:√2 (i.e. x = 841 mm; y = 1189 mm). The other sizes in the series are derived downwards by progressively halving the size above across its larger dimension. The proportions of the sizes remain constant, Figure 1.21.



1.21 *A-sizes retain the same proportion (1:√2), each size being half the size above folding A1 size*

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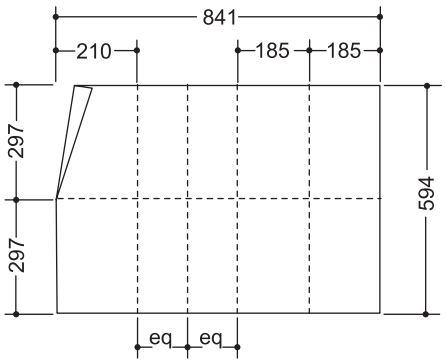
6.3 Trimmed sizes and tolerances

The A formats are trimmed sizes and therefore exact; stubs of tear-off books, index tabs, etc. are always additional to the A dimensions. Printers purchase their paper in sizes allowing for the following tolerances of the trimmed sizes:

- For dimensions up to and including 150 mm, þ1.5 mm
- For dimensions greater than 150 mm up to and including 600 mm, þ2 mm
- For dimensions greater than 600 mm, þ3 mm. Recommended methods of folding the larger A-sized prints are given in Figure 1.22.

A size	mm
A0	841 × 1189
A1	594 × 841
A2	420 × 594
A3	297 × 420
A4	210 × 297
A5	148 × 210
A6	105 × 148
A7	74 × 105
A8	52 × 74
A9	37 × 52
A10	26 × 37

measurements represent trimmed sizes



folding A1 size

1.22 *A-series of paper sizes*

7 ORDNANCE SURVEY MAPS

7.1 Scales

Ordnance Survey maps are available to the following scales: 1:50000, 1:25000, 1:10000, 1:2500 and 1:1250. However, computer methods of storage and retrieval mean that maps can be reproduced to any desired scale. Architects and surveyors inevitably need to refer back to old maps and plans from time to time. These may have been drawn to almost any scale, but the common scales to which OS maps were drawn were as follows: 1 inch to the mile (1:63360), 6 inches to the mile (1:10560), 88 feet to the inch (1:1056).

7.2 Bench marks and levels

Points used for measuring and marking levels are known as *bench marks*. On a particular site a temporary *bench mark* (TBM) may be established, to which all other levels on that site are referred. The level value allocated to the TBM may be to Ordnance Datum; more commonly it is given an arbitrary value. This value should be large enough not to require any negative levels (including levels of drains, etc.), as these can lead to errors. All levels in and around buildings are recommended to be given to three decimal places, although BS 1192 permits two decimal places for landscape work.

The heights of Ordnance Survey bench marks are given in Bench Mark Lists obtainable from Ordnance Survey Headquarters, Adanac Drive, Southampton, SO16 0AS. Modern OS maps to the larger scales include Ordnance Bench Marks related to Newlyn Datum. Older maps may have levels to Liverpool Datum; levels on maps other than of Great Britain will be related to other datums. Where known, the datum and date of levelling should be stated. OS maps include contours. On the 1:10000 series the contour interval is 10 metres in the more mountainous areas and 5 metres in the remainder of the country.

8 REFERENCES

AEC (UK) BIM Standard – Version 1.0 November 2009, free download from http://www.aec-uk.org
BS 6750: 1986 Modular co-ordination in building. International Organisation for Standardisation
BS 8541–2: 2011 Library objects for engineering and construction – Part 2 Recommended 2D symbols of building elements for use in building information modelling
BS 5606: 1990 Guide to accuracy in building
BS EN ISO 9431: 1999 Construction drawings. Spaces for drawing and for text, and title blocks on drawing sheets
BS 1192: 2007 Collaborative production of architectural, engineering and construction information. Code of practice
BIP-2207: 2010 Building Information Management: A Standard Framework and Guide to BS 1192, Mervyn Richards
BS 29481-1: 2010 Building information modelling. Information delivery manual – Methodology and format
Government Construction Strategy: Cabinet Office: June 2011
A report for the Government Construction Client Group, Building Information Modelling (BIM) Working Party Strategy Paper: Department of Business, Innovation and Skills: July 2011
ISO 2776: 1974 Modular co-ordination – co-ordinating sizes for door-sets – external and internal general
ISO 6512: 1982 Modular coordination – Storey heights and room heights
ISO 1040: 1983 Modular co-ordination – multimodules for horizontal co-ordinating dimensions
ISO 1006: 1983 Modular co-ordination – basic module
ISO 1791: 1983 Modular co-ordination – vocabulary
ISO 2848: 1984 Modular co-ordination – principles and rules
ISO/TR 8390: 1984: Modular coordination – application of horizontal multimodule
ISO 16739: Industry Foundation Classes for AEC/FM data sharing
RIBA Outline Plan of Work 2007 (UPDATED): Including Corrigenda Issued January 2009 – available as a free download from http://www.ribabookshops.com

9 CASE STUDY – USING BUILDING INFORMATION MODELLING FOR PROJECT DELIVERY

Project: 5 Churchill Place, London
Client: Canary Wharf Group Plc
Architects: HOK International Ltd
Structural Engineer: WSP
Services Engineer: HMP
Contractor: Canary Wharf Contractors Ltd



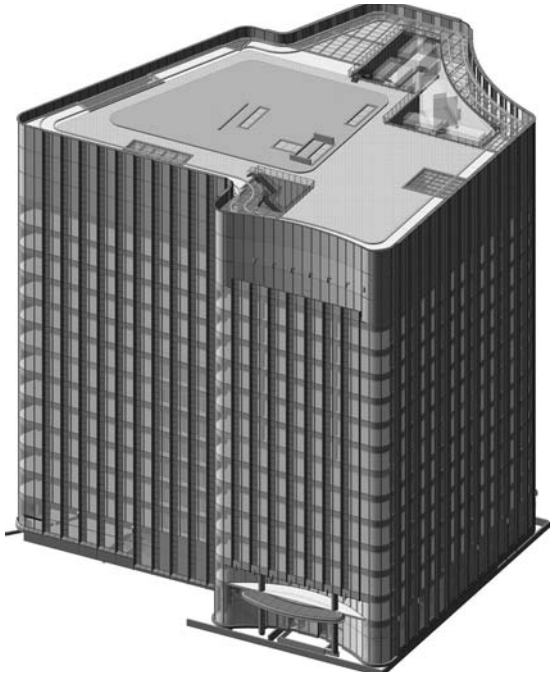
1 *5 Churchill Place, London, completed 2008*

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Situated at the eastern gateway to Canary Wharf, the site presented a particular challenge built partially over water, comprising a complex series of irregular existing ramps, platforms and marine decks between ground and dock level. The design concept developed by HOK used Building Information Modelling (BIM) in a collaborative manner with the design team, creating a single project environment to promote full coordination as early as possible in the design process.

The result is a structurally complex office building with a floor area of 28,000 m^2 net, spread over 14 storeys with a three-level basement, clad in alternating clear glass and granite panels. The distinctive elevations draw inspiration from optical art so that, as the observer's vantage point moves, the character and materials of the building change. Depending on the perspective view, the dominant building material appears to be glass, granite or metal.

Glass on the northern elevation maximizes natural light with minimal solar gain. Stainless steel edges catch light and sun reflections. With high emphasis on sustainability, the building was specifically designed to achieve a BRE Environmental Assessment Method (BREEAM) rating of excellent, and the computability of the design data was an essential part of ensuring this was achieved. Environmental data and projected performance criteria were continually evaluated in relation to the complex structural geometry.

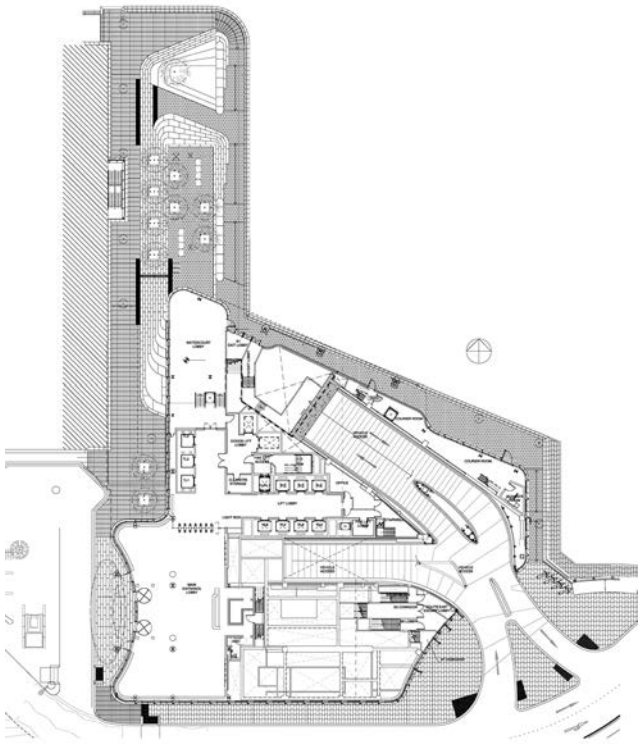


2 *Building model as a complete volume*

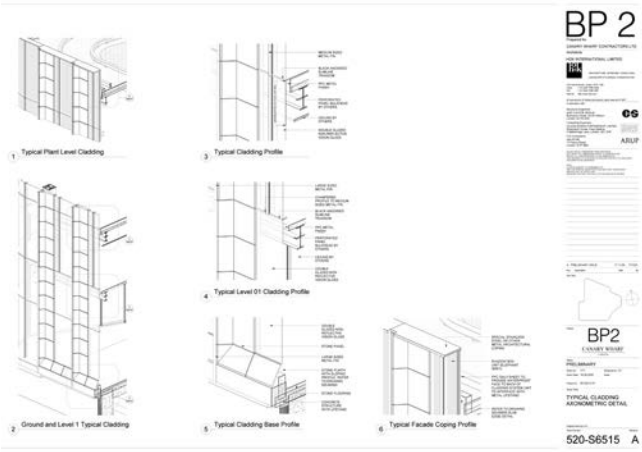
Using a BIM process and integrated software solutions were key factors in helping the design team to deliver the project, while at the same time demonstrating the commitment to building SMART; wherein Integrated Practice, Information Modelling and Sustainability are combined to deliver the best solution for the client. BIM provided the design platform for concept design, design development and detail design – and the same model was used to generate photographic quality visual renderings to illustrate the design for the stakeholders.

The project design team adapted quickly to this new way of working; an eight person team working together in close proximity on the architectural design model. This approach encouraged better communication, a greater understanding of what the team members where working on and how this complex building would be assembled.

The BIM software is essentially a database design solution, and one of the major benefits of this software is that all general arrangements – floor plans, sections and elevations – are extractions from the overall model. This ensures that the drawing deliverables are at all times coordinated and up to date. If a change is made in one part of the model all the associated views of the model are automatically updated.



3 *Floor plans, and other key drawings such as sections, can be extracted from the BIM model rather than created independently*

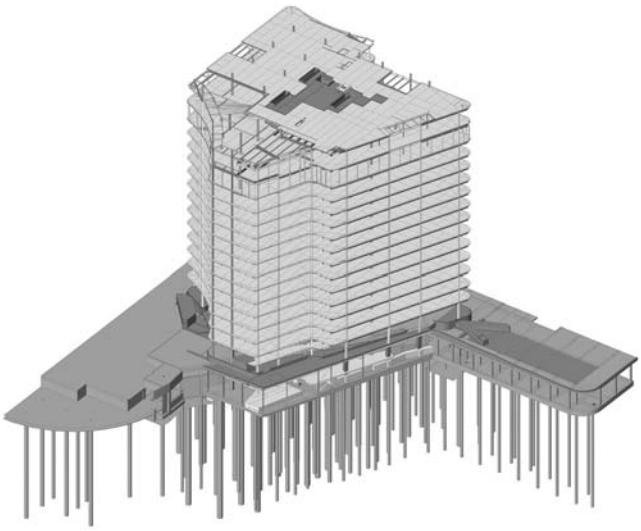


4 *Typical isometric facade. Architect and structural engineer exchanged models and data to improve cooperation and create efficient workflows*

All the details produced for this project were coordinated callout views from the virtual building model; these views were then placed on drawing sheets. Working with the model as a background gave the detailer an accurate profile of which elements need to be enhanced with additional linework, drafting components, dimension and keynotes which are anchored into the model. 3D isometric views were also used to help interrogate more complex details and assemblies.

HOK and WSP, the structural engineers, regularly shared their respective building models: the architectural model being used as background information for the structural concrete, steelwork and analysis model, which in turn was linked back into the architectural model to illustrate the structural engineer's design. The sharing of model data and the ease of interoperability led to improved workflow coordination.

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5 *Structural model. This complex 3D model, used by the steelwork contractor for fabrication, was also used by the design team for clash detection and detail coordination*

The client recognised the benefits of this collaborative approach to design and delivery, and actively encouraged the use of the BIM approach by the project team. The client was also keen to explore the value that BIM could obtain from the supply chain.

The structural model was further developed by the steelwork contractor for fabrication. This more complex 3D steelwork fabrication model was then used by the design team in a clash detection check. All the principal MEP elements were modelled in 3D, together with all of the major plant areas and risers – ensuring detail coordination.

The design team worked in an integrated manner with the contractor and the specialist trade contractors, the client knew what was possible and what they wanted from BIM, and all parties bought into the process, the key trade contractors being involved in development and review of the design with the construction manager actively managing the review process.

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2 People and space

Updated by Professor Norman Wienand

Professor Norman Wienand is head of department for the Natural and Built Environment at Sheffield Hallam University

KEY POINTS:

- *Certain dimensions are crucial to individual use and health*
- *Satisfying the average situation is unlikely to help the majority*
- *Each case must be carefully considered with all classes of users, particularly people with different abilities, in mind*

Contents

1 Introduction
2 Anthropometrics
3 Ergonomics
4 Sanitary facilities
5 Domestic space standards
6 Bibliography

1 INTRODUCTION

1.1 Universal design

As a general aim, this chapter should be viewed primarily as a starting point in the design process, as a guide to the principles and conventions that govern how particular building types are planned to suit their eventual occupants. A primary and guiding principle adopted throughout is the concept of universal (or inclusive) design.

> Universal Design refers to the design and composition of an environment so that it can be accessed, understood and used to the greatest extent possible by all people, regardless of their age, size, ability or disability.
>
> Disability Discrimination Act, 2005

The benefits of adopting this position include the production of designs that aim to exclude no one from enjoying the end results. This also has the potential to future proof the building for adaptation later. However this inclusive approach can have some considerable associated problems. For instance, the section on *Anthropometrics* will illustrate that simply identifying the broad range of physical size for users can be problematic, as is the design of appropriate *Ergonomic* living environments when bespoke solutions are not always possible but may also exclude many other users. Universal design is therefore often a compromised solution but the guiding principle ensures that it is the best possible fit under any particular circumstances.

1.2 Specialist guides

In recent years, specialist and readily accessible design guides have been produced by bodies such as the RIBA or the Centre for Excellence in Universal Design, Dublin. As these guides interpret and clarify legislative requirements in a highly comprehensible manner, reference is made to each of these guides by pointing to them as sources of further detailed information and particularly how that information is developed.

This chapter is therefore an introduction to the principles of anthropometrics and ergonomics, the setting up of basic sanitary and domestic spaces standards, but premised on the notion that this information is the preface to further research and design review.

2 ANTHROPOMETRICS

2.1 Size and variation

The human form comes in many different shapes and sizes and designing to accommodate people in whatever capacity requires a working knowledge of the interaction between designed objects or spaces and the ultimate users. Much of this knowledge can be intuitive because we all have experience of our own. However this knowledge can also be limiting as it is not just about proportion, scale or ease of movement; there are health and safety issues involved as well as designing for inclusion and equality in access. Anthropometrics is concerned with the size and variations of the human body and when combined with ergonomics, the allied study of the interaction of humans and the designed world, we have two entire scientific disciplines devoted to the subject. This section aims to introduce only the basic concepts involved and will point to reference sources for further information.

2.2 Primary data

Much of the primary anthropometrical data comes from a collection of various different studies conducted over the last twenty years and can be surprisingly inaccurate when used in isolation. Understanding the value of anthropometric data therefore also needs an understanding of the basic statistical tools that allow us to make good use of the data. Firstly, we have to recognise that there is no standard human shape type; average height people can be thin, fat, young or old. Average heights can vary between ages, sexes, and different ethnic and national backgrounds. For example, the Dutch are Europe's tallest people and a study of Polish industrial workers suggests that they are Europe's shortest.

The primary data collected on individual population proportions is usually presented as a frequency distribution curve, Figure 2.1. Also known as a bell curve because of its shape, it represents a cross section of the distribution of data for any particular dimension

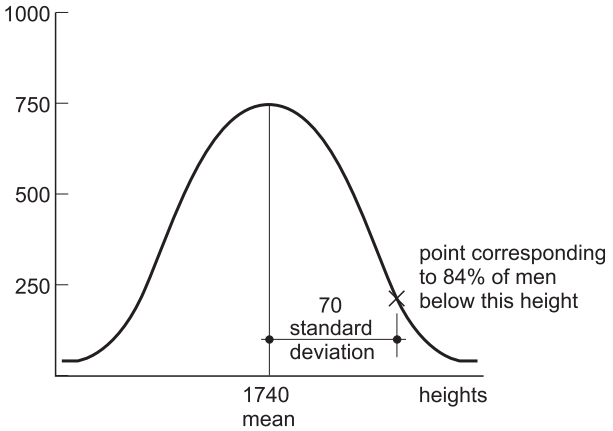


Figure 2.1 *Normal distribution 'bell' curve. The y-axis plots the numbers of men (in this example) in a group who are the height given on the x-axis (within certain limits). In a normal distribution the average, the mean and the median are all equal*

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across a particular population. So using height for an example, the curve will indicate that at one end the number of short people starts from roughly zero and builds to the peak where the largest numbers are, representing the average (or mean) in most cases and then decreasing as the number of taller people also diminishes towards the highest end in a symmetrical pattern.

2.3 Percentiles

This bell curve allows us to derive some very useful information commonly referred to as the percentiles. Statistically, we can use this symmetrical curve to illustrate that if we split the curve at the mid point we will have 50 per cent of the population measured falling on one side of the divide and 50 per cent on the other. This midway point is called the 50th percentile or abbreviated to 50th %ile. At either end we can also split the curve, removing the lowest and the highest 5 per cent. By doing this we end up with a range of sizes that excludes the top and bottom 5 per cent, giving us the range that will accommodate 90 per cent of a particular population. These ends are known as the 5th %ile and the 95th %ile respectively.

This is very useful information when designing something for large populations where accommodating the top or bottom 5 per cent can prove unnecessarily difficult or expensive. The size of seats on a train, for instance, allows more passengers to be carried if seat sizes are limited to the 95th %ile. However, using the 95th %ile would be wholly inappropriate if designing a fire escape that would prevent 5 per cent of the population from getting out. Where the population size is fairly consistently variable such as in the UK, the 5%ile and 95%iles will accommodate 90 per cent of the population and are used for most design solutions where safety is not an issue. In other countries, the USA in particular where there are discrete pockets in the population that may have a larger number within the outer 5 per cent ranges, the 1%ile and 99%iles are more commonly used incorporating 98 per cent of the population.

2.4 Standard deviation

In order to move between percentiles we have to manipulate the data concerned provided we have two basic pieces of information. The mean in most cases is represented by the peak of the curve, but we have not yet considered the width of the 'bell'. Essentially the wider the base of the curve, the more variable are the values and this spread is called the standard deviation (SD). For example, the bell curve for the height of all women in a population compared to the population of women high jumpers would be expected to be flatter as the average height would be lower and the spread wider as the number of female high jumpers is likely to be constrained to a smaller group of tall women. The mean and the SD allow us to calculate the other percentiles using the formula:

$$X_p = m + zSD$$

where: X_p is the value you are looking for
p represents the percentile in question
SD is the standard deviation
z is a constant for selected percentiles found in Table I.
m is the mean value or 50th %ile.

So, calculating the 99th %ile for British adult women with an average height of 1620 mm and a SD of 61 (found in Table II), we see that for $p = 99$, $z = 2.33$. Therefore the 99th %ile for women's height is: 1620 + 2.33 x 61 = 1762 mm.

To include women high jumpers, we may need to go to the 99.999th %ile where $z = 4.26$ so the 99th %ile for women's height is: 1620 + 4.26 x 61 = 1880 mm.

2.5 Extracting information from the tables

Anthropometric data comes in a standard form for any particular population, normally based on two postures, standing and sitting, with 36 measurements in total. There is a standard format for taking these measurement as well such as standing against an upright surface and keeping the parts of the ear in line with parts of the eye to keep the head in a standardised position. This defined positioning needs to be accounted for when using the data to design for different postures, a reclining chair for instance.

Table I Percentile z values
Selected p and z values for the normal distribution curve

Percentile *(p)*	*z* value
0.001	−4.26
0.01	−3.72
0.1	−3.09
1	−2.33
2.5	−1.96
5	−1.64
10	−1.28
25	−0.67
50	0.00
99.999	4.26
99.99	3.72
99.9	3.09
99	2.33
97.5	1.96
95	1.64
90	1.28
75	0.67
50	0.00

2.6 Standing and sitting dimensions

The particular dimensions are numbered to correspond to the information in the anthropometric tables. The number of different anthropometric tables provided here has been limited to British adults up to 65 years old (Table II), British adults over 65 (Table III) and two for British children aged 11 years to accommodate those in primary education (Table IV) and those aged 18 years to accommodate those in secondary education (Table V). Those over 65 tend to shrink slightly with age and, more significantly, the body tends to be less flexible in adapting to dimensionally unfavourable situations.

It is important to recognise that these data refer to naked sizes so extra needs to be added to account for clothing. Clothing and particularly shoe heights can vary according to the situation but as a general rule it is accepted that for most situations it is appropriate to add a specific, although different, amount to all dimensions for men and women. Specific situations will have to be calculated individually such as areas where tool belts may be worn, extra thick clothing may be required or fashion may dictate extra high heels for periods.

- Add 25 mm to all dimensions for men.
- Add 45 mm to all dimensions for women.

Clearance is the extra space needed to accommodate people comfortably or safely. Where health and safety concerns dictate clearances, advice should be sought elsewhere. However, there are some general rules that can be applied for personal space requirements. These space standards assume face-to-face interaction with other people and place a radius around individuals depending on the following social interactions:

- Intimate up to 450 mm.
- Personal 450 to 1200 mm.
- Social 1200 to 3600 mm.
- Public over 3600 mm.

These standards are often broken however, as air travel or the London Underground at rush hour will clearly demonstrate. It is also worth noting that intruding into this personal space is more acceptable if it is not on the facing side.

Table II British adult dimensions up to 65 years old

This table provides anthropometric data for adults aged 19 to 65, corresponding to the numbered measurements in Figure 2.2. For other percentiles, use the SD and 50th %ile values and the method shown in Section 2.4.

	Men				Women			
DIMENSIONS	**5th %ile**	**50th %ile**	**95th %ile**	***SD***	**5th %ile**	**50th %ile**	**95th %ile**	***SD***
STANDING								
1 Stature	1640	1760	1880	*73*	1520	1620	1720	*61*
2 Eye height	1530	1650	1770	*72*	1415	1515	1615	*60*
3 Shoulder height	1330	1445	1555	*69*	1225	1320	1410	*57*
4 Elbow height	1020	1105	1195	*54*	940	1015	1090	*45*
5 Hip height	850	935	1020	*52*	745	815	885	*43*
6 Knuckle height	695	765	835	*42*	665	725	785	*35*
7 Fingertip height	595	665	730	*40*	565	630	690	*38*
SITTING								
8 Sitting height	855	915	980	*37*	800	855	915	*35*
9 Sitting eye height	740	795	855	*36*	690	745	800	*33*
10 Sitting shoulder height	545	600	655	*33*	510	560	610	*31*
11 Sitting elbow height	195	245	300	*32*	180	230	275	*28*
12 Thigh – thickness	130	160	185	*16*	120	150	175	*16*
13 Thigh – outer length	545	595	650	*32*	520	565	615	*29*
14 Thigh – inner length	445	500	555	*34*	430	475	525	*29*
15 Knee height	495	550	605	*33*	460	500	545	*26*
16 Under thigh height	400	445	495	*30*	355	400	445	*27*
17 Shoulder breadth a)	415	465	510	*29*	355	395	435	*24*
18 Shoulder breadth b)	370	405	440	*21*	330	360	390	*18*
19 Hip width	300	350	400	*31*	300	350	400	*29*
20 Chest depth	185	225	270	*26*	190	235	275	*26*
21 Abdominal depth	195	240	280	*26*	185	220	260	*22*
22 Elbow – shoulder length	335	370	405	*21*	305	330	360	*17*
23 Elbow – fingertip length	445	480	515	*22*	400	430	465	*19*
24 Arm – shoulder to fingertip	730	790	850	*37*	660	710	760	*32*
25 Arm – shoulder to grip	615	670	730	*34*	560	605	650	*29*
APPENDAGES								
26 Head length	185	195	210	*8*	170	180	190	*7*
27 Head breadth	145	155	165	*7*	135	145	155	*5*
28 Hand length	175	190	210	*10*	160	175	190	*9*
29 Hand breadth	80	90	95	*5*	70	75	85	*4*
30 Foot length	245	270	290	*15*	220	240	260	*12*
31 Foot breadth	90	100	110	*7*	80	90	100	*5*
REACH								
32 Span	1670	1815	1955	*86*	1500	1615	1730	*70*
33 Elbow span	875	955	1035	*49*	785	855	925	*42*
34 Vertical grip reach – standing	1950	2085	2220	*83*	1805	1915	2030	*70*
35 Vertical grip reach – sitting	1155	1260	1360	*63*	1070	1155	1245	*52*
36 Forward grip reach	730	790	845	*36*	655	705	755	*31*

(Source: Pheasant & Haslegrave, 2006, p. 245, table 10.2)

Tabel III British adult dimensions over 65 years old

This table provides anthropometric data for adults aged over 65, corresponding to the numbered measurements in Figure 2.2. For other percentiles, use the SD and 50th %ile values and the method shown in Section 2.4.

	Men				Women			
DIMENSIONS	**5th %ile**	**50th %ile**	**95th %ile**	***SD***	**5th %ile**	**50th %ile**	**95th %ile**	***SD***
STANDING								
1 Stature	1575	1685	1790	*66*	1475	1570	1670	*60*
2 Eye height	1470	1575	1685	*65*	1375	1475	1570	*59*
3 Shoulder height	1280	1380	1480	*62*	1190	1280	1375	*56*
4 Elbow height	975	1055	1135	*49*	910	985	1055	*44*
5 Hip height	820	895	975	*47*	740	810	875	*42*
6 Knuckle height	670	730	795	*38*	645	705	760	*35*
7 Fingertip height	575	635	695	*36*	550	610	670	*37*
SITTING								
8 Sitting height	815	875	930	*36*	750	815	885	*41*
9 Sitting eye height	705	760	815	*34*	645	710	770	*38*
10 Sitting shoulder height	520	570	625	*32*	475	535	590	*36*
11 Sitting elbow height	175	220	270	*29*	165	210	260	*28*
12 Thigh – thickness	125	150	175	*15*	115	145	170	*16*
13 Thigh – outer length	530	580	625	*29*	520	565	615	*29*
14 Thigh – inner length	430	485	535	*31*	430	480	525	*29*
15 Knee height	480	525	575	*30*	455	500	540	*26*
16 Under thigh height	385	425	470	*27*	355	395	440	*26*
17 Shoulder breadth a)	400	445	485	*26*	345	385	425	*23*
18 Shoulder breadth b)	350	375	405	*17*	320	350	380	*17*
19 Hip width	305	350	395	*28*	310	370	430	*37*
20 Chest depth	225	260	290	*20*	220	265	305	*26*
21 Abdominal depth	245	300	355	*33*	225	270	320	*30*
22 Elbow – shoulder length	320	350	385	*19*	295	320	350	*17*
23 Elbow – fingertip length	425	460	490	*20*	390	420	450	*19*
24 Arm – shoulder to fingertip	700	755	810	*34*	640	690	740	*31*
25 Arm – shoulder to grip	595	645	695	*30*	540	590	635	*28*
APPENDAGES								
26 Head length	175	190	200	*7*	165	175	185	*7*
27 Head breadth	140	150	160	*6*	130	140	150	*5*
28 Hand length	170	185	200	*9*	155	170	185	*9*
29 Hand breadth	75	85	90	*5*	65	75	80	*4*
30 Foot length	235	255	280	*13*	210	230	250	*12*
31 Foot breadth	85	95	105	*6*	80	85	95	*5*
REACH								
32 Span	1605	1735	1860	*78*	1460	1570	1685	*68*
33 Elbow span	840	915	985	*44*	760	830	900	*41*
34 Vertical grip reach – standing	1840	1965	2090	*75*	1725	1835	1950	*68*
35 Vertical grip reach – sitting	1110	1205	1295	*57*	1040	1125	1210	*52*
36 Forward grip reach	700	755	805	*32*	640	685	735	*30*

(Source: Pheasant & Haslegrave, 2006, p. 248, table 10.5)

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Table IV British children dimensions aged 11 years old

This table provides anthropometric data to be used for primary school children, corresponding to the numbered measurements in Figure 2.2. For other percentiles, use the SD and 50th %ile values and the method shown in Section 2.4.

	Boys				Girls			
DIMENSIONS	**5th %ile**	**50th %ile**	**95th %ile**	***SD***	**5th %ile**	**50th %ile**	**95th %ile**	***SD***
STANDING								
1 Stature	1325	1430	1535	*65*	1310	1440	1570	*79*
2 Eye height	1215	1315	1415	*62*	1195	1325	1455	*78*
3 Shoulder height	1060	1160	1260	*60*	1050	1165	1280	*69*
4 Elbow height	795	890	985	*57*	800	890	980	*56*
5 Hip height	685	765	845	*50*	670	750	830	*48*
6 Knuckle height	560	620	680	*35*	575	645	715	*42*
7 Fingertip height	460	520	575	*35*	475	545	615	*42*
SITTING								
8 Sitting height	685	740	795	*34*	680	745	810	*41*
9 Sitting eye height	575	620	665	*28*	570	635	700	*39*
10 Sitting shoulder height	425	470	515	*26*	415	470	525	*33*
11 Sitting elbow height	160	200	240	*24*	155	200	245	*26*
12 Thigh – thickness	100	120	140	*11*	100	125	150	*16*
13 Thigh – outer length	435	480	525	*28*	430	490	550	*37*
14 Thigh – inner length	345	395	445	*30*	365	410	455	*26*
15 Knee height	420	460	500	*25*	405	455	505	*30*
16 Under thigh height	330	375	420	*26*	335	375	415	*24*
17 Shoulder breadth a)	300	345	390	*26*	285	340	395	*34*
18 Shoulder breadth b)	280	315	350	*21*	280	315	350	*21*
19 Hip width	220	265	310	*27*	225	280	335	*34*
20 Chest depth	130	170	210	*24*	115	175	240	*38*
21 Abdominal depth	150	190	230	*23*	145	195	245	*29*
22 Elbow – shoulder length	270	300	325	*16*	265	300	330	*20*
23 Elbow – fingertip length	350	385	420	*22*	340	385	430	*28*
24 Arm – shoulder to fingertip	560	630	700	*43*	555	630	705	*46*
25 Arm – shoulder to grip	460	530	600	*43*	455	530	605	*46*
APPENDAGES								
26 Head length	170	185	200	*8*	155	170	185	*8*
27 Head breadth	135	145	155	*5*	125	135	145	*5*
28 Hand length	140	155	170	*10*	135	155	175	*11*
29 Hand breadth	60	70	80	*5*	60	70	80	*5*
30 Foot length	205	225	245	*13*	195	220	245	*14*
31 Foot breadth	75	85	95	*7*	75	85	95	*7*
REACH								
32 Span	1310	1440	1570	*78*	1270	1415	1560	*87*
33 Elbow span	685	760	830	*44*	660	750	835	*53*
34 Vertical grip reach – standing	1575	1740	1905	*100*	1575	1760	1945	*111*
35 Vertical grip reach – sitting	895	990	1080	*56*	900	990	1085	*56*
36 Forward grip reach	535	595	655	*37*	530	600	670	*42*

(Source: Pheasant & Haslegrave, 2006, p. 272, table 10.31)

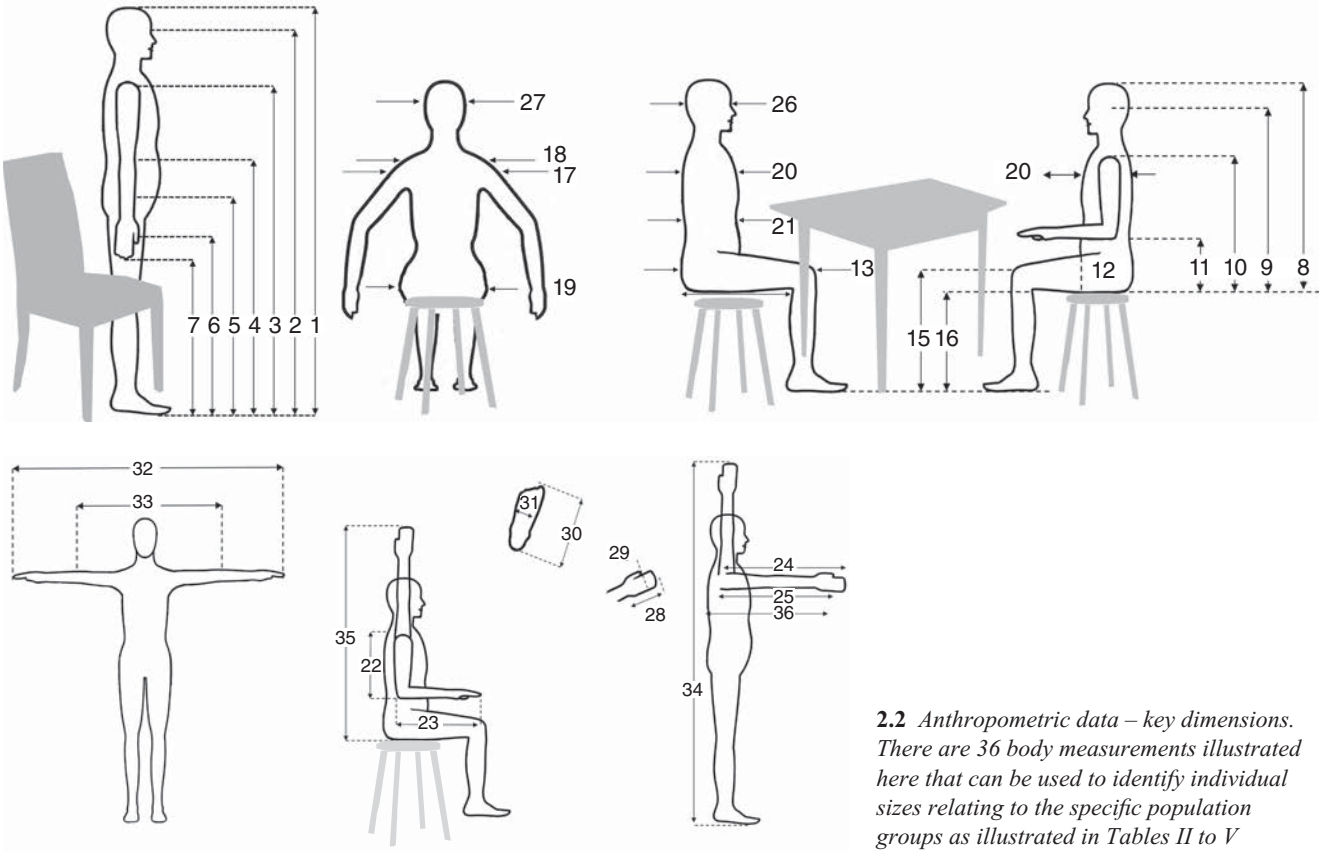
Table V British children dimensions aged 18 years old

This table provides anthropometric data to be used for secondary school children, corresponding to the numbered measurements in Figure 2.2. For other percentiles, use the SD and 50th %ile values and the method shown in Section 2.4.

	Boys				Girls			
DIMENSIONS	**5th %ile**	**50th %ile**	**95th %ile**	***SD***	**5th %ile**	**50th %ile**	**95th %ile**	***SD***
STANDING								
1 Stature	1660	1760	1860	*60*	1530	1620	1710	*56*
2 Eye height	1555	1650	1745	*59*	1430	1520	1610	*55*
3 Shoulder height	1355	1445	1535	*54*	1235	1320	1405	*52*
4 Elbow height	1010	1105	1175	*44*	940	1010	1080	*42*
5 Hip height	865	935	1005	*43*	755	820	885	*40*
6 Knuckle height	705	765	825	*35*	670	725	780	*32*
7 Fingertip height	585	640	700	*35*	560	610	665	*32*
SITTING								
8 Sitting height	860	915	970	*32*	800	855	910	*32*
9 Sitting eye height	745	800	855	*32*	695	745	795	*30*
10 Sitting shoulder height	550	600	650	*30*	515	560	605	*28*
11 Sitting elbow height	200	245	290	*26*	185	230	275	*26*
12 Thigh – thickness	135	160	185	*15*	120	145	170	*14*
13 Thigh – outer length	545	590	635	*26*	515	560	605	*28*
14 Thigh – inner length	450	500	550	*29*	435	480	525	*27*
15 Knee height	505	550	595	*26*	455	500	545	*26*
16 Under thigh height	405	445	485	*25*	365	405	445	*25*
17 Shoulder breadth a)	415	455	495	*23*	360	395	430	*21*
18 Shoulder breadth b)	365	395	425	*17*	335	360	385	*16*
19 Hip width	300	340	380	*25*	300	345	390	*27*
20 Chest depth	190	225	260	*21*	195	235	275	*24*
21 Abdominal depth	205	240	275	*21*	185	220	255	*20*
22 Elbow – shoulder length	340	370	395	*17*	310	335	360	*16*
23 Elbow – fingertip length	450	480	510	*18*	395	425	455	*17*
24 Arm – shoulder to fingertip	740	790	840	*31*	660	710	760	*29*
25 Arm – shoulder to grip	615	665	715	*31*	550	595	645	*29*
APPENDAGES								
26 Head length	185	200	215	*8*	170	180	190	*7*
27 Head breadth	145	155	165	*5*	135	145	155	*5*
28 Hand length	175	190	205	*8*	160	175	190	*8*
29 Hand breadth	85	90	95	*4*	70	75	80	*4*
30 Foot length	250	270	290	*12*	220	240	260	*11*
31 Foot breadth	90	100	110	*5*	80	90	100	*5*
REACH								
32 Span	1695	1810	1925	*71*	1520	1620	1720	*62*
33 Elbow span	890	955	1020	*40*	795	855	920	*38*
34 Vertical grip reach – standing	2045	2150	2255	*65*	1830	1970	2110	*85*
35 Vertical grip reach – sitting	1170	1250	1335	*52*	1065	1150	1235	*52*
36 Forward grip reach	675	740	805	*41*	610	670	730	*37*

(Source: Pheasant & Haslegrave, 2006, p. 279, table 10.38)

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2.2 *Anthropometric data – key dimensions. There are 36 body measurements illustrated here that can be used to identify individual sizes relating to the specific population groups as illustrated in Tables II to V*

3 ERGONOMICS

3.1 Introduction

Ergonomics is strictly the science of work including the people, the methods and the tools they use, but it also includes the places they work in and significantly also the psychological aspects of that environment (Pheasant & Haslegrave 2006). For the purposes of ergonomic design however we can limit ourselves to the collection of data that with appropriate referencing permit satisfactory, although conventional, design solutions focused on the user. The term conventional design is used here to differentiate it from the equally important (if not more so) universal design referred to in the introduction.

True ergonomic design aims to *fit the job to the worker and the product to the user*, including equal reference to criteria such as efficiency, ease of use, comfort, health & safety and quality of working life (Pheasant & Haslegrave 2006). Here we limit ourselves to some practical data for use in conventional domestic and non-domestic building design. This data is broken down into two main areas:

- Personal working spaces – heights and reach when sitting or standing.
- Maintenance and access – openings and space requirements.

3.2 Personal working spaces

Sitting at work

Given the variation in human dimensions, it follows that the spaces humans require will also vary and can be planned for by using the statistical tools provided. In addition however, there are also strict regulatory requirements governing the design and manufacture of most work related furniture. The design of an office desk for example could be subject to requirements coming under the jurisdiction of:

- International Standards (ISO)
- European Standards (EN)
- British Standards (BS)
- British Health & Safety (HSE).

The sizes required for computer workstations are therefore tightly controlled as well as following ergonomic principles. Figure 2.3 illustrates the sizes required for desks to accommodate computers and associated chairs. These dimensions are simplified however as the actual requirements are understandably complicated. For instance, the height of a desk should be suitable for everyone who may need to use it. A height of 740 mm can accommodate 95 per cent of the population whereas a height adjustable desk (from 660 mm to 900 mm) can accommodate almost everyone.

Standing at work and home

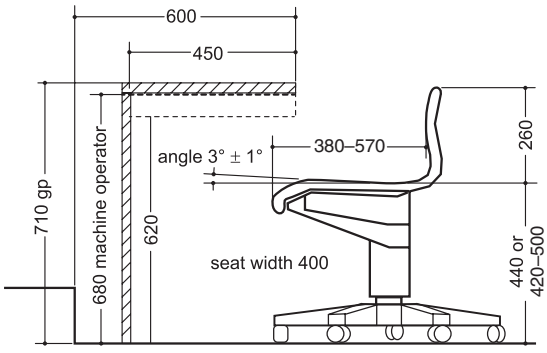
Common practice for work surface heights suggests:

- For delicate tasks – from 50–100 mm above elbow height.
- For manipulative tasks needing some force – from 50–100 mm below elbow.
- For heavy work – from 100–300 mm below elbow height.

With the great variety of human sizes and the variety of tasks usually associated with work surfaces, standardised work surface heights are by definition compromised solutions. However specialist tasks can be accommodated and surface heights designed around those tasks.

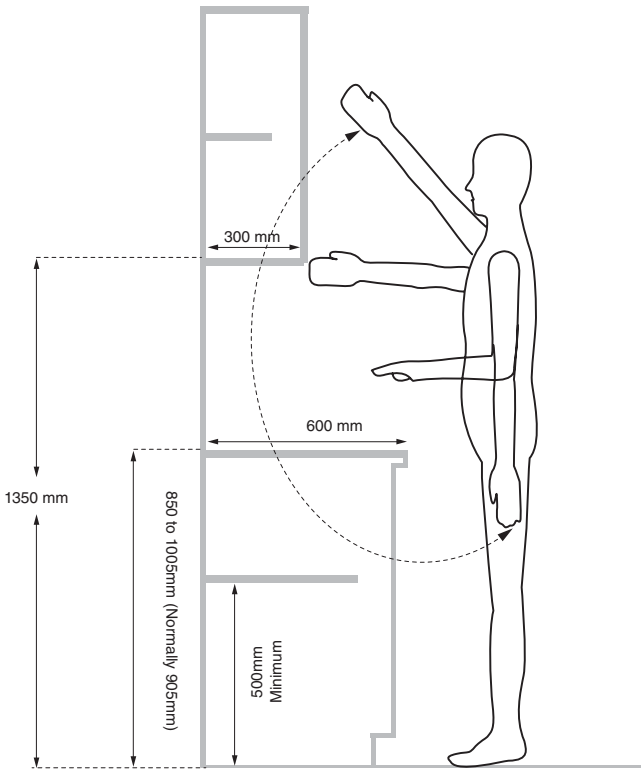
Kitchen heights

Domestic kitchen worktops are included here as functional working areas because they illustrate both the basic design requirements and the compromises necessary to accommodate standard population



2.3 *Sitting worktop – useful working dimensions for deskspace or computer workstations but more detailed information should be sought for specialist or specific tasks*

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2.4 *Sitting worktop – useful working dimensions for kitchens or similar spaces but more detailed information should be sought for specialist or specific tasks*

variations. Although Figure 2.4 illustrates the normal heights for kitchen units the story behind these figures makes useful reading.

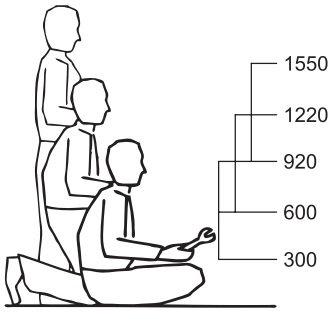
As with the common practice heights above, research (Pheasant & Haslegrave 2006) suggests that there are also three 'working heights' for kitchen design. But the weighted conclusions pointed to the ideal height as being 100 mm below elbow height. For the 50%ile for British adults this provides a figure of 905 mm for women and 990 mm for men. However the range from the 5%ile women to the 95%ile men goes from 830 to 1005 mm. The dimensions recommended here assume that the data will be used to design for a wide range of the British population but aimed specifically to accommodate 95 per cent of the elderly whose strength, reach etc., is most likely to be limited. For more specific populations where heights can be individualised as in specific workplaces, please refer to specialist literature e.g. British Health & Safety (HSE).

Accessing storage at work and home.

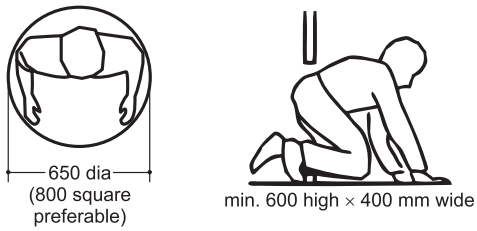
The ideal layout of storage space and its accessibility bears a strong relationship to the weights involved, the frequency of use and the range of people involved. Here again we turn to the domestic kitchen to detail recommendations for storage zones. The heaviest and certainly the most dangerous items to be used and stored are dishes and pots lifted into and out of ovens. Research (Noble 1982) suggests that 300 mm deep and 1400 mm high (reduced to 1350 mm when reaching over an obstruction) shelves can be used by 95 per cent of the elderly population. As this group are more likely to have difficulty in kneeling and bending, deep shelves should be kept above 500 mm. It is worth noting here that the optimal storage height is also the most advantageous worktop height, resulting in maximum demand for space in this zone.

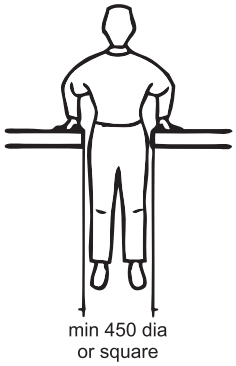
3.3 Maintenance, access and openings

Buildings need constant maintenance, whether it is the services that are located within the building or the building fabric itself. These are not publically accessible spaces and, as there is a requirement to provide a safe working environment, also fall within relevant Health & Safety legislation (the list is extensive but can be accessed at www.hse.gov.uk). As the access required is also very task specific, it is well beyond the scope of this work to go into any detail, particularly as it could legitimately be restricted to certain people, i.e. those who are sufficiently able and agile. Some general and basic dimensions are provided in Figures 2.5 to 2.10.

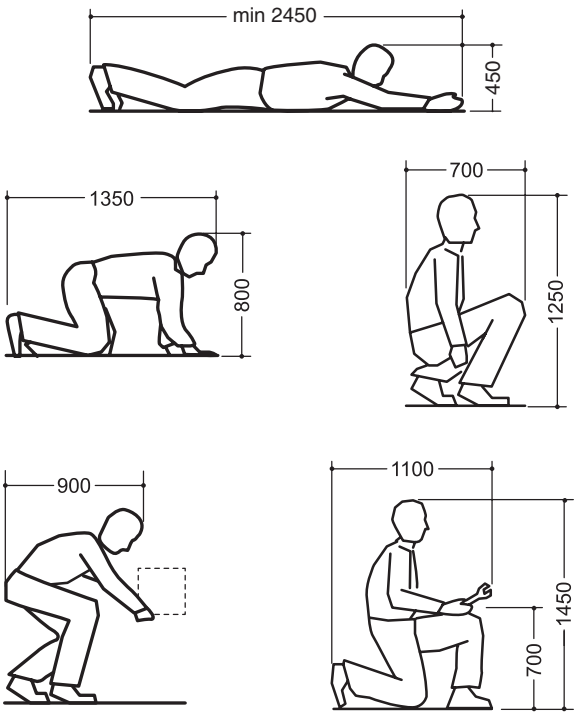


2.5 *Body clearance: maintenance reach levels*



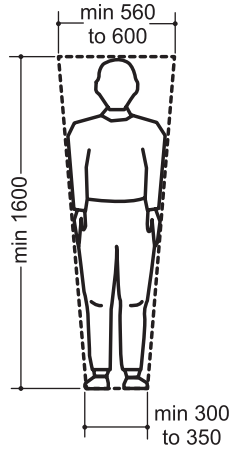


2.6 *Service accesses*

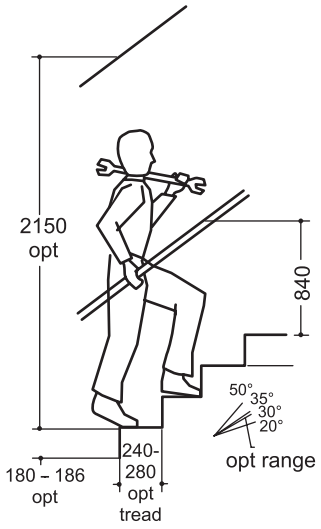


2.7 *Body clearances*

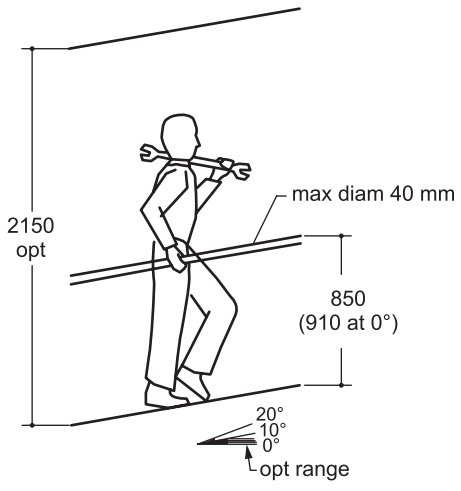
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2.8 *Service access: catwalk*



2.9 *Service access: stairs*



2.10 *Service access: ramps*

4 SANITARY PROVISION

4.1 Inclusivity

The space requirements for sanitary facilities should be designed to accommodate the needs of all a building's users as those users could include adults and children of all ages, sizes and abilities. Be they independent, accompanied, or assisted, it is assumed that a universal (or inclusive) design approach will be adopted to ensure that the facilities can be accessed and used by that diverse population.

The extent of the provision in a particular building will depend on its type and size, the occupancy, patterns of use and gender ratio. It is recognised that females take longer to use toilet facilities than males so the gender ratio should be taken into account, recognising that the ratio may change over time. To illustrate this the British Toilet Association recommends that the required number of female cubicles should equal *twice* the number of male cubicles and urinals added together.

The added value of an inclusive design approach that addresses the needs of one group can have benefits for many others as well. Level access facilities designed for wheelchair users are also helpful for people with sticks, crutches, frames, pushchairs, luggage or other mobility aids, larger compartments likewise and clear signage can help those with reading difficulties or whose first language is not English, as well as the poorly sighted. Wheelchair-accessible compartments can also be preferable for those using assistance dogs, those with dwarfism, parents with small children, those accompanied by carers, anyone with luggage and many more.

It is estimated that about 20 per cent of the adult population in the UK (around 11.7 million people) are covered by the disability legislation, there are around 5,000 working assistance dogs and around half a million people use a wheelchair all or part of the time. In addition there are 3.3 million families with children under the age of five (*Housing Design Standards, Evidence Summary*, 2010).

4.2 Design aspects

Provision of sanitary facilities

In the provision of sanitary facilities compromise is always probably necessary because of the large gap between what is desirable and what is possible. Therefore minimum requirements provide the starting point for particular building types and circumstances. Good design practice would use these as minima but with the aim of inclusive design solutions always uppermost. The overall scale of the provision will depend on:

- The size and particular nature of the building as well as the people being catered for. This is an aspect that should be considered very early in the design process and should involve consultation with a wide range of interested parties from users to regulatory authorities. For particular building types, suggested gender ratios are given in Table VI.

Table VI Gender ratios

The figures given here are based on predicted ratios and can be used to provide an initial assessment of the balance of sanitary facilities required.

Building type	Predicted ratio
Assembly buildings	50% male and 50% female
Swimming pools	50% male and 50% female
Cafes, nightclubs, restaurants	50% male and 50% female
Theatres and concert halls	50% male and 50% female
Public houses	**75% male and 25% female**
Shopping centres	**35% male and 65% female**

(Source, p 14, table 5.1, *Building for Everyone: A Universal Design Approach, Sanitary facilities 5,* Centre for Excellence in Universal Design, Dublin, 2012)

- Access routes and convenience in relation to other key facilities within a building. Routes to toilets should be as short as possible. In large public buildings, the horizontal travel distance to the nearest toilet facilities should not exceed 40 m. In schools, this is reduced to 25 m. In addition, a clearly identified, fully accessible unisex toilet should be provided on each floor of a building with a lift. If no lift is available accessible toilet facilities should provided at the entrance level. The sanitary requirements for schools are given in Table VII.

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Table VII Sanitary requirements in schools

Type of school	Sanitary item	Number	*Notes*
special	wc urinal	1 per 10 pupils	*Not more than 2/3 of boys' appliances to be urinals*
	washbasin	1 per WC or urinal	*Every WC or urinal to be close to a washbasin*
	shower	1 per 10 pupils	*Where provided*
nursery	WC	1 per 10 pupils, not less than 4	
	washbasin	1 per WC or urinal	
	sink, bath or shower	1 per 40 pupils	
primary	wc and urinal	1 per 10 pupils under 5 years 1 per 15 pupils over 5 years	*Not more than 2/3 of boys' appliances to be urinals*
	washbasin	1 per WC or urinal	*Every WC or urinal to be close to a washbasin*
	shower	1 per 10 pupils	*Where provided*
secondary	boys' WC and urinal	1 per 20 pupils	*Not more than 2/3 of boys' appliances to be urinals*
	girls' WC	1 per 20 pupils	
	washbasin	1 per WC or urinal where there are up to 3 appliances 2 per 3 WCs or urinals where there are more than 3 appliances	*Every WC or urinal to be close to a washbasin*
	shower	1 per 10 pupils	*Easy access for all places where physical education takes place*
boarding school (residential)	boys' WC and urinal	1 per 5 boarders, 2/3 to be urinals	*These provisions are in addition to those sanitary items shown above in this table, unless they are close to living and sleeping areas*
	girls' WC	1 per 5 boarders	
	washbasin	1 per 3 boarders	
	bath and shower	1 per 10 boarders, minimum 25% to be baths	

(Source, Armitage Shanks, *Schools Solutions . . . what works and why, an informative guide to school washroom requirements*, 2007)

- Likely use patterns such as those in a concert arena or cinema having a much greater demand during the intervals. The number in this case should serve the maximum number of people likely to make use of the facilities at these times. The sanitary requirements for some public assembly settings are given in Tables VIII to Table X.

Table VIII Sanitary requirements in cinemas, theatres etc.

Sanitary item	Males	Females
WC	In single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 1 for up to 250 males plus 1 for every additional 500 (or part of 500) males.	In single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 2 for up to 40 females 3 for 41 to 70 females 4 for 71 to 100 females plus 1 for every additional 40 (or part of 40) females.
Urinal	In single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 2 for up to 100 males plus 1 for every additional 80 (or part of 80) males.	
Wash Basins	1 per WC plus 1 per 5 (or part of 5) urinals.	1, plus 1 per 2 (or part of 2) WCs.
Cleaners' Sink	Adequate provision should be made for cleaning facilities including at least one cleaners' sink.	

(Source: the Food Team, Environmental Health, Canterbury City Council, n.d.)

Table IX Sanitary requirements in cafes & restaurants etc.

Sanitary item	Male customers	Female customers
WC	1 per 100 up to 400 males plus 1 for every additional 250 (or part of 250) males	2 per 50 up to 200 females plus 1 for every additional 100 (or part of 100) females
Urinal	1 per 50 males	
Wash Basins	1 per WC and plus 1 per 5 (or part of 5) urinals.	1 per WC
Cleaners' Sink	Adequate provision should be made for cleaning facilities including at least one cleaners' sink.	

(Source: the Food Team, Environmental Health, Canterbury City Council, n.d.)

Table X Sanitary requirements in hotels & guest houses

Type of accommodation	Sanitary facilities	Number	Notes
Hotel with en-suite accommodation	En-suite	1 per residential guest bedroom	*Containing: bath/shower, WC and wash basin*
	Staff bathroom	1 per 9 residential staff	*Containing: bath/shower, WC and wash basin*
	Bucket/cleaners' sink	1 per 30 bedrooms	*At least 1 on every floor*
Hotels and guest houses without en-suite accommodation	WC	1 per 9 guests	
	Wash basin	1 per bedroom	
	Bathroom	1 per 9 guests	*Containing: bath/shower, wash basin and additional WC*
	Bucket/cleaner's sink	1 per floor	
Tourist Hostels	WC	1 per 9 guests	
	Wash basin	1 per bedroom or 1 for every 9 guests in a dormitory	*Containing: bath/shower, washbasin and additional WC*
	Bathroom	1 per 9 guests	
	Bucket/cleaner's sink	1 per floor	

(Source: the Food Team, Environmental Health, Canterbury City Council, n.d.)

Layouts for sanitary facilities – accessible facilities

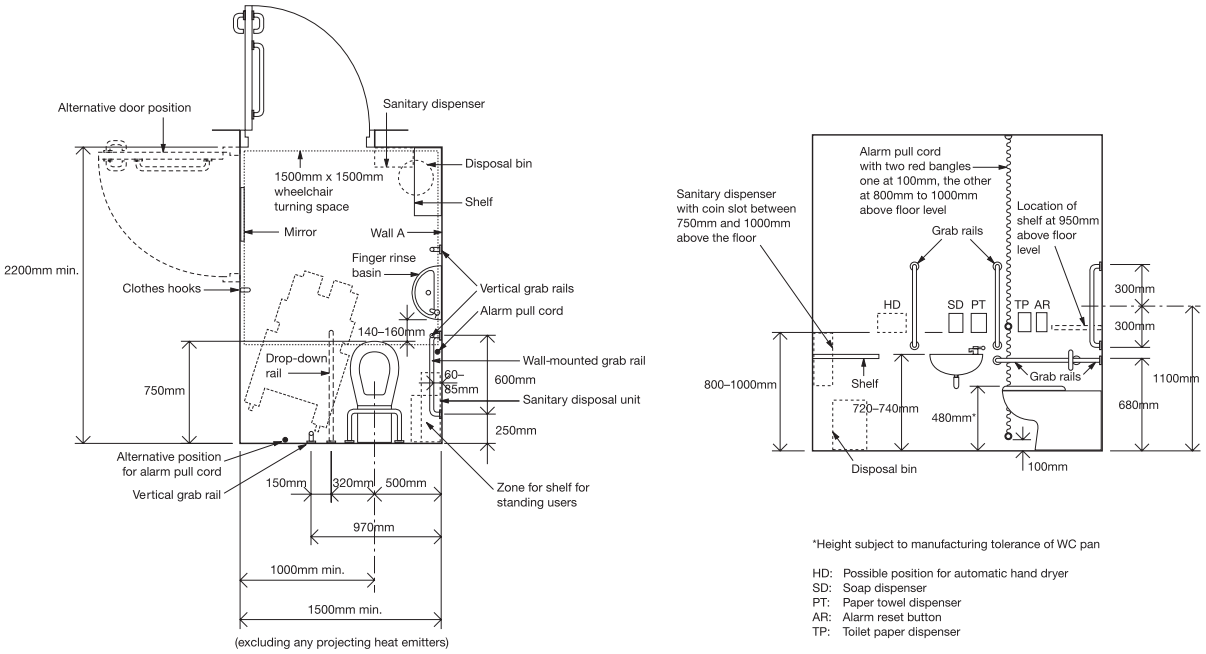
There are clear minimum size requirements for accessible sanitary facilities as outlined in Part M of the Building Regulations where recommended layouts and positions of individual appliances are also covered. In addition, the *Good Loo Design Guide* (2004) and the Volume 5 (Sanitary Facilities) (2012) from the Centre for Excellence in Universal Design are exceptionally good design guides in this area, covering the principles in depth. Figures 2.11 to 2.17 outline the requirements for accessible sanitary accommodation. Figures 2.11 to 2.16 contain public sector information licensed under the Open Government License v2.o.

Compartments and cubicles

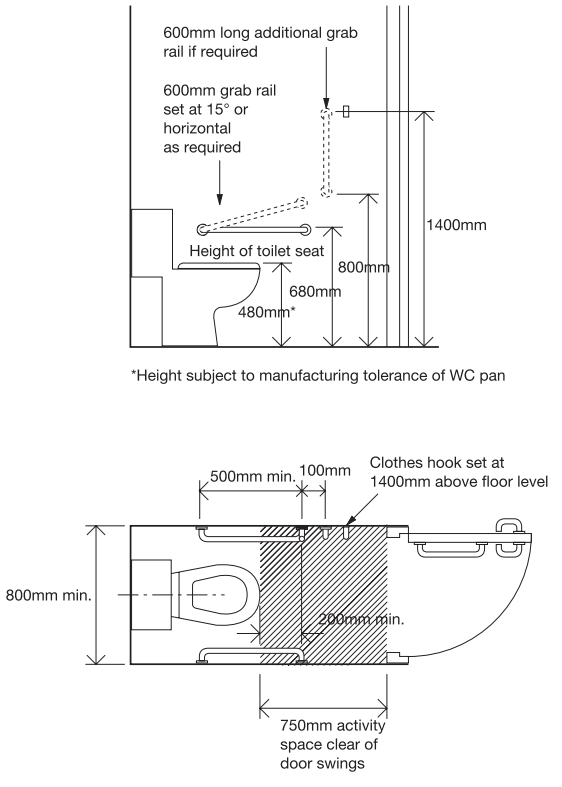
To provide the requisite numbers of sanitary facilities within a defined space envelope there is still the need to provide some that do not meet the accessibility standards. WC *compartments* (fully enclosed) and WC *cubicles* (partitions only) need to ensure privacy. The doors are traditionally a problem area as inward opening doors require more space and outward opening doors compromise the safety of others outside of the cubicle. The space requirements and possible layouts for single WC layouts with both opening styles are illustrated in Figures 2.18 to 2.22.

Hand washing facilities are also a requirement and can be provided within each compartment/cubicle, although efficient space use would normally place them in an adjoining space if possible. The space requirements and possible layouts for single WC layouts with washbasins and both opening door styles are illustrated in Figures 2.23 to 2.29.

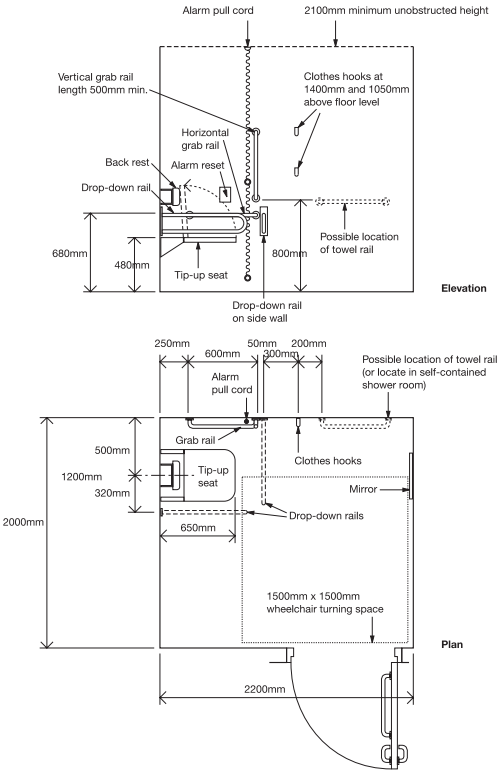
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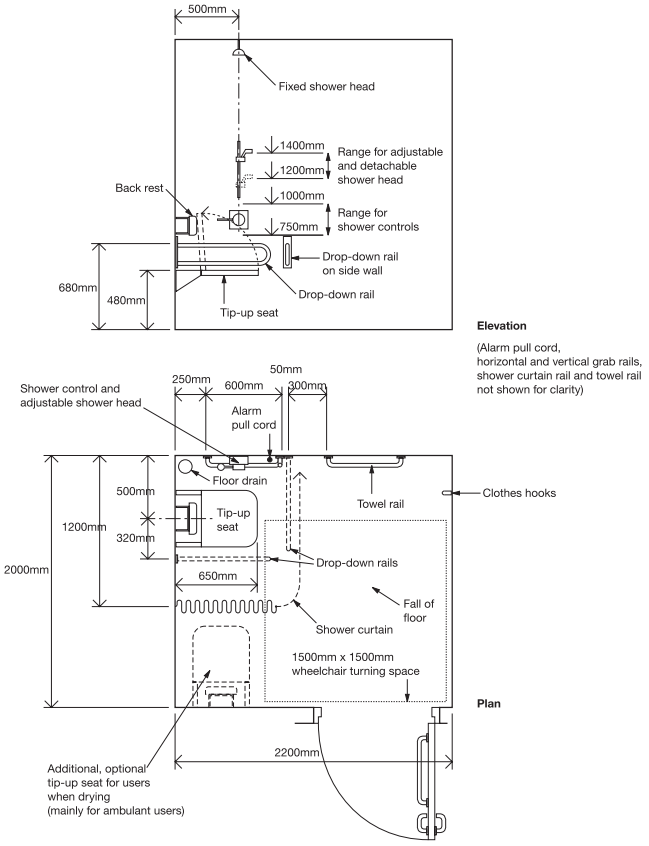
2.11 *Unisex wheelchair-accessible toilet (Source: Building Regulation Part M Diagrams 18, 19, 20)*



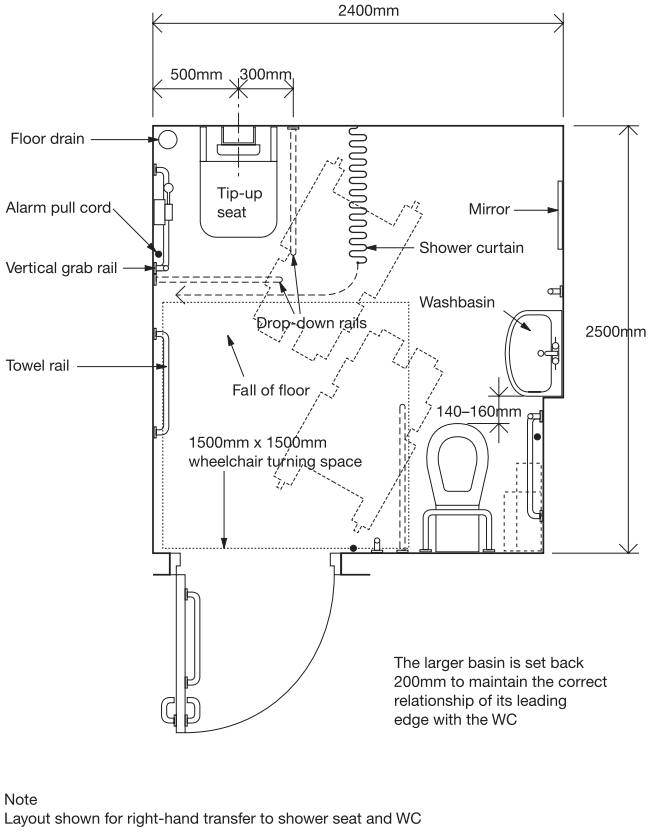
2.12 *Accessible toilet cubicle (Source: Building Regulation Part M Diagram 21)*



2.13 *Accessible self-contained changing room (Source: Building Regulation Part M Diagram 22)*

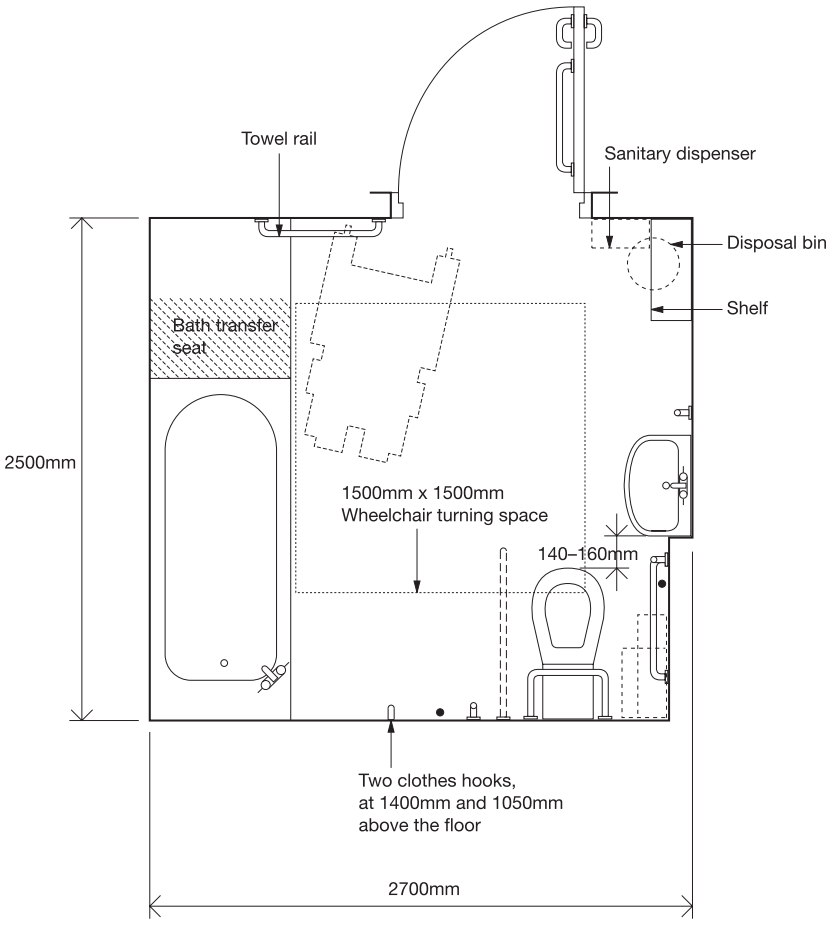


2.14 *Accessible self-contained changing room with shower (Source: Building Regulation Part M Diagram 23)*



Note
Layout shown for right-hand transfer to shower seat and WC

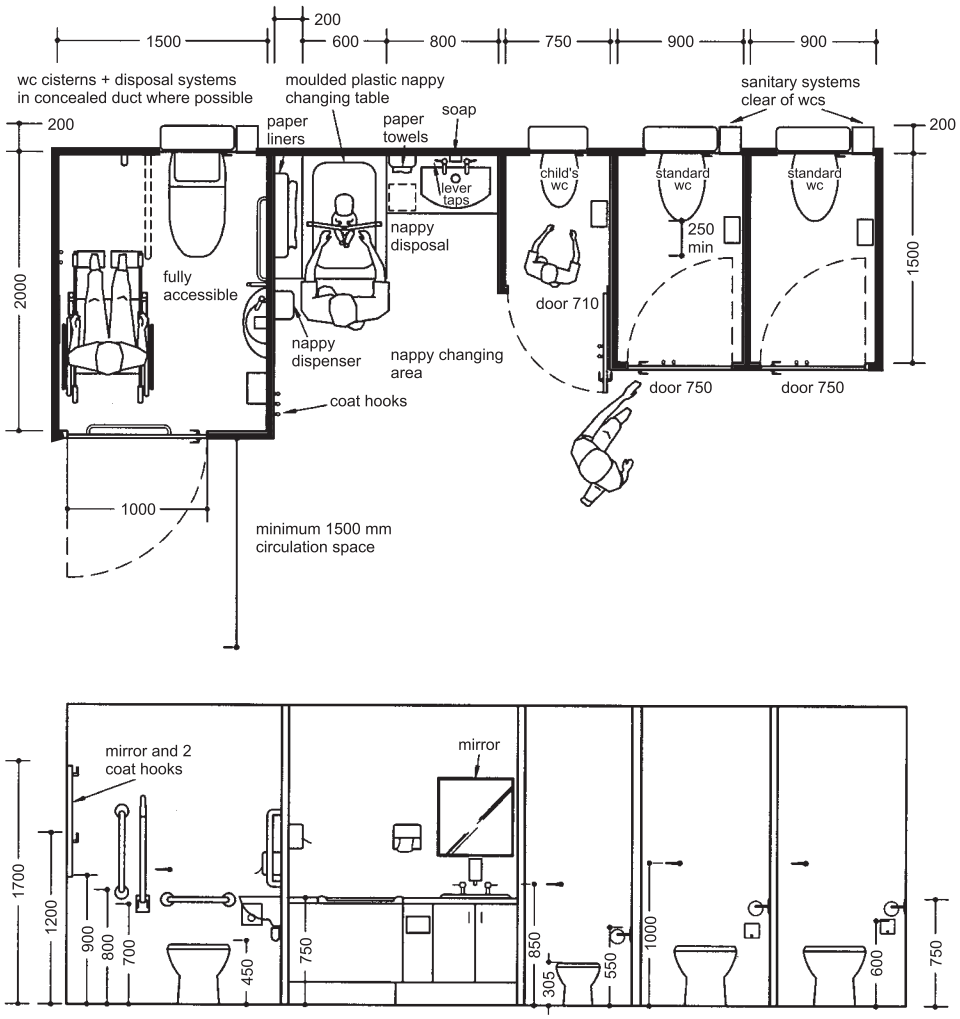
2.15 *Accessible self-contained changing room with toilet & shower (Source: Building Regulation Part M Diagram 24)*



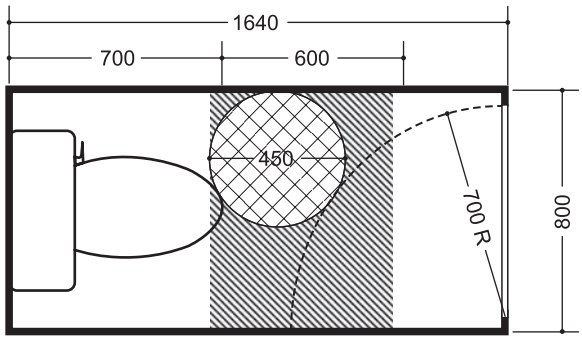
Note
Layout shown for right-hand transfer to bath and WC

2.16 *Accessible self-contained changing room with bath (Source: Building Regulation Part M Diagram 25)*

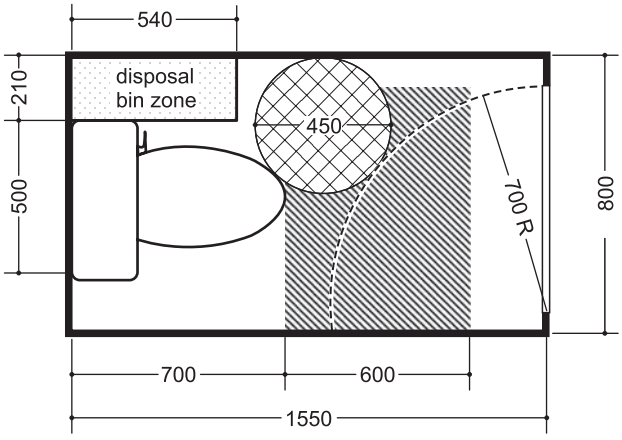
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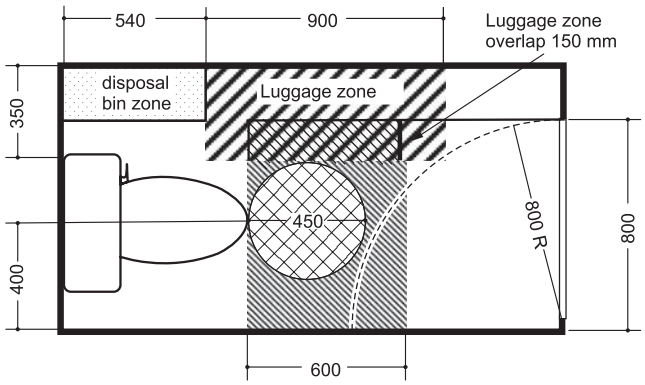
2.17 *A possible layout including baby changing facilities*



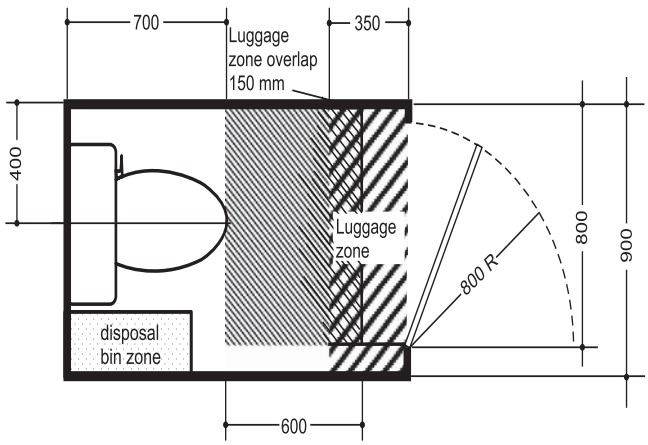
2.18 *WC cubicle, inward-opening door, no sanitary bin zone*



2.19 *WC cubicle, inward-opening door, sanitary bin zone*

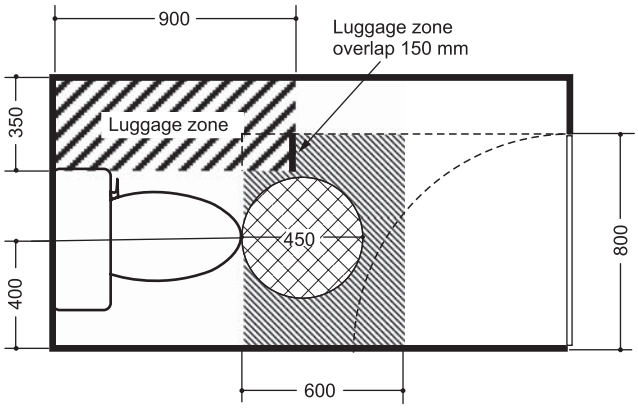


2.20 *Public WC cubicle, inward-opening door*

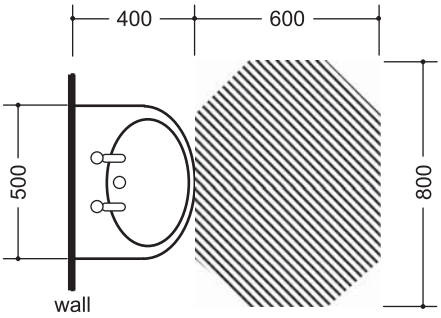


2.21 *Public WC cubicle, outward-opening door*

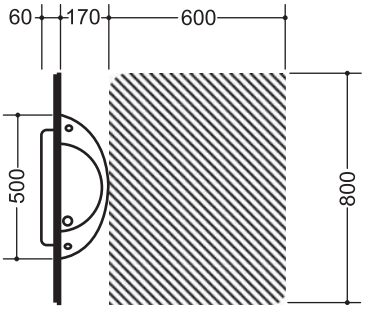
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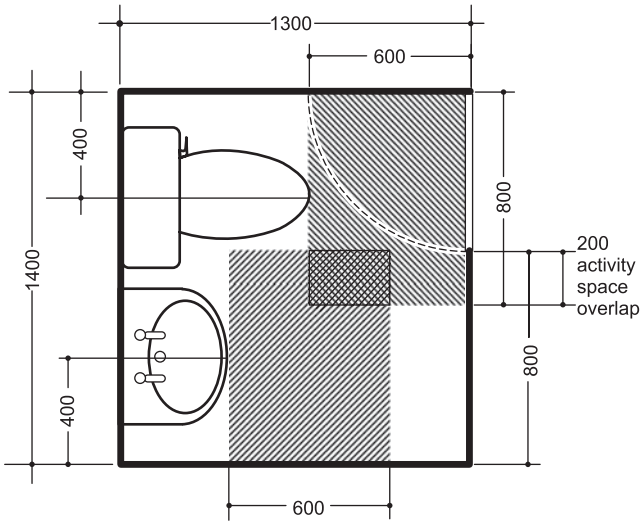
2.22 *Alternative public WC cubicle, inward-opening door, no sanitary bin*



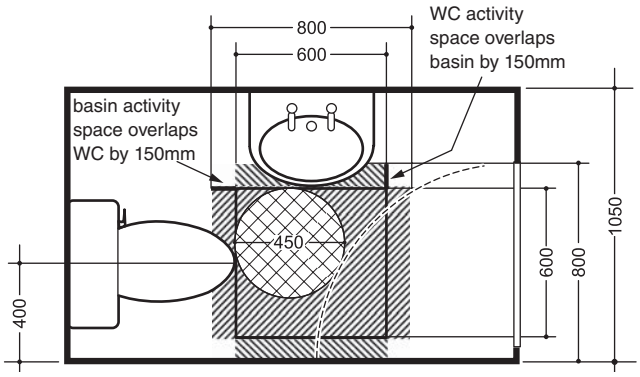
2.23 *Hand-rinse basin and activity space*



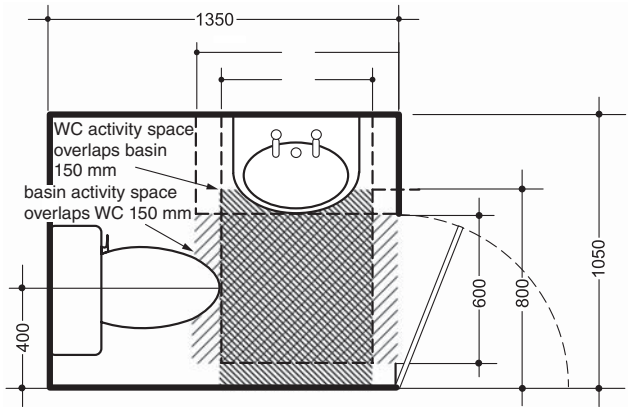
2.24 *Recessed hand-rinse basin and activity space*



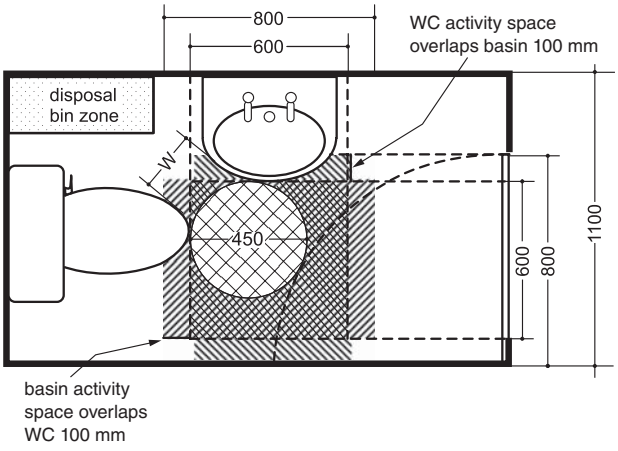
2.25 *WC and washbasin compartment, appliances on same wall*



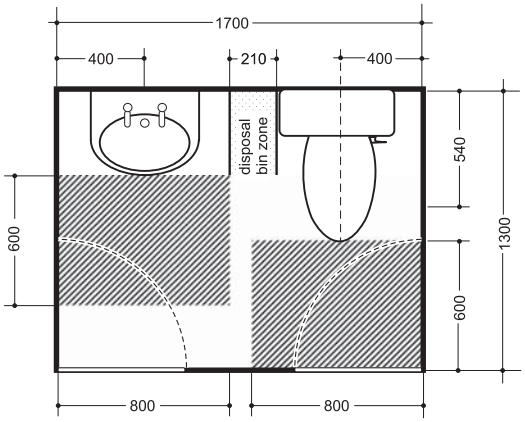
2.26 *WC and washbasin compartment, inward-opening door, appliances on adjacent walls*



2.27 *WC and washbasin cubicle, outward-opening door, appliances on adjacent walls*



2.28 *WC and washbasin cubicle, sanitary bin zone, appliances on adjacent walls*

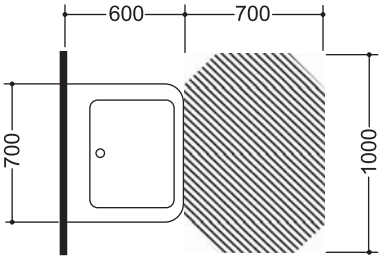


2.29 *WC and washbasin cubicle, sanitary bin zone, appliances on same wall 785 mm to 800 mm for most other situations*

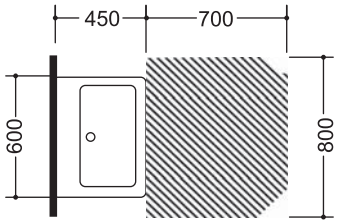
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Communal sanitary spaces

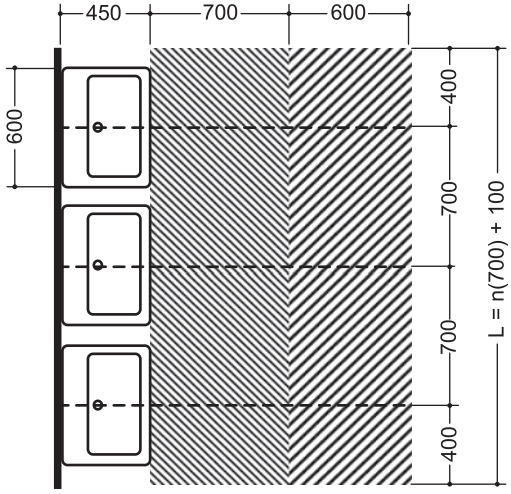
The communal provision of hand washing facilities is the more common and space efficient solution and the space requirements for both individual basins and larger groups are illustrated in Figures 2.30 to 2.33. Fixing heights vary from 700 mm as ideal for smaller children, 760 mm in hospitals and 785 mm to 800 mm for most other situations.



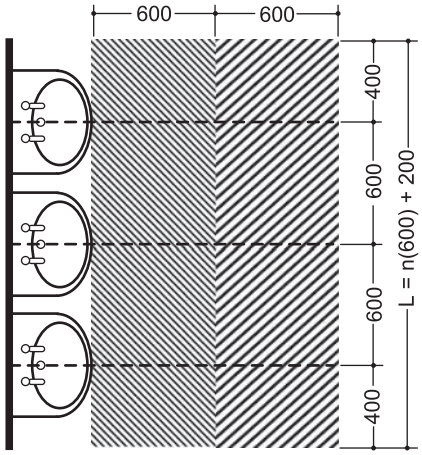
2.30 *Domestic washbasin and activity spaces*



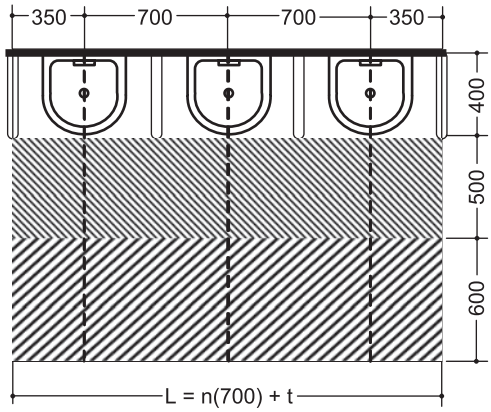
2.31 *Non-domestic washbasin and activity space*



2.32 *Range of non-domestic washbasins, activity and circulation spaces*



2.33 *Range of hand-rinse basins (non-recessed), activity and circulation spaces*



2.34 *Range of urinals, activity and circulation spaces*

Individual urinals (for male use only) are also commonly provided as groups, ranged along rows in a communal fashion. Normally fixed with the leading edge 610 m above floor level with one at 510 mm for small boys. The space requirements are illustrated in Figure 2.34.

Hand drying facilities are generally expected to be provided in close association with the washbasins (up to two washbasins per dryer) and if electrically powered to also have a towel type backup. Heights of 800 mm to 1200 mm are recommended to cover a wider range of people. Positioning within the communal space should avoid doors and obstructions whilst also taking into account traffic flows, aiming to be positioned en route from the washbasins to the exit.

5 DOMESTIC SPACE STANDARDS

There is evidence that space standards are related to health and well-being and although not part of UK national planning frameworks, space standards do currently exist in some district and local planning guidance. These include the Lifetime Homes standard that aims to ensure that new dwellings can adapt to the needs of their occupants, particularly as they change in later life and The Mayor of London's *London Housing Design Guide* (2010).

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3 People and movement

Updated by Professor Norman Wienand

Professor Norman Wienand is head of department for the Natural and Built Environment at Sheffield Hallam University

KEY POINTS:

- *Buildings are generally static but people need to move around them in many different ways*
- *Circulation strategies must be carefully considered with all classes of users, particularly people with different abilities, in mind*
- *Mechanical movement of people in buildings is highly effective but due to the high cost, must be expertly designed to achieve the requisite operating efficiency*

Contents

1. Introduction
2. Access to buildings
3. Horizontal movement within buildings
4. Vertical movement within buildings
5. Mechanical movement around buildings

1 INTRODUCTION

The aim here is to ensure that the design process is founded on the principle that all people – regardless of age, gender or ability – should be able to gain access to buildings and once inside, they should be able to use the building whether it is a home, a place of work or even if just visiting. This means that people moving about that building – its very lifeblood – should be carefully considered in the earliest stages of the design process. It therefore recognises that the overall strategy may need to include plans for access to the building and also horizontal circulation as well as vertical movement between storeys, whether mechanical or human-powered.

This chapter provides some basic design information. But it must not be used to bypass the fundamental principle that a design team should include expert input on the very complicated matter of circulation and the physical constraints, psychological aspects and long-term sustainability of the building. To illustrate this point, lift shafts in particular (a significant structural element) can be designed and arranged to serve the required population needs as part of an overall circulation strategy in the very early stages of the design process.

Figures 3.1 to 3.6, 3.8–3.13, 3.16 contain public sector information licensed under the Open Government Licence v2.0.

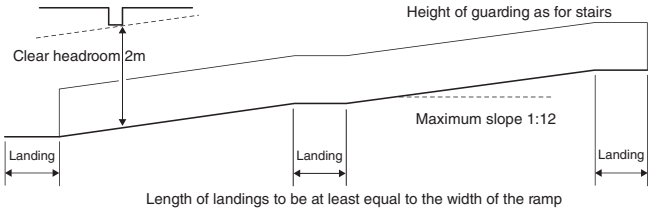
2 ACCESS TO BUILDINGS

2.1 Background

All people should be able to reach the main entrance of the building from the site boundary or designated car parking provision in a way that is suitable and safe. Essential aspects of the design process therefore are the slope involved, the width of access and the materials used in construction. In particular, access routes should be designed so that people can travel along them safely 'without excessive effort and without the risk of tripping or falling' (according to Part M of the Building Regulations). They should also be wide enough to accommodate people moving in different directions.

2.2 Ramps and gradients

A ramp is essentially a sloping pathway, used where a difference in levels exists between the site access point and the main building entrance. There are some clear design requirements (Figure 3.1). First among these is the concept that a slope is not a comfortable place to be for many people, particularly those with impaired mobility because of gravity pulling them down the slope. Level approaches and landings are therefore essential to allow people to stop and take breath if necessary. The length of slope between landings and the steepness (gradient) are also crucial. In addition, any design solution should recognise that some ambulant disabled people find ramps particularly difficult and prefer a stepped access.



3.1 *Ramp design – essential elements are the slope, length and defined landing areas for resting (Source: Building Regulation Part K1 1.10)*

Slope gradients are normally defined in terms of their height to distance ratio. A 1:20 slope is therefore one where for every 1 metre achieved vertically, 20 metres has also been travelled horizontally. This ratio can also be expressed as a percentage where a 1:20 slope equals a 5 per cent change in height for any particular distance travelled. It can also be viewed as an angle of slope where 1:20 equals 2.86°.

For reference, a 1:1 slope (100 per cent), equal to 45°, illustrates that expressions of slope can be counterintuitive.

In designing ramps, it is usual to use the terms 'going' for the horizontal distance travelled and 'rise' for the vertical distance (terms also used in staircase design). Because of the potential difficulties outlined above, ramp gradients and lengths are strictly controlled. Part M of the Building Regulations states that no ramp should have 'a going more than 10 m or a rise more than 500 mm' between level landings. This equates to a 1:20 gradient, although slightly steeper slopes are allowed if the distance travelled is less; for a maximum going of 5 m, a gradient of 1:15 is allowed and at 2 m going it rises to 1:12. Figure 3.2 illustrates the relationship of ramp going and rise and can be used to interpolate for dimensions between the three examples.

2.3 Ramp design

- **Width:** Ramps should be a minimum of 1.8 m wide to allow people and wheelchairs to pass freely. This can be reduced to 1.5 m provided passing spaces (1.8 m) are provided (reduced to 0.9 m for domestic situations).
- **Landings:** Ramps should have level landings. These are defined as 1:60 maximum slope along their length and 1:40 slope cross-fall to allow water drainage. They should be at least 1.2 m long at the foot and head of the ramp with intermediate landings of 1.5 m. Where it is not possible to see the full length of the ramp, 1.8 m square passing space landings should be provided (reduced to 1.2 m for domestic situations).
- **Handrails:** Handrails should be provided on both sides of a ramp (see section **4.3**).
- **Kerbs:** A 100 mm minimum high kerb should be provided on any open side of a ramp and be clearly visible.
- **Surfaces:** All surfaces should be slip resistant especially when wet, and landings should be clearly noticeable and visually contrasting.

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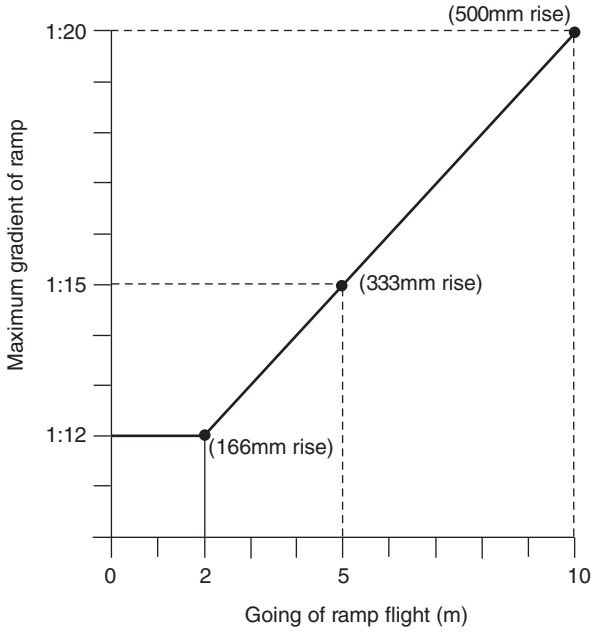
2.4 Stairs

The design of a staircase or a stepped access involves the combination of gradient and the idea of a standard footfall – the step itself. For more complex staircase design, the three-dimensional aspect becomes important where the flight of stairs has to repeat itself above the original, following on from one storey to another so that maintaining sufficient headroom is a primary concern.

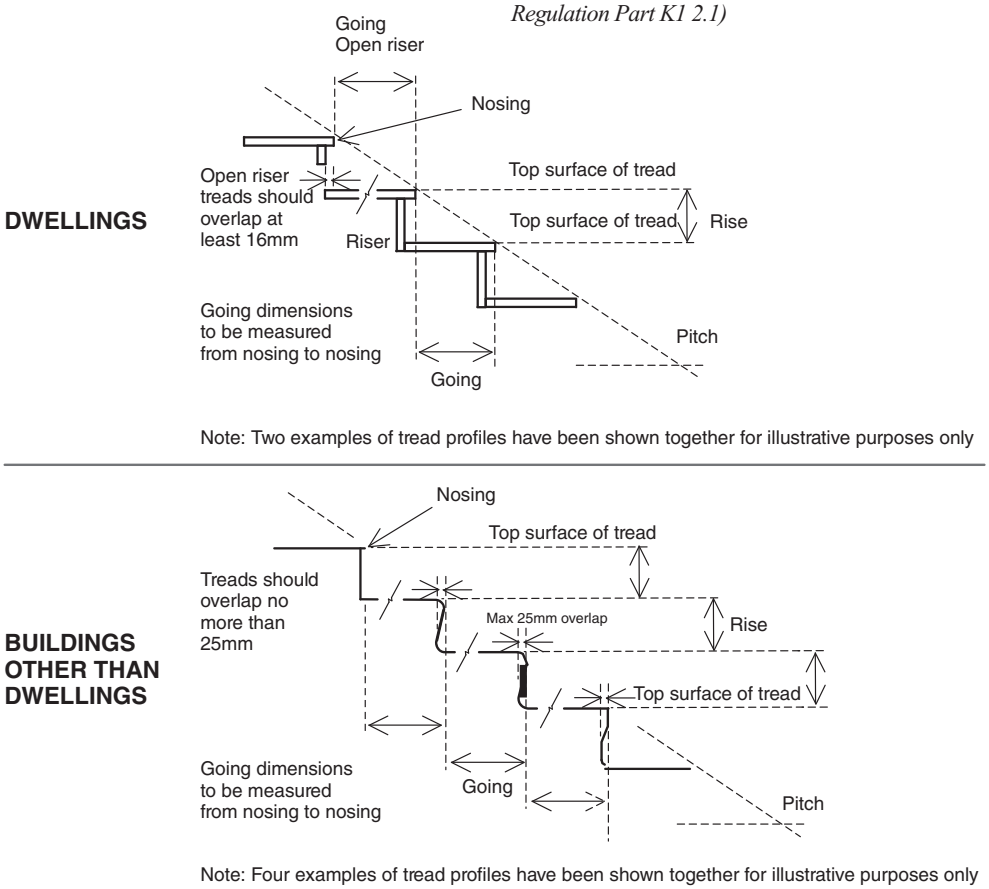
2.5 Step design

One major advantage of steps over ramps is that while ramps offer a sloping surface that can be difficult for many, steps essentially offer a level landing at each step. It is worth noting that a single step rise is not recommended under most circumstances.

As with ramp design, steps have a going and a rise, but in this case it exists for each individual step as well as the overall flight. Traditionally, where space was short, steps were designed with a 'nosing' (Figure 3.3) which for any particular going, allowed a larger space for the footfall. The going is measured from the nosing to nosing but the footfall is in effect the going plus the nosing. For many ambulant disabled or poor sighted people the nosing can present a real hazard as it can catch the toe of the foot when going forward. Poorly sighted people may understandably wish to push their foot to the back of each step to ensure that they are totally secure.



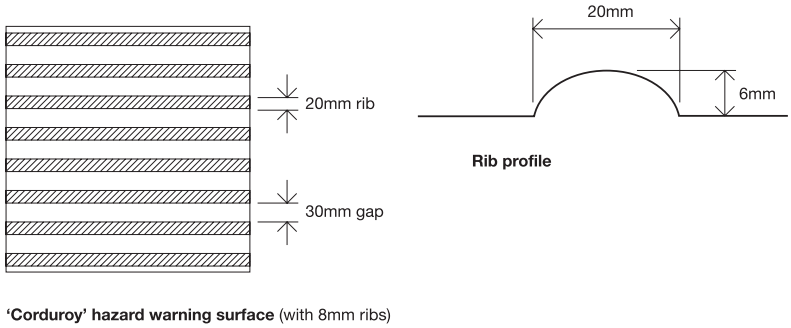
3.2 *Slope design – various permutations can be obtained from this diagram across the permissible range (Source: Building Regulation Part K1 2.1)*



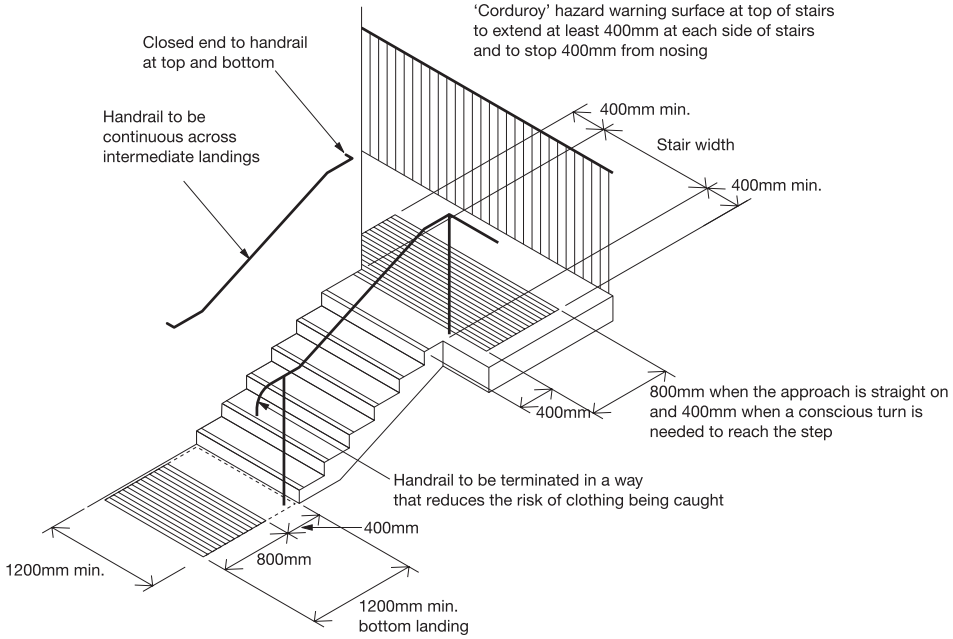
3.3 *Step design – essential elements are the rise, the going and the pitch. See section 4.2 for more on pitch calculation (Source: Building Regulation Part K1 1.1)*

2.6 External stepped access design

- **Width:** Access stairs should be no less than 1.2 m wide (reduced to 0.9 m for domestic situations).
- **Treads**: Treads should be consistent throughout the flight with a rise of between 150 mm and 170 mm and with a going of between 280 mm and 450 mm (reduced to between 75 mm and 150 mm rise with a minimum going of 280 mm in domestic situations). There should be no open risers.
- **Landings:** Access stairs should have landings provided not less than 1.2 m wide, for every 12 risers for a going of less than 350 mm or 18 risers if the going is more than 350 mm (total of 1.8 m rise in domestic situations). There should be at least a 1.2 m level approach at the foot and head of the stair with intermediate landings also of 1.2 m (reduced to 0.9 m for domestic situations).
- **Handrails:** Handrails should be provided on both sides (see Figure 3.4). In the case of stair access that is wider than the minimum, additional



'Corduroy' hazard warning surface (with 8mm ribs)



3.4 *Stepped access design – essential elements are the surfaces, landings and handrails (Source: Building Regulation Part M Diagram 4)*

handrails are required along the centre line to ensure that the effective width of access is not less than 1.0 m, or more than 1.8 m wide.

- **Surfaces:** External stepped access routes need to have warning surfaces provided. These are commonly termed a corduroy hazard warning strip and provide a clearly identifiable change in surface condition that warns of an approaching change in level. A 55 mm wide visually contrasting material is also required on both the tread and riser of each step.

2.7 Access doors

Unless designing main (or alternative access) entrance doors it is important to consider all potential users. Wheelchair users will have certain requirements, as will the poorly sighted or those with limited strength. For example, a manually operated self-closing door set with sufficient power to close against normal wind speeds will probably be beyond the strength capacity of most wheelchair users or those with limited strength.

Specifically, this limit is exceeded when 'the opening force at leading edge of the door is not more than 30N at the leading edge from 0° (the door in the closed position) to 30° open, and not more than 22.5N at the leading edge from 30° to 60° of the opening cycle' (from Building Regulations Part M 2.17 paragraph a). Revolving doors are not considered accessible because of the difficulties they create for a whole host of potential users.

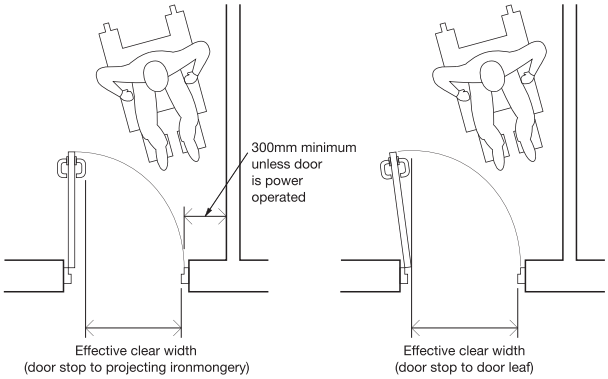
Preferences:

- Glazed doors allow people to see potential obstacles and others approaching, but must also be made visually noticeable for the poorly sighted.
- Powered sliding doors do not waste the space associated with the arc of a door swing, and automatic opening sliding doors do not require access to a manual opening device.
- An opening and closing system operated by remote sensors requires no contact with the door.

2.8 Door width

To take account of different door styles and support systems, the 'effective clear width' is referred to as it states the total width of opening available that is devoid of any obstructions caused by such items as door handles, hinges or limited turning capacity. Unpowered access doors should also have a minimum of 300 mm extra unobstructed space alongside the operating latch to allow for wheelchair approach.

Figure 3.5 provides the minimum effective door widths as defined by Part M of the Building Regulations.



3.5 *Effective door width – wheelchair users need more space to access the opening controls (Source: Building Regulation Part M Diagram 9)*

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3 HORIZONTAL MOVEMENT WITHIN BUILDINGS

3.1 Entrance lobbies

Providing a lobby space at the entrance to a building makes sense in many ways. Environmentally, it can limit uncontrolled air movement, reducing heat loss and draughts. It can also provide a space to shed rainwater to avoid the associated slip hazard further in the building, and it can also provide transitional lighting levels.

3.2 Entrance lobby design

- **Size:** The lobby should be large enough to allow a wheelchair user (accompanied) or a parent with a pushchair to negotiate the doors at either end, clear of the opening arc of the other door, see Figure 3.6. For a lobby length, this means adding 1570 mm to the space created by the arcs. For width, it is the effective clear door width plus 300 mm to allow wheelchair access to the operating system.
- **Surfaces:** Floor surfaces to lobbies should be level without changes in surface that may constitute a trip hazard. They should also assist in the removal of rainwater but without impeding the movement of pushchairs and wheelchairs. Coir matting, for example, is not suitable.

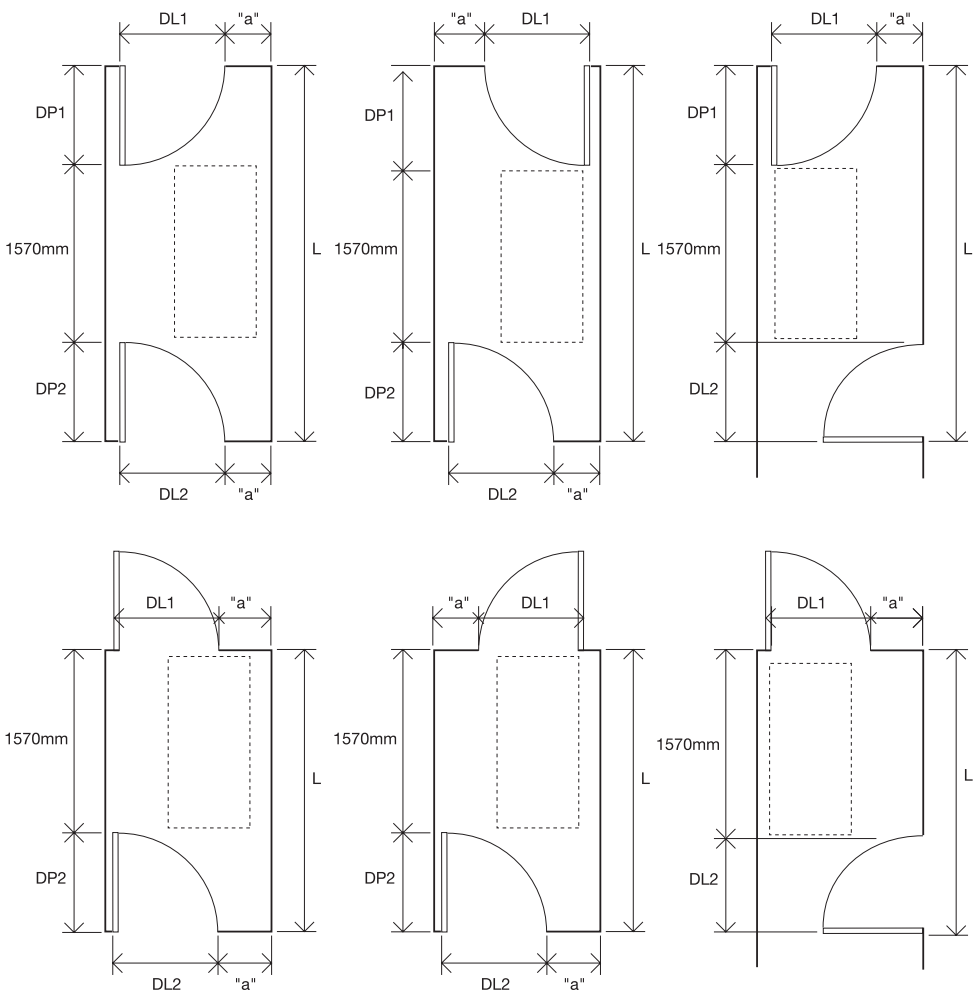
3.3 Corridors

The provision of corridors within buildings will aim to satisfy many different requirements. To satisfy inclusive design principles, minimum sizes and surface material conditions should be expected for general horizontal movement around a building. For other, non-standard access, a more ergonomic approach can be employed.

3.4 Inclusive corridor design

- **Width:** The corridor should be large enough to allow wheelchair users (accompanied) or a parent with a pushchair to move freely. Localised narrowing is acceptable provided the basic principle is not compromised. A minimum unobstructed width of 1200 mm is required with 1800 mm square passing places at intervals.
- **Surfaces:** Floor surfaces to corridors should be level (see Figure 3.2) with a non-slip surface without patterns that may be mistaken for stairs. There should be sufficient contrast between the floor, wall and ceiling to assist people with visual impairment, together with good lighting levels.

For non-standard corridor widths Figure 3.7a–e gives some indication of what can be used.

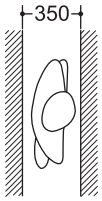


DL1 and DL2 = door leaf dimensions of the doors to the lobby
DP1 and DP2 = door projection into the lobby (normally door leaf size)
L = minimum length of lobby, or length up to door leaf for side entry lobby
"a" = at least 300mm wheelchair access space (can be increased to reduce L)
1570mm = length of occupied wheelchair with a companion pushing (or a large scooter)

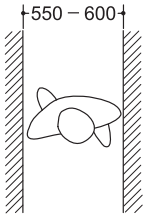
NB: For every 100mm increase above 300mm in the dimension "a" (which gives a greater overlap of the wheelchair footprint over the door swing), there can be a corresponding reduction of 100mm in the dimension L, up to a maximum of 600mm reduction.

3.6 *Lobby design with single doors – essential element is adequate space to manoeuvre (Source: Building Regulation Part K1 1.10)*

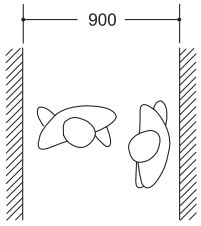
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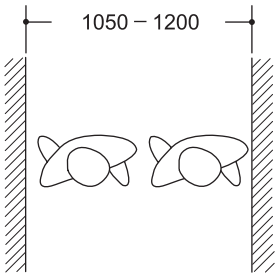
3.7a *Edging width: suitable for short distances or occasional use*



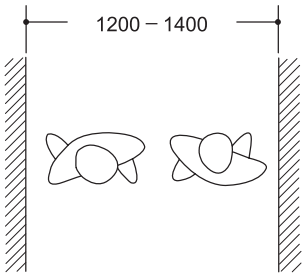
3.7b *One person width (750 clearance would give comfort for various postures)*



3.7c *Normally used by one person, but occasional passing required*



3.7d *Two people use in same direction*



3.7e *Two people passing*

3.5 Corridor widths

Corridor handling capacity (C_c) in people per minute can be calculated using:

$$C_c = 60\ v\ D\ W$$

where: v is the average pedestrian speed (m/s)
D is the average pedestrian density (people per m^2)
W is the corridor width (m)

Free flow design: D = 0.3 people per m^2 and v = 1.0 to 1.3 m/s
Full flow design: D = 1.4 people per m^2 and v = 0.6 to 0.8 m/s

Note: People tend to wander about in corridors

4 VERTICAL MOVEMENT WITHIN BUILDINGS

4.1 Internal stairs

Internal stairs come in three basic forms:

- private stairs as would be found in domestic situations
- utility stairs that cover escape and maintenance requirements
- general access stairs that cover most of the remaining circumstances.

A fourth version includes certain assembly buildings such as sports stadia, theatres or cinemas where the access stairs form part of the slant of the floor where seating is designed to maximise sightlines for spectators. In these cases, the stairs need to follow those inclines so the resulting designs are very project specific. However, there are specific Building Regulations covering these instances and reference should be made to Part K1, Section 1.4 for further information and guidance.

4.2 Stair pitch

In the case of private stairs, the maximum pitch is 42°. The pitch or angle of the stair is not designated as a gradient as in the case of ramps, but as an angle derived from an arithmetic computation of the rise and going.

From basic trigonometry:

Tangent Function: $\tan(\theta) =$ ***Opposite/Adjacent***

where θ is the angle we require, *opposite* is the rise and *adjacent,* the going, we can derive:

Stair pitch $(\theta) = \tan^{-1}$ *(rise/going)*

Or, using a specific example, where the rise is 170 mm and the going is 250 mm:

$\tan^{-1}(170/250) = 34.2°$

A simpler rule of thumb for normal stairs (based on the approximate adult stride on a stair) suggests that the going plus twice the rise should fall between 550 mm and 700 mm:

Going + (2 × rise) = 550 mm to 700 mm

Or, using the same example where the rise is 170 mm and the going is 250 mm:

250 + (2 × 170) = 590 mm

For the maximum and minimum rise and goings, refer to Table I but it is also worth noting that for schools, the recommended rise is 150 mm with a going of 280 mm.

Table I Rise and going
The range of permissible design dimensions for common stairs.

	Rise (mm)		Going (mm)	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Private stairs	150	220	220	300
Utility stairs	150	190	250	400
General access stairs	150	170	250	400

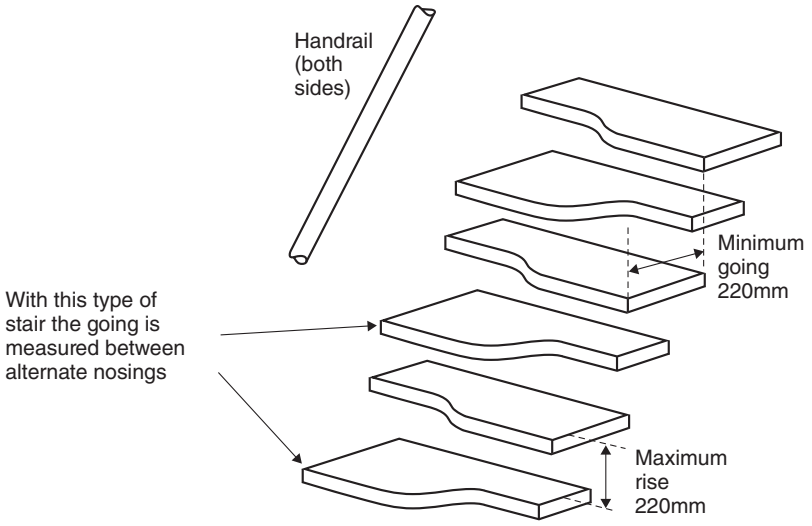
Source: Part K

Under certain limited domestic circumstances, an alternating stair can be used (Figure 3.8). In order to save space and increase the pitch to well over the standard 42°, these stairs maintain the minimum going of 220 mm and the maximum rise of 220 mm but only for each individual footfall. These stairs require people to walk up taking each step alternatively, so someone who may have to negotiate one step at a time for both feet would have to zigzag up the stair. Equally, turning around halfway up can be problematic, requiring both feet on one step to avoid encountering a double rise going down.

4.3 Internal stair design

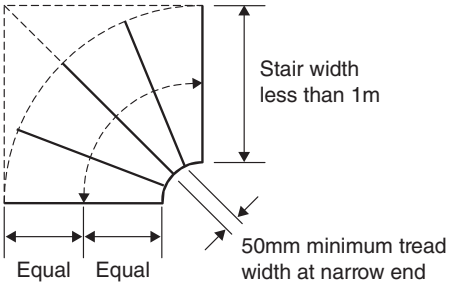
- **Width:** Stairs should not be less than 1.2 m wide. (There is no minimum in domestic situations but 850 mm is suggested with 600 mm when the stair is serving only one room.)
- **Treads:** Treads should be consistent throughout the flight with a rise and going as shown in Table I. There should be no open risers (except in domestic situations where they are constructed

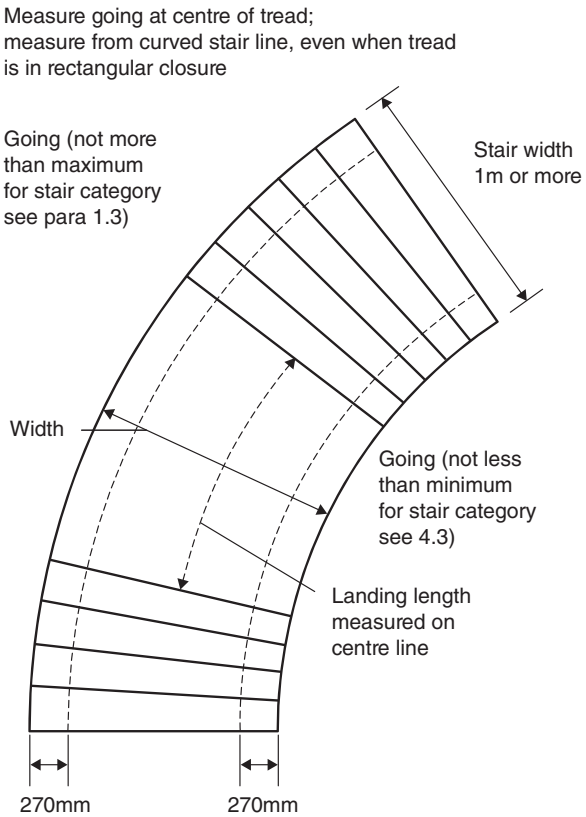
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3.8 *Alternating stair tread layout (Source: Building Regulation K1 1.10)*

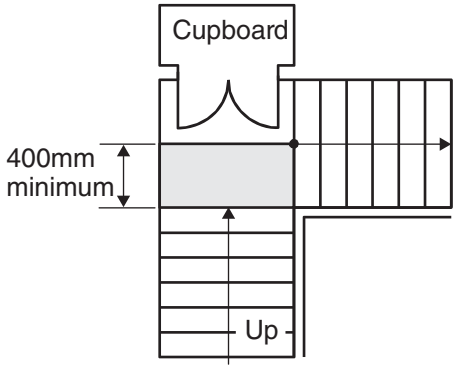
with a minimum 16 mm overhang and a 100 mm diameter sphere cannot pass through the risers). For tapered treads, the standard design principles should still be adhered to but with the going measured at the middle of the stair, subject to a minimum 50 mm tread at the narrow end (Figure 3.9).



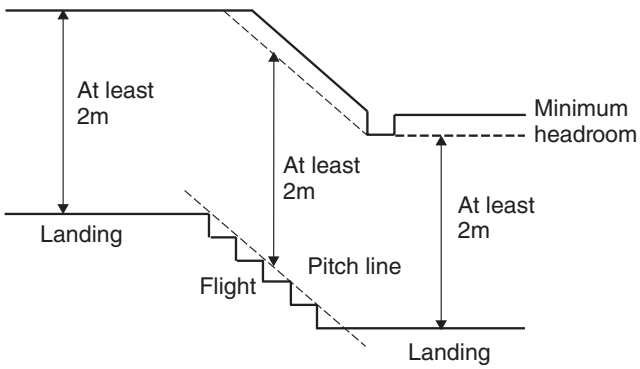


3.9 *Curved staircase and tapering treads – essential elements are the going and the minimum tread size (Source: Building Regulation Part K1 1.9)*

- **Landings:** Stairs should have landings provided not less than 1.2 m long, for every 16 risers in the case of a utility stair and for every 12 risers for general access stairs (Figure 3.10). There should be at least a 1.2 m level approach at the foot and head of the stair with intermediate landings also of 1.2 m (reduced to the stair width with 400 mm unobstructed by door openings for domestic situations).
- **Handrails:** Handrails should be provided on both sides (see Figure 3.3). In the case of general access stairs that are wider than the minimum, additional handrails are required to ensure that the effective width of access is not less than 1.0 m or more than 2.0 m wide.
- **Headroom:** A minimum of 2000 mm clear headroom should be provided at all landings and access points as well as above the pitch line, measured at the outer limit of each going (Figure 3.11).



3.10 *Staircase landings (Source: Building Regulation Part K1 1.7)*



3.11 *Staircase headroom – essential elements are the points at which it is measured (Source: Building Regulation Part K1 1.3)*

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4.4 Staircase handling capacity

Staircase handling capacity (C_s) in people per minute can be calculated using:

$$C_s = 0.83\ (60\ v\ D\ W)$$

where: v is the average pedestrian speed (m/s)
D is the average pedestrian density (people per m^2)
W is the corridor width (m)
Free flow design: D = 0.6 people per m^2 and v = 0.6 to 0.8 m/s
Full flow design: D = 2.0 people per m^2 and v = 0.6 to 0.8 m/s

Note: People tend to walk in an orderly fashion on stairs.

4.5 Handrails

The design of handrails needs to take account of the principle that all people, regardless of age, gender or ability should be able to use them. They could in certain circumstances provide a physical aid to assist ambulant disabled in hauling themselves upward and therefore be subject to significant loading. They should also provide a distinctive visual contrast to assist in location.

In most circumstances, handrails should be fixed between 900 mm and 1100 mm above the floor or pitch line (see Figure 3.12) and subject to the design requirements set out in Figure 3.13.

4.6 Guarding

Handrails and stair guarding serve distinctly different purposes although they can also be combined into one element. Where handrails, usually wall mounted, are used to assist in negotiating stairs as a handhold, stair guarding is there to prevent people falling over an exposed edge of the stair; banisters serve both purposes.

In the case of staircase design, guarding should be provided to the same height requirements as the associated handrails when there is a drop of more than 600 mm.

Building Regulation Part K1 requires that in buildings that will be used by children under five, additional conditions come into force. Inclusive design principles suggest that this should include all buildings where children under five may visit, thereby including almost all buildings.

These additional yet very sensible requirements suggest that guarding should be designed to accomplish the following:

- Prevent children being held fast by the guarding.
- Ensure that a 100 mm sphere cannot pass through any openings in the guarding.
- Prevent children from readily being able to climb the guarding.

5 MECHANICAL MOVEMENT WITHIN BUILDINGS

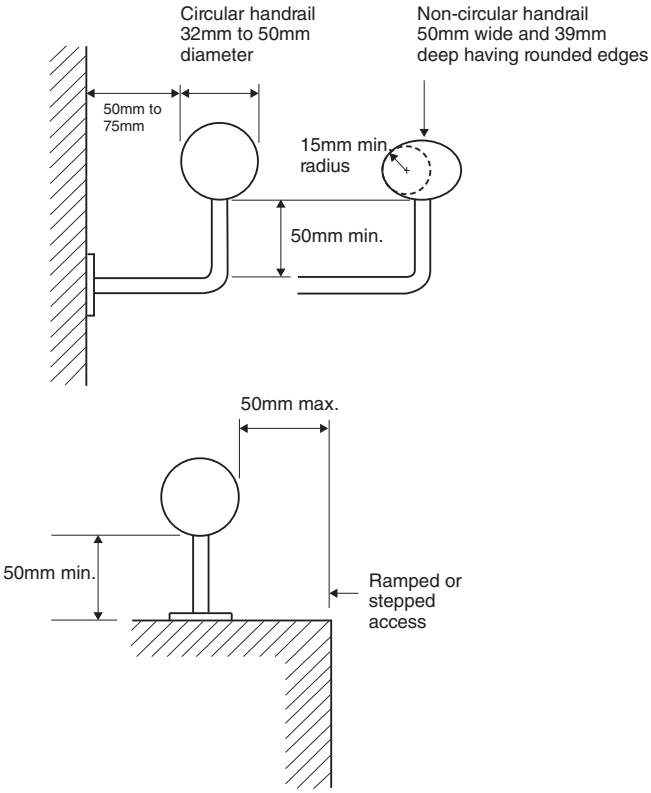
5.1 Introduction

Mechanical devices for moving people around buildings are now essential aspects of all large building design and they involve significant energy demands and safety backups for when energy supplies are restricted. Before reliable and safe systems were produced, the effective height of buildings was restricted to the number of storeys individuals would be happy to walk up. It is worth noting that mechanical systems are often found to be a compromise between moving small number of people very quickly (with a low overall population movement) and moving large numbers of people more slowly (with high overall population movement).

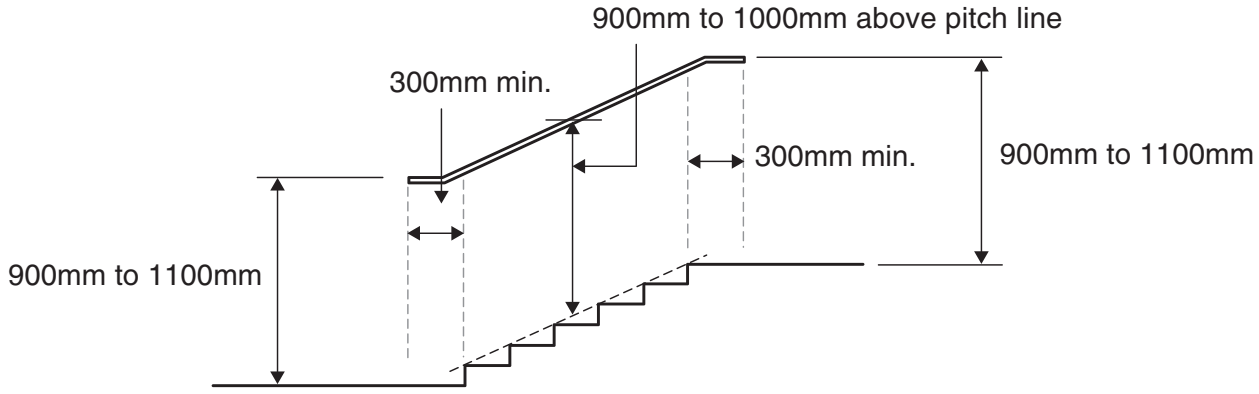
5.2 Escalators

Escalators are essentially moving staircases but where the people on them are expected to remain standing on one step whilst the step itself moves. For this reason, the rise and going are not governed by the same criteria as normal stairs. It is also why climbing a static escalator is more difficult than conventional stairs.

- Escalators typically operate at speeds of 0.5 m/s to 0.65 m/s (0.75 m/s in London Underground).
- Escalators are normally constructed at 30° incline.
- People walk up stairs typically at 0.5 m/s.
- Depending on the design (speeds and width), escalators can move more than 10 000 people per hour.



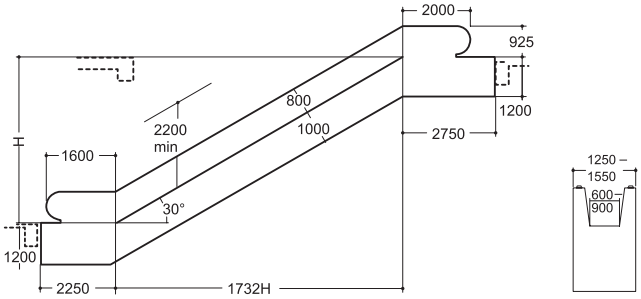
3.13 *Handrail design – essential elements are those related to grip and structural integrity (Source: Building Regulation Part K1 1.13)*



3.12 *Handrail positioning – essential elements are the dimensions and structural integrity (Source: Building Regulation Part K1 1.12)*

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The standard shape of an escalator is provided by a steel truss that supplies the framework to support the moving staircase between storeys (see Figure 3.14). The individual steps in an escalator are roughly triangular in section and connected to two different guiding tracks that loop around the system and govern the relative position of each step as well as the movement. One track is the driving mechanism (chain) where the leading edge of the step is connected on each side and the step is essentially pulled around the loop in this way. The lower edge simply follows with two wheels located in a guiding track. This follows the main drive chain but by altering the relative position of the track to the drive chain, the position of each step is changed. By altering the space between the two loops, the steps are kept horizontal throughout the journey and as the pitch flattens at the top and bottom, they fold onto each other. This process is assisted by a series of grooves where each step fits together with the next in a tongue and groove alignment.



3.14 *Dimensions of 30° escalator, elevation and section*

The movement of an escalator is powered by an electric motor housed within the truss and geared to move the drive chain and the handrail as required keeping it aligned with the steps. The handrail is simply a synthetic rubber conveyer belt looped around a similar path but off set from the main step drive mechanism.

Design and construction considerations:

- Clear access areas should be provided equal to twice the escalator tread width in length and the escalator tread width plus 100 mm either side in overall width.
- Minimum clear headroom of 2130 mm (measured vertically from the pitch line) should be maintained across the whole of the system.
- The handrail should have 100 mm clearance horizontally and 25 mm clearance vertically from any adjacent surfaces.
- All connecting floor surfaces should be continuous with any abrupt change in level limited to a maximum of 6 mm.

(Source: Kone's Escalators and Autowalks Planning Guide, page 49, Section 6.2 parts A to D)

Escalator handling capacity (C_e) in people per minute can be calculated using:

$$C_e = 60\ (V\ k\ s)$$

where: V is the speed along the incline (m/s)
k is the average density of people (people per step)
s is the number of steps per metre (m) e.g. for a 400 mm step rise, $s = 2.5$

Step density is theoretically related to escalator width where:

600 mm wide $k = 1.0$
800 mm wide $k = 1.5$
1000 mm wide $k = 2.0$

People tend not to fill escalator stairs to capacity, so use half these values.

An example from Table II indicates a 1000 mm wide step at 0.50 m/s will carry 150 people per minute, in reality this should be assumed to be 75 people per minute or 4500 people per hour.

Table II Escalator design

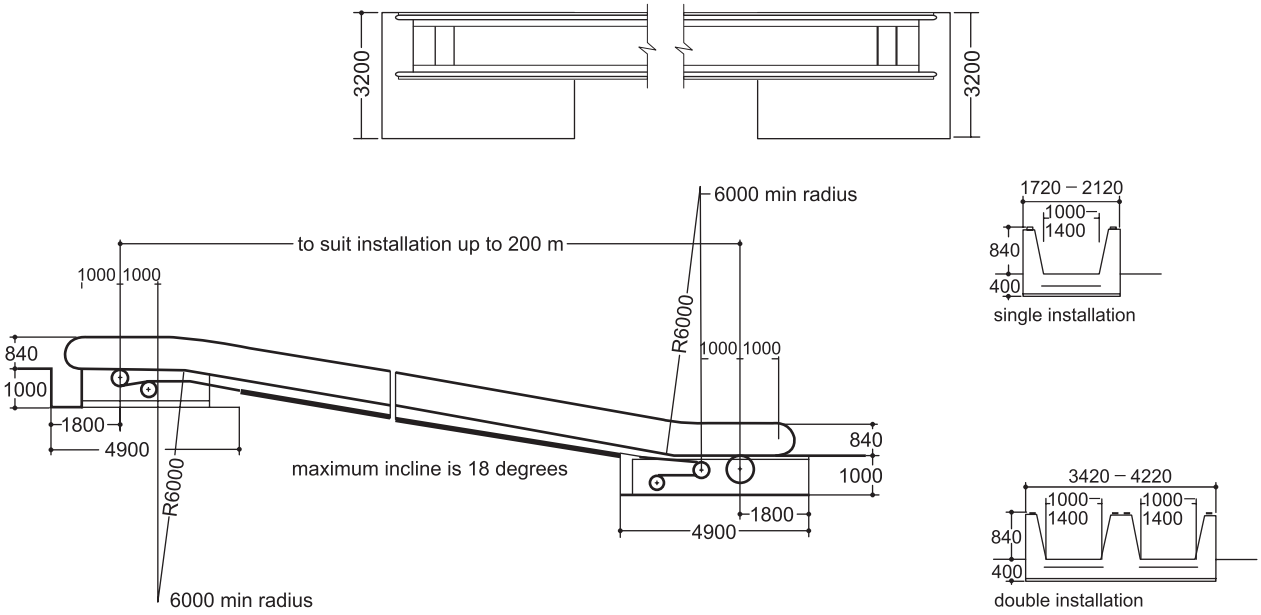
Essential elements to consider are the step size, the speed and the degree of occupancy on each step.

	1000mm Step width People per minute		800mm Step width People per minute		600mm Step width People per minute	
Speed	**Theory**	***Practice***	**Theory**	***Practice***	**Theory**	***Practice***
0.50 m/s	150	*75*	113	*57*	75	*38*
0.65 m/s	195	*98*	146	*73*	98	*49*
0.75 m/s	225	*113*	169	*85*	113	*57*

(Source: Barney, 2003, p. 13, Table 1.8)

5.3 Moving walkways

Moving walkways (or a mechanised passenger conveyor system) can be assumed to have the same design and performance characteristics as escalators, moving similar amounts of people and subject to similar speed and operating mechanics (Figure 3.15). They generally come in two forms. The pallet variety is simply a flat escalator with individual



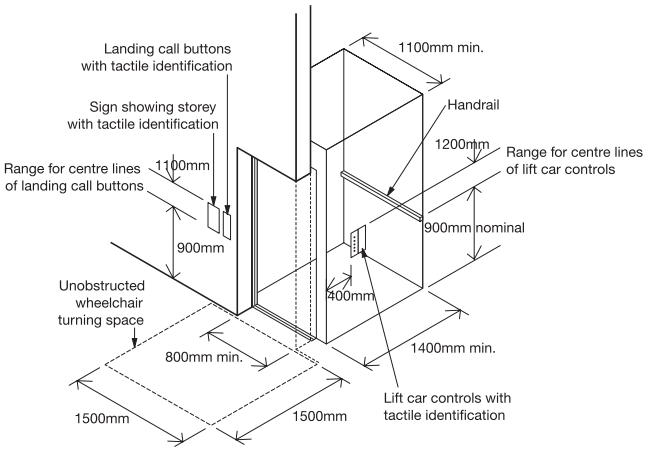
3.15 *A one-speed mechanised passenger conveyor system, may be flat, or up to 12° for prams, shopping trolleys, etc., or up to 15° for special installations. Other systems available permit 'valley' and 'hill' longitudinal profiles; also surface laying of conveyor on drive motor on existing floors. Capacity of system shown is 7200 persons per hour. Systems are available up to 8000 pph. Speed range is 0.45–0.6 m/s. Tread widths, 1000–1400 mm*

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steps (pallets) running horizontally (or inclined as required). These do have a potential advantage due to the interconnection provided by extended grooves between each step, allowing the speed to be varied over the journey. The grooves close up at lower embarking and disembarking speeds but increase during the middle higher speed portion of the journey. The second form has a continuous conveyor belt constructed of metal belts or rubber walkways running over rollers.

5.4 Lifts

In most circumstances, a passenger lift is the most suitable method of vertical transportation within buildings. Because of their reliance on a power source they should always also have a fire protected stair access provided as well. They also come in a wide range of sizes from a simple two storey hydraulic lift to the sophisticated operating systems needed in 100 storey skyscrapers. A lift car size of 2000 mm wide by 1400 mm deep will provide adequate space for any wheelchair and a number of other users although Figure 3.16 illustrates the minimum size required.



3.16 *Lift design – key minimum dimensions (Source: Building Regulation Part M Diagram 11)*

A well-designed passenger lift provision will include most, if not all, of the inclusive design principles. However in certain refurbishment situations, a full scale lift provision is not possible and in those cases, specific wheelchair platform stairlift or lifting platform may be suitable. Wheelchair platform stairlifts differ from lifting platforms in that they take a single wheelchair up a flight of stairs by means of a mechanical rail and traction device. Lifting platforms by contrast raise a platform that can accommodate a wheelchair plus attendant or partially sighted people over a certain vertical distance. These can be relatively short distances such as negotiating a change in level or more fully enclosed journeys between storeys.

5.5 Wheelchair platform stairlifts and lifting platforms

Where a platform stairlift is installed, the minimum stair widths need to be increased to accommodate the extra width required by the stairlift (Figure 3.17). They also require a platform of 800 mm wide and 1250 mm deep and are limited to a speed of 0.15 m/s. In addition, they should also have controls that restrict usage to those in need and authorised to do so. These controls should include a 'continuous pressure' control device where if the pressure is released, the lift comes to a halt.

5.6 Lifting platforms

Lifting platforms, like stairlifts, are not replacements for a good passenger lift service and therefore are also not ideal. Both require the continuous pressure control device which can be too strenuous for some users to maintain. Lifting platforms have the same speed restriction and minimum platform size for single wheelchair users. In addition, however, they are also restricted to a 2000 mm travel if they are not enclosed. Where they are enclosed, the minimum dimensions increase to 900 mm wide and 1400 mm deep and if the wheelchair user has an attendant, to 1100 mm wide and 1400 mm deep.

5.7 Hydraulic lifts

These lifts appear the same as any other standard lift design in that the most apparent aspect, the lift car, would not be any different. The difference lies in the driving mechanism (Figure 3.18). Hydraulic lifts use a hydraulic ram to move the lift car between storeys and because it consists of a piston that is forced upwards by a fluid pumping system (usually oil) they are limited to the structural and height restrictions of the piston. Some use a hole in the ground to house the piston when fully descended, others use telescopic pistons. The mechanism is relatively simple in that an electrically operated pump forces the fluid from a reservoir into the piston to ascend and a valve allows and controls the returning oil when descending. Even if the reservoir were to fail, the action of having to force the oil back through the system means that hydraulic lifts would return to ground level fairly slowly and therefore also safely.

In action, as the ascending lift car approaches the correct floor, a control system gradually reduces the pumping speed. At each floor, with the pump off, the oil in the cylinder cannot flow back through the pump, and with the valve closed the car is supported by the full piston. To descend, the control system opens the valve so that the oil in the cylinder can return to the reservoir. It is the weight of the car and contents that push down on the piston driving the oil back into the reservoir. To stop the car at a lower floor, the control system simply closes the valve.

Although a very safe mechanism, hydraulic lifts are limited in scope because of the length of pistons required and also because they are relatively energy intensive when compared with the alternative traction system. In raising a lift car and its contents, a hydraulic system has to produce all of the required power via the pump to overcome the force of gravity for the full weight of the lift car and load. In a traction system, the weight of the lift car is balanced by a counterweight so that moving only the difference in weights requires power.

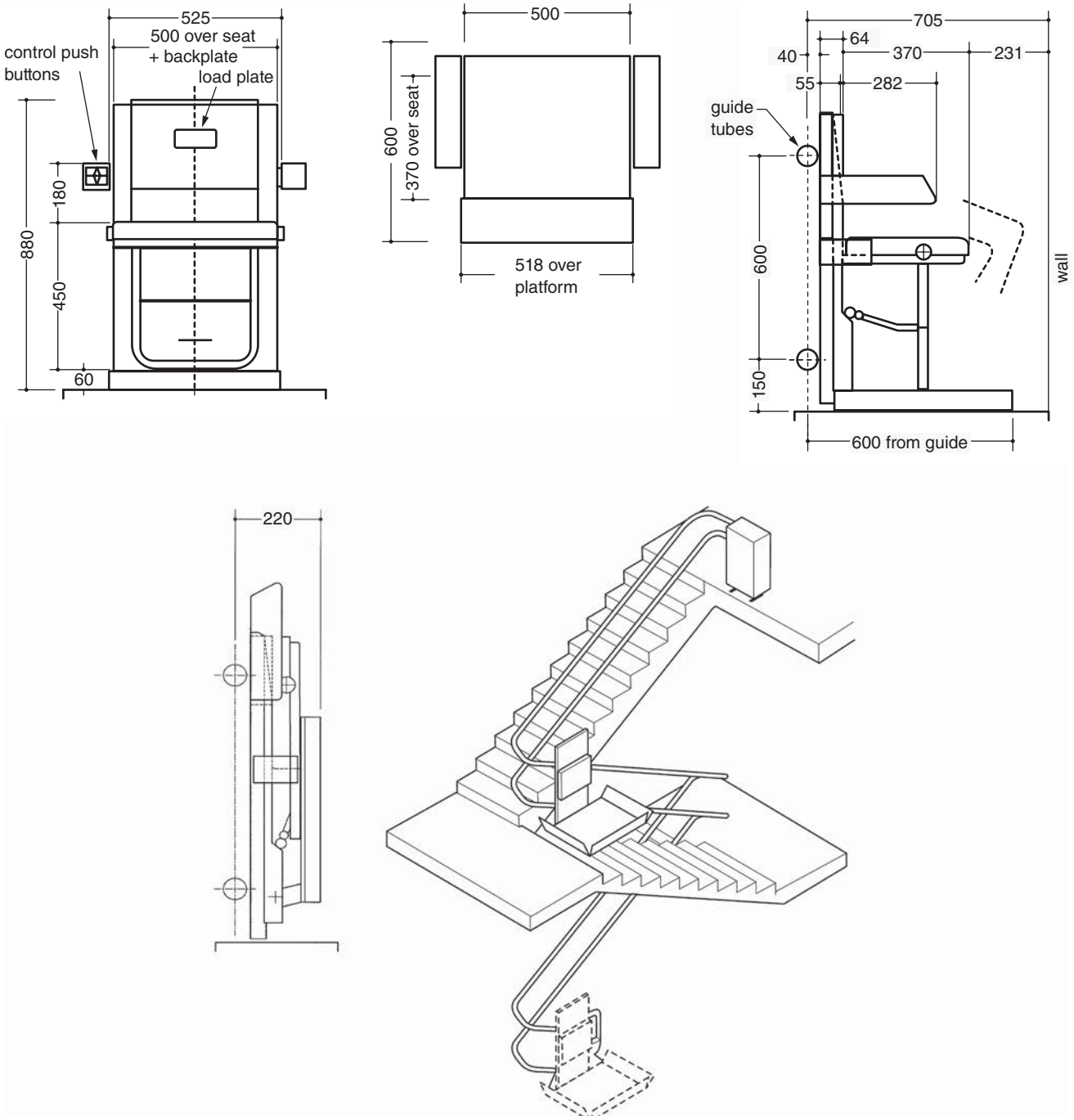
5.8 Traction lifts

The most common design for lifts is the traction variety where the lift car is raised and lowered by steel wire ropes attached to the car and looped around a **sheave**. In effect a pulley, the sheave has grooves around the edge, designed and shaped to grip the ropes so that a rotating sheave moves the ropes simply because of the friction between the two. In higher speed lifts, the ropes are wrapped around the sheave twice to provide extra friction. A traction lift therefore works by an electric motor turning the sheave directly (or via a gearing system), either one way or another to ascend or descend.

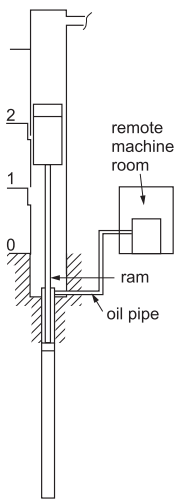
The great advantage of traction lifts is that the ropes are also connected to a counterweight on the other side of the sheave. The counterweight is normally designed to balance the lift car at 40 per cent capacity, considered to be the average load in use. When loaded equally like this, the sheave motor has little work to do in moving the lift up or down. In addition to guide rails in the lift shaft, traction lifts usually locate the sheave, motor and control system in a machine room above the lift shaft, adding to the overall height required as well as the overall structural loading on the building (Figure 3.19).

The safety of traction systems depends on two fundamental principles. Firstly, the fear that a rope may snap or become disconnected is overcome by using multiple ropes, typically four to eight wound steel wire ropes where each rope individually can support the lift car. Secondly, they will also use a braking system. Physical braking systems typically use a governor and sprung flyweights that activate when the lift is travelling too fast and then through linkages bring the braking system into operation. Electromagnetic braking systems keep the brakes open in normal operation so that a loss of power would trigger them. They can also be used as part

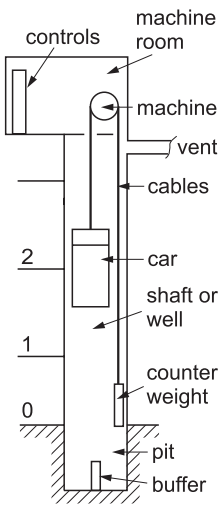
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3.17 *Details of stair lift for wheelchair, or for seated passenger. (Courtesy of Gimson Stairlifts Ltd)*



3.18 *Schematic diagram of a direct-acting hydraulic lift with remote machine room*



3.19 *Schematic diagram of a conventional electric traction lift with high-level machine room*

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of the control system at each stop. In addition to overrun braking protection at the top and bottom of shafts, a heavy-duty piston shock absorber system at the bottom will cushion a runaway car's landing.

- Gearless traction lifts – the industry standard – typically operate at speeds in excess of 2.5 m/s.
- Geared traction lifts – more efficient – typically operated at speeds between 1.75 and 2.5 m/s (Otis 2011).

5.9 Design of lift systems

The design of lift systems is a complicated and in most instances, a specialist operation. This is because of the very many parameters involved including such things as the number of lifts available, the populations being served, usage patterns (peak flows), number of storeys being served and also the quality of the service required, to name just a few. Specialist design services will include evaluation of 'round trip times', passenger demands, limitations and assumptions around peak traffic flows as well as car size, number and location, clearly well beyond the scope of this chapter. Yet there is some basic information that is useful and can form the basis of ongoing design work.

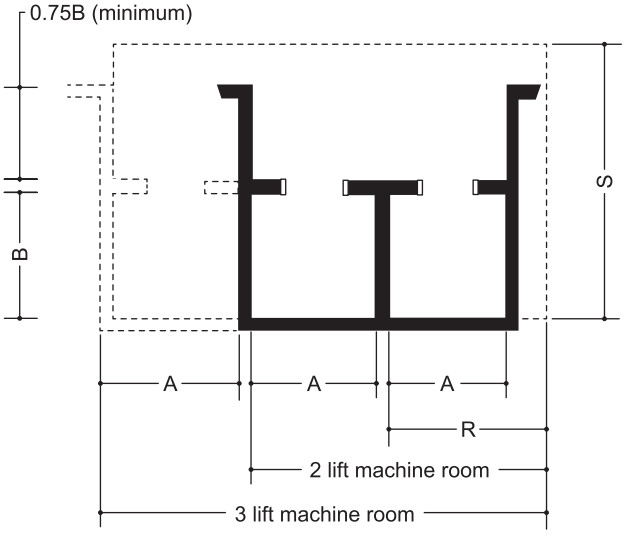
5.10 Handling capacity of lifts

It is important to recognise that lifts provide a different service to that of stairs and escalators discussed previously. Where escalators can carry large amounts of people relatively slowly, lifts carry much smaller amounts much more quickly.

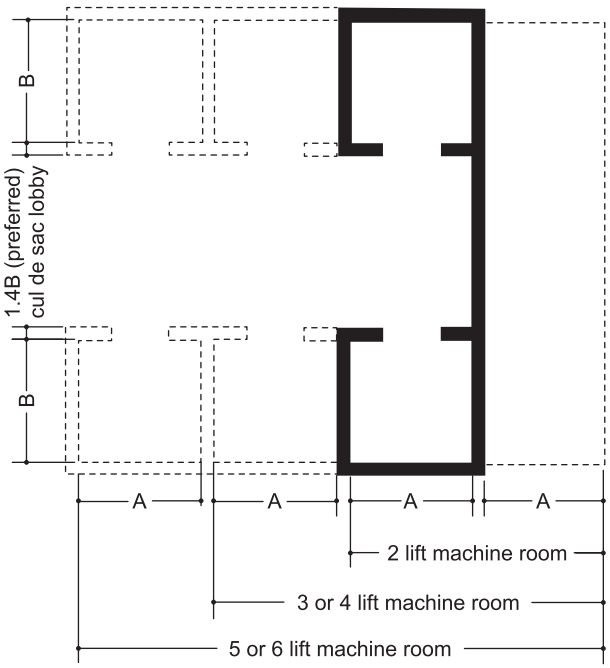
- A previous example showed a relatively small 1000 mm wide escalator at 0.50 m/s carrying 75 people per minute or 4500 people per hour.
- The most efficient group of 8 lifts serving 14 floors at full 21 person capacity can only handle 50 people per minute or 3000 people per hour.
- Take that down to 3 lifts in 8 storeys at 10 person capacity and the figure reduces to 16 people per minute or 960 people per hour.

5.11 Location and number of cars

The most efficient design layout for lift lobbies is in a cul-de-sac layout as indicated in Figures 3.20 and 3.21 as it provides the shortest distance from any waiting position; it also provides the best view of all lifts in operation and, most importantly, it avoids obstruction by passers-by.



3.20 *Plan of recessed lobby and machine room for multi-lift installation – dimensions refer to the values in Table IV*



3.21 *Plan of cul-de-sac lobby and machine room – dimensions refer to the values in Table IV*

Lift cars are rated by their load capacity in kilograms and the number of people they can carry. The load capacity is defined in EN81(1998) and must not be exceeded but people capacity ratings can be misleading and experience has found that in reality, the figure should be adjusted for variations in people size, luggage etc. A further reduction comes from statistical analysis of passenger behaviour suggesting that a 20 per cent reduction should be applied to get the true capacity of individual cars.

In very tall buildings, where the number of lift cars becomes very large to serve all storeys from the access point, 'sky lobbies' provide an intermediate access point where a specific lift will only take people to this point for further distribution at higher 'local' levels.

Table III Lift car requirements

Effective lift system design is a specialist design function but some basic assumptions can be made relating to the number of cars to the number of storeys and populations served.

Number of storeys served	Number of lifts in group	Approximate population served per storey
4	1 to 2	60 to 200
5	1 to 2	30 to 200
6	2 to 3	50 to 200
7	2 to 4	70 to 210
8	2 to 5	50 to 210
9	3 to 6	75 to 200
10	3 to 6	60 to 160
11	3 to 6	50 to 170
12	3 to 6	50 to 145
13	3 to 6	45 to 125
14	3 to 6	40 to 110
15	4 to 6	50 to 100
16	4 to 6	45 to 90
17	4 to 6	40 to 80
18	4 to 6	40 to 70

Table III provides a range of information on the number of lift cars required to serve various storeys for a typical office building with associated population numbers per floor.

Table IV provides information on design capacity, rated capacity, car size and the required structural size requirements for two different lift traffic systems.

Table IV Lift specification

Effective lift system design is a specialist design function but some basic assumptions can be made relating to car size, shaft dimensions and traffic flows.

	Car size C × D	Shaft size A × B	Machine room S × R	Load rating (Kg)	Rated Capacity (people)	Design Capacity (people)
Light traffic				320	4	3.6
	1100 × 950	1800 × 1600	3200 × 2500	400	5	
				450	6	5.0
	1100 × 1400	1800 × 2100	3700 × 2500	630	8	6.3
	1350 × 1400	1900 × 2300	3700 × 2500	800	10	7.6
	1100 × 2100	1800 × 2600	4200 × 2500	1000	13	9.1
General purpose lifts	1600 × 1400	2400 × 2300	4900 × 3200	1000	13	9.1
	1950 × 1400	2600 × 2300	4900 × 3200	1250	16	
				1275	16	11.0
	1950 × 1750	2600 × 2600	5500 × 3200	1600	21	13.5
	1600 × 2400	2400 × 3000	5800 × 3200	1800	24	14.9
	1500 × 2700	2400 × 3300	5800 × 3200	2000	26	16.0
	1800 × 2700	2700 × 3300	5800 × 3500	2500	33	19.0

Note: machine room sizes are for traction lifts, the size is considerably reduced for hydraulic lifts.

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4 Access and inclusion

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KEY POINTS:

- *Consider the needs of all disabled people not just wheelchair users, who form a small percentage of such a diverse group of people*
- *At some times in their lives, people may require the same provision that is made for disabled people; flexibility is all important*

Contents

1 Inclusive design
2 People
3 Mobility equipment
4 Reach
5 Walking distances
6 Toilets

1 INCLUSIVE DESIGN

1.1 Design principles

Good design reflects the diverse nature of people and does not impose barriers of any kind. Designing inclusively guarantees accessibility to all, including disabled people, older people and families with small children.

'The Principles of Inclusive Design' (CABE) encourage high quality, inclusive design in the built environment. Incorporating these principles ensures projects are:

- Inclusive – everyone uses safely, easily and with dignity
- Responsive – takes account of what people say they need and want
- Flexible – allows different people to use in different ways
- Convenient – everyone uses without too much effort or separation
- Accommodating – for all, regardless of age, gender, mobility, ethnicity or circumstances
- Welcoming – no disabling barriers that might exclude some people
- Realistic – recognising that one solution may not work for all and offering additional solutions as required.

1.2 Design process

In order to deliver inclusive environments, the principles of inclusive design must be integrated into the design process from first principles. Making environments easy to use for everyone requires consideration other than just physical factors. These include signage/way-finding, lighting, visual contrast, controls and door furniture, and materials.

Inclusive design relates as much to the design process as to the final product, bonding user-experience with professional expertise and management practice. The process extends from inception, through the planning process, detailed design, construction to occupation, management and operation.

The goal of creating aesthetic and functional environments that can be used equally by everyone, irrespective of age, gender, faith or disability, requires a creative and inclusive design process working towards accommodating a diverse range of users.

Following the minimum provisions of the building regulations or best practice guidance alone will not deliver inclusive projects. For this, the involvement of design team, client and community are required.

2 PEOPLE

2.1 Disabled people

The UK's Disability Discrimination Act 1995 (DDA) defines a person as having a disability if they have a physical or mental impairment, which has a substantial and long-term adverse effect on their ability to carry out normal day-to-day activities. It is estimated that approximately 20 per cent of the UK population (over 10 million people) may have rights under the DDA.

While the spatial needs of wheelchair users and people with mobility impairments are important in terms of designing the physical environment, it is also necessary to understand the barriers experienced by people with learning difficulties and mental illness, visual impairments and hearing impairments as well as conditions such as HIV, cancer, heart disease or diabetes.

2.2 Benefits

In general, designing to provide access, whether physical or intellectual, will yield results that benefit the community at large. Many aspects of an inclusively designed environment will be helpful to all or most disabled people (and many others as well). In order to deliver the whole, it is useful to understand the diverse and complex nature of disability, recognising that degrees of disability vary greatly as do the combinative effect of multiple impairments.

2.3 Statistics

Some key statistics relating to disability are:

- Some 70 per cent of disabled people in the UK have reduced or limited mobility. They represent 14 per cent of the overall population.
- Wheelchair users account for only 0.85 per cent of the general population.
- About 2 million people in the UK (approximately 4 per cent of the UK population) define themselves as having a sight problem or seeing difficulty.
- There are over 8 million deaf or hard of hearing people in the UK (14.5 per cent of the population).
- There are 700,000 in the UK who are severely or profoundly deaf
- 14 per cent of the UK population have difficulty on reaching, stretching or have reduced dexterity.
- 5.6 million people have difficulty with physical coordination.
- 3.9 million people in the UK have difficulty learning and understanding.
- 700 000 people have difficulties in perceiving risk.

2.4 Older people

The number of older people in the population is increasing. Many of them have or will have an impairment of some kind. Over the next 30 years, while the overall population is expected to rise by less than 7 per cent, the proportion of the population over 65 will increase by approximately 40 per cent, doubling the number of people over 65. In addition, the proportion of the population over 80 is expected to treble.

There is a correlation between age and disability. Approximately 5 million people over the age of 65 have a longstanding illness and more than half the population over 75 has some kind of disability. Two-thirds of disabled people are over pension age.

People also tend to shrink slightly with age. More significantly, the body tends to be less flexible in regard to adapting to dimensionally unfavourable situations. Older people tend to have more than one impairment. It is, therefore, more important that design allows for older people.

Table I gives dimensions for people between the ages of 65 and 80.

Table I Dimensions for British people aged 65–80

		Men percentiles			Women percentiles		
		5th	50th	95th	5th	50th	95th
Standing							
1	Stature	1575	1685	1790	1475	1570	1670
2	Eye height	1470	1575	1685	1375	1475	1570
3	Shoulder height	1280	1380	1480	1190	1280	1375
4	Elbow height	975	895	975	740	810	875
5	Hand (knuckle) height	670	730	795	645	705	760
6	Reach upwards	1840	1965	2090	1725	1835	1950
Sitting							
7	Height above seat level	815	875	930	750	815	885
8	Eye height above seat level	705	760	815	645	710	770
9	Shoulder height above seat level	520	570	625	475	535	590
10	Length from elbow to fingertip	425	460	490	390	420	450
11	Elbow above seat level	175	220	270	165	210	260
12	Thigh clearance	125	150	175	115	145	170
13	Top of knees, height above floor	480	525	575	455	500	540
14	Popliteal height	385	425	470	355	395	440
15	Front of abdomen to front of knees	210	280	350	325	295	365
16	Buttock–popliteal length	430	485	535	430	480	525
17	Rear of buttocks to front of knees	530	580	625	520	565	615
19	Seat width	305	350	395	310	370	430
Sitting and standing							
20	Forward grip reach	700	755	805	640	685	735
21	Fingertip span	1605	1735	1860	1460	1570	1685
23	Shoulder width	400	445	485	345	385	380

Table II Statures (or equivalents) for Britons in various age groups

	Percentiles		
	5th	50th	95th
New-born infants	465	500	535
Infants less than 6 months old	510	600	690
Infants 6 months to 1 year old	655	715	775
Infants 1 year to 18 months	690	745	800
Infants 18 months to 2 years	780	840	900

	Boys/men percentiles			Girls/women percentiles		
	5th	50th	95th	5th	50th	95th
Children, 2 years old	850	930	1010	825	890	955
Children, 3 years old	910	990	1070	895	970	1045
Children, 4 years old	975	1050	1125	965	1050	1135
Children, 5 years old	1025	1110	1195	1015	1100	1185
Children, 6 years old	1070	1170	1270	1070	1160	1250
Children, 7 years old	1140	1230	1320	1125	1220	1315
Children, 8 years old	1180	1280	1380	1185	1280	1375
Children, 9 years old	1225	1330	1435	1220	1330	1440
Children, 10 years old	1290	1390	1490	1270	1390	1510
Children, 11 years old	1325	1430	1535	1310	1440	1570
Children, 12 years old	1360	1490	1620	1370	1500	1630
Children, 13 years old	1400	1550	1700	1430	1550	1670
Children, 14 years old	1480	1630	1780	1480	1590	1700
15 years old	1555	1690	1825	1510	1610	1710
16 years old	1620	1730	1840	1520	1620	1720
17 years old	1640	1750	1860	1520	1620	1720
18 years old	1660	1760	1860	1530	1620	1710
Aged 19–25	1640	1760	1880	1520	1620	1720
Aged 19–45	1635	1745	1860	1515	1615	1715
Aged 19–65	1625	1740	1855	1505	1610	1710
Aged 45–65	1610	1720	1830	1495	1595	1695
Aged 65–85	1575	1685	1790	1475	1570	1670
Elderly people	1515	1640	1765	1400	1515	

2.5 Children and adolescents

Statures (or equivalents) for various ages in Britain are given in Table II (Statures (or equivalents) for Britons in various age groups).

Where facilities are to be used solely by small children, specific heights should be adjusted to meet their requirements. There are approximately 3.3 million families in the UK with children under 5. Design in general should also consider the needs of children, for example, when providing family facilities or sinks at lower heights in toilets.

It is also worth noting that approximately 7 per cent of children in the UK are disabled (around 770 000). Disabled children and young people currently face multiple barriers, making it more difficult for them to achieve their potential, to achieve the outcomes their peers expect and to succeed in education.

Disabled parents and carers should be considered at all stages of the design process.

2.6 Large people

Obesity also needs to be considered. The prevalence of obesity in children aged under 11 increased from 9.9 per cent in 1995 to 13.7 per cent in 2003. This trend is expected to continue. Since the 1980s, the prevalence of obesity in adults has trebled. Well over half of all adults in the UK are either overweight or obese, almost 24 million adults.

Pregnant women, like large people, can be disadvantaged by the design of the environment. Long routes and stairs can be very tiring, narrow seats, doors and small toilet cubicles are other common barriers.

In certain buildings such as football stadia, deliberately narrow doorways are used to ensure control over entry. In these cases, and also where turnstiles are used, additional provision for large people should be made.

Where there is fixed seating, for example, in a theatre, there should be a number of easily accessed amenity seats, which may have increased legroom, have removable arms or fold-down arms and may include a space for an assistance dog.

3 MOBILITY EQUIPMENT

3.1 Key dimensions

Wheelchair users need quite a lot of space to move comfortably and safely; people who walk with two sticks may require a wider circulatory route than someone using a wheelchair. It is worth noting that a double pushchair may be wider than an occupied electric wheelchair.

3.2 Wheelchairs users

The range of wheelchair dimensions is considerable, particularly given the overall length and width that an occupied wheelchair may extend to. The figures given for the width of a wheelchair user do not usually make allowance for their elbows and hands. The ISO standard for wheelchairs (ISO 7193) notes that to propel a wheelchair manually a clearance of not less than 50 mm, preferably 100 mm, on both sides is required.

At the present time, the maximum length a conventional wheelchair user with leg supports or an electric scooter is likely to occupy is 1600 mm. Conventionally seated wheelchair users do not usually occupy a length of more than approximately 1250 mm. However, if a wheelchair user has a companion then the combined length of the space they occupy will be typically 1375 mm – design guidance allows for 1570 mm.

The average height of wheelchair users is 1080 mm but can range as high as 1535 mm. The average height of a scooter user is approximately 1170 mm but can range as high as a maximum of 1500 mm.

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In designing for wheelchair users, the critical dimensions are:

- eye height, around 120–130 mm below seated height, giving a 5th–95th per cent range for wheelchair users from 960 to 1250 mm (1080–1315 mm for scooter users)
- knee height, 500–690 mm
- seat height, 460–490 mm
- ankle height, manual wheelchair users, 175–300 mm; electric wheelchair users, 380–520 mm
- height to bottom of foot support, 60–150 mm.

The ground clearance offered by typical scooters currently on the market can vary from 80 to 125 mm. The climbing capacity of typical scooters on the market also varies depending on the motor power and battery charge; however, most vary between 10° and 20°.

3.3 Wheelchair-user dimensions

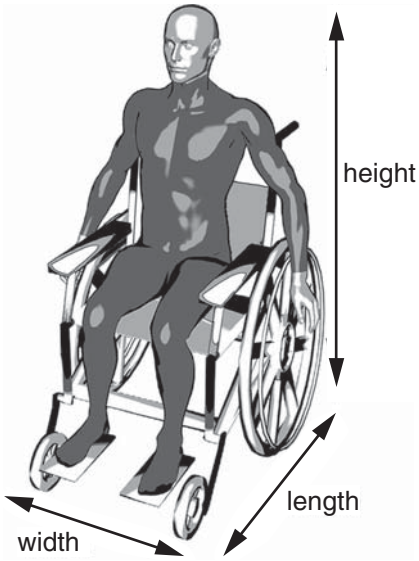
These dimensions exclude the wheelchair user and only consider length and width, Figure 4.1. Dimensions in Table III are given for occupied and unoccupied wheelchairs over a range of wheelchair types including scooters.

3.4 Pushchair dimensions

The length and width dimensions of child pushchairs are very much variable. There is not, as is the case with manual wheelchairs, a standard model for informing design criteria. Table IV gives common dimensions.

3.5 Turning spaces

Mobility aid vehicles clearly need adequate space to turn around and this will need to be considered in particular along circulation routes and in queue systems, Tables V and VI.



4.1 *Wheelchair dimensions*

Table III Wheelchair dimensions

Chair type (excluding children)	Occupied		Unoccupied	
	Length (mm)	Width (mm)	Length (mm)	Width (mm)
Manual wheelchair	850–1250	560–800	700–1200	560–750
Attendant propelled	1200–1570	560–700	800–1350	550–660
Electric wheelchair	860–1520	560–800	700–1400	560–750
Electric scooter	1170–1600	630–700	1170–1500	620–640

Table IV Pushchair dimensions

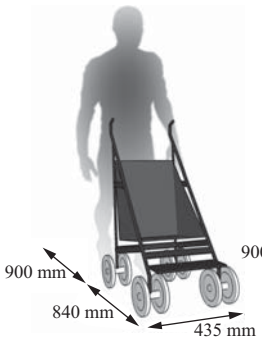
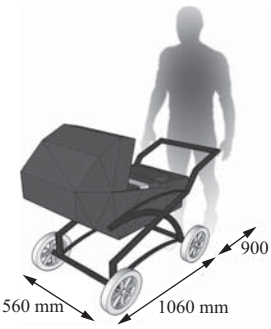
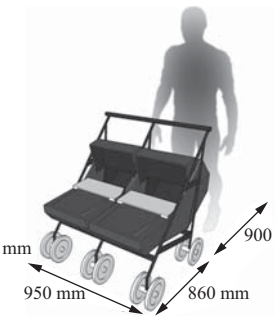
Single buggy	Double buggy	Single Pushchair	Double Pushchair	Double Pushchair
				
Length = 840 mm Width = 435 mm	Length = 840 mm Width = 740 mm	Length = 1060 mm Width = 560 mm	Length = 860 mm Width = 950 mm	Length = 1210 mm Width = 560 mm

Table V Space required for users of self-propelled wheelchairs to turn through 90° (Figure 4.2)

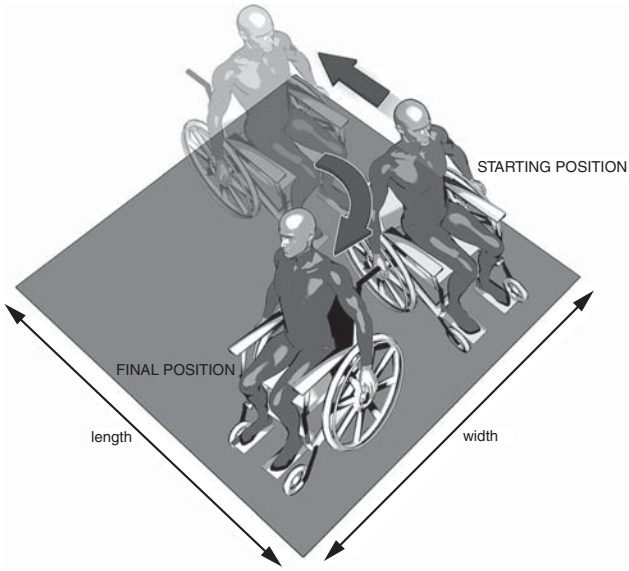
Chair type	Space required	
	Length (mm)	Width (mm)
Manual wheelchair	1345*	1450*
Attendant propelled	1200–1800	1500–1800
Electric wheelchair	1600*	1625*
Electric scooter	1400–2500	1300–2500

*90% of users.

Table VI Space required for users of self-propelled wheelchairs to turn through 180° (Figure 4.3)

Chair type	Space required	
	Length (mm)	Width (mm)
Manual wheelchair	1950*	1500*
Attendant propelled	1600–2000	1500–1800
Electric wheelchair	2275*	1625*
Electric scooter	2000–2800	1300–2200

*90% of users



4.2 *Wheelchair users performing a 90° turn*

3.6 Considerations for people that use a stick, cane or crutches

It is important to consider people with a visual impairment that use a cane, Figure 4.4, or people with a mobility impairment that may prefer to walk using crutches, Figures 4.5 and 4.6.

Most people who use crutches use them for a short time following an accident, and will be inexpert in their use. Users fall into two broad groups: those who have some use of both legs and feet, and those who have use of only one leg. Those who can use only one leg require a handhold wherever there are steps, even at a single step at a building threshold.

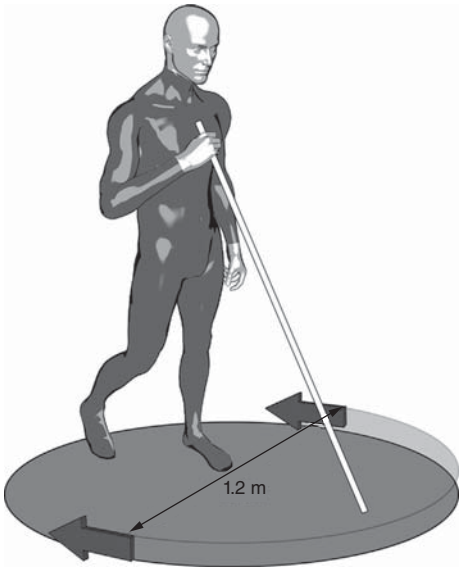
3.7 Space provision for assistance dogs

Assistance dogs include guide dogs and hearing dogs. While people primarily with sensory impairments have an assistance dog, people with mobility impairments and wheelchair users may also have an assistance dog. Inclusive Mobility identifies that people with assistance dogs require a clear unobstructed width of at least 1100 mm.

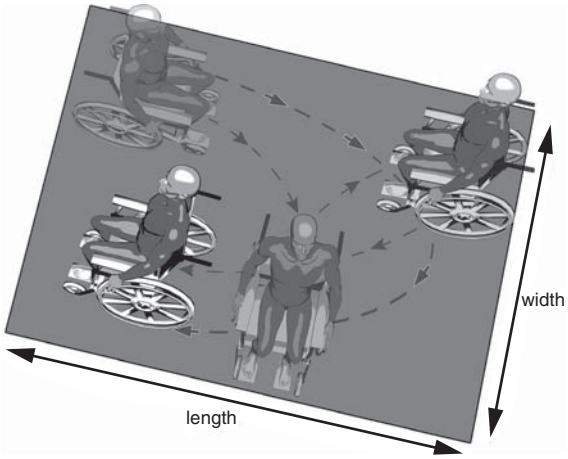
4 REACH

4.1 Range

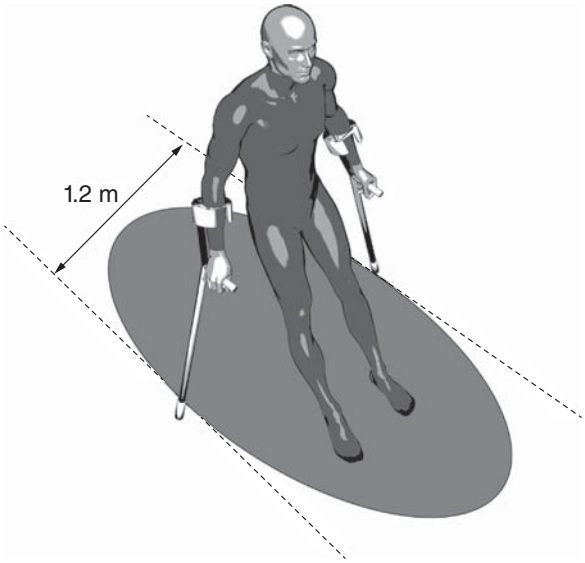
The distance and angle that an individual can reach is dependent on their size, agility, dexterity and whether they are seated or standing.



4.4 *Blind person with cane*



4.3 *Wheelchair users performing a 180° turn*



4.5 *Person on crutches*



4.6 *Person with a walking frame*

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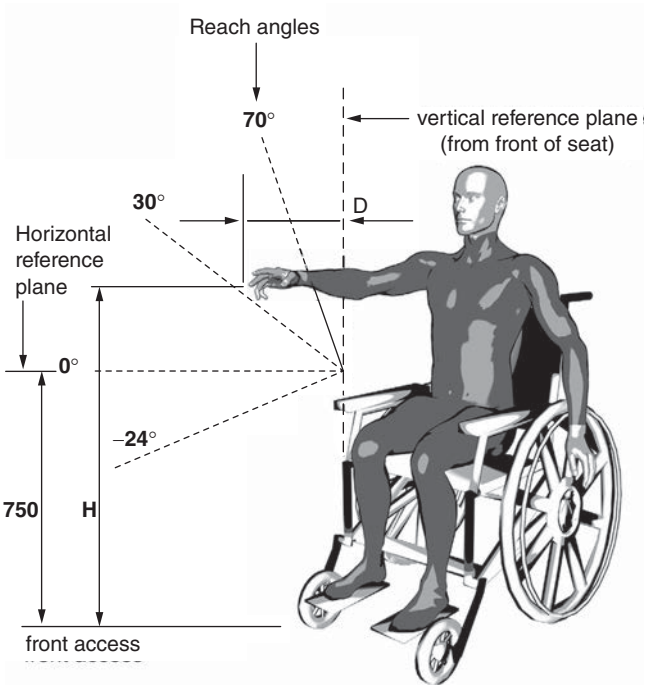
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Table VII Reach ranges

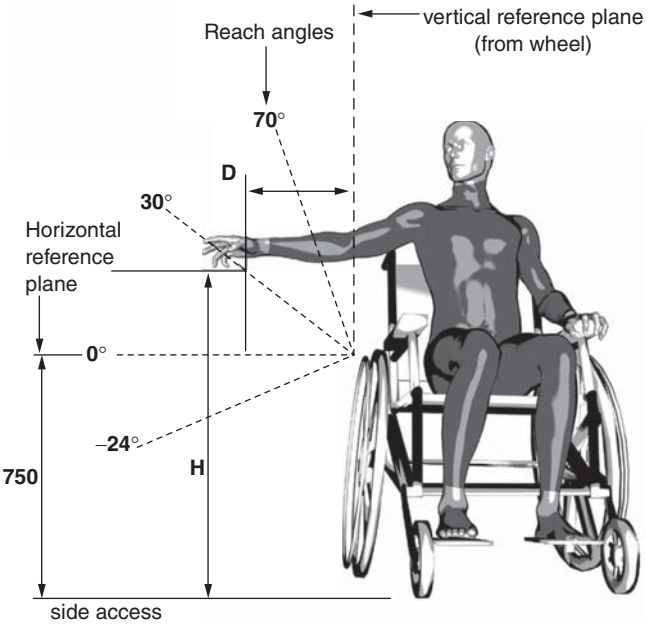
Person	Access	Reach angle	Height (H)		Depth (D)	
			Comfortable	Extended	Comfortable	Extended
Wheelchair user	Front	+70	1000	1150	90	120
		Horizontal* (750)	–	–	180	230
		–24	650	650	120	200
	Side	+70	1060	1170	100	135
		Horizontal** (750)	–	–	220	310
		–24	665	630	165	230
Ambulant disabled	Front	+70	1500	1625	200	250
		Horizontal (850)	–	–	280	400
		–24	750	700	180	310

* With suitable knee recess provided.

**With suitable knee recess provided.



4.7 *Front access*



4.8 *Side access*

The ability of a seated person, for example, in a wheelchair to reach, forward, sideways, upwards or downwards is different than someone standing.

Reach distance forms an arc, based on shoulder level. Reach range can be described as easy or comfortable (reach without much movement of the torso) or maximum or extended (just possible with movement of the torso). Research carried out for the preparation of BS 8300:2001 gives figures for comfortable and extended reach ranges, see Table VII and Figures 4.7 and 4.8.

5 WALKING DISTANCES

5.1 Mobility ranges

Walking distances were researched in some detail in the late 1980s. US regulations, for example, note that on distances over 100 feet (30 m) disabled people are apt to rest frequently. These regulations suggest that to estimate travel times over longer distances, allowance should be made for 2 minutes rest time every 30 m.

Research based on a follow-up study to the London Area Travel Survey found that of disabled people who were able to walk, approximately 30 per cent could manage no more than 50 m without stopping or severe discomfort. A further 20 per cent could only manage between 50 and 200 m.

Mobility ranges vary enormously between individuals with age and disability, while factors such as weather, topography (gradients) and obstacles can also affect mobility ranges.

In pedestrian schemes, travel distances should not exceed:

- 50 m on unprotected routes
- 100 m on covered routes
- 200 m on completely enclosed routes.

Where gradients exist travel distances should be reduced. Conversely, the provision of seating and resting places can extend the distance people can traverse. The recommended maximum distance on level ground between resting places should be no more than 50 m.

5.2 Changes in level

Any gradient less than 1:60 can be considered level. Changes in level cause problems for many people, particularly people with mobility or visual impairments. Even a single step can prevent access for someone with a mobility impairment and can present a trip hazard for all people.

Where changes in level cannot be avoided, slopes or ramps should be designed in a user-friendly manner, although it should be noted that ramps are not always the ideal solution and can take up a great deal of space.

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Table VIII Maximum ramp length between landings

Gradient	Length of ramp between level landings (m)
1:20	10
1:19	9
1:18	8
1:17	7
1:16	6
1:15	5
1:14	4
1:13	3
1:12	2

Slopes or ramps provide access for people who use wheels, such as wheelchair users or parents with pushchairs. However, some people may find it easier to negotiate a flight of steps than a ramp and for them, the presence of handrails for support is essential. Where a change in level no greater than 300 mm, a ramp may be acceptable as the only means of access, avoiding the need for steps. Otherwise, steps would also be required.

Where ramps are provided, they should be no steeper than 1:12 but preferably 1:20. Table VIII indicates the maximum length of a ramp before level landings are required.

It should be noted that if the level change exceeds 2 m, then the ramps become very difficult to use for many people including wheelchair users. There should be an alternative means of access for wheelchair users, such as a lift. (Details of lifts are given in Chapter 3.)

Many people find long flights of stairs difficult to use; therefore, the maximum recommended number of steps should be 12 in a flight. If there are successive flights, it is important there are resting places, at least 1200 mm long (preferably 1800 mm) across the full width of the stair. There should be an unobstructed landing space at the top and bottom of a flight of stairs to avoid any collision.

The design of suitable stairs will be dependent on a variety of factors such as location (external or internal), building type, floor-to-floor levels and other dimension constraints as well as whether they are fire escape stairs. As a rule of thumb, a comfortable step will have a rise of between 150 and 170 mm with a going between 280 and 425 mm deep, with a preference for a minimum of 300 mm.

Stair risers should be closed. Steps without projecting nosings remove a potential trip hazard. If necessary, the projection of a step nosing over the tread should be a maximum of 25 mm. All nosings should be made apparent on both the riser and tread, which will assist people ascending and descending the stair.

Stairs and steps should have a minimum clear width between handrails of 1000 mm. A handrail should be provided on both sides of the stair to allow people a choice as some people may only have strength on one side of their body.

If the width of stairway is greater than 1800 mm there should be central/additional handrails to give people extra support. The channels themselves should not be less than 1000 mm between handrails. This precludes the design of stairs between 1800 and 2000 mm in width.

6 TOILETS

6.1 Provision

Without adequate toilets many people, especially disabled people, are limited in their ability to go out to work, to shop and so forth. The majority of disabled people do not require the use of unisex wheelchair accessible WCs.

It is important that all toilet facilities are accessible, catering for a wide range of people, including older people and children. Therefore, things such as door opening pressures, range of heights of sinks and urinals, easy to use door furniture and tap design are key design factors in making all toilets useable.

Another consideration is that women may require to use toilets more frequently than men and on average take longer than men (this is particularly true during menstruation or during and after pregnancy). The British Toilet Association recommends that twice the number of male cubicles plus number of male urinals is the appropriate number of cubicles for women.

6.2 Children's toilets

Children are often not considered in the design of toilets. Many children can be deterred from independent use of toilet facilities by poor design and specification. It should also be possible in developments that are likely to have many children using them, for example, leisure facilities, to provide separate children's toilets. These could be provided with associated family facilities, such as nappy-changing facilities. Nappy-changing facilities must never be situated in accessible toilets. It is important that separate wheelchair accessible nappy-changing areas are provided.

There are approximately 1.6 million people who have continence problems. Up to 4 million people, mainly men, are affected by 'shy bladder syndrome' (avoidant paruresis) and therefore the layout of toilets should provide 'line of sight' privacy, an adequate number of cubicles and privacy screens.

6.3 Adult-changing facilities

In larger developments, consideration should also be given to adult-changing facilities. Some people, including people with profound and multiple disabilities, need to be laid flat to be changed within WC accommodation. If adult-changing facilities are not provided, people may have to change a person on the floor. This is undignified, unhygienic and involves heavy lifting by others, such as carers or personal assistants, which could cause serious back injuries.

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5 Capital and whole life costs of buildings

David Holmes, Chris Bicknell and John Davies

Davis Langdon, an AECOM Company

KEY POINT:
- Clear communication with clients from the beginning of the project is vital
- Changes made later in the project are more difficult and more costly to implement than those made at an earlier stage
- Maintenance and operational costs of a building dwarf the construction costs
- Whole life costing is a valuable tool to enhance decision making, but can be heavily influenced by decisions on time-span and discounted cash flow

Contents

1 Introduction
2 Why are construction costs so important?
3 Procurement
4 New rules of measurement and cost estimating
5 Whole life costs
6 Conclusion

1 INTRODUCTION

This chapter examines the relationship between cost and value in construction projects, and discusses why architects should pay particular attention to their client's budgetary constraints. We also describe the degree of risk which clients accept when undertaking construction projects, and the steps which designers can take to mitigate these risks. In describing the estimating and cost planning process, we explain the discipline of the cost planning process, and the importance of the achievement of an appropriate level of fixity of design and specification at the conclusion of each RIBA project stage. We also describe the information that is available to cost consultants in preparing estimates at different project stages, and the degree of certainty that can be attached to these estimates.

The expenditure on design and construction can have significant leverage relative to the costs of occupation. For example, appropriate investment in design and construction could potentially have a significant and valuable impact on the productivity of building occupiers. With many buildings procured by the public sector on the basis of design, build and operate arrangements such as LIFT, used for primary healthcare, whole life costing is being taken far more seriously today than hitherto. Furthermore, with the growing significance of the sustainability agenda, concerned with managing energy consumption, carbon emissions and other environmental impacts, opportunities to invest to save energy and to mitigate environmental impacts are taken increasingly seriously.

2 WHY ARE CONSTRUCTION COSTS SO IMPORTANT?

2.1 Cost planning

Cost planning is a key due diligence step in preparing for a construction project. Cost planning informs the client and the project team how much a proposed project is likely to cost. Additionally, cost planning will tell when the expected expenses will most likely occur, a cash flow programme. This information is critical for obtaining project financing and for determining whether a project can be affordable.

Very few clients have the luxury of an unlimited budget, and even with generous funding, all clients will want to make sure that the proposed design solution represents the best way of meeting their purpose and that their investment makes the best use of their resources. Financial discipline on a project does not mean that budgets have to be unrealistically tight. However, it does mean that the client's investment should be managed responsibly by the project team to focus on elements which relate specifically to the client's value criteria. Typical value criteria influencing projects are discussed below.

2.2 The value agenda

For many buildings, particularly those constructed for commercial markets, the client's principal measure of worth is the building's exchange value, typically measured by rental or sales revenue. Exchange value is used by clients in investment appraisals to determine whether projects are financially viable. In effect, exchange value determines the 'bottom line' of most schemes. Exchange value is generally defined by third parties and, particularly in commercial property markets, it is often difficult to secure a premium valuation for innovation. As a result, clients may have surprisingly little room for manoeuvre in setting their construction budgets. Exchange value issues can affect public sector projects too. Many public sector clients operate internal marketplaces where facilities are bought – using the volume of demand to establish the size and quality of the building that can be afforded.

Value is of course not just about financial considerations and there are many other ways in which buildings are able to contribute benefits to their owners, occupiers and neighbours. Some of the sources of these are listed below:

- *Operational value*. The benefits generated through the occupation and use of the building, which might include greater staff productivity, or improved educational outcomes associated with a new school.
- *Social value*. The broader benefits to society of a development, which might include local residents feeling more secure in their neighbourhood following the completion of an urban realm improvement project.
- *Brand value*. Messages communicated by a building derived from its design, and which reflect positively on the occupier. The DEFRA building at Alnwick is a good example of this benefit; a flagship development designed to achieve exemplary standards of sustainability and environmental performance.
- *Civic/esteem value*. The contribution that a development can make to a neighbourhood in terms of physical improvement to the quality of the building fabric, public realm and so on, this benefit is secured by all users of the neighbourhood. The reflected prestige that neighbouring buildings can secure from proximity to a high quality development, be it Tate Modern or a major redevelopment scheme such as Kings Cross in London, can be secured by owners and occupiers of neighbouring buildings and may reflect in an increase in the exchange value of the neighbouring buildings.

Whilst not all of these sources of value have an immediate financial dimension, all require a focused and disciplined approach by the design team to concentrate effort and investment on aspects of the design which

maximise the client's, end users' and wider community benefits, without compromising the fundamental financial viability of the project.

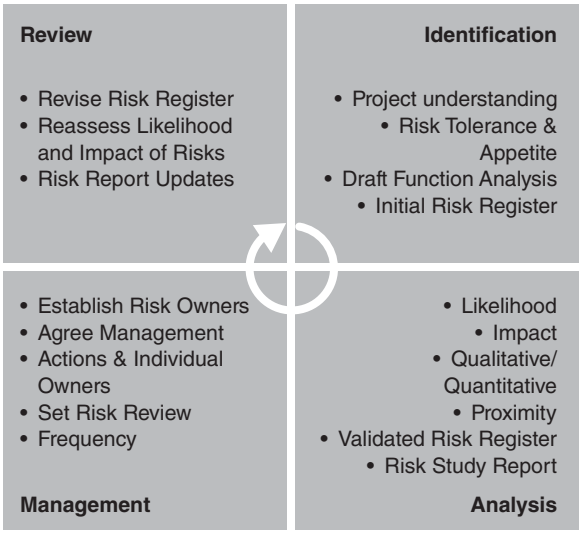
2.3 Risk and value management

Risk and value management should be carried out throughout a project lifecycle, with early involvement of the entire integrated project team to minimise/manage risks. Risk management ensures that risks are identified as early in the project life cycle as possible and their potential impacts are understood and allowed for, and where possible their impacts minimised. The main emphasis is to identify the risks, analyse them and then ensure that they are effectively managed in order to minimise negative consequences and maximise opportunities. Rigorous follow up of identified risk mitigation actions and regular updates of the Risk Register are essential if the full benefits of Risk Management are to be realised.

The project team create a Risk Register and assign a RAG traffic light system to each risk (Table I). Obviously Red risks need actioning immediately. Rigorous follow up of identified risk mitigation actions and regular updates of the Risk Register are essential if the full benefits of Risk Management are to be realised (Figure 5.1).

Table I Risk matrix of probability and impact

		Probability		
Risk description		**Low**	**Medium**	**High**
Impact	Low	Green	Green	Amber
	Medium	Green	Amber	Red
	High	Amber	Red	Red



5.1 *Risk management circle*

High Impact and High Probability risks will need addressing immediately and the project team need to ensure that the risk is owned by someone in the team – which could be the client. All need to agree what measures are required to ensure a successful outcome. Value management is about adding or enhancing value and not solely about cutting cost, although this may be a by-product. The principles and techniques of value management aim to provide the required quality at optimum whole-life cost during the process of developing a project.

3 PROCUREMENT

3.1 Strategy

Selection of the procurement strategy and contract selection is one of the most important decisions facing the client. It has been estimated that the optimum strategy can influence the overall project cost by between 10–15%.

Source: Treasury guidance to Government Departments

The primary consideration in the procurement of construction projects is the need to obtain best value for money in the whole life of the service or facility. The design and operation of the facility should maximise the delivery of effective services; this is most likely to be achieved through integration of the design, construction, operation and ongoing maintenance. Some compromises will almost certainly have to be made to achieve an optimum balance of risk, benefit and funding for a particular project.

3.2 Influencing factors

- Project objectives – example, to provide office space for 1,000 people to deliver the client services.
- Constraints – such as budget and funding; the timeframe in which the project has to be delivered.
- Cultural factors – such as considerations about the workspace environment that will best support the way people work.
- Risks – such as late completion of the facility; innovative use of materials; carbon reduction strategies.
- The client's capabilities to manage a project of this type.
- The length of operational service required from the facility.

3.3 Procurement routes and associated risk

Critical issues:

- Relationship between design and construction
- Allocation of design risk (time, cost, quality)
- Allocation of construction risk (time, cost, quality)
- Status of design at point of committing to construction
- Incidence of change
- The project brief.

3.4 Design and build

- Design team employed by client to develop brief.
- Project design progressed to suitable stage prior to tender.
- Employer's requirements issued to main contractors who submit their contractor's proposals, lump sum tender and agreed programme.
- Main contractor has an obligation to deliver the project as defined within the contractor's proposals to the cost and programme agreed within the returned tender.
- Contractor retains responsibility for the design and design development.

3.5 Traditional lump sum

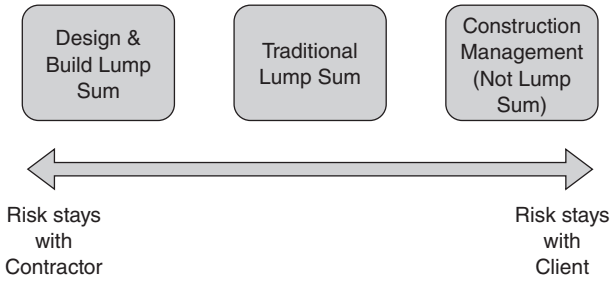
- Design team employed by client to develop brief.
- Project design completed prior to tender.
- Main contractor submits a lump sum tender and agreed programme.
- Main contractor has responsibility to deliver the project as specified to the cost and programme agreed at tender stage.
- Client retains responsibility of sufficiency of design.

3.6 Construction management

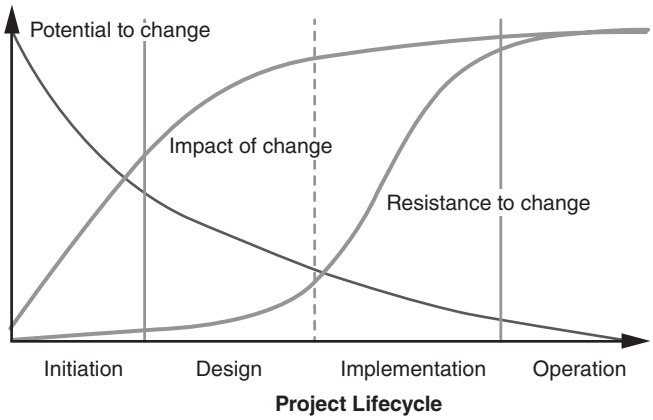
- Fundamentally different approach to the two previous routes – no main contractor is appointed.
- The brief is developed by a design team appointed by the client who are responsible for developing the design.
- A construction manager is appointed by the client as a fee earning consultant to programme, coordinate and manage the design and construction activities executed by the trade contractors.
- Trade contractors are employed directly by the client.

Figure 5.2 is looking at financial risk and who owns it for the most common procurement options. Management of risk is an ongoing process throughout the life of the project, as risks will be constantly changing. Risk management plans should be in place to deal quickly and effectively with risks if they arise. It is important to work as an integrated project team from the earliest

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5.2 *Procurement routes*



5.3 *Relationship between programme and change*

possible stages on an open book basis to identify risks throughout the team's supply chains.

3.7 Design stages

As a client's brief and concept designs are developed, a greater degree of fixity in terms of the design solution and predicted costs can be provided by the project team. This process is discussed in more detail in the section focused on cost planning. However the design develops and cost certainty increases, so does the cost of changing the design, and the client and project team's resistance to change. This relationship is illustrated in Figure 5.3 and emphasises why it is so important to stick to the discipline of progressive sign-off at the end of each design stage.

As a project progresses to the appointment of contractors, the client's overall financial commitment becomes better defined. More risk can also be transferred to third parties if the client so wishes. Whilst under most procurement routes the client is required to accept risks associated with design performance, they will generally seek to transfer commercial and construction risks to the contractor through some form of a fixed-price, lump sum contract. Quite clearly, if the design information upon which the client obtains a contractual commitment is not complete, is ambiguous or is not fully coordinated then, not only will the client retain outstanding design risk, but will also find that the basis of his commercial risk transfer to the contractor is weakened.

Evidence from Construction Key Performance Indicators, published by the BIS, indicates the scale of this potential problem, showing that fewer than 80 per cent of projects are completed with +/– 10 per cent of their original tender sum. Moreover, only around 50 per cent of projects are completed within +/– 5 per cent of the tender sum. Whilst some of this cost variation may reflect client changes, or problems on site, it is likely that some of these increases will have resulted from the consequences of continuing design development.

In order to mitigate the client's risk it is incumbent upon the team to ensure that the design is completed to the appropriate level of detail and fixity required by the procurement route. To do otherwise risks rendering some of the effort expended in design development and cost planning abortive.

3.8 Order of cost estimating and elemental cost planning

For which of you, intending to build a tower, sit not down first, and count the cost, whether he have sufficient to finish it? Lest happily, after he has laid the foundation, and is not able to finish it, all the onlookers begin to mock him, saying, 'This man began to build, and was not able to finish'.

St Luke (Ch. 14)

It is often said that the first cost received by the client is the cost that is always remembered, so it is important that the entire project team clearly understand each other's requirements and that estimates submitted to the client include all relevant heads of cost.

4 NEW RULES OF MEASUREMENT AND COST ESTIMATING

4.1 Rules

The Standard Method of Measurement (SMM) has provided quantity surveyors with rules of measurement for building works since 1922. These rules enabled quantity surveyors to measure building work items for inclusion in bills of quantities which, in turn, are used for the purpose of obtaining a tender price for a building project in a consistent way. The SMM does not provide specific guidance on the measurement of building works for the purpose of producing cost estimates or cost plans.

In May 2009 the New Rules of Measurement (NRM) Order of cost estimating and elemental cost planning were introduced by the RICS. The NRM have been written to provide a standard set of measurement rules that are understandable by all those involved in a construction project, including the employer, thereby aiding communication between the project/design team and the employer. In addition, the NRM should assist the quantity surveyor/cost manager in providing effective and accurate cost advice to the employer and the rest of the project/design team.

4.2 Order of cost estimate

The purpose of an *order of cost estimate* is to establish if the proposed building project is affordable and, if affordable, to establish a realistic *cost limit* for the building project. The *cost limit* is the maximum expenditure that the *employer* is prepared to make in relation to the completed building project, which will be managed by the project team (i.e. authorised budget).

Order of cost estimates are produced as an intrinsic part of RIBA Work Stages A: Appraisal and B: Design Brief, or OGC Gateways 1 (Business Justification) and 2 (Delivery Strategy). There are comprehensive guidelines within the NRM and readers are recommended to read the relevant sections of the NRM where more detailed explanations and examples can be found.

At this early stage, in order for the estimate to be representative of the proposed design solution, the key variables that a designer needs to have developed to an appropriate degree of certainty are:

- The floor areas upon which the estimate is based
- Proposed elevations
- The implied level of specification.

Table II sets out feasibility cost information for a range of building types, illustrating the range of costs that can relate to a particular building function.

The variation in costs illustrated in Table II is driven by a wide range of factors and they are not minimum and maximum costs. They only give an indication of typical costs received.

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Table II Sample of a typical order of cost estimating rates

Office buildings	Construction cost (£/m² gifa)
Offices for letting	
low rise, air conditioned, high quality speculative	1,125 to 1,375
medium rise, air conditioned, high quality speculative, 8–20 storeys	1,475 to 1,825
medium rise, air conditioned, city fringe, deep plan speculative office towers	1,750 to 2,150
Offices for owner occupation	
low rise, air conditioned	1,225 to 1,475
medium rise, air conditioned	1,575 to 1,925
high rise, air conditioned	1,875 to 2,300
Offices, prestige	
high rise, air conditioned, iconic speculative towers	2,700 to 3,300
Housing	
Private developments	
Single detached houses	890 to 1,380
Houses two or three storey	780 to 1,930
High-quality apartments in residential tower – Inner London	2,290 to 2,500
High-quality multi-storey apartments – Inner London	1,770 to 2,030
Mid market apartments in residential tower – Outer London	1,770 to 2,140
Affordable apartments in mixed tenure development – Inner London	
three-to-four storey villa – Inner London	1,230 to 1,460
multi-storey	1,410 to 1,560

The building costs set out in Table II should be applied to the gross internal floor area of a building. The rates are current at third quarter 2011 based on an outer London location, they include preliminaries and contractor's overheads and profit but do not include demolitions, external works and services, loose furniture and equipment or specialist installations. Professional fees and VAT are also excluded.
(Source: Spon's Architects' and Builders' Price Book, 2011, Taylor & Francis)

The scope of sources of additional costs which are not related to the floor areas of the building, including external works, fittings and furniture and loose equipment.

Rates will need to be updated to current estimate base date by the amount of inflation occurring from the base date of the cost data to the current estimate base date. The percentage addition can be calculated using published indices (i.e. tender price indices (TPI)) or derived from in-house sources of indices.

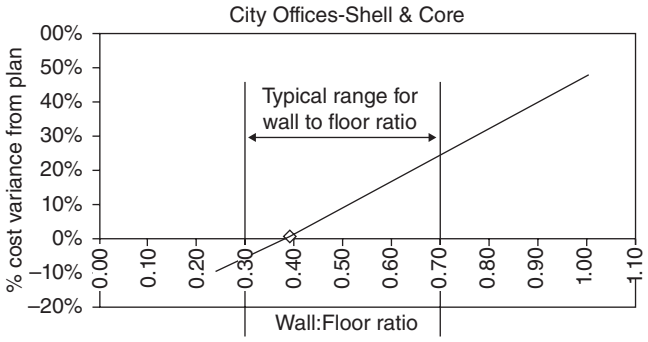
Main contractor's preliminaries, overheads and profit need to be added to the cost of building works. Generally this is a percentage addition ascertained from previous benchmarked studies. The accuracy associated with feasibility estimates of this nature is probably no better than +/– 20–25 per cent. However, most clients require a single point estimate, even at the earliest stage of a project, and the architect and cost consultant must agree an appropriate allowance for design development and other unknowns, balancing requirements for early cost certainty alongside the need for competitive, value for money solutions appropriate to the client's needs.

4.3 Wall to floor ratio

One common measure of efficiency is the wall to floor ratio for the building. Figure 5.4 shows the ratio can effect the cost of a tall office tower.

If you simply pick an average price from the rate range in Table II then it may not reflect the true building complexity. A wall to floor ratio of 0.40 is a relatively simple box. The addition of recesses, returns, increased floor to floor heights to that box can add a significant cost to the building. This is particular relevant in tall towers, where the external façade represents a significant proportion of the overall building cost. Similarly a higher than assumed specification can add significant cost to the project.

In the UK cost plans are typically organised into 'building elements'. Consistently defined elements, such as substructure, frame,



5.4 *Example of a wall to floor ratio. Source: Davis Langdon*

external walls, are widely used by cost consultants when preparing cost plans. They enable the costs of buildings or individual elements to be benchmarked with data from other similar schemes. As the design becomes increasingly detailed, budgets are set for each element providing further discipline for the project team as the design develops. According to client preference, and depending upon the procurement route adopted, some estimates may also be organised in accordance with trade-based packages. The definition of the content of packages varies from project to project. For projects procured either on the basis of construction management or two-stage tenders, estimates prepared in a packages format provide a direct link between the documentation necessary to procure the package, and the management of its costs.

4.4 Formal cost planning stages

The NRM schedules a number of formal cost planning stages (Figure 5.5), which are comparable with the RIBA Design and Pre-Construction Work Stages and OGC Gateways 3A (Design Brief and Concept Approval) and 3B (Detailed Design Approval) for a building project. The employer is required to 'approve' the cost plan on completion of each RIBA Work Stage before authorising commencement of the next RIBA Work Stage.

Formal cost plan	RIBA work stage
1	C: Concept
2	D: Design Development
3	E: Technical Design
	F: Production Information

5.5 *Formal cost planning stages*

Formal Cost Plan 1 is prepared at a point where the scope of work is fully defined and key criteria are specified but no detailed design has begun. Formal Cost Plan 1 will provide the frame of reference for Formal Cost Plan 2. Likewise, Formal Cost Plan 2 will provide the frame of reference for Formal Cost Plan 3. Neither Formal Cost Plans 2 or 3 involve the preparation of a completely new elemental cost plan; they are progressions of the previous cost plans, which are developed through the cost checking of price significant components and cost targets as more design information and further information about the site becomes available.

The cost targets within each formal cost plan approved by the employer will be used as the baseline for future cost comparisons. Each subsequent cost plan will require reconciliation with the preceding cost plan and explanations relating to changes made. In view of this, it is essential that records of any transfers made to or from the risk allowances and any adjustments made to cost targets are maintained, so that explanations concerning changes can be provided to both the employer and the project team.

Cost consultants recognise that the design process is not linear, and in many instances the cost plan will include allowances based

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Table III Sample cost planning rates

External walls – brick and block cavity walling		
Item	**Unit**	**Range £**
Cavity wall; block outer skin; 50 mm insulation; lightweight block inner skin; outer block rendered	m^2	61.00–79.00
Extra for		
Architectural masonry outer block	m^2	1.50–1.950
75 mm thick cavity insulation	m^2	4.60–5.90
Cavity wall; facing brick outer skin; 50 mm thick insulation; plasterboard on stud inner skin; emulsion paint	m^2	83.00–110.00
machine made facings; PC £350.00/1000		
hand made facings; PC £475.00/1000	m^2	98.00–125.00
Cavity wall; facing brick outer skin; 50 mm thick insulation; with plaster on		
lightweight block inner skin; emulsion		
machine made facings; PC £350.00/1000	m^2	86.00–110.00
hand made facings; PC £475.00/1000	m^2	105.00–140.00
Add or deduct for		
each variation of £100.00/1000 in PC value	m^2	0.90–1.20
Extra for		
heavyweight block inner skin	m^2	1.50–1.95
insulating block inner skin	m^2	3.70–4.80
75 mm thick cavity insulation	m^2	4.60–5.90
100 mm thick cavity insulation	m^2	5.80–7.50

The estimating rates set out above should be applied to the quantity of the work itself, calculated using approximate quantities. The rates are current at third quarter 2011 based on an outer London location, include for all labour, materials, plant and incidental items. The rates also include for the contractor's overhead and profit. Preliminaries, professional fees and VAT are excluded.
(Source: Spon's Architects' and Builders' Price Book, 2011, Taylor & Francis)

upon informed assumptions as to what the designer's eventual solution will be. Working together effectively, an architect and cost consultant can ensure that the cost plan provides appropriate allowances for the realisation of the design, whilst at the same time delivering a cost effective and functional solution. Where the designer does not engage actively in the cost planning process, there is a risk that a cost consultant will make inappropriate allowances for incomplete work, potentially creating unnecessary constraints for future design development.

Table III sets out examples of cost planning rates used in a typical stage D plan. The rates are presented as a range to account for variations in specification, quantity and working method. A higher rate might apply for discontinuous work for example. In the cost plan itself, a single rate will be used, which the cost manager feels reflects the complexity and specification of the project.

Cost planning items at this stage are headline descriptions of the work and their selection and pricing should follow the principles of the *pareto rule*, where 80 per cent of the value of the work is captured by 20 per cent of the measurable items. Cost planning rates such as these include all costs associated with materials, labour, interfaces and detailing, together with specialist contractors and main contractor's overheads and profit. Many of these rates are obtained by 'market testing' with indicative costs obtained from contractors. Architects sometimes undertake elements of market testing themselves. If an architect does undertake such market testing exercises, then in presenting the results to the design team and client they should ensure that all costs necessary to complete the work have been included, and proper allowance has been made for the cost implications of the procurement route adopted.

At stage D, the cost plan is intended to provide a greater degree of accuracy. For this to be achieved, the design needs to have reached a corresponding degree of certainty and detail so that quantities can be relied upon, sources of complexity recognised and the cost implications of the proposed specification can be properly assessed.

In preparing cost plans, cost consultants obtain information from a wide range of sources which will include:

- Prices of similar work undertaken on previously completed projects.
- Quotations obtained from suppliers and specialist contractors.
- Cost information published by third parties, including price books, journal articles and so on.

In order to normalise this diverse range of information for location, price inflation etc., cost consultants apply a range of adjustment factors derived from the statistical analysis of large project data-sets, undertaken by bodies such as the Building Cost Information Service (BCIS) or large practices who have their own in-house research teams.

When presenting estimates, to the client, the cost consultant and design team make some important decisions with regard to costs that are included and excluded from an estimate. Heads of costs which are typically excluded from a cost plan, but might need to be reinstated or included elsewhere in the client's budget include:

- Site acquisition costs
- Professional and statutory fees
- Furniture, fittings and equipment
- Costs related to planning agreements (sections 106 and 278)
- Contributions to major infrastructure projects
- The client's own project management, finance and insurance costs
- Overall project contingencies
- Value Added Tax
- Local authority and statutory authority charges for road closures etc.
- Costs of services diversions and off-site services reinforcement.

Clearly the list of exclusions for any particular project could be very extensive. The intention of presenting them in the cost plan is to make it clear that the client may potentially be exposed to these additional costs and that allowances have to be made somewhere within the overall project budget.

The cost plan is generally submitted as part of the RIBA stage design report. It is a detailed document, which requires a considerable amount of time and effort to prepare. It also provides a valuable resource for the project team to monitor the development of the design. In order for it to be an effective control document, the cost plan must provide an accurate reflection of the quantum and specification of the design at the conclusion of the design stage. This

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means that whilst designers can continue to develop detailed design solutions ahead of the completion of a stage, they should freeze the key parameters of their design sufficiently early for the cost plan to be produced with some certainty. Whilst technology such as CAD-based measurement has sped up the production process, proper allowance still has to be made in the programme for the compilation of the cost plan based on relatively firm information.

Other considerations which may be made at this time include:

- Capital allowances for provision of tax relief on items such as plant and machinery, industrial building allowance, hotel building allowance
- Land remediation allowances
- Grants.

It is recommended that specialist advice is sought to maximise the availability and magnitude of capital allowances.

4.5 Option studies

Throughout the design process, architects and engineers need to examine alternative design solutions, be it structural options, different air conditioning systems or alternative floor finishes. The cost consultant can contribute to the selection of preferred solution through the preparation of a option study, taking into account the full cost implications of each choice, which might include effects on the costs of other building elements, overall project duration and so on. Increasingly, option studies are prepared on the basis of whole life costs, taking into account the operational dimensions of specification as well as short-term considerations based on capital cost, programme and procurement.

4.6 Cost checking

Once the Formal Cost Plan 3 is agreed, and the client approves substantial investment in the preparation of production information, then the focus of the cost consultant should shift from projecting what the cost of the scheme should be, to ensuring that the design, as it develops, remains within the set budget. In these circumstances, the cost consultant will produce detailed estimates of specific elements or trade packages, which will confirm whether or not the architect's scheme can be delivered within the disciplines of allowances stated in the Cost Plan.

5 WHOLE LIFE COSTS

5.1 Lifetime

Buildings are long lived assets, and often have quite high operational costs, related to heating, ventilation and lighting, repair, maintenance and so on. Research undertake by CeBe (Constructing Excellence in the Built Environment) referred to in the introduction has identified that the cost of maintenance over a building's lifetime can equate to 3 times the original construction cost. Furthermore the costs of the operation, including the salaries of occupants equate to 35 times the build cost.

What these findings illustrate is that the lifetime costs of running and occupying a building dwarf the initial design and build costs, so if the design can be changed to reduce operating costs or enhance staff productivity, the client may agree to invest additional capital costs to find these improvements.

Given these opportunities, it is surprising that whole life costing has not been adopted more widely, but with the sustainability agenda very high up on many clients' agendas, designers can be expected in the future to demonstrate a greater appreciation of long term performance issues of their building designs.

Before getting into detail and having briefly touched on the sustainability agenda, it is important to clarify the distinction between life cycle costs and life cycle analysis (LCA). The former is concerned with calculating the costs associated with the operation and occupation of an asset, and is the subject of this chapter. By contrast, life cycle analysis is concerned with the full range of environmental impacts of a building, covering embodied impacts, construction and operational effects, together with those associated with asset disposal. As well as greenhouse gases, the scope of LCA will include impacts on landfill, water, biodiversity and so on.

The whole life cost agenda is potentially a very powerful tool for designers to create the case for investment in design which promotes greater productivity, flexibility, durability or longer operational life. However, as with all forms of analysis, the whole life cost assessment needs to be prepared in a way which meets the client's objectives and which provides an accurate representation of future performance. The problems affecting the take-up of whole life cost analysis include difficulties in obtaining unambiguous and corroborated performance and durability data, together with widespread confusion surrounding the use of discounted cashflows.

5.2 Considerations

Without getting into the detail of the production of whole life cost estimates, architects should be aware of the following considerations:

- The purpose of the assessment, as whole life cost studies are typically produced for three purposes:
  - An estimate of the operational cost of an asset. In this instance, the whole life cost study should cover all potential sources of cost associated with the occupation of a building. These cost centres might include energy, cleaning, insurances, maintenance and so on. Total operating cost assessments such as these are typically used by clients to confirm that they will be able to afford to run and maintain their assets.
  - Capital asset replacement. Whole life costs studies which focus solely on modelling the operational life of durable assets such as mechanical systems; roof finishes etc., that require replacement during the life of the building, enabling the client to plan for long term maintenance obligations.
  - Option comparisons. Option studies can be prepared to identify preferred options on the basis of long term performance. The approach could be used to select alternatives that have either different energy use, maintenance or replacement profiles such as window systems, floor finishes, air conditioning options. In an extreme case the choice between a leased building or a self-financed scheme could be supported. Option studies involve the comparison of alternatives which might have different life spans, replacement cycles, income or expenditure profiles. As a result, in many instances comparison can only be undertaken using *discounted cash flow techniques*. The use of discounting enables cash flows which occur in different time frames to be totalled and compared on a like for like basis, enabling a best value option to be selected on the basis of *net present cost/value*.

5.3 Life cycle factors

When reviewing the results of option studies based on life cycle cost methodologies, the architect should ensure that the following aspects of the study have been properly taken into account:

- Discount rate, the selection of the discount rate should take into account the client's requirements. In the case of the public sector discount rates are published by the Treasury, and in the private sector, discount rates generally reflect the client's cost of finance or expectations for rates of return. As it can have such an impact on the end result, the discount rate must always be confirmed by the client.
- That costs for all options have been consistently calculated. Where appropriate both cost and income streams associated with each option should be considered. For example, all cleaning and maintenance costs should be included in a floor finishes assessment together with some revenues associated with the disposal of high value, long-life assets such as stone finishes.

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WINDOW WHOLE LIFE COSTS – WORKED EXAMPLE

	Life expectancy	Capital Cost of Installation £/m²	Annual cost of Maintenance £/m²	PERIODIC COSTS Redecorations interval (years)	Redecorations cost (£/m²)	replace gaskets/beads interval (years)	replace gaskets/beads cost (£/m²)	Repair sills/frames interval (years)	Repair sills/frames cost (£/m²)
PC Aluminium	55	£320.00	£3.00	5 after 25	£24.00	15	£22.00	n/a	£0.00
Painted Softwood	30	£300.00	£2.50	5	£12.00	15	£25.00	5 after 20	£15.00

Year	Discount Factor	Powder Coated Aluminium						Painted Softwood					
		Installation £/100 m²	R&M £/100 m²	Periodic Redecs £/100 m²	Periodic Replacement £/100 m²	Periodic Repairs £/100 m²	Periodic Total £/100 m²	Installation £/100 m²	R&M £/100 m²	Periodic Redecs £/100 m²	Periodic Replacement £/100 m²	Periodic Repairs £/100 m²	Periodic Total £/100 m²
0	1.000	32,000						30,000					
5	0.681		204						170	816.70			816.70
10	0.463		139						116	555.83			555.83
15	0.315		95		693.53		693.53		79	378.29	788		1166.39
20	0.215		64						54	257.46		322	579.28
25	0.146		44	350.44			350.44		37	175.22		219	394.25
30	0.099		30	238.51	219		457.14	3,876	25				
35	0.068		20	162.32			162.32		17	81.16			81.16
40	0.046		14	110.47			110.47		12	55.24			55.24
45	0.031		9	75.19	68.92		144.11		8	37.59	78		115.91
50	0.021		6						5	25.59		32	57.57
TOTAL £/100 m²		32,000.00	3,670.05	936.93	981.08	0.00	1918.02	33,875.72	3,058.37	2,383.08	866.42	572.83	3822.33
NET PRESENT COST £/m²							£375.88						£407.56

5.6 *Whole life cost comparison. Source: Davis Langdon*

- Presentation. The presentation of a whole life cost study based on discounted cash flow should make it clear that the reported cost does not reflect what the client or end user will actually pay. Furthermore, if the net present cost differential between two or more options is relatively small, the team should ensure that other criteria, such as the initial capital expenditure, are considered in the selection of the preferred option.
- Accuracy. The report should clearly state how accurate and reliable the source information upon which it is based is.

Figure 5.6 is a simple worked example of a whole life cost based option study examining the capital and maintenance costs of softwood and aluminium windows over an extended period of 50 years. The comparison illustrate that the aluminium windows, installed at a £20/m² cost premium have a lower life time costs.

Features of the example that are worth noting include:

- Total cost. This example is based on a discounted cashflow and the results are presented as a 'Net Present Cost'. This is the cost of all expenditure over the 50 year period, discounted to the present day at a rate of 8 per cent per annum.
- Effects of discounting. The costs of all future work are discounted to comparison on a like for like basis. This has the effect of reducing the significance and cost of future expenditure. The higher the discount rate, the lower the value of future expenditure. On this basis, high discount rates favour projects with lower initial capital costs. The effects of the discount factor can be seen in the declining cost of repair and maintenance over the study period. Even by year 5, at a discount rate of 8 per cent, the present day cost of £300 is discounted to £204.
- Inclusion of relevant costs only. Other operational costs that would be the same for the two options, cleaning for example, are excluded from the study.
- The importance of the length of the study period. In the worked example, the requirement to replace timber windows at 30 years is the key driver behind the differences in Net Present Cost. If the duration of the study were limited to 25 years, painted softwood would emerge the preferred option.

6 CONCLUSION

Clients will judge the success of their capital projects by many criteria, and there is no doubt that the imagination shown by the design team in delivering a carefully targeted solution to their client's requirements, together with a commitment to achieving a good level of finished quality will be very high on most clients' agendas. Delivery on budget is also usually a high priority, and unlike other aspects of project delivery is easy to monitor and measure. Design teams need to work closely with their cost consultants to make sure that budgets are appropriate, and that design solutions directly address aspects of the client's brief which deliver greatest value.

Techniques such as whole life costing and value management can be used by the cost consultant and design team to help to identify design solutions which best meet the client's requirements.

By collaborating closely from the earlier stages of a project to establish an appropriate capital cost budget, and by maintaining the discipline of working within the budget set by the client and project team, the design team will give itself the best opportunity of delivering a project which meets the design team's expectations, the client's requirements and provides all parties with an appropriate financial reward.

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6 Structure

David Adler, Norman Seward and Andrew Peters

This chapter, originally written by David Adler and Norman Seward, was revised by Andrew Peters in 2011. Andrew Peters is a senior lecturer in the Department of Planning and Architecture at the University of the West of England and an architect in practice

KEY POINTS:

- *Current Codes of Practice require experts for the analysis and design of the specific type of structure and material*
- *Simplified approximate analysis and design methods as well as even simpler 'rules of thumb' do exist, but should not replace a rigorous final approach*

Contents

1 Introduction
2 Basic structural theory
3 Structural materials
4 Masonry
5 Timber
6 Reinforced concrete
7 Structural steelwork and other metals
8 Glass
9 Other materials
10 Foundations
11 Thumb-nail structures
12 Bibliography

1 INTRODUCTION

1.1 Scope

Structural engineering ensures that the loads of the building and its contents are transmitted safely and economically to the ground, allowing for considerations of function, aesthetics, internal and external environment and incorporating restraints imposed by other members of the building team, legislation, etc.

Structural engineering requires the use of mathematics to determine the forces in the framing elements of a structure (structural analysis). Sizing of these elements is then carried out based on interpretation of guidance provided in Codes of Practice relevant to the material being used (structural design). A competent structural engineer will have suitable training and be experienced in the required analysis and design techniques. Innovative and non-standard structures may require special consideration with the use of model testing to confirm analytical assumptions and member sizing.

1.2 Complexity

In recent years, mathematical methods prescribed in new Codes of Practice, particularly the Eurocodes, have become more complex, making the use of computer programs essential.

1.3 Philosophy

The treatment of the subject in this chapter is necessarily brief. It will be even less comprehensive than in previous editions, but will still try to give the architect something of a feel for structure, and help him or her in discussions with a structural engineer. And this is the key. An understanding of the numbers involved is not as important as an appreciation of the structural 'philosophy'. A grasp of how the structure is 'working' will enable the architect to have a meaningful conversation with a structural engineer. It should always be remembered that structure will have a definable impact on a design and if the wish is to keep control of that design even a basic level of involvement with the engineer will be beneficial. Because of the complexity of the methods now used, Local Authorities are increasingly insisting on the submission of calculations prepared by a Chartered Engineer from the recognized qualifying bodies, the Institution of Structural Engineers and the Institution of Civil Engineers who are entitled to use the designations CEng MIStructE or CEng MICE, respectively.

1.4 Key factors

There are three important factors in structural analysis and design:

- accurate assessment of the behaviour of the structural form;
- accurate identification and calculation of all the forces acting;
- full knowledge of the properties of the structural materials.

An outline of the methods used is given below.

2 BASIC STRUCTURAL THEORY

2.1 Introduction

This section will summarise basic structural concepts and the terms that might be met in dealing with structural matters. Examination in greater depth may be found in the references given at the end of the chapter.

2.2 Limit state

Current techniques in the majority of structural engineering Codes of Practice are based on the concept of limit state design. Traditionally, design involved calculating the maximum stress and deflection in a member under working load. That stress was compared with the stress in that material known, through experiment, to lead to failure. Safe design included a margin, called the *factor of safety*, between the working and failure stress values. This traditional method was generally referred to as *permissible stress* design.

It is however important to anticipate how the form of the structure will behave under increasing load as factors other than excessive stress can cause building failure. These are known as *limit states* and must all be considered for satisfactory design. Apart from collapsing completely (*limit state of collapse or ultimate limit state*), a building may crack locally so badly as to let in the weather, it may deflect until the users feel unsafe (*limit state of deflection or serviceability limit state*). The task of the structural designer is to ensure that none of the possible limit states is ever reached.

In the case of the ultimate limit state, this is done by making sure that ultimate material stresses are not exceeded under critical ultimate load combinations. Ultimate stresses are derived by dividing the material failure stress by a prescribed material safety factor and ultimate loads are calculated by multiplying the loads (see Section 2.3) by prescribed load factors. Both material and load factors are listed in the Codes of Practice relevant to the material being used.

The serviceability limit states of cracking and deflection are checked using working loads rather than ultimate loads, as the actual crack width and deflection in service is of interest.

2.3 Loads

In Section 2.2, reference was made to loads. A load is an example of a force, and the term is usually used to describe those outside forces that

act on a building structure. In Eurocodes, all loads and factors producing stress or deflection are called actions. Actions are of four types:

- Dead loads: from the weight of the structure itself and that of other fixed parts of the building such as cladding, finishes, partitions, etc.
- Imposed loads: from the weight of people, furniture and of materials stored in the building.
- Dynamic loads: these are of many origins. The most common dynamic load on a building is that caused by wind, which can produce horizontal and vertical pressures and suctions. Other dynamic loads are produced by moving machinery such as overhead cranes in large workshops and by earthquakes. For the purposes of design, dynamic loads were often transformed into approximate equivalent static loadings. The widespread availability of sophisticated analytical software now allows more accurate dynamic analysis to be carried out.
- The fourth type of action is one that is not produced by an outside force, but by internal factors such as thermal expansion.

2.4 Force units

Forces, including loads, are measured in Newtons (N). One Newton is the force required to give a mass of 1 kg an acceleration of 1 m/s^2. A tip to remember is that a Newton is about the weight of an apple. Most forces in structural engineering are expressed in kN (kilonewtons). Table I gives conversions from and to SI, MT and FPS (Imperial) units for loadings of all types.

2.5 Mass and weight

Confusion often arises between the terms *mass* and *weight*. Outside nuclear physics, the *mass* of an object is a fixed quantity which is a basic property of that object. Its *weight* will depend on the mass, but also on the value of the gravitational effect on the object. This is not a constant, but can vary, not only in extra-terrestrial conditions but even very slightly on different places on earth. However, for all practical purposes the acceleration of gravity is taken as 9.81 m/s^2, so that the weight of a kilogram mass is 9.81 N. This figure is invariably rounded up to 10 for ease of computation.

Table I Various conversions for loadings

Point loads
1 N = 0.102 kgf = 0.225 lbf
1 kN =101.972 kgf = 224.81 lbf = 0.1004 tonf
1 MN = 101.972 tf = 224.81 kipf = 100.36 tonf
1 kgf = 9.807 N = 2.205 lbf
1 tf = 9.807 kN = 2.205 kipf = 0.9842 tonf
1 lbf = 4.448 N = 0.4536 kgf
1 kipf = 4.448 kN = 453.59 kgf = 0.4536 tf
1 tonf = 9.964 kN = 1.016 tf
Linearly distributed loads
1 N/m = 0.0685 lbf/ft = 0.206lbf/yd
1 kN/m = 68.5 lbf/ft = 0.0306 tonf/ft
1 kgf/m = 9.807 N/m = 0.672 lbf/ft = 2.016 lbf/yd
1 tf/m = 9.807 kN/m = 0.672 kipf/ft = 2.016 kipf/yd = 0.3 tonf/ft = 0.9 tonf/yd
1 lbf/ft = 14.59 N/m =1.488 kgf/m
1 kipf/ft = 14.58 kN/m =1.488 tf/m
1 ton/ft = 32.69 kN/m = 3.33 tf/m
1 tonf/yd = 10.90 kN/m = 1.11 tf/m
Superficially distributed loads
1 N/m^2 = 0.0209lb/ft^2
1 kN/m^2 = 20.89 lb/ft^2
1 MN/m^2 = 9.324 tonf/ft^2
1 kgf/m^2 = 9.80665 N/m^2 = 0.2048lbf/ft^2 =1.843lbf/yd^2
1 tf/m^2 = 9.80665 kN/m^2 = 0.2048 kipf/ft^2 = 0.0914 tonf/ft^2 = 0.823 tonf/yd^2
1 lb/ft^2 = 47.88 N/m^2 = 4.88 kgf/m^2
1 kipf/ft^2 = 47.88 kN/m^2 = 4.88 tf/m^2
1 tonf/ft^2 = 107.25 kN/m^2 =10.93 tf/m^2
1 tonf/yd^2 = 11.92 kN/m^2 = 1.215 tf/m^2
Densities
1 N/m^3 = 0.00637 lbf/ft^3
1 kN/m^3 = 6.37lbf/ft^3
1 MN/m^3 = 2.844 tonf/ft^3
1 kg/m^3 = 0.0624lb/ft^3 (mass density)
1 t/m^3 = 62.4lb/ft^3
1 lb/ft^3 = 16.02 kg/m^3 1 lbf/ft^3 =157 N/m^3
1 ton/ft^3 = 35.88 t/m^3 1 ton/ft^3 = 351.9 kN/m^3
1 ton/yd^3 = 1.33 t/m^3

Table II Densities of bulk materials

	kg/m^3	kN/m^3
Aggregates		
Coarse		
Normal weight, e.g. natural aggregates	1600	15.7
Fine		
Normal weight, e.g. sand	1760	17.3
Bricks (common burnt clay)		
Stacked	1602–1920	15.7–18.8
Cement		
Bags	1281	12.6
Concrete, plain		
Aerated	480–1600	
brick aggregate	1840–2160	
Clinker	1440	14.1
stone ballast	2240	22.0
natural aggregates	2307	
Concrete, reinforced 2% steel	2420	23.7
Glass		
Plate	2787	27.3
Gypsum		
Plaster	737	7.2
Metals:		
Aluminium cast	2771	27.2
Iron		
Cast	7208	70.7
Wrought	7689	75.4
Lead:		
cast or rolled	11 325	111.1
Stone		
Bath	2082	20.4
masonry, dressed	2403	23.6
Granite	2643	25.9
Marble	2595–2835	25.4–27.8
Slate:		
Welsh	2803	27.5
Timbers:		
Ash (Canadian)	737	7.2
Balsawood	112	1.1
Beech	769	6.9
Birch	641	6.3
Cedar, western red	384	3.8
Deal, yellow	432	4.2
Ebony	1185–1330	11.6–13.1
Elm		
English	577	5.6
Fir:		
Douglas	529	5.2
Silver	481	4.7
Hemlock, western	497	4.9
Iroko	657	6.4
Larch	593	5.8
Mahogany: (African)	561	5.5
Maple	737	7.2
Oak: English	801–881	7.8–8.6
Pine: New Zealand	609	6.0
Plywood	481–641	4.7–6.3
Plastic bonded	721–1442	7.0–14.2
Resin bonded	721–1362	7.0–13.4
Poplar	449	4.4
Spruce Canadian	465	4.6
Sycamore	609	6.0
Teak, Burma or African	657	6.4
Walnut	657	6.4
Whitewood	465	4.6
Water	1001	9.8

2.6 Loading assessment

Perhaps, the most important calculation the structural engineer carries out relates to the accurate assessment of loading. Table II shows the loads of various materials which may comprise the

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Table III Superficial masses of materials in kg/m³ and weights in N/m². This is based on figures in BS 648:1964, and should be taken as approximate

	kg/m²	N/m²
Aluminium sheet		
Corrugated (BS 2855) (including 20% added weight for laps 'as laid') 0.71 mm	2.9	28
Battens		
Slating and tiling, 40 × 20 mm softwood 100 mm gauge	3.4	33
Blockwork, walling (per 25 mm thickness)		
Clay		
Hollow	25.5	250
Concrete		
Stone aggregate		
Cellular	40.0	392
Hollow	34.2	335
Solid	53.8	528
Lightweight aggregate		
Cellular	28.3	278
Hollow	25.5	250
Solid	31.7	311
Aerated		
Based on 560 kg/m³	14.4	141
Based on 800 kg/m³	19.2	188
100 mm thick	52.4	514
115 mm thick	56.9	558
Brickwork (all per 25 mm thick)		
Clay		
Solid		
Low density	50.0	490
Medium density	53.8	528
High density	58.2	571
Perforated		
Low density, 25% voids	38.0	373
Low density, 15% voids	42.3	415
Medium density, 25% voids	39.9	391
Medium density, 15% voids	46.2	453
High density, 25% voids	44.2	433
High density, 15% voids	48.0	471
Concrete	57.7	566
Flagstones		
Concrete 50 mm thick	115	1130
Natural stone 50 mm thick	56	549
Floors		
Hollow concrete units (including any concrete topping necessary for constructional purposes)		
100 mm	168	1650
150 mm	217	2130
200 mm	285	2800
Glass		
Float 6 mm	16.7	164
Gypsum panels and partitions		
Dry partition		
65 mm thick	26.5	260
Lathing		
Wood	6.3	62
Lead sheet (BS 1178)		
0.118 in (3.0mm)	34.2	335
Plaster		
Gypsum		
Two coat, 12 mm thick		
Normal sanded undercoat and neat finishing	20.8	204
One coat, 5 mm thick, neat gypsum	6.7	66
Lime (non-hydraulic and hydraulic) 12 mm thick	23.1	227
Lightweight		
Vermiculite aggregate, two coat, ditto	10.5	103
Plasterboard, gypsum		
Solid core		
9.5 mm	8.3	81
12 mm	10.6	104
18 mm	16.1	158
Plywood		
Per mm thick	0.6 ± 0.1	6 + 1
Rendering		
Portland cement: sand (1:3) 12 mm thick	27.7	272
Screeding		
Portland cement: sand (1:3) 12 mm thick	27.7	272
Slate		
Welsh		
Thin	24.4	239
Thick	48.8	479
Steel		
Mild, sheet Corrugated (1 mm)	15.6	153
Stonework, natural		
Note: For cramps add 80 kg/m³ (5lb/ft³)		
Limestone		
Light, e.g. Bathstone		
100 mm thick	206.6	2026
Medium, e.g. Portland stone		
100 mm thick	225.9	2215
Heavy, e.g. marble		
20 mm thick	53.7	527
Sandstone		
Light, e.g. Woolton		
100 mm thick	221.1	2168
Medium, e.g. Darley Dale		
100 mm thick	230.7	2262
Heavy, e.g. Mansfield Red		
100 mm thick	240.3	2357
Granite		
Light, e.g. Peterhead		
50 mm thick	129.7	1272
Medium, e.g. Cornish		
50 mm thick	134.5	1319
Heavy, e.g. Guernsey		
50 mm thick	144.2	1414
Thatching		
Reed (including battens) 300 mm thick	41.5	407
Tiling, roof		
Clay		
Plain Machine made, 100 mm gauge	63.5	623
Concrete		
Stone aggregate		
Plain		
75 mm gauge	92.8	910
100 mm gauge	68.4	671
115 mm gauge	61.0	598
Interlocking (single lap)	48.8 ± 7.3	479± 72

fabric of a building that may be included in the dead load computation. It also gives the densities of materials that may be stored within it: part of the imposed loads. The figures are given both in the usual mass density form: kg/m³, and also in the more convenient weight density kN/m³. Some loadings are more conveniently calculated from superficial or linear unit weights, and a few are given in Table III. For a comprehensive list of weights of building materials, reference should be made to BS648 *Schedule of weights of building materials.*

Table IV indicates minimum imposed loads that should be allowed for in designing buildings for various purposes. These figures are intended to allow for the people in the building, and the kind of material normally stored. However, these loads sometimes need to be checked against the figures in Tables II and III for more unusual circumstances.

2.7 Structural elements

For convenience of design, large structures are broken up into elements. These are of different types according to the function they perform in the building. Before describing each type, it will be necessary to explore the forces that are found internally in the materials of the structure.

2.8 Stress and strain

If a bar of uniform cross-section has an outward force applied at each end, Figure 6.1, it will stretch slightly. This stretch is called the strain in the bar, and is defined as the extension divided by the original length.

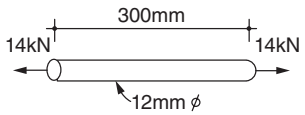
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Table IV Typical minimum imposed floor loads extracted from BS 6399 – 1 Loading for buildings: Code of practice for dead and imposed loads

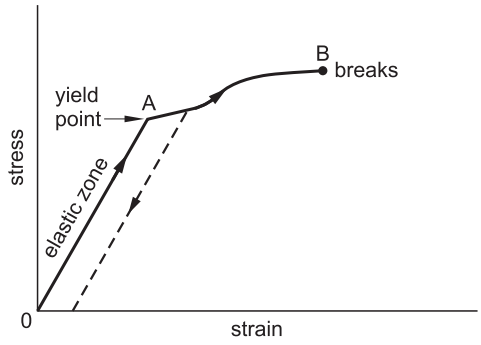
Type of activity/or occupancy for part of the building or structure	Examples of specific use		Uniformly distributed load (kN/m²)	Concentrated load (kN)
A Domestic and residential activities (also see category C)	All usages within self-contained single family dwelling units. Communal areas (including kitchens) in blocks of flats with limited use (see note 1) (for communal areas in other blocks of flats see C3 and below)		1.5	1.4
	Bedrooms and dormitories except those in single family dwelling units and hotels and motels		1.5	1.8
	Bedrooms in hotels and motels		2.0	1.8
	Hospital wards			
	Toilet areas			
	Communal kitchens except in flats covered by note 1		3.0	4.5
	Balconies	Single family dwelling units and communal areas in blocks of flats with limited use (see note 1)	1.5	1.4
		Guest houses, residential clubs and communal areas in blocks of flats except as covered by note 1	Same as rooms to which they give access but with a minimum of 3.0	1.5/m run concentrated at the outer edge
		Hotels and motels	Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
B Offices and work areas not covered elsewhere	Operating theatres, X-ray rooms, utility rooms		2.0	4.5
	Work rooms (light industrial) without storage		2.5	1.8
	Offices for general use		2.5	2.7
	Kitchens, laundries, laboratories		3.0	4.5
	Rooms with mainframe computers or similar equipment		3.5	4.5
	Factories, workshops and similar buildings (general industrial)		5.0	4.5
	Balconies		Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
C Areas where people may congregate	Public, institutional and communal dining rooms and lounges, cafes and restaurants (see note 2)		2.0	2.7
C1 Areas with tables	Reading rooms with no book storage		2.5	4.5
	Classrooms		3.0	2.7
C2 Areas with fixed seats	Assembly areas with fixed seating (see note 3)		4.0	3.6
	Places of worship		3.0	2.7
C3 Areas without obstacles for moving people	Corridors, hallways, aisles, stairs, landings, etc. in institutional type buildings (not subject to crowds or wheeled vehicles), hostels, guest houses, residential clubs, and communal areas in blocks of flats not covered by note 1. (For communal areas in blocks of flats covered by note 1, see A.)	Corridors, hallways, aisles, etc. (traffic foot only)	3.0	4.5
		Stairs and landings (foot traffic only)	3.0	4.0
	Corridors, hallways, aisles, stairs, landings, etc. in all other buildings including hotels and motels and institutional buildings	Corridors, hallways, aisles, etc. (foot traffic only)	4.0	4.5
		Corridors, hallways, aisles, etc. subject to wheeled vehicles, trolleys, etc.	5.0	4.5
		Stairs and landings (foot traffic only)	4.0	4.0
	Balconies (except as specified in A)		Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
C4 Areas with possible physical activities (see clause 9)	Dance halls and studios, gymnasia, stages		5.0	3.6
C5 Areas susceptible to overcrowding (see clause 9)	Assembly areas without fixed seating, concert halls, bars, places of worship and grandstands		5.0	3.6
	Stages in public assembly areas		7.5	4.5
D Shopping areas	Shop floors for the sale and display of merchandise		4.0	3.6
E Warehousing and storage areas. Areas subject to accumulation of goods. Areas for equipment and plant	General areas for static equipment not specified elsewhere (institutional and public buildings)		2.0	4.5
	Reading rooms with book storage, e.g. libraries		4.0	4.5
	General storage other than those specified		2.4 for each metre of storage height	7.0
	File rooms, filing and storage space (offices)		5.0	4.5
	Stack rooms (books)		2.4 for each metre in storage height but with a minimum of 6.5	7.0
	Dense mobile stacking (books) on mobile trolleys, in public and institutional buildings		4.8 for each metre of storage height but with a minimum of 9.6	7.0
	Plant rooms, boiler rooms, fan rooms, etc. including weight of machinery		7.5	4.5
F	Parking for cars, light vans, etc. not exceeding 2500 kg gross mass, including garages, driveways and ramps		2.5	9.0

Note 1. Communal areas in blocks of flats with limited use refers to blocks of flats not more than three storeys in height and with not more than four self-contained single family dwelling units per floor accessible from one staircase.
Note 2. Where these same areas may be subjected to loads due to physical activities or overcrowding, e.g. a hotel dining room used as a dance floor, imposed loads should be based on occupancy C4 or C5 as appropriate. Reference should also be made to clause 9.
Note 3. Fixed seating is seating where its removal and the use of the space for other purposes is improbable.

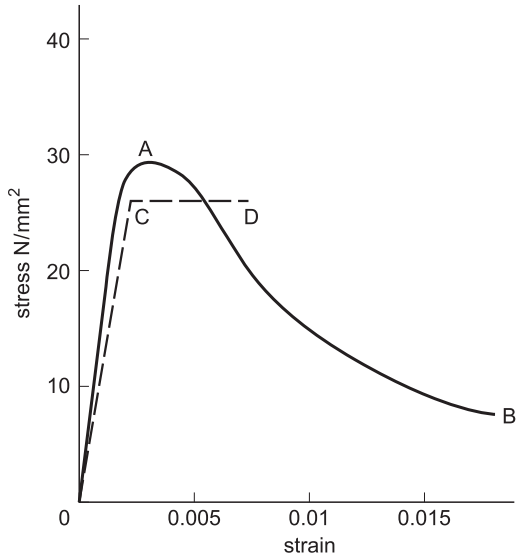
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6.1 *A bar of uniform cross-section under a tensile force*



6.2 *Stress–strain diagram for steel showing the yield point where Hooke's Law (stress is proportional to strain) no longer operates. Dotted line shows deformation caused when stress is reduced after the yield point, material does not return to its original form*



6.3 *Stress–strain diagram for a typical concrete*

The *stress* on this bar is the force on the cross-section divided by its area. The relationship between the strain and the stress is an important factor in structural engineering. Figure 6.2 shows a graph of this relationship for steel. The length OA is a straight line and is called the *elastic zone.* In the *elastic zone*, the ratio of stress to strain is a constant called *Young's Modulus*. At A, there is a sudden change called the *yield point. Hooke's Law*, which says that stress and strain are proportionate, only applies in the elastic zone. Beyond this point along the curve AB there is no constant relationship between the stress and the strain. In fact, even if there is no increase in stress, the strain can increase over time until the bar breaks at B. This length of curve is known as the *plastic zone*.

In Figure 6.3, OAB shows the actual stress/strain relationship for a typical concrete. This, for many practical purposes, can be substituted by OCD. OC is the elastic and CD the plastic zone.

2.9 Units of stress

The basic SI unit of stress is the N/m^2 (which is also called the Pascal, Pa), but this is too small a unit for practical purposes. The correct form for the normal unit is the mega Pascal, MPa or mega Newton MN/m^2 but this is expressed by engineers in units of N/mm^2.

2.10 Tension members

If the stress in a member tends to lengthen it, it is said to be in *tension*. Elements in tension are called *ties*. In many ways, this is the simplest kind of stress. Some materials, steel members in particular are ideal for resisting it. Cables, wires and chains can be used to carry tension. Materials such as stone, cast iron and unreinforced concrete have little or no resistance to tension.

2.11 Compression members

If the stress in a member tends to shorten it, it is in *compression*. Elements in compression are called *struts, columns, piers or stanchions*. The term used depends on their location and the material of which they are made.

Most materials other than cables, wires and chains can be used to carry compression. However, there is an instability phenomenon that occurs in compression members called *buckling*. For some members, particularly those that are slender in comparison with their length, increase in compressive load will cause bending until failure occurs in tension on one side. It is this buckling effect that can be the cause of the collapse of slender towers and high walls of masonry construction.

2.12 Pin-jointed frames

Some structures are designed and constructed of members that act as struts and ties. Analysis methods assume that the members are pin jointed at their ends, which allows only the development of compressive or tensile forces in each member. A roof truss is typical of this type, the general term for which is *pin-jointed frame*. In practice, very few such structures are actually physically pin-jointed (although some have been built), but the use of flexible bolted connector plates adequately approximates the theoretical assumption of a pin at member ends.

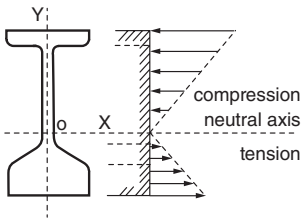
2.13 Bending

Unlike struts and ties which transmit only compressive and tensile forces along their length, beam members support loads by bending action. Internal forces known as bending moments are developed within the beam allowing it to support loads acting at right angles to its length. An example of beam action is that of a lintel spanning an opening and carrying the applied loads from floor and walls above safely around the opening.

Bending is the phenomenon by which a single member of significant depth develops both compression and tension across its section. Consider the case of a beam supported at each end with a load in the centre of the span, the deflected shape is a downward sag resulting in maximum compression in the top layers of the beam, and maximum tension in the bottom layers. Somewhere in the middle of the beam will be layer with no stress at all. This layer is known as the *neutral axis*, Figure 6.4. The externally applied bending moment is resisted by an internal moment in the beam which is a function of the product of the compressive and tensile forces and the distance between their lines of action.

2.14 Materials in bending

Since the internal moment of resistance of a beam depends upon the development of both compressive and tensile forces, only materials that are strong in both compression and tension are generally suitable



6.4 *Structural member under pure bending*

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Table V Comparison of material properties

Property	Masonry (clay brickwork)	Reinforced concrete (with 4% reinforcement)	Steel (mild steel)	Wood (whitewood)	Glass reinforced plastic (polyester)	Annealed glass	Fabric (polyester yarn with pvc coating)
Type of material	Ceramic	Cementitious with metal	Metal	Natural Composite	Synthetic Composite	Glass	Polymer
Weight (p) kN/mm^3	22	24	78	4.5	18	25	14
Tensile strength (σ_{TS}) N/mm^2	1	18	400	75	250	5000 but fracture governed	1000
Compressive strength (σ_c) N/mm^2	15	45	400	25	150	1000 but complimentary tensile strength will govern	none
Coefficient of thermal expansion (α) × 10^{-6}/°C	6	12	12	4	14	7.7–8.8	. . .

for beams. Steel and timber are good examples of such materials. Stone, being weak in tension, makes poor bending members. The ancient Greeks had to construct buildings with closely spaced columns, as stone lintels would not span very far. Only when the arch had been invented could the spans be increased, because the arch is wholly in compression. Cast iron is weak in tension, although not as weak as stone. The bottom flanges of cast iron beams were often larger than the top flanges to allow for this inequality in strength. Concrete is also poor under tensile force, so steel is used in the tension zone (which is usually at the bottom, except for cantilevered and continuous beams – see below), to reinforce concrete beams.

2.15 Beams

Beams can be categorised as follows:

- *Simply supported*. The beam ends are assumed to be completely free to move rotationally resulting in zero moment at each end. In addition, one end is assumed to be supported on a roller bearing allowing freedom of movement in the direction of the beam length resulting in zero horizontal reaction at the roller bearing end. If the loading is uniformly distributed along the length of the beam then the bending moment will be a maximum at midspan. This type of beam is known as statically determinate as the support reactions and bending moments can be calculated using the basic equations of equilibrium.
- *Cantilever*. This beam type is supported only at one end where it is fixed in both position and rotationally. The bending moment will be zero at the free end and a maximum at the support causing tension in the top of the beam.
- *Encastré or fixed end*. This beam is built-in at both ends. This type of beam is statically indeterminate as the values of the bending moments are not calculable by normal statistical methods. These values actually depend on a number of imponderables, such as how much fixity exists at each support. Maximum moments will occur in encastré beams either at midspan or at one, other or both ends, depending upon the disposition of the loads.
- *Continuous*. A beam on several supports is known as a continuous beam. Generally, the maximum moments occur over the supports. Tension in the beam section over the supports occurs at the top but occurs at the bottom at midspan. Continuous concrete beams have to be reinforced accordingly.
- *Lintels*. Beams that are supported on brickwork, such as lintels over doorways and windows, are not considered structurally encastré, and are normally designed as simply supported.

2.16 Bending moments

In order to design a beam, an engineer first calculates the bending moments at critical sections generated by the worst case loading combination. Maximum internal stresses are then computed at those sections. For anything other than the simplest structure, this can be a time-consuming and complicated matter. For a large number of the simpler cases, the moment at midspan of an assumed simply supported beam will suffice to give a safe answer, if not perhaps the most economical. Table V gives maximum bending moments and deflections for the common cases likely to be met.

2.17 Bending stresses

Once the bending moment M is known, the stress f at any layer at distance y from the neutral axis can be found from elastic or plastic theory relationships. The choice of elastic or plastic design theory is dictated by the code of practice for the material being considered.

For elastic design, the relationship is:

$$\frac{M}{y} = \frac{f}{l}$$

The stress in the extreme fibre of a beam therefore depends on the *second moment of area* (I) of the cross-section, proportional to the cube of the depth of the section. Suffice it to say that the larger the depth of the section, the smaller will be the maximum stress. It is therefore beneficial to choose cross-section shapes that have large I-values for the given area of material. For this reason, the most common shape of cross-section for a steel beam is an I, a greater distance between the flanges results in a reduction of material for the required second moment of area.

There is a limit to this, however. Since the top flange is in compression, if it becomes too slender it can buckle. This is particularly significant in the design of steelwork and is the reason that beams have to be checked for lateral torsional buckling when the compression flange is not fully restrained.

2.18 Shear

In addition to internal forces generated by bending moments, most beam cross-sections will also have to carry a force in the plane of the section, called a *shear force*. Generally, the shear will be greatest at the supports of a beam, and least at midspan.

In the case of an I-section, the shear force acts mainly within the web connecting together the two flanges that are in compression and tension. If the web becomes too slender it can buckle under the influence of the shear force.

2.19 Deflection

Since the top of a loaded beam is in compression, it must reduce in length; the bottom, in tension, must stretch. This will lead to the beam taking up a curved form: in the case of a simply supported beam with vertical loading, it will sag. Excessive sagging is not only unsightly, but also may cause damage to finishes such as plaster ceilings, or cause load to be transferred onto partitions that are not designed to carry such load. Formulae are published in many texts giving the deflections of various kinds of beams under different loads.

3 STRUCTURAL MATERIALS

3.1 Behaviour

The third major factor in structural design is an adequate knowledge of the behaviour of the materials used. The basic palette of materials consists of masonry (stone, brick and block), timber, steel

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and reinforced concrete. Design in new materials such as plastics, fabric and glass are becoming more widespread.

4 MASONRY

4.1 Use

Masonry is the general term used for loadbearing construction in brick, block and stone; these are materials of interest to architects. Since they and the mortar that is used to fill the gaps between their elements are all weak in tension, such construction is normally used to carry only simple compressive forces in vertical elements such as walls and piers, sometimes in arches. Masonry can also be used to resist lateral loads from soil and water pressures in retaining walls and wind loads when used in loadbearing masonry or when used as a cladding to a framed building structure. Masonry can be reinforced with steel bars and/or mesh to increase its tensile resistance and hence overall strength.

4.2 Design

Design of masonry should be carried out in accordance with *BS5268 – 1 Code of practice for the use of masonry. Structural use of unreinforced masonry*, a limit state code based upon plastic design theory. The Eurocode for masonry, BS EN 1996-3:2006, *Eurocode 6; Design of masonry structures. Simplified calculation methods for unreinforced masonry structures* will replace BS5628 on its withdrawal.

The Institution of Structural Engineers *Manual for the design of plain masonry in building structures* (the Red Book) offers design guidance for simple structural masonry.

4.3 Vertical loadbearing elements

A *wall* is a vertical load-carrying element whose length in plan is at least four times its width, otherwise it is a *column*. A *pier* is a column integral with a wall. References to walls apply also to columns and piers unless stated otherwise.

The load-carrying capacity of a wall depends on:

- the crushing strength of the masonry unit;
- the composition of the mortar;
- the size and shape of the masonry unit;
- the height of the wall relative to its width – its slenderness ratio;
- the eccentricity of the loading.

Figures 6.5 and 6.6 give information on typical masonry designs. Although popular in the past, masonry is rarely used for floors nowadays. However, vaults and domed roofs continue to be built in traditional types of buildings such as churches.

5 TIMBER

5.1 Structure of timber

Timber is probably the oldest building material used. Wood is composed of hollow tubular fibres of cellulose impregnated with the resin lignin, packed closely together not unlike a bundle of drinking straws. The result is that the material is strong in the longitudinal direction – in tension and compression – but weak along the interface between the fibres.

5.2 Advantages of timber

Consequently, timber has the supreme virtue of 'toughness'. It usually gives a forewarning of imminent failure, as the weakness between the fibres inhibits the progress of transverse cracks. Even when failure has occurred, there is often enough residual strength to carry a substantial load. Its principal drawbacks are susceptibility to insect and fungal attack and vulnerability to fire. Biological resistance can be fortified by treatment and a constant charring rate allows fire resistance to be designed in by over sizing members for the required period.

Timber is one of that minority of materials that is almost equally strong in tension and compression. This strength is such that buckling of the compression flange of bending members is rarely a problem. Rectangular sections are easily formed and used for this purpose. Timber is easily worked by hand and machine tools and it is simple to connect with other members, both other timber members and those of steel, masonry and concrete. However, even moderately stressed connections require plenty of room to accommodate the required number of fixings and usually this is the defining factor in sizing timber elements. For instance, on a simple dining table the section of the legs is not related to its need to withstand the compressive forces due to vertical downward forces but more to do with how the leg is fixed to the table top or sub-frame.

5.3 Design

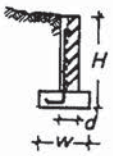
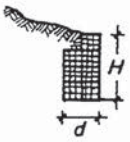
Advances in the technology of timber started in the railway era when it was used for elaborate viaducts and bridges. These were generally constructed by trial and error, calculation methods being developed later. In recent years, these methods of calculation have been taken to the point where it has become an extremely specialised field. The use of the current Codes of Practice by nonspecialists is not recommended. In complicated timber structures, the sizes of the members tend to depend more on the design of the connections than on the internal stresses.

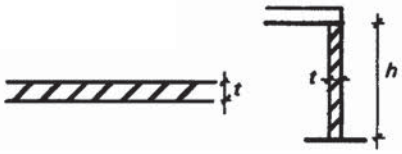
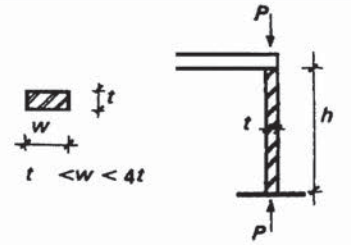
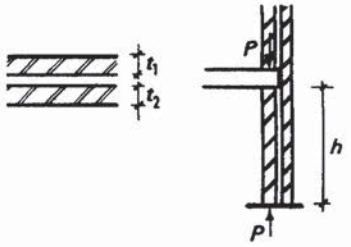
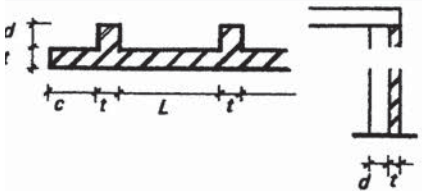
Design of timber should be carried out in accordance with BS 5268-2:2002 *Structural use of timber. Code of practice for*

Element	Horizontal and vertical section	Typical heights (h) (m)	h/d between lateral supports	Critical factors for sizing	Remarks
Masonry column		1–4	15–20	Buckling and crushing ($h/d>6$) Crushing ($h/d<6$) Bending	h is vertical distance between lateral supports and d is thickness of column
Masonry wall		1–5	18–22	Buckling and crushing ($h/d>6$) Crushing ($h/d<6$) Bending	h is vertical distance between horizontal lateral supports; wall may also have vertical lateral supports
Reinforced and prestressed masonry columns and walls		2–7	20–35	Bending	h is vertical distance between horizontal lateral supports; wall may also have vertical lateral supports

6.5 *Masonry – vertical support elements*

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Element	Section	Typical heights (H) (m)	Typical H/d	Remarks
Reinforced masonry retaining wall		1–6	10–15	Wall made of reinforced hollow blocks or units with reinforced concrete pockets w about $H/2$–$2H/3$
Masonry rubble in baskets (gabions)		1–3	1–2	Rubble masonry gabion walls usually more economic than thick mass concrete retaining wall

Plan/on element	Vertical section	Formulae for preliminary sizing only – elastic theory	Remarks
Single wall		$\frac{h}{t} < 20$	Formula valid when lateral movement is prevented at top and bottom of wall, at right angles to wall; such restraint usually provided by floor and roof construction Wall has greater bending strength in the horizontal direction so that vertical supports would be preferred to horizontal supports Walls fail by crushing if $h/t < 10$ or by buckling and crushing if $h/t > 10$
Column Cavity wall	 	$\frac{h}{t}$ and $\frac{2h}{w} < 20$ $p < \frac{t.w.u}{5}$ where u is ultimate compressive strength of small masonry sample $\frac{h}{t_{cf}} < 20$ where t_{cf} is greater of t_1, t_2 or $2/3\ (t_1 + t_2)$	Column illustrated given lateral restraint at top in one direction only and effective height of column in that direction taken as actual height; effective height in direction at right angles taken as twice actual height Columns fail by crushing if slenderness ratio, $h_{cf}/t < 10$ where h_{cf} is unfactored value of load applied near centre of column t_1 and t_2 are thicknesses of leaves of cavity wall which are tied together Wall illustrated has vertical load from floor taken by inner leaf only
Single wall with piers or intersecting walls		$\frac{L}{t} < 20$ $\frac{2.5c}{t} < 20$	Vertical piers or intersecting walls used to restrain walls as alternative to horizontal supports at top and bottom of wall. Dimension c is distance of outhang from last vertical support d is depth of pier of intersecting wall which should be greater than 500 mm

6.6 *Masonry elements carrying gravity loads*

permissible stress design, materials and workmanship, a permissible stress design code based upon elastic design theory. The Eurocode for timber, BS EN 1995-1-1:2004, *Eurocode 5. Design of timber structures. General. Common rules and rules for buildings* will replace BS5268 on its withdrawal.

5.4 Timber sources and grades

Timber can be home-produced or imported from many places. There is a degree of standardisation, but the designer can encounter a wide variation in qualities. The structural properties of some common types are given later in Figure 6.10, and Tables VI and VII.

5.5 Large timber sections

Because of the shape and composition of the tree trunks from which timber comes, it is difficult to directly produce the larger size sections often required for modern construction, particularly for beams. For such larger sections, smaller timbers are glued together to form *laminated beams*, Figure 6.7. These are extremely useful for many purposes, and manufacturers produce handbooks giving comprehensive data for their use.

5.6 Timber frame

Over 80 per cent of the world's housing is composed of timber frame and it is becoming more common in the UK. Figures 6.8, 6.9 and 6.10 give information relating to vertical support in timber and on frame and wall systems.

5.7 Roof trusses

The average UK architect meets timber in two common places: roof trusses and floor joists. Nowadays, most trusses are of the

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Table VI Maximum permissible spans for rafter members shown in Figure 6.11 (ref BS 5268-3 Table B2)

Strength class of timber[b]	Finished size[c]	Pitch								
	mm	15° m	17½° m	20° m	22½° m	25° m	27½° m	30° m	32½° m	35° m
C16	35 × 72	5.06	5.17½	5.34	5.49	5.63	5.77	5.91	6.06	6.21
	35 × 97	6.35	6.53	6.70	6.87	7.05	7.22	7.40	7.57	7.75
	35 × 120	7.55	7.75	7.94	8.15	8.36	8.54	8.74	8.94	9.14
	35 × 145	8.83	9.07	9.29	9.53	9.74	9.97	10.21	10.43	10.67
	38 × 72	5.25	5.40	5.54	5.68	5.82	5.97	6.11	6.26	6.41
	38 × 89	6.16	6.33	6.50	6.66	6.83	7.00	7.16	7.33	7.50
	38 × 114	7.48	7.53	7.87	8.07	8.28	8.47	8.67	8.81	9.07
	38 × 140	8.73	8.98	9.25	9.49	9.71	9.95	10.18	10.41	10.65
	47 × 72	5.83	5.98	6.12	6.26	6.41	6.56	6.70	6.85	7.00
	47 × 97	7.32	7.50	7.69	7.88	8.06	8.25	8.44	8.63	8.81
	47 × 120	8.51	8.73	8.96	9.19	9.41	9.64	9.87	10.10	10.32
	47 × 145	9.63	9.90	10.16	10.43	10.71	10.99	11.25	11.53	11.79
C22	35 × 72	5.60	5.76	5.92	6.09	6.25	6.41	6.57	6.74	6.90
	35 × 97	7.03	7.23	7.42	7.62	7.82	8.02	8.22	8.41	8.61
	35 × 120	8.35	8.58	8.80	9.03	9.26	9.48	9.71	9.93	10.15
	35 × 145	9.76	10.04	10.29	10.56	10.80	11.00	11.00	11.00	11.00
	47 × 72	6.46	6.63	6.79	6.95	7.12	7.29	7.45	7.62	7.78
	47 × 97	8.10	8.31	8.53	8.74	8.95	9.16	9.38	9.59	9.80
	47 × 120	9.41	9.67	9.93	10.19	10.45	10.70	10.96	11.22	11.47
	47 × 145	10.65	10.96	11.26	11.57	11.88	12.00	12.00	12.00	12.00
	35 × 72	5.96	6.12	6.30	6.46	6.63	6.80	6.96	7.13	7.25
	35 × 97	7.50	7.71	7.92	8.12	8.33	8.54	8.74	8.94	9.00
	35 × 120	8.71	8.95	9.20	9.42	9.66	9.89	10.12	10.15	10.15
	35 × 145	10.25	10.54	10.80	11.00	11.00	11.00	11.00	11.00	11.00
C24										
	38 × 72	6.19	6.34	6.51	6.66	6.83	6.99	7.14	7.30	7.43
	38 × 89	7.27	7.46	7.65	7.83	8.02	8.21	8.39	8.57	8.74
	38 × 114	8.66	8.90	9.14	9.36	9.59	9.82	10.06	10.15	10.21
	38 × 140	10.16	10.45	10.72	10.99	11.25	11.25	11.25	11.25	11.25
	47 × 72	6.87	7.01	7.14	7.28	7.42	7.55	7.69	7.82	7.96
	47 × 97	8.64	8.81	8.99	9.17	9.35	9.52	9.70	9.87	10.05
	47 × 120	9.81	10.07	10.32	10.58	10.83	11.10	11.34	11.60	11.85
	47 × 145	11.10	11.41	11.73	12.00	12.00	12.00	12.00	12.00	12.00

[a]These maximum permissible spans are suitable for trussed rafters fabricated and used in accordance with the conditions given in Annex B.
[b]Subject to the visual grading criteria in 5.1.2.
[c]Measured at a moisture content of 20% and subject to the manufacturing tolerance in 5.1.3.

Table VII Maximum permissible spans for ceiling ties (ref BS 5268-3 Table)

Strength class of timber[b]	Finished size[c]	Pitch								
	mm	15° m	17½° m	20° m	22½° m	25° m	27½° m	30° m	32½° m	35° m
	35 × 72	3.70	3.97	4.24	4.50	4.77	5.02	5.29	5.55	5.82
	35 × 97	5.13	5.51	5.90	6.28	6.65	7.03	7.41	7.78	8.15
	35 × 120	6.29	6.79	7.29	7.78	8.24	8.72	9.20	9.69	10.14
	35 × 145	7.36	8.04	8.71	9.38	10.05	10.73	11.00	11.00	11.00
C16										
	38 × 72	3.85	4.14	4.42	4.69	4.97	5.24	5.52	5.79	6.07
	38 × 89	4.84	5.20	5.56	5.89	6.27	6.63	6.98	7.33	7.68
	38 × 114	6.15	6.64	7.13	7.60	8.07	8.55	9.02	9.49	9.95
	38 × 140	7.27	7.94	8.59	9.25	9.91	10.57	11.23	11.25	11.25
	47 × 72	4.31	4.63	4.95	5.26	5.58	5.89	6.20	6.51	6.82
	47 × 97	5.81	5.26	6.70	7.14	7.57	8.01	8.45	8.88	9.31
	47 × 120	6.91	7.50	8.09	8.67	9.25	9.82	10.37	10.94	11.50
	47 × 145	7.77	8.59	9.33	10.11	10.88	11.66	12.00	12.00	12.00

[a]These maximum permissible spans are suitable for trussed rafters fabricated and used in accordance with the conditions given in Annex B.
[b]Subject to the visual grading criteria in 5.1.2.
[c]Measured at a moisture content of 20% and subject to the manufacturing tolerance in 5.1.3.

gang-nail type supplied to order for the required conditions. The manufacturer will supply calculations based on the Code of Practice for submission to the local building inspector.

5.8 Floor joists

For the design of floor joists Table VIII gives a guide to maximum spans of joists for timber of strength class C16, based on the TRADA publication 'Span tables for solid timber members in floors, ceilings and roofs (excluding trussed rafter roofs) for dwellings' alternatively, calculations should be prepared for final design by a qualified engineer in accordance with BS 5268.

6 REINFORCED CONCRETE

6.1 Composition

Reinforced concrete is one of the most prolific and versatile structural materials available to the designer. It is composed of two distinct materials: concrete and reinforcement, each of which can

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Table VIII Permissible clear spans for domestic floor joists (m) (Ref TRADA Technology Design Aid DA 1/2004)

Table 6 Permissible clear spans for domestic floor joists Imposed load not exceeding 1.5 kN/m²
Strength Class C 16 Service class 1 or 2

Size of joist		Dead load (kN/m²) excluding self-weight of joist								
		Not more than 0.25			More than 0.25 but not more than 0.50			More than 0.50 but not more than 1.25		
		Spacing of joists (mm)								
Breadth (mm)	Depth (mm)	400	450	600	400	450	600	400	450	600
		Maximum clear span (m)								
38	97	1.84	1.70	1.31	1.73	1.56	1.22	1.43	1.31	1.04
38	120	2.45	2.34	1.88	2.33	2.17	1.72	1.91	1.76	1.42
38	145	2.96	2.84	2.49	2.83	2.69	2.30	2.43	2.26	1.84
38	170	3.46	3.33	2.89	3.30	3.12	2.70	2.82	2.66	2.28
38	195	3.96	3.78	3.28	3.75	3.54	3.07	3.21	3.03	2.62
38	220	4.46	4.23	3.67	4.20	3.96	3.44	3.59	3.39	2.93
44	97	1.97	1.86	1.50	1.87	1.77	1.39	1.59	1.46	1.17
44	120	2.58	2.47	2.14	2.46	2.36	1.94	2.12	1.95	1.58
44	145	3.11	2.99	2.68	2.97	2.85	2.51	2.62	2.47	2.05
44	170	3.63	3.49	3.11	3.48	3.34	2.91	3.03	2.86	2.48
44	195	4.16	4.00	3.53	3.98	3.81	3.30	3.45	3.25	2.82
44	220	4.68	4.51	3.95	4.48	4.26	3.70	3.86	3.64	3.16
47	97	2.03	1.92	1.59	1.93	1.82	1.47	1.67	1.53	1.23
47	120	2.63	2.53	2.26	2.52	2.42	2.05	2.22	2.05	1.66
47	145	3.17	3.05	2.77	3.04	2.92	2.59	2.70	2.55	2.15
47	170	3.71	3.57	3.21	3.55	3.42	3.00	3.14	2.96	2.56
47	195	4.25	4.09	3.64	4.07	3.91	3.41	3.56	3.36	2.91
47	220	4.75	4.61	4.08	4.58	4.39	3.82	3.99	3.76	3.26
50	97	2.10	1.98	1.68	1.98	1.88	1.56	1.75	1.61	1.29
50	120	2.69	2.58	2.33	2.57	2.47	2.15	2.29	2.14	1.74
50	145	3.24	3.12	2.83	3.10	2.98	2.67	2.78	2.63	2.24
50	170	3.79	3.65	3.31	3.63	3.49	3.10	3.23	3.05	2.64
50	195	4.34	4.17	3.76	4.15	3.99	3.52	3.67	3.47	3.01
50	220	4.82	4.69	4.20	4.67	4.50	3.94	4.11	3.88	3.36
63	97	2.33	2.21	1.93	2.20	2.09	1.83	1.94	1.85	1.54
63	120	2.90	2.79	2.54	2.78	2.67	2.42	2.50	2.40	2.05
63	145	3.60	3.36	3.06	3.35	3.22	2.92	3.01	2.89	2.56
63	170	4.09	3.93	3.58	3.91	3.77	3.42	3.52	3.39	2.97
63	195	4.67	4.50	4.10	4.48	4.31	3.92	4.03	3.88	3.37
63	220	5.10	4.96	4.61	4.94	4.80	4.41	4.54	4.34	3.77
75	120	3.07	2.96	2.69	2.94	2.83	2.57	2.65	2.54	2.29
75	145	3.70	3.56	3.24	3.54	3.41	3.10	3.19	3.07	2.78
75	170	4.32	4.16	3.79	4.14	3.99	3.63	3.73	3.59	3.23
75	195	4.87	4.73	4.34	4.72	4.56	4.15	4.27	4.11	3.67
75	220	5.32	5.17	4.82	5.15	5.01	4.67	4.77	4.63	4.11
ALS/CLS										
38	140	2.86	2.74	2.41	2.73	2.60	2.18	2.34	2.16	1.76
38	184	3.74	3.58	3.11	3.56	3.36	2.91	3.04	2.87	2.48
38	235	4.73	4.50	3.91	4.45	4.21	3.66	3.82	3.60	3.12
89	184	4.86	4.73	4.33	4.71	4.55	4.15	4.27	4.11	3.73
89	235	4.80	5.65	5.28	5.63	5.47	5.11	5.22	5.07	4.72
		See clause 4.1.4								

be varied in strength, disposition and quantity to fulfil almost any requirement.

The concrete component is itself an amalgam of at least three constituents: aggregate, cement and water. These are mixed together into a homogeneous mass, placed in formwork and left for the chemical and physical changes to occur that result in a hard and durable material. The strength and durability will depend on the quality and quantity of each of the constituents, and whether any additives have been introduced to the wet mix. Onsite mixing of concrete for structural purposes is only carried out for larger jobs which merit the setting up of a batching plant. Concrete mixed offsite at the premises of the ready-mix supplier is a quality controlled product, designed to meet the requirements of the specifier. An indication of early concrete strength can be assessed by 7 or 14 day tests, but the specified strength can only be checked by crushing cubes of hardened concrete at 28 days. Cylinder tests are specified for strength comparison of mixes designed in accordance with Eurocodes. The crushing test will not necessarily indicate that sufficient cement has been included to fulfil the requirement for long-term durability. Sometimes additives are included in the mix to promote workability, early strength, frost resistance, etc. Deterioration in the material due to some of these factors may not become evident for some years, but may then be disastrous. For properties of various types of concrete, see Chapter 7 Section 5.

6.2 Specification

Provided a clear specification is prepared and concrete placement is checked by site staff, the concrete should fulfil its function indefinitely. This specification should be in accordance with BS 8500-1 *Complementary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier* and BS EN 2006 – 2. *Complementary British Standard to BS EN 206-1. Specification for constituent materials and concrete,* which cover not only strength requirements but also minimum cement content, aggregate size, cement type and other relevant aspects.

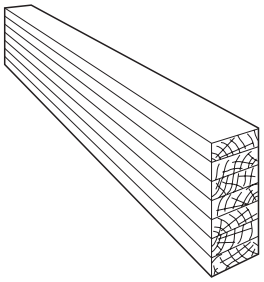
Table IX Span to depth ratios for preliminary design

Beams	
Simply supported beams	20
Continuous beams	25
Cantilever beams	10
Slabs	
Slabs spanning in one direction, simply supported	30
Slabs spanning in one direction, continuous	35
Slabs spanning in two directions, simply supported	35
Slabs spanning in two directions, continuous	40
Cantilever slabs	12

6.3 Design

Design of reinforced concrete should be carried out in accordance with BS 8110-1:1997 *Structural use of concrete. Code of practice for design and construction*, the limit state code for the structural use of concrete in buildings and structures. The Eurocode for concrete BS EN 1992-1-1: 2004 *Eurocode 2. Design of concrete structures. General rules and rules for buildings* will replace BS8110 on its withdrawal. A succinct guide to the requirements of BS 8100

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6.7 *A laminated timber beam*

can be found in the *Manual for the Design of Reinforced Concrete Building Structures* (the Green Book), prepared by the Institution of Structural Engineers.

6.4 Reinforcement

Reinforcement is generally steel rods, although other materials such as glass fibres and steel fibres have been tried in cladding units and steel and polypropylene fibres are now commonly used for crack control in floor slabs on ground. The reinforcing bars may be smooth round mild steel, in which case the bars are referred to as R25, etc. the letter R indicating mild steel and the numbers indicating the diameter in millimetres.

The other type of bar reinforcement is a high-yield bar referred to as T25, etc. In this case, the letter indicates hot rolled or cold worked high-yield steel and the numbers refer to the plain bar diameter of equivalent cross-sectional area. The actual bar size will be about 10% greater than this due to the deformation.

6.5 Mesh reinforcement

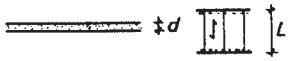
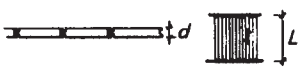
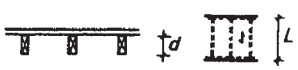
For many structural elements, such as slabs and walls, it is convenient to use reinforcement in the form of a pre-welded mesh consisting of bars in both directions. Care should be taken in specifying the correct mesh as they have different areas of bars in each direction depending upon their designation letter. An 'A' square mesh has the same area of bars in each direction. A 'B' structural mesh has larger bars in the main direction and the area of bars in the cross direction satisfies the minimum area of secondary reinforcement requirement of BS 8110. It is important therefore to ensure that a structural mesh is oriented correctly, as indicated on the reinforcement drawing in order that structural strength is not compromised. A 'C' long mesh is similar to a 'B' mesh except that the area of cross wires does not meet the requirements of BS 8110. These meshes are generally used for reinforcing slabs on ground.

6.6 Reinforcement position

Concrete is strong in compression, but weak in tension and reinforcement is used to compensate for this weakness. Adequate

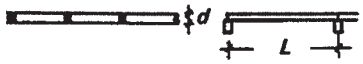
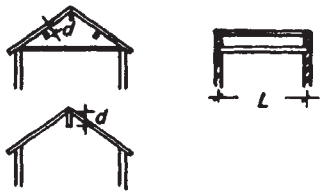
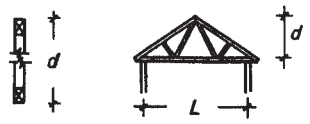
Element	Horizontal and vertical section	Typical heights (h) (m)	h/d between lateral supports	Critical factors for sizing	Remarks
Glued laminated timber column		2–4	15–30	Splitting and crushing ($h/d < 15$) Crushing and buckling ($h/d > 15$)	Ratio $w/d \approx 2$–3 Multi-storey columns may require lower h/d ratios than those given.
Stud frame wall panel		2–4	20–35	Crushing and buckling Thickness of insulation required	Studs usually at about 400mm centres with plywood or other sheeting nailed to it.
Solid timber column		2–4	15–30	Warping or distortion of timber	Multi-storey columns may require lower h/d ratios than those given

6.8 *Wood – vertical support elements*

Element	Section and plan	Typical depths (d) (mm)	Typical spans (L) (m)	Typical L/d	Critical factors for sizing/remarks
Particle boards		12–30	0.3–0.6	24	Strength Creep deflection
Plywood floor decking		12–30	0.3–0.9	30–40	Deflection Point loads Strength
Softwood floor boards		16–25	0.6–0.8	25–35	Deflection Strength
Joists with floor board – Softwood – Hardwood		200–300 100–250	2–6 2–7	12–20 22–28	Deflection Spacing of joists is about 450–600 mm
Glued laminated timber beam		180–1400	5–12	14–18	Deflection Ratio d/b about 3–5 to prevent instability of unrestrained section.

6.9 *Wood – floors*

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Element	Section and elevation	Typical depths (d) (mm)	Typical spans (L) (m)	Typical L/d	Critical factors for sizing/remarks
Roof planks		25–75	2–6	45–60	Deflection Planks assumed to be simply supported
Plywood floor decking		10–20	0.3–1.2	50–70	Deflection Decking assumed to be continuous
Stressed skin plywood roof panels		100–450	3–7	30–35	Deflection Panel assumed to be simply supported Dimension a is about 300–500 mm
Joists with roof deck – Softwood – Hardwood		100–225 100–250	2–6 3–8	20–25 30–35	Deflection Joists assumed to be simply supported and spaced at 600 mm
Roof purlins – Softwood – Hardwood		150–300 200–400	2–5 3–8	10–14 15–20	Available length and depth of wood Bending strength Purlin assumed to be vertical, simply supported and carrying about 2 m width of roof
Glued laminated timber beam with roof deck		180–1400	4–30	15–20	Deflection Beams assumed to be simply supported with spacing $L/3$–$L/5$ Ratio d/b about 5–8
Trussed rafter without purlins		1200–2000	6–10	4–6	Strength of joints Bending in rafter Assumed spacing 600mm

6.10 *Wood – roofs, beam and deck*

reinforcement must therefore be placed wherever any tension is likely to occur. Simply spanning beams are reinforced near the bottom, with most reinforcement at midspan. Shear forces also produce tensile stresses – links or stirrups are used to reinforce the concrete against the effects of these stresses. Sometimes the compressive strength of the concrete is insufficient for the loading. In this case, reinforcing bars can be used to help take the compression as well. Such use for reinforcement is expensive and is only used when increasing the size of the beam is not possible.

In cantilever beams, the tension occurs near the top. These beams have their heaviest reinforcement at the top, with most near the support.

6.7 Effective depth

The effective depth of a beam is the distance from the top (or compression flange) to the centroid of area of the tensile steel reinforcement. It is indicated by the symbol d.

6.8 Minimum reinforcement

Stresses arise in concrete not only from the applied loads but also from a variety of other causes. For example, when concrete dries and sets it tends to shrink slightly. If it cannot move, it will tend to crack. Similar cracking will occur if movement induced by thermal expansion and contraction is inhibited. Consequently, to reduce the tendency to form large cracks, a modicum of reinforcement is used throughout, allowing the formation of a multitude of fine cracks which are invisible to the naked eye.

6.9 Deflection

In addition to limiting the stresses below the ultimate values, reinforced concrete must possess sufficient stiffness to prevent deflection or deformation which might impair the strength or efficiency of the structure, or produce unsightly cracks in finishes or partitions.

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6.10 Concrete cover to reinforcement

In all cases, there must be sufficient concrete cover to reinforcement. This is:

- To preserve it from corrosion
- To ensure an adequate bond with the concrete
- To ensure sufficient protection in case of fire.

Tables A.6, A.10, A.12 and A.13 of BS 8500-1 give limiting values for the nominal cover of concrete made with normal weight aggregates. In no case should the cover be less than the nominal maximum aggregate size, or, for the main reinforcement, the bar size.

7 STRUCTURAL STEELWORK AND OTHER METALS

7.1 Metals

Steel is by far the metal most widely used for building structures, but other materials are used in ancillary elements.

7.2 Design

Design of steelwork should be carried out in accordance with BS 5950-1:2000 *Structural use of steelwork in building. Code of practice for design. Rolled and welded section*, a limit state code based upon plastic theory. Eurocode 3 BS EN 1993-1-1:2005. *Design of steel structures. General rules and rules for buildings*, should be used after the withdrawal of BS 5950.

A book of tables published by the Steel Construction Institute, (the blue book) gives dimensions and section properties of currently manufactured steel sections. Tables X–XIII show the dimensions for universal beams, columns and joists. This book also contains capacity tables which may be used to quickly determine the suitability of a particular section for preliminary design. More rigorous calculations to BS 5950 are generally required for final design. The *Manual for the design of steelwork building structures* issued by the Institution of Structural Engineers provides guidance for design.

7.3 Grades of steel

Steel for structural purposes is available in the United Kingdom in three grades increasing in strength: S275, which corresponds to the previous description of ‘mild steel’, S355 and S460.

8 GLASS

8.1 Use

Glass is being used to create spectacular structures in modern architecture and it can be incorporated as a structural material in a number of ways.

8.2 Design

The structural use of glass requires an understanding of the behaviour of both the structure and the material. The inherent brittle nature of glass dictates consideration of the nature and consequences of any failure modes.

The choice of international standards for the design of edge supported glass panels is wide-ranging, but BS 6262-1:2005, *Glazing for buildings. General methodology for the selection of glazing*, is the current British Standard.

8.3 Types of glass

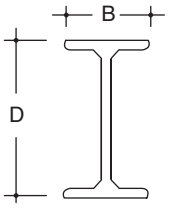
A number of processes are used to produce the main glass types used in structures.

Annealed float glass is made by melting the ingredients (silicon, soda ash and recycled broken glass) together. The molten glass is then poured onto a float bath of molten tin where it undergoes controlled cooling after which it is further cooled in an annealing oven. The resulting product exhibits elastic properties, but suffers brittle fracture under impact, bending and thermal loading. Typical properties of annealed glass are shown in Table V.

Toughened glass is produced by heating and then rapidly cooling annealed glass. This results in a glass core which is in tension, sandwiched between surface layers which are in compression. Toughened glass therefore has an ability to sustain higher stresses than annealed glass. Toughened glass is prone to sudden shattering due to nickel sulphide inclusions. Such failure will also be instigated if the compressive surface layers are breached by scratching.

Table X Properties of steel and aluminium

Property	Prestressing strand	High strength low-alloy steel	Structural carbon steel	Cold formed steel	Casting steel	Wrought iron	Grey cast iron	Wrought aluminium Alloy
Carbon content %	0.60–0.90	0.10–0.28	0.10–0.25	0.20–0.25	0.15–0.50	0.05	2.50–4.50	. . .
Weight kN/m^3	77	77	77	77	77	75	71	27
Tensile strength N/mm^2	1200–1800	400–700	400–560	280–600	400–600	300–350 (in line of rolling)	150–350	200–550
Yield stress or 0.2% proof stress N/mm^2 – stress at or near which permanent deformation starts	1100–1700	340–480	240–300	200–500	200–400	180–200 (in line of rolling)		120–500
Elastic modulus kN/mm^2	165	210	210	210	210	190	210	70
Elongating % – ductility	4	15	15–25	12–25	15–20	8–25	2	8–20
Weldability	Not suitable for welding	Good with right alloys	Good if low-carbon steel	Generally good	Moderate	Generally poor	Poor	Good if right alloys
Coefficient of thermal expansion × 10^{-6}/°C	12	12	12	12	12	12	12	24
Temperature at which metal has 50% of room temperature strength °C	350–500	500	500	500	500	500	can crack at high temperature	190
Corrosion resistance of untreated metal	Poor	Moderate to good	Poor	Poor to moderate	Moderate	Good	Good	Very good



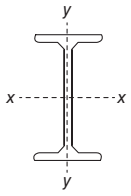
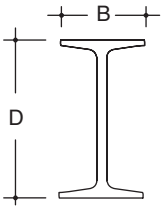


Table XI Universal beams

Dimensions

Section Designation	Mass per Metre	Depth of Section	Width of Section	Thickness		Root Radius	Depth between Fillets	Ratios for Local Buckling		Dimensions for Detailing			Surface Area	
				Web	Flange			Flange	Web	End Clearance	Notch		Per Metre	Per Tonne
		D	B	t	T	r	d	b/T	d/t	C	N	n		
	Kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m²	m²
305×165×54	54.0	310.4	166.9	7.9	13.7	8.9	265.2	6.09	33.6	6	90	24	1.26	23.3
305×165×46	46.1	306.6	165.7	6.7	11.8	8.9	265.2	7.02	39.6	5	90	22	1.25	27.1
305×165×40	40.3	303.4	165.0	6.0	10.2	8.9	265.2	8.09	44.2	5	90	20	1.24	30.8
305×127×48	48.1	311.0	125.3	9.0	14.0	8.9	265.2	4.47	29.5	7	70	24	1.09	22.7
305×127×42	41.9	307.2	124.3	8.0	12.1	8.9	265.2	5.14	33.1	6	70	22	1.08	25.8
305×127×37	37.0	304.4	123.4	7.1	10.7	8.9	265.2	5.77	37.4	6	70	20	1.07	29.0
305×102×33	32.8	312.7	102.4	6.6	10.8	7.6	275.9	4.74	41.8	5	58	20	1.01	30.8
305×102×28	28.2	308.7	101.8	6.0	8.8	7.6	275.9	5.78	46.0	5	58	18	1.00	35.4
305×102×25	24.8	305.1	101.6	5.8	7.0	7.6	275.9	7.26	47.6	5	58	16	0.992	40.0
254×146×43	43.0	259.6	147.3	7.2	12.7	7.6	219.0	5.80	30.4	6	82	22	1.08	25.1
254×146×37	37.0	256.0	146.4	6.3	10.9	7.6	219.0	6.72	34.8	5	82	20	1.07	29.0
254×146×31	31.1	251.4	146.1	6.0	8.6	7.6	219.0	8.49	36.5	5	82	18	1.06	34.2
254×102×28	28.3	260.4	102.2	6.3	10.0	7.6	225.2	5.11	35.7	5	58	18	0.904	31.9
254×102×25	25.2	257.2	101.9	6.0	8.4	7.6	225.2	6.07	37.5	5	58	16	0.897	35.6
254×102×22	22.0	254.0	101.6	5.7	6.8	7.6	225.2	7.47	39.5	5	58	16	0.890	40.5
203×133×30	30.0	206.8	133.9	6.4	9.6	7.6	172.4	6.97	26.9	5	74	18	0.923	30.8
203×133×25	25.1	203.2	133.2	5.7	7.8	7.6	172.4	8.54	30.2	5	74	16	0.915	36.4
203×102×23	23.1	203.2	101.8	5.4	9.3	7.6	169.4	5.47	31.4	5	60	18	0.790	34.2
178×102×19	19.0	177.8	101.2	4.8	7.9	7.6	146.8	6.41	30.6	4	60	16	0.738	38.8
152×89×16	16.0	152.4	88.7	4.5	7.7	7.6	121.8	5.76	27.1	4	54	16	0.638	39.8
127×76×13	13.0	127.0	76.0	4.0	7.6	7.6	96.6	5.00	24.1	4	46	16	0.537	41.3



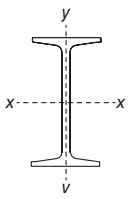
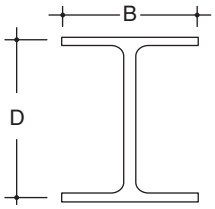


Table XII Joists

Dimensions

Section Designation	Mass per Metre	Depth of Section	Width of Section	Thickness		Root Radius	Depth between Fillets	Ratios for Local Buckling		Dimensions for Detailing			Surface Area	
				Web	Flange			Flange	Web	End Clearance	Notch		Per Metre	Per Tonne
		D	B	t	T	r	d	b/T	d/t	C	N	n		
	Kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m²	m²
254×203×82 #	82.0	254.0	10.2	19.9	19.6	19.6	9.7	166.6	5.11	16.3	7	104	44	14.8
254×114×37 ¥	37.2	254.0	7.6	12.8	12.4	12.4	6.1	199.3	4.46	26.2	6	60	28	24.2
203×152×52 #	52.3	203.2	8.9	16.5	15.5	15.5	7.6	133.2	4.62	15.0	6	78	36	17.8
152×127×37 #	37.3	152.4	10.4	13.2	13.5	13.5	6.6	94.3	4.81	9.07	7	66	30	19.8
127×114×29 #	29.3	127.0	10.2	11.5	9.9	9.9	4.8	79.5	4.97	7.79	7	60	24	22.0
127×114×27 #	26.9	127.0	7.4	11.4	9.9	9.9	5.0	79.5	5.01	10.7	6	60	24	24.2
127×76×16 ¥	16.5	127.0	5.6	9.6	9.4	9.4	4.6	86.5	3.97	15.4	5	42	22	31.0
114×114×27 ¥	27.1	114.3	9.5	10.7	14.2	14.2	3.2	60.8	5.34	6.40	7	60	28	22.8
102×102×23 #	23.0	101.6	9.5	10.3	11.1	11.1	3.2	55.2	4.93	5.81	7	54	24	23.9
102×44×7 #	7.5	101.6	4.3	6.1	6.9	6.9	3.3	74.6	3.65	17.3	4	28	14	46.6
89×89×19 #	19.5	88.9	9.5	9.9	11.1	11.1	3.2	44.2	4.49	4.65	7	46	24	24.4
76×76×15 ¥	15.0	76.2	8.9	8.4	9.4	9.4	4.6	38.1	4.76	4.28	6	42	20	27.9
76×76×13 #	12.8	76.2	5.1	8.4	9.4	9.4	4.6	38.1	4.54	7.47	5	42	20	32.1

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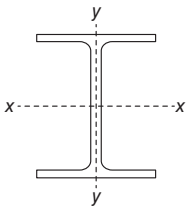


Table XIII Universal columns

Dimensions

Section Designation	Mass per Metre	Depth of Section	Width of Section	Thickness		Root Radius	Depth between Fillets	Ratios for Local Buckling		Dimensions for Detailing			Surface Area	
				Web	Flange			Flange	Web	End Clearance	Notch		Per Metre	Per Tonne
		D	B	t	T	r	d	b/T	d/t	C	N	n		
	Kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m^2	m^2
254×254×167	167.1	289.1	265.2	19.2	31.7	12.7	200.3	4.18	10.4	12	134	46	1.58	9.45
254×254×132	132.0	276.3	261.3	15.3	25.3	12.7	200.3	5.16	13.1	10	134	38	1.55	11.7
254×254×107	107.1	266.7	258.8	12.8	20.5	12.7	200.3	6.31	15.6	8	134	34	1.52	14.2
254×254×89	88.9	260.3	256.3	10.3	17.3	12.7	200.3	7.41	19.4	7	134	30	1.50	16.9
254×254×73	73.1	254.1	254.6	8.6	14.2	12.7	200.3	8.96	23.3	6	134	28	1.49	20.4
203×203×86	86.1	222.2	209.1	12.7	20.5	10.2	160.8	5.10	12.7	8	110	32	1.24	14.4
203×203×71	71.0	215.8	206.4	10.0	17.3	10.2	160.8	5.97	16.1	7	110	28	1.22	17.2
203×203×60	60.0	209.6	205.8	9.4	14.2	10.2	160.8	7.25	17.1	7	110	26	1.21	20.1
203×203×52	52.0	206.2	204.3	7.9	12.5	10.2	160.8	8.17	20.4	6	110	24	1.20	23.0
203×203×46	46.1	203.2	203.6	7.2	11.0	10.2	160.8	9.25	22.3	6	110	22	1.19	25.8
152×152×37	37.0	161.8	154.4	8.0	11.5	7.6	123.6	6.71	15.5	6	84	20	0.912	24.7
152×152×30	30.0	157.6	152.9	6.5	9.4	7.6	123.6	8.13	19.0	5	84	18	0.901	30.0
152×152×23	23.0	152.4	152.2	5.8	6.8	7.6	123.6	11.2	21.3	5	84	16	0.889	38.7

Laminated glass is produced by bonding two layers of glass with a layer of acrylic resin. The resulting material does not shard on impact but remains intact, minimising the risk of injury on failure.

9 OTHER MATERIALS

9.1 Fabric

Plastics are used in the manufacture of many structural fabrics which are finding increasing uses. See Chapter 7, Section 7.12.

10 FOUNDATIONS

10.1 Nature

The purpose of a foundation is to transmit the dead and live loads from a building structure to the ground. The nature of the foundation will depend on:

- the characteristics of the soil;
- the magnitude of the loads from the structure;
- the nature of the loads from the structure.

In the majority of buildings, the loads transmitted to the ground will arrive either as point loads down columns or line loads down walls. For the type of building with which these notes deal, the magnitudes of these loads will not be so great as to significantly affect the choice of foundation system.

10.2 Soil

This will basically depend on the strength of the soil to carry the load. The term 'soil' in this context means not vegetable material suitable for growing crops (topsoil), but the material forming the surface of the earth to a depth of about 100 m, which is not so hard as to be classified as a 'rock'.

The technology of the physical properties of soil is called soil mechanics. It is not appropriate to deal in depth with this subject, but some simple principles are useful to appreciate the design of foundations.

10.3 Bearing pressure

The bearing pressure that can be carried by the soil is the additional load that can be carried on a unit area. A soil stratum at a depth of, say, 3 m is already carrying the weight of that 3 m (overburden) of soil. In fact, the bearing capacity of many soils increases substantially with depth. This is because a common mode of failure under excessive load is sideways spillage of the soil, often accompanied by upward heave of the material around the area of application. Obviously this is much less likely where the load is carried at some depth.

Since the bearing capacity represents the additional load the soil can carry, the greater the depth, the smaller proportion of the total (or gross) pressure this will form. In fact, it is even possible to produce zero or negative net pressure by removing the overburden, and replacing it with something weighing much less, for example a hollow box. This is the principle by which loads can be carried on soft marshy soil; the analogy is that of a boat floating on water. In many cases, the architect will be told what the bearing capacity of the soil is at normal foundation depth – about 1 m.

10.4 Pad and strip foundations

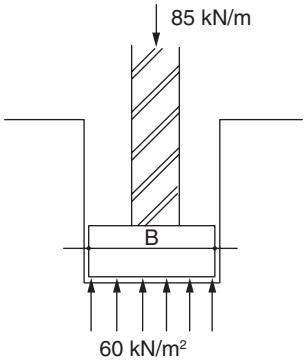
These are the types of foundation most commonly met by architects, and their design should only require the use of an engineer if there are complications. Care should however be taken in soft soils where settlement rather than bearing capacity is the critical criterion. See Figures 6.11 and 6.12 for examples.

10.5 Other foundation types

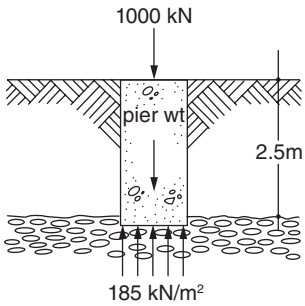
It is frequently found that the loads of the building are so large, or the bearing capacity of the soil is so poor, that suitable pad or strip foundations will be either very deep, or required to be so large that adjoining bases impinge on one another. The two common solutions to this problem are:

- Raft foundations, Figure 6.13, where the bases are combined together to form one large base. The raft has to be so reinforced to cater for the stresses induced by inequalities of loading and bearing capacity
- Piles, Figure 6.14, which are devices for carrying loads down to deeper levels than would otherwise be practical.

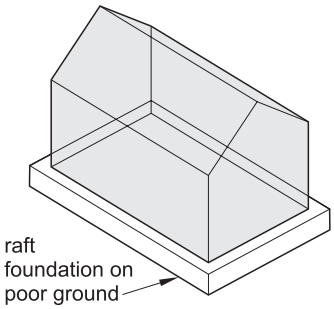
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6.11 *Width of a strip foundation, section (Example 1)*



6.12 *Concrete pier of gravel layer (Example 2)*



6.13 *Raft foundation as used on poor ground*

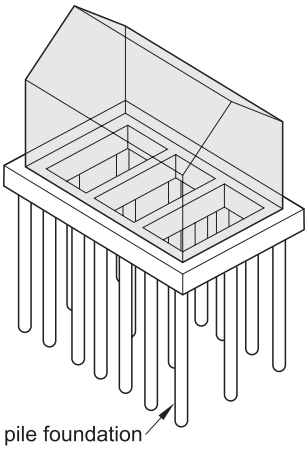
Raft foundations are beyond the scope of this section; however, useful guidance on raft design is given in the Structural Foundation Designers Manual (see Bibliography).

10.6 End-bearing piles

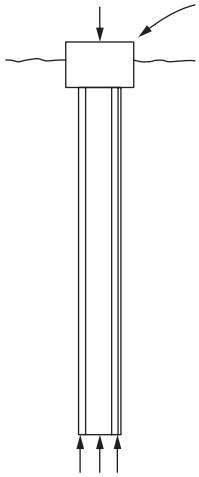
Piles can be divided into those that carry their loads into the soil mainly by end bearing, Figure 6.15 and those that act by virtue of the shaft friction at the interface between the pile length and the soil, Figure 6.16. End-bearing piles normally sit on rock or gravel strata with high bearing capacities. They may consist of a precast concrete shaft, driven into place with a large mechanical hammer. Alternatively, a hollow shell is driven and afterwards filled with wet concrete to form the pile. In either of these cases, the amount of penetration achieved at each hammer blow is an indication of the load carrying capacity of the pile. A design method for simple end-bearing piles in the shape of the short-bored variety sometimes used in housing is illustrated in Figure 6.17.

10.7 Skin-friction piles

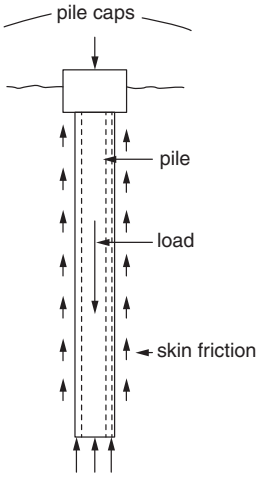
Skin-friction piles, mostly appropriate for cohesive soils such as clays, are usually bored, Figure 6.16. In this method, a circular hole is excavated in the ground by a large auger or other methods. If



6.14 *Alternative pile foundation*



6.15 *End-bearing pile*

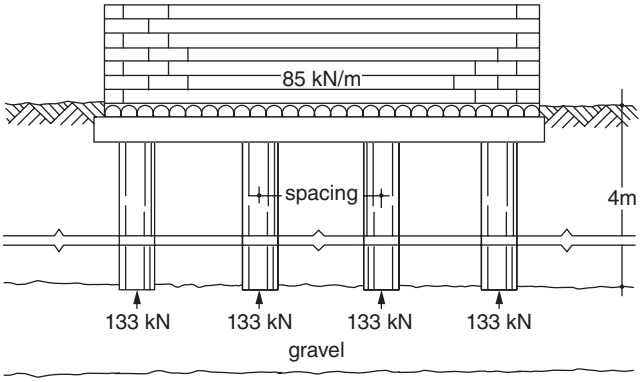


6.16 *Friction pile*

necessary, the sides of the hole are temporarily sleeved. When the necessary depth has been reached, reinforcement is lowered into the hole and concrete is poured in. Some method of compacting the concrete is employed, so that all cavities in the ground are properly filled. The sleeve is withdrawn as the concrete goes in, to ensure intimate contact between pile and soil.

The capacity of this type of pile is not self-evident as in the case of driven piles. Calculation is used to determine the length of pile required, based on the shear strength of the clay at various depths below the ground. Parameters for soil properties are gained by carrying out a site investigation prior to the design.

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6.17 *Short-bored piles (Example 3)*

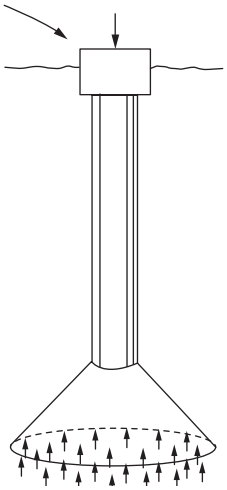
While the calculations themselves are not particularly difficult, the subject is one where engineering judgment is required in their interpretation. It is recommended that this type of pile should be designed by the specialist piling contractor and checked by the consulting engineer, with adequate supervision and testing on site to ensure that the pile is suitable for the design loads.

10.8 Pile testing

In both driven and bored piles, it is usual to carry out one or more tests on the actual piles on each contract. On very large contracts, additional piles are tested to failure, but normally one of the working piles is loaded to 1.5 times the working load to prove the efficacy of the design. These maintained load static tests are expensive and time consuming, requiring the use of large concrete blocks (kentledge) or the installation of tension piles against which a jacking load can be applied to the test pile. Other, more rapid methods of testing by measuring the dynamic response of the pile to a hammer strike at the pile head can be employed, but engineering judgement is required to determine the correct regime and method/methods of test required.

10.9 Under-reamed piles

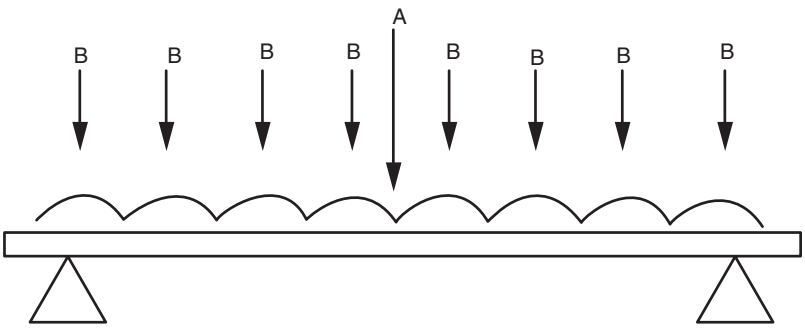
There is a third type of pile which is a bored end-bearing pile. The shaft is augured in the usual way, but when the required depth has been reached a special tool is used to enlarge the base to a bell-shape, Figure 6.18. These piles are substantial in size, and remote inspection of the base must be carried out to check the integrity of the soil on which the load will rest. It is not often possible to test this type of pile using static methods due to the magnitude of the loads carried.



6.18 *Under-reamed pile*

11 THUMB-NAIL STRUCTURES: WHAT ARCHITECTS NEED TO CONSIDER

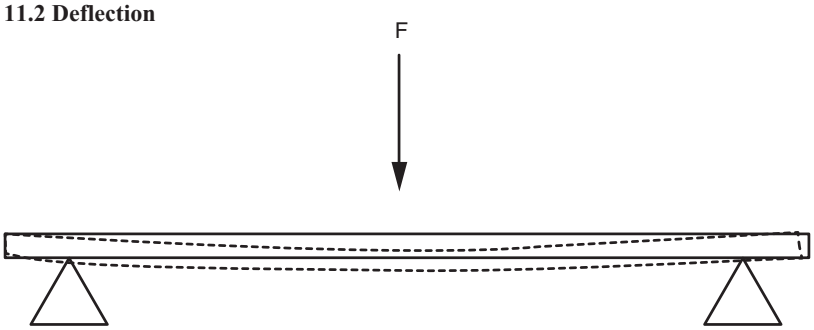
11.1 Dead loads



A = a POINT LOAD e.g. a piece of furniture, machinery or even a person, where a force is concentrated in a small area.
B = a UNIFORMLY DISTRIBUTED LOAD e.g. books in a library, cars in a car park etc., where a force is distributed over a wider area.

In reality most loads imposed upon a structural member are a combination of both POINT LOAD and UDL

11.2 Deflection



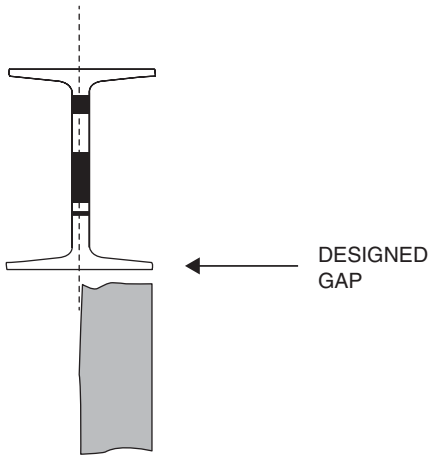
When a force is applied [F] the beam will be in BENDING and will DEFLECT

It is the size of this DEFLECTION that architects need to be aware of:

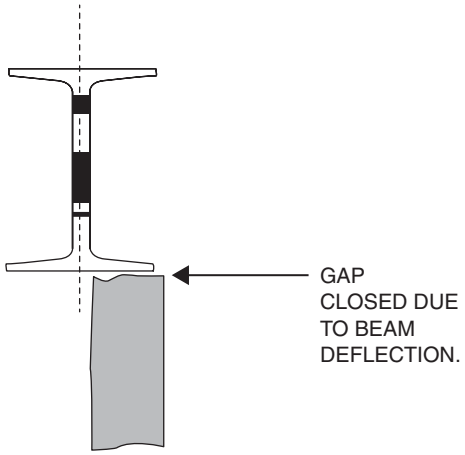
SERVICEABILITY
Will the DEFLECTION be so great that items of furniture move or users will feel unsteady?

LOAD TRANSFER
Will the DEFLECTION be so great that loads intended to be taken by the framing member (i.e. beam or floor plank) are transferred to infill panels?

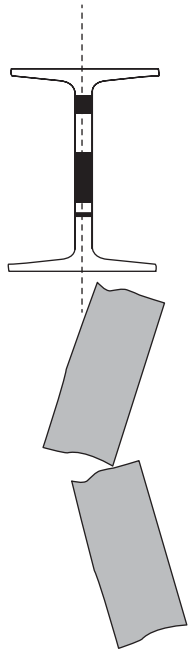
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The infill blockwork is built up to within 10–15 mm of the u/s of the steel beam depending on the designed DEFLECTION. The gap will be filled with a compressible compound



The MOVEMENT JOINT must be greater than the designed deflection in the beam

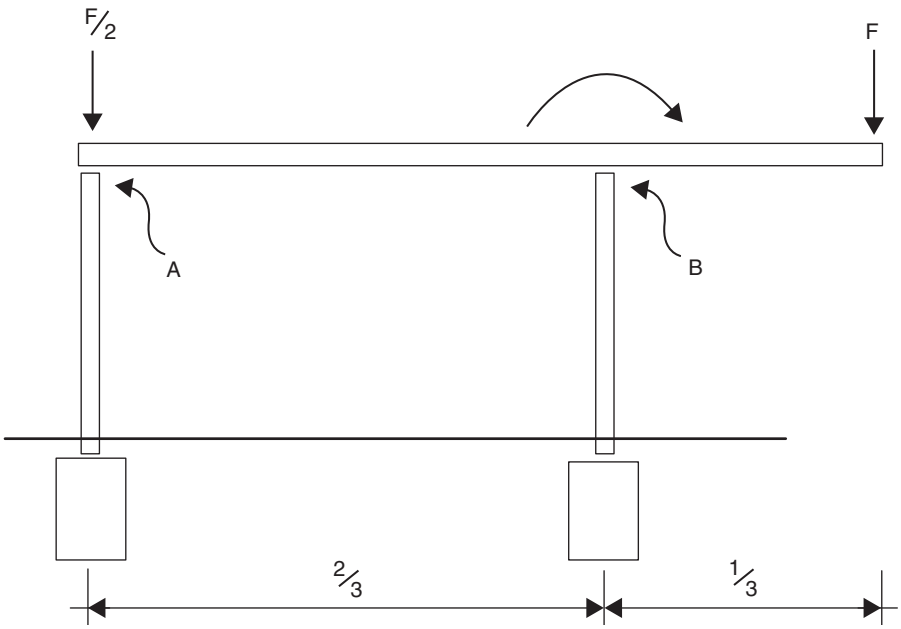


If the DEFLECTED beam comes into contact with an infill panel or blockwork the latter may BUCKLE as it will not have been designed to take the loading

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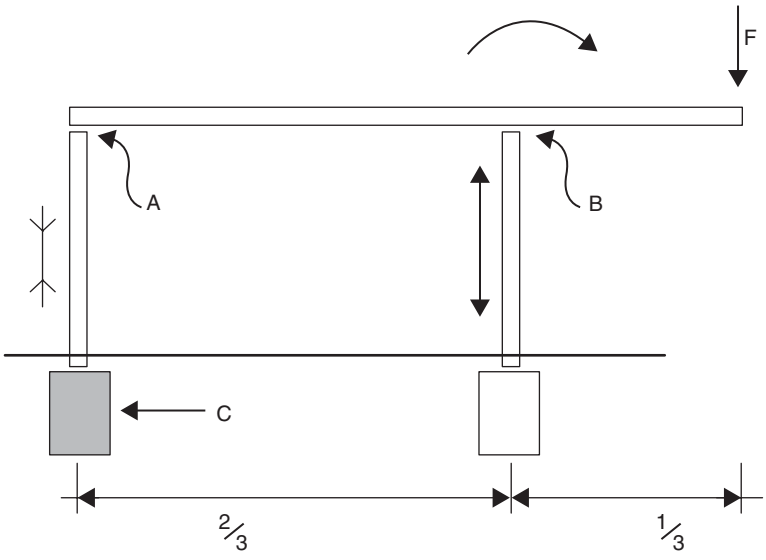
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11.3 Cantilever

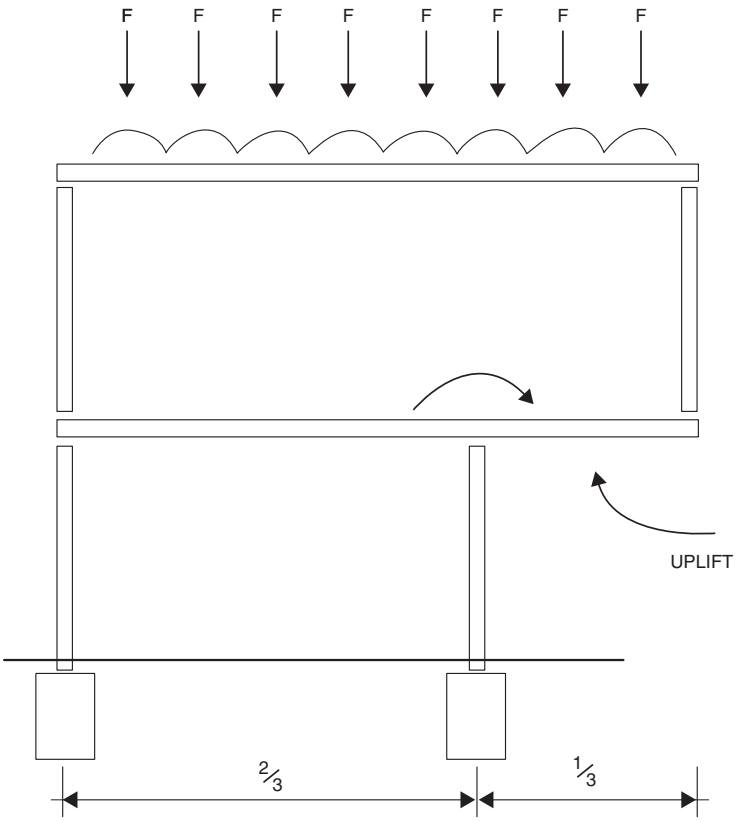


The diagram illustrates a very simple CANTILEVER arrangement achieved by balancing loads alone. This is an unlikely scenario.

More likely is that there will be a PIN or MOMENT connection at A & B



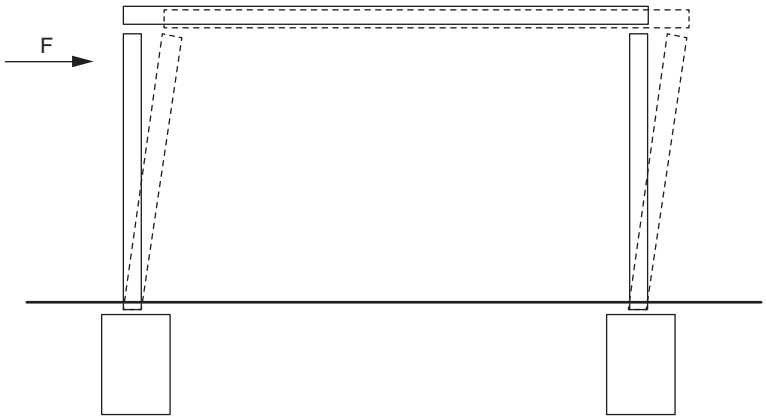
The beam will be in ROTATION about B. The column below B will be in COMPRESSION and the column below A will be in TENSION. Being in tension it will require RESTRAINT – some means of keeping it from pulling out of the ground. This may take the form of a heavy or deep (or both) foundation at C.



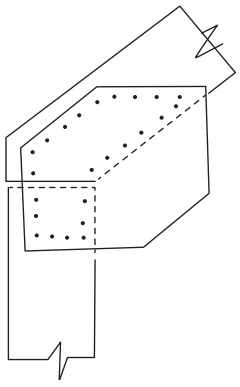
In reality the forces will be far more complex than those indicated but the rule-of-thumb for a CANTILEVER of 2/3 BACKSPAN and 1/3 cantilever remains

UPLIFT (due to wind) needs to be addressed as much as other forces

11.4 Bracing, racking and tri-angulation



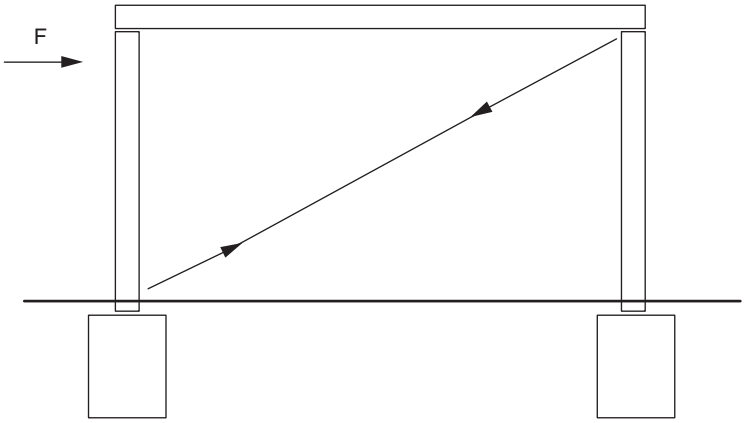
A LATERAL force (e.g. wind) imposed upon a structure will induced RACKING unless precautions are taken to mitigate this.



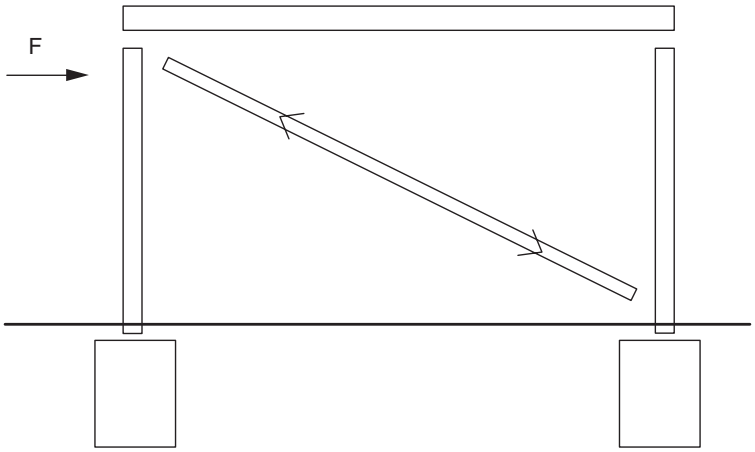
One method of achieving this to provide sufficiently robust MOMENT connections where the major structural members come together. A PORTAL frame used in many warehouses and other industrial buildings is an example of this.

Another method (other design parameters considered) to BRACE the frame is by introducing an element that will TRIANGULATE the structure. This element may be acting in COMPRESSION or TENSION (or both).

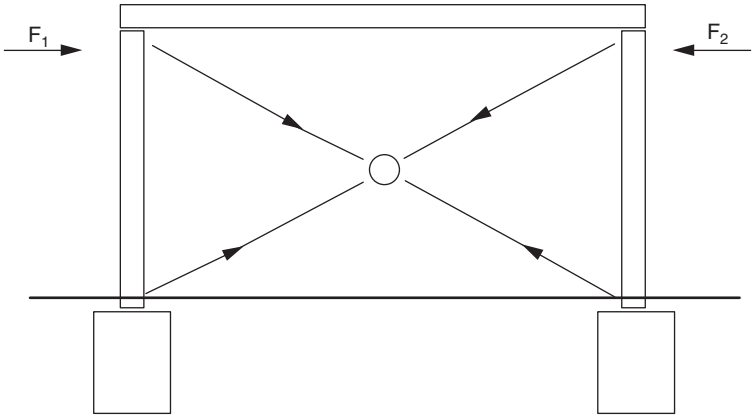
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Member in TENSION (may therefore be a wire or cable – a TIE)



Member in COMPRESSION (member would need to be substantial and able to resist compressive forces – a STRUT). Note that a lateral force exerted from the right side of the frame would put the diagonal member into TENSION. A single strut can be designed to resist both TENSION and COMPRESSION.



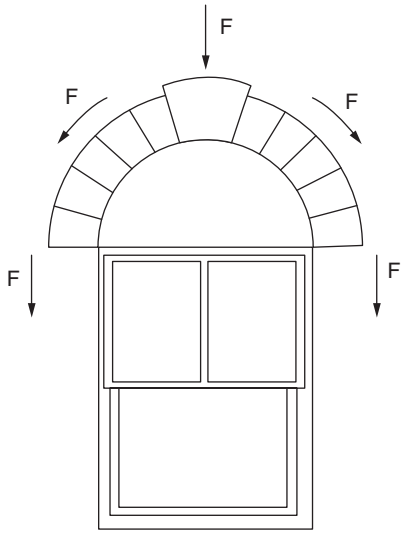
Unpredictable lateral forces (and that is most of them) need to be addressed by designing elements that resist both compression and tension. This can be achieved by using 1 strut or alternatively 2 ties – the latter is often preferred for aesthetic reasons.

Another means available to resist RACKING is the use of board or sheet material, such as plywood or OSB. In addition the newer sheathing materials provide adequate bracing as well as acting as a breathable moisture barrier.

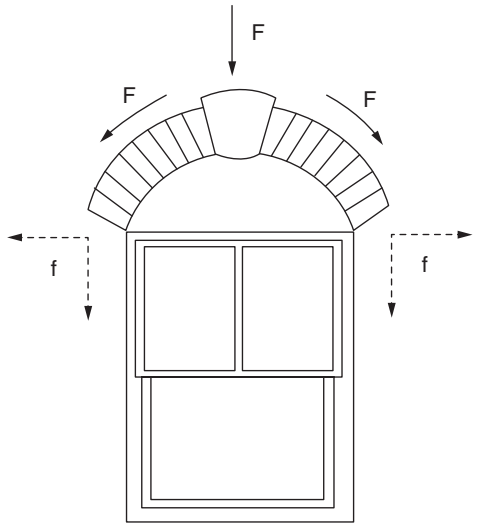
11.5 Arching

The ARCH is an ancient method of spanning and its use has enabled our ancestors to span far greater distances than would have been achievable using stone or timber lintels.

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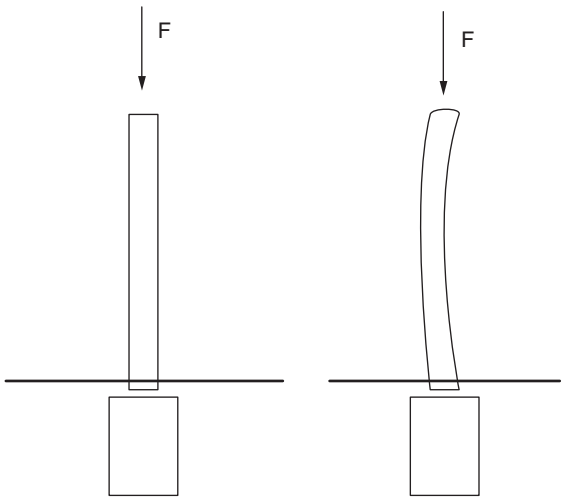


The early ‘Roman’ arch, semi-circular in shape resolves its forces vertically where the arch ‘springs’. The lack of a horizontal component means that very thick walls or buttressing is not so important in ensuring the arch does not collapse.



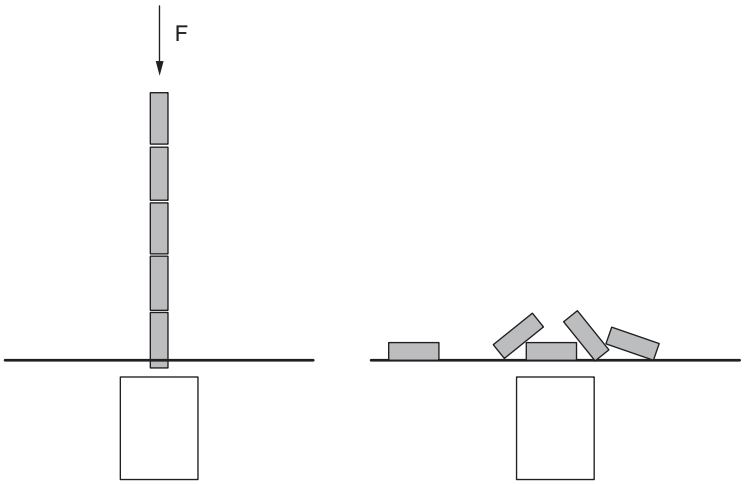
The later ‘GOTHIC’ arch, pointed at the top and not resolving its forces vertically at the spring point requires something, usually the mass of the wall or additional buttresses and piers to resist the horizontal forces.

11.6 Buckling



It is evident that as F increases, BUCKLING is likely to occur. In theory a perfectly vertical force acting through a perfectly vertical column along the central axis would result in a compressive force. In practice construction is less than perfect.

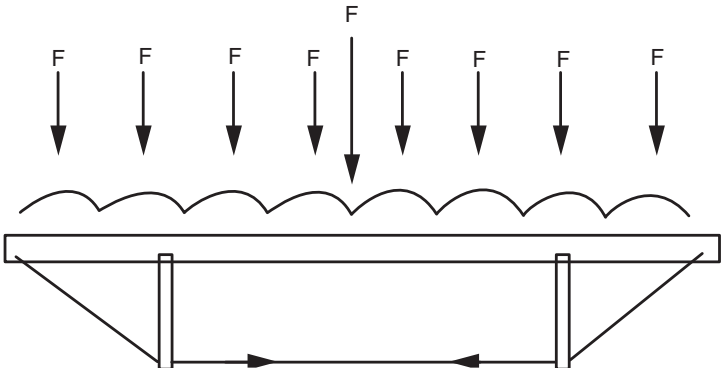
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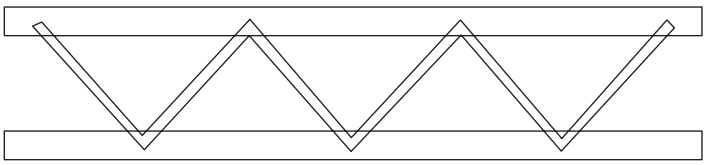
In a column buckling will tend to cause deflection, in block-work or brickwork the result can be collapse.

11.7 Increasing the effective span

We know that the effective span of a beam can be extended by increasing the value of the Y-axis. However, this can be achieved by a number of methods.



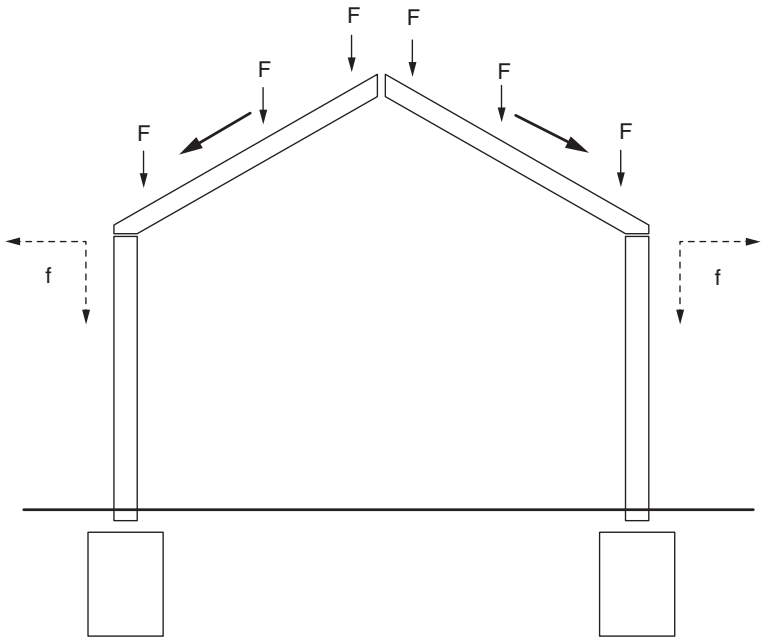
A bow-string truss is a system of tension members held away from the main member. The lower horizontal ten-sion member effectively deepens the beam.



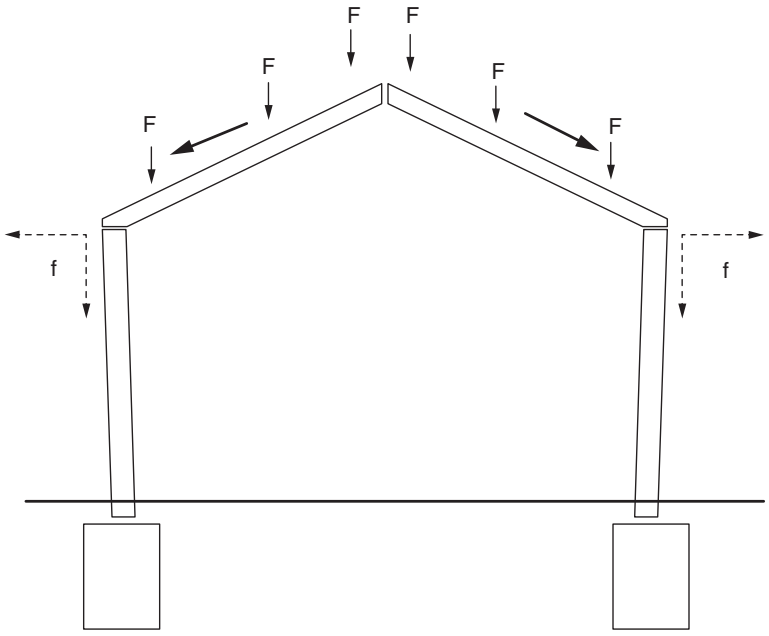
The same is true for a truss where the top and bottom flanges are separated by angled struts.

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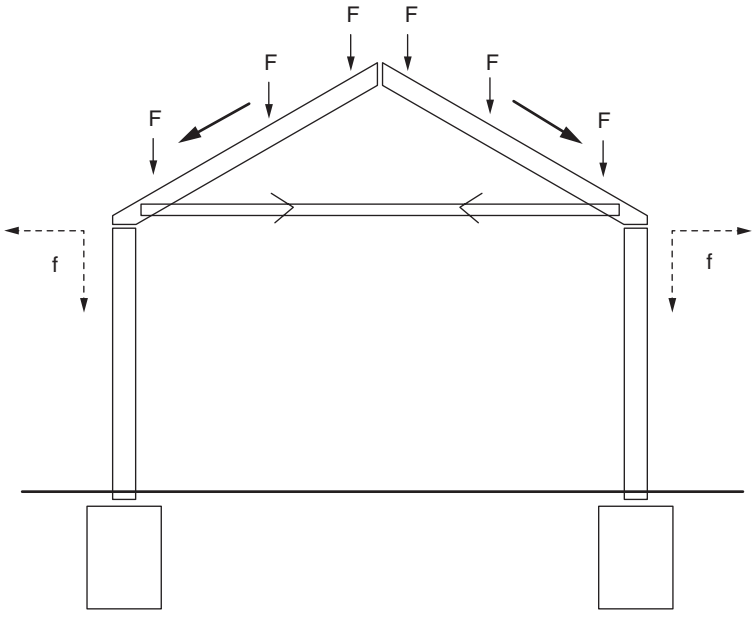
11.8 Roofing



The members of a simple pitched roof arrangement resolve their DEAD and LIVE load forces along the line of the pitch. In practice this single force is resolved into vertical and horizontal components.



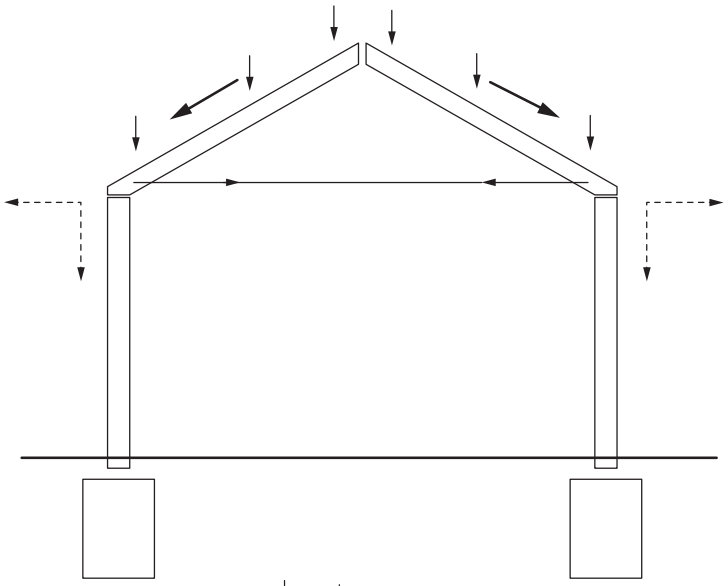
It can be seen that the horizontal component forces the vertical supporting members (they may be columns, they may be walls) outwards allowing the roof to collapse downward. The eaves being pushed outward is a sign of this.



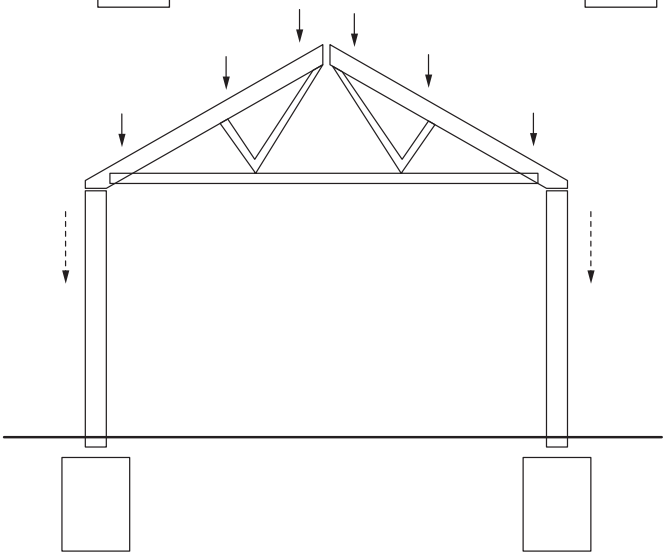
One way of avoiding this is to tie across the rafters either with timber (working as a tension and compression member) or with wire (tension only).

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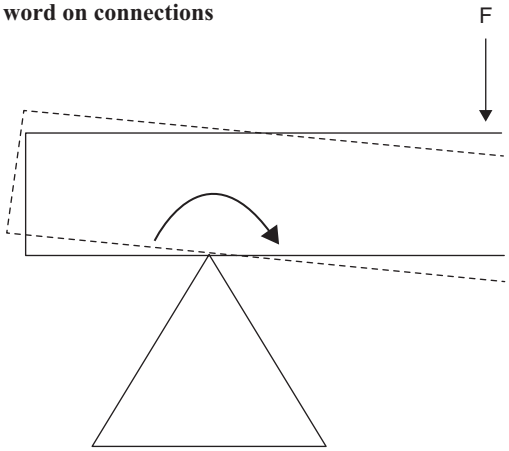


A steel TIE is sometimes used in situations where a heavy timber member may not be aesthetically appropriate.



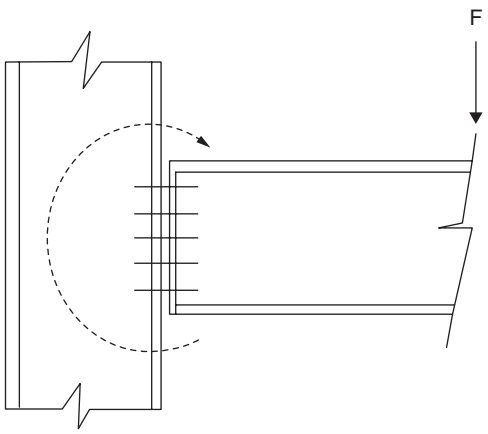
The common roof truss, used by volume house builders is a lightweight and efficient way of designing a domestic scale roof structure. However, the potential of using the roof space is lost.

11.9 A word on connections



PIN JOINT

As the beam deflects due to the imposed loads it is free to ROTATE about the support.

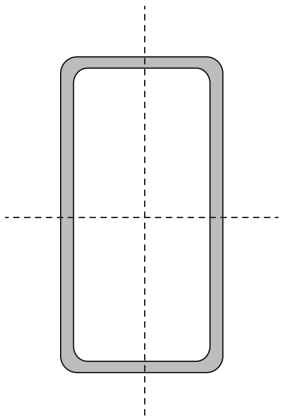


MOMENT JOINT

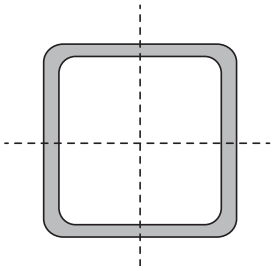
In reality most connections are either bolted or welded (steel), bolted or nailed (timber) or cast (in situ concrete).

11.10 Typical sections

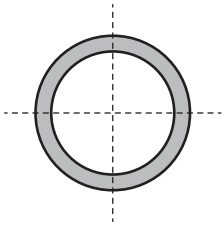
For various constructional and aesthetic reasons the architect often favours a steel section that the engineer is less keen on. The channel section is commonly suggested for a number of reasons although the engineer will point out that because of its eccentric profile it is far less efficient than the RHS or I section.



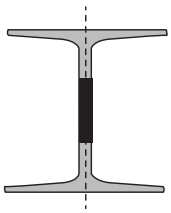
Rectangular Hollow Section (RHS)



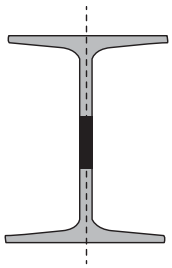
Square Hollow Section (SHS)



Circular Hollow Section (CHS)



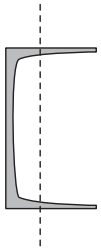
Universal Column (UC)



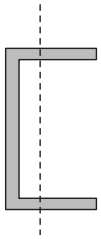
Universal Beam (UB)

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Channel



Parallel Flange Channel (PFC)

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7 Materials

Arthur Lyons with AHR Architects (formerly Aedas)

Dr Arthur Lyons authors texts on building materials and architecture. He was formerly head of quality, principal lecturer and teacher fellow in the Leicester School of Architecture, Faculty of Art, Design and Humanities, De Montfort University, Leicester. He is currently an honorary visiting researcher to the University. AHR Architects is an interdisciplinary design and building consultancy.

KEY POINT:

- *Standards and specifications are constantly changing; always refer to current regulations and manufacturers' details*

Contents

1 Introduction
2 Steel
3 Timber
4 Bricks and blocks
5 Concrete (cement)
6 Aluminium
7 Roofing and cladding
8 Glass
9 Ceramic materials
10 Stone and cast stone
11 Plastics
12 Glass-fibre reinforced plastics, concrete and gypsum
13 Plaster and board materials
14 Insulation materials
15 Sealants, gaskets and adhesives
16 Paints, wood stains and varnishes
17 Commodities
18 Bibliography
19 Acknowledgements

1 INTRODUCTION

The majority of construction materials are supplied to metric dimensions; however, a few materials still retain their imperial designations. Where appropriate, the listings are taken from British and European Standards or trade organisations and will therefore not necessarily correspond to the full ranges offered by individual suppliers. Inevitably, changes in published Standards and Building Regulations will occur, affecting availability of particular products. Specifiers are, therefore, always advised to check current availability and delivery times.

2 STEEL

2.1 General

BS 6722: 1986 defines the recommended dimensions for ferrous and non-ferrous metal wires, bars and flat products. These preferred dimensions are listed in Tables I and II.

2.2 Steel sheet, plate and bars

Steel sheet: Cold reduced mild steel sheet is produced with standard thickness ranging from 0.5 to 3.2 mm (Table III). Hot rolled sheet (< 3 mm) and plate (≥3 mm) is produced with a range from 1.6 to 150 mm (Table IV). Standard dimensions are given in the tables.

Steel bars – flats, rounds, squares and hexagons: The standard sizes for flats, rounds and squares are given in Tables V–VII, respectively.

The standard BS EN 10061: 2003 gives the preferred dimensions for hot rolled hexagon bars (Table VIII); however, standard stock is in the range 7–75 mm.

Table I Recommended thicknesses (mm) for ferrous and non-ferrous metal bars and flat products (BS 6722: 1986)

0.10, *0.11*, 0.12, *0.14*, 0.16, *0.18*, 0.20, *0.22*, 0.25, *0.28*, 0.30, *0.35*, 0.40, *0.45*, 0.50, *0.55*, 0.60, *0.70*, 0.80, *0.90*, 1.0, *1.1*, 1.2, *1.4*, 1.6, *1.8*, 2.0, *2.2*, 2.5, *2.8*, 3.0, *3.5*, 4.0, *4.5*, 5.0, *5.5*, 6.0, *7.0*, 8.0, *9.0*, 10.0, *11.0*, 12.0, *14.0*, 16.0, *18.0*, 20.0, *22.0*, 25.0, *28.0*, 30.0, *35.0*, 40.0, *45.0*, 50.0, *55.0*, 60.0, *70.0*, 80.0, *90.0*, 100.0, *110.0*, 120.0, *140.0*, 160.0, *180.0*, 200.0, *220.0*, 250.0, *280.0*, 300.0

Note: First preference ordinary type, second preference italics.

Table II Recommended widths and lengths (mm) for ferrous and non-ferrous metal flat products (BS 6722: 1986)

400, 500, 600, 800, 1000, 1200, 1250, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 8000, 10000.

Table III Cold reduced steel sheet

Thickness (mm)	0.5	0.6	0.7	0.8	1.0	1.2	1.6	2.0	2.5	3.0	3.2
Mass (kg/m²)	3.93	4.71	5.50	6.28	7.85	9.42	12.56	15.70	19.63	23.55	25.12

Note: Standard range from Tata Steel.
Standard sheet sizes are 2000 × 1000, 2500 × 1250 and 3000 × 1500 mm and coil widths 750–2000 mm.

Table IV Hot rolled steel sheet and plate

Thickness (mm)	1.6	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0	12.5	15
Mass (kg/m²)	12.6	15.7	19.6	23.6	31.4	39.6	47	63	79	98	118
Thickness (mm)	20	22	25	30	32	35	40	45	50	55	60
Mass (kg/m²)	157	173	196	236	252	275	314	353	393	432	471
Thickness (mm)	65	70	75	80	85	90	95	100	120	130	150
Mass (kg/m²)	510	550	589	628	667	707	746	785	942	1021	1178

Note: Standard range from Tata Steel.
Typical size range for plate – Width: 1000–3000 mm, Length: 2000–9000 mm.

2.3 Structural steel sections

Most steel sections of British origin are still based on the old imperial sizes although sized in metric dimensions and billed in kilograms or tonnes. Tables IX–XI summarise the standard dimensions, but it should be noted these are quoted as nominal sizes and that exact dimensions should be verified from manufacturers' data.

Tolerances on nominal dimensions for joists and channels are given in BS 4-1: 2005, and for I and H sections in BS EN 10034: 1993. Some structural steel sections, listed in Table XII, are made in metric co-ordinated sizes.

Structural steel hollow sections: Structural hollow sections may be hot finished or cold formed. Hot finished structural steel hollow sections are manufactured in either 275 or 355 MPa minimum yield strength steel (e.g. S275J2H or S355J2H respectively) to BS EN 10210-1: 2006. Cold formed sections, produced in both 235 and 355 MPa minimum yield strength steel, are limited to thicknesses of 8 and 16 mm, respectively. Hot finished hollow structural steel is available as square, rectangular, circular and oval sections. Cold

Table V Hot rolled flats

	Thickness (mm)																	
Width (mm)	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**60**	**65**	**75**
10	×																	
12	×																	
13	×	×	×	×														
15	×	×	×															
16	×	×	×		×	×												
20	×	×	×	×	×	×	×											
22	×		×			×												
25	×	×	×	×	×	×	×	×	×									
30	×	×	×	×	×	×	×	×	×	×								
35	×	×	×	×	×	×	×	×										
40	×	×	×	×	×	×	×	×	×	×	×							
45	×	×	×	×	×	×	×	×	×	×	×							
50	×	×	×	×	×	×	×	×	×	×	×		×					
55			×	×	×	×	×	×	×	×	×							
60	×	×	×	×	×	×	×	×	×	×	×	×	×					
65	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×			
70	×		×	×	×	×	×	×	×	×	×		×		×			
75	×	×	×	×	×	×	×	×	×	×	×		×		×	×	×	
80	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	
90	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×			
100	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
110	×		×	×	×	×	×	×	×	×	×		×	×	×			
120			×	×	×	×	×	×	×	×	×							
130	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×		×
140				×	×	×	×	×	×	×	×							
150	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×
160				×		×	×	×	×	×								
180			×	×	×	×	×	×	×	×	×		×		×			
200		×		×	×	×	×	×	×	×	×		×	×	×			×
220			×	×	×	×	×	×	×	×	×		×		×			
250				×	×	×	×	×	×	×	×		×	×	×			
275				×	×	×	×											
300				×	×	×	×	×	×	×	×		×	×	×	×		
350						×	×	×	×	×	×		×					
375							×	×	×	×	×		×					
400						×	×	×	×	×	×		×					
450							×	×	×	×								
500						×	×	×	×	×	×							

Note: Stock range from Tata Steel.
Tolerances on dimensions and shape for flat steel bars are given in BS EN 10058: 2003.

Table VI Rounds

Diameter (mm)	Mass/length (kg/m)	Diameter (mm)	Mass/length (kg/m)	Diameter (mm)	Mass/length (kg/m)
6	0.22	70	30.20	165	168.0
8	0.39	75	34.70	170	178.0
10	0.62	80	38.50	180	200.0
12	0.89	85	44.50	185	211.0
13	1.04	90	49.90	190	223.0
15	1.39	95	55.60	195	234.0
16	1.58	100	61.70	200	247.0
20	2.47	105	68.00	210	272.0
22	2.98	110	74.60	220	298.0
25	3.85	115	81.50	230	326.0
30	5.55	120	88.00	240	356.0
32	6.31	125	96.30	250	385.0
35	7.55	130	104.0	260	417.0
40	9.86	135	112.0	270	448.0
45	12.50	140	121.0	275	466.0
50	15.41	145	130.0	280	483.0
55	18.63	150	139.0	300	555.0
60	22.20	155	148.0	305	573.0
65	26.00	160	158.0		

Note: Stock range from Tata Steel.
Tolerances on dimensions and shape for round steel bars are given in BS EN 10060: 2003.

Table VII Squares

Side length	Mass/length (kg/m)
8.0	0.50
10.0	0.79
12.0	1.13
15.0	1.77
16.0	2.01
20.0	3.14
25.0	4.91
30.0	7.07
35.0	9.62
40.0	12.6
45.0	15.9
50.0	19.6
60.0	28.3
65.0	33.2
75.0	44.2

Note: Stock range from Tata Steel.
Tolerances on dimensions and shape for square steel bars are given in BS EN 10059: 2003.

formed hollow structural steel is available as square, rectangular and circular sections.

The standard BS EN 10210-2: 2006 covers hot finished sections to the following maximum sizes: circular – outside diameter 2500 mm, square – outside dimensions 800 × 800 mm, rectangular – outside dimensions 750 × 500 mm and oval – outside dimensions 500 × 250 mm, although not all section sizes available are fully described in the standard.

2.4 Steel alloys

Weather-resistant steel: Weather-resistant steels (BS 7668: 2004 and BS EN 10025-5: 2004) are structural steels alloyed with a small proportion of copper, which together with other alloying constituents has the effect of making the natural rust adhere tenaciously to the surface to prevent further loss by spalling. The design

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Table VIII Hexagons (BS EN 10061: 2003)

Width across flats (mm)	Mass/length (kg/m)	Width across flats (mm)	Mass/length (kg/m)
13	1.15	37.5	9.56
14	1.33	39.5	10.6
15	1.53	42.5	12.3
16	1.74	47.5	15.3
17	1.96	52	18.4
18	2.20	57	22.1
19	2.46	62	26.1
20.5	2.86	67	30.5
22.5	3.44	72	35.2
23.5	3.75	78	41.4
25.5	4.42	83	46.8
28.5	5.52	88	52.6
31.5	6.75	93	58.8
33.5	7.63	98	65.3
35.5	8.56	103	72.1

Note: Preferred dimensions to BS EN 10061: 2003.
Tolerances on dimensions and shape for hexagon steel bars are given in BS EN 10061: 2003.

Table IX British Standard structural steel sections to BS4: Part 1: 2005
Universal beams (BS4: Part 1: 2005)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
1016 × 305	*487, 437, 393, 349, 314, 272, 249, 222*
914 × 419	388, 343
914 × 305	289, 253, 224, 201
838 × 292	226, 194, 176
762 × 267	197, 173, 147, 134
686 × 254	170, 152, 140, 125
610 × 305	238, 179, 149
610 × 229	140, 125, 113, 101
610 × 178	*100, 92, 82*
533 × 312	*272, 219, 182, 150*
533 × 210	138, 122, 109, 101, 92, 82
533 × 165	*85, 74, 66*
457 × 191	*161, 133, 106,* 98, 89, 82, 74, 67
457 × 152	82, 74, 67, 60, 52
406 × 178	*85,* 74, 67, 60, 54
406 × 140	53, 46, 39
356 × 171	67, 57, 51, 45
356 × 127	39, 33
305 × 165	54, 46, 40
305 × 127	48, 42, 37
305 × 102	33, 28, 25
254 × 146	43, 37, 31
254 × 102	28, 25, 22
203 × 133	30, 25
203 × 102	23
178 × 102	19
152 × 89	16
127 × 76	13

Note: Dimensions in italics are Tata Steel production in addition to the standard range of BS4–1: 2005 sections.

Universal columns (BS4: Part 1: 2005)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
356 × 406	634, 551, 467, 393, 340, 287, 235
356 × 368	202, 177, 153, 129
305 × 305	283, 240, 198, 158, 137, 118, 97
254 × 254	167, 132, 107, 89, 73
203 × 203	*127, 113, 100*, 86, 71, 60, 52, 46
152 × 152	*51, 44*, 37, 30, 23

Note: Dimensions in italics are Tata Steel production in addition to the standard range of BS4–1: 2005 sections.

Joists with taper flanges (BS4: Part 1: 2005)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
254 × 203	82
254 × 114	37
203 × 152	52
152 × 127	37
127 × 114	29, 27
127 × 76	16
114 × 114	27
102 × 102	23
102 × 44	7
89 × 89	19
76 × 76	15, 13

Table IX (continued)

Universal bearing piles (BS4: Part 1: 2005)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
356 × 368	174, 152, 133, 109
305 × 305	223, 186, 149, 126, 110, 95, 88, 79
254 × 254	85, 71, 63
203 × 203	54, 45

Note: Tolerances on dimensions and shape for structural steel I and H sections are given in BS EN 10034: 1993 and for taper flange I sections in BS 10024: 1995.

Table X Structural hollow sections
Hot finished circular hollow sections (BS EN 10210–2: 2006)

Nominal external diameter (mm)	Thickness (mm)
1219	*25, 20, 16, 14.2, 12.5, 10*
1168	*25, 20, 16, 14.2, 12.5, 10*
1067	*30, 25, 20, 16, 14.2, 12.5, 10*
1016	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
914	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
813	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
762	*50, 40, 30, 25, 20, 16, 14.2, 12.5, 10, 8, 6.3*
711	*60, 50,* 40, *30, 25, 20, 16, 14.2, 12.5, 10, 8, 6.3*
1219	*25, 20, 16, 14.2, 12.5, 10*
1168	*25, 20, 16, 14.2, 12.5, 10*
1067	*30, 25, 20, 16, 14.2, 12.5, 10*
1016	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
914	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
813	*30, 25, 20, 16, 14.2, 12.5, 10, 8*
762	*50, 40, 30, 25, 20, 16, 14.2, 12.5, 10, 8, 6.3*
711	*60, 50,* 40, *30, 25, 20, 16, 14.2, 12.5, 10, 8, 6.3*
610	*50,* 40, *30, 25, 20, 16, 14.2, 12.5, 10, 8, 6.3*
508	*50, 40, 36, 30, 25, 20,* **16**, *14.2,* **12.5, 10**, *8, 6.3*
457	40, *30,* 25, *20,* **16**, *14.2*, **12.5, 10, 8**, *6.3*
406.4	*40, 30, 25, 20,* **16**, *14.2*, **12.5, 10, 8**, 6.3
355.6	*25, 20,* 16, *14.2, 12.5, 10, 8, 6.3*
323.9	*25, 20,* **16**, *14.2*, **12.5, 10, 8, 6.3**, *5.0*
273	*25, 20,* **16**, *14.2*, **12.5, 10, 8, 6.3**, *5.0*
244.5	*25, 20,* **16**, *14.2*, 12.5, 10, 8, *6.3, 5.0*
219.1	*20,* 16, *14.2*, **12.5, 10, 8, 6.3, 5.0**
193.7	*16, 14.2*, 12.5, **10, 8, 6.3, 5.0**
177.8	*12.5, 10, 8, 6.3, 5.0*
168.3	12.5, **10, 8, 6.3, 5.0**, *4.0*
139.7	12.5, **10, 8, 6.3, 5.0**, *4.0*
114.3	*10, 8,* **6.3, 5.0**, 4.0, **3.6**, **3.2**
101.6	*10, 8, 6.3, 5.0, 4.0, 3.2*
88.9	6.3, **5.0, 4.0, 3.2**
76.1	**5.0**, 4.0, **3.2,** 2.9, *2.6*
60.3	**5.0**, 4.0, 3.2, *2.6*
48.3	**5.0**, 4.0, 3.2, *2.6*
42.4	5.0, 4.0, 3.2, 2.6
33.7	4.0, 3.2, 2.6
26.9	3.2, *2.6*, *2.3*
21.3	*3.2, 2.6, 2.3*

Note: Not all listed sizes are readily available.
Standard Tata Steel hot finished circular hollow sections are in bold, non-regular production sizes are in normal type. Other dimensions quoted in BS EN 10210–2: 2006 are in italics.
Cold formed circular hollow sections (BS EN 10219-2: 2006) are manufactured with dimensions ranging from 26.9 × 2 mm to 508 × 16 mm.

Hot finished square hollow sections (BS EN 10210–2: 2006)

Nominal side dimensions (mm)	Thickness (mm)
400 × 400	*20,* **16,** *14.2*, **12.5, 10**
350 × 350	**16,** *14.2*, **12.5, 10, 8.0**
300 × 300	**16,** *14.2*, **12.5, 10, 8.0,** 6.3
260 × 260	*16, 14.2, 12.5, 10, 8.0, 6.3*
250 × 250	**16,** *14.2*, **12.5, 10, 8.0, 6.3**
220 × 220	*16, 14.2, 12.5, 10, 8.0, 6.3*
200 × 200	**16,** *14.2*, **12.5, 10, 8.0, 6.3, 5.0**
180 × 180	**16,** *14.2*, **12.5, 10, 8.0, 6.3,** *5.0*
160 × 160	*16, 14.2*, 12.5, **10, 8.0, 6.3, 5.0**
150 × 150	*16, 14.2*, **12.5, 10, 8.0, 6.3, 5.0**
140 × 140	**12.5, 10, 8.0, 6.3, 5.0**
120 × 120	**12.5, 10, 8.0, 6.3, 5.0**
100 × 100	**10, 8, 6.3, 5.0, 4.0**
90 × 90	**8.0, 6.3, 5.0, 4.0,** 3.6
80 × 80	**8.0, 6.3, 5.0,** 4.0, **3.6,** *3.2*, **3.0**
70 × 70	8.0, 6.3, **5.0,** *4.0*, **3.6,** *3.2*
60 × 60	8.0, **6.3, 5.0, 4.0**, 3.2, 3.0, *2.6*
50 × 50	**6.3, 5.0**, **4.0**, **3.2,** 3.0, *2.6*
40 × 40	**5.0**, **4.0,** 3.2, 3.0, *2.6*

Note: Not all listed sizes are readily available.
Standard Tata Steel hot finished square hollow sections are in bold, non-regular production sizes are in normal type. Other dimensions quoted in BS EN 10210–2: 2006 are in italics.
Cold formed square hollow sections (BS EN 10219-2: 2006) are manufactured with dimensions ranging from 25 × 25 × 2 mm to 300 × 300 × 12.5 mm.

Table X (continued)

Hot finished rectangular hollow sections (BS EN 10210–2: 2006)

Nominal external dimensions (mm)	Thickness (mm)
500 × 300	*20*, **16,** *14.2*, 12.5, **10**, 8.0
500 × 200	16, 12.5, 10, 8.0
450 × 250	**16,** 14.2, **12.5, 10, 8.0**
400 × 200	**16**, 14.2, **12.5, 10, 8.0**
350 × 250	*16, 14.2, 12.5, 10, 8.0, 6.3*
350 × 150	16, 12.5, 10, 8.0
300 × 200	**16**, *14.2*, **12.5, 10, 8.0, 6.3**
300 × 100	12.5, **10, 8.0**
260 × 180	*16, 14.2, 12.5, 10, 8.0, 6.3*
250 × 150	**16,** *14.2*, **12.5, 10, 8.0, 6.3, 5.0**
200 × 150	**10, 8.0**
200 × 120	12.5, **10, 8.0, 6.3, 5.0**
200 × 100	*16*, **12.5, 10, 8.0, 6.3, 5.0**
180 × 100	*12.5, 10, 8.0, 6.3, 5.0, 4.0*
160 × 80	*12.5*, **10, 8.0, 6.3, 5.0, 4.0**
150 × 100	12.5, **10, 8.0,** 6.3**, 5.0,** *4.0*
140 × 80	*10, 8.0, 6.3, 5.0, 4.0*
120 × 80	**10, 8.0, 6.3, 5.0**, *4.0*
120 × 60	*10*, **8.0, 6.3, 5.0**, *4.0*, **3.6**
100 × 60	**8.0, 6.3, 5.0**, *4.0*, 3.6, *3.2*
100 × 50	10**, 8.0, 6.3, 5.0, 4.0**, **3.2, 3.0**
90 × 50	*8.0*, 6.3, **5.0**, *4.0*, 3.6, *3.2*
80 × 40	8.0, 6.3, 5.0, 4.0, 3.2
60 × 40	*6.3,* 5.0, 4.0*, 3.6, 3.2,* 3.0*, 2.6*
50 × 30	*5.0, 4.0,* 3.2*, 2.6*

Note: Not all listed sizes are readily available.
Standard Tata Steel hot finished rectangular hollow sections are in bold, non-regular production sizes are in normal type. Other dimensions quoted in BS EN 10210–2: 2006 are in italics.
Cold formed rectangular hollow sections (BS EN 10219-2: 2006) are manufactured with dimensions ranging from 40 × 20 × 2 mm to 400 × 200 × 12.5 mm.

Hot finished oval hollow sections (BS EN 10210–2: 2006)

Nominal external dimensions (mm)	Thickness (mm)
500 × 250	**16, 12.5, 10**
480 × 240	*14, 12, 10*
400 × 200	**16**, *14*, **12.5**, *12*, **10, 8**
320 × 160	*14, 12, 10, 8.0*
300 × 150	**16, 12.5, 10, 8**
250 × 125	**12.5**, *12*, **10, 8, 6.3**, *6.0*
220 × 110	*10, 8, 6.0*
200 × 100	**12.5, 10, 8**, *6.3*, **6.0, 5.0**
180 × 90	*10, 8, 6.0*
150 × 75	*10, 8,* 6.3, **6.0**, **5.0**, **4.0**
120 × 60	*8, 6.0, 5.0, 4.0, 3.2*

Note: Not all listed sizes are readily available.

Tata Steel hot finished oval hollow sections are in bold type. Other dimensions quoted in BS EN 10210–2: 2006 are in italics.

Table XI Channels and angles
Equal angles (BS EN 10056–1: 1999)

Nominal dimensions (mm)	Thickness (mm)
200 × 200	**24, 20, 18, 16**
150 × 150	**18, 15, 12, 10**
120 × 120	**15, 12, 10, 8**
100 × 100	**15, 12, 10, 8**
90 × 90	**12, 10, 8, 7, 6**
80 × 80	**10, 9, 8**, 7, **6**
75 × 75	**10**, 9, **8**, 7, **6**
70 × 70	**10**, 9, **8**, 7, **6, 5**
65 × 65	9, 7, 6
60 × 60	**10**, 9, **8**, 7, **6**, **5**, 4
55 × 55	**6**
50 × 50	**8, 6**, 7, **5**, 4, **3**
45 × 45	8, 7, **6, 5, 4.5**, 4, 3
40 × 40	**6, 5, 4, 3**
35 × 35	5, 4, 3.5
30 × 30	**5**, 4, **3**
25 × 25	**5**, 4, **3**
20 × 20	5, 4, 3

Note: Standard Tata Steel stock dimensions are in bold, non-regular production sizes are in normal type.
The standard BS EN 10056–1: 1999 refers to a wider range up to 250 × 250 mm.
Tolerances on dimensions and shape for equal leg angles are given in BS EN 10056–2: 1993.

Unequal angles (BS EN 10056–1: 1999)

Nominal dimensions (mm)	Thickness (mm)
200 × 150	**18, 15, 12**
200 × 100	**15, 12, 10**
150 × 90	**15, 12, 10**
150 × 75	**15, 12, 10**
130 × 65	10, 8
125 × 75	**12, 10, 8**

Table XI (continued)
Unequal angles (BS EN 10056–1: 1999)

Nominal dimensions (mm)	Thickness (mm)
120 × 80	12, 10, 8
100 × 75	**12, 10**, 9, **8**
100 × 65	**10**, 9**, 8, 7**
100 × 50	10, 8, **6**
90 × 70	8
90 × 65	8, 6
80 × 65	10, 8, 6
80 × 60	**8**, 7, **6**
80 × 40	8, 6
75 × 55	9. 7, 5
75 × 50	**10, 8**, 7, **6**, 5
70 × 50	6
65 × 50	**8**, 7, **6, 5**
60 × 40	**7, 6, 5**
60 × 30	**6, 5**
50 × 40	**5**
50 × 30	5
45 × 30	5, 4
40 × 25	**4**
40 × 20	4, 3
30 × 20	4, 3

Note: Standard Tata Steel stock dimensions are in bold, non-regular production sizes are in normal type.
Tolerances on dimensions and shape for unequal leg angles are given in BS EN 10056–2: 1993.

Parallel flange channels

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
430 × 100	64
380 × 100	54
300 × 100	46
300 × 90	41
260 × 90	35
260 × 75	28
230 × 90	32
230 × 75	26
200 × 90	30
200 × 75	23
180 × 90	26
180 × 75	20
150 × 90	24
150 × 75	18
125 × 65	15
100 × 50	10

Note: Standard Tata Steel stock dimensions.
Tolerances on dimensions, mass and shape for hot rolled steel channels are given in BS EN 10279: 2000.

Tapered flange channels

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
76 × 38	6.7

Note: Standard Tata Steel stock dimensions. A range of dimensions from 140 × 60 × 7 mm to 40 × 20 × 5 mm are also available.

Tolerances on dimensions, mass and shape for hot rolled steel channels are given in BS EN 10279: 2000.

Table XII Metric structural sections
Beams with parallel flanges (Euronorm 19–57)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
750 × 265	222, 210, 196, 185, 173, 160, 147, 137
600 × 225	184, 154, 144, 122, 108
550 × 210	159, 134, 123, 106, 92
500 × 200	129, 111, 107, 91, 79
450 × 190	104, 95, 92, 78, 67
400 × 180	84, 82, 76, 66, 57
360 × 170	70, 66, 57, 50
330 × 160	60, 57, 49, 43
300 × 150	52, 49, 42, 37
270 × 135	44, 42, 36, 31
240 × 120	37, 34, 31, 26
220 × 110	32, 29, 26, 22
200 × 100	27, 25, 22, 18
180 × 90	22, 21, 19, 15
160 × 80	18, 16, 13
140 × 75	14, 13, 11
120 × 65	10, 8.7
100 × 55	8.1, 6.9

Note: Dimensions and properties to Euronorm 19-57/DIN 1025. Tolerances to EN 10034: 1993.

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Table XII (continued)
Parallel wide flange beams (Euronorm 53–62)

Nominal dimensions (mm)	Standard mass per unit length (kg/m)
1000 × 300	349, 314, 272, 222
900 × 300	333, 291, 252, 198
800 × 300	317, 262, 224, 172
700 × 300	301, 241, 204, 166, 150
650 × 300	293, 225, 190, 138
600 × 300	285, 212, 178, 175, 151, 137, 129
550 × 300	278, 199, 166, 120
500 × 300	270, 187, 155, 107
450 × 300	263, 171, 140, 124, 100
400 × 300	256, 155, 125, 107, 92
360 × 300	250, 142, 112, 84
340 × 300	248, 134, 105, 79
320 × 300	245, 127, 98, 74
300 × 300	238, 117, 88, 70
280 × 280	189, 103, 76, 61
260 × 260	172, 93, 68, 54
240 × 240	157, 83, 60, 47
220 × 220	117, 72, 51, 40
200 × 200	103, 61, 42, 35
180 × 180	89, 51, 36, 29
160 × 160	76, 43, 30, 24
140 × 140	52, 34, 25, 18
120 × 120	52, 27, 20, 15
100 × 100	41, 20, 17, 12

Note: Dimensions and properties to Euronorm 19-57/DIN 1025. Tolerances to EN 10034: 1993.

detailing of weathering steel (Cor-Ten®) must ensure that rainwater run-off does not cause staining to adjacent materials, particularly concrete and glass, during the first few years of exposure to rain. Also detailing should ensure no entrapment of pockets of water or damp debris to prevent continuing corrosion at these locations. Weather-resistant steel has been used for exposed structures in buildings, bridges and as a cladding material.

Stainless steel: Stainless steels are a range of alloys containing at least 10.5 per cent chromium. The corrosion resistance of the material is due to the natural passive film of chromium oxide, which is naturally regenerated if the surface is scratched. The grades of stainless steel for construction are listed in Table XIII (BS EN 10088-1: 2005). Stainless steel is available in hollow and standard sections for structural use and in sheet form for cladding, roofing and trim.

2.5 Coated steels

The range of metal-coated steels includes traditional hot-dip galvanized steel, aluminium–zinc alloy-coated and terne-coated steels. The durability of zinc-coated steel is dependent on the thickness of the coating and the environment, also the avoidance of contact with other metals particularly copper, and the alkalis in wet mortar and plaster. In addition to hot-dip galvanizing, a zinc coating may be applied by molten metal spraying, sherardizing or electrolytically. Aluminium–zinc alloy coatings are more durable than the equivalent thickness of pure zinc. The standard alloys contain 5 per cent (ZA) and 55 per cent (AZ) aluminium in zinc respectively. A further alloy containing 1.6 per cent silicon is durable without further protection in non-aggressive environments. Terne, an alloy of lead and tin, hot-dipped onto either steel or stainless steel, produces a durable cladding and roofing material. Tin coated stainless steel, manufactured by electrodeposition, is also used for roofing where an appearance similar to lead is required, but without the associated risk of lead theft.

Table XIII Stainless steel grades for different environmental conditions (BS EN 10088–1: 2005)

Type	Metallic alloying components (%)	Number	Suitable environments
Austenitic	Chromium/nickel 18–10	1.4301	Rural and clean urban
	Chromium/nickel/molybdenum 17–12–2	1.4401	Industrial and marine
Ferritic	Chromium 17	1.4406	Interior
Duplex	Chromium/nickel/molybdenum 22–5–3	1.4462	Severe industrial and marine

The predominant organic coatings to steel are polyvinyl chloride plastisol (PVC[P]), polyvinylidene fluoride (PVDF) and polyurethane on zinc–aluminium alloy or zinc-coated steel. PVC[P] has a leather grain finish, PVDF has a smooth finish with good colour stability and polyurethane offers colour and metallic gloss finishes. The products are available in a wide range of colours for use in roofing, cladding and interior finishes. Other organic finishes include polyester incorporating acrylic beads and patterned or textured polyvinyl chloride (PVC) film.

2.6 Steel reinforcement for concrete

For details of sizes of steel reinforcement, refer to Chapter 6, Structure.

Concrete should be specified to BS EN 206: 2013, and steel reinforcement to BS 4449: 2005 + A2: 2009 (bar/coil and decoiled steel), BS 4482: 2005 (steel wire) and BS 4483: 2005 (steel fabric). The Standard BS 4482: 2005 refers to 250 MPa yield strength plain bars and the higher grade steel, 500 MPa, for plain, ribbed and indented bars. The Standard BS 4449: 2005 specifies high yield steel (500 MPa) with three levels of ductility, for ribbed bars. Austenitic stainless steel may be used for concrete reinforcement where failure due to corrosion is a potential risk. Stainless steels suitable for reinforcement are specified in BS 6744: 2001 + A2: 2009.

3 TIMBER

3.1 General

For the supply of both softwoods and hardwoods, independent global certification schemes operated by the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) ensure sustainable forest management and a verifiable chain of custody.

Timber used in building is either softwood or hardwood, depending on species; each may be supplied sawn or finished.

Sizes are usually quoted 'ex', meaning the sawn size. Structural timber is classified into strength classes (Table XIV) to BS EN 338: 2009 (and pr EN 338: 2013) for both softwoods and hardwoods.

Table XIV Relationship between strength classes and physical properties for structural softwoods and hardwoods (BS EN 338: 2009, incorporating pending pr EN 338: 2013)

Softwood species												
Strength class	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Bending strength (MPa)	14	16	18	20	22	24	27	30	35	40	45	50
Mean density (kg/m³)	350	370	380	390	410	420	430	460	470	480	490	520

Hardwood species														
Strength class	D18	D24	D27	D30	D35	D40	D45	D50	D55	D60	D65	D70	D75	D80
Bending strength (MPa)	18	24	27	30	35	40	45	50	55	60	65	70	75	80
Mean density (kg/m³)	570	580	610	640	650	660	700	740	790	840	960	1080	1080	1080

Note: C refers to coniferous softwoods and D refers to deciduous hardwoods.
Timber conforming to C45 and C50 may not be readily available.

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3.2 Softwood

Target cross-sectional sizes for sawn softwood based on imperial and metric units (Tables XV and XVI respectively) have been agreed within the European Union (BS EN 1313-1: 2010), but with provision for additional complementary sizes for twelve of the individual member states. The complementary preferred cross-sectional sizes for the UK and Ireland are included in Table XVII. Permitted tolerances on structural timber to BS EN 336: 2013 are given in Table XVIII.

Joinery timber requires a high level of finish and straightness, and is classified into seven quality classes (BS EN 942: 2007) according to the number and size of visible natural defects, particularly knots.

A wide range of standard softwood profiles are available. Tongue-and-groove boarding to BS 1297: 1987 is to thicknesses of 16, 19, 21 and 28 mm with standard widths of 65, 90, 113 and 137 mm.

Table XV Common target cross-sectional sizes based on imperial measure (BS EN 1313–1: 2010)

	Width (mm)						
Thickness (mm)	75	100	125	150	175	200	225
38		X	X	X			
50		X	X	X	X	X	X
63		X	X	X	X		
75				X	X	X	X
100						X	

Table XVI Common target cross-sectional sizes based on metric measure (BS EN 1313–1: 2010)

	Width (mm)							
Thickness (mm)	80	100	120	140	160	180	200	220
50	X	X	X	X	X	X	X	X
60		X	X	X	X	X		
80		X	X	X	X	X	X	
100	X	X	X	X	X		X	
120	X	X	X		X	X	X	
140	X	X		X		X		
160	X	X	X		X		X	

Table XVII Complementary preferred target cross-sectional sizes in United Kingdom (UK) and Ireland (IR) (BS EN 1313–1: 2010)

Thickness	Width (mm)											
(mm)	75	100	115	125	138	150	175	200	225	250	275	300
35	IR	IR	IR	IR		IR	IR	IR	IR		IR	
38	UK		UK		UK		UK	UK	UK	UK	UK	UK
44	IR	IR	IR	IR		IR	IR	IR	IR			
47	UK	UK		UK		UK	UK	UK	UK	UK		UK
50	UK									UK		UK
	IR											
63	IR							UK	UK			
								IR	IR			
75		UK		UK						UK	UK	UK
		IR		IR							IR	
100						UK			UK	UK	UK	UK
150						UK		UK				UK
250										UK		
300												UK

Note: The Standard BS EN 1313–1: 2010 also gives complementary preferred target cross-sectional sizes for Austria, Switzerland, Germany, Finland, France, Italy, Netherlands, Norway, Sweden and Poland.

Table XVIII Permitted deviations of cross-sectional sizes of structural timber (BS EN 336: 2013)

Maximum deviations from target sizes	Tolerance class T1	Tolerance class T2
Thicknesses and widths ≤ 100 mm	–1 to + 3 mm	–1 to + 1 mm
Thicknesses and widths >100 and ≤ 300 mm	–2 to + 4 mm	–1.5 to + 1.5 mm
Thicknesses and widths >300 mm	–3 to + 5 mm	–2.0 to + 2.0 mm

Note: Permitted deviations of cross-sectional sizes for general sawn softwood timber to BS EN 1313–1: 2010 correspond to the data for Tolerance class T1.

Regularly available softwood species and their origin include Douglas Fir (N. America and UK), Western Hemlock (N. America), European Larch (Europe), Parana Pine (S. America), Corsican Pine (Europe), Pitch Pine (Southern USA), Radiata Pine (S. Africa, S. America and New Zealand), Scots Pine (UK and Europe), Southern Pine (Southern USA), Yellow Pine (N. America), Spruce (Canada), Sitka Spruce (N. America and UK), Western Red Cedar (N. America) and European Whitewood (Europe and Russia).

3.3 Hardwood

Hardwood is normally supplied in planks of specified thickness but arbitrary width and length, depending on species and thickness. The preferred dimensions including complementary thicknesses are given in Table XIX. Maximum reductions for planing are listed in Table XX.

Table XIX Standard sizes of sawn hardwood (BS EN1313–2: 1999)

Preferred thicknesses EU (mm)	20	27	32	40	50	60	65	70	80	100
Complementary thicknesses UK (mm)	19	26		38	52		63	75		

Preferred widths
EU 10 mm intervals for widths between 50 mm and 90 mm, 20 mm intervals for widths of 100 mm or more.

Preferred lengths
EU 100 mm intervals for lengths between 2.0 m and 6.0 m, 50 mm intervals for lengths less than 1.0 m.

Table XX Maximum reductions from sawn sizes of hardwoods by planing two opposed faces (BS EN1313–2: 1999)

	Reduction from sawn sizes of width or thickness (mm)				
Typical application	15 to 25	26 to 50	51 to 100	101 to 150	151 to 300
Flooring, matchings, interlocked boarding and planed all round	5	6	7	7	7
Trim	6	7	8	9	10
Joinery and cabinet work	7	9	10	12	14

Regularly available hardwood species and their origin include American Ash (USA), European Ash (Europe), Beech (Europe), American Birch (N. America), European Birch (Europe and UK), Iroko (W. Africa), Jelutong (Malaysia), Keruing (S.E. Asia), Mahogany (Africa), American Mahogany (Central and S. America), Maple (N. America), Meranti/Red Lauan (Malaysia), Meranti/ White Lauan (S.E. Asia), American Red Oak (N. America), American White Oak (N. America), Obeche (W. Africa), Sapele (W. Africa), Teak (Burma, Indonesia and Thailand) and Utile (Africa). Predominant UK production includes oak, sweet chestnut, ash, beech and sycamore.

3.4 Strength classes

Timber for structural purposes is machine or visually graded into an appropriate strength class. The machine strength classes, which relate directly to bending strength, range from C14 to C50 for softwood species (coniferous), and D18 to D80 for hardwood species (deciduous). The characteristic physical properties of timber in the various strength classes are listed in BS EN 338: 2009 and pending pr EN 338: 2013.

3.5 Use classes

Timber and all timber products are, to a greater or lesser degree affected by moisture. The environmental conditions in which wood and wood products are used, are therefore categorised into five use classes by BS EN 335: 2013 as in Table XXI.

3.6 Timber products

The wide range of products manufactured from wood includes laminated timber, cross-laminated timber (CLT), laminated veneer

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Table XXI Use classes for wood and wood-based products (BS EN 335: 2013)

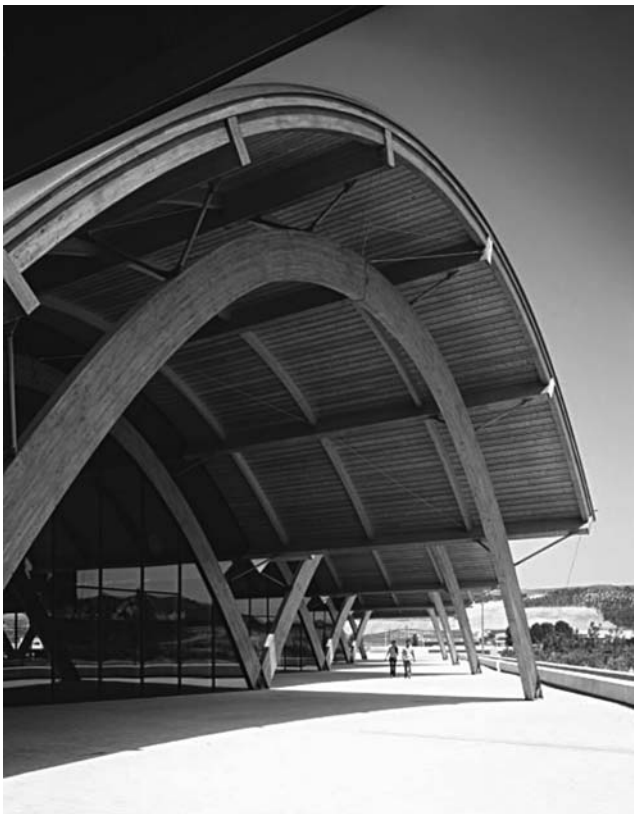
Use Class	General service situation for wood or wood-based products
Class 1	Inside a construction and not exposed to weather or wetting.
Class 2	Under cover and not exposed to weather but where occasional but not persistent wetting may occur.
Class 3	
3.1	Above ground and exposed to weather, but will not remain wet for long periods. Water will not accumulate.
3.2	Above ground and exposed to weather, and will remain wet for long periods. Water may accumulate.
Class 4	Direct contact with ground and/or fresh water.
Class 5	Permanently or regularly submerged in salt water.

lumber (LVL), plywood, particleboard, fibreboard and modified wood.

Laminated timber: Laminated timber sections, Figure 7.1, can be manufactured to any transportable size, typically 30 m although spans of over 50 m are possible. Strength-graded timber sections, continuously glued with resin adhesive and the use of scarf or finger jointing within the laminates ensure a uniform structural product. Sections may be joined on site by finger jointing (BS EN14080: 2013). Units are classified to the appropriate overall strength class GL24, 28, 32 or 36 to BS EN 1194: 1999. Standard stock straight sections range typically between 35 mm and 200 mm in thickness and between 90 mm and 630 mm in depth although larger standard sections are available from some suppliers. Arches, cranked beams, portal frames and other geometrical forms are made to design specification.

Laminated veneer lumber: LVL is manufactured by laminating timber strands with polyurethane resin followed by heat or microwave curing under pressure. It can be produced in sheets or billets up to 26 m long and subsequently machined as solid timber. It is frequently used in I-section joists for roof and floor construction. The three grades appropriate to different environmental conditions (BS EN 14279: 2004 + A1: 2009) are listed in Table XXII. The requirements for structural LVL are detailed in BS EN 14374: 2004.

Cross-laminated timber: CLT (X-LAM) is similar to conventional plywood except that the laminates are thicker. Panel thicknesses are generally between 50 mm and 300 mm, although 500 mm can be produced. Stock panel sizes are up to 15 × 4.8 m, but the standard production limit is 24 m (subject to transportation limits). Panels manufactured from spruce, larch or pine are classified by surface quality which is either planed or sanded (BS EN 13017-1: 2001), Table XXIII.



7.1 *Laminated timber: Bodegas Protos, Spain. Architect: Rogers Stirk Harbour+Partners*

Plywood: Plywood is classified (BS EN 313-1: 1996) according to its construction and properties including durability, strength and surface condition. Bonding properties and biological durability for Use Classes 1–3 (dry, humid and exterior conditions) are specified in BS EN 636: 2012. Softwood plywood (predominantly pine and spruce) is imported from North America and Scandinavia. Temperate hardwood products are imported from Finland (birch) and Germany (beech), while tropical hardwood sheets are imported from Indonesia, Malaysia, South America and Africa. The standard sheet sizes are 1220 mm × 2440, 3050 and 3660 mm but larger sizes to 3660 × 3050 mm are available especially for concrete formwork. Thicknesses range typically from 4 to 30 mm.

Particleboards: Particleboards are manufactured from particles of wood, flax or hemp and a binder. Wood particleboard (BS EN 309: 2005) and cement-bonded particle board (BS EN 634-2: 2007) are bonded with resin and cement binder, respectively.

Oriented strand board (OSB) is manufactured from larger wood flakes and binder to BS EN 300: 2006.

The standard sizes of wood particleboard (chipboard) are 2440 × 1220, 2750 × 1220, 3050 × 1220 and 3660 × 1220 mm, with the common thicknesses within the range 12–38 mm. Two generic manufacturing processes are used for the production of wood particleboard giving products with different properties. The pressed product is stronger, whereas the extruded board (BS EN 14755: 2005) may be solid or with void spaces. Standard grades of wood particleboard are hygroscopic and respond to changes in humidity, but humid-resistant grades are tolerant to occasional wetting. Grades of wood particleboard and extruded particleboard are listed in Tables XXIV and XXV.

Cement-bonded particle board has good resistance to fire, water, fungal attack and frost. The Standard (BS EN 634-2: 2007) specifies only one grade as in Table XXVI. Board sizes are typically 1200 × 2400, 2660 or 3050 mm with standard thickness of 12 and 18 mm, although sheets up to 40 mm thickness are manufactured.

Table XXII Grades of laminated veneer lumber (BS EN 14279: 2004)

Type	Exposure class	Exposure	Purpose/loading
LVL/1	class 1	dry	load-bearing
LVL/2	class 2	humid	load-bearing
LVL/3	class 3	exterior conditions (with appropriate finish)	load-bearing

Note: Dry, humid and exterior Service Classes are defined in BS EN 1995–1–1: 2004 + A2: 2014.

Table XXIII Surface quality classification of cross-laminated timber (BS EN 13017–1: 2001)

Class	Grade	Typical use
Class C	Standard	Non-visible
Class AB	Interior grade	Residential visible
Class BC	Interior grade	Industrial visible

Table XXIV Grades of wood particleboard (BS EN 312: 2010)

Type	Exposure	Colour coding		Purpose/loading
P1	Dry	White, white	blue	General purpose
P2	Dry	White	blue	Interior fitments
P3	Humid	White	green	Non-load-bearing
P4	Dry	Yellow, yellow	blue	Load-bearing
P5	Humid	Yellow, yellow	green	Load-bearing
P6	Dry	Yellow	blue	Heavy-duty load-bearing
P7	Humid	Yellow	green	Heavy-duty load-bearing

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Table XXV Grades of extruded wood particleboard (BS EN 14755: 2005)

Grade	Description
ES	Extruded Solid: Board with a minimum density of 550kg/m^3
ET	Extruded Tube: Board with a minimum solid density of 550kg/m^3
ESL	Extruded Solid Light: Board with a density of less than 550kg/m^3
ETL	Extruded Tube Light: Board with a solid density of less than 550kg/m^3

Note: Grades ET and ETL must have at least 5 mm of material over the void spaces.

Table XXVI Grade of cement-bonded particleboard (BS EN 634–2: 2007)

Exposure	Colour coding		Purpose/loading
Dry, humid and exterior	White, white	brown	Non-load-bearing

Note: Within the one grade there are two Technical Classes 1 and 2 which relate only to the modulus of elasticity in bending.

Table XXVII Grades of oriented strand board (OSB) (BS EN 300: 2006)

Grade	Exposure	Colour coding		Purpose/loading
OSB/1	Dry	White	blue	General purpose Interior fitments
OSB/2	Dry	Yellow, yellow	blue	Load-bearing
OSB/3	Humid	Yellow, yellow	green	Load-bearing
OSB/4	Humid	Yellow	green	Heavy duty load-bearing

Note: Boards of grades OSB/3 and OSB/4 are suitable for Use Classes 1 and 2 to BS EN 335: 2013.

OSB is graded (Table XXVII) to its anticipated loading and environmental conditions (BS EN 300: 2006). It is available in sheet thicknesses from 6 to 38 mm, although the standard range is from 9 to 18 mm.

Fibreboards: Fibreboards (BS EN 622-1: 2003) are manufactured from wood or other plant fibres, and generally are bonded under pressure using the natural adhesive properties and felting of the fibres. In the case of medium density fibreboard (MDF) a resin bonding agent is used. Essentially, differing degrees of compression give rise to the product range, although some products are impregnated with additives. Tables XXVIII–XXXI give the grades of MDF (BS EN 622-5: 2009), hardboard (BS EN 622-2: 2004), mediumboard (BS EN 622-3: 2004) and softboard (BS EN 622-4: 2009), respectively.

Modified wood: Wood may be modified either by heat treatment or by chemical reagents. Thermal modification (DD CEN/TS 15679: 2007) involves the heating of usually pine or spruce, but also certain hardwoods, to between 180°C and 240°C within an inert atmosphere The durability is significantly increased, but with some reduction in strength. Thermally modified timber classes are listed in Table XXXII. Chemical modification involves the acetylation (Accoya®) or furfurylation (Kebony®) of the timber leading to a Class 1 durable material, without changes to the physical properties of the material.

Table XXVIII Grades of medium density fibreboard (MDF) (BS EN 622–5: 2009)

Grade	Exposure	Colour coding		Purpose / loading
MDF	Dry	White, white	blue	General purpose Interior fitments
MDF.H	Humid	White, white	green	General purpose
MDF.LA	Dry	Yellow, yellow	blue	Load-bearing
MDF.HLS	Humid	Yellow, yellow	green	Load-bearing (Instantaneous or short-term loading only)
L–MDF	Dry			
L–MDF.H	Humid			
UL1–MDF	Dry			Insulating panels with limited stiffening function
UL2–MDF	Dry			Insulating panels with a stiffening function
MDFRWH	Underlay conditions			Rigid underlays in roofs and walls. [Instantaneous (e.g. wind) or short-term loading (e.g. snow) only]

Note: Prefix L refers to light, Prefix UL refers to ultra-light and RW refers to roof and walls.

Table XXIX Grades of hardboard (BS EN 622–2: 2004)

Grade	Exposure	Colour coding		Purpose/loading
HB	Dry	White, white	blue	General purpose
HB.H	Humid	White, white	green	General purpose
HB.E	Exterior	White, white	brown	General purpose
HB.LA	Dry	Yellow, yellow	blue	Load-bearing
HB.LA1	Humid	Yellow, yellow	green	Load-bearing
HB.LA2	Humid	Yellow	green	Heavy-duty load-bearing

Table XXX Grades of mediumboard (BS EN 622–3:2004)

Grade	Exposure	Colour coding		Purpose/loading
MBL	Dry	White, white	blue	General purpose
MBH	Dry	White, white	blue	General purpose
MBL.H	Humid	White, white	green	General purpose
MBH.H	Humid	White, white	green	General purpose
MBL.E	Exterior	White, white	brown	General purpose
MBH.E	Exterior	White, white	brown	General purpose
MBH.LA1	Dry	Yellow, yellow	blue	Load-bearing
MBH.LA2	Dry	Yellow	blue	Heavy-duty load-bearing
MBH.HLS1	Humid	Yellow, yellow	green	Load-bearing
MBH.HLS2	Humid	Yellow	green	Heavy-duty load-bearing

Note: MBL refers to low density medium board and MBH refers to high density medium board.

Table XXXI Grades of softboard (BS EN 622–4: 2009)

Grade	Exposure	Colour coding		Purpose / loading
SB	Dry	White, white	blue	General purpose
SB.H	Humid	White, white	green	General purpose
SB.E	Exterior	White, white	brown	General purpose
SB.LS	Dry	Yellow, yellow	blue	Load-bearing (Instantaneous or short-term loading only)
SB.HLS	Humid	Yellow, yellow	green	Load-bearing (Instantaneous or short-term loading only)

Table XXXII Classes of thermally modified timber

Classes	Typical uses
Softwoods	
Class D (212°C)	Garden structures, external cladding, exterior doors, window frames, decking, internal floors and internal decoration
Class S (190°C)	Construction materials, structural components, garden furniture, interior floors, exterior doors and window frames
Hardwoods	
Class D (212°C)	Garden furniture, patio floors, interior floors and interior decoration
Class S (190°C)	Construction materials, mouldings, furniture, interior floors and interior decoration

4 BRICKS AND BLOCKS

4.1 Bricks

The standard work size for UK clay bricks is 215 × 102.5 × 65 mm (coordinating size 225 × 112.5 × 75 mm). However, larger units up to 490 mm in length offer variations in bonding and enhanced horizontal effects. Clay bricks are supplied in a wide variety of face colours, textures (including glazed), frost resistance/active soluble salt content (Table XXXIII) and other properties. Most UK bricks are defined by the National Annex to BS EN 771-1: 2011 as High Density masonry units. The National Annex refers to the standard UK brick size, also to the two grades of Engineering/DPC bricks common within the UK (Table XXXIV). The standard BS EN 771-1: 2011 lists the wide-ranging specifications required for clay

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Table XXXIII Freeze/thaw resistance and active soluble salt content limits for clay bricks (High Density units) (BS EN 771–1: 2011)

Durability designation	Freeze/thaw resistance
F2	Masonry subjected to severe exposure
F1	Masonry exposed to moderate exposure
F0	Masonry subjected to passive exposure
	Active soluble salt content
S2	Sodium/potassium 0.06%. magnesium 0.03%
S1	Sodium/potassium 0.17%. magnesium 0.08%
S0	No requirement

Table XXXIV Properties of clay engineering bricks (High Density [HD] units) (National Annex to BS EN 771–1: 2011)

	Clay engineering bricks	
Performance characteristics	**Class A**	**Class B**
Compressive strength (MPa)	125	75
Water absorption (% by mass) and also when used as DPC units	4.5 (and DPC 1)	7.0 (and DPC 2)
Freeze/thaw resistance category	F2	F2
Active soluble salt content category	S2	S2

Note: For HD DPC bricks water absorption not compressive strength is the defining limitation. DPC 1 refers to damp-proof courses for buildings and DPC 2 for external works.

bricks. Only imported calcium silicate bricks (BS EN 771-2: 2011) are available. The UK standard sizes for concrete bricks are covered by the National Annex to BS EN 771-3: 2011 (Table XXXV). Brick manufacturers usually offer specials from within the British Standard range (BS 4729: 2005).

An extensive range of fired clay blocks of low and high density other than bricks is illustrated in BS EN 771-1: 2011, but not all are readily available from UK suppliers.

4.2 Blocks

The standard BS EN 771-3: 2011 does not limit the sizes of dense and lightweight concrete blocks (masonry units), but it does refer to a fairly restricted range listed in Table XXXVI. In addition the Standard BS 6073-2: 2008 lists work sizes for aggregate coursing units and aircrete blocks (Table XXXVII). Additional sizes for floors and foundations are available, although each manufacturer produces a restricted range.

Table XXXV Standard work sizes for concrete bricks (National Annex to BS EN 771–3: 2011)

Length (mm)	Width (mm)	Height (mm)
215	103	65
290	90	90
190	90	90
190	90	65

Table XXXVI Common work sizes of concrete blocks (BS EN 771–3: 2011)

	Width (mm)									
Length (mm)	**75**	**90**	**100**	**140**	**150**	**190**	**200**	**215**	**225**	**Height (mm)**
390		*	*	*		*	*			190
440	*	*	*	*	*	*	*	*	*	215

Note: Asterisk indicates common size to BS EN 771–3: 2011. Other widths may be available but manufacturers do not normally produce the complete range.

Masonry unit sizes are recorded as length, width and height in that order to BS EN 771-3: 2011. Tolerances on block sizes for concrete and autoclaved aerated concrete blocks are given in Tables XXXVIII and XXXIX respectively.

5 CONCRETE

5.1 Cement

Cements are classified according to their main constituents, such as Portland cement or blast furnace cement. The standard BS EN 197-1: 2011 lists five main types of cement:

Table XXXVII Typical work sizes of aggregate coursing and aircrete blocks (BS 6073–2: 2008)

	Length (mm)	Width (mm)	Height (mm)
Aggregate coursing blocks			
	190	90	65
	190	90	90
	215	100	65
	290	90	90
	440	90	65
	440	100	65
	440	90	140
	440	100	140
Aircrete standard blocks			
	440	50–350	215
	610	50–350	215
	620	50–350	215
Aircrete coursing blocks			
	215	90–150	65
	215	90–150	70

Note: Other heights of aircrete blocks are available for foundations and for thin layer mortar construction.

CEM I Portland cement
CEM II Portland-composite cement
CEM III Blast furnace cement
CEM IV Pozzolanic cement
CEM V Composite cement

Within these five main types a wide range of additional constituents including silica fume, natural or industrial pozzolanas, calcareous or siliceous fly ash and burnt shale may be incorporated. The full range of permitted compositions and strength classes are listed in the standard BS EN 197-1: 2011.

Appropriate properties of aggregates for concrete are listed in the standard BS EN 12620: 2013.

5.2 Concrete

The five methods for the specification of concrete mixes are described in BS 8500-1: 2006 + A1: 2012 and BS EN 206: 2013:

Designated concrete
Designed concrete
Prescribed concrete
Standardised prescribed concrete
Proprietary concrete

Table XXXVIII Limit of tolerance on block sizes (BS EN 771–3: 2011)

Dimensions	Tolerance category			
	D1 (mm)	**D2 (mm)**	**D3 (mm)**	**D4 (mm)**
Length	+3	+1	+1	+1
	–5	–3	–3	–3
Width	+3	+1	+1	+1
	–5	–3	–3	–3
Height	+3	+2	+1.5	+1
	–5	–2	–1.5	–1

Note: BS 6073–2: 2008 states that tolerance categories D3 and D4 are intended for use with thin-layer mortar joint systems. Therefore, most units used within the UK conform to tolerance categories D1 and D2.

Table XXXIX Limit of tolerance on autoclaved aerated concrete block sizes (BS EN 771 4: 2011)

Dimensions	Standard mortar joints (mm)	Thin layer mortar joints TLMA (mm)	Thin layer mortar joints TLMB (mm)
Length	+3 to –5	±3	±1.5
Height	+3 to –5	±2	±1.0
Width	±3	±2	±1.5
Flatness of bed faces	No requirement	No requirement	≤1.0
Plane parallelism of bed faces	No requirement	No requirement	≤1.0

For routine applications designated concrete is usually appropriate. The purchaser correctly specifies the proposed use and the mix designation, and the producer fulfils the normal performance criteria. In designed concrete the purchaser takes more responsibility for the mix by specifying a complete set of performance criteria. For prescribed concrete the purchaser specifies all materials including any admixtures by weight. Standardised prescribed concretes are a set of five standard mixes for routine applications as in housing. Proprietary concrete must fulfil the appropriate performance criteria but the composition is to the producer's choice.

5.3 Reinforced concrete

Reinforced concrete is described in Chapter 6, Structure.

5.4 Concrete components

Paving flags: Concrete paving flags are manufactured to the requirements of BS EN 1339: 2003. The standard does not specify preferred dimensions, except a maximum length of 1m. UK flags, however, are traditionally supplied in the dimensions given in Table XL. Tactile flags are used in the pedestrian pavement adjacent to pedestrian crossings to indicate their presence to people who are visually impaired.

The standard (BS EN 1339: 2003) refers to four classes of flag related to ranges of strength and durability. Class 1 flags are appropriate for light domestic use (gardens/drives), Class 3 flags are suitable for normal public areas, but Class 4 are required for very heavy pedestrian and vehicular use. Class 1 products are not resistant to freeze/thaw effects, but Class 3 flags are resistant to repeated freezing and thawing and the regular use of de-icing salts.

Roofing tiles: Concrete plain roofing tiles may normally be used on pitches down to 30° or 35°. Some concrete interlocking tiles may be used down to a 12.5° or 15° pitch, subject to manufacturer's specification. Concrete slates are manufactured with either deep or shallow profiles to emulate thin or rustic natural slate.

Precast concrete panels: Precast concrete panels, Figure 7.2, may be cast vertically or horizontally, although the latter is more common. Horizontally cast units may be manufactured face up or face down according to the surface finish required. Moulds may be of plywood, plastics or steel and indirect finishes, e.g. bush hammering, can be applied. Appropriate reinforcements and/or facings of stone or brick may be incorporated into the moulds.

6 ALUMINIUM

6.1 General

Wrought aluminium and its alloys are designated by the letters European Norm Wrought Aluminium (EN AW) followed by a unique four digit coding to BS EN 573-1: 2004. The standard BS EN 573-3: 2013 details the chemical composition and form of the products. Table XLI gives examples of the standard construction alloys. Aluminium may also be cast into components. Aluminium is used for a wide range of non-structural products, Figure 7.3. The range of aluminium finishes includes anodizing, texturing, metallic (zinc) and plastic (polyester or PVC) coatings.

Table XL Typical sizes and types of paving flags

Paving flag designation	Nominal size (mm)	Work size (mm)	Thickness (mm)
A	600 × 450	598 × 448	50 or 63
B	600 × 600	598 × 598	50 or 63
C	600 × 750	598 × 748	50 or 63
D	600 × 900	598 × 898	50 or 63
E	450 × 450	448 × 448	50 or 70
F	400 × 400	398 × 398	50 or 65
G	300 × 300	298 × 298	50 or 60

6.2 Aluminium bars and flats

Aluminium bars are made to the dimensional requirements of BS 6722: 1986 (see Tables I and II, Section 2.1). Stock sizes for round section typically range from 3 to 200 mm diameter, for square section from 3 to 180 mm side and for flat sections from 3 to 70 mm × 10 to 250 mm depending upon the manufacturer.

6.3 Aluminium structural sections

Table XLII based on BS 1161: 1977 gives the sizes of standard I, T and channel sections.

Table XLI Aluminium alloys in construction

Code number	Composition	Typical application
EN AW-1080A	99.8% pure	Flashings
EN AW-1050A	99.5% pure	Flashings
EN AW-1200	99% pure	Fully supported sheet roofing, insulating foils
EN AW-3103	Manganese alloy	Profiled roofing and cladding
EN AW-5083SP	Superplastic alloy Magnesium/manganese alloy	Rainscreen cladding
EN AW-6061	Magnesium/silicon/copper alloy	Tubular structural forms
EN AW-6063	Magnesium/silicon alloy	Extruded sections – curtain walling, windows and doors
EN AW-6082	Structural aluminium Magnesium/manganese/silicon alloy	Load-bearing structures

Note: A more comprehensive list is quoted in BS EN 1999–1–1: 2007 + A1:2009.



7.2 *Pre-cast concrete cladding panels: Hilton Hotel, Liverpool. Architect: AHR Architects*

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7.3 *Perforated aluminium ceiling panels: North Satellite Concourse, Hong Kong International Airport. Architect: AHR Architects*

Table XLII Aluminium alloy structural sections (BS 1161: 1977)

Equal angles

	Thickness (mm)	Mass/length (kg/m)
120 × 120	10	6.47
	7	4.68
100 × 100	8	4.31
	6	3.34
80 × 80	6	2.59
	5	2.23
60 × 60	5	1.62
	3.5	1.17
50 × 50	4	1.08
	3	0.84
40 × 40	3	0.65
30 × 30	2.5	0.40

Unequal angles

Nominal size (mm)	Thickness (mm)	Mass/length (kg/m)
140 × 105	11	7.26
	8.5	5.83
120 × 90	10	5.65
	7	4.11
100 × 75	8	3.77
	6	2.94
80 × 60	6	2.26
	5	1.96
60 × 45	5	1.41
	3.5	1.03
50 × 38	4	0.95
	3	0.74

Channels

	Thickness (mm)		
Nominal size (mm)	Web	Flange	Mass/length (kg/m)
240 × 100	9	13	12.5
200 × 80	8	12	9.19
180 × 75	8	11	8.06
160 × 70	7	10	6.58
140 × 60	7	10	5.66
120 × 50	6	9	4.19
100 × 40	6	8	3.20
80 × 35	5	7	2.29
60 × 30	5	6	1.69

Table XLII (continued)

I-sections

	Thickness (mm)		
Nominal size (mm)	Web	Flange	Mass/length (kg/m)
160 × 80	7	11	7.64
140 × 70	7	10	6.33
120 × 60	6	9	4.77
100 × 50	6	8	3.72
80 × 40	5	7	2.54
60 × 30	4	6	1.59

Tees

Nominal size (mm)	Thickness (mm)	Mass/length (kg/m)
90 × 120	10	5.68
75 × 100	8	3.79
60 × 80	6	2.27
45 × 60	5	1.42
38 × 50	4	0.95

7 ROOFING AND CLADDING

7.1 General

The choice of roofing materials is related to a combination of cost, durability and particularly aesthetics. Many roofing materials such as asphalt are available only in neutral colours, but single-layer PVC, for example, is available in a range of colours. Metal roofing systems give visual articulation, and the choice of the particular metal or coated metal determines both the initial and weathered finish. In all cases careful detailing enhances the period to first maintenance.

Sheet metal for roofing and cladding is covered in the standards BS EN 14782: 2006 and BS EN 14783: 2013 for self-supporting and fully supported sheet metal, respectively. The standards list minimum thicknesses for aluminium, steel, stainless steel, zinc and copper, also lead for fully supported systems. However, it is noted that European Union member states may require thicknesses greater than those described. The standard BS 8747: 2007 relates to reinforced bitumen membranes for roofing and traditional mastic asphalt is covered by BS 6925: 1988.

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7.2 Steel

The standard BS EN 508-1: 2014 details typical profiles for self-supporting sheet and tile steel roofing. The minimum thickness for the finished coated steel is 2.4 ± 0.2 mm.

The standard BS EN 505: 2013 gives information on fully supported steel roofing for which the minimum sheet thickness is 0.6 mm. The metallic and organic coatings listed in these standards are described in Section 2.5 Coated Steels.

7.3 Stainless steel

Stainless steel as a sheet roofing material is covered by BS EN 508-3: 2008 for the self-supporting material and by BS EN 502: 2013 for the fully supported product. The standard BS EN 508-3: 2008 gives examples of sheet and tile profiles also organic coatings including polyvinylchloride (plastisol), polyvinylidene fluoride, polyurethane and polyesters. The standard BS EN 502: 2013 lists the equivalent data for fully supported roofing systems.

Table XLIII gives the most commonly used grades of stainless steel sheeting with and without organic coatings. The appropriate grade and finish depends upon the local environment and durability requirements.

7.4 Aluminium

The Code of Practice for aluminium sheet roof and wall covering, CP143 Part 15: 1973, is still current. Sheeting comes to site in coils, and is passed continuously through a machine to form standing seams in-situ. This long strip system removes the necessity to form joints transverse to the standing seams up to a maximum of 7 m. The standard thickness for long strip aluminium roofing is 0.8 mm and the recommended maximum width of 450 mm produces standing seams at 375 mm centres. A minimum fall of 1.5° is recommended. The standard BS EN 507: 2000 gives the specification for fully supported sheet aluminium roofing and the standard factory applied organic coatings including polyesters, acrylics, alkyds, polyurethanes and polyvinylidene fluoride.

Self-supporting aluminium sheet is described in BS EN 508-2: 2008, which gives examples of profiles for sheet and tile units also the standard organic coatings.

7.5 Copper

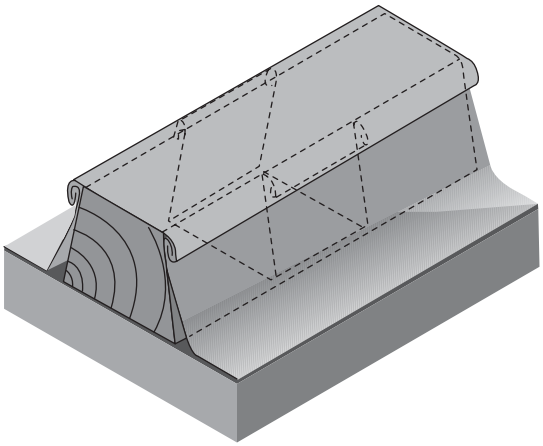
The standard grade of copper for fully supported and self-supported roofing is Cu-DHP (C106) (phosphorus deoxidized non-arsenical copper) to BS EN 1172: 2011. Sheet copper is available in a range of thicknesses from 0.4 to 1.0 mm (up to 3.0 mm for curtain walling) with 0.6 and 0.7 mm the standard thicknesses for roofing. Sheet widths range from 500 to 1000 mm with 600 mm standard for roofing. The standard BS EN 504: 2000 gives the specification for fully supported sheet copper roofing.

The two methods of copper roofing available are traditional, Figure 7.4, and long-strip. Fully annealed copper strip is normally used in traditional roofing as detailed in Table XLIV. For long-strip roofing, 1/8 to 1/4 hard temper copper strip is required to prevent buckling with thermal movement. Typical long strip dimensions are listed in Table XLV. Copper sheet is also used for tiles, Figure 7.5.

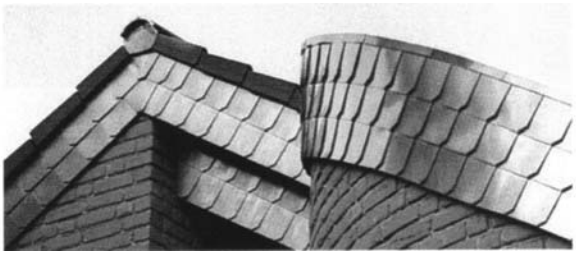
Table XLIII Stainless steel self supported and fully supported sheet

	Steel designation	
Steel grade	**Steel name**	**Steel number**
Ferritic with organic coaling	X6Cr13	1.4000
Ferritic with or without organic coaling	X6Cr17	1.4016
	X6CrMol7–l	1.4113
	X3CrTi17	1.4510
	X2CrMoTi18–2	1.4521
Austenitic with or without organic coating	X5CrNi18–10	1.4301
Austenitic/molybdenum with or without organic coating	X5CrNiMo17–12–2	1.4401

Note: X is carbon content, Cr Chromium, Ni Nickel, Mo Molybdenum and Ti Titanium.



7.4 *Traditional batten roll copper roofing (courtesy of Copper in Architecture)*



7.5 *Copper tiles (courtesy of Aurubis)*

Table XLIV Standard thicknesses and sizes of copper sheet for traditional roofing

Sheet thickness (mm)	Standard width of sheet to form bay (mm)	Bay width with standing seam (mm)	Bay width with batten roll (mm)	Length of each sheet (m)	Mass (kg/m²)
0.60	600	525	500	1.8	5.4
0.70	750	675	650	1.8	6.3

Note: The maximum sheet length is 2.0 m.

The standard BS EN 506: 2008 describes the use of Cu-DHP copper for self-supporting profiled sheet and tile roofing systems.

Prepatinised copper is available if the immediate effect of green colouration is required, alternatively a gold-coloured copper/aluminium/zinc alloy may be used if the copper colour is to be retained externally.

Copper alloys have good antimicrobial properties at room temperature and normal humidity. Alloys high in copper content (e.g. phosphor bronze and brass) can control bacteria such as MRSA and E.*coli* and are therefore beneficial for use in touch surface applications for hospitals and other public locations.

Direct contact between copper and aluminium, steel or zinc should be avoided to prevent bi-metallic corrosion in the presence of moisture. Lead, stainless steel and brass are normally unaffected. Rainwater run off from exposed bitumen and cedar wood can cause corrosion.

7.6 Lead

The sizes of milled lead sheet and strip are specified in BS EN 12588: 2006, and summarised in Table XLVI. The traditional UK lead codes are not referenced in the European Standard; however, the current Code of Practice for fully supported lead sheet roof and wall coverings, BS 6915: 2001, does refer to lead codes in addition to metric thicknesses. Sand-cast lead is manufactured for conservation work. Patination oil can be applied to new lead work to prevent the production of unsightly white lead carbonate staining. Typical lead roof details are shown in Figure 7.6.

Table XLV Recommended widths of copper strip for the long strip system

Width of strip (mm)	400	450	500	600	670
Standing seam centres (mm)	325	375	425	525	595

Note: Using 0.6 or 0.7 mm copper strip at ¼ or ½ hard temper with a fixed zone of 1.5 m within a maximum 10 m length.

Table XLVI Milled lead sheet and strip sizes (BS EN 12588: 2006 and BS 6915: 2001)

Lead code	Thickness (mm)	Average weight (kg/m²) (based on larger thicknesses)	Colour coding
3	1.25 or 1.32	14.97	Green
	1.50 or 1.59	18.03	Yellow
4	1.75 or 1.80	20.41	Blue
5	2.00 or 2.24	25.40	Red
6	2.50 or 2.65	30.06	Black
7	3.00 or 3.15	35.72	White
8	3.50 or 3.55	40.26	Orange

Note: The 1.50 mm (1.59 mm) thickness sheet does not appear in the standard BS 6915: 2001, and has no equivalent Code number. Code 3 lead sheet is not suitable for roofing, cladding and gutters.

Whilst lead is not prone to bi-metallic corrosion in most non-marine building applications, the use of a building paper underlay is appropriate on hardwood roofs (particularly oak) and bitumen painting of the lead for contact with cedar shingles, hardwood cills and new concrete or mortar is advised.

7.7 Zinc

Zinc is covered by BS EN 988: 1997. The standard thicknesses are 0.6, 0.65, 0.7, 0.8 and 1.0 mm (Table XLVII). Preferred lengths are 2.0 and 3.0 m, in a range of widths from 100 to 1000 mm. Pure zinc sheet roofing is no longer used, as it had a lifetime of approximately 40 years in urban conditions (CP 143-5: 1964). However, zinc-copper-titanium alloy is the standard product and may be used directly or coated. Factory induced patina is grey or black, but mineral pigments rolled into the surface and coated with a protective film produce subtle red, blue, green or brown preweathered finishes. Lacquered finishes include green, blue, red, brown, grey and gold. The minimum thickness to BS EN 501: 1994 for fully supported roofing is 0.6 mm. Either traditional or long-strip roofing may be used with titanium zinc. A minimum fall of 3° is recommended. Where bays are longer than 3 m, a fixed zone and sliding clips will be required to accommodate thermal movement.

The standard BS EN 506: 2008 describes the use of zinc-copper-titanium alloy for self-supporting sheet and tile profile roofing systems. Organic coatings including polyvinyl chloride (plastisol), polyvinylidene fluoride, polyesters and acrylic are listed.

Table XLVII Zinc-copper-titanium alloy standard sheet thicknesses (BS EN 988: 1997)

Nominal thickness (mm)	Approximate mass (kg/m²)
0.60	4.3
0.65	4.7
0.70	5.0
0.80	5.8
1.00	7.2

7.8 Titanium

Titanium sheet (0.3–0.4 mm) may be used as roofing or cladding. The 99 per cent pure material used for construction work has a density (4510 kg/m³) intermediate between that of steel and aluminium and a low coefficient of expansion (8.9×10^{-6} °C). The natural oxide film can be thickened by anodising to a range of colours between blue and cream, or a textured finish may be applied.

7.9 Reinforced bitumen membranes for roofing

The standard BS 8747: 2007 is a guide to the selection and specification of reinforced bitumen roofing membranes. It describes the standard types of glass-fibre and polyester based reinforced bitumen roofing membranes, also the high performance polymer-modified bitumen membranes manufactured with atactic polypropylene (APP) or styrene–butadiene–styrene (SBS).

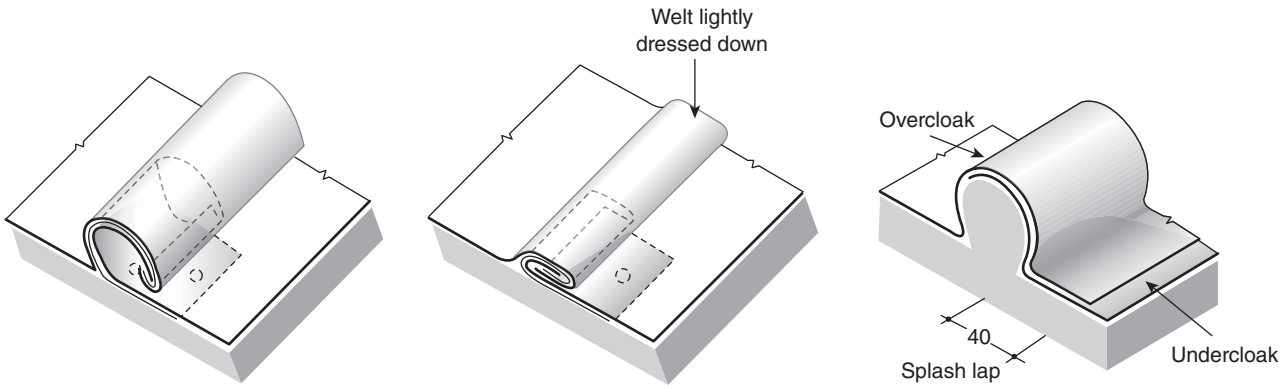
The measurable tensile class S and resistance to puncture class P are categorised in Table XLVIII. The standard describes SNPN combinations appropriate to specified standard constructions.

The Annex to BS 8747: 2007 describes the under slating/tiling sheets and perforated venting layers as listed in Table XLVIII with reference to the superseded standard BS 747: 2000.

Table XLVIII Reinforced bitumen membranes to BS 8747: 2007

Description	Type (former BS 747 designation)	Colour code	Tensile class S	Puncture class P	SNPN classification
Glass fibre – fine granule surface	3B	Red	S1	P1	S1P1
Glass fibre – mineral surface	3E	Red	S1	P1	S1P1
Polyester – fine granule underlay	5U	Blue	S2	P3	S2P3
Polyester – fine granule surface	5B/180	Blue	S4	P4	S4P4
Polyester – fine granule surface	5B/250	Blue	S5	P5	S5P5

Note: The puncture class P is derived from a combination of resistance to impact (subclass D) and resistance to static loading (subclass L).
BS 747: 2000 has been superseded and was withdrawn in 2007, but the former designations are referenced in BS 8747: 2007.
Type 1F membranes are underlays for discontinuous roofs.
Type 3G is not classified to BS 8747 as it is a venting layer and not waterproof.
Type 4A membranes are underlays for mastic asphalt.



7.6 *Traditional lead roofing – hollow roll and welt joins wood-cored, (diagrams taken from Rolled Lead Sheet: The Complete Manual published by the Lead Sheet Association.*

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Table XLIX Mastic asphalt grades (BS 6925: 1988)

Type	Composition
BS 988B	100% bitumen
BS 988T25	75% bitumen, 25% lake asphalt
BS 988T50	50% bitumen, 50% lake asphalt
Specified by manufacturers	Polymer-modified grades

The characteristics of bitumen roofing membranes are described in BS EN 13707: 2013 and BS 8217: 2005 is the current Code of Practice.

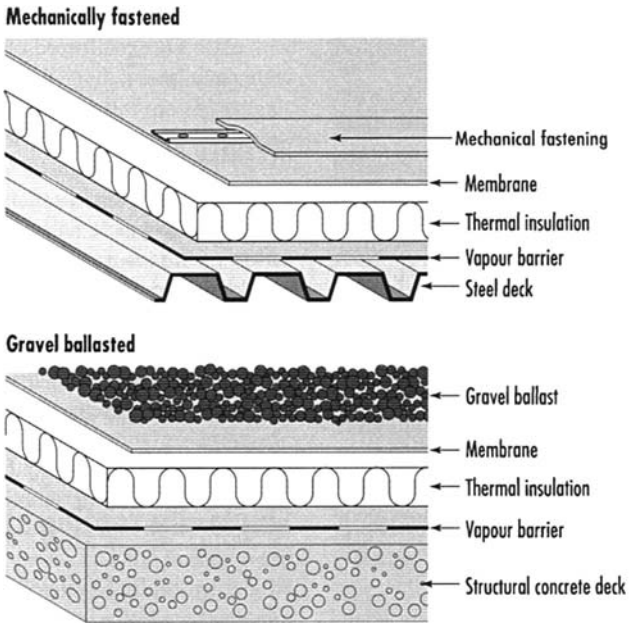
7.10 Mastic asphalt roofing

Mastic asphalt for roofing (also flooring and damp-proofing) is specified in BS 6925: 1988, to the grades listed in Table XLIX. Polymer modified mastic asphalts containing SBS are more durable with enhanced flexibility. BS 8218: 1998 is the current Code of Practice for mastic asphalt roofing.

7.11 Single-ply roofing systems

Single-ply roofing systems are described in the standard BS EN 13956: 2012. They usually consist of a continuous membrane between 1 and 3 mm thick covering any form of flat or pitched roof with limited access. The membrane material is typically a thermoplastic, elastomeric or a modified bitumen system which may be glass-fibre or polyester reinforced. Joints between sheets are either heat or solvent welded or sealed with adhesives. The waterproofing sheet may be fixed to the substructure by mechanical fastening, full or partial adhesive bonding or by ballasting to prevent wind uplift, Figure 7.7. Mechanically fixed sheets require the fastenings to be covered by a further layer of waterproofing material, usually at the joints between sheets. Many membranes are backed with a polyester fleece to smooth out any discontinuities in the substructure and where appropriate to assist adhesive bonding. Certain materials are available in a variety of colours or have mineral finishes.

Within the range of thermoplastic systems PVC, flexible polyolefin (FPO), flexible polypropylene alloy (FPA), vinyl ethylene terpolymer (VET), chlorinated polythene (CPE), chlorosulphonated polyethylene (CSM) and polyisobutylene (PIB) are standard products. While ethylene propylene diene monomer (EPDM) and SBS or APP modified bitumen are the standard elastomeric and bitumen-based products, respectively. The modified bitumen products are usually up to 5 mm in thickness.



7.7 *Typical single-ply roofing system – mechanically fastened and gravel ballasted*

7.12 Tensile fabric structures

The two alternative materials for tensile roof structures are PVC-coated polyester fabric and PTFE-coated woven glass fibre. PVC-coated polyester is available in a variety of colours and has an anticipated lifespan of approximately 10–15 years, although this can be increased by the application of fluoropolymer lacquers to the exposed weathering surface. The more expensive white PTFE-coated glass fibre material is self-cleaning and non-combustible with an anticipated lifespan of 25+ years. A range of standard design canopies and shelters are commercially available as alternatives to bespoke designs.

7.13 Green roofs

Green roofs are defined as either extensive or intensive according to the type of planting and the associated loading. Extensive roofs are not designed for general access, but are planted with low maintenance, drought and frost tolerant species such as sedums, herbs and grasses. Only occasional access will be required for weeding and the filling of any bare patches. Intensive roofs, which support recreational activity with hard and soft landscaping, require depths of soil typically between 200 and 300 mm, and for large trees up to 1500 mm, giving additional structural loading. Intensive green roofs with access require appropriate health and safety edge protection. Biodiverse or wildlife roofs replicate particular species habitats, which may have been lost from the building site and may incorporate areas of gravel, stones or decaying timber as well as traditional planting. A typical green roof will require a multi-layer system, Figure 7.8 to support the planting and to ensure secure waterproofing of the substructure. Green roofs have the advantage of significantly reducing rapid rainwater run-off as a Sustainable Drainage System (SuDS), whilst enhancing air quality and giving improved thermal and acoustic insulation to the roof.

8 GLASS

8.1 General

The selection of glazing for buildings is highly complex due to the wide variety of design requirements that need full consideration. A suitable methodology to ensure appropriate attention to all significant factors is described in the British Standard BS 6262-1: 2005. The additional parts of the standard BS 6262 give more detailed information on the following aspects of glazing for buildings.

BS 6262	Glazing for buildings:
BS 6262-1: 2005	General methodology for the selection of glazing.
BS 6262-2: 2005	Code of practice for energy, light and sound.
BS 6262-3: 2005	Code of practice for fire, security and wind loading.
BS 6262-4: 2005	Code of practice for safety related to human impact.
BS 6262-6: 2005	Code of practice for special applications. (This relates mainly to structural fixings)
BS 6262-7: 2005	Code of practice for the provision of information.

The key design requirements from BS 6262-1: 2005 are listed in Table L together with additional commentary. Types of glass fulfilling the functions are listed in Table LI.

Current Building Regulations with a focus on Dwelling (DER) and Building Emission Rates (BER) for energy conservation make the use of solar control and energy efficient glazing systems virtually mandatory in most new building situations. The Building Regulations Part L1A and Part L2A 2010 (2013 edition) give concurrent notional specifications for new dwellings and new buildings other than dwellings, respectively. The notional criteria for new dwellings (including the Target Fabric Energy Efficiency

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Table L Design requirements for glazing in buildings (BS 6262–1: 2005)

Design requirements	Additional considerations
Natural Lighting	View in and out by day and night. Size and shape of glazing, aesthetic considerations. Appropriate natural and artificial task and amenity lighting levels. Legislative requirements. Glare from sun, sky, reflections/diffraction. Privacy – embossed, etched, sandblasted, and coloured glass; variable transmission glass. Clear white glass.
Thermal considerations	Energy balance of solar gains versus heat losses. Dwelling Emission Rate. Dwelling Fabric Energy Efficiency. Building Emission Rate. Building Regulations – Part L. Double/triple glazing, low emissivity glass, inert gas fill, Window Energy Ratings and Door Set Energy Ratings, U-values. Solar control glass – body tinted/reflective coated, glazing orientation. Active and static shading devices. Intelligent glass. Condensation.
Sound	Acoustic control from inside/outside. Low, middle and high frequency band sounds. Glass thickness, laminated glass of differing thicknesses with inter-layers, double glazing spacing with sound absorbing material, sealed systems.
Safety	Location of glass – impact damage, barriers, manifestation (BS 6262–4: 2005). Toughened glass, heat-strengthened glass, laminated glass, applied plastic films. Radiation protection. Antibacterial glass.
Security	Protection of persons and property. Vandalism, use of firearms and explosives. Laminated glazing resistant to manual attack, one-way observation glass, alarm glass, glass blocks.
Fire	Classification – integrity (E)/insulation (I)/radiation (W). Regulations. Georgian wired glass, toughened, laminated glass. Non-insulating, insulating, partially insulating glass.
Durability	Verify durability of glass or plastics glazing sheet materials.
Wind loading	Determine wind pressure (BS EN 1991-1-4: 2005 + A1: 2010).
Maintenance	Access, ease and cost of replacement, self-cleaning glass.

Note: In addition glass may be used as a structural material. Applications include walkways, stairs and all-glass structures constructed with laminated toughened glass joined with metal fixings or clear high-modulus structural adhesives.

(TFEE) rate) approximate to the Code for Sustainable Homes Code Level 3, but there is no direct relationship. For replacement windows in existing dwellings, a Window Energy Rating (WER) at band C is the norm, but many manufacturers are targeting A+, A and B rated units. In addition, health and safety legislation and regulation requires the use of safety glasses in many locations.

9 CERAMIC MATERIALS

9.1 General

The wide selection of ceramic building products arises from the diverse range of natural and blended clays. Clay bricks are described in Section 4.1.

9.2 Roof tiles

Ceramic roof tiles are manufactured from finely screened clay, to produce the traditional red, brown or buff finish, or sanded to increase the product range including brindles and blue. Plain clay tiles, including fishtail, club, arrowhead and beavertail features are normally hung to a minimum pitch of 30° or 35°. Alternatives include interlocking plain tiles, pantiles and Roman tiles with plain, sanded or glazed finish, suitable for lower pitches to individual manufacturers' specification, Figure 7.9. Specific flat clay interlocking tiles are compatible with photovoltaic tiles of the same profile. Standard accessories include hip, valley, verge and ridge tiles also vents and finials.

The types, tolerances and physical properties of clay roofing tiles are defined in BS EN 1304: 2013. The current Code of Practice for slating and tiling is BS 5534: 2014.

9.3 Floor and wall tiles

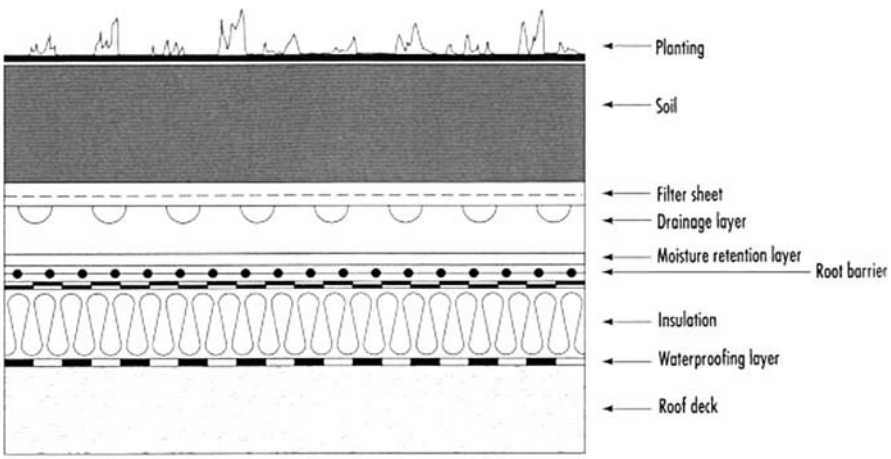
Tiles for floors and walls, manufactured by dry-pressing or extrusion, are classified in BS EN 14411: 2012. The standard refers to both glazed and unglazed tiles. Key physical properties include water absorption, breaking strength, durability and abrasion resistance. The Codes of Practice for wall and floor tiling under various conditions are the Parts 1–5 of the British Standard BS 5385.

Floor tiles, Figure 7.10, are manufactured from a range of clays, typically fired to high temperatures (e.g. 1130°C) to ensure sufficient vitrification to give a highly durable and water-resistant product. Water absorption of Group 1 tiles to BS EN 14411: 2012 is less than 3 per cent. Group 2 tiles have a water absorption range between 3 per cent and 10 per cent, and for Group 3 tiles the range is over 10 per cent. Where high slip resistance is required a studded profile or carborundum grit may be incorporated into the surface. Floor tiles are graded Class 0 (least) to Class 5 (greatest) according to their resistance to abrasion. Wide ranges of stock sizes are produced by individual manufacturers.

Wall tiles are generally manufactured from earthenware clay to which talc or limestone has been added to ensure a white product when fired. Glaze may be added before a single firing or after an initial biscuit stage before a second firing. Adhesives for tiles are classified in BS EN 12004: 2007 + A1: 2012 and grouts in BS EN 13888: 2009. Wide ranges of square and rectangular sizes are currently available.

9.4 Ceramic components

Sanitary ware is manufactured from vitreous china which limits water penetration through any cracks or damage to the glaze to a maximum of 0.5 per cent. For large units such as WCs and basins, a controlled drying out period of the moist clay is required before firing to prevent cracking. Glaze containing metallic oxides for colouration is applied to all visually exposed areas before firing.



7.8 *Typical green roof system*

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Table LI Types of glass and glazing

It should be noted that glass fulfils many functions concurrently, and the following table should only be used as general guidance on specific key glazing functions.

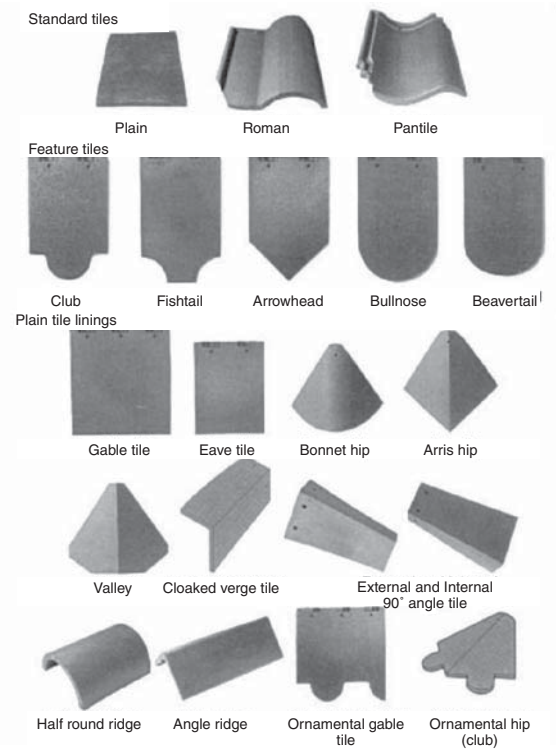
Function / Type	Description
LIGHTING AND VISUAL LINK	
Float glass	Standard annealed glass product (Type A breakage with sharp edges) (Typical maximum size 9000 × 3200 mm - larger units subject to transportation)
White glass	Reduced level of iron oxide impurities giving high light transmission, virtually colourless (Typical maximum size 6000 × 3210 mm)
Privacy	
Embossed / texture	Range of decorative patterns with differing levels of privacy (obscuration factors) (Typical maximum sizes 2160 × 1650 mm and 2140 × 1320 mm)
Screen printed	White or coloured ceramic frit printed and fused onto clear or tinted float glass (Typical maximum size 2800 × 1400 mm)
Etched/sand blasted	Range of acid etched or sand blasted designs on clear or tinted glass Bespoke designs (Typical maximum size 3210 × 2400 mm)
Translucent finish	Diffusing frosted standard or white float glass (Typical maximum size 3210 × 2400 mm)
Electro-optic glass	Changes by electrical switching from transparent to translucent (liquid crystal film interlayer)
Coloured glass	Through coloured glass, bevels and laminated plastic films Standard and bespoke designs
THERMAL CONSIDERATIONS	
Solar Control	
Coated glass	Off-line metal or metal oxide sputter coatings (neutral, silver, blue, green, grey) (maximum control) On-line pyrolytic coating (clear, neutral, silver, grey, bronze, blue/green) (medium control) (Typical maximum sizes 6000 × 3210 mm and 5180 × 3300 mm)
Body-tinted glass	Body-tinted glass (green, bronze, blue, grey) (lower control) (Typical maximum sizes 6000 × 3210 mm and 5180 × 3300 mm)
Laminated glass	Tinted plastic interlayers
Blinds	Insulating glass units with integral blinds operated by hand or mechanical control
Thermal Insulation	
Multiple glazing	Double/triple glazing systems with inert gas fill (90% argon – standard) (Typical maximum size 6000 × 3210 mm)
Low emissivity glass	Soft off-line ultra-low emissivity coating (ε_n 0.04) Pyrolytic low emissivity hard coating on clear and tinted glass (ε_n 0.15)
SOUND	
Noise control	Laminated glass with 0.8 mm PVB (polyvinyl butyral) interlayer Sealed units with differing thicknesses of glass or large spacing and acoustic insulation around perimeter
SAFETY	
Toughened	Five times stronger than annealed glass – safety glass (Type C breakage into relatively harmless granules) (Typical maximum sizes 4200 × 2000 mm and 4500 × 2440 mm)
Heat soaked toughened glass	Reduces the risk of spontaneous breakage of toughened glass due to nickel sulphide inclusions
Heat-strengthened	Half the strength of toughened glass and breaks into pieces like annealed glass Not a safety glass (Often used in laminated glass.) (Type A breakage with sharp edges)
Laminated	Laminated glass gives protection from injury in case of breakage PVB interlayer for flat glass – resin interlayer for curved laminates (Type B breakage – cracks but the fragments hold together)
Plastic film	A range of thin plastic films to change the optical and/or thermal properties of glass Thick structural plastic interlayer – 1.52 or 2.28 mm (Appropriate plastics film coverage to annealed glass can give a Type B breakage as in laminated glass)
SECURITY	
Laminated	Accident/vandalism/resistant to manual attack/bullet or explosion resistant depending upon number and thickness of glass laminates (PVB layers 0.4 or 0.8 mm) (Type B breakage – cracks but the fragments hold together)
One-way vision	Requires low level of lighting on the observer's side (7:1 lighting ratio required)
FIRE PROTECTION	**E = Integrity, I = Insulation, W = Radiation**
Non-insulating wired glass	Wired glass – polished or cast giving 30 or 60 min integrity only (E30 to E60) (Up to 120 min in specialist steel frames) (Type B breakage – cracks but the fragments hold together) Heavier grade of wire to meet BS 6206: 1981 impact test (Typical maximum sizes 3300 × 1980 (polished), 3353 × 1829 (cast))
Integrity	Restricts flame and hot gases only. (E30) – (E60) E120 in specialist steel frames
Integrity and insulation	Laminated with interlayers. 30, 60, 90, 120, 180 min insulation (in appropriate frame system) (EI 30, EI 60 single glazing and up to EI 180 in double glazing units) (Intumescent or gel interlayers)
Integrity with some radiation protection	Laminated with interlayers Reduced heat radiation EW 30 to EW 60 giving 30 or 60 minutes integrity with some radiation protection
MAINTENANCE	
Self-cleaning	Hydrophilic and photocatalytic on-line coating spreads water and oxidises dirt on the surface Clear and blue available
SPECIAL APPLICATIONS	
Spandrel glass	Range of colours and screen print designs Annealed, toughened or laminated
Curved glass	CIP (cast in place) if required laminated Also double glazing units
Mirror glass	Mirror (Typical maximum sizes 3210 × 2000 mm)
Anti-reflective glass	Coated on both faces. Appropriate for shop fronts etc.
Radiation protection	X-ray and gamma ray protection Lead rich glass – amber colour Lead and barium glass – neutral colour
GLASS SYSTEMS	
	Double and triple glazed systems. Fixings to BS 6262–6: 2005 – bolts, sealant, fins or tension wires High efficiency 90% argon fill double glazing units up to U = 1.1 W/m²K Triple glazing units up to U = 0.8 W/m²K, or U = 0.5 W/m²K with two low-e coatings and two argon fills Maximum efficiency with krypton fill and warm edge spacer systems

Solar factor: The fraction of the incident solar radiation directly transmitted by the glass, including heat absorbed by the glass and re-emitted to the interior.
Shading coefficient: The ratio of the solar factor of a glass relative to that of 3 mm clear float glass.
Light reflectance: The fraction of the incident light that is reflected by the glass.
U-value: The measure of heat loss through the component or unit, measured in W/m²K.
Weighted noise reduction: A single figure rating for the sound insulation of building elements.

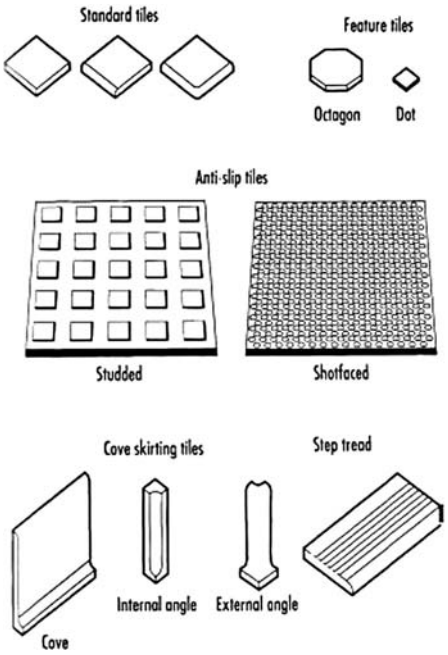
Combinations of functions e.g. self-cleaning and patterned glass are available.
The descriptions of breakages are in accordance with BS EN 12600: 2002.
Critical locations for safety glass are illustrated in BS 6262–4: 2005.
Where there is a risk of human impact on glass in buildings, its manifestation is required in the form of lines, patterns or logos between 850 and 1000 mm also between 1400 and 1600 mm above floor level (BS 6262–4: 2005).
Maximum sheet sizes are not necessarily safe sizes.

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7.9 *Standard and feature roof tiles*



7.10 *Floor tiles*

The quality of vitreous china sanitary appliances is categorised in BS 3402: 1969. The specifications for vitrified clay pipes, typically manufactured from salt glazed earthenware, are Parts 1–7 of BS EN 295.

9.5 Terracotta

The russet colour of terracotta is associated with the presence of iron oxide within the clay. Terracotta is used for traditional features, particularly decorative wall blocks, ridge tiles and roofing finials. In addition it is manufactured into durable rainscreen cladding units for fixing into proprietary façade systems. Faience, which is glazed terracotta, is a highly durable material, but it can be chipped on impact.

10 STONE AND CAST STONE

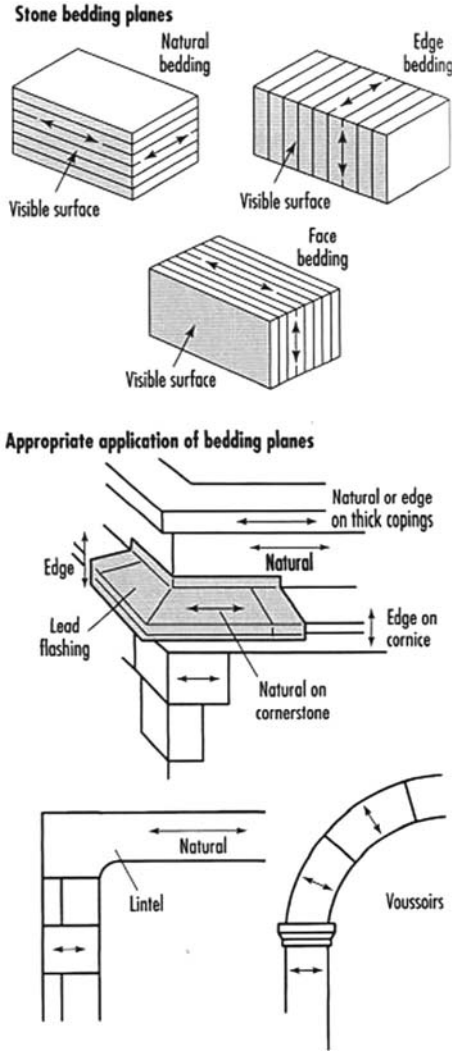
10.1 General

Natural stone may be classified as igneous (e.g. granite), metamorphic (e.g. slate, marble and quartzite) or sedimentary (e.g. sandstone and limestone). Cast stone (BS EN 771–5: 2011) is often manufactured to emulate the natural materials. Igneous stones, such as granite and basalt, are the most durable materials, whereas the softer sandstones and limestones are more workable for shaping to the required form, particularly when directly extracted from the quarry. Low grade slate delaminates and marble can be affected by acid environments. Sedimentary stone should be laid correctly according to the natural bedding planes, Figure 7.11, and may be tooled to a variety of finishes, Figure 7.12.

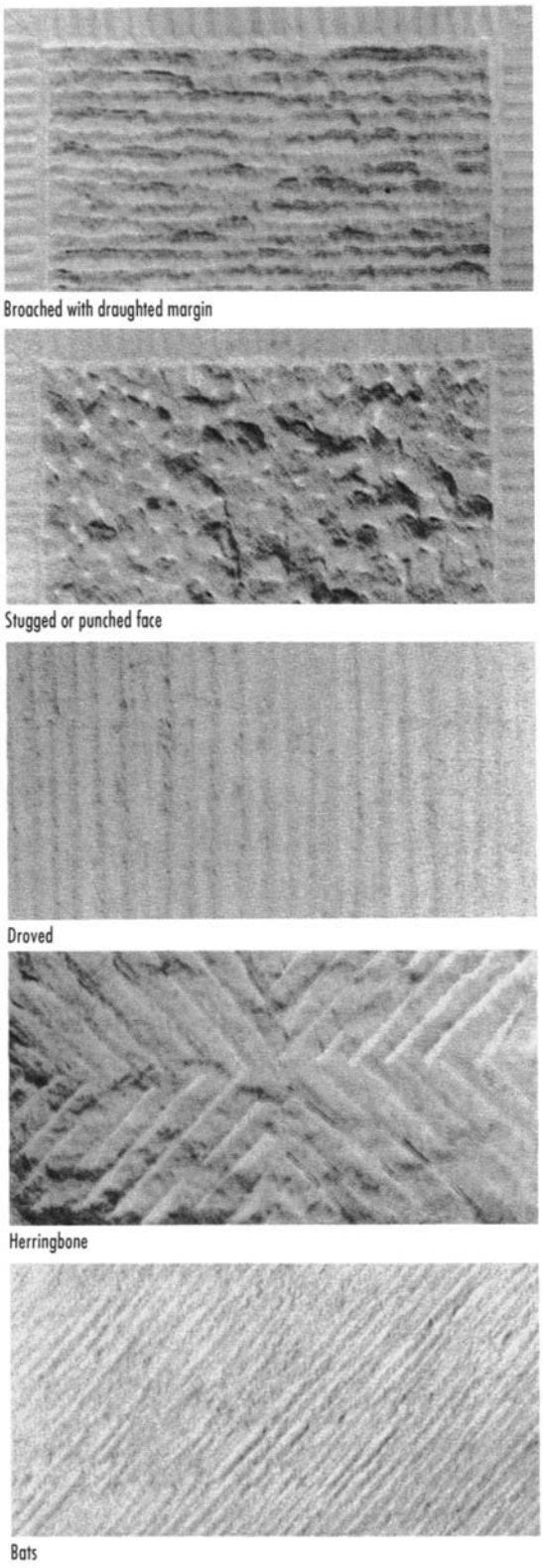
Thin section natural stone (6 mm) may be bonded to lightweight backing materials as an alternative to traditional heavyweight cladding attached with durable fixings, Figure 7.13. The detailed classification of stones and stone-working terminology is listed in BS EN 12670: 2002. The Code of Practice for the design and installation of natural stone cladding and lining is BS 8298 Parts 1–4: 2010. The technical specifications for stone masonry units and slabs for cladding are BS EN 771 Part 6: 2011 and BS EN 1469: 2004 (pr EN 1469: 2012) respectively. The specification for cast stone is BS 1217: 2008. Traditional stone walling is illustrated in Figure 7.14.

10.2 Granite

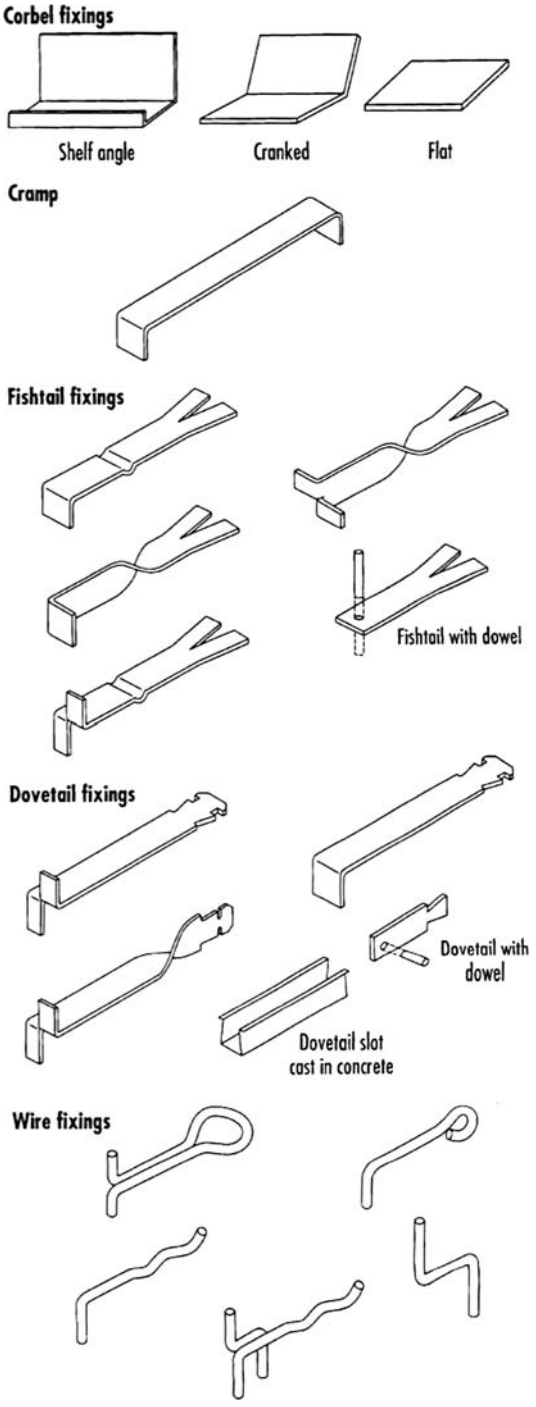
Most granites are hard and dense and are therefore highly durable building materials, impermeable to water and resistant to impact damage. Colours from within the UK range from red through pink and grey to virtually black. Imported colours also include blue,



7.11 *Natural stone bedding planes*



7.12 *Tooled stone finishes*



7.13 *Typical fixings for stone cladding*

green, yellow and brown. The range of finishes include flamed, picked, fine tooled, honed and polished. For maximum colour and crystalline sparkle a highly polished finish is required. The high cost material is frequently used as a cladding (40 mm externally, 20 mm internally) or cast directly onto concrete structural units.

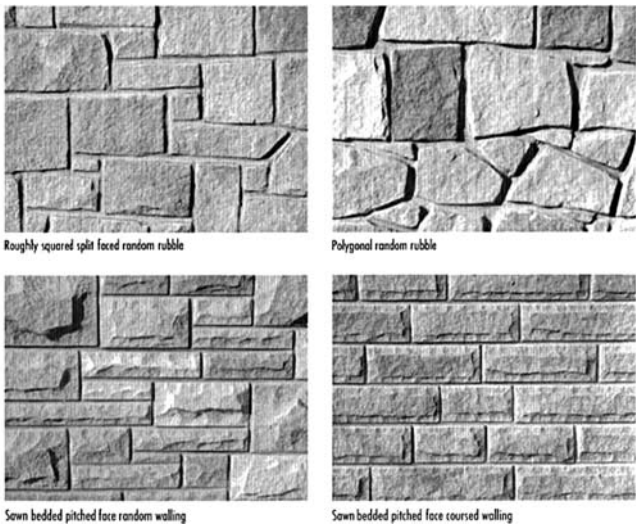
10.3 Slate

Roofing slates range in thickness between 4 mm and 10 mm according to their origin. Roofing slates are traditionally riven, although a range of textured to polished finishes are optional for larger components such as flooring, sills and cladding. Colours from within the UK include blue, blue/grey, silver/grey, green and plum red. Slates are imported from Spain, China, Canada, France, Ireland, Brazil and India. The minimum pitch for slate roofing under sheltered conditions is 20°, or 22.5° in exposed situations, and fixings must be copper or aluminium. Recycled slates are generally available for conservation work.

10.4 Marble

Marble is metamorphosed limestone in which the calcium carbonate has been recrystallised forming the characteristic veined patterns. Pure calcite is white, but colours arise from the impurities in the original limestone. The range of colours available within Europe includes red, pink, violet, brown, green, beige, cream, grey and black. Marble is used for external and internal cladding, flooring and tiling.

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7.14 *Traditional stone walling*

10.5 Quartzite

Quartzite is metamorphosed sandstone which, as a hardwearing material, is frequently used for flooring. Most quartzite is imported from Norway, Italy, Brazil and Ireland where it is available in white, grey, grey-green, blue-grey, yellow and ochre colours.

10.6 Sandstone

Sandstone is formed by the natural cementing together of sand particles by calcium carbonate, silica, iron oxide or dolomite, giving calcareous, siliceous, ferruginous or dolomitic sandstones respectively. Sandstones may be coarse or fine in texture and range in colour from white, buff and grey through to brown and red. They are generally frost resistant. Finishes include sawn, split-faced and various tooled surfaces. Apart from UK supplies, sandstones are imported from Spain and Italy. Sandstone cladding is normally 75–100 mm thick, and must be fixed with non-ferrous cramps and corbels.

10.7 Limestone

Limestones consist mainly of calcium carbonate arising from recrystallised calcite or accumulations of fossilised shells. Oölitic limestones are formed by the crystallisation of concentric layers of calcium carbonate, producing spheroidal grains or oöliths. English limestones are off-white, cream, grey and blue, but additional colours are imported from France, Ireland and Portugal. Externally limestones must not be mixed with or located above sandstones as this may cause rapid deterioration of the sandstone.

10.8 Cast stone

The appearance of natural stones, such as Bath, Cotswold, Portland and York, can be recreated from concrete manufactured with appropriate stone dust and cement. Either a dry or wet casting system is used. Where standard steel reinforcement is incorporated it requires 40 mm cover from visual faces unless galvanised. Corrosion-resistant non-ferrous materials require a minimum 10 mm cover. Many architectural components such as classical columns and balustrades are standard items, but custom-made products can be cast to designers' specifications.

10.9 Gabions

Gabions are wire cages filled with crushed stone, Figure 7.15. The cages are usually constructed from heavy gauge woven or welded steel mesh which may be coated for protection or in stainless steel. Most sizes are based on the metre module. The standard use is for earth-retaining civil engineering applications.



7.15 *Natural stone filled gabions: Small Animals Hospital, Glasgow. Architect: Archial (photograph: Andrew Lee)*

11 PLASTICS

11.1 General

The plastics used in the construction industry are generally low-density non-load-bearing materials. Unlike metals, they are not subject to corrosion, but they may be degraded by the action of direct sunlight, with a corresponding reduction in mechanical strength. Many plastics are flammable unless treated; the majority emit noxious fumes in fires. Typical reaction to fire is cited in Table LII. The family of plastics used in construction is shown in Figure 7.16. Table LIII lists their typical uses in building.

PVC (polyvinyl chloride) accounts for 40 per cent of the plastics used within construction, predominantly in pipes, but also in cladding, electrical cable insulation, windows, doors and flooring applications. Foamed plastics for thermal and acoustic insulation are formulated either as open or closed-cell materials, the latter being resistant to the passage of air and water.

Whilst some materials such as rubber and cellulose derivatives are based on natural products, the majority of plastics are produced from petrochemical products.

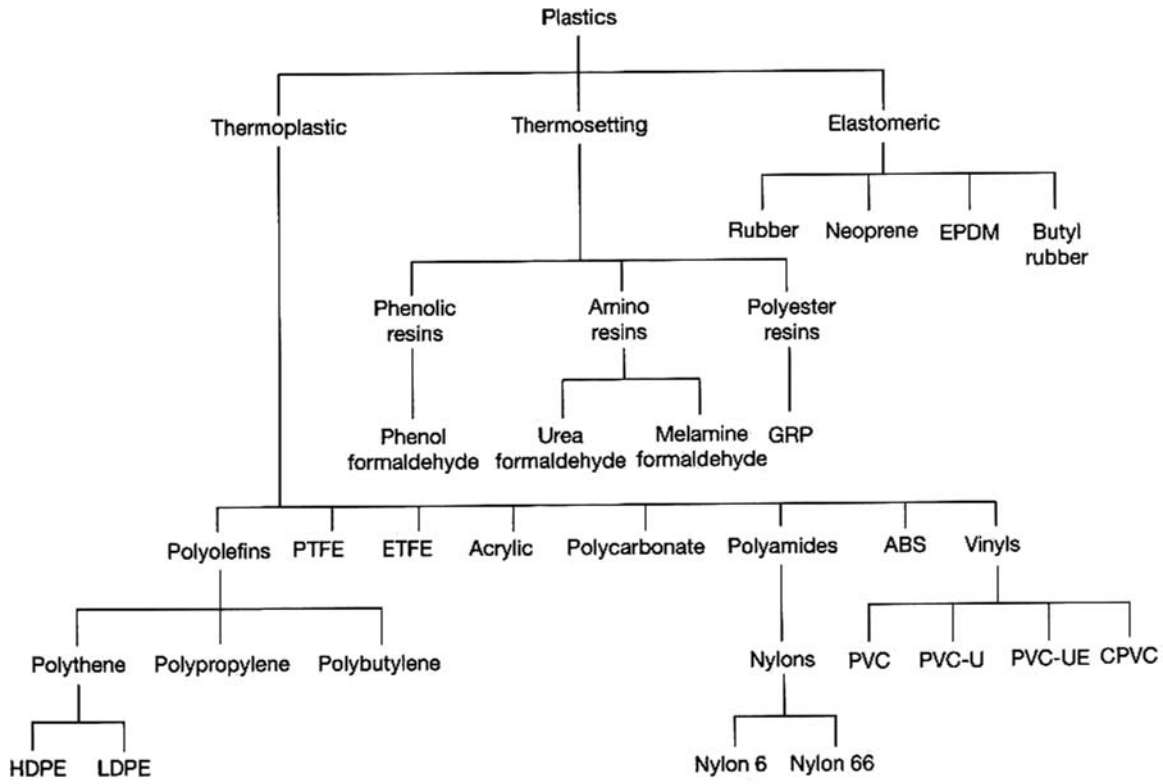
11.2 Thermoplastics

Thermoplastics soften on heating and reset on cooling. The process is reversible and generally can be repeated without significant degradation of the material. Polyethylene (polythene) is available with a range of physical properties as listed in Table LIV. Polyvinyl chloride (PVC), the most widely used plastic material, is available in the unplasticised form (PVC-U) and the plasticised product (PVC). Chlorinated polyvinyl chloride (CPVC) has a higher softening point than the standard PVC material. Extruded cellular unplasticised polyvinyl chloride (PVC-UE) is used in the manufacture of components of uniform section, such as cladding and fascias. The full range and typical construction uses of thermoplastics are listed in Table LIII.

11.3 Thermosetting plastics

Thermosetting plastics have a three-dimensional cross-linked molecular structure. This prevents the material melting when

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7.16 *Plastics used in construction*

heated. Thermoset components are usually produced from partially polymerised powder, or by mixing two components, such as a resin and hardener, immediately prior to forming. The cross-linked structure of thermosetting polymers gives rise to good heat-resistant properties. The materials are generally resistant to ignition, but will burn within a fire. Typical uses are listed in Table LIII.

11.4 Elastomers

Elastomers are long-chain polymers in which the natural zigzag molecular chains are free to straighten and relax when stretched and released. The degree of elasticity depends upon the extensibility of the helical molecules and the degree of cross-linking between the adjacent chains. Rubber is based on the natural latex product, whereas neoprene and other copolymers are petrochemical products. Standard elastomers and their typical uses in construction are listed in Table LIII.

Table LII Behaviour of common building plastics in fire

Material	Behaviour in fire
Thermoplastics	
Polyethylene, polypropylene	Melts and burns readily
Polyvinyl chloride	Melts, does not burn easily, but emits smoke, carbon monoxide and hydrogen chloride
PTFE/ETFE	Does not burn, but at high temperatures evolves toxic fumes
Polymethyl methacrylate	Melts and burns rapidly, producing burning droplets
Polystyrene	Melts and burns readily producing black smoke and burning droplets (BS 6203: 2003 – Expanded polystyrene)
ABS copolymer	Burns readily
Polyurethane	The foam burns readily producing highly toxic fumes including cyanides and isocyanates
Thermosetting plastics	
Phenol formaldehyde, melamine formaldehyde, urea formaldehyde	Resistant to ignition, but produces noxious fumes including ammonia
Glass-fibre reinforced polyester (GRP)	Burns producing smoke, but flame-retardant grades are available
Elastomers	
Rubber	Burns readily producing black smoke and sulphur dioxide
Neoprene	Better fire resistance than natural rubber

11.5 Composite plastics

Composite plastics include glass-fibre reinforced polyester which is described in Section 12.2.

Wood plastic composites formed from polyethylene, polypropylene or PVC, blended with natural fibre products including wood chips, hemp or sisal, are durable materials. They have the significant advantage of incorporating recycled materials or waste by-products from other processes. These materials are described in BRE Digest 480: 2004 and relevant characteristics are listed in the publication DD CEN/TS 15534-2: 2007. Wood plastic composites are used for products such as cladding (EN 15534 Part 5: 2014), external decking (EN 15534 Part 4: 2014), fencing and garden furniture, where durability is advantageous.

12 GLASS-FIBRE REINFORCED PLASTICS, CONCRETE (CEMENT) AND GYPSUM

12.1 General

Composites such as the glass-fibre reinforced materials GRP (glass-fibre reinforced polyester), GRC (glass-fibre reinforced cement) and GRG (glass-fibre reinforced gypsum) rely on the advantageous combination of the disparate physical properties associated with the individual component materials.

12.2 Glass-fibre reinforced plastics

The majority of glass-fibre reinforced plastics are manufactured from polyester resin, although other thermosetting resins may be used. For most purposes the glass fibres are in the form of continuous rovings or chopped strand; however, the highest strength products are obtained with aligned fibres or woven glass-fibre fabrics. The proportion of glass fibres ranges from 20 per cent to 80 per cent, depending upon the strength required. Higher strength materials can be achieved using carbon or polyaramid fibres. The traditional laying-up process is used for the manufacture of most components. The mould is coated with release agent and then the gel coat applied, followed by the required thickness of GRP, which may incorporate reinforcements and fixing devices.

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Table LIII Typical uses of plastics in construction

Material	Examples of plastics in construction
Thermoplastics	
Polyethylene	
Low density (LD)	DPC, DPM, vapour checks, roof sarking
High density (HD)	Cold water tanks, cold water plumbing
Cross-linked (PEX)	Hot and cold water plumbing
Polypropylene (PP) (BS EN ISO 1873–1: 1995)	Pipework and fittings, cold water plumbing, drainage systems, water tanks, WC cisterns, DPCs, fibres in fibre-reinforced concrete
Polybutylene (PB) (BS EN ISO 8986–1: 2009)	Hot and cold water pipework and fittings
Polyvinyl chloride	
Unplasticised (PVC-U)	Rainwater goods, drainage systems, cold water, underground services, window and door frames, conservatories, garage doors, translucent roofing sheets, cold water tanks
Extruded unplasticised (PVC-UE) (BS 7619: 2010)	Claddings, barge boards, soffits, fascias, window boards
Plasticised (PVC)	Tile and sheet floor coverings, single-ply roofing, cable insulation, electrical trunking systems, sarking, tensile membrane structures, glazing to flexible doors, door seals, handrail coatings, vinyl-film finishes to timber products
Chlorinated (CPVC)	Hot and cold water systems
ETFE (BS EN ISO 12086–1: 2006)	Inflated systems for translucent wall and roof membranes
PTFE (BS EN ISO 12086–1: 2006)	Sealing tape for plumbing, tensile membrane structures, low-friction movement joints
Polymethyl methacrylate (BS EN ISO 8257–1: 2006)	Baths, shower trays, kitchen sinks, glazing, roof lights, luminaires
Polycarbonate (BS EN ISO 7391–1: 2006)	Vandal-resistant glazing, spa baths, kitchen sinks
Polystyrene	Bath and shower panels, decorative expanded polystyrene tiles
ABS copolymer	Pipes and fittings, rainwater goods, drainage systems, shower trays
Nylons	Electrical conduit and trunking, low-friction components – hinges, brush strips for sealing doors and windows, carpet tiles and carpets, shower curtains
Thermosetting plastics	
Phenol formaldehyde	Decorative laminates
Melamine formaldehyde	Laminates for working surfaces and doors, moulded electrical components, WC seats
Urea formaldehyde	Decorative laminates
Glass-fibre reinforced polyester (GRP)	Cladding and roofing panels, simulated cast iron rainwater goods, cold water tanks, spa baths, garage doors, decorative tiles and panels
Elastomers	
Rubber	Flooring, door seals, anti-vibration bearings
Neoprene	Glazing seals, gaskets
EPDM	Glazing seals, gaskets, single-ply roofing systems
Butyl rubber	Sheet liners to water features and land-fill sites
Nitrile rubber	Tile and sheet flooring

Table LIV Grades of polyethylene

Grades of polyethylene		Density (kg/m^3)
LLDPE	Linear low-density polyethylene	900–939
VLDPE	Very low-density polyethylene	880–915
LDPE	Low-density polyethylene	916–925
MDPE	Medium-density polyethylene	926–940
HDPE	High-density polyethylene	941–970
HMWPE	High molecular weight polyethylene	947–950
UHMWPE	Ultra-high molecular weight polyethylene	930–935
PEX	Cross-linked polyethylene	926–970

12.3 Glass-fibre reinforced concrete (cement)

Glass-fibre reinforced concrete is produced from a mixture of alkali-resistant glass fibres, Portland cement, sand and water. Typically 5 per cent by weight of 25–40 mm glass fibres are used within the cement matrix. Most GRC units are manufactured by spraying the cement slurry to the required thickness within an appropriate mould, although extrusion and injection moulding techniques are also possible for small components. GRC is a durable material with high impact strength and low permeability to moisture. It is frequently used for lightweight cladding and soffit panels. Guidance on factory quality control is given in BS EN 1169: 1999.

12.4 Glass-fibre reinforced gypsum

Glass-fibre reinforced gypsum with typically 5 per cent of standard E-glass fibres, has enhanced impact strength and fire resistance compared to standard gypsum plaster boards. Standard GRG boards are available in a range of thicknesses between 5 mm and 15 mm. The material is easily worked and can be curved on site. GRG boards offer good fire protection to steelwork, when up to 120 minutes' fire protection can be achieved using a double layer of 30 mm boards with staggered joints and appropriate fixings.

13 PLASTER AND BOARD MATERIALS

13.1 General

The majority of plaster types used within construction are based on retarded hemi-hydrate gypsum. This is manufactured by heating rock gypsum to between 130°C and 170°C. Keratin is the standard retarding agent which is added to adjust the setting time to between 1.5 and 2 hours. Other additives and admixtures include fillers, fibres, lime, lightweight aggregates, pigments and plasticisers.

13.2 Gypsum plaster

Undercoat and one-coat plasters are blended with anhydrous gypsum, limestone, clay and sand to produce the required water-retention properties and setting time. Lime is incorporated in finish-coat plaster to accelerate the set. Lightweight aggregates are commonly expanded perlite and exfoliated vermiculite. On smooth surfaces or low suction backgrounds an initial bonding coat is required. Typical applications for walls are 11 mm for undercoats with a finish coat of 2 mm or a single 13 mm coat.

The types of gypsum binders and plasters are categorised in BS EN 13279-1: 2008, Table LV.

13.3 Plasterboard

Plasterboard consists of a gypsum core bonded to strong paper liners. The finish surface may be either tapered or square edged. A plaster skim is usually applied as a finish. Standard board sizes are 900 mm and 1200 mm wide and 9.5, 12.5, 15 or 19 mm thick. Nail fixings should be driven straight in leaving a shallow depression.

Table LV Types of gypsum binders and plasters (BS EN 13279–1: 2008)

Notation	Designation
A	Gypsum binder for further processing
A1	Gypsum binder for direct use
A2	Gypsum binder for direct use on site
A3	Gypsum binder for further processing
B	Gypsum plaster
B1	Gypsum building plaster
B2	Gypsum-based building plaster (minimum 50% gypsum)
B3	Gypsum-lime building plaster (>5% lime)
B4	Lightweight gypsum building plaster (inorganic or organic aggregates)
B5	Lightweight gypsum-based building plaster
B6	Lightweight gypsum-lime building plaster
B7	Enhanced surface hardness gypsum plaster
C	Gypsum plaster for special purposes
C1	Gypsum plaster for fibrous reinforcement
C2	Gypsum mortar
C3	Acoustic plaster
C4	Thermal insulation plaster
C5	Fire protection plaster
C6	Thin-coat plaster, finishing product
C7	Finishing product

Table LVI Types of plasterboard (BS EN 520: 2004 + A1: 2009)

Type	Designation
A	Gypsum plasterboard with a face suitable for a gypsum finish coat or decoration
H	Gypsum plasterboard with a reduced water absorption rate
E	Gypsum sheathing board for external walls but not permanently exposed to weather conditions
F	Gypsum plasterboard with improved core adhesion at high temperatures
P	Gypsum baseboard to receive gypsum plaster
D	Gypsum plasterboard with controlled density
R	Gypsum plasterboard with enhanced strength
I	Gypsum plasterboard with enhanced surface hardness

Types of plasterboard are listed in BS EN 520: 2004 + A1: 2009, Table LVI. These include a range of products with a high density core for sound insulation, enhanced moisture resistance, increased fire protection and greater impact resistance.

The types of natural fibre reinforced gypsum boards are listed in BS EN 15283: 2008 + A1: 2009, Table LVII.

Composite thermal/acoustic plasterboard panels are categorised in BS EN 13950: 2014 and prefabricated cellular paperboard core panels are defined in BS EN 13915: 2007.

13.4 Accessories for plastering

Angle and stop beads are manufactured from galvanised or stainless steel and aluminium as perforated strip or expanded metal. Beads for internal plastering are described in BS EN 13658-1: 2005. Angle beads for plasterboard are defined in BS EN 14353: 2007 + A1: 2010. Self-adhesive 50 mm or 100 mm glass fibre tape is normally used across joints between plasterboards and in standard plastering.

13.5 Special plasters

Special plasters include renovating plaster for use following the successful installation of damp-proofing and X-ray plaster containing barium sulphate for use in medical environments. Fibrous plaster (BS EN 13815: 2006 and BS EN 15319: 2007) is used for casting ornate plasterwork. Projection plaster is sprayed onto the background as a ribbon from a mechanical plastering machine; it then coalesces for trowelling to a smooth finish.

13.6 Calcium silicate boards

Calcium silicate boards are manufactured from silica with lime and/or cement, usually incorporating additional fillers and fibres to produce the required density. Calcium silicate boards are durable and non-combustible with good chemical and impact resistance. Standard thicknesses are 6, 9 and 12 mm, although thicknesses

Table LVII Types of fibre-reinforced gypsum boards (BS EN 15283: 2008 + A1: 2009)

Type	Designation
GM	Gypsum board with mat reinforcement
GM-H1, GM-H2	Gypsum board with mat reinforcement and reduced water absorption rate
GM-I	Gypsum board with mat reinforcement and enhanced surface hardness
GM-R	Gypsum board with mat reinforcement and enhanced strength
GM-F	Gypsum board with mat reinforcement and improved core cohesion at high temperatures
GF	Gypsum fibre board
GF-H	Gypsum fibre board with reduced water absorption rate
GF-W1, GF-W2	Gypsum fibre board with reduced surface water absorption rate
GF-D	Gypsum fibre board with enhanced density
GF-I	Gypsum fibre board with enhanced surface hardness
GF-R1, GF-R2	Gypsum fibre board with enhanced strength

up to 100 mm incorporating vermiculite are manufactured for fire protection lightweight boards. Appropriate products achieve 240 minutes' fire resistance.

14 INSULATION MATERIALS

14.1 General

Thermal and sound insulating materials may be categorised variously according to their use in construction, physical forms or material of origin. Generally the key forms of materials are:

Structural insulation materials
Rigid and semi-rigid sheets and slabs
Loose fill, blankets, rolls and applied finishes
Multi-layer thermo-reflective products

Table LVIII gives typical thermal conductivity values for a range of building materials.

14.2 Inorganic insulation materials

Foamed concrete: Foamed concrete with an air content of 30–80 per cent is fire and frost-resistant. It does however, exhibit a higher drying shrinkage than dense concrete. It is used for insulation under floors and on flat roofs where it can be laid to an appropriate fall.

Lightweight aggregate concrete: Lightweight concrete materials offer a wide range of insulating and load-bearing properties. Typical aggregates include expanded perlite, exfoliated vermiculite, expanded polystyrene, foamed blast furnace slag, expanded clay and pulverised fuel ash. The range of thermal properties is listed in Table LVIII.

Wood wool slabs: Wood wool slabs manufactured from long wood shavings and Portland or magnesite cement are non-combustible and resistant to rot. They combine load-bearing and insulating properties, and are typically used for roof decking. For longer spans up to 3 m, units with steel edge channel reinforcement are available. Composite slabs of rigid polystyrene or mineral wool between wood wool layers offer high levels of thermal insulation. The standard BS EN 13168: 2012 gives the specification for wood wool (WW) insulation products.

Mineral wool: Mineral wool is manufactured from blended volcanic rock which is melted and spun into fibres. The material is available as loose fill, blanket, batts, semi-rigid or rigid slabs, ceiling and dense boards, according to the degree of compression during manufacture. Mineral wool is non-combustible and resistant to decay. Typical uses include loft, cavity wall and frame insulation. In addition to thermal insulation, mineral wool absorbent quilts are effective at reducing sound transmission within plasterboard separating walls. The standard BS EN 13162: 2012 gives the specification for mineral wool (MW) insulation products.

Glass wool: Glass wool is made by spinning glass into fibres by the Crown process, similar to that for mineral wool fibres. The material is available as loose fill, rolls, semi and rigid batts and compression-resistant slabs. Laminates with plasterboard and PVC

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Table LVIII Typical thermal conductivity values for building materials

Material	Thermal conductivity (W/mK)
Aerogel	0.013
Phenolic foam	0.018–0.031
Polyurethane foam (rigid)	0.019-0.023
Foil-faced foam	0.021
Polyisocyanurate foam	0.023–0.025
Sprayed polyurethane foam	0.024
Extruded polystyrene	0.029
Expanded PVC	0.030
Mineral wool	0.031–0.039
Glass wool	0.031–0.040
Expanded polystyrene	0.033–0.040
Cellulose (recycled paper)	0.035–0.040
Sheep's wool	0.037–0.039
Rigid foamed glass	0.037-0.055
Flax	0.038
Urea formaldehyde foam	0.038
Hemp wool	0.040
Corkboard	0.042
Coconut fibre board	0.045
Perlite board	0.045–0.050
Fibre insulation board	0.050
Straw bales	0.060
Exfoliated vermiculite	0.062
Thatch	0.072
Wood wool slabs	0.077
Medium-density fibreboard (MDF)	0.10
Foamed concrete (low density)	0.10
Lightweight to dense concrete	0.10–1.7
Compressed straw slabs	0.10
Softwood	0.13
Orientated strand board (OSB)	0.13
Hardboard	0.13
Particleboard/plywood	0.14
Gypsum plasterboard	0.19
Bituminous roofing sheet	0.19
Cement bonded particleboard	0.23
Unfired clay blocks	0.24
Calcium silicate boards	0.29
GRC – lightweight	0.21–0.5
GRC – standard density	0.5–1.0
Mastic asphalt	0.5
Calcium silicate brickwork	0.67–1.24
Clay brickwork	0.65–1.95
Glass sheet	1.05

Notes: Individual manufacturers' products may differ from these typical figures. Additional data is available in BS 5250: 2011, BS EN 12524: 2000 and BS EN ISO 10456: 2007.

are also manufactured. The standard BS EN 13162: 2012 gives the specification for glass wool insulation products.

Cellular glass: Cellular or foamed glass is manufactured from a mixture of crushed glass and carbon powder. The black material is durable, non-combustible and water resistant due to its closed-cell structure. The material is used for insulation in roof-top car parks and green roofs where high compressive strength is required due to the loading. The standard BS EN 13167: 2012 gives the specification for cellular glass (CG) insulation products.

Exfoliated vermiculite: Exfoliated vermiculite is manufactured by heating the natural micaceous material, causing it to expand to a product with approximately 90 per cent air by volume. The non-combustible material is used as loose fill, sprayed fire protection to exposed structural steelwork and in fire-stop seals. The standards BS EN 14317-1: 2004 and BS EN 14317-2: 2007 give the specification for exfoliated vermiculite (EV) insulation products before and after installation respectively.

Expanded perlite: Expanded perlite is manufactured by heating natural volcanic rock minerals. It is used as loose or bonded in-situ insulation for roofs, ceilings, walls and floors. Additionally it is available as preformed boards. The non-combustible material (EPB) is described in the standard BS EN 13169: 2012. It is also specified in BS EN 14316 Part 1: 2004 and Part 2: 2007 for before and after installation respectively.

14.3 Organic insulation materials

Cork: Cork is harvested from the cork oak on a 9- or 10-year cycle. For the production of insulating boards, the natural cork granules are expanded then formed under heat and pressure into blocks, bonded by the natural resin within the cork. Cork products are unaffected by the application of hot bitumen in flat roofing systems. The standard BS EN 13170: 2012 gives the specification for expanded cork (ICB) insulation products.

Table LIX Standard grades of polystyrene (BS EN 13163: 2012)

Grade (BS 3837)	Type (BS EN 13163)	Description	Typical density (kg/m³)	Thermal conductivity (W/mK)
SD	EPS 70	Standard duty	15	0.038
HD	EPS 100	High duty	20	0.036
EHD	EPS 150	Extra high duty	25	0.035
UHD	EPS 200	Ultra high duty	30	0.034

Note: BS EN 13163: 2012 lists the range of types from EPS 30 to EPS 500.

Wood fibre board: Wood fibre products are manufactured from a slurry of wood fibres which is compressed, causing the fibres to felt together. A bonding agent may be added. The degree of compression dictates the final density and insulating properties of the product. The product is available as roll, batts or semi-rigid slabs and boards. The standard BS EN 13171: 2012 gives the specification for wood fibre (WF) insulation products.

Expanded polystyrene: Expanded polystyrene is a closed-cell product unaffected by water, but readily dissolved by organic solvents. It is combustible producing noxious black fumes. Polystyrene beads may be used as loose fill. Four grades of polystyrene boards are listed in Table LIX. Polystyrene boards must be protected with heat-resisting insulation when hot bitumen is to be applied. Although a closed-cell material, polystyrene boards are good sound absorbers for use within building voids. Grey expanded polystyrene, incorporating graphite, has enhanced thermal insulating properties. The standard BS EN 13163: 2012 gives the specification for expanded polystyrene (EPS) insulation products.

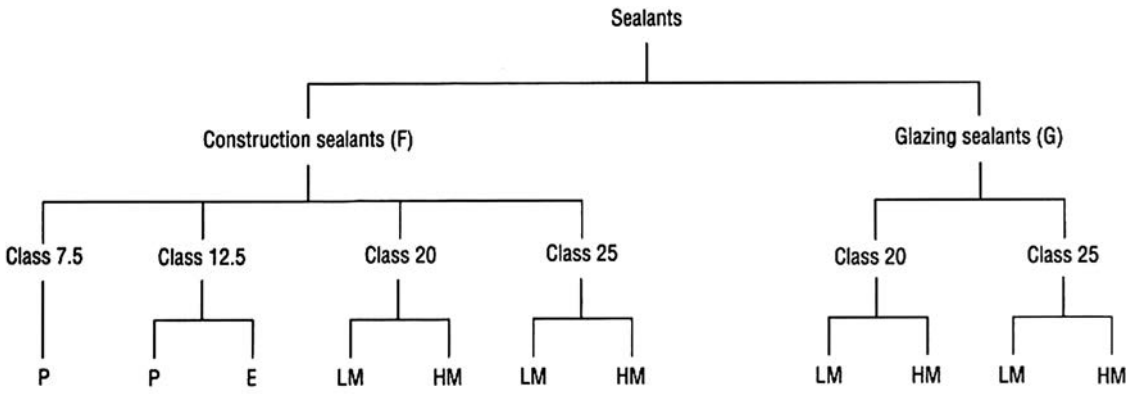
Extruded polystyrene: Extruded polystyrene is normally produced by a vacuum process. It is slightly stronger in compression than expanded polystyrene, but has a lower thermal conductivity. Its closed cell structure, is highly resistant to water absorption, so the material is frequently used below concrete slabs and on inverted roofs, as well as for standard cavity wall and pitched roof insulation. Laminates with flooring grade particleboard and with plasterboard are available. The standard BS EN 13164: 2012 gives the specification for extruded polystyrene (XPS) insulation products.

Polyurethane foam: Rigid polyurethane foam is a closed-cell foam, blown mainly by carbon dioxide but also with pentane. Polyurethane foam is a combustible material producing smoke and noxious fumes, but a flame-resistant material is available. The material is thermally stable and can be used under hot bitumen, and good durability permits its use for inverted roofs. Polyurethane foam is frequently used in composite panels due to its good adherence to profile metal sheeting and other materials. Flexible polyurethane foam is an open-cell material offering good noise absorbing properties. The standards BS EN 13165: 2012 and BS EN 14315: 2013 give the specification for rigid polyurethane foam (PUR) insulation products.

Polyisocyanurate foam: Polyisocyanurate foam used for wall and floor insulation is combustible, but is more resistant to fire than polyurethane foam and can be treated to achieve a fire-resistant rating. The material tends to be rather brittle and friable. The standard BS EN 14315: 2013 gives the specification for in-situ polyisocyanurate foam (PIR).

Phenolic foam: Phenolic foams are used as alternatives to polyurethane and polyisocyanurate foams where a self-extinguishing low smoke emission material is required. Phenolic foams are closed-cell materials which are stable up to 120°C. The standard BS EN 13166: 2012 gives the specification for products of phenolic foam (PF).

Expanded PVC: Expanded PVC is produced as open, partially open and closed-cell foams, which are self-extinguishing in fire. The low density open-cell material has good sound absorbing qualities. Expanded PVC is typically used in sandwich panels and wall linings.



7.17 *Classification of sealants in construction*

Sheep's wool: Sheep's wool, as a renewable resource insulation material, is available in batts ranging from 50 mm to 100 mm thick. It is a hygroscopic material reversibly absorbing and releasing water vapour which has a stabilising effect on the internal temperature of the building. It is normally sprayed with borax as a fire retardant and insect repellent.

Cellulose: Cellulose insulation is manufactured from shredded waste paper. It is treated with borax as a flame retardant and insect repellent. Cellulose insulation may be used in floors and ventilated lofts. For other cavities the material is dry injected filling the void spaces. The material is hygroscopic. The standard BS EN 15101 Parts 1 and 2: 2013 gives the specification for loose fill cellulose insulation (LFCI).

14.4 Multi-layer thermo-reflective materials

Thermo-reflective insulating products consist of multi-layers of aluminium foil, non-woven fibrous wadding and thin cellular plastics. The aluminium foil may be plain or reinforced. The material acts by reducing conduction, convection and radiation. High levels of insulation can be achieved in relatively thin quilts which may be loose laid or fixed.

15 SEALANTS, GASKETS AND ADHESIVES

15.1 General

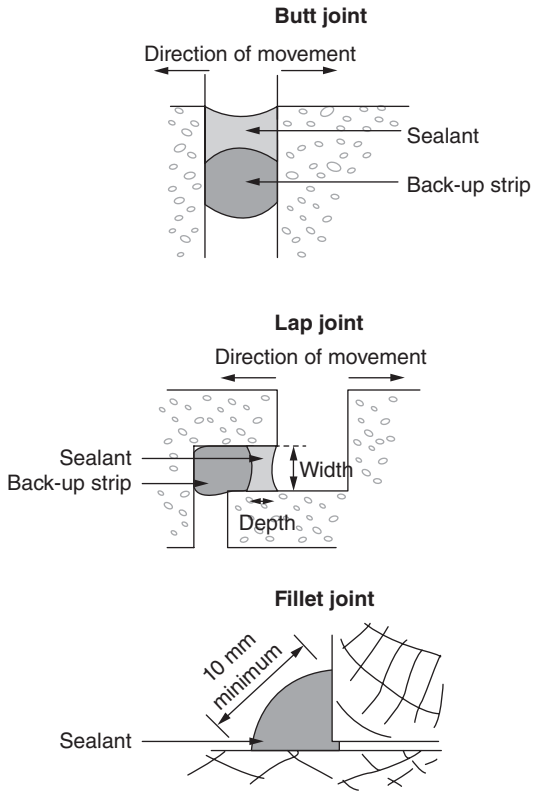
Although used in relatively small quantities compared with the load-bearing construction materials, sealants, gaskets and adhesives play a significant role in the perceived success or failure of buildings. A combination of correct detailing and appropriate use of these materials is necessary to prevent the need for expensive remedial work. Selections of typical uses are listed as examples.

15.2 Sealants

Sealants are classified as either for glazing or construction, Figure 7.17.

The standards BS 6213: 2000 + A1: 2010 and BS EN ISO 11600: 2003 +A1: 2011 relate to the definitions and specification of sealants in construction joints. Sealants are generally classified according to their movement accommodation as either plastic or elastic. Elastic sealants may be of low or high modulus. Sealants must be matched to the appropriate application. Typical joint design and sealant systems are illustrated in Figures 7.18 and 7.19, respectively.

Plastic sealants: Plastic materials include butyl, acrylic, polymer/bitumen sealants also oil-based mastics and linseed oil putty. Butyl sealants have a rubbery texture and are mainly used in small joints, preferably protected from direct sunlight. Acrylic sealants are typically used around windows for new and remedial work.



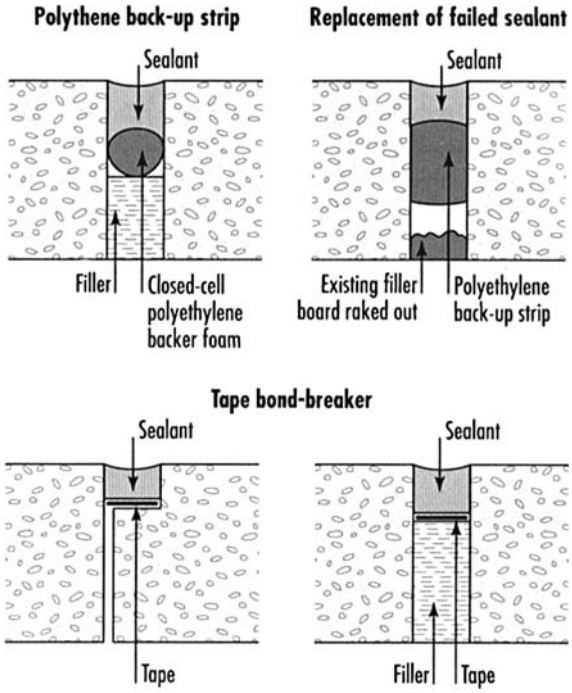
7.18 *Butt, lap and fillet joints*

Solvent-based bitumen sealants are frequently used in gutters and flashings. Hot poured bitumen is used in asphalt and concrete movement joints.

Elastoplastic sealants: Polysulphide sealants are available as one- or two-component systems. The one-component systems cure slowly by absorption of moisture from the air. They are suitable for joints up to 25 mm. The two-component systems cure within 24–48 hours and are generally used for wider structural movement joints in masonry and precast panel systems.

Elastic sealants: Elastic sealants include polyurethane, silicone and epoxy materials. Polyurethane sealants are available as one- and two-component systems and are typically used in glazing, curtain walling, cladding panels and floors. Silicone sealants are available as high- and low-modulus systems. The high-modulus material is typically used in glazing, curtain walls, tiling and around sanitary ware. The low-modulus systems are used around

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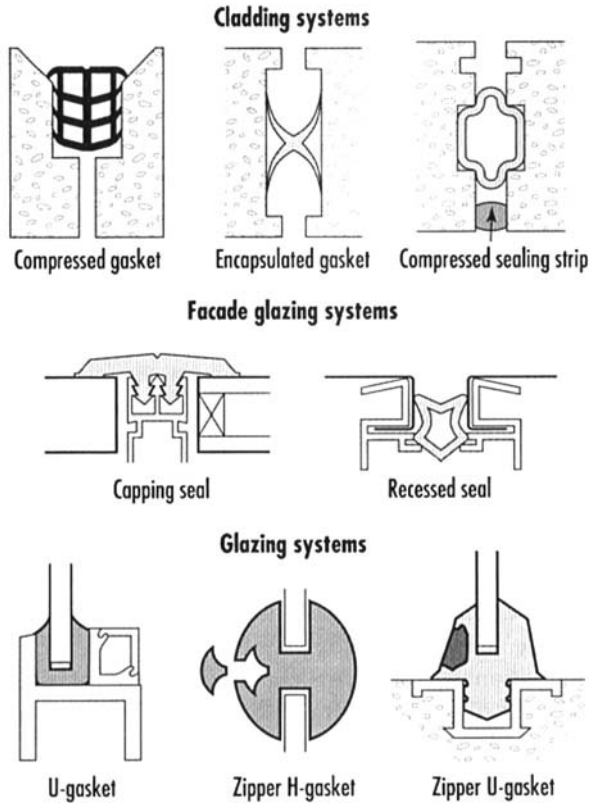


7.19 *Typical sealant systems*

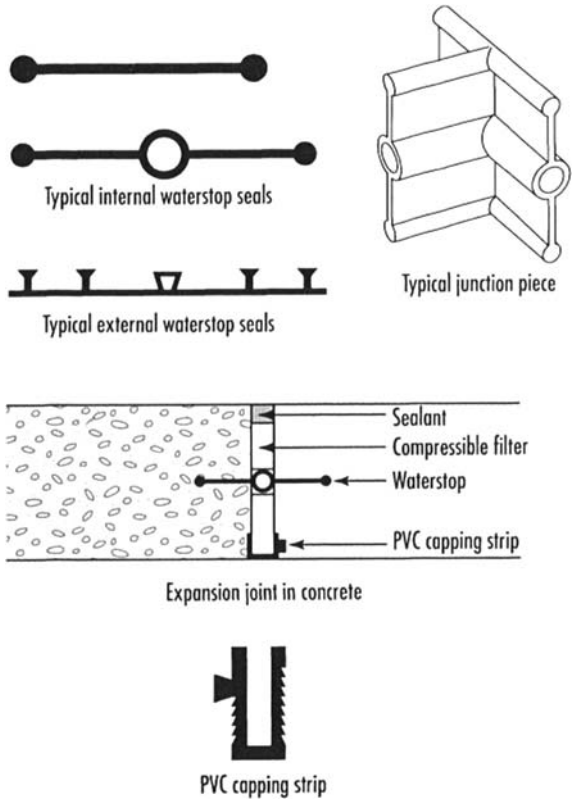
PVC-U and aluminium glazing systems and for cladding. Epoxy sealants are used in stress-relieving joints where larger movements in compression than tension are anticipated, for example in floor joints and tiling in swimming pools.

15.3 Gaskets

Gaskets, Figure 7.20, are lengths of flexible components of various profiles which may be solid or hollow and manufactured from either cellular or non-cellular materials. Typical applications include the weather sealing of precast concrete cladding units and façade systems. The standard materials are neoprene, EPDM and silicone rubbers. Within cladding systems, gaskets may be compressed or encapsulated. In glazing systems, gaskets are either encapsulated or fixed with a zipper component. Waterstop seals manufactured from rubber or PVC are used in concrete construction joints, Figure 7.21.



7.20 *Typical gaskets for cladding and glazing systems*



7.21 *Concrete waterstop seals*

Table LX Classification of tile adhesives by composition and properties (BS EN 12004: 2007 + A1: 2012)

Classification	Composition and properties
Type	
Type C	Cementitious adhesive – hydraulic binding resin
Type D	Dispersion adhesive – aqueous organic polymer resin
Type R	Reaction resin adhesive – one or two component synthetic resin
Class	
Class 1	Normal adhesive
Class 2	Improved adhesive
Class F	Fast setting adhesive
Class T	Reduced slip adhesive
Class S1	Deformable adhesive
Class S2	Highly deformable adhesive

15.4 Adhesives

Tile adhesives: The standard BS EN 12004: 2007 + A1: 2012 classifies ceramic tile adhesives into three types: cementitious (C), dispersion (D) and reaction resin (R) also sub-classes as listed in Table LX.

The majority of ceramic floor tile adhesives are cement based. Grouting can be coloured as required. Thin-bed epoxy based adhesives are more water and chemical resistant and may be used where repeated spillage is anticipated.

Wall tile adhesives are usually polyvinyl acetate (PVA), acrylic or cement-based compositions. The acrylic-based adhesives are more resistant to water than the PVA materials, and therefore appropriate for domestic showers, etc. The water resistant cement-based products are useable both internally and externally. Polymer-modified cement-based adhesives are appropriate for fixing marble, granite and slate up to 15 mm in thickness.

Vinyl floor tile and wood block adhesives are generally rubber/bitumen, rubber/resin or modified bitumen emulsions.

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Wood adhesives: The majority of wood adhesives are based on polyvinyl acetate (PVA). Water-resistant PVA adhesives which partially cross-link on curing are suitable for external use but not for immersion in water. Structural thermosetting wood adhesives are mainly two-component systems based on phenolic or amino-plastic resins. Their Service Class conditions are specified in the standard BS EN 301: 2013.

Epoxy resin adhesives: Epoxy resins are two-component thermosetting adhesives which produce high strength durable bonding. Epoxy resins may be used both internally and externally for fixing metals, ceramics, glass, timber, rigid plastics and concrete.

Cyanoacrylate adhesives: Cyanoacrylate resins are single-component adhesives which bond components held in contact. Curing is quickly activated by surface moisture. The bonding is resistant to chemical attack but does not offer high impact resilience.

Hot-melt adhesives: Hot-melt adhesives for application by glue gun are usually based on the thermoplastic copolymer ethyl vinyl acetate (EVA). Formulations are available for joining materials to either rigid or flexible substrates. Similar adhesives are used in iron-on plastic and wood edging veneer.

Gap-filling adhesives: Gun-grade gap filling adhesives are normally rubber/synthetic rubber resins with filler reinforcement. Both solvent-borne and solvent-free systems are available. Typical uses include fixing timber and timber products to plaster and masonry.

Plastic pipe adhesives: Solvent-based vinyl resins are used for bonding PVC-U and ABS pipes and fittings. The adhesive is applied to both components which are then united and slightly rotated to ensure a full seal.

Bitumen-based adhesives: Bitumen-based adhesives for bonding bituminous sheet roofing may be applied hot or from solvent or emulsion based formulations. Products require even spreading to eliminate air pockets which could cause delamination.

16 PAINTS, WOOD STAINS AND VARNISHES

16.1 Paints

The Code of Practice BS 6150: 2006 + A1: 2014 gives a detailed description of paint systems and their appropriate applications to the full range of building materials. The Code includes the preparation of surfaces, selection of paints systems and maintenance. Paints and varnishes specific to exterior wood are described in BS EN 927-1: 2013, and classified for masonry and concrete in BS EN 1062-1: 2004, for steel in BS EN 12944-5: 2007 and for internal surfaces BS EN 13300: 2001.

Colours can be specified according to several systems. The British Standards BS 5252: 1976 (237 colours) and BS 4800: 2011 (122 colours) define colours and colour for building purposes respectively. However colour may also be specified by other systems including: the *RAL® Classic System* (213 colours), the *Natural Colour System®* (1950 colours), the *Colour Palette®* notation or *Pantone®*. Some colour systems permit a conversion to RGB computer or CMYK printing colours. Visual comparison of paint colours based on observation and controlled illumination conditions is specified in BS EN ISO 3668: 2001.

Paint systems generally incorporate a primer, offering protection and good adherence to the substrate, an undercoat, usually an alkyd resin or acrylic emulsion providing cover, and a finishing coat providing a durable decorative surface. Finishing coats may be gloss, silk or matt finish. The majority of paints are increasingly becoming water-borne in response to environmental considerations.

16.2 Special paints

Special paints include light-reflecting, heat-resisting, intumescent, flame-retardant, water-repellent, multi-colour, masonry, anti-graffiti and fungicide products. Acrylated rubber paints are resistant to chemical attack; micaceous iron oxide paints have good resistance to moisture on iron and steelwork and epoxy paints are resistant to abrasions, oils and dilute aqueous chemicals. Anti-microbial coatings incorporating silver ions can reduce bacteria levels within medical environments.

16.3 Natural wood finishes

Natural wood finishes include wood stains, varnishes and oils. Wood stain microporous coatings for exterior use usually require a basecoat preservative, followed by a low-, medium- or high-build finish. Generally for sawn timber deeply penetrating systems are appropriate, whereas for smooth planed timber a medium- or high-build system offers the best protection from weathering. Whilst some solvent-based systems are available, many are now water-based to reduce VOC emissions.

Most varnishes are based on modified alkyd resins either as solvent- or water-based systems. Polyurethane finishes may be matt, satin or gloss. The solvent-based polyurethane systems generally give a harder and more durable coating. Most varnishes for external use incorporate screening agents to reduce the degradation effects of ultra-violet light.

Finishes such as teak and tung oil are used mainly for internal applications where the visual effect of the wood grain is to be featured. Certain formulations, high in solids giving a micro-porous UV-resistant finish, are however, suitable for external applications.

17 COMMODITIES

17.1 Windows

The typical range of window and doorset types (BS 644: 2012) is illustrated in Figure 7.22. BS 6375 Parts 1–3: 2009 gives guidance on the performance, selection and specification of windows and doors. The Code of Practice for the installation of windows and external doorsets is BS 8213-4: 2007. The European terminology for windows and doors is referenced in BS EN 12519: 2004. Most standard windows are based on increments of 150 mm in height. A standard range of timber window sizes is listed in Table LXI.

Table LXI Standard timber frame window sizes

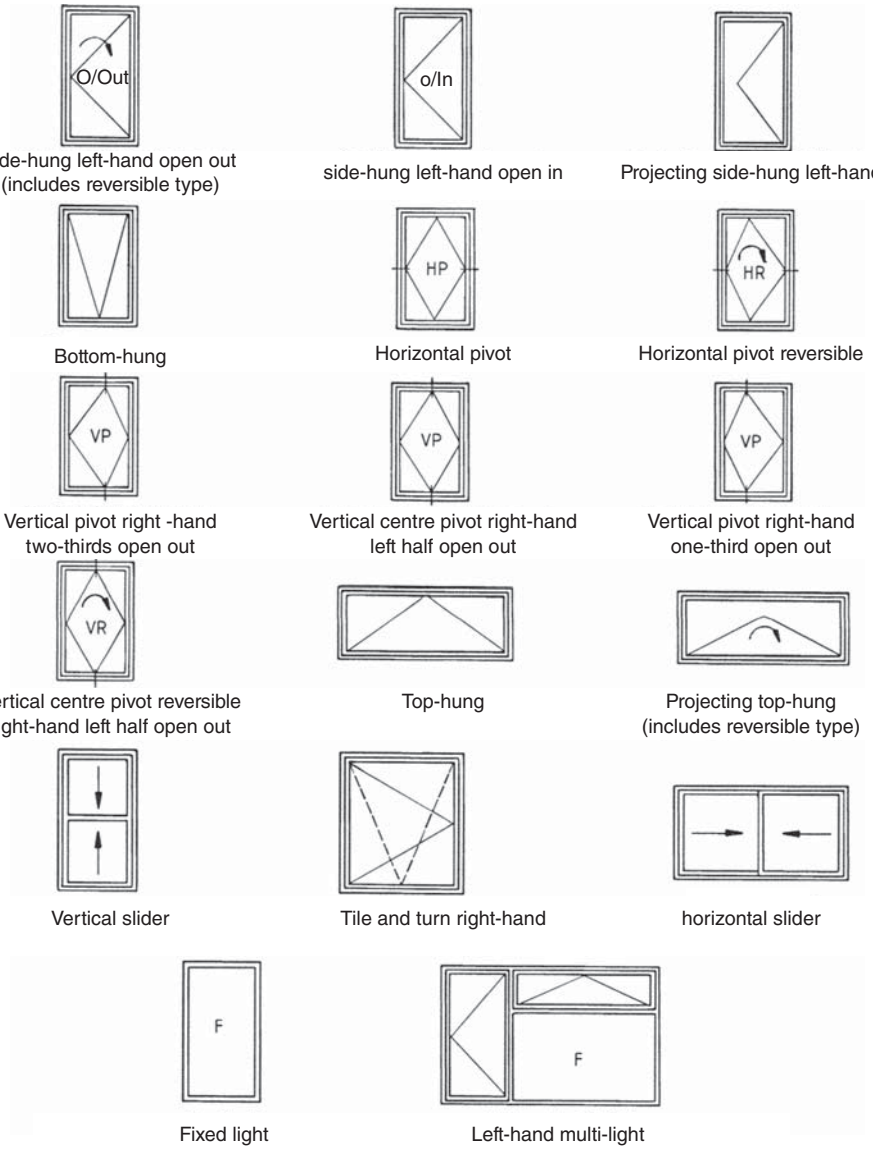
Standard window heights (mm)						
450	600	750	900	1200	1350	1500
Standard window widths (mm)						
488	630	915	1200	1342	1770	2339

Note: Imperial sizes are also available from some manufacturers.

The following standards relate to windows constructed from the standard materials: Timber (BS 644: 2012), Aluminium alloy (BS 4873: 2009), Steel (BS 6510: 2010) and PVC-U (BS 7412: 2007). Timber and aluminium composite windows are referenced in BS 644: 2012. The safety aspects of cleaning windows are specified in the Code of Practice BS 8213-1: 2004. Where required by the Building Regulations Part B 2006 (incorporating amendments 2010 and 2013), fire egress windows must be provided with a clear opening of greater than 0.33 m^2 and minimum clear dimensions of 450 mm (e.g. 450 × 735 mm). The bottom of the openable area must not be more than 1100 mm above the floor. These windows must not be restricted or lockable with removable keys. Aspects of domestic window security are covered by PAS 24: 2012 and BS 8220-1:2000.

Safety considerations (BS 6180: 2011) dictate that any opening window less than 800 mm from the floor should be protected to 800 mm by a barrier or restricted to less than 100 mm opening. It is a requirement (BS 6262-4: 2005) that all glazing less than 800 mm above floor (or ground level) should be of safety glass. Large openings up to 1100 mm above floor level should be guarded to that level when there is a drop outside of more than 600 mm (BS 8213-1: 2004).

Window Energy Ratings (WERs) are an established measure of window energy efficiency. A formula combines the elements of solar heat transmittance, *U*-value and air infiltration to produce an overall rating on the A+ to G scale, with A+ the most energy efficient for the whole window unit. Standard building practice



7.22 *Standard timber window and doorsets – British Standard BS 644: 2012 (permission to reproduce extracts from: BS 644: 2012 Timber windows and doorsets. Fully furnished factory assembled windows and doorsets of various types. Specification is granted by the British Standards Institute.)*

effectively requires windows with a minimum rating of C, but many manufacturers are producing windows that are A+, A or B rated and increasingly these will be demanded.

17.2 Doors

The majority of UK doors are manufactured to imperial dimensions but the imperial sizes are also quoted in metric units. Standard imperial sizes for internal doors are 1981 mm × 457, 533, 610, 686, 762, 838, and 864 mm. The metric sizes for internal doors are 2040 mm × 526, 626, 726, 826 and 926 mm. Standard thicknesses are 35 and 40 mm.

Fire doors, typically 35, 44 or 54 mm thick, are rated either to BS 476-22: 1987 (e.g. FD 30) or to the European Standard BS EN 13501-2: 2007 + A1: 2009 (e.g. E30) for integrity in minutes. The ratings are normally subject to the use of appropriate frames with intumescent strips and any fire-resistant glazing being factory-fitted. In certain locations the Building Regulations Part E, related to the passage of sound, require minimum sound reduction criteria, and these can be achieved by the used of appropriately sealed doorsets.

The standard imperial sizes for external inward opening doors are 1981 mm × 686, 762, 813, 838 and 914 mm. The corresponding frame sizes are 2081 mm × 783, 859, 910, 935 and 1011 mm. Additionally a taller 2032 mm × 813 mm door is standard, matched to a 2132 mm × 910 mm frame.

The standard metric size for external doors is 2000 mm × 807 mm with a frame size of 2100 mm × 900 mm with a sill or 2053 mm × 900 mm without a sill. The larger 2040 mm × 826 mm metric doors require a 2140 mm × 920 mm frame with a sill or 2093 mm × 920 mm without a sill.

The Building Regulations Part M 2004 (incorporating 2010 and 2013 amendments) requires a wheelchair access into buildings, preferably level but with any threshold no higher than 15 mm and any upstands over 5 mm chamfered or rounded. Normally the minimum effective clear entrance width required is 800 mm in new buildings, but 1000 mm in buildings used by the general public. Visibility zones are required in doors or side panels between 500 mm and 1500 mm from floor level. The height for door controls to be used by people in wheelchairs should be between 750 and 1000 mm from the floor.

Door Set Energy Ratings (DSERs) range from A to G, depending on U-value and air leakage. The scheme covers all external pedestrian doors. F and G ratings are normally appropriate only for listed buildings and architecturally sensitive locations.

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17.3 Curtain walling

Curtain walling can be used within commercial buildings or domestic properties where a large visual glazed area is required; this is advantageous because of the natural light it provides. If treated sensitively large glazed areas of façades can be aesthetically pleasing and create a contemporary, open-air look both inside and outside the building.

Curtain walling is loosely defined in the standards (BS EN 13830: 2003 + pr EN 13830: 2013) as an external vertical building enclosure produced by elements mainly of timber, metal or plastic. This standard applies to curtain walling consisting of vertical and horizontal members, connected together and anchored to the supporting structure of the building and in-filled to form a lightweight space enclosing continuous skin, which does not take on any load-bearing characteristics of the building structure. The standard applies to curtain walling ranging from a vertical position to 15° from the vertical. It can include elements of sloping glazing contained within the curtain wall.

Curtain walling embraces many different forms of construction but generally comprises one of the following:

- Stick construction – light carrier framework of site assembled components supporting prefabricated opaque and/or translucent infill panels.
- Unitised construction – pre-assembled interlinking storey height or multi-storey height modules, complete with infill panels.
- Spandrel construction – pre-assembled interlinking part-storey height modules, complete with infill panels.

The standard specifies characteristics of curtain walling and provides technical information on the varying performance requirements which apply throughout Europe, the test criteria and sequence of testing to which the product is subjected, in order to demonstrate conformity. Reference is also made to other European standards which relate to products incorporated into curtain walling. Curtain walling is not a product which can be completed in all respects within a manufacturing area, but is a series of components and/or prefabricated units which only become a finished product when assembled together on site. This standard is applicable to the whole of the curtain walling, including the flashings, closures and copings.

Curtain walling should be sufficiently rigid to resist wind loads (BS EN 13116: 2001), sustain its own weight and transfer associated loads to the building structure. It must be resistant to impact (BS EN 14019: 2004), the transfer of heat/cold and sound, and be air (BS EN 12152: 2002) and water tight (BS EN 12154: 2000). It must be designed to be fire resistant, prevent the transmission of fire or smoke through voids and react to fire within prescribed limits. These and other factors, such as durability, water vapour permeability, equipotentiality (bonding to electrical earth), seismic shock resistance, thermal shock resistance, building thermal movement and resistance to live horizontal loads, must be proven by testing and calculation methods defined in the standards.

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BS EN 413 Masonry cement: Part 1: 2011 Composition, specifications and conformity criteria.
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BS EN 1339: 2003 Concrete paving flags. Requirements and test methods.
BS EN 10080: 2005 Steel for the reinforcement of concrete. Weldable reinforcing steel. General.
BS EN 12620: 2013 Aggregates for concrete.
BS EN 13055 Lightweight aggregates: Part 1: 2002 Lightweight aggregates for concrete, mortar and grout.
BS EN 13263 Silica fume for concrete: Part 1: 2005 Definitions, requirements and conformity.
BS EN 14216: 2004 Cement. Compositions, specifications and conformity criteria for very low heat special cements.
BS EN 15167 Ground granulated blast furnace slag for use in concrete, mortar and grout: Part 1: 2006 Definitions, specifications and conformity criteria.

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18.5 Aluminium

BS 1161: 1977 Specification for aluminium alloy sections for structural purposes.

BS EN 485 Aluminium and aluminium alloys. Sheet, strip and plate:

Part 1: 2008 Technical conditions for inspection and delivery.
Part 2: 2013 Mechanical properties.
Part 3: 2003 Tolerances on dimensions and form for hot-rolled products.

BS EN 573 Aluminium and aluminium alloys:

Part 1: 2004 Numeral designation system.
Part 3: 2013 Chemical composition and form of products.

BS EN 754 Aluminium and aluminium alloys. Extruded rod/bar, tube and profiles:

Part 1: 2008 Cold drawn rod, bar and tube. Technical conditions.
Part 2: 2013 Cold drawn rod, bar and tube. Mechanical properties.
Part 3: 2008 Round bars, tolerances on dimension and form.
Part 4: 2008 Square bars, tolerances on dimension and form.
Part 5: 2008 Rectangular bars, tolerances on dimension and form.
Part 6: 2008 Hexagonal bars, tolerances on dimension and form.
Part 7: 2008 Seamless tubes, tolerances on dimension and form.

BS EN 755 Aluminium and aluminium alloys. Extruded rod/bar, tube and profiles:

Part 1: 2008 Technical conditions for inspection and delivery.
Part 2: 2013 Mechanical properties.
Part 3: 2008 Round bars, tolerances on dimension and form.
Part 4: 2008 Square bars, tolerances on dimension and form.
Part 5: 2008 Rectangular bars, tolerances on dimension and form.
Part 6: 2008 Hexagonal bars, tolerances on dimension and form.
Part 7: 2008 Seamless tubes, tolerances on dimension and form.
Part 9: 2008 Profiles, tolerances on dimension and form.

BS EN 1999-1-1:2007 + A2: 2013 Design of aluminium structures. General structural rules.

18.6 Roofing and cladding

BS 4842: 1984 Liquid organic coatings for application to aluminium extrusions, sheet and preformed sections for external architectural purposes.

BS 4868: 1972 Specification for profiled aluminium sheet for building.

BS 6229: 2003 Flat roofs with continuously supported coverings. Code of practice.

BS 6915: 2001 + A1: 2014 Design and construction of fully supported lead sheet roof and wall coverings. Code of practice.

BS 6925: 1988 Specification for mastic asphalt for building and civil engineering.

BS 8217: 2005 Reinforced bitumen membranes for roofing. Code of practice.

BS 8218: 1998 Code of practice for mastic asphalt roofing.

BS 8747: 2007 Reinforced bitumen membranes for roofing. Guide to selection and specification.

BS EN 501: 1994 Roofing products from metal sheet. Specification for fully supported roofing products of zinc sheet.

BS EN 502: 2013 Roofing products from metal sheet. Specification for fully supported products of stainless steel sheet.

BS EN 504: 2000 Roofing products from metal sheet. Specification for fully supported roofing products of copper sheet.

BS EN 505: 2013 Roofing products from sheet metal. Specification for fully supported roofing products of sheet steel.

BS EN 506: 2008 Roofing products from metal sheet. Specification for self-supporting products of copper or zinc sheet.

BS EN 507: 2000 Roofing products from metal sheet. Specification for fully supported products of aluminium sheet.

BS EN 508 Roofing products from metal sheet. Specification for self-supporting products of steel, aluminium or stainless steel sheet:

Part 1: 2014 Steel.
Part 2: 2008 Aluminium.
Part 3: 2008 Stainless steel.

BS EN 988: 1997 Zinc and zinc alloys. Specification for flat rolled products for building.

BS EN 1172: 2011 Copper and copper alloys. Sheet and strip for building purposes.

BS EN 1179: 2003 Zinc and zinc alloys. Primary zinc.

BS EN ISO 9445 Continuously cold-rolled stainless steel. Tolerances on dimensions and form:

Part 1: 2010 Narrow strip and cut lengths.
Part 2: 2010 Wide strip and plate/sheet.

BS EN 10140: 2006 Cold rolled narrow steel strip. Tolerances on dimensions and shape.

BS EN 12588: 2006 Lead and lead alloys. Rolled lead sheet for building purposes.

BS EN 13108-6: 2006 Bituminous mixtures. Material specifications. Mastic asphalt.

BS EN 13707: 2013 Flexible sheets for waterproofing. Reinforced bitumen sheets for waterproofing. Definitions and characteristics.

BS EN 13859-1: 2014 Flexible sheets for waterproofing. Definitions and characteristics of underlays. Underlays for discontinuous roofing.

BS EN 13956: 2012 Flexible sheet for waterproofing. Plastic and rubber sheets for roof waterproofing. Definitions and characteristics.

BS EN 14782: 2006 Self-supporting metal sheet for roofing, external cladding and internal lining. Product specification and requirements.

BS EN 14783: 2013 Fully supported metal sheet and strip for roofing, external cladding and internal lining. Product specification and requirements.

BS EN 14964: 2006 Rigid underlays for discontinuous roofing. Definitions and characteristics.

CP 143 Code of practice. Sheet roof and wall coverings:

Part 5: 1964 Zinc.
Part 12: 1970 Copper. Metric units.
Part 15: 1973 Aluminium. Metric units.

18.7 Glass

Technical information:

Pilkington Building Products (www.pilkington.com)

Saint-Gobain Glass, (uk.saint-gobain-glass.com)

BS 6180: 2011 Barriers in and about buildings. Code of practice.

BS 6206: 1981 Specification for impact performance requirements for flat safety glass and safety plastics for use in buildings.

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BS 6262 Glazing for buildings:

Part 1: 2005 General methodology for the selection of glazing.
Part 2: 2005 Code of practice for energy, light and sound.
Part 3: 2005 Code of practice for fire, security and wind loading.
Part 4: 2005 Code of practice for safety related to human impact.
Part 6: 2005 Code of practice for special applications.
Part 7: 2005 Code of practice for the provision of information.

BS EN 1991-1-4: 2005 Eurocode action on structures. General actions.
BS EN ISO 12543 Glass in building. Laminated glass and laminated safety glass:

Part 1: 2011 Definitions and descriptions of component parts.
Part 2: 2011 Laminated safety glass.
Part 3: 2011 Laminated glass.

BS EN 12600: 2002 Glass in building. Pendulum test. Impact test method and classification for flat glass.
BS EN 13022 Glass in building. Structural sealant glazing:

Part 1: 2014 Glass products for structural sealant glazing systems.
Part 2: 2014 Assembly rules.

BS EN 13363 Solar protection devices combined with glazing. Calculation of solar and light transmittance:

Part 1: 2003 Simplified method.
Part 2: 2005 Detailed calculation method.

18.7 Ceramic materials

BS 3402: 1969 Specification for quality of vitreous china sanitary appliances.
BS 5385 Parts 1-5 2006 – 2009 Wall and floor tiling.
BS 5534: 2014 Code of practice for slating and tiling (including shingles).
BS EN 295: 2012 – 2013 Vitrified clay pipes and fittings for drains and sewers.
BS EN 1304: 2013 Clay roofing tiles and fittings. Product definitions and specifications.
BS EN 12004: 2007 Adhesives for tiles. Requirements, evaluation of conformity, classification and designation.
BS EN 13888: 2009 Grout for tiles. Requirements, evaluation of conformity, classification and designation.
BS EN 14411: 2012 Ceramic tiles. Definitions, classification, characteristics, evaluation of conformity and marking.

18.8 Stone and cast stone

BS 1217: 2008 Cast stone. Specification.
BS 8298: Code of practice for design and installation of natural stone cladding and lining:

Part 1: 2010 General.
Part 2: 2010 Traditional handset external cladding.
Part 3: 2010 Stone-faced pre-cast concrete cladding systems.
Part 4: 2010 Rainscreen and stone on metal frame cladding systems.
Part 5: pending Internal linings.

BS EN 771 Specification for masonry units:

Part 5: 2011 Manufactured stone masonry units.
Part 6: 2011 Natural stone masonry units.

BS EN 1469: 2004 Natural stone products. Slabs for cladding. Requirements.
BS EN 12670: 2002 Natural stone. Terminology.

18.9 Plastics

BS 743: 1970 Specification for materials for damp-proof courses.
BS 3012: 1970 Specification for low and intermediate density polythene sheet for general purposes.
BS 3757: 1978 Specification for rigid PVC sheet.
BS 4901: 1976 Specification for plastics colours for building purposes.
BS 5955-8: 2001 Plastics pipework (thermoplastics materials).
BS 6203: 2003 Guide to the fire characteristics of expanded polystyrene materials.
BS 6398: 1983 Specification for bitumen damp-proof courses for masonry.
BS 6515: 1984 Specification for polyethylene damp-proof courses for masonry.
BS 7619: 2010 Extruded cellular unplasticized white PVC (PVCUE) profiles. Specification.
BS 8215: 1991 Code of practice for design and installation of damp-proof courses in masonry construction.
BS EN 1013: 2012 Light transmitting single skin profiled plastic sheets for internal and external roofs, walls and ceilings. Requirements and test methods.
BS EN ISO 1873 Plastics. Polypropylene (PP) moulding and extrusion materials: Part 1: 1995 Designation system and basis for specifications.
BS EN ISO 7391 Plastics. Polycarbonate (PC) moulding and extrusion materials: Part 1: 2006 Designation system and basis for specifications.
BS EN ISO 8257 Plastics. Polymethyl methacrylate (PMMA) moulding and extrusion materials: Part 1: 2006 Designation system and basis for specifications.
BS EN ISO 8986 Plastics. Polybutene-1 (PB-1) moulding and extrusion materials: Part 1: 2009 Designation system and basis for specifications.
BS EN ISO 11542 Plastics. Ultra high molecular weight polyethylene (PE-UHMW) moulding and extrusion materials: Part 1: 2001 Designation system and basis for specifications.
BS EN ISO 12086 Plastics. Fluoropolymer dispersions and moulding and extrusion materials: Part 1: 2006 Designation system and basis for specifications.
BS EN 14909: 2012 Flexible sheets for waterproofing. Plastic and rubber damp-proof courses. Definitions and characteristics.
BS EN 15347: 2007 Plastics. Recycled plastics. Characterisation of plastics waste.
DD CEN/TS 15534 Parts 2: 2007 Wood-plastics composites (WPC).
BS EN 15534 Parts 1, 4 and 5: 2012 Composites made from cellulose-based materials and thermoplastics.

18.10 Glass-fibre reinforced plastics, concrete (cement) and gypsum

BRE Digest 480: 2004 Wood plastic composites and plastic lumber.
BS EN 492: 2012 Fibre-cement slates and fittings. Product specification.
BS EN 494: 2012 Fibre-cement profiled sheets and fittings. Product specification.
BS EN 1013: 2012 Light transmitting single skin profiled sheets for internal and external roofs, walls and ceilings.
BS EN 1169: 1999 Precast concrete products. General rules for factory production control of glass-fibre reinforced cement.
BS EN 12467: 2012 Fibre-cement flat sheets. Product specification and test methods.
BS EN 15422: 2008 Precast concrete products. Specification of glass fibres for reinforcement of mortars and concretes.

18.11 Plaster and board materials

Technical information:

British Gypsum: The White Book. 2009 (updated 2011) www.british-gypsum.com/literature/white-book

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British Gypsum: The Fire Book, 2011 www.british-gypsum.com/literature/fire-book
BS EN 520: 2004 Gypsum plasterboards. Definitions, requirements and test methods.
BS EN 13279-1: 2008 Gypsum binders and gypsum plasters. Definitions and requirements.
BS EN 13658-1: 2014 Metal lath and beads. Definitions, requirements and test methods. Internal plastering.
BS EN 13815: 2006 Fibrous gypsum plaster casts. Definitions, requirements and test methods.
BS EN 13915: 2007 Prefabricated gypsum plasterboard panels with a cellular paperboard core.
BS EN 13950: 2005 Gypsum plasterboard thermal / acoustic insulation composite panels.
BS EN 14353: 2007 Metal beads and feature profiles for use with gypsum plasterboards.
BS EN 15283 Gypsum boards with fibrous reinforcement:

Part 1: 2008 Gypsum boards with mat reinforcement.
Part 2: 2008 Gypsum fibre boards.

BS EN 15319: 2007 General principles of design of fibrous (gypsum) plaster works.

18.12 Insulation materials

BS 3837–1: 2004 Expanded polystyrene boards. Boards and blocks manufactured from expandable beads.
BS 5250: 2011 Code of practice for control of condensation in buildings.
BS EN ISO 10456: 2007 Building materials and products. Hygrothermal properties.
BS EN 12524: 2000 Building materials and products. Hygrothermal. properties. Tabulated design values.
BS EN 13162: 2012 Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification.
BS EN 13163: 2012 Thermal insulation products for buildings. Factory made products of expanded polystyrene (EPS). Specification.
BS EN 13164: 2012 Thermal insulation products for buildings. Factory made products of extruded polystyrene foam (XPS). Specification.
BS EN 13165: 2012 Thermal insulation products for buildings. Factory made rigid polyurethane foam (PUR) products. Specification.
BS EN 13166: 2012 Thermal insulation products for buildings. Factory made products of phenolic foam (PF). Specification.
BS EN 13167: 2012 Thermal insulation products for buildings. Factory made cellular glass (CG) products. Specification.
BS EN 13168: 2012 Thermal insulation products for buildings. Factory made wood wool (WW) products. Specification.
BS EN 13169: 2012 Thermal insulation products for buildings. Factory made products of expanded perlite (EPB). Specification.
BS EN 13170: 2012 Thermal insulation products for buildings. Factory made products of expanded cork (ICB). Specification.
BS EN 13171: 2012 Thermal insulation products for buildings. Factory made wood fibre (WF) products. Specification.
BS EN 13499: 2003 Thermal insulation products for buildings. External thermal insulation composite systems (ETICS).
BS EN 14063-1: 2004 Thermal insulation products for buildings. In-situ formed expanded clay lightweight aggregate products. Specification for loose-fill products before installation.
BS EN 14315 Thermal insulation products for building. In-situ formed sprayed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products:

Part 1: 2013 Specification for the rigid foam spray system before installation.
Part 2: 2013 Specification for the installed insulation products.

BS EN 14316 Thermal insulation products for buildings. In-situ thermal insulation formed from expanded perlite (EP) products:

Part 1: 2004 Specification for bonded and loose-fill products before installation.
Part 2: 2007 Specification for the installed products.

BS EN 14317 Thermal insulation products for buildings. In-situ thermal insulation formed from exfoliated vermiculite (EV):

Part 1: 2004 Specification for bonded and loose-fill products before installation.
Part 2: 2007 Specification for the installed products.

BS EN 15101 Thermal insulation products for building. In-situ formed loose fill cellulose (LFCI) products:

Part 1: 2013 Specification for the products before installation.
Part 2: 2013 Specification for the installed products.

18.13 Sealants, gaskets and adhesives

BS 6213: 2000 Selection of construction sealants. Guide.
BS EN 301: 2013 Adhesives, phenolic and aminoplastic for load-bearing timber structures.
BS EN ISO 11600: 2003 Building construction jointing products. Classification and requirements for sealants.
BS EN ISO 12004: 2007 Adhesives for tiles. Requirements, evaluation of conformity, classification and designation.

18.14 Paints, wood stains and varnishes

BS 4800: 2011 Schedule of paint colours for building purposes.
BS 5252: 1976 Framework for colour co-ordination for building purposes.
BS 6150: 2006 Painting of buildings. Code of practice.
BS EN 927-1: 2013 Paints and varnishes. Coating materials and coating systems for exterior wood. Classification and selection.
BS EN 1062-1: 2004 Paints and varnishes. Coating materials and coating systems for exterior masonry and concrete. Classification.
BS EN ISO 3668: 2001 Paints and varnishes. Visual comparison of the colour of paints.
BS EN ISO 12944-5: 2007 Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Protective paint systems.
BS EN 13300: 2001 Paints and varnishes. Water-borne coating materials and coating systems for interior walls and ceilings. Classification.

18.15 Commodities; windows, doors and curtain walling

Windows and doors

Technical information:

Jeld-Wen Windows, patio doors, and external doorsets, 2012, www.jeld-wen.co.uk
Jeld-Wen Internal, external doors, patio doors and external doorsets, 2013, www.jeld-wen.co.uk
BS 459: 1988 Specification for matchboarded wooden door leaves for external use.
BS 476–22: 1987 Fire tests on building materials and structures. Fire resistance of non-loadbearing elements of construction.
BS 644: 2012 Timber windows. Fully finished factory-assembled windows and doorsets of various types. Specification.
BS 1245: 2012 Pedestrian doorsets and door frames made from steel sheet. Specification.
BS 4787-1: 1980 Internal and external doorsets, door leaves and frames. Specification for dimensional requirements.
BS 4873: 2009 Aluminium windows and doorsets. Specification.

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BS 6180: 2011 Barriers in and about buildings. Code of practice.
BS 6262–4: 2005 Glazing for buildings. Code of practice for safety related to human impact.
BS 6375 Performance of windows and doors:

Part 1: 2009 Classification for weathertightness and guidance on selection and specification.
Part 2 2009 Classification for operation and strength characteristics and guidance on selection and specification.
Part 3: 2009 Classification for additional performance characteristics and guidance on selection and specification.

BS 6510: 2010 Steel-framed windows and glazed doors.
BS 7412: 2007 Specification for windows and doorsets made from unplasticized polyvinyl chloride (PVC-U) extruded hollow profiles.
BS 8213 Windows, doors and rooflights:

Part 1: 2004 Design for safety in use and during cleaning of windows. Code of practice.
Part 4: 2007 Code of practice for the survey and installation of windows and external doorsets.

BS 8220–1: 2000 Guide for security of buildings against crime. Dwellings.
BS EN 1529: 2000 Door leaves. Height, width, thickness and squareness. Tolerance classes.
BS EN 12519: 2004 Windows and pedestrian doors. Terminology.
BS EN 13501-2: 2007 Fire classification of construction products and building elements.
BS EN 14220: 2006 Timber and wood-based materials in external windows, external door leaves and external doorframes. Requirements and specifications.
BS EN 14221: 2006 Timber and wood-based materials in internal windows, internal door leaves and internal doorframes. Requirements and specifications.
BS EN 14351-1: 2006 Windows and doors. Product standard, performance characteristics.
PAS 24: 2012 Enhanced security performance requirements for doorsets and windows in the UK.

Curtain walling
BS EN ISO 140 Acoustics. Measurement of sound insulation in buildings and of building elements.
BS EN ISO 717 Acoustics. Rating of sound insulation in buildings: Part 1: 2013 Airborne sound insulation.
BS EN 1991 Eurocode 1: Actions on structures: Part 1-1: 2002 General actions. Densities, self-weight, imposed loads for buildings.
BS EN 12152: 2002 Curtain walling. Air permeability. Performance requirements and classification.
BS EN 12153: 2000 Curtain walling. Air permeability. Test method.
BS EN 12154: 2000 Curtain walling. Watertightness. Performance requirements and classification.
BS EN 12155: 2000 Curtain walling. Watertightness. Laboratory test under static pressure.
BS EN 12179: 2000 Curtain walling. Resistance to wind load. Test method.
BS EN 12600: 2002 Glass in building. Pendulum test. Impact test method and classification for flat glass.
BS EN 13116: 2001 Curtain walling. Resistance to wind load. Performance requirements.
BS EN 13119: 2007 Curtain walling. Terminology.
BS EN 13501 Fire classification of construction products and building elements:

Part 1: 2007 Classification using test data from reaction to fire tests.
Part 2: 2007 Classification using data from fire resistance tests, excluding ventilation services.

BS EN 13830: 2003 Curtain walling. Product standard.
BS EN 13947: 2006 Thermal performances of curtain walling. Calculation of thermal transmittance. Simplified method.
BS EN 14019: 2004 Curtain walling. Impact resistance. Performance requirements.

19 ACKNOWLEDGEMENTS

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8 Thermal environment

Phil Jones

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KEY POINTS:

- Safety and comfort for the inhabitants are the main considerations for an internal environment
- The efficient use of energy and reduction in greenhouse gas emissions come a close second

Contents

1 Introduction
2 Heat transfer mechanisms
3 Thermal comfort
4 Site and climate
5 Building fabric
6 Condensation
7 Infiltration and ventilation
8 Heating and cooling systems
9 Prediction and measurement

1 INTRODUCTION

1.1 Thermal design

Thermal design is concerned with the heat transfer processes that take place within a building, and between the building and its surroundings and the external climate, Figure 8.1. It is primarily concerned with providing comfort and shelter for the building's occupants and contents. Thermal design therefore includes consideration of the

- climate
- building form and fabric
- building environmental services
- occupants and processes contained within the building.

It is also concerned with the energy used to provide heating, cooling and ventilation of buildings, and the local and global impact of energy use, especially in relation to carbon dioxide emissions. The thermal design should be integrated with the visual and acoustic aspects of the design in order to achieve an overall satisfactory environmental solution.

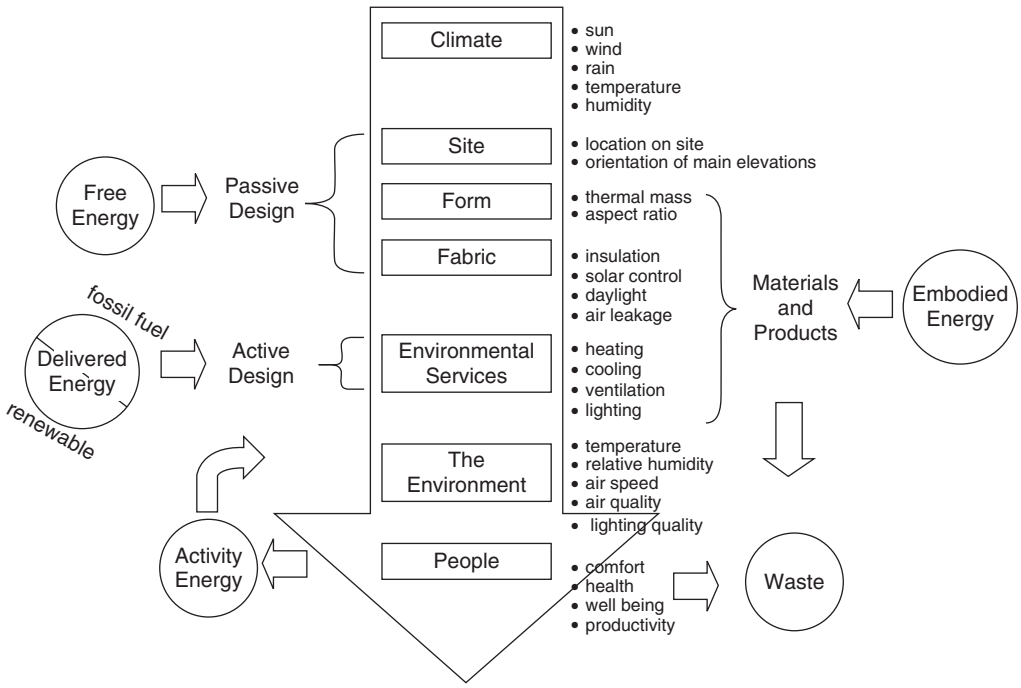
1.2 Three stages to thermal design

Stage 1: Internal environmental conditions for occupants or processes

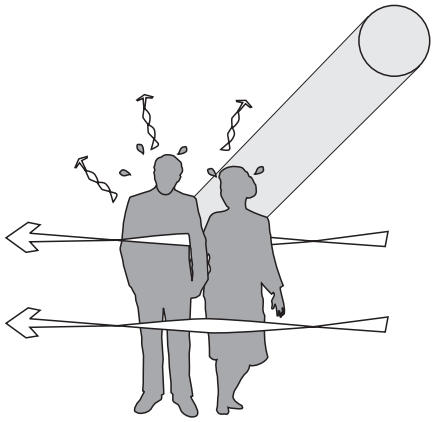
The prime aim is to create spaces that are comfortable, healthy and productive for their occupants, Figure 8.2. People will spend typically 90 per cent of their time indoors. The environments people live and work in must promote a good quality of life. Thermal conditions should be within acceptable comfort limits and the indoor air quality should be free from any harmful pollutants. Buildings must also provide appropriate thermal conditions for their contents, processes and for maintaining the building fabric itself. The required environmental conditions of all spaces should be clearly defined at the initial design stage in relation to the activities and contents of the space.

Stage 2: Climate modification through the building envelope

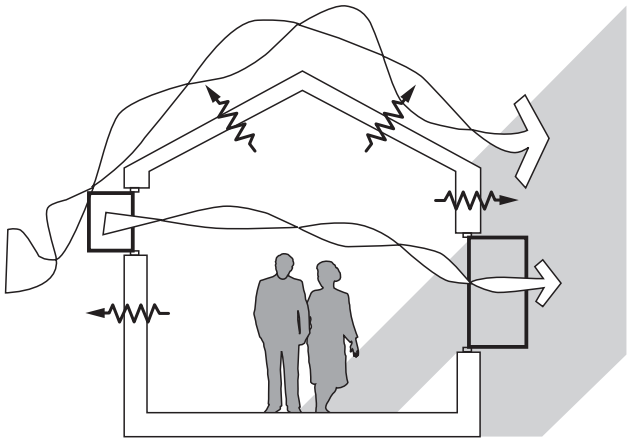
Buildings can be designed to interact with the external environment in order to benefit from the natural energy of the sun and wind, Figure 8.3. The envelope of the building can be used to 'filter' or 'modify' the external climate to provide internal comfort conditions for much of the year without the use of fuel. The heat from the sun can be used to heat spaces in winter or to drive air movement for ventilation and cooling through



8.1 *Thermal design to achieve comfort for a given climatic condition. Passive design is related to building form and fabric. Active design is related to mechanical services, energy use and environmental impact. The environmental conditions must be suitable for the health and comfort of the occupants. There are a number of energy inputs associated with a building's construction and operation*



8.2 *Thermal comfort is influenced by air temperature, air movement, relative humidity and the surrounding radiant environment*

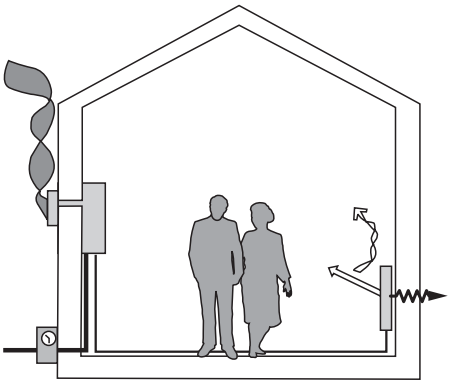


8.3 *Climatic modification can be achieved through manipulation of a building's form and construction usually referred to as Passive Design*

buoyancy forces. The building form and fabric can be used to control solar gains in summer to avoid overheating. The wind can also be used to provide ventilation and cooling. The fabric of the building can be used to insulate against heat loss or gain, and using thermal mass to stabilise the internal environment against extremes of temperatures (hot or cold). The form, mass, orientation and construction of the building need to be designed in response to the climate and specific location. This process is often termed 'passive design'.

Stage 3: Mechanical services

If a building is designed to respond positively to the climate then its dependence on mechanical services to heat, cool and ventilate spaces can be minimised, Figure 8.4. However, there are few climates in the world where mechanical systems can be eliminated altogether. In temperate climates such as the UK a heating system will still generally be required during the winter period, and some buildings require mechanical cooling in summer. In hot climates, mechanical cooling is often needed, sometimes the whole year round, for example, for commercial buildings. These services should be provided in an energy-efficient way in order to minimise energy use from fossil fuels, and to reduce the impact that buildings have on polluting the environment. Low and zero carbon sources of energy should be considered, such as renewable energy sources, including wind power, photovoltaics, solar thermal, biomass, combined heat and power (CHP) and ground source heat pumps. The mechanical systems and their controls should be designed to be able to respond to the specific needs of the occupants and be simple to use. Systems should be commissioned and



8.4 *Mechanical services should be designed to minimise energy use and environmental impact*

recalibrated against any change of use throughout the lifetime of the building.

It is important to adopt a holistic integrative approach to thermal design incorporating an appropriate blend of architectural (passive design) and engineering (active design) solutions.

1.3 Energy inputs

Thermal design is closely associated with energy use and carbon dioxide emissions. However, of all the energy inputs to a building, Figure 8.1, it is only the energy from fossil fuel sources that have associated carbon dioxide emissions. There will be free energy from the sun, wind and external temperatures that can be used to heat, cool, light and ventilate the building. This passive design approach uses the building's envelope, form and glazing to optimise the benefits from external environmental conditions.

The delivered energy is that used to provide electricity and heat to the environmental systems. This has traditionally been supplied from electricity and gas grid systems and involves the use of fossil fuels either to generate electricity or to produce heat. The aim of sustainable design is to replace fossil fuel sources of delivered energy with renewable and low and zero carbon energy supply systems.

The embodied energy is that associated with processed materials and products used during a building's construction and fit-out. This includes the process energy to acquire natural resources and to produce the materials and components, and the transport energy associated with their production and delivery to site. As the delivered energy is reduced through a more energy efficient design, the embodied energy becomes of increasing significance. In some low carbon buildings the embodied energy is equal to the lifetime delivered energy. The embodied energy is closely linked with the life-cycle and environmental costs of raw materials and material manufacture, lifetime durability and end of use disposal. In sourcing a building material or component the embodied energy is a major factor in determining its sustainability. The use of local materials is favoured as transportation energy costs are reduced. In general terms the more highly processed a material is, the higher its embodied energy. The highest embodied energy is found in metals (steel requires 75,000 kWh/m^3), compared to building timber (typically 1500kWh/m^3) or those made from salvaged materials or local natural materials, which can require virtually no energy. It is also preferable to use reclaimed materials, or materials with a high recycled content such as metals although the process of recycling adds to their embodied energy. Sustainable design should encourage construction systems which use fewer materials. Some construction types are inherently more wasteful than others. Standardisation, the use of less packaging and using more locally sourced off-site construction methods should be encouraged. Transportation of materials also plays a significant role in embodied energy calculations, especially

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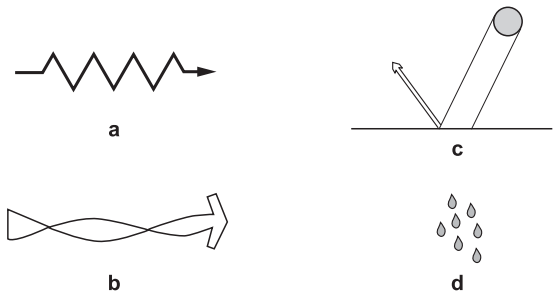
Table I Embodied energy of common building materials

Materials	Embodied energy (MJ/Kg)	Embodied carbon (KgC/Kg)
Bricks		
General	3	0.060
Limestone	0.85	–
Cement		
General	4.6+/–2	0.226
Portland cement, wet kiln	5.9	0.248
Portland cement, semi-wet kiln	4.6	0.226
Portland cement, dry kiln	3.3	0.196
Portland cement, semi-dry kiln	3.5	0.202
Fibre cement	10.9	0.575
Mortar (1:3 cement: sand mix)	1.4	0.058
Mortar (1:4)	1.21	0.048
Mortar (1:0.5:4.5 cement: lime: sand mix)	1.37	0.053
Mortar (1:1:6 cement: lime: sand mix)	1.18	0.044
Mortar (1:2:9 cement: lime: sand mix)	1.09	0.039
Soil-cement	0.85	0.038
Concrete		
General 1:2:4 as used in construction of buildings under three storeys	0.95	0.035
Precast concrete, cement: sand: aggregate		
1:1:2	1.39	0.057
1:1.5:3	1.11	0.043
1:2.5:5	0.84	0.030
1:3:6	0.77	0.026
1:4:8	0.69	0.022
Autoclaved aerated blocks (AACs)	3.5	0.076–0.102
Fibre-reinforced	7.75	0.123
Road and pavement	1.24	0.035
Road example	2.85MJ/m^2	51KgC/m^2
Wood-wool reinforced	2.08	–
Glass		
General	15	0.232
Fiberglass (Glasswool)	18	0.417
Toughened	23.5	0.346
Steel		
General, 'typical' (42.3% recycled content)	24.4	0.482
General, primary	35.3	0.749
General, secondary	9.5	0.117
Bar & rod, 'typical' (42.3% recycled content)	24.6	0.466
Bar & rod, primary	36.4	0.730
Bar & rod, secondary	8.8	0.114
Engineering steel, secondary	13.1	0.185
Galvanised sheet, primary	39	0.768
Pipe, primary	34.4	0.736
Plate, primary	48.4	0.869
Section, 'typical' (42.3% recycled content)	25.4	0.485
Section, primary	36.8	0.757
Section, secondary	10	0.120
Sheet, primary	31.5	0.684
Wire	36	0.771
Stainless	56.7	1.676
Timber		
General	8.5	0.125
Glue laminated timber	12	–
Hardboard	16	0.234
MDF	11	0.161
Particle board	9.5	0.139
Plywood	15	0.221
Sawn hardwood	7.8	0.128
Sawn softwood	7.4	0.123
Veneer particleboard (furniture)	23	0.338

Source: G. P. Hammond and C. I. Jones (2008) Embodied energy and carbon in construction materials. In *Proceedings of the ICE – Energy*, 161/2: 87–98.

where buildings are remotely located. Typically the embodied energy of a house might be between 500 and 1000kWh/m^2, whilst delivered energy for a house built to current standards might be less than 50kWh/m^2/year. Table I gives values of embodied energy in units of Mj/Kg, which can be converted to kWh/m^3 by multiplying by (material density/3.6). Values of embodied energy for a specific material can vary depending on the process assumed in their production, including any recycled material.

The activity energy is that derived from the use of the building. This is generally in the form of heat emitted from the processes of cooking, lighting, the use of small power, and the heat generated by the occupants themselves and the specific processes that occur in buildings. All these can provide a useful heat gain to the building in the winter, but can give rise to overheating in the summer and for some building types even in winter. In many countries, the energy use associated with occupant activities is increasing, through more consumer electrically powered goods. Typical internal energy loads are presented later in Table XXXV.



8.5 *Heat is transferred by: a Conduction; b Convection; c Radiation; d Evaporation*

2 HEAT TRANSFER MECHANISMS

2.1 Introduction

There are four types of heat transfer that relate to thermal environmental design, Figure 8.5. These are conduction, convection, radiation and evaporation. They are described below with examples of how they relate to building thermodynamics.

Heat is a form of energy, measured in joules (J). The rate of energy use is termed power which is measured in watts (W), where:

1W=1J/s (1kW=1000J/s)

Another unit of energy is the kilowatt-hour (kWh), where:

1kWh = 3600J (or 3.6MJ)

and the therm (which is equal to 100,000 British thermal units (BTU) and is approximately the energy equivalent of burning 100 cubic feet of natural gas) where:

1 therm = 29.3 kWh

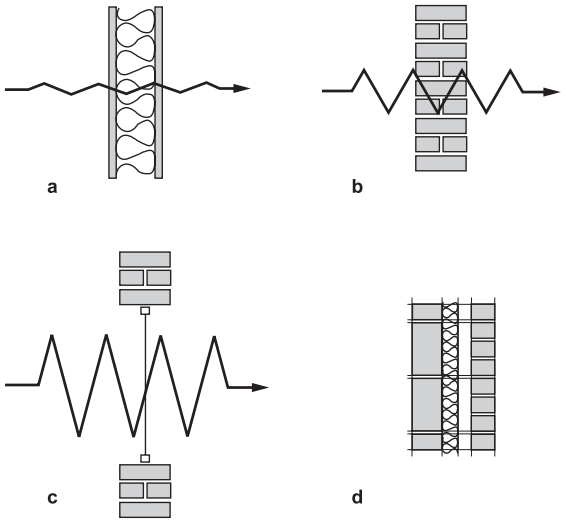
2.2 Conduction

Conduction normally applies to heat transfer through solids. It is the transfer of heat from molecule to molecule from relatively warm to cool regions. The rate of heat transfer through a solid is dependent on its thermal conductivity, or k-value. The k-value is loosely related to the density of the material, Figure 8.6 (see Table II). High-density materials generally have high k-values – they are termed 'good conductors' of heat (e.g. high-density concrete and metals). Low-density materials have low k-values – they are termed 'good thermal insulators' (e.g. mineral fibre batts and low-density concrete blocks). The thermal resistance of a given thickness of material in a construction is calculated by dividing its thickness by its k-value:

$$R = x/k \quad (1)$$

where R = thermal resistance (m^{2}K/W)
x = thickness (m)
k = thermal conductivity (W/m-K)

Materials with a high thermal resistance provide good thermal insulation.



8.6 *Comparison of thermal conduction properties of different constructions. a Mineral wool has a low density (25kg/m³) and is a good thermal insulator (k = 0.035 W/m-K). b Bricks have a relatively high density (1700kg/m³) and is a fairly poor insulator (k = 0.84 W/m-K). c Glazing has a relatively high density (1700kg/m³) and a poor insulator (k = 1.05 W/m-K). d Walls need to have structural and weatherproofing properties as well as thermal insulation properties. Most wall constructions are therefore composed of a number of layers, the resistances of which can be added to give an appropriate overall thermal resistance of the wall*

Table II Thermal conductivity and density of common building materials

Material	Density (kg/m³)	Thermal conductivity (W/m.K)
Walls		
Brickwork (outer leaf)	1700	0.84
Brickwork (inner leaf)	1700	0.62
Cast concrete (heavyweight)	2000	1.70
Cast concrete (lightweight)	620	0.20
Concrete block (heavyweight, 300mm)	2240	1.31
Concrete block (mediumweight, 300mm)	1940	0.83
Concrete block (lightweight, 300mm)	1800	0.73
Concrete block (insulating)	470	0.11
Cement mortar	1860	0.72
Fibre board (preformed)	240	0.042
Plasterboard	950	0.16
Timber	720	0.14
Glass (solid)	2500	1.05
Surface finishes		
Rendering (moisture content 8%)	1330	0.79
Plaster (dense)	1200	0.52
Plaster (lightweight)	720	0.23
Calcium silicate brick	2000	1.50
Roofs		
Aerated concrete slab	500	0.16
Asphalt (roofing, mastic)	2230	1.15
Roofing felt layer	960	0.19
Screed	1200	0.41
Stone chippings	1800	0.96
Tile	1900	0.84
Wood wool slab	500	0.10
Floors		
Cast concrete (dense, reinforced)	2000	1.30
Screed	2100	0.41
Timber flooring	720	0.14
Insulation		
Expanded polystyrene slab	23	0.035
Glass wool quilt	12	0.040
Glass wool board	25	0.035
Phenolic foam board	30	0.040
Polyurethane board	24	0.023
Paper (cellulose)	43	0.042
Straw board	310	0.05

Source: CIBSE Guide A: Environmental Design, 2006.

The resistivity, *r,* of a material is the inverse of its conductivity *k,* that is,

$$r = 1/k$$

Example 1

What is the thermal resistance of a wall comprising 102.5mm brick, 200mm mineral wool slab insulation, 100mm lightweight concrete block?

Material	Thickness (m)	k-value (W/m/K)	Resistance (m² K/W)
Brick	0.1025	0.84	0.12
Insulation	0.20	0.035	5.71
Block (insulating)	0.10	0.11	0.91
Total thermal resistance	–	–	6.74

Notes:
1) Values for conductivity are from Table II.
2) The thermal resistance of each layer is calculated according to formula 1:R = x/k.
3) The main contribution to the total thermal resistance is from the mineral wool slab insulation.
4) Thermal resistance will be used later in the calculation of *U*-values (in Section 5).

2.3 Convection

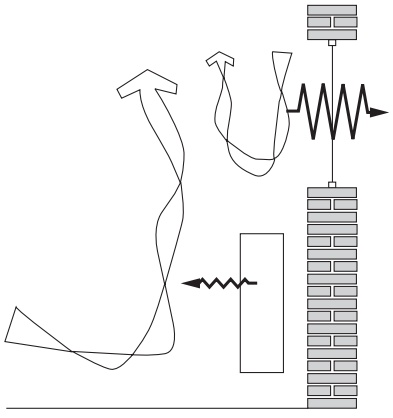
Convection takes place in a fluid such as air or water. Once heated the fluid becomes less dense and more buoyant. Fluids are normally heated by conduction from a warm surface such as the electric element in a hot water cylinder, or the hot surface of a panel heater. A cold surface will conduct heat from the adjacent fluid, thereby cooling the fluid. This will make the fluid more dense and cause the fluid to become less buoyant, for example, causing a down-draught from the internal surface of a cold window. For a typical room, the relatively warm and cool surfaces set up a series of interacting convective flow patterns. The convection of air in a room is an integral part of most heating and cooling systems.

In the example, Figure 8.7, heat is conducted from the air to the cooler surface of the glazing, causing a downdraught. Heat is conducted to the air from the warmer surface of the panel heater, causing an updraught. Although panel heaters are usually called radiators they mainly provide heat (typically 60–70 per cent) through convection. The formula for convective heat transfer from a surface to air is:

$$Q_c = h_c x\ (t_a - t_s) \qquad (2)$$

where Q_c = convective heat transfer (W)
h_c = convective heat transfer coefficient ($Wm^{-2}K^{-1}$)
t_a = air temperature (°C)
t_s = surface temperature (°C)

Heat flow upwards from a horizontal surface: $h_c = 4.3 Wm^{-2}K^{-1}$
Heat flow downwards from a horizontal surface: $h_c = 1.5\ Wm^{-2}K^{-1}$
Heat flow from a vertical surface: $h_c = 3.0 Wm^{-2}K^{-1}$
Note: Values of h_c are at room temperature (21°C).



8.7 *Typical convection patterns generated by relatively warm (panel heater) and cool (glazing)*

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2.4 Radiation

Radiation is the transfer of heat between two surfaces without heating the air between them. Solar heat travels by radiation from the sun to the earth through the vacuum of space. Radiant heat is in the infrared part of the electromagnetic spectrum (which includes X-rays, ultraviolet, visible light, infrared, microwaves and radio waves – which differ from each other by their wavelength and frequency). The sun emits radiation with wavelengths between 0.29 and 3.0 mm, which includes the visible spectrum (0.38 and 0.78 mm), Figure 8.8. The hotter the emitting body, the shorter the wavelength. Infrared radiation below a wavelength of 3.0 mm (or 3000 nm) is termed short-wave; above this it is termed long-wave. The sun therefore emits most of its heat energy as short-wave radiation, while lower-temperature surfaces, such as buildings, tend to emit only long-wave radiation.

Glass is relatively transparent to short-wave radiation while opaque to long-wave radiation. This is the principle of the 'greenhouse effect', Figure 8.9, which is important in 'passive solar design'. The short-wave radiation from the sun passes through glass and warms up the internal surfaces, which in turn emit long-wave radiation which is 'trapped' within the space. The only heat loss therefore takes place by conduction through the glass. A similar effect takes place in the atmosphere which gives rise to global warming. The 'greenhouse gases' (including carbon dioxide and methane) act like the glass in the greenhouse in letting through the short-wave solar radiation but blocking the longer wave radiation re-emitted by the earth's surface.

Solar radiation incident on solid walls will heat up the external wall surface, Figure 8.10. This heat is conducted through the wall where it will result in a rise in the internal surface temperature. The internal surface will then radiate long-wave radiation in proportion to its surface temperature and emissivity (see Section 2.6). Normal glazing, however, is mostly transparent to 'short-wave' solar radiation and radiative heat is transmitted directly through the glass, Figure 8.11. Some glass types are designed to be more absorbing in order to reduce the direct solar transmission (see also Sections 5.6 to 5.13).

2.5 The Stefan-Boltzmann law

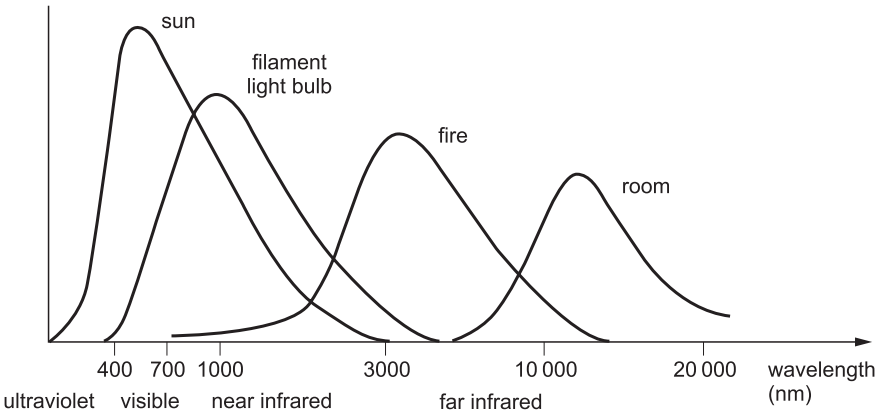
The amount of radiation emitted by a surface is related to its temperature and emissivity according to the Stefan-Boltzmann law:

$$Q_r = (5.673 \times 10^{-8}) \times E \times T^4 \qquad (3)$$

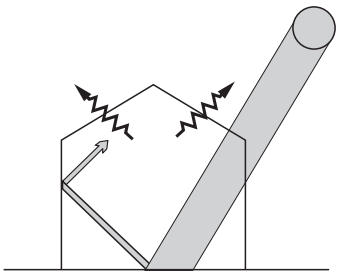
where Q_r = radiation emitted by the surface
E = surface emissivity
T = surface temperature (°C)
5.673×10^{-8} = Stefan-Boltzmann constant (W/m^2 K^4)

2.6 Emissivity and absorptance

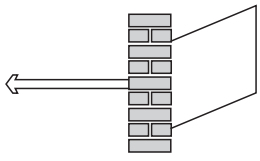
The emissivity of a surface is the amount of radiation emitted by the surface compared to that radiated by a matt black surface (a 'black body') at the same temperature. The best emitters are matt dark surfaces and the worst are silvered surfaces (although they are good reflectors of radiation). The emissivity of a surface varies between 0 and 1, with most common building materials, such as bricks and plaster, having an emissivity of about 0.85 to 0.95. The absorptivity is the amount of radiation absorbed by a surface compared to that absorbed by a black body. For low-temperature surfaces, values for absorptivity and emissivity are presented in Table III.



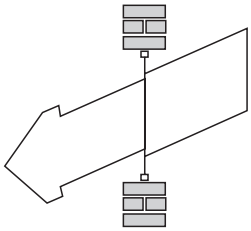
8.8 *Spectrum of long-wave (low-temperature) and short-wave (solar) radiation; Vertical axis is not to scale*



8.9 *Heat transfer process in a greenhouse, which forms the basis of passive solar design*



8.10 *Solar radiation incident on a solid wall of passive solar design*



8.11 *Radiation transmission through glass*

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Table III Surface emissivities/absorptivities

Finish	Absorptivity	Emissivity
Aluminium, dull/rough polished	0.40–0.65	0.18–0.30
Aluminium, polished	0.10–0.40	0.03–0.06
Asbestos cement, old	0.83	0.95–0.96
Asbestos cement, new	0.61	0.95–0.96
Brick, dark	0.63–0.89	0.85–0.95
Brick, light	0.36–0.62	0.85–0.95
Galvanised iron, new	0.64–0.66	0.22–0.28
Galvanised iron, old	0.89–0.92	0.89
Glass (normal)	–	0.88
Glass (hemispherical)	–	0.84
Limestone	0.33–0.53	0.90–0.93
Marble	0.44–0.592	0.90–0.93
Paint (zinc)	0.30	0.95
Wood, oak	–	0.89-0.90

Source: CIBSE Guide A: Environmental Design, 2006.

2.7 Evaporation

Evaporation takes place when a liquid such as water changes state to a vapour. A vapour is a mixture of gases which exerts a vapour pressure. The water molecules that escape from the liquid tend to have a higher energy content than those left behind and so the average energy content of the liquid is reduced, and therefore its temperature is also reduced. In order for evaporation to take place, the vapour pressure of water (in the form of droplets or a wetted surface) must be greater than the partial pressure of the water vapour in the surrounding atmosphere. The lower the relative humidity of the air, the greater the evaporation that will take place. The evaporation rate can be calculated as follows:

$$W = (8.3 \times 10^{-4})\, h_c/135 \times (p_{va} - p_s) \qquad (4)$$

Where W = rate of evaporation from the surface
h_c = convective heat transfer coefficient
p_{va} = vapour pressure in air
p_s = saturation vapour pressure at surface temperature.

Evaporation produces local cooling on wetted surfaces. This can be used to advantage in hot countries where roof ponds, cooled by evaporation, can be used to cool the roof construction. The tradition in some hot dry countries is to simply spray the floors of courtyards with water to cool the floor surface. Air passed over wetted surfaces is cooled and its moisture content is raised. The rate of evaporation increases with increased liquid temperature, reduced vapour pressure of the surrounding atmosphere, or increased air movement across the wetted surface.

Condensation is the reverse of evaporation and takes place when air comes into contact with a relatively cold surface. The air adjacent to the cold surface is cooled and becomes saturated and the vapour condenses into a liquid forming droplets on the surface (condensation is dealt with in more detail in Section 6).

2.8 Thermal capacity

The thermal capacity of a material is a measure of its ability to store heat from the surrounding air and surfaces. Generally, the more dense a material, the greater its capacity to store heat (Table IV). Therefore, high-density materials, such as concrete, will store more heat than low-density materials, such as mineral wool. The thermal capacity of a material can be calculated from the formula:

$$\text{Thermal capacity (J/kgK)} = \text{volume (m}^3\text{)} \times \text{density (kg/m}^3\text{)} \times \text{specific heat (J/kg:K)} \qquad (5)$$

Dense masonry materials typically have 100 times the thermal capacity of lightweight insulating materials (Table IV).

Table IV Density, specific heat and thermal capacity of common materials

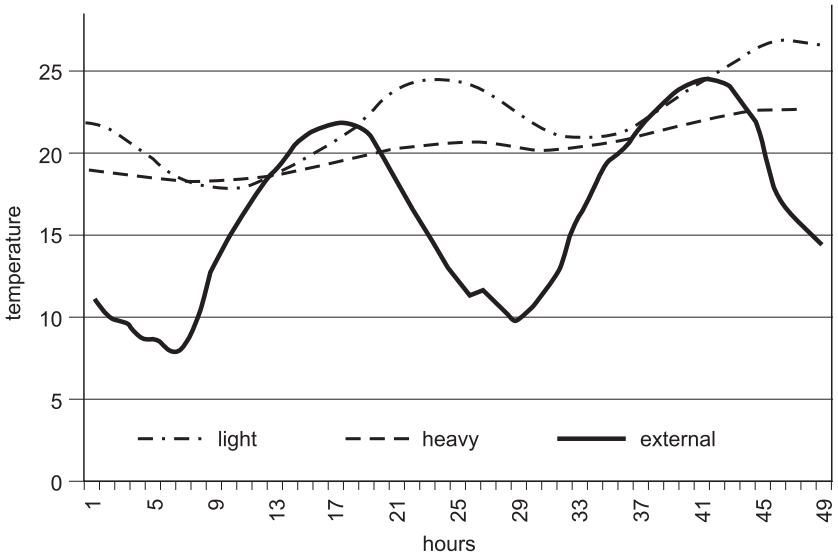
Material	Density (kg/m³)	Specific heat (J/kg.K)	Thermal capacity (J/K.m³)
Granite	2880	840	2419×10^3
Brick	1700	800	1360×10^3
Concrete (dense)	2240	840	1882×10^3
Concrete (light)	620	840	521×10^3
Mineral fibre	12	710	9×10^3
Polystyrene board	23	1470	34×10^3

Source: CIBSE Guide A: Environmental Design, 2006.

2.9 Thermal capacity and thermal response

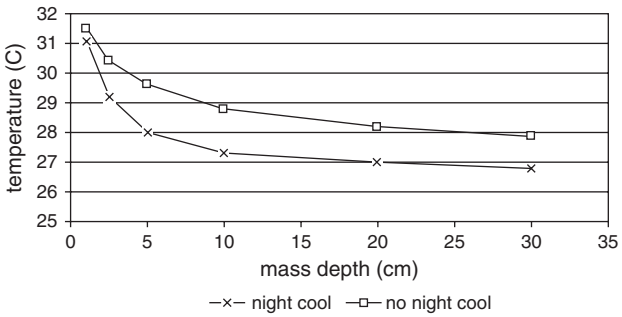
Lightweight buildings will respond quickly to heat gains, Figure 8.12, from either internal sources (people, lights, machines) or external sources (solar radiation, high external air temperatures). They have a relatively low thermal capacity. The internal air will therefore warm up quickly as the mass of the building will have a relatively low capacity to absorb internal heat. They will also cool down quickly when the heat source is turned off, as there is little residual heat in the construction to retain air temperatures. They are more likely to overheat during warm weather and be cool during colder weather. They therefore require a more responsive heating/cooling system, and are more suited to intermittent occupancy.

Heavyweight buildings are slower to respond to changes of temperature, Figure 8.12, and therefore have the potential to maintain a more stable internal environment. Buildings constructed of heavyweight materials will have a high thermal capacity. They will be slow to heat up as the mass of the



8.12 *Thermal responses of lightweight and heavyweight buildings against external temperature over a two-day period*

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8.13 *Typical reduction in peak temperatures with increasing thermal mass thickness without night cooling (night time infiltration 0.1 ac/h; daytime ventilation 1 ac/h), and with night cooling(nighttime ventilation 5.0 ac/h; daytime ventilation 1 ac/h)*

building will absorb heat from the space. However, they will also be slow to cool down and are able to retain relatively high internal air temperatures between heating periods. Heavyweight buildings can maintain relatively cooler internal environments in warmer weather by absorbing peaks in heat gains. Typical cooling effects may be up to 3° to 5°C reduction, Figure 8.13, in internal air temperature peaks due to thermal mass effects. In addition, the mean radiant temperature will be lower due to the lower surface temperatures. The use of chilled surface cooling is discussed also in Section 8.3.

The thermal mass effect is related to the exposed surface area of material and its thickness and heat capacity. Surface area is relatively more important than thickness of material. For example, for absorbing short-term (diurnal) peaks in heat gain, the thickness of the thermal mass layer needs only be about 5 to 10 cm, Figure 8.13.

3 THERMAL COMFORT

3.1 Introduction

The body produces heat through metabolic activities and exchanges heat with its surroundings by conduction, convection and radiation (typically 75 per cent), and evaporation (typically 25 per cent). Thermal comfort is achieved when there is a balance between metabolic heat production and heat loss. It is mainly dependent on the thermal environmental conditions and the activity and clothing of the person in that environment.

3.2 Metabolic activity

The human body produces metabolic heat as a result of its muscular and digestive processes. It has to maintain a constant core temperature of 37°C. If the core body temperature is reduced by more than about 1°C hypothermia sets in; if it increases by more than about 1°C the person may suffer a heat stroke. The body must therefore lose the metabolic heat it generates in a controlled way. Clothing is one way of controlling heat loss. There are also physiological control mechanisms; for example, shivering when cold increases metabolic activity; the formation of 'goose-pimples' increases the body's surface resistance to heat loss; sweating when warm increases heat loss by evaporation. The heat generated by metabolic activity is measured in units of MET (1 MET = 58.2 W/m^2 of body surface area; the average surface area of an adult is 1.8 m^2). Typical values of MET for different activities are given in Table V.

3.3 Clothing

Clothing provides insulation against body heat loss. The insulation of clothing is measured in units of CLO (1 CLO = 0.155 m^{2}K/W; the units are those of thermal resistance). Values of CLO for typical clothing ensembles are given in Table VI.

Table V Metabolic heat generation for different activities at 20°C in MET and in watts (W) for sensible (S) and latent (L) heat loss

Activity	MET	S(W)	L(W)
Seated at rest (theatre, hotel, lounge)	1.1	90	25
Light work (office, dwelling, school)	1.3	100	40
Standing activity (shopping, laboratory)	1.5	110	50
Standing activity (shop assistant, domestic)	2.2	130	105
Medium activity (factory, garage work)	2.5	140	125
Heavy work (factory)	4.2	190	250

Source: CIBSE Guide A: Environmental Design, 2006.

Table VI Clothing resistance in CLO and thermal resistance

	CLO	Thermal resistance (m^{2}K/W)
Nude	0	0
Light summer clothes	0.5	0.08
Light working ensemble	0.7	0.11
Winter indoor	1.0	0.16
Heavy business suit	1.5	0.23

Source: CIBSE Guide A: Environmental Design, 2006.

3.4 Air temperature

Air temperature is often taken as the main design parameter for thermal comfort. The CIBSE recommended range for internal air temperature is between 19 and 23°C in winter and not exceeding 27°C in summer. The air temperature gradient between head and feet is also important for comfort; the temperature at feet should generally not be less than 4°C below that at head.

3.5 Radiant temperature

Radiant temperature is a measure of the temperature of the surrounding surfaces, together with any direct radiant gains from high temperature sources (such as the sun). The mean radiant temperature is the area-weighted average of all the surface temperatures in a room. If the surfaces in a space are at different temperatures then the perceived radiant temperature in a space will be affected by the position of the person in relation to the various surfaces, with the closer or larger surface areas contributing more to the overall radiant temperature. Comfort can be affected by radiant asymmetry, and people are especially sensitive to warm ceilings (a 10°C radiant asymmetry from a warm ceiling can give rise to 20 per cent comfort dissatisfaction). The vector radiant temperature is a measure of the maximum difference in a room between the radiant temperatures from opposite directions.

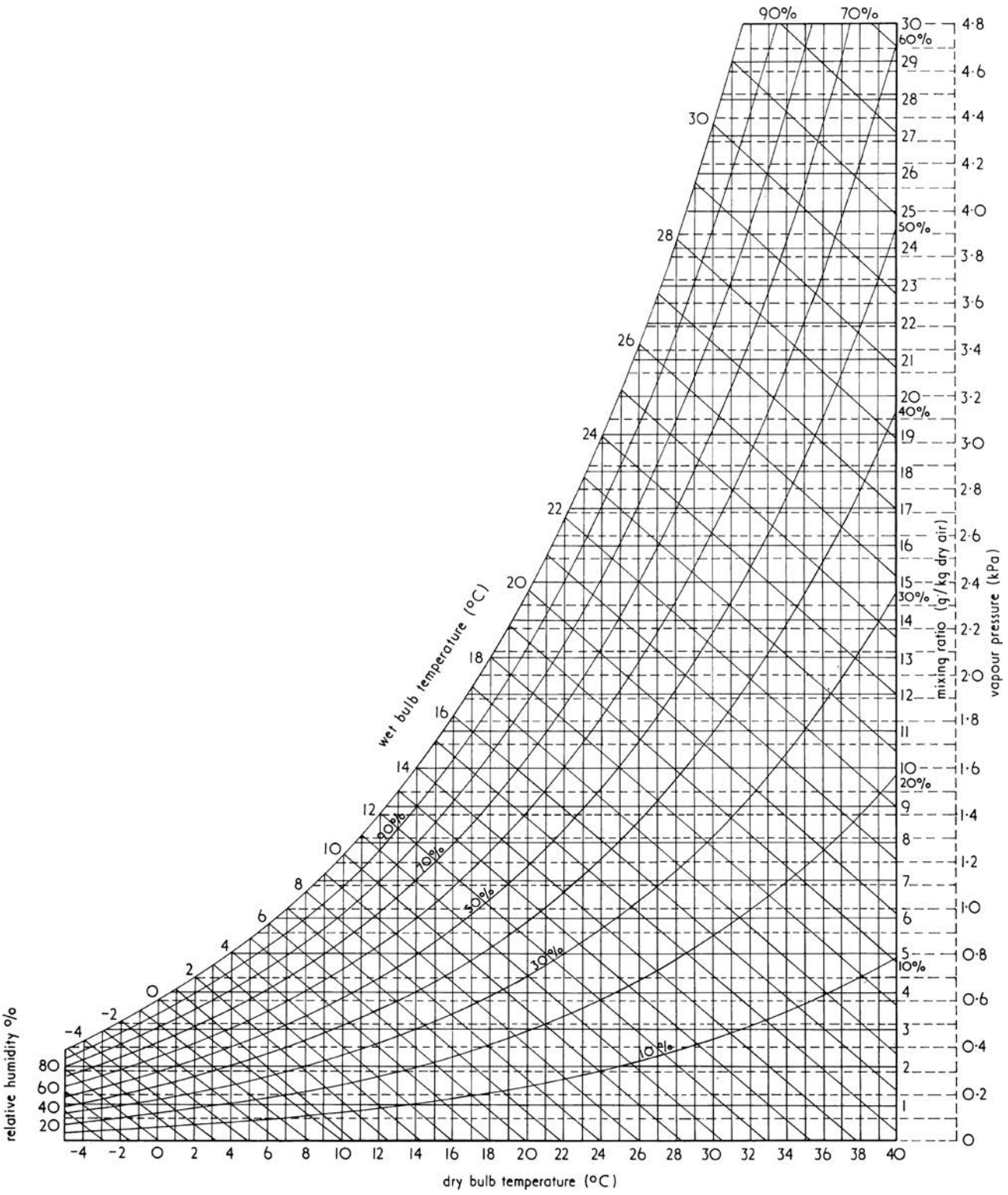
3.6 Relative humidity

Relative humidity (RH) of a space will affect the rate of evaporation from the skin. The RH is a percentage measure of the amount of vapour in the air compared to the total amount of vapour the air can hold at that temperature. When temperatures are within the comfort range (19–23°C) the RH has little effect on comfort as long as it is within the range 40–70 per cent. At high air temperatures (approaching average skin temperature of 34°C) evaporation heat loss is important to maintain comfort. Wet bulb temperature is a measure of the temperature of a space using a wetted thermometer. A 'dry bulb' temperature sensor will exchange heat with the surrounding air by convection. A wet bulb thermometer loses additional heat by evaporation and can be used in combination with a dry bulb, to obtain a measure of RH by referring to the psychrometric chart, Figure 8.14. An example of the use of this is shown in Figure 8.15, where a dry bulb temperature (dbt) of 19°C and a wet bulb temperature (wbt) of 14°C indicates a relative humidity (RH) of 60 per cent.

3.7 Air speed

Air speed is a measure of the movement of air in a space. People begin to perceive air movement at about 0.15 m/s. Air speeds greater than 0.2 m/s can produce a 20 per cent and greater comfort dissatisfaction due to perceived draught. For most naturally ventilated spaces the air speed will be less than 0.15 m/s, away from

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8.14 *Psychrometric chart (from figures in CIBSE Guide). This relates dry bulb temperature, wet bulb temperature and moisture content to relative humidity (RH)*

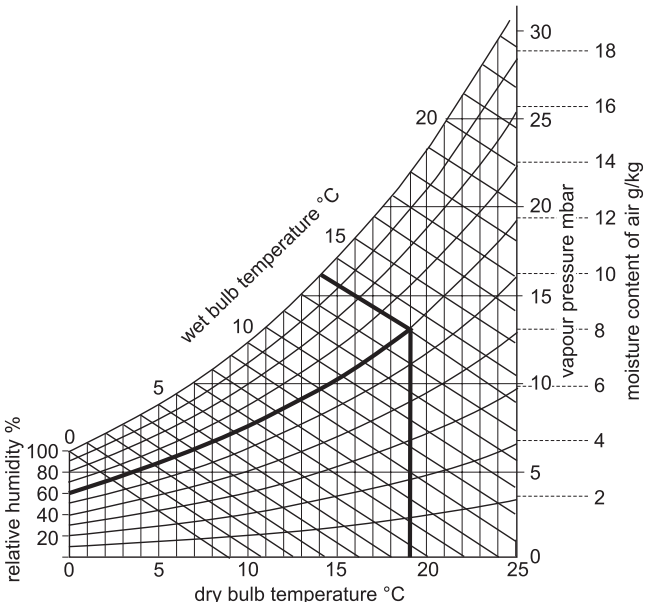
the influence of open windows and in the absence of major downdraughts from cold internal surfaces. For mechanically ventilated spaces, the air speed is generally greater than 0.15 m/s and could be greater than 0.2 m/s in areas close to air supply devices or where supply air jets are deflected by downstand beams or other geometric features of the space, and such speeds should be avoided. It is possible to counter draught discomfort to a certain extent by increasing air temperatures, as indicated in Figure 8.16.

3.8 Thermal comfort: compensation and adaption

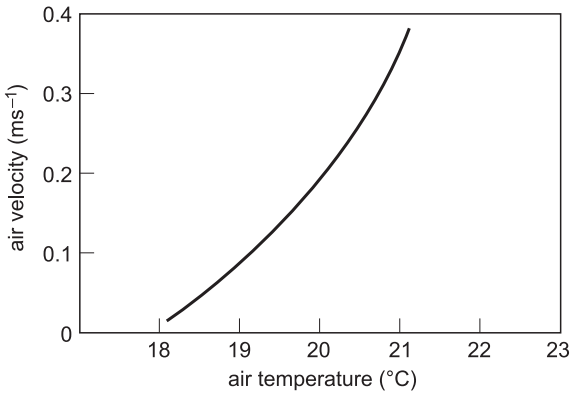
The perception of thermal comfort is a function of the combination of the physical environment (air and radiant temperature, air movement and relative humidity) and the activity and clothing level of the person. To some extent the environmental factors are compensatory. For example, during cool conditions, an increase in air movement can be compensated for by an increase in air temperature, while in warm conditions, an increase in relative humidity can be compensated for by an increase in air movement. People can also adapt their clothing levels, activity levels and posture in response to the prevailing thermal conditions. In this way they are varying either their rate of metabolic heat production or their rate of body heat loss. Thermal indices use combinations of the comfort parameters in a compensatory way to provide a single measure of thermal comfort.

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8.15 *A psychrometric chart showing that a dry bulb temperature of 19°C and a wet bulb temperature of WC relates to an RH of 60%*



8.16 *The interaction of air temperature and air movement on perceived comfort*

The *resultant temperature,* sometimes called *globe temperature,* can be used to give a more representative measure of comfort than air temperature alone. It is a combination of air temperature and mean radiant temperature, in a proportion comparable to that of the body's heat loss. At low air speeds (<0.1 m/s) the following relationship can be applied:

$$t_{res} = 0.5\, t_{mrt} + 0.5\, t_a \qquad (6)$$

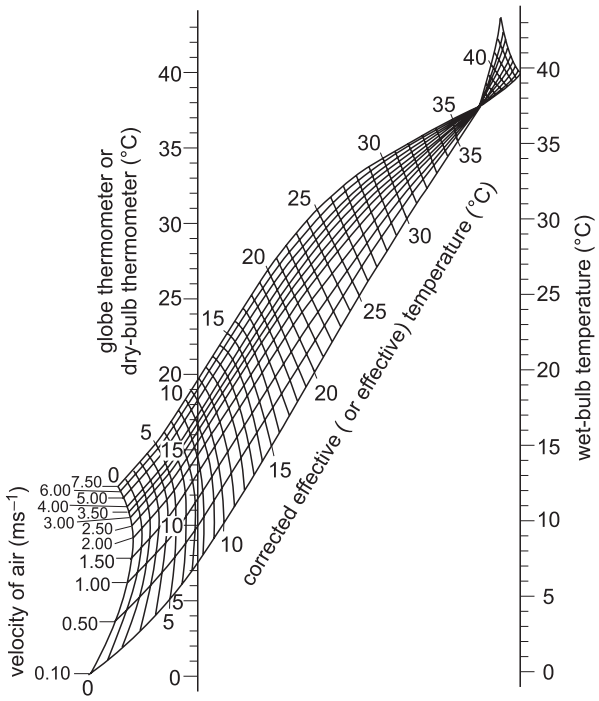
where t_{res} = resultant temperature (°C)
t_{mrt} = mean radiant temperature (°C)
t_a = air temperature (°C)

The resultant temperature can be measured at the centre of a black globe of 100 mm diameter (although globes between 25 and 150 mm will give acceptable results).

The *corrected effective temperature (CET)* relates globe temperature, wet bulb temperature and air speed. It is equivalent to the thermal sensation in a standard environment with still, saturated air for the same clothing and activity. CET can be represented in nomogram form as shown in Figure 8.17.

3.9 PMV and PPD

The *predicted mean vote (PMV)* is a measure of the average response from a large group of people voting on the scale below:



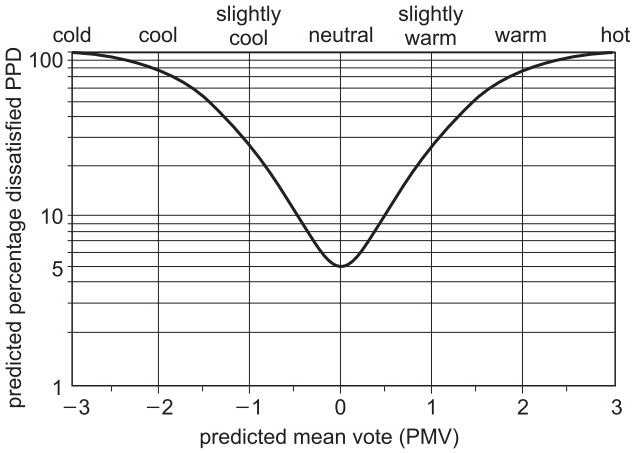
8.17 *Nomogram for estimating corrected effective temperature (CET)*

Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	–1
Cool	–2
Cold	–3

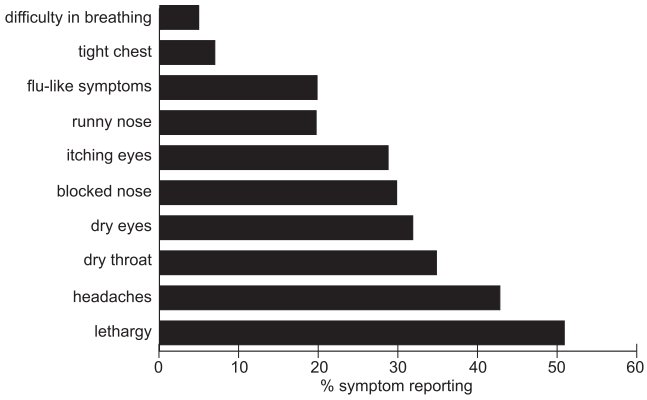
The PMV can be calculated from *Fanger's comfort equation* which combines air temperature, mean radiant temperature, RH and air speed together with estimates of activity and clothing levels. The *percentage people dissatisfied (PPD)* provides a measure of the percentage of people who will complain of thermal discomfort in relation to the PMV. This is shown graphically in Figure 8.18 and can be calculated from:

$$PPD = 100 - 95 \exp(-0.03353\, PMV^4 - 0.2179\, PMV^2) \qquad (7)$$

The implication of PPD is that there is no condition where every one will experience optimum comfort conditions. It predicts that for a typical occupied work place, there will always be 5 per cent of people who will report discomfort.



8.18 *PPD as a function of PMV*



8.19 *Sample percentage sick building syndrome symptom reporting for air conditioned offices*

Table VII Air and infiltration rates for building types

Type of building	Air t_{el} (°C)	Air infiltration allowance (h^{-1})
Art galleries and museums	19–21	1
Assembly and lecture halls	22–23	0.5
Airport terminals:		
Baggage reclaim	12–19	
Check-in areas	18–20	
Customs areas	12–19	
Departure lounges	19–21	
Banking halls	19–21	1–1.5
Bars	20–22	1
Canteens and dining rooms	22–24	1
Churches and chapels	19–21	0.5–1
Computer rooms	19–21	
Conference/board rooms	22–23	
Dining and banqueting halls		0.5
Exhibition halls	9–21	0.5
Factories:		
Sedentary work	19–21	
Light work	16–19	
Heavy work	11–14	
Up to 300m^3 volume		1.5–2.5
300m^3 to 3000m^3		0.75–1.5
3000m^3 to 10,000m^3		0.5–1.0
Over 10,000m^3		0.25–0.75
Fire stations, ambulance stations:		
Watch rooms	22–23	0.5–1
Recreation rooms	20–22	0.5–1
Gymnasia		0.75
Flats, residences and hostels:		
Living rooms	20–23	1
Bedrooms	17–19	0.5
Bed-sitting rooms		1
Bathrooms	26–27	2
Toilets	19–21	1.5
Service rooms		0.5
Hall/Stairs/Landing	19–24	1.5
Kitchen	17–19	
Public rooms		1
Hospitals:		
Wards and patient area	22–24	2
Circulation spaces	19–24	1
Consulting/treatment rooms	22–24	
Nurses stations	19–22	1
Operating theatres	17–19	0.5
Waiting rooms		1
Storerooms		0.5
Hotels:		
Bathrooms	26–27	1
Bedrooms	19–21	1
Public rooms		1
Corridors		1.5
Foyers		1.5
Laboratories		1
Law courts	19–21	1
Libraries:		
Reading rooms	22–23	0.5–0.7
Stack rooms	19–21	0.5
Store rooms	15	0.25
Offices:		
General	21–23	1
Executive	21–23	
Open plan	21–23	
Private		1
Storerooms		0.5
Police cells	19–21	5
Railway/coach stations		
Concourse (no seats)	12–19	
Ticket office	18–20	
Waiting room	21–22	
Restaurants and cafes	22–24	1
Schools and colleges:		
Classrooms	19–21	2
Lecture rooms	19–21	1
Studios	19–21	1
Retail buildings:		
Shopping malls	19–24	
Small shops, department stores	19–21	
Supermarkets	19–21	
Sports pavilions:		
Dressing rooms	22–24	1
Hall	13–16	
Squash courts	10–12	
Swimming pools:		
Changing rooms	23–24	0.5
Pool hall	23–26	0.5
Television studios	19–21	
Warehouses:		
Working and packing spaces		0.5
Storage space		0.2

The values quoted for rates of air infiltration in this table should not be used for the design of mechanical ventilation, air conditioning or warm air heating systems.

3.10 Sick building syndrome (SBS)

This is a term used to describe a set of commonly occurring symptoms that affect people at their place of work, usually in office-type environments, and which disappear soon after they leave work. These symptoms include dry eyes, watery eyes, blocked nose, runny nose, headaches, lethargy, tight chest and difficulty with breathing. A typical percentage of symptom reporting for air-conditioned offices is shown in Figure 8.19. *The personal symptom index (PSI)* is often used as a measure of the average number of symptoms per person for a whole office or zone.

Workers who report high levels of symptoms also often report problems associated with thermal comfort, and in general perceive the air quality as stale, dry and warm. Studies have indicated that air-conditioned buildings appear to have a higher level of complaint of SBS than naturally ventilated buildings. Possible reasons for this include cost cuts in their design, difficulties and complexities in their maintenance and operation, problems associated with hygiene and cleanliness (especially the air-distribution ductwork) and low ventilation effectiveness due to short-circuiting between supply and extract. Workers with a higher risk of symptoms are those in open-plan offices more than those in cellular ones, clerical workers more than managerial, women more than men, those in public sector buildings more than private, those in air-conditioned offices more than naturally ventilated ones, and those buildings where there is poor maintenance and poor operation of controls.

3.11 Ventilation and indoor air quality

Ventilation is required to maintain good air quality for health and comfort. Tables VII and VIII give recommended values for internal temperatures, infiltration rates and ventilation rates. The outside air requirement for occupants is generally taken as 10l/s/person. Ventilation is considered in more detail in Section 7.

Table VIII Ventilation rates for various types of building

Building use	Air supply rate
Public and commercial buildings	8L/Person
Hotel bathrooms	12L/Person
Hospital operating theatres	650 to 1000m^3/s
Toilets	>5 air change per hour
Changing rooms	10 air change per hour
Squash courts	4 air change per hour
Ice rinks	3 air change per hour
Swimming pool halls	1.5L/m^2 (of wet area)
Bedrooms and living rooms in dwellings	0.4 to 1 air change per hour
Kitchens in dwellings	60L/s
Bathrooms in dwellings	15L/s

Source: CIBSE Guide B: Heating, Ventilating, Air Conditioning and Refrigeration, 2005.

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4 SITE AND CLIMATE

4.1 Introduction

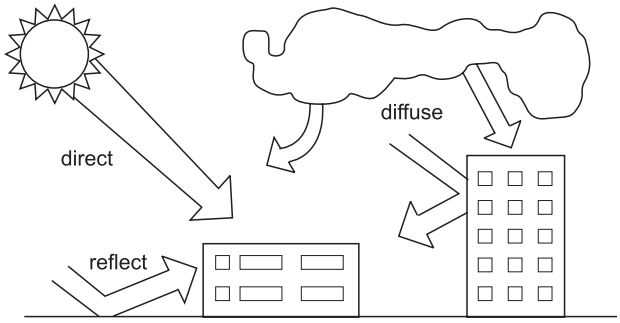
The site and climatic conditions have a major impact on the thermal design of a building, and should be considered during the early stages of design. Also, the building will modify the existing climate of the site to create a specific microclimate surrounding itself and affecting the microclimate of existing neighboring buildings. Climate data is available for many parts of the world, often as hourly values compiled into a standard *Test Reference Year (TRY)* format. The climate conditions that relate directly to thermal design include:

- solar radiation, sun path and cloud cover;
- wind speed and direction;
- air temperature;
- relative humidity;
- rainfall and driving rain index.

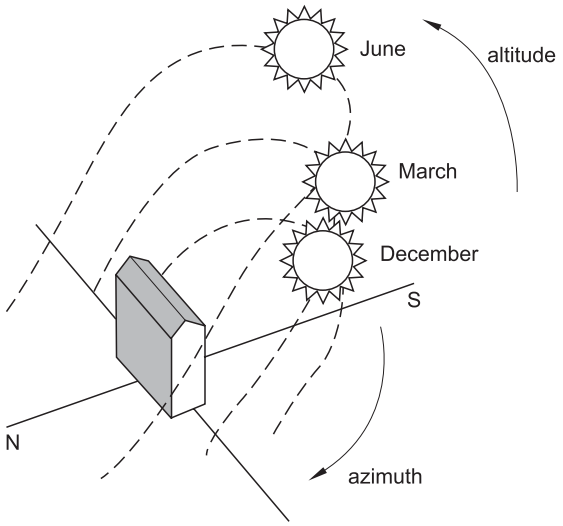
4.2 Solar radiation and sun path

Solar radiation impacts on the building in three forms, Figure 8.20:

- direct radiation, from the position of the sun in the sky;
- diffuse radiation, from the whole of the visible sky;
- reflected radiation *(albedo)* from adjacent surfaces.



8.20 *Direct, diffuse and reflected solar radiation*



8.21 *Sun angles indicating azimuth and altitude*

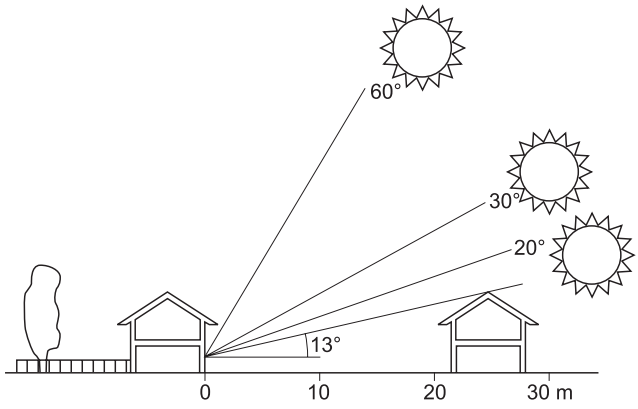
All three components will vary according to time of day, time of year and cloud cover, and how much sky is seen by the building depending on natural and man-made obstructions. The solar path can be determined from the altitude and azimuth angles of the sun as in Figure 8.21. Typical values of solar radiation are given in Tables IX and X, and the effect of sun angle and overshadowing in Figure 8.22. The annual variation of possible hours of daily sunshine for the UK is presented in Figure 8.23.

Table IX Solar altitude, and direct and diffuse solar radiation (cloudy and clear sky) at mid-day for South-east England

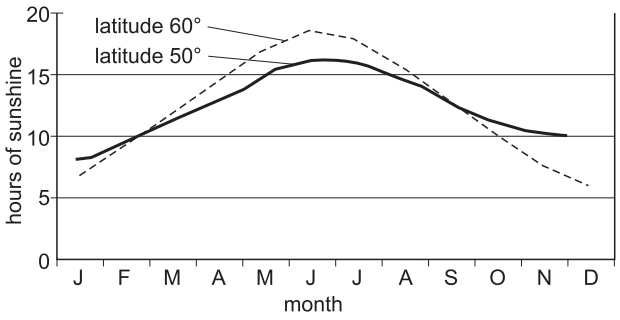
			Diffused (W/m²)	
Month	**Altitude**	**Direct Normal (W/m²)**	**Cloudy**	**Clear**
June	64	900	310	100
July/May	60	895	295	100
August/April	52	865	255	95
September/March	40	815	195	85
October/February	2	700	140	75
November/January	20	620	90	60
December	17	560	75	50

Table X Daily mean solar irradiances (W/m²) on vertical and horizontal surface, diffused for cloudy/clear sky condition

	S	**SE/SW**	**E/W**	**NE/NW**	**N**	**H**	**DF**
June	105	135	140	85	35	295	120/50
July/May	110	140	135	75	20	270	110/45
August/April	150	150	115	45	5	215	90/40
September/March	175	145	80	20	0	140	60/30
October/February	165	120	50	5	0	80	35/20
November/January	125	90	25	0	0	35	20/15
December	100	70	20	0	0	25	15/10



8.22 *Sun angle and overshadowing*



8.23 *The annual variation of possible hours of sunshine for the UK. Northern regions receive more hours in summertime*

The largest component of solar radiation is the direct radiation, but the reflected radiation can be significant where there are hard light-coloured reflective surfaces adjacent to the building, either from the built form itself or from existing buildings and landscaping. Table XI contains data on reflected radiation for different surfaces (the solar absorption of a surface is: 1 – reflectance).

Cloud cover is measured in octal on a scale of 0 to 8, with 0 being completely cloudless and 8 completely overcast. The diffuse radiation component will be higher for an overcast sky as shown in Table IX. Cloudiness (C) is a measure of the proportion of cloud in the sky. C is zero for a clear sky and 1 for an overcast sky.

4.3 External air temperature

The external air temperature will affect the rate of transmission and convective heat loss from a building. It will typically vary over a

Table XI Reflected radiation for different surfaces

Surface	Reflectance (R)
Glass	0.10
Concrete, light grey	0.25—0.40
Brick, fletton	0.30
Brick, white gault	0.70
Timber panelling, oak	0.25
Plaster, pink	0.65
White emulsion paint on plain plaster surface	0.80
White emulsion paint on no-fines concrete	0.60
White emulsion paint on wood wool slab	0.50
White asbestos cement; Portland cement, smooth	0.40
Portland cement, rough	0.25
Cement screed	0.45
PVC tile, cream/brown/dark brown	0.45/0.25/0.10
Paper, white	0.80
Stainless steel	0.35
Asphalt	0.15
Uncultivated field	0.26
Bare soil	0.17
Grass	0.25
Water	0.05–0.22
Snow (fresh)	0.80–0.90
Snow (old)	0.45–0.70

Source: CIBSI Lighting Guide LG10:1999.

24-hour period (the diurnal variation) and over a year (seasonal variation). It will also vary with location. Table XII presents the average monthly external air temperature for different locations within the UK. Figure 8.24 shows the typical diurnal temperature variations for southern England.

4.4 Sol-air temperature

When solar energy is absorbed by an external wall it has the same effect, in relation to heat loss, as a rise in external air temperature. The sol-air temperature is the external air temperature which, in the absence of solar radiation, would give rise to the same heat transfer through the wall as takes place with the actual combination of external temperature and incident solar radiation:

$$t_{sa} = (\alpha I_s + \varepsilon I_l)\, R_{so} + t_{ao} \qquad (8)$$

where t_{sa} = sol-air temperature
t_{ao} = external air temperature
α = solar absorptance
ε = long-wave emissivity
R_{so} = external surface resistance
I_s = solar irradiance (W/m^2)
I_l = long-wave radiation loss (W/m^2)
= 93–79 C (horizontal surfaces)
= 21–17 C (vertical surfaces)
C = cloudiness (see para 4.2)

4.5 External relative humidity

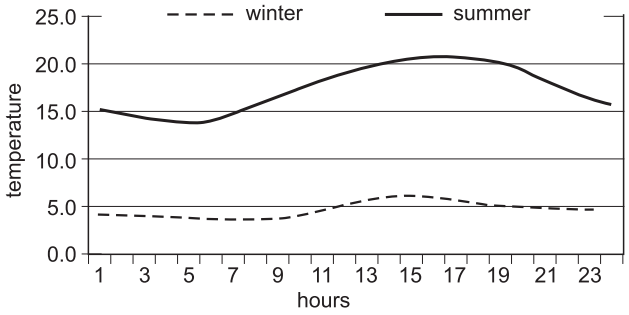
The external RH will vary with external air temperature and moisture content of the air. During periods of warmer weather, the RH may be relatively low due to the higher external air temperatures, although at night it will rise as the air temperature falls, Figure 8.25. During cold weather the external RH can rise typically to over 90 per cent. Figure 8.26 presents seasonal average RH values for the UK.

4.6 Rainfall and driving rain index

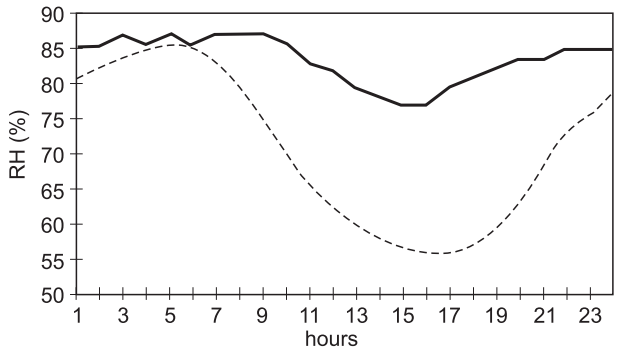
Rainfall can affect thermal performance. If an external surface is wet then it will lose heat by evaporation and this will reduce the external surface temperature, sometimes to below air temperature, increasing heat loss. Wind-driven rain ('driving rain') can penetrate some constructions, causing a reduction in thermal resistance. In areas of high incidence of driving rain, care must be taken to select constructions that provide protection against rain penetration.

4.7 Wind

The impact of wind on a building has two main consequences for thermal design. It affects the convective heat loss at the external



8.24 *Diurnal UK variations for winter (January) and summer (June) for south-east England*



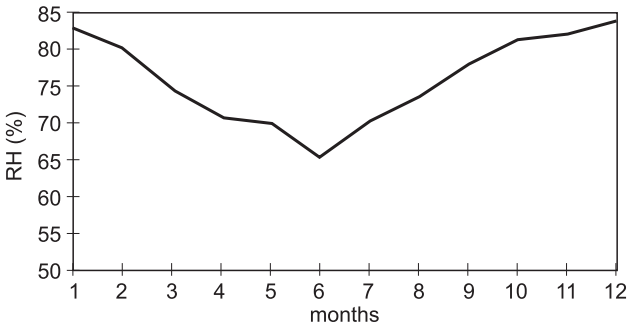
8.25 *Diurnal RH variation for January (solid) and June (dotted)*

Table XII UK average daily temperature

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Belfast													
Max.	8.3	10.8	11.3	15.3	18.9	19.5	23.4	23.6	19.5	15.6	11.7	12.9	15.9
Min.	–2.2	–1.7	0.4	2.8	2.6	4.6	8.1	9.0	7.1	2.0	0.6	–0.2	2.8
Ave.	4.0	4.1	6.0	7.9	10.8	12.7	14.9	14.6	11.9	9.7	6.6	5.2	9.0
Glasgow													
Max.	11.0	11.1	12.6	13.4	16.2	21.0	22.2	24.4	20.4	18.4	14.2	11.5	16.4
Min.	–2.3	–4.8	–3.6	–1.7	0.5	3.5	6.4	7.0	4.2	–1.0	–2.9	–3.2	0.2
Ave.	4.8	3.7	6.0	6.5	9.8	13.3	14.8	14.3	12.3	9.9	5.1	5.5	8.8
London													
Max.	10.1	9.7	13.1	13.7	19.7	23.5	30.3	25.6	20.7	17.3	17.1	13.7	17.9
Min.	–1.3	–2.2	1.4	0.0	3.5	6.2	10.3	9.4	7.5	1.4	2.6	–1.1	3.1
Ave.	5.3	3.4	8.0	8.1	11.2	15.8	19.7	16.9	13.1	9.9	10.4	6.7	10.7
Cardiff													
Max.	13.9	14.7	14.9	14.3	22.7	23.5	22.6	26.8	23.1	18.4	15.1	12.2	18.5
Min.	2.5	1.7	4.1	3.3	6.2	9.3	10.6	11.6	9.4	4.9	1.6	–1.1	5.3
Ave.	7.5	9.1	10.1	9.4	15.6	15.7	16.9	17.4	15.6	12.2	8.1	7.5	12.1

Source: Energy Plus Weather Data.

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8.26 *Seasonal average daily RH values for the UK*

surfaces, as well as the ventilation and infiltration rate and the associated heat loss.

4.8 Wind speed and direction

Wind speed is measured in m/s or sometimes in knots where 1 knot equals 0.4 m/s. Wind direction is usually measured at eight points of the compass or, when required in more detail, in degrees clockwise from south. The wind speed and direction can be represented by a *wind rose,* Figure 8.27, which indicates the relative frequency and speed of wind from different directions.

It is often useful to know the average temperatures associated with each wind direction, Figure 8.28. For example, for a specific location, the main prevailing wind may have relatively warmer temperatures, whereas a less frequent wind direction might have cold temperatures and give rise to greater problems.

Wind speed increases with height due to the frictional drag of the ground. The profile of variation with height is called the *boundary layer,* and it will vary from town to open country locations, as shown in Figure 8.29, and according to the relationship:

$$v/v_r = kH^a \quad (9)$$

where v = mean wind speed (m/s) at height H (m)
v_r = mean wind speed (m/s) at height 10 m
values of k and a from Table XIII

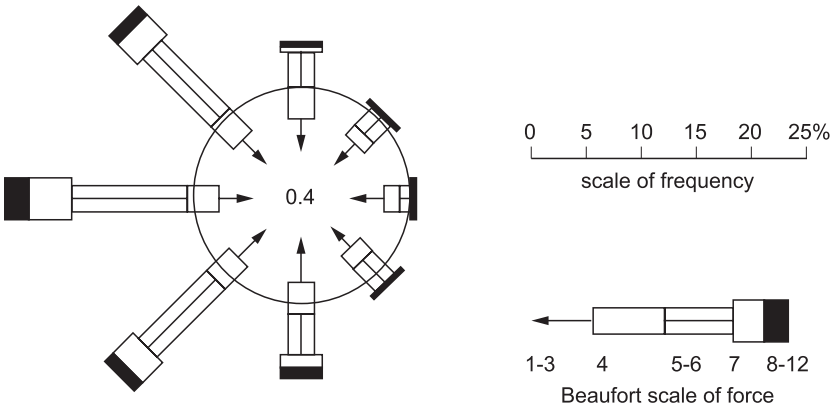
4.9 Dynamic and static wind pressures

The static pressure (P_s) of the air is the pressure in the free-flowing air stream (as shown on the isobars of a weather map). Differences in static pressure arise from global thermal effects and cause windflow. The dynamic pressure (P_d) is the pressure exerted when the wind comes into contact with an object such as a building, Figure 8.30. The total or stagnation pressure (P_t) is the sum of the static and dynamic pressures ($P_t = P_s + P_d$). In most cases P_s can be ignored in thermal design as it is usual to deal with pressure differences across a building, i.e. the difference in P_d. The dynamic wind

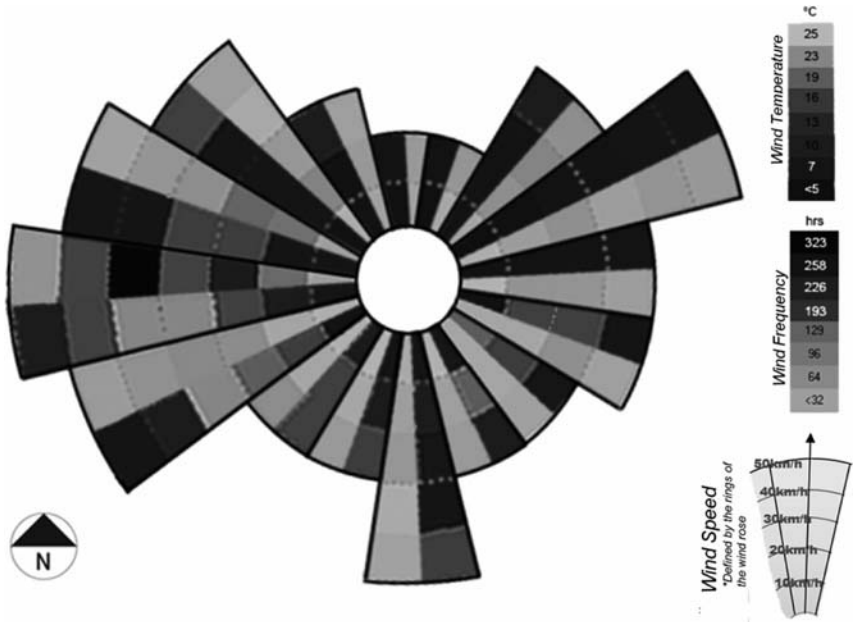
Table XIII Values of coefficients for formula (9)

Terrain	k	a
Open, flat country	0.68	0.17
Country with scattered wind breaks	0.52	0.19
Urban	0.35	0.22
City	0.21	0.24

Source: CIBSE Guide A: Environmental Design, 2006.

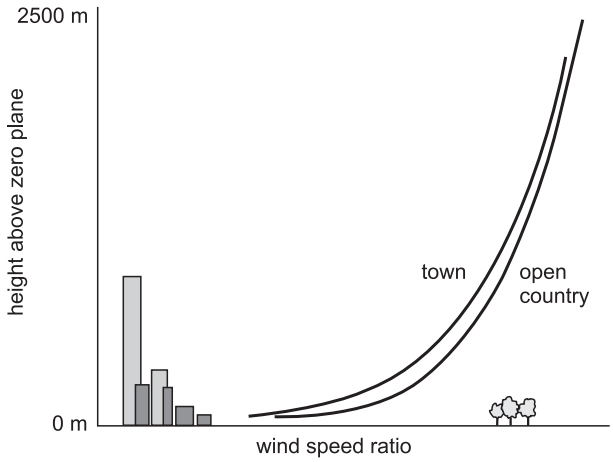


8.27 *Standard wind rose*

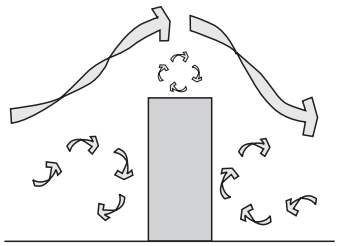


8.28 *Wind rose with temperature*

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8.29 *Boundary layer wind profile*



8.30 *Wind pressure over a building envelope*

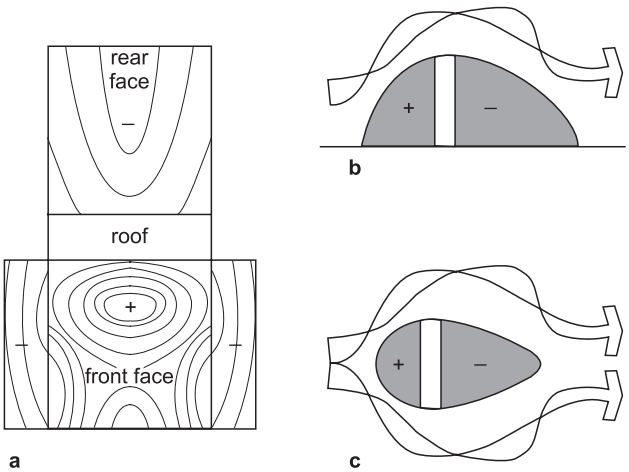
pressure is related to the air density *(ρ)* and the square of the wind speed (v) ($P_d = 0.5.\ \rho.\ v^2$ (Pa)).

4.10 Pressure coefficients

The impact of wind on the building form generally creates areas of positive pressure on the windward side of a building and negative pressure on the leeward and sides of the building. The pressure coefficient is the relative pressure at a specific location on the building and it can be used to calculate the actual dynamic pressure for a given wind speed and air density.

$$P_d = C_p \times 0.5\ \rho v^2 \text{ (Pa)} \qquad (10)$$

where ρ = density of the air (kg/m)
v = wind speed (m/s) at a reference height, h (m)
C_p = pressure coefficient measured with reference to the wind speed at the height h.



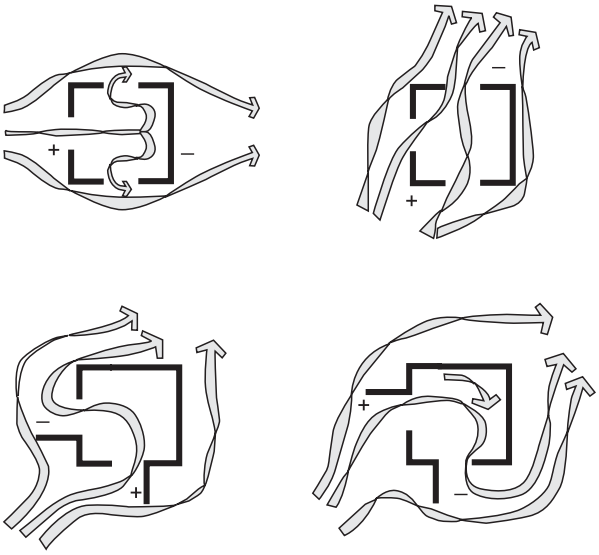
8.31 *Pressure coefficients can be manipulated by the form of the building: a Pressure distribution; b Section; c Plan*

The pressure coefficients are dependent on general building form, as shown in the example in Figure 8.31. A scale model of the building can be placed in a wind tunnel to predict C_{ps}. Building form is the main determinant of pressure distribution for a given wind direction. Openings should then be located to produce the required 'cross-ventilation' from pattern, Figure 8.32.

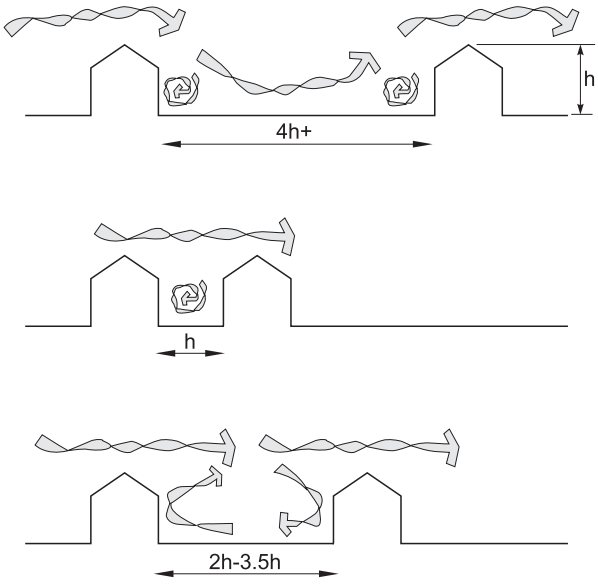
4.11 External sheltered areas

There are 'rules of thumb' which can be applied to estimate the impact of wind on buildings, in relation to creating external sheltered areas (e.g. courtyards). These are shown in Figure 8.33. The figures show that distances between buildings should be less than about 3.5 times the building height, in order to create shelter from the prevailing wind.

Barriers can be used to reduce wind speed and create external sheltered areas. Porous barriers are often more suitable than 'hard' barriers as they reduce wind speed and do not induce counter wind flow areas as shown in Figure 8.34. High wind conditions can be created by downdraughts from tall buildings (as in Figure 8.30), wind 'canyons' or acceleration around corners Figure 8.35.

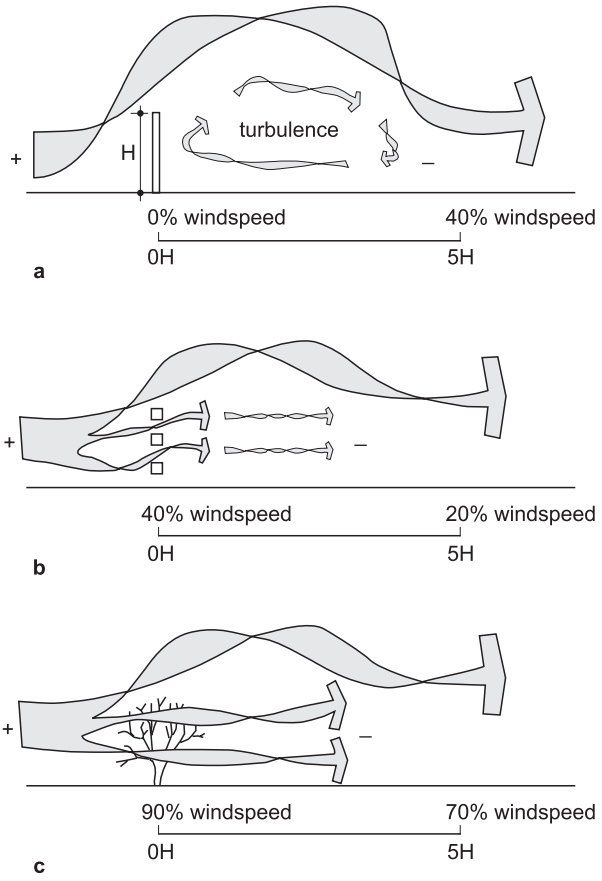


8.32 *Typical wind flow pattern around a high-rise building*

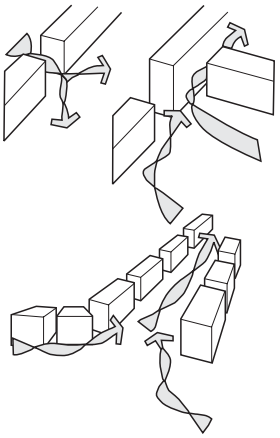


8.33 *Building spacing and provision of sheltered external spaces*

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8.34 *Barriers and their effect on wind flow: a Dense barrier; b Medium barrier; c Loose barrier*



8.35 *Localised high wind speeds can be caused by 'canyon' effects and acceleration around corners*

4.12 Site analysis

An overall site analysis should identify the prevailing wind, the seasonal sun paths, and existing shelter and obstructions, well as other aspects, such as noise sources and views, as in Figure 8.36.

4.13 Global warming

It is now generally accepted that there will be global warming based on the past emission of greenhouse gases. The current predicted average temperature rise due to global warming for the UK is around 2°C by the middle of this century, and between 3 and 6°C by the end of the century. By 2080 degree days are predicted to fall by about between 25 to 40 per cent from north UK down to London respectively, and since the early 1980s until now there has already been a 10 per cent reduction. Buildings should therefore be designed to respond to future weather data rather than historical data and there is now future weather data available through CIBSE. The thermal design will likely be affected by increases in



8.36 *Example of environmental site analysis*

temperature and increases in extreme events of wind and rain. In some countries there may be untypical cooler periods, for example in the hotter places where heating was not required there may be the need in future, while in more temperate climates cooling may become more an issue. The predicted increase in summer temperatures in temperate climates might lead to the adoption of a heavyweight construction with ventilation night cooling or ground cooling. There should be more attention to shading and microclimate design to reduce heat gains. There is therefore the need to adopt an adaptive approach to design to allow for future climate change, as well as a mitigating approach to reduce carbon dioxide emissions in order to reduce climate change.

5 BUILDING FABRIC

5.1 U-values

The U-value of the wall, roof or floor element of a building can be used to provide an estimate of its heat loss (or gain). The U-values of typical construction types are given in Table XIV. The U-value of a wall construction can be calculated using the following procedure:

1 Calculate the resistance of the individual layers of the construction (see Section 2 and refer to *k*-values in Table I).

$$R_{1,2,3...} = x/k \quad (11)$$

where $R_{1,2,3...}$ = thermal resistance of element 1, 2, 3 . . . (m^2K/W)
x = thickness (m)
k = thermal conductivity (W/mK)

Select the appropriate values for the internal and external surface resistances (R_si and R_{se}) by referring to Tables XV and XVI.

2 Select the appropriate resistance of any air cavities (R_{cav}) by referring to the standard Table XVII.
3 Calculate the total thermal resistance (R_{total}) of the wall using the following formula:

$$R_{total} = R_1 + R_2 + R_3 + \ldots + R_{si} + R_{se} + R_{cav} \quad (12)$$

4 Calculate the U-value, that is, the conductance, of the wall using the following formula:

$$\text{U-value} = 1/R_{total} \quad (13)$$

The heat loss (Q_f) associated with an element of the construction of area (A) and with a temperature difference (D_T) across it can be estimated as follows:

$$Q_f = U \times A \times D_T \quad (14)$$

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Table XIV U-values of typical construction types

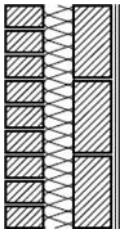
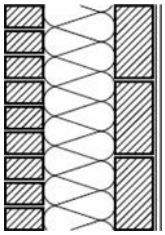
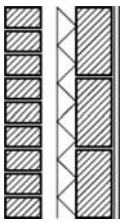
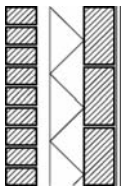
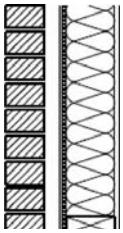
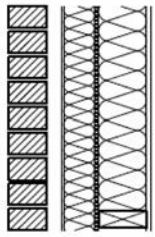
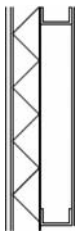
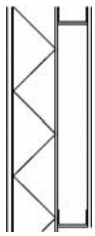
Type	2010 Building Regulation		2013 Projected Targets	
Masonry walls	**U = 0.28W/m²/K** *(from left to right)* Brickwork (102.5mm, k = 0.77W/mk) Glass wool (90mm, k = 0.035W/mk) Blockwork (100mm, k = 0.11W/mk Plaster (6mm, k = 0.16W/mk)		**U = 0.15W/m²/K** *(from left to right)* Brickwork (102.5mm,k = 0.77W/mk) Glass wool (210mm, k = 0.035W/mk) Blockwork (100mm, k = 0.11W/mk Plaster (6mm, k = 0.16W/mk)	
Masonry walls with cavity	**U = 0.28W/m²/K** Brickwork (102.5mm, k = 0.77W/mk) Cavity (50mm) Polyurethane (60mm, k = 0.029W/mk) Blockwork (100mm, k = 0.11W/mk Plaster (6mm, k = 0.16W/mk)		**U = 0.15W/m²/K** Brickwork (102.5mm, k = 0.77W/mk) Cavity (50mm) Polyurethane (125mm, k = 0.029W/mk) Blockwork (100mm, k = 0.11W/mk Plaster (6mm, k = 0.16W/mk)	
Timber frame walls	**U = 0.28W/m²/K** Brickwork (102.5mm, k = 0.77W/mk) Cavity (50mm) Mineral wool (140mm, k = 0.035 W/mk) Blockwork (100mm, k=0.11W/mk Plaster (6mm, k=0.16W/mk)		**U = 0.15W/m²/K** Brickwork (102.5mm, k = 0.77W/mk) Cavity (50mm) Mineral wool outside of frame (90mm, k = 0.035) Mineral wool (140mm, k = 0.035) Blockwork (100mm, k = 0.11W/mk Plaster (6mm, k = 0.16W/mk)	
Composite steel panel walls	**U = 0.28W/m²/K** Composite panel (80mm) Steel structure		**U = 0.15W/m²/K** Composite panel (125mm) Steel structure	
Timber truss roof	**U = 0.20W/m²/K** *(from top down)* Roof slats (12.5mm, k = 0.84W/mk) Timber rafter Mineral wool insulation above rafters (75mm, k = 0.035 W/mk) Mineral wool insulation between rafters (125mm, k = 0.035 W/mk)		**U = 0.13W/m²/K** *(from top down)* Roof slats (12.5mm, k = 0.84W/mk) Timber rafter Mineral wool insulation above rafters (125mm, k = 0.035 W/mk) Mineral wool insulation between rafters (200mm, k = 0.035 W/mk)	

Table XV Internal surface resistance, R_{si}

Building element	Direction of heat flow	Surface resistance (m²K/W)
Walls	Horizontal	0.13
Ceiling or roofs (flat or pitched), floor	Upward	0.10
Ceiling or floors	Downward	0.17

Source: CIBSE Guide A: Environmental Design, 2006.

Table XVI External surface resistance, R_{se}

		Surface resistance (m²K/W)		
Building element	Direction of heat flow	BS NE ISO 6946 (normal design value)	Sheltered	Exposed
Wells	Horizontal	0.04	0.06	0.02
Roofs	Upward	0.04	0.06	0.02
Floors	Downward	0.04	0.06	0.02

Source: CIBSE Guide A: Environmental Design, 2006.

Table XVII Values of surface and airspace resistance (m²K/W)

Structure	External surface resistance	BS NE ISO 6946 (normal design value)	Airspace resistance
External walls	0.04	0.13	0.18
Party walls and internal partitions	0.13	0.13	0.18
Floors			
Pitched	0.04	0.10	0.16
Flat	0.04	0.10	0.16
Ground floors	0.04	0.17	0.21
Internal floors/ceilings	0.13	0.13	0.18

Example 2

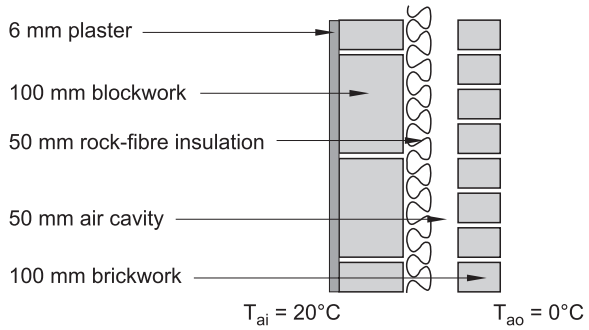
U-value calculation

Calculate the U-value of the insulated cavity wall construction shown in 8.37 for a normal exposure site. Estimate the rate of heat loss through 10 m² of the fabric for a 20°C temperature difference across the wall.

The Resistance is calculated in Table XVIII, giving a total resistance of 3.57 m²K/W.

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Hence U-value = 1/3.57 = 0.28 W/m²K
and heat loss Q_t = 0.28 × 10 × 20 = 56 W



8.37 *Construction of wall in Example 2*

Table XVIII Calculation for Example 2

	Thickness (m)	K-value (W/mK)	Resistance (m²K/W)
Rsi	–	–	0.13
Plaster	0.006	0.16	0.08
Blockwork	0.10	0.11	0.91
Cavity Insulation	0.06	0.029	2.10
Airgap	0.50	–	0.18
Brickwork	0.1025	0.84	0.12
Rse	–	–	0.04
Total	–	–	3.57

5.2 Thermal insulation

A high standard of thermal insulation in buildings in a temperate climate such as in the UK has the following benefits:

1 It reduces the rate of heat loss, and therefore buildings use less energy to maintain comfortable internal thermal conditions. This also means that people are more able to afford to heat their buildings to comfortable conditions, and
2 It raises internal surface temperatures and therefore reduces the risk of surface condensation.

5.3 Types of insulation

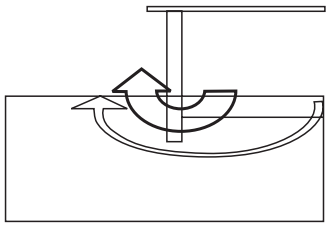
Most thermal insulating materials have k-values of 0.03–0.04 W/mK. The most common types are:

- Mineral fibre – this can be glass fibre or rock fibre and is available in lower-density roll form or higher-density batt form. The roll form is usually used to insulate roofs, while the batt form is often used in walls where, because of its greater rigidity, it is more appropriate to vertical fixing. Mineral fibre insulation forms a good attachment to the inner skin of the construction, leaving no air gap. It is often used in wall and roof industrial cladding type constructions. Mineral fibre may also be in a loose form that can be 'blown' into a cavity, to 'cavity fill' an existing or new construction (see below).
- Rigid board – this is usually made from foamed plastic or foamed glass. *k*-values are typically 0.037 W/m-K. It can be gas filled to give lower *k*-values, although boards which use ozone-depleting gases should be avoided. If rigid board insulation is used, it is essential to achieve a good attachment to the inner skin of the construction in order to avoid airflow between the inner skin and the insulation layer, which will detract from its U-value performance. The cavity should be kept clean and mortar 'snobs' and other sources of blockage on the inner skin should be eliminated before the insulation is fixed. Rigid board insulation is often used in composite 'factory made' cladding system constructions, where it is installed between two layers of metal sheeting.
- Blown insulation cavity fill, including mineral or cellulose fibres or plastic granules. Insulation is blown into the cavity after completion of construction. Care is needed in installing blown insulation in order to avoid any voids in the insulation in areas where the insulation has difficulty in penetrating, for example, blocked areas of the cavity. This method of cavity insulation has the advantage that it can be applied to existing constructions. Recycled paper insulation, for example, produced from 100 per cent recycled newspaper, has very low embodied energy compared to most other insulation materials. It has a *k*-value of 0.035 W/m-K.
- Low-density concrete blocks. Blocks with densities down to 480kg/m³ give thermal insulation with *k*-values of 0.11 W/mK. Such blocks are normally 210 mm in thickness and are used for the inner skin of a construction; this may be an infill panel or a loadbearing wall. They contribute to the thermal insulation of cavity construction, especially when the cavity needs to be left empty for weather resistance in exposed locations. Lightweight blockwork requires sufficient expansion joints to avoid cracking.

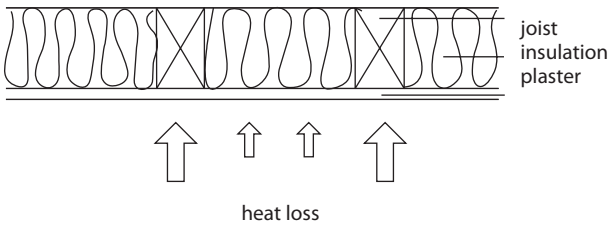
5.4 Thermal bridging

Thermal bridging takes place through the details of a construction that have relatively low thermal resistance to heat flow; they have a high U-value in comparison with the rest of the construction. Common areas of thermal bridging are around windows, doors and structural elements. Heat will flow from high to low temperatures by conduction along the path of 'least thermal resistance'. In the case of jambs, sills, lintels and floor edges, the least resistance path will generally be along the highly conductive materials such as metal and dense concrete. Heat loss at thermal bridges can be reduced by adding insulation and thermal breaks, and ensuring that the insulation is continuous over the building envelope. If thermal bridging occurs it will result in increased heat loss and increased risk of condensation.

There are two types of thermal bridging, non-repeating and repeating. The heat loss through solid ground floors is a specific case of a non-repeating thermal bridge where heat will follow the three-dimensional line of least thermal resistance as shown in Figure 8.38. Where there are structural elements such as timber joists in ceilings, these are repeating thermal bridges, Figure 8.39.



8.38 *The edge losses are dominant in floor heat loss*



8.39 *Increase in heat loss through repeating thermal bridging due to structural elements*

The heat loss due to repeating thermal bridging can be included in a standard U-value calculation using the 'combined method'. The heat loss at a non-repeating thermal bridge can be estimated from its thermal transmittance, or psi (ψ) value. This is defined as the rate of heat flow per degree temperature difference per unit length of a thermal bridge, measured in W/mK. ψ values can be obtained from measurement or from detailed calculations. If the ψ value is known (Table XIX): the heat loss $_{(HTB)}$ through a thermal bridge can be estimated using,

$$H_{TB} = l \times \psi$$

where l = length of the thermal bridge in meters.

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Table XIX Common ψ values

Junction detail in external wall	Default ψ value (W/mK)
Steel lintel with perforated steel base plate	0.50
Other lintels (including other metal lintels)	0.30
Sill	0.04
Jamb	0.05
Ground floor	0.16
Intermediate floor within a dwelling	0.07
Eaves (insulation at ceiling level)	0.06
Corner (normal)	0.09
Corner (inverted)	–0.09

Source: SAP 2009.

This must then be added to the elemental heat loss for the wall, roof, or floor.

5.5 Installation of insulation

The following guidelines should be followed when designing an insulated construction.

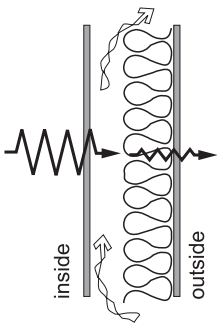
Insulation should always be located on the 'warm and dry side' of a ventilated cavity (unless informed otherwise, it is usual to assume that all cavities are ventilated). If a cavity or air gap is ventilated on the warm side of the insulation this could provide a 'short circuit' for heat loss as indicated in Figure 8.40.

Avoid air infiltration through or around the insulation material as indicated in Figure 8.41. This will result in short-circuiting of heat loss. Ensure continuity of insulation at design details, e.g. eaves and floor junctions.

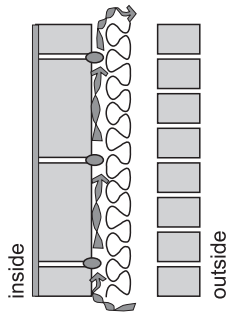
- Ensure that there is a vapour barrier on the warm side of the insulation to guard against condensation, and degrading of the insulation properties through dampness.
- Avoid compression of low-density insulation when installed in a construction.

5.6 Glazing

Glass is the main material used for glazing. It is available in a wide range of configurations with different thermal properties.



8.40 *Insulation should not be placed on the cold side of a ventilated cavity as its insulation value will be considerably reduced*



8.41 *Mortar snobs may distance the insulation from the inner skin introducing airflow on the warm side of the insulation and short-circuiting the heat flow through convective losses*

5.7 Thermal performance of glass

Glass is transparent to short-wave infrared radiation and opaque to long-wave radiation (see Section 2.4). It is also a good conductor of heat. Although glass transmits the short-wave infrared part of the solar radiation spectrum, it will also reflect and absorb a proportion of the radiation as shown in Figure 8.42, the amount of which will vary with solar angle of incidence.

5.8 U-Value of glass

The main thermal resistance for a single layer of glass can be attributed to the surface resistances. The glass material itself has practically no thermal resistance.

Example 3

Calculate the U-value of a single layer of glass

Internal surface resistance is 0.13

External surface resistance is 0.04

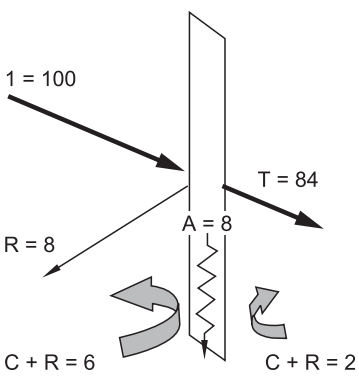
For a *k*-value of glass of 1.05 and thickness of 6 mm the resistance can be calculated:

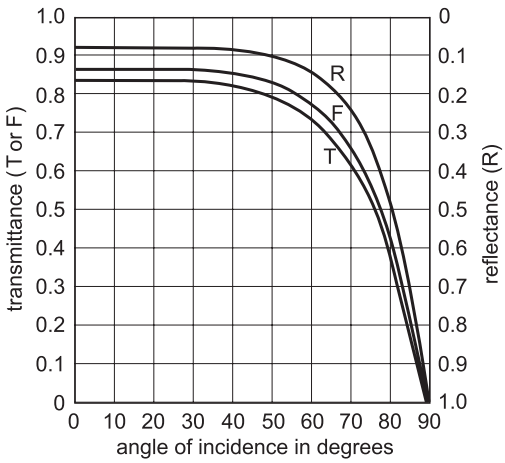
R= 0.13 + 0.006/1.05 + 0.04

Total resistance (R) = 0.1757 m^2K/W

U-value is 1/R = 5.7W/m^2K

Adding layers of glass will improve the insulating properties of glazing due to the resistance of the trapped layer of air (or another gas). The thermal resistance of an air- or gas-filled cavity increases in proportion to its width up to about 20 mm and remains constant up to 60 mm, after which it decreases slightly. Increasing the layers of glass will reduce the solar transmittance by about 80 per cent per layer for standard glass. The glazing frame can provide a thermal bridge, which will increase the overall U-value of the glazing system (Table XX).





8.42 *Transmitted, reflected, absorbed and re-emitted solar radiation as a percentage of incident value for 4 mm single glazing, and graph indicating variation of solar transmittance with angle of incidence:*

Incident (I) =100%, Reflected (R) = 8%, Transmitted (T) = 84%, Absorbed (A) =8%
Convected and radiated inside (C +R) =2%
Convected and radiated outside (C + R) = 6%

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Table XX Typical U-value and G-value for vertical glazing systems

Glazing systems	Glass pane U-value (W/m²K)	Window U-value with PVC frames (W/m²K)	G-value
Single glazing	5.75	4.80	0.85
Double glazing, air filled	2.76	3.30	0.76
Double glazing, low-e, air filled	1.45–1.85	1.80–2.70	0.63–0.72
Double glazing, low-e, argon filled	1.21–1.65	1.70–2.60	0.63–0.72
Triple glazing, low-e, air filled	–	1.40–2.0	0.57–0.64
Triple glazing, low-e, argon filled	–	1.30–1.90	0.57–0.64

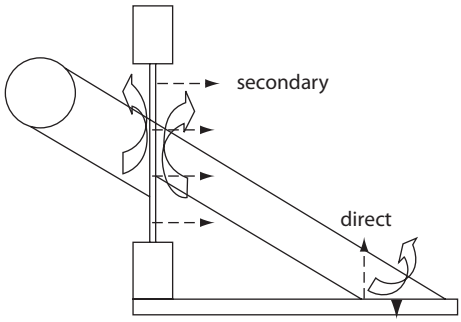
Source: U-values are from: CIBSE Guide A: Environmental Design, 2006; and G-values are from SAP 2009, total solar energy transmittance for glazing.

5.9 Low-emissivity glass

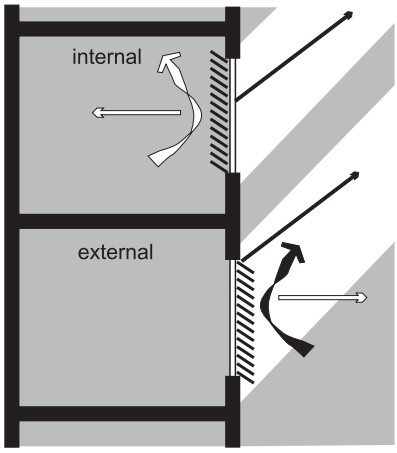
A coating of metal oxide can be applied to a glass surface to reduce its emissivity. This will reduce its long-wave radiation loss, which will reduce the overall transmission loss by about 30 per cent. The low-emissivity coating is usually applied to the inside surface of the inner pane of a double-glazed unit.

5.10 G-value of glazing

The g-value of a glazing system is a measure of the total solar gains to a space, which includes the direct 'short wave' transmitted gains through the glass and the secondary gains through the heated internal glass surface due to absorption of solar gains within the glazing system, Figure 8.43. The direct gains themselves will be absorbed by internal surfaces the subsequent rise in surface temperature will result in convective and radiant gains to the space. The transmission of solar radiation through windows can be reduced by different glazing treatment or the use of blinds or solar shading. Blinds can be incorporated within a layered glazing system to provide additional solar control, Figure 8.44. Internal blinds convert short-wave radiant heat gains to convective and long-wave radiant heat gains. Blinds located externally or between layers of glass are more effective in reducing solar heat gains. In some cases it may be necessary to ventilate the cavity which contains the blinds, otherwise the solar heat gains 'trapped' within the glazing system may give rise to secondary heat gains through the heated internal glass surface. As a rule of thumb the internal glass surface temperature should be no more than 5°C above the internal air temperature in order to avoid excess secondary heat gains and thermal discomfort near the glazing zone.



8.43 *Comparison of heat gains through external and internal shading. Typically there could be solar gain of 12% for external white louvres, and 46% for internal white louvres*



8.44 *Direct and secondary solar heat gains through a glazing system*

5.11 Layered glazing systems

In recent years there has been an increase in layered glazing systems in buildings allowing large areas of glazing to maximise daylight and for architectural aesthetics, while provided good thermal insulation and solar control. Solar control is often achieved by a combination on glazing treatment and blinds, resulting in G-values below 0.15 (Table XXI).

Table XXI Solar control system

Single glazing	Double glazing	Triple glazing
G-value ~ 0.80	G-value ~ 0.60	G-value ~ 0.50
		
Double skin façade with external blind	Double skin façade with interpane blind	Double skin façade with internal blind
G-value ~ 0.12–0.57	G-value ~ 0.28–0.61	G-value ~ 0.44–0.66
		

Note:
The example G-values of double skin façade with blind are based on the G-value of double skin façade is 0.75 with the slat angles range from 20°to 70°.
The G-value of the double glazing system (when without the roller blind) is 0.75
Source: Mylona, A. 2007. Modelling the thermal performance of complex glazing systems. Welsh School of Architecture, Cardiff University.

There are a range of options for blinds. Louvre type 'venetian' blinds can be controlled in terms of their opening angle and this will affect their G-value as well as where they are positioned within the glazing system. Material 'roller' blinds can reflect, absorb and transmit solar radiation according to their colour and materiality. In some cases external blinds are made of diffuse glass which reflects sunlight whilst allowing daylight to enter.

5.12 Matrix glazing systems

Matrix glazing systems are designed to make maximum use of daylight, while at the same time controlling solar heat gain. They usually consist of a reflective matrix located between two layers of glass. The blades of the reflector are angled to respond to the particular orientation of the glass and the requirement for accepting or rejecting the solar heat gains, Figure 8.45.

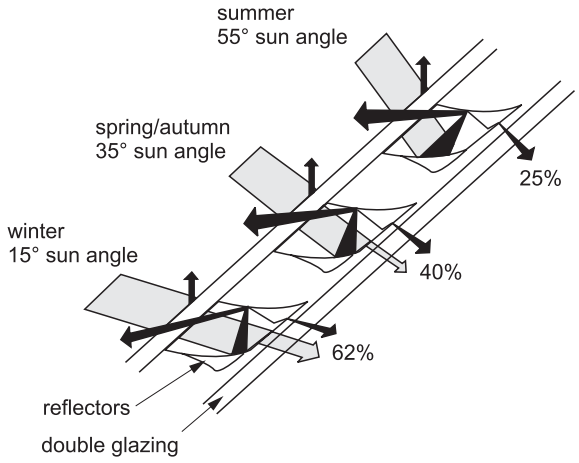
5.13 Transparent insulation material (TIM)

This can be applied to the face of an opaque south-facing facade to provide insulation while at the same time allowing the passage of solar gains to the solid wall behind, Figure 8.46. It can also be installed between two layers of glass where light but not view is required.

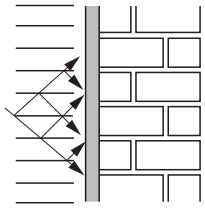
6 CONDENSATION

6.1 Introduction

Condensation occurs when moist air meets a relatively cool surface. Water condenses out of the air and is deposited on the cool



8.45 *Matrix glazing system*



8.46 *Transparent insulation material (TIM)*

surface. It can result in dampness, surface mould growth and deterioration of the building fabric.

6.2 Terminology

- The amount of water vapour that the air can contain is limited and when this limit is reached the air is said to be *saturated.*
- The saturation point varies with temperature. The higher the air temperature, the greater the amount of water vapour it can contain.
- Water vapour is a gas, and in a mixture of gases such as air, the water vapour contributes to the total vapour pressure exerted by the air.
- The ratio of the vapour pressure in any mixture of water vapour and air to the vapour pressure of saturated air at the same temperature is the *relative humidity* (RH).
- If air is cooled it will eventually reach saturation point, that is, 100 per cent RH, and any further cooling will cause the vapour to condense. The temperature at which condensation occurs is called the *dewpoint* temperature.

6.3 Surface condensation

When air with a relatively high RH comes into contact with a cold surface condensation can take place. The risk of surface condensation depends on:

- Air and surface temperature
- Moisture content of the air

6.4 Mould growth

Surface condensation can cause mould growth. Mould spores can germinate at RHs above 80 per cent. If the RH is generally greater than 70 per cent for long periods mould will spread.

6.5 Estimating surface temperature

The following formula can be used to estimate the surface temperature:

$$\text{Temperature drop between the air and the surface} = \Delta T \times U \times R_{si} \quad (15)$$

where ΔT = inside/outside air temperature difference
U = wall U-value
R_{si} = internal surface resistance

Example 4

What is the internal surface temperature of single glazing (U-value – 5.8W/m²K), if the internal air temperature is 20˚C and the external air temperature is 0˚C? The internal surface resistance is 0.123 mK/W.

$D_T = 20$ $U = 5.8$ $R_{si} = 0.123$

Temperature drop (air to wall surface) = 20 × 5.8 × 0.123
= 13.9°C

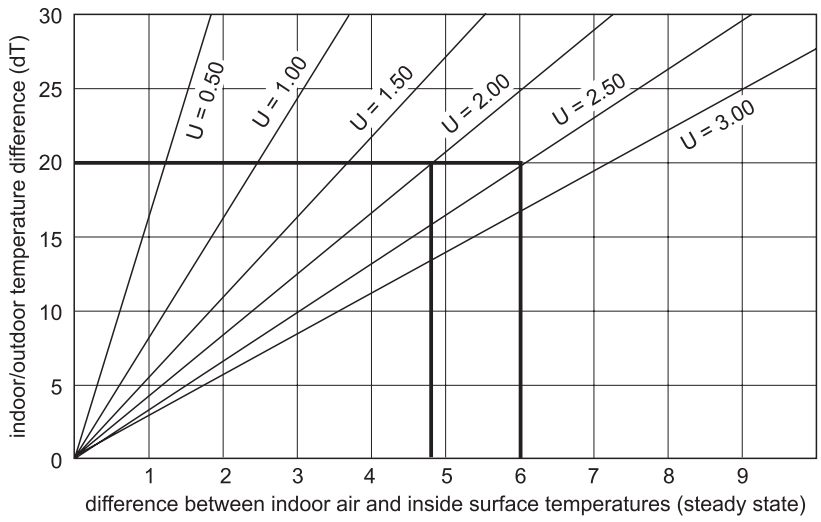
Therefore the internal surface temperature = 20 – 13.9 = 6.1°C

6.6 Surface temperature and U-value

The internal surface temperature is affected by the U-value of the construction element, Figure 8.47. The higher the U-value, the lower the internal surface temperature for a given heat input to the space. Thermal bridging constitutes a localised increase in U-value which will result in a lower surface temperature. High U-value elements at risk include single glazing and thermal bridging.

6.7 Moisture content of the air

Moisture is contained in the external air and this is added to by various building use activities (Table XXII). The main moisture sources are:



8.47 *Internal air-to-surface temperature versus inside/outside temperature difference for different U-values*

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Table XXII Moisture addition to internal air

Room type	kg/kg dry air
Dwelling	0.0034
Offices shops, classrooms	0.0017
Catering	0.0068

External air: external air enters the building through ventilation. Its RH will depend on its moisture content and temperature. For example, on a typical winter's day external air at 90 per cent RH and 5°C will contain about 5 g/kg (dry air) of water vapour. Saturated air at 0°C will contain 3.8 g/kg. These values can be obtained from the psychrometric chart, Figure 8.14; see Section 3.6.

Drying out: building materials contain moisture (Table XXIII). A building could take a year to dry out after construction. A new house might contain 4000 litres of water which will be released during the drying-out period.

Table XXIII Moisture content of materials

	Water content	
Material	Protected	Exposed
Brick (fired clay)	1% by volume	5% by volume
Brick (calcium silicate)	1% by volume	5% by volume
Dense aggregate concrete	3% by volume	5% by volume
Blast furnace slag concrete	3% by weight	5% by volume
Pumice aggregate concrete	3% by weight	5% by volume
Other lightweight aggregate concrete	3% by weight	5% by volume
Autoclaved aerated concrete	3% by weight	5% by volume

Source: CIBSE Guide A: Environmental Design, 2006.

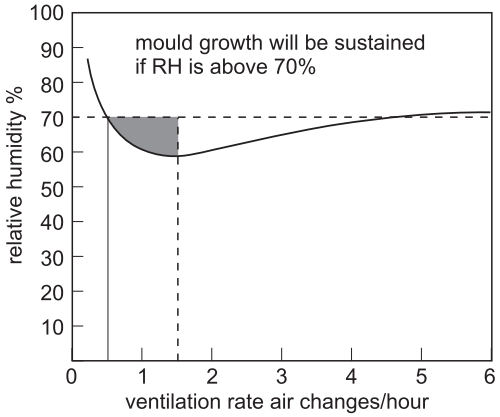
Occupants: moisture is produced as a result of occupants' activities (Table XXIV). On average, 3.4 g/kg of moisture is added to the air by internal activities in a house.

6.8 Causes of surface condensation

Minimising the risk of surface condensation requires a balanced approach to heating, ventilation and insulation, together with minimising moisture production:

Heating: inadequate heating can result in low air temperatures and higher levels of RH. It also means colder surface temperatures. Intermittent heating can result in the fabric and surface temperatures significantly cooler than the air temperature (during warm-up). Warm moist air coming into contact with cool surfaces can then result in condensation. Partial heating of a house can result in warm, moist air convecting to cooler rooms with cooler surfaces. Surface areas shielded from heating (e.g. behind wardrobes) will be more at risk.

Ventilation: low ventilation rates will result in a build-up of moisture in the air causing higher levels of RH. Too much ventilation could give rise to lower internal air temperatures which will again increase the RH, and also reduce surface temperatures. Ventilation should therefore be balanced as illustrated in Figure 8.48.



8.48 *Ventilation rate versus RH, indicating that low and high rates can give rise to higher RHs*

Table XXIV Moisture emission rates within houses

Source	Moisture produced
Combustion in room heater/cookers without flues	
Paraffin	0.1 kg/h/kW
Natural gas	0.16 kg/h/kW
Butane	0.12 kg/h/kW
Propane	0.13 kg/h/kW
Household activities	
Cooking (3 meals)	0.9–3.0 kg/day
Dish washing (3 meals)	0.15–0.45 kg/day
Clothes washing	0.5–1.8 kg/day
Cloth drying (indoors)	2–5 kg/day
Baths/showers	0.2–0.5 kg/person/day
Floor washing	0.5–1.0 kg/day
Indoor plants	0.02–0.05 kg/day
Perspiration and respiration of building occupants	0.04–0.06 kg/day

Source: CIBSE Guide A: Environmental Design, 2006.

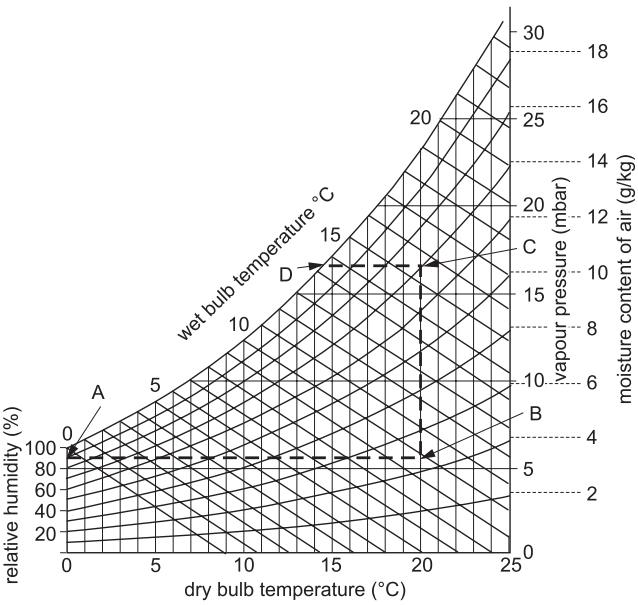
6.9 Estimating risk of surface condensation

The risk of surface condensation can be estimated if the RH and air and surface temperatures are known.

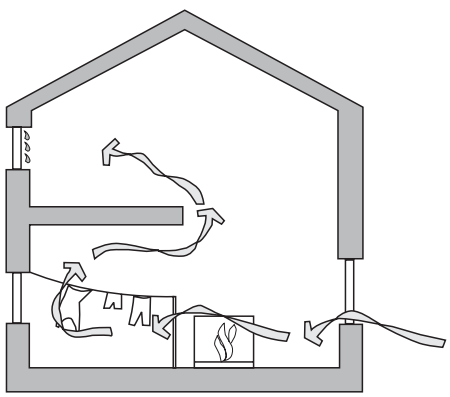
Example 5

Predict the risk of surface condensation using the psychrometric chart Figure 8.49.

- The outdoor dry-bulb air temperature is 0°C and contains 3.8 g/kg of moisture, which gives an RH of 100% (point A).



8.49 *Illustration to Example 5: predicting the risk of surface condensation using a psychrometric chart*



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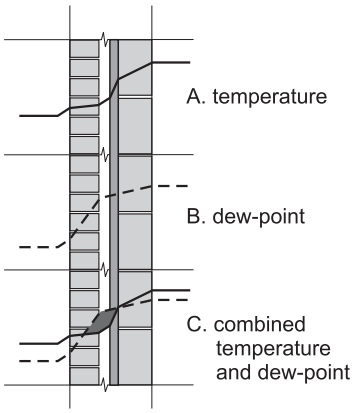
- On entering the building the air warms to 20°C. If its moisture content remains the same, its RH will reduce to 27% (point B).
- Internal activities are assumed to generate additional moisture of 7 g/kg, increasing the RH to 70% (point C).
- The dewpoint temperature for air at 70% RH is 15°C (point D).

This means that condensation will occur if the air comes into contact with a surface at a temperature of 15°C or less.

Referring to the graph in Figure 8.47 for an internal/external air temperature difference of 20°C, surface condensation will occur if the U-value is greater than 2 W/m^{2}K, in which case the internal surface temperature will be 15°C, i.e. 5°C less than the air temperature.

6.10 Interstitial condensation

Condensation can occur within a construction. The dewpoint temperature profile of a wall can be predicted. If the actual temperature at any point within the construction falls below the dewpoint temperature then there is a risk of interstitial condensation taking place, as shown in Figure 8.50.



8.50 *Set of three diagrammatic representations of:*

A Temperature profile through wall,
B Dewpoint temperature profile, and
C Overlap of these two profiles indicating area of interstitial condensation risk

6.11 Vapour resistance

A material will resist the passage of vapour depending on its vapour resistivity or vapour resistance (Tables XXV and XXVI) (analogous to thermal resistivity). The vapour resistance of a given thickness of material within a construction is:

$$V_r = x \times v_r \qquad (16)$$

where v_r = vapour resistivity (Ns/kg-m)
x = thickness of material (m)
V_r =vapour resistance (Ns/kg)

6.12 Vapour pressure

The vapour pressure can be estimated from the moisture content using a psychrometric chart. The dewpoint temperature for a given vapour pressure will be the dry bulb temperature at 100% RH. The drop in vapour pressure across a given thickness of material in a construction is:

$$dV_p = (V_T/V_K) \times dV_p \qquad (17)$$

where dV_p = drop in vapour pressure across a given thickness of material (kPa)
V_r = vapour resistance of material (Ns/kg)
V_r = vapour resistance of construction (Ns/kg)
dV_p = vapour drop across construction (kPa)

Table XXV K-value and vapour resistivity and resistances

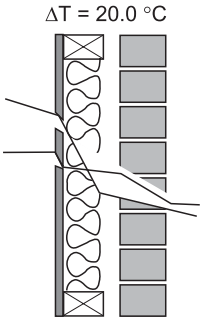
Material	K-value (W/m·K)	Vapour resistivity (MNs/g)
Brickwork (heavyweight)	0.84	45–70
Concrete (blocks, lightweight)	0.66	15–150
Render	1.3	100
Plaster (cement based)	0.72	75–205
Wood (pine)	0.12	45–1850
Plywood	0.12	150–2000
Fibreboard	0.042	150–375
Hardboard	0.14	230–1000
Plasterboard	0.16	30–60
Compressed strawboard	0.1	45–70
Wood-wool slab	0.11	15–40
Expanded polystyrene	0.035	100–750
Glass wool	0.04	5–7
Phenolic (closed cell)	0.04	150–750

Source: CIBSE Guide A: Environmental Design, 2006.

Table XXVI Vapour resistance of membranes

Membranes	Vapour resistance (MNs/g)
Average gloss paint	40–200
Polythene sheet	110–120
Aluminium foil	4000

Source: CIBSE Guide A: Environmental Design, 2006.



8.51 *Construction of wall in Example 6*

Example 6

Calculate the dewpoint temperature and actual temperature across a construction, Figure 8.51.

1 Calculate thermal resistance of each layer.
2 Calculate temperature drop across each layer: $\Delta t = \Delta T \times U \times R_s$
3 Plot temperature profile.
4 Calculate vapour resistance for each layer from formula (16).
5 Calculate vapour pressure drop across each layer from formula (17).
6 Calculate vapour pressure at the interface of each layer.
7 Look up dewpoint temperature on psychrometric chart, Figure 8.14.
8 Plot dewpoint temperature profile.
9 Check crossover for condensation risk.

The calculation and results are shown in Table XXVII.

7 INFILTRATION AND VENTILATION

7.1 Ventilation

Ventilation is the process of supplying and removing air by natural or mechanical means to and from any space. It is a combination of infiltration and purpose ventilation. Purpose ventilation can be either natural (opening windows), or mechanical (turning on a fan), or a combination of each. Ventilation rate is measured in air changes per hour (ac/h), m^3/s or litres per second per person (l/s/p). Typical ventilation rates are in Table XXVIII and more detailed rates can be found in Tables VII and VIII.

7.2 Air infiltration

Air infiltration is the term used to describe the fortuitous leakage of air through a building due to imperfections in the structure, such as:

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Table XXVII Calculation for Example 6

The values between the main columns are the temperatures (°C) at the interfaces of the materials.

	Temp.	Inside surface	Plaster-board	Insulation	Cavity	Brick	Outside surface	Temp.
Thickness			0.15	0.05	0.05	0.1		
Thermal resistance		0.12	0.9	2.5	0.18	0.12	0.055	2.1
Temperature drop		0.78	0.59	16.31	1.17	0.78	0.36	
Temperature	**20.0**	**19.2**	**18.6**	**2.3**	**1.2**	**0.4**		**0.0**
Vapour resistance (X x V_r)			7.9	2.8		6.3		
Vapour pressure crop			0.3	0.1		0.25		
Vapour pressure				1.0	0.9	0.9		0.65
Dewpoint temperature	**10.7**			**7.0**	**6.0**	**6.0**		**0.8**

Table XXVIII Typical ventilation rates

Building type	l/s/person
Domestic:	
Habitable rooms	0.4–1.0
Kitchens	60
Bathrooms	15
Offices	10
Schools	10
Bars	10

Source: CIBSE Guide A: Environmental Design, 2006.

- cracks around doors, windows, infill panels;
- service entries, pipes, ducts, flues, ventilators;
- through porous constructions, bricks, blocks, mortar joints.

7.3 Natural ventilation

Natural ventilation is the movement of outdoor air into a space through intentionally provided openings, such as windows, doors and non-powered ventilators. This is in addition to the ventilation due to air infiltration. In many cases, for much of the year infiltration alone will provide sufficient outdoor air to ventilate the building. However, it is uncontrollable, and if excessive, it can incur a high-energy penalty and/or make the building difficult to heat (or cool) to comfort levels.

7.4 Mechanical ventilation

Mechanical ventilation is the movement of air by mechanical means to and/or from a space. It can be localised using individual wall or roof fans, or centralised with ducted distribution. It is controllable and can, for example, incorporate a heat-recovery system to extract heat from exhaust air and use it to pre-heat supply air.

7.5 Build tight, ventilate right!

Infiltration is present in both naturally ventilated and mechanically ventilated spaces. It is considered 'best practice' to reduce the infiltration as much as possible by sealing measures, and then to depend on controllable natural or mechanical means to provide the main ventilation.

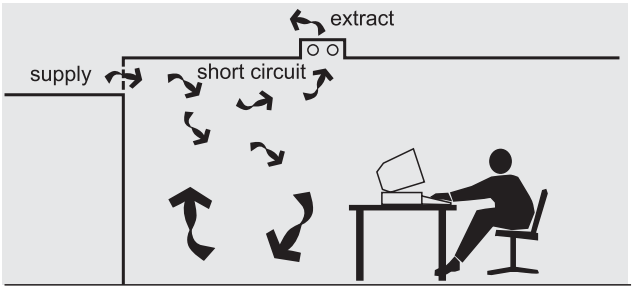
7.6 Ventilation effectiveness and efficiency

The term *ventilation effectiveness* is used to describe the fraction of fresh air delivered to the space that reaches the occupied zone. It should ideally be 100 per cent. However, if air 'short-circuits' between supply and extract points then it could be greatly reduced, down to as low as 50 per cent, Figure 8.52.

The term *ventilation efficiency* is used to describe the ability of a ventilation system to exhaust the pollutants generated within the space. For a specific pollutant, it is the mean concentration level of the pollutant throughout the space in relation to its concentration at the point of extract. The ventilation efficiency at a single location is the ratio of pollutant concentration at that location in the space to its concentration at the point of extract.

$$\text{Ventilation efficiency } E = (C_e - C_s)/(C_o - C_s) \quad (18)$$

where E = ventilation effectiveness
C_e = concentration of pollutant in extract
C_s = concentration of pollutant in supply
C_o = concentration of pollutant at occupant location



8.52 *Short-circuiting of air between supply and extract reduces ventilation effectiveness and efficiency*

If there is a significant level of the pollutant in the supply air then this should be subtracted from the internal and exhaust concentration levels.

7.7 Metabolic carbon dioxide as an indicator of air quality

Metabolic carbon dioxide is often used as an indicator of air quality. For naturally ventilated spaces in winter when windows are closed, the carbon dioxide level may rise to typically 1500 ppm for offices, and 2500 ppm for school classrooms. For mechanically ventilated buildings the carbon dioxide level should not rise above 1000 ppm and will generally be less than 800 ppm. Metabolic carbon dioxide can also be used to estimate ventilation efficiency using formula (18).

7.8 Ventilation heat loss

The air supplied to a space has to be heated in winter and sometimes cooled in summer. In a mechanical ventilation system, this is achieved by pre-heating or cooling the air before it is delivered to the space. For natural ventilation it is usually achieved by incoming fresh air mixing with air already in the space and then this mixture is heated by the heating system, for example by contact with 'radiator' surfaces. The air that is exhausted from the space, through natural or mechanical means, contains heat energy. For a mechanical ventilation system this heat is sometimes recovered through a heat exchanger – otherwise it is wasted. The ventilation component of heat loss can be a significant and sometimes major proportion of the total building heat loss. It can also be very variable, especially in naturally ventilated buildings, as it depends on external wind velocity and air temperature.

The heat lost or gained through ventilation can be estimated from:

$$Q_v = V_a \times \text{volume} \times \Delta T \times C\rho/3600 \quad (19)$$

or

$$Q_v = V_l \times \text{number of people} \times \Delta T \times C\rho/1000 \quad (20)$$

where Q_v = heat loss or gain in watts
V_a = ventilation rate in air changes per hour (ac/h)
V_l = ventilation rate in litres per second per person (1/s/p)
C_ρ = volumetric heat capacity of air = 1200 Jm–3K^{-1}
ΔT = internal/external air temperature difference (°C).

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An increase in internal/external temperature difference causes an increase in ventilation rate and an increase in heat loss or gain.

When designing a heating system the ventilation rate used to calculate the design heat loss should correspond to a design ventilation rate. However, when estimating seasonal energy performance the ventilation rate will be the average ventilation rate over a heating season.

7.9 Natural ventilation design

Natural ventilation through leakage and purpose ventilation is a result of two processes, termed *stack effect* and *wind effect.*

7.10 Stack effect

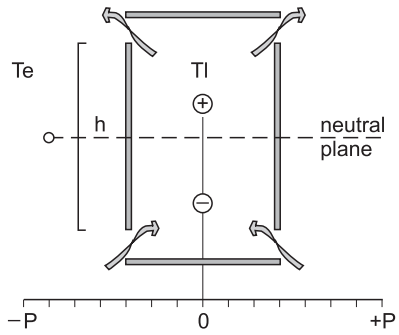
Stack effect occurs when there is a difference between the inside and outside air temperature. If the inside air temperature is warmer than the outside air it will be less dense and more buoyant. It will rise through the space escaping at high level through cracks and openings. It will be replaced by cooler, denser air drawn into the space at low level. Stack effect increases with increasing inside/outside temperature difference and increasing height between the higher and lower openings. The neutral plane, Figure 8.53, occurs at the location between the high and low openings at which the internal pressure will be the same as the external pressure (in the absence of wind). Above the neutral plane, the air pressure will be positive relative to the neutral plane and air will exhaust. Below the neutral plane the air pressure will be negative and external air will be drawn into the space. The pressure difference due to stack is estimated from:

$$P_s = -\rho \times T \times g \times h \times (l/T_e - l/T_i) \quad (21)$$

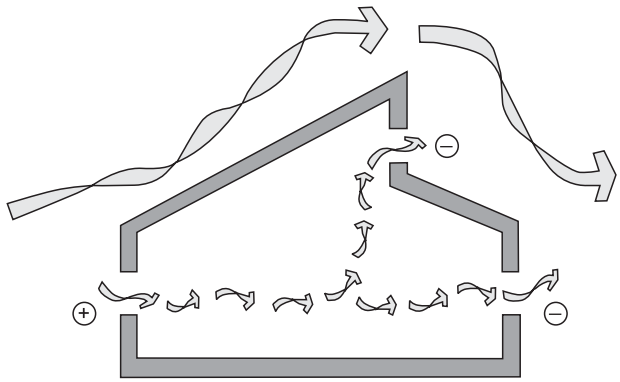
where P_s = pressure difference in pascals (Pa)
ρ = density of air at temperature T
g = acceleration due to gravity = 9.8 m/s^2
h = height between openings (m)
T_i = inside temperature in kelvins, and
T_e = external temperature in kelvins.

7.11 Wind effect

Wind effect ventilation, sometimes referred to as *cross-ventilation,* is caused by the pressure differences on openings across a space due to the impact of wind on the external building envelope, Figure 8.54. Pressure differences will vary, depending on wind speed and direction and location of the openings in the envelope. The pressure at any point on a building envelope can be calculated for a given



8.53 *Pressure gradient due to stack effect, indicating the location of the neutral plane*



8.54 *Wind driven cross-ventilation*

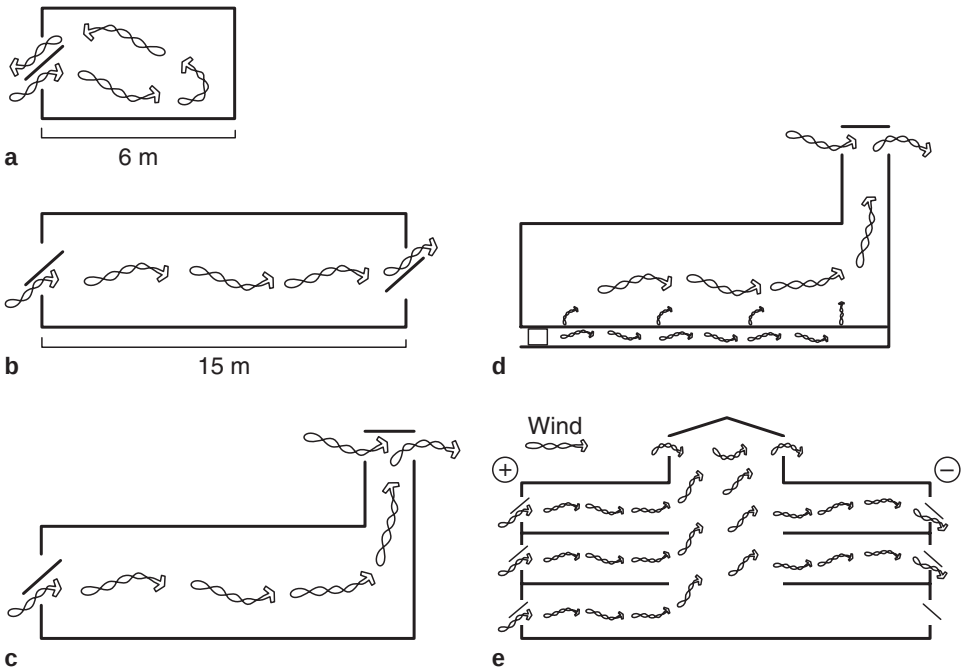
wind speed and direction if the pressure coefficient at the point is known (see Section 4.10). Pressure coefficients are usually derived from wind tunnel tests. The pressure difference across a building due to wind can be estimated from:

$$P = 0.5\rho v^2(Cp_1 - Cp_2) \quad (22)$$

where P_w = pressure difference across the building (Pa)
Cp_1 and Cp_2 = pressure coefficients across the building in relation to the wind speed (v) and air density (ρ).

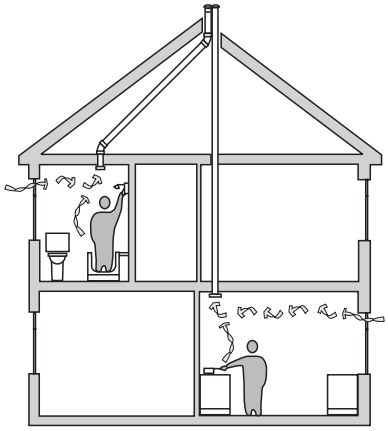
7.12 Natural ventilation strategies

Figure 8.55 presents a range of natural ventilation strategies with depths limits for single-sided and cross-ventilated spaces.



8.55 *Natural ventilation strategies: a Single-sided; b Cross-ventilation; c Cross-ventilation with chimney; d Cross-ventilation with underfloor supply; e Atrium: stack and wind effects*

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8.56 *Passive stack ventilation (PSV) can be used instead of mechanical ventilation for local extract, for example in kitchens and bathrooms*

Figure 8.56 illustrates *passive stack ventilation (PSV)* used in domestic buildings.

8 HEATING AND COOLING SYSTEMS

8.1 Introduction

The purpose of heating systems is to maintain internal air and radiant temperatures within the comfort zone. During the 'heating season' a building will lose heat through the fabric and through air infiltration and ventilation. However, a building will also gain heat from internal sources (cooking, electric power and people) and from external solar heat gains through areas of glazing. A heating system is required to make up the difference between the heat gains and the heat losses. If a building is well insulated, has a low air infiltration rate and controlled ventilation then during the heating season, after some initial 'warm up' period, it can be heated some times entirely from the incidental heat gains. A heating system should be sized and controlled such that it can provide the appropriate amount of heat input when needed in an efficient and effective way.

8.2 Types of heating systems

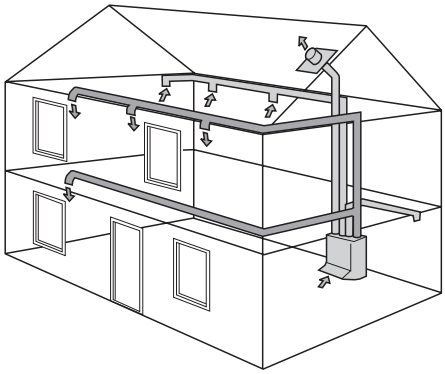
There are direct and indirect heating systems. Direct systems are located in the space, and include solid fuel fires, gas fires, direct electric panel heaters and electric storage heaters. For industrial applications there are high-temperature gas-fired radiant tubes and plaques. The main types of indirect systems are wet central heating systems, Figure 8.57, and ducted warm air systems, Figure 8.58. There are also low-temperature 'surface' heating systems such as under-floor heating, and ceiling and wall systems, where heat is input to the building's internal surface or mass.

8.3 Heat distribution

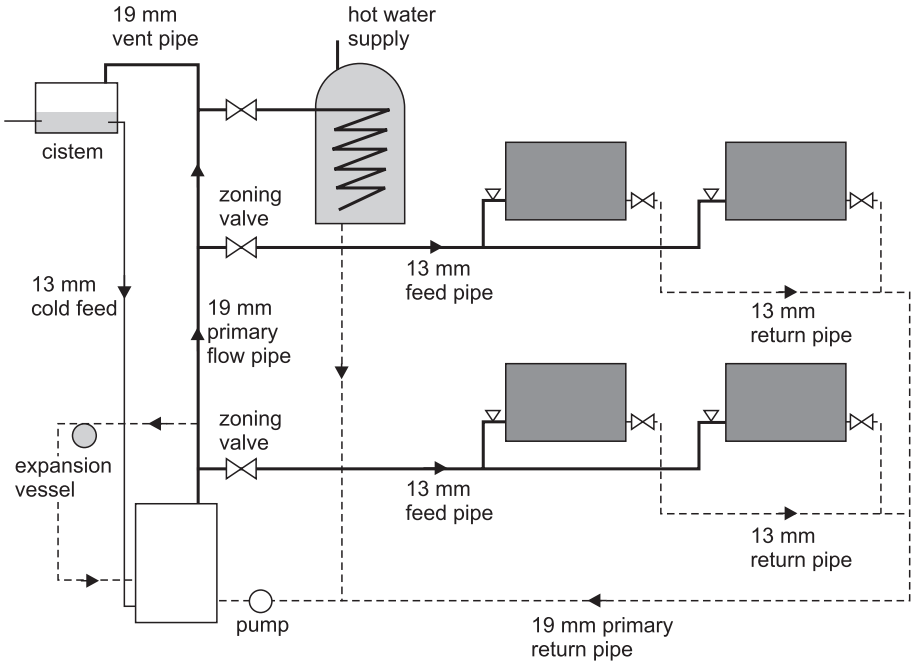
Heat can be distributed in water or in air. As water has a higher specific heat capacity than air, it requires smaller pipes in comparison to air ducts for the same heat transfer (Table XXIX). Water distribution can be 'gravity' feed or pressurised. An open system will require a header tank, whereas a pressurised system is sealed and requires a pressurisation unit. Pressurised systems can be used to carry water at temperatures higher than 100°C, and are some times used for commercial and industrial systems.

8.4 Heat emitters

Surface panel or tube heaters emit heat by a mixture of convection and radiation. The balance changes with surface temperature and finish. For low-temperature emitters the heat output is mainly convection, whereas for high-temperature emitters the radiant component of heat output increases (see Table XXX). In some cases the convective heat component may not be useful, as for overhead industrial localised heating systems. Some emitters, for example



8.58 *Domestic mechanically ventilated heat recovery system with extract in kitchen and bathroom and supply in living spaces, with heat recovery in cooker hood*



8.57 *Domestic two-pipe wet central heating system with flow and return to each radiator. The system can either be pressurised using an expansion vessel (dotted circuit); or gravity feed, in which case it requires a header tank located above the top radiator*

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Table XXIX Water is more efficient than air in transferring heat because it has a higher volumetric specific heat capacity

Specific heat capacity	Specific heat capacity (kJ/Kg·K)	Volumetric specific heat capacity (kJ/m³·K)
Water	4.2	4150
Air	1.01	1.2

Table XXX Radiant and convective output from heated surfaces, based on heating surface emissivity of 0.9

Type	Surface temperature (°C)	Direction of heat flow	Heat output (W/m²) Convective	Radiant
Underfloor heating	24	Up	18	27
Low temperature radiators	40	Vertical	75	114
Domestic radiators	70	Vertical	255	330
Medium pressure hot	110	Down	178	727
water panels		Vertical	558	727
Gas-fired radiant tubes*	150		1709	1078
	300		4414	4367
	500		8627	15184

*Gas radiant tubes are usually mounted at a high level and operate between 150 and 500°C. The convective component is generally lost to the high level; the radiant component is based on a floor level temperature of 18°C.

electric storage heaters, use a combination of heated surface plus forced convection.

8.5 Boilers

Boilers convert fuel to heat. In doing so they produce products of combustion which must be flued. The boiler efficiency (see Table XXXI) is a measure of the conversion of the energy in the fuel (its calorific value) to the useful heat extracted. Condensing boilers are also able to recover latent heat from the flue gases and therefore have a higher efficiency. Boiler efficiency is usually reduced at part-load operation. In larger buildings, modular boilers allow maximum efficiency with sequencing a number of smaller boilers instead of a few large ones so that the majority operate at full-load. Combination boilers allow for direct heating of domestic hot water, thus avoiding the need for storage and reducing the standing heat losses.

Table XXXI Boiler efficiencies

System	Seasonal efficiency %
Condensing boilers:	
Under-floor, or warm water system	90 or greater
Standard size radiators, variable temperature circuit (weather compensation)	87
Standard fixed temperature emitters (83/72°C flow/ return)*	85
Non-condensing boilers:	
Modern high-efficiency non-condensing boilers	80–82
Good modern boiler design closely matched to demand	75
Typical good existing boiler	70
Typical existing oversized boiler (atmospheric. cast-iron sectional)	45–70

*Not permitted by current Building Regulations

Source: CIBSE Guide F, Energy Efficiency in Buildings, 2004.

8.6 Distribution losses

There will be heat loss associated with the distribution system. Pipes and ducts should be well insulated (Table XXXII). There will also be standing 'case' heat losses associated with the boiler, which may be considered useful (although it is uncontrolled) if they contribute to space heating.

Table XXXII Heat losses from pipes and ducts

		Heat loss (W/m)	
	Fluid temperature (T!)	Un-insulated	With 25 mm insulation
15 mm dia pipe	50	32	6
15 mm dia pipe	70	62	11
500 mm dia duct	40	333	47

8.7 Building 'design heat loss'

Fabric and ventilation heat loss has been explained in Sections 5 and 6. The *design heat loss* of a building is its heating demand for a given external air temperature, which will vary for different parts of the UK. It can be estimated as follows:

Fabric heat loss rate: Q_f (W/°C)
Ventilation heat loss rate: Q_v (W/°C)
Total heat loss rate: $Q = Q_f + Q_v$ (W/°C)
Design internal air temperature: T_i (°C)
Design external air temperature: T_e (°C)

$$\text{Design heat loss} = Q \times (T_i - Te)\ (W) \quad (23)$$

8.8 Seasonal energy use

The seasonal energy use can be calculated from the design heat loss, but using some form of seasonal temperature instead of a design temperature. Also, an allowance has to be made for system efficiency and incidental heat gains. The seasonal temperature can be in the form of a heating season average temperature or *degree days* (Table XXXIII). If average temperature is used, then some account of seasonal heat gains are required. Degree days already assume some level of useful heat gains in relation to a *base temperature*, which is the temperature below which heating is required. The standard base temperature is 15.5°C, which takes account of typical internal heat gains.

8.9 Heat gains

There will be heat gains from internal activities and solar effects (Table XXXIV). For domestic buildings, the internal gains can be estimated depending whether the household has high, medium or low activities (Table XXXV). Not all the internal gains will usefully supplement the heating. Some may cause overheating and some may occur where or when they are not required.

Table XXXIII Seasonal energy design temperatures

Region	Seasonal Average Temperature Tsa (°C)	Annual Degree Days
Thames Valley	7.5	2033
South Eastern	6.7	2255
Southern	7.8	2224
South Western	8.3	1858
Seven Valley	7.2	1835
Midland	6.7	2425
West Pennines	6.7	2228
North Western	6.4	2388
North Eastern	5.9	2483
East Pennines	6.6	2370
East Anglia	6.7	2307
Borders	6.1	2254
West Scotland	5.8	2494
East Scotland	6.0	2577
North-east Scotland	5.5	2668
Wales	7.2	2161
Northern Ireland	6.4	2360

Source: CIBSE Guide A: Environmental Design, 2006.

Table XXXIV Solar heat gains

	Single glazing			Double glazing		
	S	SE/SW	E/W	S	SE/SW	E/W
J	14	12	6	12	10	5
F	19	16	11	16	13	9
M	35	31	23	30	26	19
A	35	34	30	29	29	26
M	42	44	42	35	37	35
J	41	45	46	35	38	39
J	39	43	42	33	36	35
A	40	41	37	34	34	31
S	39	36	29	33	30	24
O	31	27	18	26	22	15
N	19	16	9	16	13	7
D	14	12	5	12	10	4

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Table XXXV Domestic internal heat gains

Heat source	Total heat gain (kWh/day) Low	High
Occupants	4.02	5.46
Lighting	2.17	2.50
Cooker	2.89	4.25
Refrigerator	1.44	1.44
Television	0.45	0.54
Hot water	3.70	4.70
TOTAL	14.67	18.89

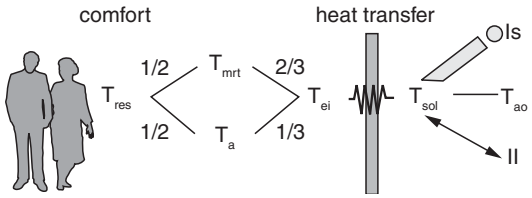
8.10 Environmental temperature

It is more accurate in cases where the radiant temperature is significantly different from air temperature to calculate the heat transfer to the internal surface of a wall using the *environmental temperature* which combines air temperature and mean radiant temperature:

$$t_{ei} = 2/3\ t_{mrt} + 1/3\ t_{ai} \quad (24)$$

where t_{ei} = environment temperature
t_{mrt} = mean radiant temperature, and
t_{ai} = air temperature.

Figure 8.59 illustrates the use of resultant temperature (formula (6)), environment temperature (formula (24)) and sol-air temperature (formula (8)).



8.59 *Resultant temperature, environmental temperature and sol-air temperature*

This may also apply to cooling where a low radiant component of the environment temperature may improve comfort because it is more comfortable to exchange heat by radiation to surrounding (cooler) surfaces than by convection to the surrounding air.

8.11 Seasonal energy use (E)

To calculate the seasonal energy use for space heating:

(i) Using average temperature:

$$E = (Q_f + Q_v) \times (T - T_a) \times \text{number of hours} - \text{seasonal heat gains}) \times eff \quad (25)$$

where E = the seasonal energy use (W)
Q_f = fabric heat loss <2
Q_v = ventilation heat loss
T_i = average internal temperature
T_{sa} = seasonal average temperature (Table XXXIII)
eff = efficiency of heating system.

(ii) Using degree days:

$$E = (Q_f + Q_v) \times \text{degree days} \times 24 \times eff \quad (26)$$

8.12 Carbon dioxide emissions

Table XXXVI gives the carbon dioxide emissions associated with fuel use.

Table XXXVI Carbon dioxide emission factors for UK in 2010

Fuel	Carbon emission per unit of delivered energy ($kgCO_2$/kWh)
Natural gas	0.206
Liquid petroleum gas (LPG)	0.251
Gas oil/ burning oil	0.290
Coal	0.382
Electricity	0.591

Source: SAP 2009.

Example 7

Calculation of seasonal heating, fuel use and carbon dioxide emission from a modern detached house located in Cardiff, and heated by a gas condensing boiler.

Fabric heat loss				
Element	**Area (m^2)**	**U-value ($W/m^2/°C$)**	**Heat loss (W/°C)**	
Walls	115	0.23	26.45	Table XIV
Roof	35	0.19	6.65	Table XIII
Floor	35	0.25	8.75	
Windows	30	2.00	60.0	Table XX
Total			102.0	
Ventilation heat loss				Formula (19)
Air change rate (/h)	**Volume (m^3)**	**Heat loss (W/°C)**		
0.75	210	52.5		Table XXIII
Total heat loss		155		
Seasonal heat loss (October–May)				Formula (25)
External temperature		7		Table XXXIII
Internal temperature		17		
Hours of use		5760		
Seasonal heat loss (kWh/year)		8910.7		
Heat gains				
Windows	**Area (m^2)**	**Unit gains (kWh/m^2)**	**Total gains (kWh)**	
Solar gains				Table XXXIV
South	10	190	1900	
North	5	0	0	
East	5	110	550	
West	10	110	1100	
Total			3550	
Internal gains				Table XXXV
People	4	370	1480	
Hot water			450	
Electrical			1100	
Cooking			950	
Total			3980	
Total heat gains (kWh/year)			7530	
Assume 50% of the gains contribute to useful heating			3765	
Heating system load (kWh/year)			5145.7	Formula (25)
Heating system efficiency (%)			88	Table XXXI
Heating system fuel use (gas) (kWh/year)			5847	
Carbon dioxide emission associated with heating fuel use (kg/year)			1111	Table XXXVI

8.13 Mechanical ventilation

Mechanical ventilation may be required in buildings as an alternative or in addition to natural ventilation. Specific applications include:

- Deep plan spaces which cannot be ventilated from the side by natural means.
- Spaces with a high occupancy or high heat gain.
- Spaces with high source levels of pollution, including industrial processes and moisture in kitchens and bathrooms.
- Where the external air quality may be poor and so the external air needs to be filtered or taken in at high level.
- Where high ventilation rates are required in winter, mechanical ventilation (with pre-heated air) can be used without incurring cold draughts.

8.14 Mechanical extract

Local mechanical extract can be used to exhaust pollutants at source (e.g. in kitchens, bathrooms and toilets; and locally for industrial processes such as solder baths and welding booths).

8.15 Mechanical supply systems

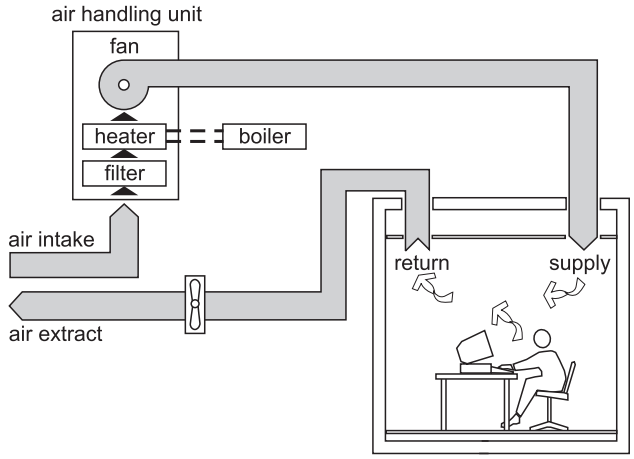
Mechanical supply systems can be used in situations where a positive flow needs to be established between a space and its surroundings. Examples are:

- in a house or apartment to maintain a minimum ventilation rate and reduce condensation risk;
- mechanical induction systems where high-velocity warm air is supplied to a space, and extract is through natural leakage;
- mechanical supply to an office and extract naturally, perhaps through an atrium or chimney/tower.

8.16 Balanced supply and exhaust

Mechanical ventilation systems in larger buildings usually have a balanced supply and extract, Figure 8.60. This allows:

- control of higher ventilation rates;
- heating and/or cooling of incoming air;
- filtration of incoming air;
- humidity control of air;
- heat recovery from exhaust to supply air.



8.60 *Components of one type of balanced supply and extract mechanical ventilation system*

8.17 Air supply rates

If the air supply is for ventilation, then the volume flow rate can be estimated from the number of occupants in the space. This will be typically 10 litres/second/person for normal environments, that is, average levels of pollution. If air is required as the sole source of heating then the volume flow rate can be estimated from the following formulae:

$$\text{Volume flow rate} = \text{design heat loss}/((T_{su} - T_{ex}) \times C_p) \quad (27)$$

where T_{su} = supply air temperature
T_{ex} = extract air temperature, and
C_p = volumetric specific heat of air

In modern 'low energy' buildings, including dwellings, the rate of air supply for ventilation is similar to that required to meet the design heat loss. Therefore warm air systems incorporating heat recovery can prove an appropriate option for a combined heating and ventilation system.

Example 8

Calculate the volume flow rate of air to ventilate a 1000 m office space, height of 2.5 m, occupied by 100 people (each requiring 8 l/s/person). If the design heat loss of the space is 15 kW, what is the volume flow rate required to (assume at room temperature) heat the space if the supply air temperature is 30°C and the extract is 23°C?

Ventilation volume flow rate = (100 × 8)/1000
= 0.8m³/s
= 0.8 × 3600/2500
= 1.12ac/h

Heating volume flow rate = 15000/((30 – 23) × 1200)
= 1.8m²/s
= 1.8 × 3600/2500
= 2.6ac/h

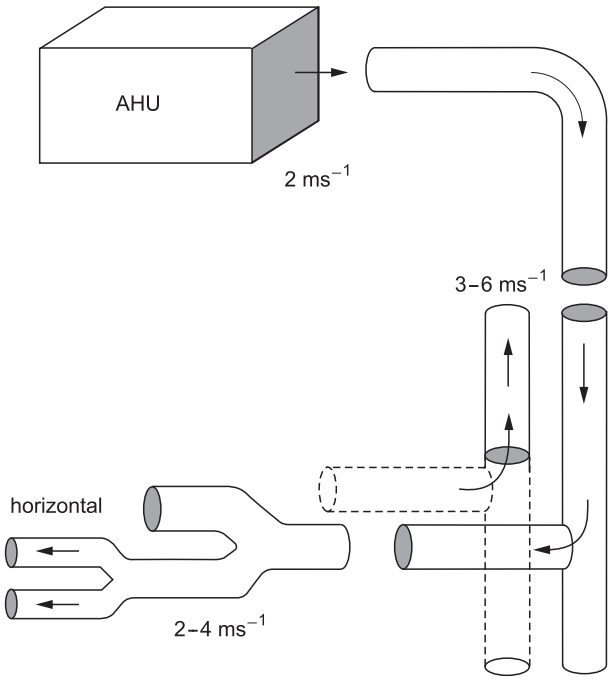
8.18 Air distribution

For a mechanical ventilation system air is distributed from an air handling unit (AHU) to the space through a system of ducts, Figure 8.61. The cross-section area of the AHU and ducts depends on the air speed for a given volume flow rate, and can be calculated from:

$$csa = \text{volume flow rate/air speed} \quad (28)$$

where *csa* is the cross-sectional area in m².

The velocity through the AHV would typically be 2m/s. The velocity through the main riser ducts may vary from 3 m/s (low velocity) to 7 m/s (medium velocity).



8.61 *Ducted air distribution system indicating typical flow velocities*

8.19 Fan power

The fan power required to supply the air through the ducted system depends on the volume flow rate and the pressure drop in the system, which are related to the air speed. For an energy-efficient mechanical ventilation system with low duct velocity, the *specific fan power* could be less than 2 kW/m³ of air supply.

8.20 Heat-recovery systems

An advantage of mechanical ventilation is that it can use heat recovery. This can be applied at all scales of building from domestic to large-scale commercial. It is especially appropriate for achieving energy efficiency in full fresh-air systems. Heat recovery is only worthwhile if the recovered heat is useful and is greater than the energy used due to the increase in fan power from the increased pressure drop of the heat-recovery equipment. Table XXXVII lists

Table XXXVII Heat-recovery systems and typical efficiencies

Heat-recovery system	Efficiency (%)
Recuperator	50 to 80 (sensitive)
Run-around coil	50 (sensitive)
Thermal wheel	65 to 90 (sensitive)
Heat pipe	50 to 60 (sensitive)
Regenerator	85 to 95 (sensitive)

Source: CIBSE Guide B, Heating, Ventilating, Air Conditioning and Refrigeration 2005.

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the efficiency ranges of heat-recovery systems. Heat-recovery systems should have a by-pass option to reduce fan power when heat recovery is not needed.

8.21 Air cooling systems

Some buildings require cooling in addition to what can be achieved from ventilation alone. Such buildings may have a high internal heat gain, where mechanical ventilation will not provide sufficient cooling, especially during warm weather. The building itself may be located in a hot climate, where air-conditioning with cooling and humidity control is necessary. Cooling of air is achieved by passing the air over cooling coils in the AHU.

8.22 Heat gains

The main reason for mechanical cooling is in response to heat gains from people, office machinery, lighting, solar gains and high external air temperatures. Solar gains have been discussed in Section 4.2. Internal gains from lighting and machines can be high (Table XXXVIII), but they are often overestimated, which can result in over-capacity of the system design. Wherever possible, internal heat gains should be minimised by specifying low energy lighting and other electrical equipment.

8.23 Room air delivery

Chilled air can be delivered to the space, either in a mixing mode or a displacement mode.

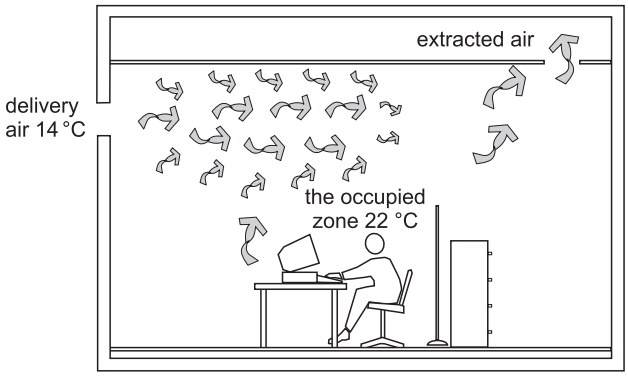
8.24 Mixing mode of air delivery

The air supplied to the space is typically about 14°C at the design cooling load. The air is jetted into the space such that it mixes with air already in the space by entrainment and when the air enters the occupied zone it is at the appropriate temperature, speed and RH for comfort, Figure 8.62. Air may be supplied from the perimeter, the ceiling or even the floor.

Table XXXVIII Internal heat gains for a typical office

Factor		Heat gains (W/m²)				
Density (/person/m²)		**4**	**8**	**12**	**16**	**20**
Sensible heat gain	People	20	10	6.7	5	4
	Equipment	25	20	15	12	10
	Lighting	12	12	12	12	12
Latent heat gain		15	7.5	5	4	3

Source: CIBSE Guide A: Environmental Design, 2006.



8.62 *Mixing mode of air delivery*

8.25 Coanda effect

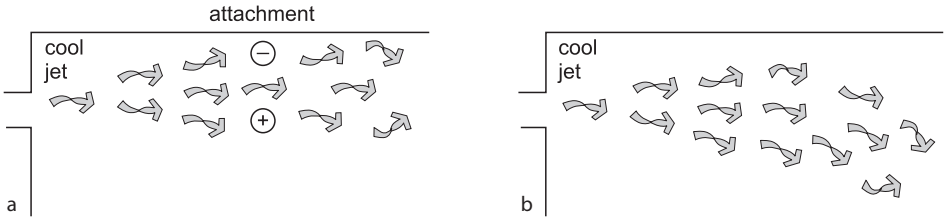
Ceiling systems often rely on the *coanda effect,* Figure 8.63a, to ensure that the cool supply air remains at high level ('sticks' to the ceiling) until it is mixed. The coanda effect does not work at low jet velocities and the jet becomes 'unstuck' and can cause cold air 'dumping', Figure 8.63b.

8.26 Displacement air delivery

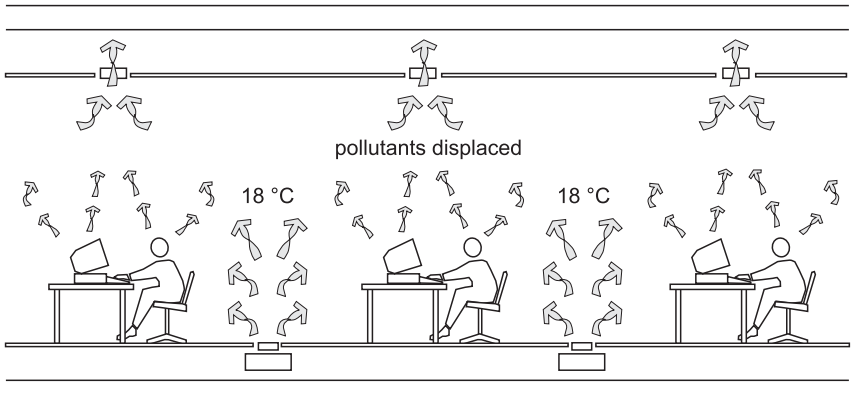
Air is supplied to the space at a low velocity such that it displaces the air already in the space towards the ceiling extract, Figure 8.64. Air is usually supplied at the floor or through low-level diffusers. However, some floor systems, that use *swirl* diffusers, are assumed to be displacement but are really mixing systems. The temperature of the air supply for these systems is usually above 18°C to avoid draughts.

8.27 Air supply

The temperature and volume flow rate of the supply air will often determine the type of system used. Displacement systems should have air delivery temperatures greater than 18°C or they are likely to cause cool draughts. So if low-temperature supply is needed to deal with a high heat load, then mixing systems are usually more suitable. Figure 8.65 shows the relationship between air supply temperature, volume flow and internal heat gains.

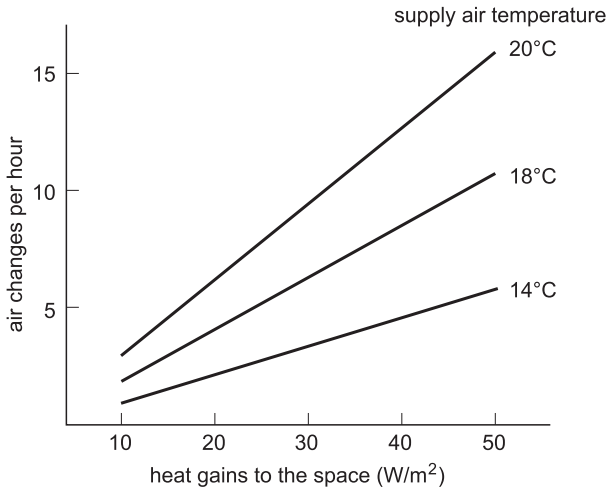


8.63 *Coanda effect*



8.64 *Air displacement system*

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8.65 *Relation between volume flow, supply air temperature and cooling load*

8.28 Central air-conditioning systems

Figure 8.66 illustrates a typical central air-conditioning system layout. Such systems may supply air with a variable air volume (VAV) or a constant air volume (CAV).

8.29 Variable air volume (VAV)

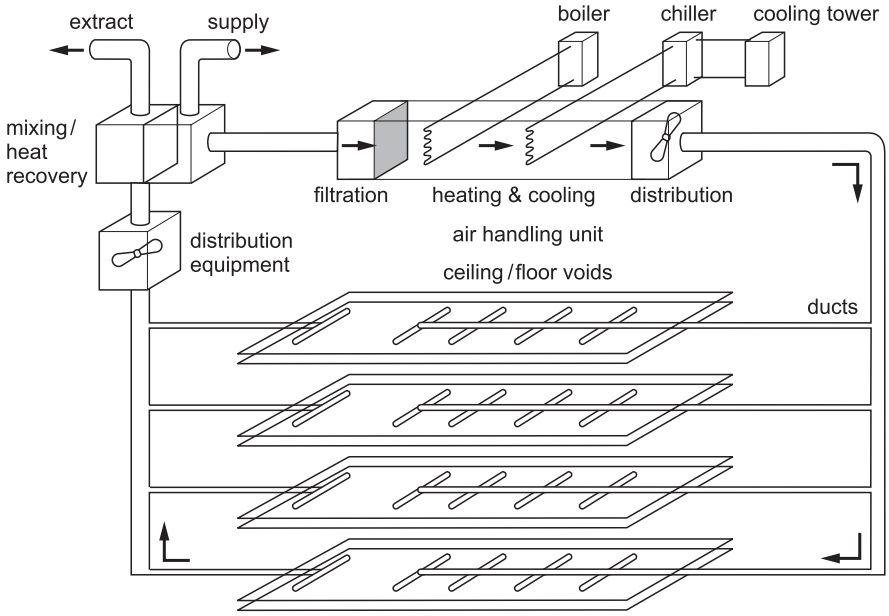
In this system the volume of air is controlled in response to the cooling load. As the cooling load is reduced the volume of air is also reduced until a minimum air supply is reached, after which the supply air temperature is increased.

8.30 Constant air volume (CAV)

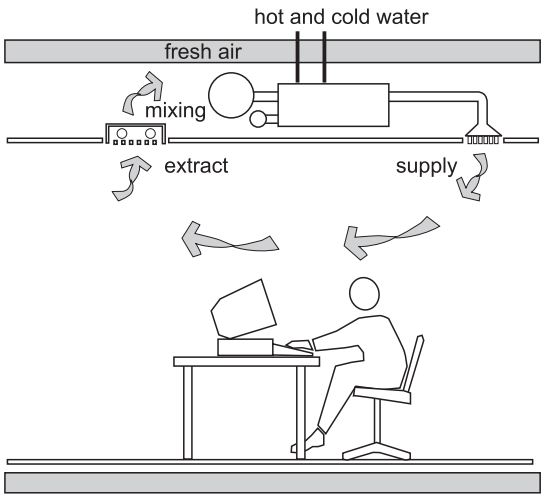
With this the air is supplied at a constant volume and the temperature of the air is varied in response to the space cooling or heating load.

8.31 Localised systems

These are usually either fan coil units or heat pump units. They can be located around the perimeter of a space or in the ceiling void,



8.66 *Layout of a central air conditioning system*



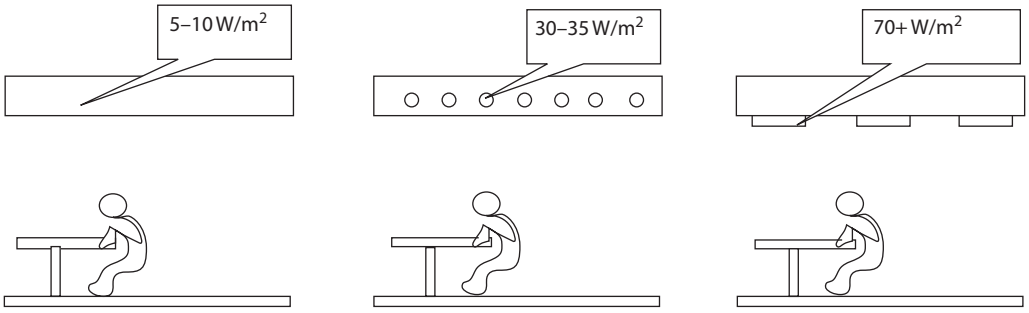
8.67 *Ceiling fan coil system*

Figure 8.67. A space may have multiple units, or one unit may supply a single floor. They usually take air from the space and heat or cool it as demanded. Ventilation air can either be supplied directly to the unit from outside or be ducted separately from a central unit which only supplies ventilation air requirements and not heating and cooling requirements. Fan coil units are served by hot and cold water systems that supply the main heating and cooling load.

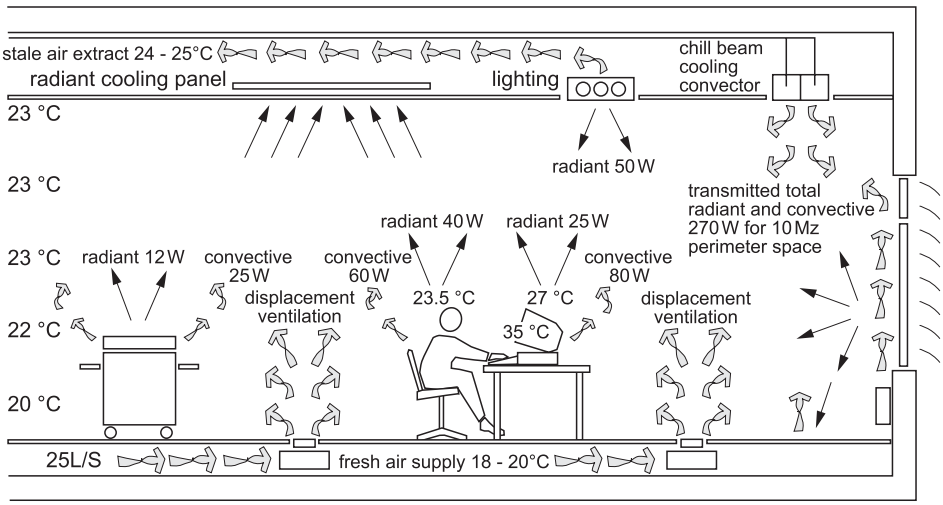
8.32 Chilled surface cooling systems

Passive cooling is achieved by means of introducing chilled surfaces in a room, which could be naturally chilled, for example using night ventilation, or actively chilled, by water or air, Figure 8.68. These surfaces absorb heat from the air in the space by convection/conduction and radiative heat exchange from warmer surfaces, including people. Chilled surface cooling devices can be in the form of fins, panels or beams. Sometimes the whole surface is cooled or heated, for example through passing water or air through the concrete floor slab and exposing the slab soffit to the room. In cooling mode, surface temperatures vary from typically 17°C for panels or beams to 20°C for chilled ceilings, with respective cooling loads of typically 70(+)W/m^2 down to 30 W/m^2. To avoid the risk of condensate forming on the chilled surfaces in situations of high relative humidity, sensors can be incorporated into the design to raise the surface temperatures. Alternatively, if mechanical ventilation is used the ventilation air can be dehumidified at the AHU. Air leakage through the facade should be minimised to avoid uncontrolled moist air entering the space. Chilled surface cooling systems can be combined with displacement ventilation, Figure 8.69.

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8.68 *Chilled surface cooling systems and their approximate cooling capacities*



8.69 *Passive cooling systems (chilled beams or panels) can be combined with displacement*

8.33 Refrigeration

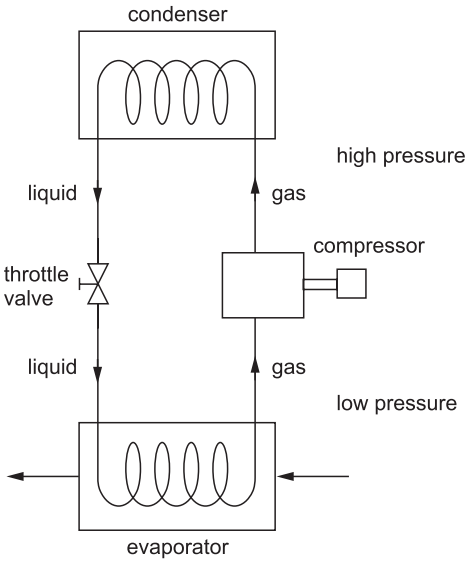
Cooling systems require some form of refrigeration equipment in order to extract heat from the cooling fluid that flows in the cooling coils in the air handling unit, or in the passive cooling system. A standard heat pump circuit is shown in Figure 8.70 and an absorption circuit in Figure 8.71. This can be used to cool or reversed to provide heating. The COP is a measure of the heat or coolth divided by the energy used to operate the heat pump.

8.34 Ground and air source heat pumps

Ground and air source heat pumps can provide a low carbon solution for heating and cooling. They are particularly suitable for providing heated or chilled water for surface heating and cooling systems. Ground source heat pumps have the advantage of working to a ground temperature of about 11°C, which enables them to retain a relatively high COP, whereas air source heat pumps work to an external temperature, which can be relatively low in winter and high in summer, reducing their operating COP considerably. However air source heat pumps, although potentially noisy, are relatively easy and low cost to install. Ground source heat pumps may have be vertical or horizontal heat exchanger (Figure 8.72).

8.35 Ground cooling

Ground cooling can be used for an air based ventilation cooling system by passing the supply air through pipes buried in the ground. The ground temperature at depths of 2 m or more remains fairly constant throughout the year. The amount of cooling obtained depends on the volume supply rate and the exposed contact surface area of the pipes. Alternatively air may be passed through a labyrinth of tunnels which have a high thermal mass in order to pre-cool it. In any system the heat absorbed by the mass must be extracted through night ventilation or natural seasonal effects. During the heating season the supply air may also be pre-heated through



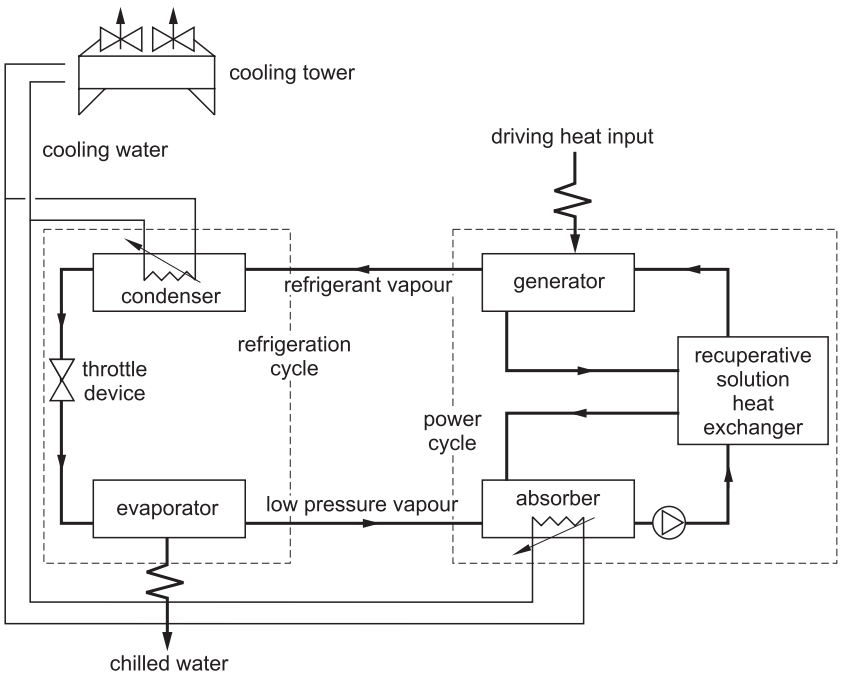
8.70 *Diagrammatic heat pump circuit. The refrigerant is in a liquid state as it enters the evaporator where it absorbs heat and changes state to gas. It is compressed to a hot gas and enters the condenser where it gives out heat and returns to liquid state. In reverse operation it can be used to cool*

the same system, when the external air temperature is lower than the ground or labyrinth surface temperature.

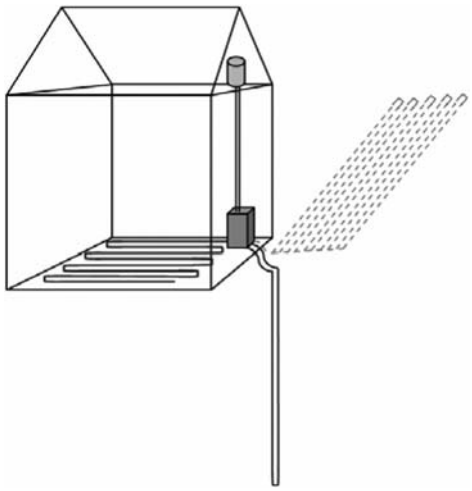
8.36 Hybrid systems

Hybrid, or mixed-mode, systems combine mechanical and natural ventilation in either a spatial or a seasonal mix. Seasonal hybrid buildings may be naturally ventilated in summer and mechanically

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8.71 *Schematic diagram of an absorption cooling system. Refrigerant vaporised in the generator passes to the condenser where it rejects heat and condenses. Its pressure (and temperature) is then reduced by a throttling device before it enters the evaporator, here it absorbs heat from the chilled water circuit and becomes a low-pressure vapour. It then returns to the absorber*



8.72 *Ground source heat pump*

ventilated in winter. Spatial hybrid buildings may have spaces that are both naturally ventilated (say, at the perimeter) and mechanically ventilated (say, in the depth of space).

8.37 Space for services

The space requirements for the location of mechanical services and their distribution systems can be considerable: typically 2–15 per cent depending on building type, and must be considered early in the design process (Table XXXIX).

8.38 Passive Haus

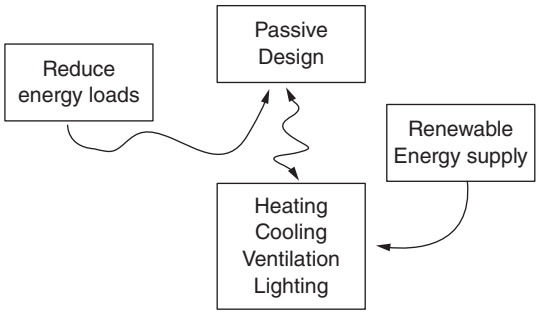
Towards the end of the 1980s and early 1990s the concept of Passive Haus was developed in Germany, with its standards for total energy demand for space heating and cooling to be less than 15 kWh/m^2/annum of floor area, and a total primary energy use for all appliances, domestic hot water and space heating and cooling of less than 120 kWh/m^2/annum. To achieve this performance standard, heating is normally combined with ventilation using a mechanical ventilation heat recovery system, where typically, heated fresh air is supplied to the main living spaces and air is extracted from kitchen and bathroom spaces. Passive Haus walls are super insulated with U-values of 0.10 to 0.15 W/(m^2.K) and triple glazing with U-values, typically 0.85 to 0.70 W/(m^2.K). For some houses air is passed through underground pipes to pre-heat (or pre-cool) the intake air for the ventilation system. Passive Haus method can typically cost up to 15 per cent more, although costs can potentially be reduced if a holistic approach is used.

Table XXXIX Typical space requirements for different systems for an office building as a percentage of total floor space

	Natural ventilation	Mechanical ventilation	Air conditioning
AHUs	–	2	4
Boiler	1.5	1.5	1.5
Chiller	–	–	2
Total	1.5	3.5	7.5

8.39 Low carbon design

Low carbon design of buildings can be divided into four stages, Figure 8.73. These stages need to be closely linked through a holistic approach to ensure that cost savings in reducing heating and cooling equipment, can contribute to increased costs, for example, for renewable energy systems. A life-time costing or life-time carbon approach can also encourage investment in aspects of low carbon design that will be realised in future reduced running costs and security of energy supply. The asset value of a low carbon building should also ensure that it does not depreciate in value and it will be relatively easy to sell or let in future.



8.73 *Schematic diagram of low carbon design using a holistic approach*

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The stages outlined in 8.73 are as follows:

1 *Reduce energy demand associated with activities*. This includes reducing the electricity load associated with lighting, small power and other electrical equipment. This will benefit in two ways. Firstly the electricity used will be directly reduced, and secondly, the heat associated with the use of electrical equipment will be reduced thereby reducing any potential cooling needs. Of course the incidental heat gains associated with equipment will be reduced from the point of providing useful heat to the space, but in a low carbon building this is not always useful and uncontrolled in relation to heating needs. The ventilation load should also be minimised by reducing any internal sources of air pollution and separately ventilating any specific sources of activity requiring additional ventilation.
2 *Passive design*. To adopt a passive design approach to reduce the energy demand associated with heating, ventilation, air conditioning and lighting. This maximises the use of the climate (Section 1.2), through solar control, use of natural daylight, thermal mass effects and natural ventilation (where appropriate). The design should be sensitive to the orientation and form of the building, its construction and distribution of glazing with shading or glazing treatment, ventilation opening and devices and use of materials. The Passive Haus standard is a useful target, although this will require mechanical ventilation with heat recovery and very high standards of thermal insulation and minimising thermal bridging. In future, reducing the embodied energy associated with construction materials and building services equipment will need to be considered, as the embodied energy becomes comparable to the operating energy over the building lifetime.
3 *Efficient environmental services*. Once the energy demand has been reduced through 1 and 2 above, the provision of heating and cooling etc. becomes simpler and more efficient. The current trend for low carbon buildings is to use surface heating and cooling, Figure 8.68, often in combination with mechanical ventilation systems, which can incorporate heat recovery and some element of heating and cooling. It is advisable to decouple the ventilation from heating and cooling, such that any air supply system is primarily designed for ventilation and the main component of heating or cooling delivered is through the surface system (heated or cooled floor, ceiling, panels, etc.). The control of environmental services should be simple and responsive to people's needs. In general, over-complicated controls quickly go out of calibration, especially with change of use, and are often illegible to the people who operate the building.
4 *Renewable energy systems*. The final stage in low carbon design is to provide the energy needed for heating, cooling, ventilation and lighting from low or zero carbon systems, such as solar PV, solar thermal, wind, biomass, hydro, heat-pumps and CHP. Once the energy demand of the building is reduced the amount of energy supply is also reduced, so making building or community integrated renewables more achievable. The thermal energy from heat pumps and solar systems is also more appropriate to the reduced temperatures required for heating low carbon buildings. Higher water temperature for cooling, say chilled ceilings, can increase the operating COP of heat pumps.

The above stages bring together many of the topics discussed in this chapter. In many ways reducing energy loads and the passive design aspect (1 and 2) are well understood by designers. What is less understood is how to provide appropriate environmental services and renewable energy systems, as part of an integrated approach to low carbon design.

8.40 Zero carbon buildings

Zero carbon buildings combine a reduced energy demand for heating, cooling, ventilation, lighting, cooking and electrical appliance load, with the use of renewable energy sources, such as solar thermal, solar PV, wind and biomass. An optimum balance of demand reduction and renewable energy supply is needed and this may differ for different building types and location. This definition of zero carbon only addresses the operating energy of the building. Other definitions might include the use of renewable energy through the lifetime of the building to offset the embodied energy incorporated in the building construction, or even to offset some lifestyle energy uses, such as transport, food and consumer goods. All definitions of zero carbon buildings imply:

- Energy demand reduction through reduced internal loads and passive design.
- Renewable energy systems, building integrated or community based.
- Energy storage either through local or grid systems (e.g. 2-way flows).

9 PREDICTION AND MEASUREMENT

9.1 Technique

There are a number of prediction and measurement techniques now available that the designer can use to help achieve a good thermal design. Prediction techniques can be used during the design to inform the design process. Measurement techniques can be applied after construction, during the 'hand-over' period, in order to check the thermal design performance. Some of the more common techniques are introduced below.

9.2 Building energy models

Computational dynamic building energy models can be used to predict the time-varying thermal performance of a building. They are able to predict the dynamic performance of a building and can account for the thermal capacity of the structure as well as time-varying response to internal heat gains and solar radiation, Figure 8.74. They will predict on a regular time interval (usually hourly) the following parameters:

- Internal air temperature
- Internal surface temperatures (including those from chilled surface cooling systems)
- Temperatures and heat flows within constructions (e.g. in relation to thermal mass effects)
- Internal relative humidity
- Energy used for space heating or cooling
- Temperature profiles through the construction (including glazed facades).

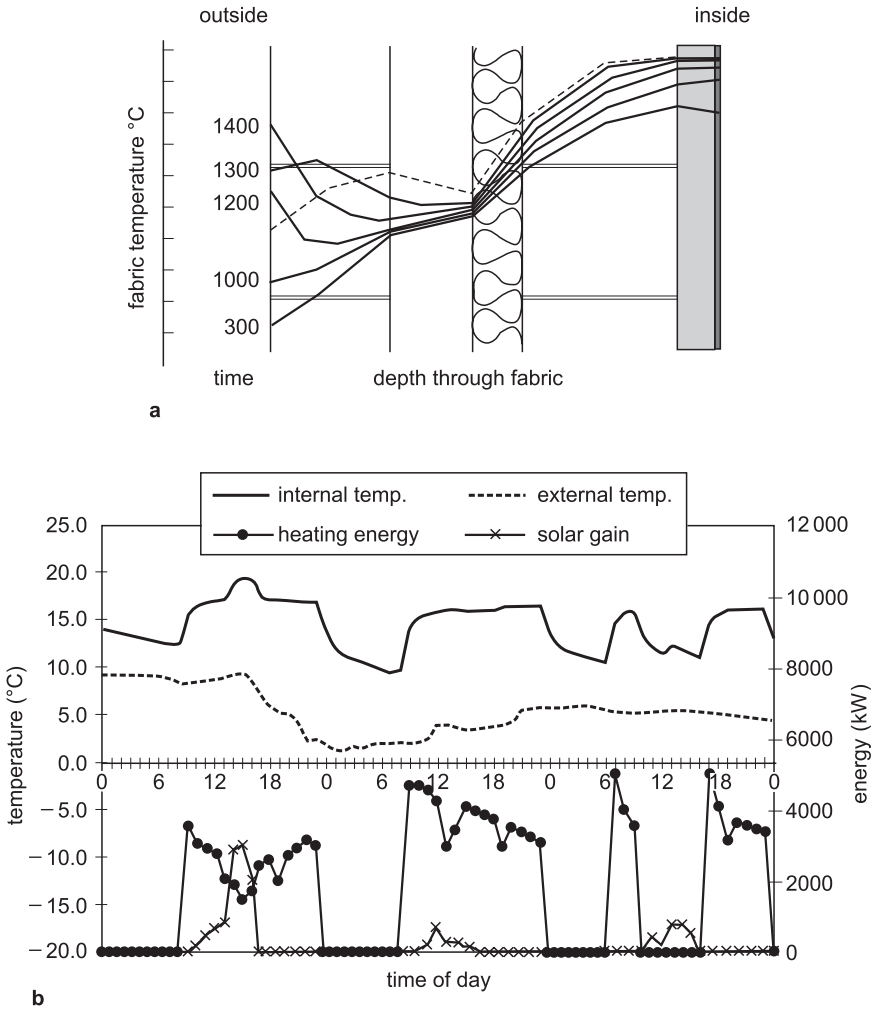
These values can be predicted for each space in the building over any time period (e.g. day, week, year). The models require the following input data:

- Meteorological data: temperature, solar, wind. This is available in standard *test reference year (TRY)* format for various sites.
- Construction data: *k*-values, density, specific heat capacity, and dimensions for materials used.
- Building geometry: areas and locations of walls, floors, etc.
- Occupancy patterns: hours of use, energy use, activities.
- Heating, ventilating and cooling operation: times of use, system and control details.

9.3 Ventilation and airflow models

Network models

Network or *zonal* models can be used to calculate the flow of air between one or more zones in a building and between the spaces and outside. They are computer based and calculate the flows between pressure nodes both within and outside the building. Their main advantage is that they can be used to calculate inter-zone

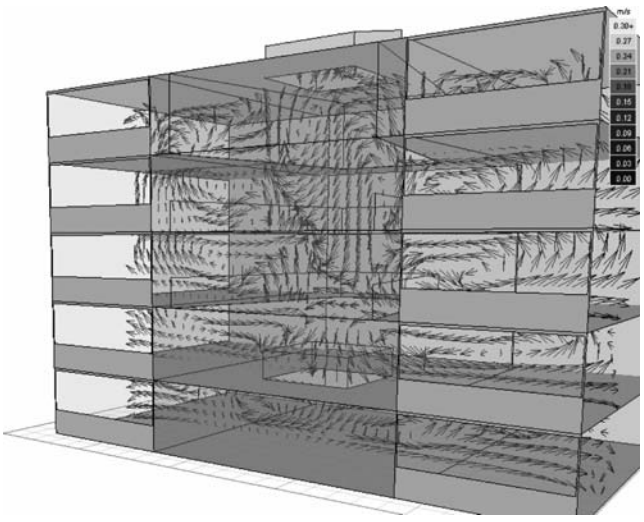


8.74 *Example of the results of the building energy model HTB2: a Predicting the temperature profile through a wall over time; b Forecasting the internal air temperature and energy use as they vary with external temperature and solar gain over a three-day period*

flows and therefore air change rates, ventilation heat transfer and the transfer of contaminants. They can be used to study new building forms, can handle a wide range of opening and crack types and can predict the interaction of buoyancy and wind-driven effects.

Computational fluid dynamics (CFD) models

CFD can be used to predict the internal airflow and heat distribution, driven by the combination of the external forces of wind and stack and the internal forces from buoyancy (warm or cold surfaces) and momentum (airjets) sources, Figure 8.75. It can also be used to predict the ventilation rate and the dispersal of a pollutant through the space or smoke movement in the event of a fire. CFD can be used to predict the external wind flow around a building and the resulting pressure field from which the pressure coefficients (C_p) can be calculated. It is therefore an extremely versatile and useful technique in the field of ventilation and air quality prediction. It is, however, highly complex and requires a high level of skill and understanding of ventilation design, building physics and computational numerical techniques in order to obtain credible solutions. However, models are becoming easier to use by the non-specialist and the need to use such models in ventilation design will eventually result in their widespread use.



8.75 *Example of the use of computational fluid dynamics (CFD) to predict air movement in an atrium*

Wind tunnel modelling

A physical model of a building and its surroundings can be constructed and placed in a wind tunnel, Figure 8.76, where it is subjected to a controlled wind flow. Pressure sensor taps can be installed at various points on the building envelope, corresponding to ventilation openings. The pressure at each opening can be measured. This can then be related to the free wind pressure, at a point of known height above the surface, in order to obtain the C_p value as described in Section 4.

9.4 Thermographic surveys

All objects emit heat energy (i.e. infrared radiation), the amount being dependent on the surface temperature and its emissivity.

Thermography is the term used to describe the process of making this heat energy visible and capable of interpretation. An infrared camera can be used to scan the surfaces of a

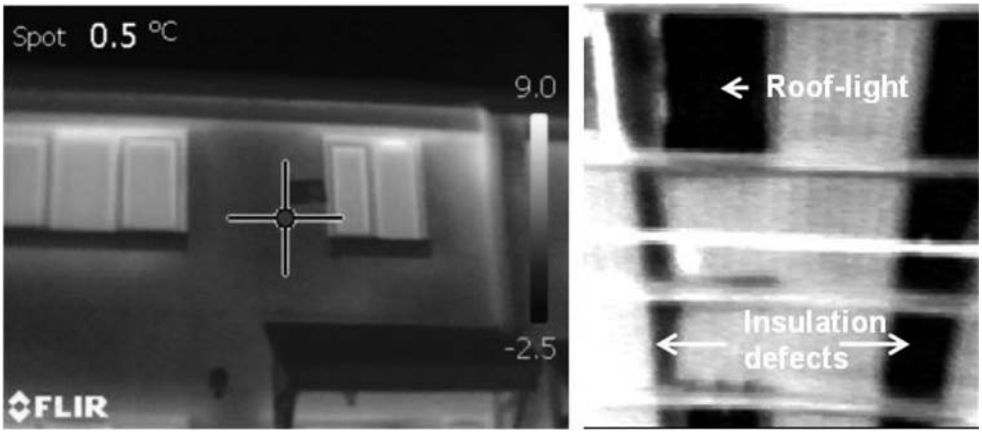
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8.76 *Boundary layer wind tunnel and model at the Welsh School of Architecture used for measuring Cps*

building and produce a 'live' heat energy picture that can be viewed. The picture appears in colour or greyscale. The differences in colour or tones of grey correspond to differences in surface temperature across the surface being viewed. Surface temperature differences of the order of 0.5°C can be identified. Areas of defective or missing insulation can be detected by identifying locally warm (viewed from the outside) or cool (viewed from the inside) surface areas. Generally images taken from the inside, compared to those taken from the outside, can exhibit greater temperature variations due to their relative higher internal surface thermal resistance, and therefore be of higher resolution. If there is air leakage into a building it can produce a locally cooled area on the internal surface which can be detected by the camera. If there is air leakage to the outside this can produce a locally heated area. Figure 8.77 presents some examples of thermographic images.



8.77 *Examples of thermographic images from outside (left) and inside (right)*

9.5 U-value measurement

The U-value of a construction can be estimated from measurements of internal and external surface temperature and heat flux. These measurements need to be carried out over a period of time to minimise the effects of thermal capacity. For lightweight cladding constructions an estimate of the U-value can be achieved in about eight hours. In heavyweight masonry construction a period of a week to ten days may be needed. Measurements should be carried out on a north-facing wall or roof to avoid interference from solar gains.

9.6 Air leakage measurements

These offer a means of assessing the airtightness of different buildings by comparison with values. The air leakage of a building can be measured by pressurising or depressurising the building using a fan measuring the volume flow of air needed to maintain a fixed pressure difference between inside and outside.

Table XL Air leakage standards, for 50Pa Internal/external pressure difference of 50Pa

	$m^3/h/m^2$ @50Pa
Domestic	7
Commercial	
Natural ventilation	10
Air conditioning	5
Industrial	15

Source: BSRIA.

Air leakage rate standards are normally specified either for whole buildings (in air changes per hour) or in normalised form relating to envelope area (m^3s^{-1} per m^2 of envelope area). Table XL presents typical design air leakage values.

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9 Light

Joe Lynes

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KEY POINTS:
- *Daylight and sunlight for energy conservation*
- *Energy-efficient electric lighting*
- *Lighting in the Building Regulations*

Contents

1 A passive solar resource
2 Daylight indoors
3 Window design
4 Electric lighting – energy efficiency
5 Lighting controls
6 Sizing an overall lighting installation
7 Display lighting
8 Visual display terminals
9 Glossary
10 Bibliography

INTRODUCTION

Recent advances in software and computer graphics mean that electric lighting design is increasingly computer-based, and handled by specialist consultants. Architects should note fresh demands of Building Regulations in this field. They should be aware of continuous gains in lamp efficacy, especially in connection with LED lamps (light emitting diodes). They should also appreciate how the choice of luminaires can affect the character of a lit interior.

Window design largely remains in architectural hands. Natural lighting has important implications for site layout and massing, and for energy conservation. Sunlight is increasingly important; solar geometry is the key to harnessing sunlight. Daylight factors remain significant, average values now replacing traditional minimum requirements. Switches and lighting controls, encouraged by Building Regulations, give extra scope for energy savings when thoughtfully applied.

1 A PASSIVE SOLAR RESOURCE

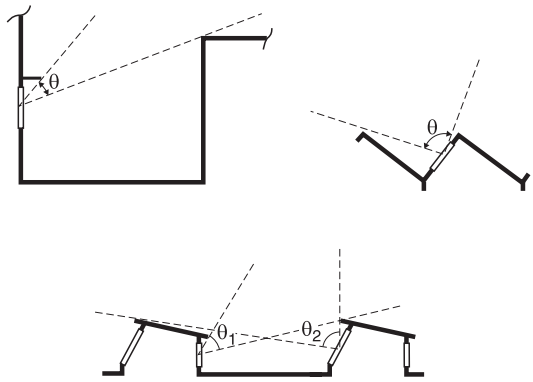
1.1 Siting and orientation

Thermal applications of solar energy have long been recognised. The potential of sunlight, direct and diffused, in saving electrical energy by reducing the demand for artificial lighting, is less obvious. Here early decisions on siting and orientation may be more effective than later decisions on fenestration. Detailed guidance on the strategy of daylighting is contained in Littlefair (2011).

High-rise buildings should ideally be sited to the north, and low-rise or low-density buildings to the south of a new development, taking care not to overshadow existing buildings. Full advantage should be taken of south-facing slopes. Terraced housing should run east-to-west, so that one wall can face south. Detached or semi-detached dwellings can be on north-south link roads. Courtyards should ideally be open to the southern half of the sky. Garages and parking spaces should preferably face north. The pitch of north-facing roofs should be shallow to minimise overshadowing.

1.2 Site planning criteria

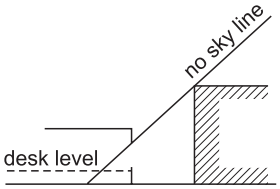
The skylight illumination reaching any point depends largely on how much sky is visible from the point in question. The amount of light striking a window (and hence entering a room) on a densely overcast day is roughly proportional to the angle θ, Figure 9.1, i.e. to the effective angle in degrees subtended in a vertical plane by the sky visible from the centre of the window.



9.1 *θ is the angle subtended at the window by the visible sky*

The BRE Report 'Site layout planning for daylight and sunlight' (Littlefair, 2011) expresses the daylight reaching a vertical wall or window, on a densely overcast day, in terms of the *vertical sky component* SC_v. This is the direct *illuminance* (lux) on the vertical surface, expressed as a percentage of the simultaneous horizontal illuminance under an unobstructed overcast sky. An unobstructed vertical surface would have a vertical sky component of 39 per cent.

An additional check on the penetration of skylight is provided by the *no-sky line,* Figure 9.2. This is the 'line' (actually a surface in three-dimensional space) which divides a room into two parts: one part is exposed to a view of the sky, the other part receives no direct daylight at all. The latter zone is disadvantaged with regard to both view and natural lighting.



9.2 *No sky is directly visible from indoors to the left of the no-sky line*

The recommendations in the BRE Report are summarised below in Sections 1.3 to 1.8 and in Table I.

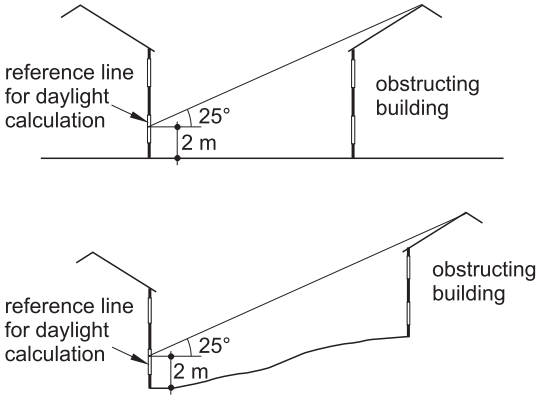
1.3 New developments – skylight potential

Two alternative checks are recommended to ensure that surrounding obstructions do not unduly detract from the natural lighting in a room. First, from a standard reference height 2 m above ground level, check whether any visible obstruction projects above the 25° horizontal roofline limit, Figure 9.3. Odd trees may be ignored. If the 25° line is substantially clear of obstruction then a target

Table I BRE criteria and planning aids

Criterion	Where	Standard	Indicator	Short cut	Count
Skylight potential	New-build	Within 4m of SC_v 27%	Skylight indicator, **39.4**	Clear above 25°	54 crosses
Skylight potential	Existing	SC_v at window at least 27%	Skylight indicator, **39.4**	25°	crosses
Skylight potential	Boundary	Within 4m of SC_v 17%	Skylight indicator, **39.4**	Clear above 34 43°	crosses
Sunlight potential	New-build	1 principal wall within 90° of due south. Within 4m of exposure to 25% of probable sunlight hours, including at least 5% in winter 6 months	Sunlight availability indicator, **39.5**	25 and 5 dots	
Sunlight potential	Existing window	25% of probable sunlight hours, including at least 5% in winter 6 months	Sunlight availability indicator, **39.5**	Clear above 25 and 25°	5 dots
Sunlight potential	Open space	Not more than 40% totally shaded at equinoxes	Sun-on-ground indicator, **39.6**	% area shaded	
Planning for sunlight			Sunpath indicator, **39.7**		

vertical sky component of at least 27 per cent should be achieved. If this first check fails, the obstruction may still be narrow enough to allow adequate daylight around its sides. To check this, it is necessary to ensure that every point on the façade, along the standard 2 m reference line, is within 4 m (measured sideways) of a point which does have a vertical sky component of 27 per cent or more. The BRE Report contains a *skylight indicator*, Figure 9.4, for estimating vertical sky components on an obstructed site.



9.3 *The 25° criterion*

1.4 New developments – sunlight potential

Incident sunlight is expressed in terms of *probable sunlight hours*. These are the total number of hours per year when the sun would, under typical cloud conditions, shine directly onto a given point.

In a new dwelling, and in any other new buildings in which sunlight would be desirable, two recommendations for incident sunlight should both be met:

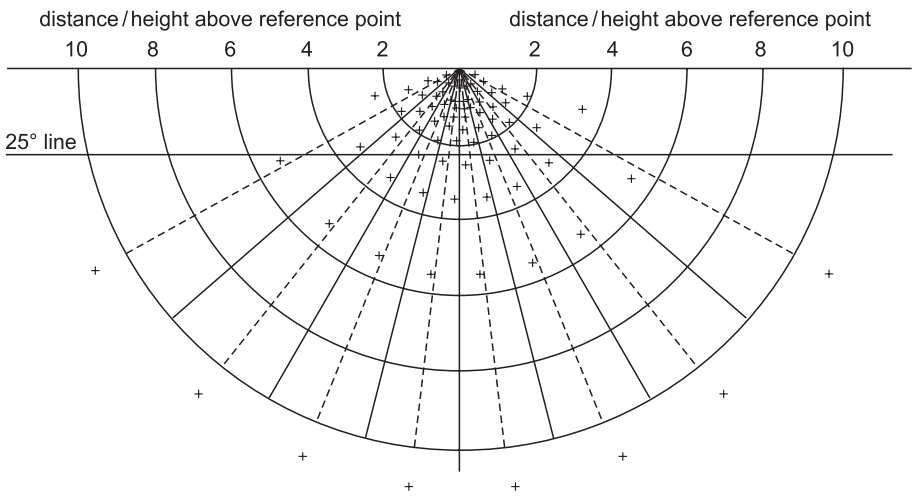
(a) One principal window wall should face within 90° of due south, and
(b) Along this window wall, every point on the standard 2 m reference line should be within 4 m (measured sideways) of a point exposed to at least one quarter of the annual probable hours of sunlight on an open site. These hours of exposure should include at least 5 per cent of probable hours of sunlight in the six winter months between 21 September and 21 March.

The BRE Report contains *sunlight availability indicators*, Figure 9.5, for three latitudes: 51.5°N (London), 53.5°N (Manchester) and 56°N (Glasgow). These can be used for estimating hours of *probable sunlight* on an obstructed site.

1.5 Existing buildings – skylight protection

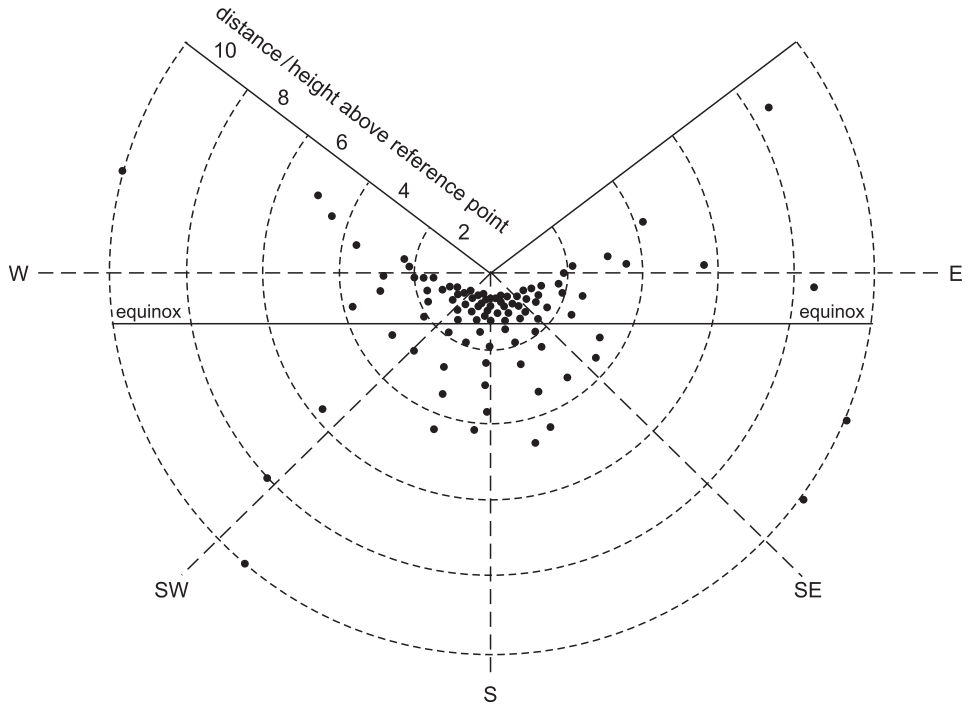
If any part of a new building or extension, seen from the lowest window of an existing building, projects above the 25° horizontal reference limit, Figure 9.3, then two further tests must be applied:

(a) The *vertical sky component* at the centre of each existing main window must be not less than 27 per cent, and not less than 0.8 times its previous value, and



9.4 *Skylight indicator (with kind permission of BRE)*

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9.5 *Sunlight availability indicator for latitude 53.5° N. The annual total of unobstructed hours of probable sunlight would be 1392 hours (with kind permission of BRE)*

(b) The area of the *working plane* within the *no-sky line,* 9.2, must not be less than 0.8 times its previous value.

The BRE *skylight indicator*, Figure 9.4, is designed for checking vertical sky components.

In some cases, legal rights to light may supplement the BRE recommendations. A right to light may be gained either by legal agreement or if a window has received the light without interruption for 20 years or more. Infringement of a right to light is judged by comparing *sky factor* contours indoors before and after the infringement.

1.6 Existing buildings – sunlight protection

If an existing living room has a main window facing within 90° of due south, one of two alternative conditions should be met: either

(a) No part of a new building, seen from the centre of the window and projected onto a vertical plane perpendicular to the window wall, is more than 25° above the horizon, or
(b) The point at the centre of the window, on the indoor plane of the window wall, must be exposed to at least a quarter of annual *probable sunlight hours*, including at least 5 per cent of annual probable sunlight hours in the six winter months between 21 September and 21 March, and not less than 0.8 times its previous sunlight hours in either period. The BRE *sunlight availability indicators*, Figure 9.5, are used to check compliance.

1.7 Adjoining development land

For a building to be a 'good neighbour', it should stand well back from the plot boundary to avoid unduly restricting well-daylit development on adjoining properties. A neighbouring site will have acceptable daylight protection if, along each common boundary line, one of the following alternative criteria is met: either

(a) No new building, seen from a point 2 m above ground level and projected onto a vertical plane perpendicular to the boundary, is more than 43° above the horizon, or
(b) Every point 2 m above the boundary line should lie within 4 m (measured along the boundary) of a point which has a *vertical sky component* (facing the new obstruction) of 17 per cent or more.

Note: There is no protection for sunlight (or view), as distinct from skylight, along boundaries.

1.8 BRE site planning aids

The Building Research Establishment has issued a number of indicators to assist designers in meeting their site planning recommendations:

- Skylight indicator, Figure 9.4;
- Sunlight availability indicator, Figure 9.5;
- Sun-on-ground indicator, Figure 9.6;
- Sunpath indicator, Figure 9.7.

Table I summarises the BRE criteria, indicating which planning aid is applicable to each criterion.

1.9 Solar geometry

The sun's apparent position in the sky is specified in terms of two angular coordinates:

- the *altitude* γ in degrees above the horizon;
- the *azimuth* α in degrees clockwise in plan, measured from due north.

These coordinates are given by the equations:

$$\gamma = \arcsin(\sin\varphi \sin\delta - \cos\varphi \cos\delta \cos 15t) \qquad \text{equation (1)}$$

$$\alpha = \arccos[(\sin\varphi - \sin\delta \sin\gamma)/(\cos\varphi \cos\gamma)] \qquad \text{equation (2)}$$

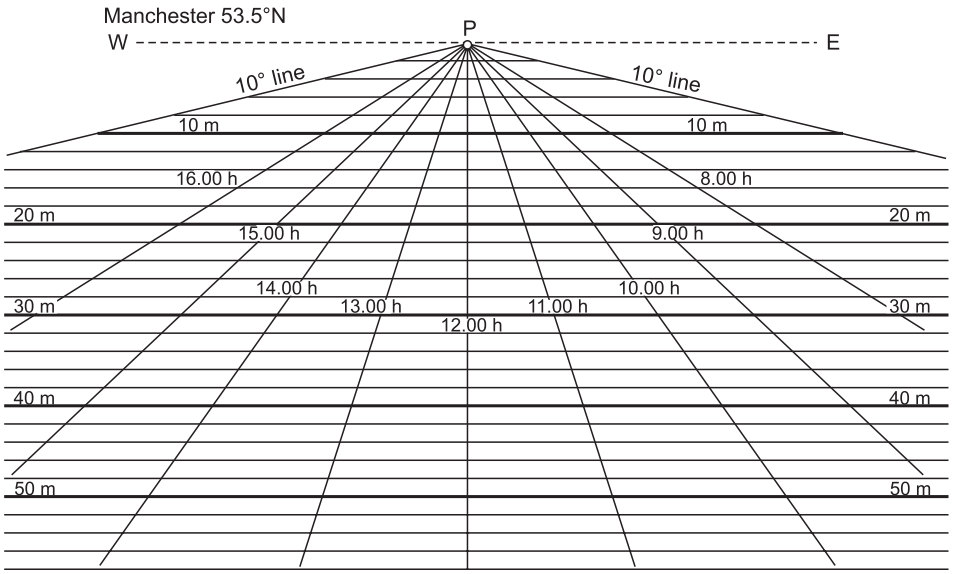
where φ = geographical latitude of site (positive in the northern hemisphere)
δ = *solar declination*, Table II (north is positive, south negative)
t = hours since midnight (note that the term $15t$ is in degrees, not in radians)

the *altitude* of the sun at noon is $(90° - (\varphi - \delta))$.

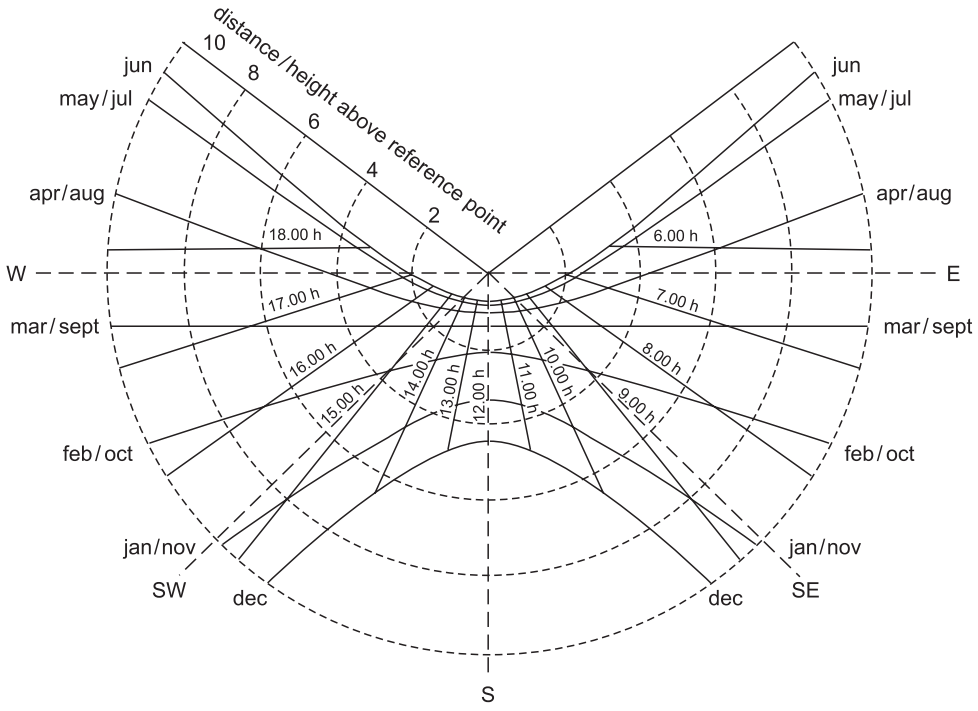
1.10 Sunlight – the use of models

A simple block model is adequate for most studies of solar penetration and for the choice of solar protection. It can be illuminated by a small lamp located as far from the model as possible to ensure near-parallel 'sunlight'. Better still, in conjunction with the matchbox sundial, one can use the real sun outdoors as a light source. The relative positions of source and model

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9.6 *Sun on ground indicator for 21 March, latitude 53.5° N (with kind permission of BRE)*



9.7 *Sunpath indicator for latitude 53.5 N (with kind permission of BRE)*

are so arranged that the direction of the incident light will replicate the direction of the sun's rays at the time and season under investigation.

One way of bringing the correct angles of sunlight to bear on the model is to mount it on a *heliodon,* Figure 9.8. A simple turntable carries a platform which is tilted so as to be parallel to the earth's surface at the relevant latitude, ground at the north pole being taken as horizontal. The artificial sun is moved above or below this horizontal datum plane, depending on the season/*declination*; it may slide up and down a vertical scale, Figure 9.9, whose solstice-to-solstice height subtends 46.6° at the centre of the tilted heliodon platform. The centre of the vertical scale should be level with the platform. The earth's daily rotation is simulated by spinning the tilted platform so that the movement of shadows throughout a chosen day can be observed.

Table II Solar declinations

Dates	Solar declination
22 June	23.4°N (Summer solstice)
21 May/24 July	20°N
26 April/28 August	10°N
21 March/23 September	0° (Equinox)
23 February/20 October	10°S
21 January/22 November	20°S
22 December	23.4°S (winter solstice)

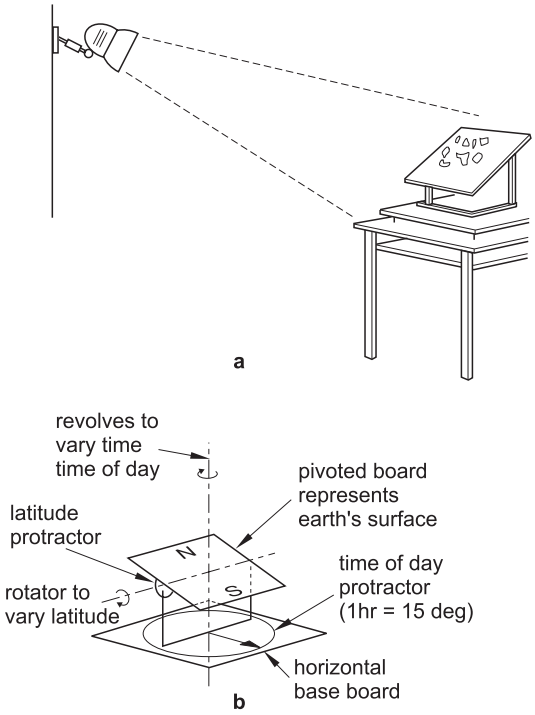
The matchbox sundial, Figure 9.10, has been described as the poor person's heliodon. It comprises a stick (the 'gnomon') standing in a folded tray which fits inside a matchbox. A grid of lines on the tray traces the position of the shadow of the tip of the gnomon at

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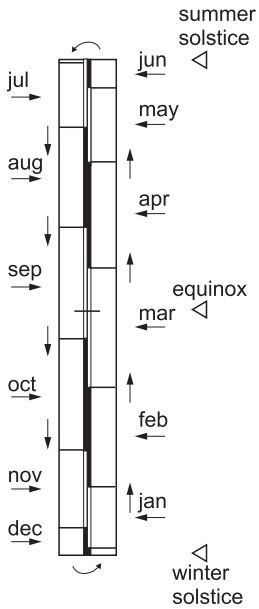
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different hours and seasons. The seven monthly shadow orbits correspond to the dates and *solar declinations* shown in Table II. The matchbox sundial illustrated is suitable only for latitude 53.5°N. To use it elsewhere, tilt it about an east-west axis through an angle equal to the difference in latitude, shadows being shorter as you approach the equator.

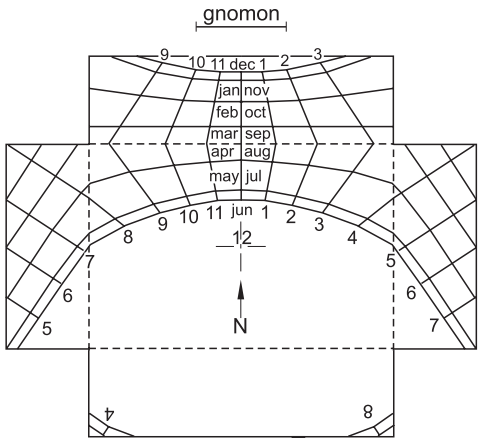
Align the north point on the sundial with the north point of the model. Shine a distant lamp on the sundial, casting the shadow of the gnomon at the month and time of day under consideration. The pattern of sunlight and shadow should be correct on the model. Ideally this is a three-person activity. The first person – the tallest! – holds the lamp as far from the model as possible. The second watches the sundial and directs the first accordingly. The third takes photographs – always from due north in the northern hemisphere,



9.8 *The heliodon: a In use; b Explanatory diagram*



9.9 *Graduated season scale for heliodon. A lamp slides up and down this scale to simulate the sun's position month by month*



9.10 *Matchbox sundial for latitude 53.5° N*

otherwise a shadow of the photographer, camera and tripod will appear in the photograph. Remember to include in each photograph a card to show the time and date under investigation. Otherwise you may not be sure afterwards which photograph is which!

The alternative 'aviator method' avoids the need for colleagues, and for plunging your environment into darkness, but there are no photographs to show for it. This approach depends on the fact that the sun never 'sees' a shadow. Solar shadows are cast only on surfaces hidden from direct sunlight. Place a matchbox sundial, correctly orientated, beside a model. Align your eye with the tip of the gnomon, and with the chosen time and date marks. Those parts of the model which you can see from that position will be sunlit at the chosen time. Those parts which are concealed will be in shadow. The aviator method also works with a heliodon if you place your eye in the position of the 'sun'.

Model studies are useful for three types of sunlight investigation:

1 Seeing how far direct sunlight can penetrate inside a modelled room, and how effectively it is controlled by sunbreaks.
2 Seeing how adjacent buildings intercept each other's sunlight.
3 Judging the quality of sunlight illumination received indoors after reflection from the ground and from nearby sunlit buildings; this is more applicable to dry tropical areas than to the UK.

2 DAYLIGHT INDOORS

2.1 Daylight factors

Daylight design in the UK has traditionally been based on the convention of a Standard Overcast Sky for three reasons:

(a) Prudence: if the natural lighting is sufficient on an overcast day it is likely to be more than adequate when the sun shines.
(b) Convenience: a densely overcast sky looks the same whichever direction (in plan) one faces – north, south, east or west. The effect of orientation vanishes from the calculation but not, one hopes, from the designer's awareness!
(c) Given the overall brightness profile of a Standard Overcast Sky, the *illuminance* at any given point indoors must be directly proportional to the simultaneous outdoor illuminance under the unobstructed overcast sky vault, whether the sky itself is bright or dull.

The constant ratio of indoor to unobstructed outdoor illuminance is usually expressed as a percentage, and is referred to as the *daylight factor*. Thus the daylight factor at a given point may be defined as the *illuminance* (lux) at that point, expressed as a percentage of the simultaneous horizontal illuminance under an unobstructed overcast sky.

Until recently it was customary to specify natural lighting levels in terms of the minimum daylight factor in a given interior. This

involved a painstaking calculation at the end of which there was little assurance that people's impression of daylit spaces would actually correlate with the minimum daylight factors. The current trend is to express the natural lighting of a room in terms of the average (as distinct from the minimum) daylight factor. This requires only a back-of-the-envelope calculation (see Section 2.3), and yields, for each room, a single figure which characterises the daylight level.

Limitations of the average daylight factor must not be overlooked. In a medium-sized room we can usually form a unitary impression of the natural lighting: we sum it up as 'bright', 'adequate', 'dim', etc., as the case may be. But in a deeper side-lit space our impression is more complex; one end of a room may look bright, the other end dim by comparison. To interpret an average daylight factor with discernment we need to know at what point the concept will break down.

Broadly speaking, a side-lit room is too deep – or the natural lighting unbalanced – when either the *no-sky line,* Figure 9.2, cuts off a substantial area of the *working plane*, and/or

when $l/w + l/h > 2 / (1 - R_b)$ equation (3)

where l = depth of room from window to back wall
w = width of room measured across the window wall
h = height of window head above floor
R_b = area-weighted average *reflectance* in back half of room

Unless the average daylight factor has been ruled out by one of the above considerations, it may be quoted with confidence to characterise the daylit appearance of a room. Thus an average daylight factor greater than 5 per cent will generally give the impression of generous natural lighting (except, of course, on a dull day or in the evening); an average below 2 per cent would be judged gloomy, and electric lighting would be switched on as soon as an occupant entered the room.

2.2 The use of models in daylight prediction

Scale model rooms have often been used for the prediction of daylight factors. The basic laws of illumination (the additivity, inverse square and cosine laws acting together) dictate that daylight factors in a perfectly scaled model must agree with those in the full-scale building. Unfortunately immediate application of this principle is fraught with pitfalls for the unwary.

Architectural models commissioned for other purposes are unlikely to be suitable. Joints and corners must be perfectly light-tight. Walls must be opaque: balsa and white card are out. Surface colours, and especially *reflectances,* must be correctly simulated. Glass *transmittance* must also be correct or, failing that, must be offset by applying a correction factor to the end result. Outdoor obstructions must be properly scaled, at least with regard to their angular subtense, and also finished appropriately. Finally the measured daylight factor must be adjusted to take account of dirt on the glass and on room surfaces, and to allow for any curtains or glazing bars, and for absorption of light by furniture and other impediments.

In principle the daylight factor inside a model can be obtained by measuring the indoor illuminance at some chosen position with a lightmeter, and expressing it as a percentage of the illuminance on the roof of the model. This assumes that the roof of the model is exposed to the whole sky vault. It assumes too that the sky is densely overcast; this requirement follows from the definition of a *daylight factor.*

The necessity of waiting for overcast conditions to occur unaccompanied by rain, snow or gusty winds has led, logically enough, to the development of artificial skies, providing a Standard Overcast brightness profile at the flick of a switch. These too have their pitfalls. Mirror-box skies produce multiple reflections of the model above horizon level. Those too small to accommodate a model inside will be unsuitable for testing rooflights. Sky domes will suffer from parallax and horizon errors unless the 'sky' is very large compared with the model under test.

Since most of the potential errors would cause daylight measurements in models to be overestimated, one can anticipate that, unless exceptional precautions are taken, daylight factors measured in a model will considerably exceed those in the real building. This need not discourage the use of models. However one may wonder why a designer would bother with daylight factors when he or she can judge and fine-tune the daylit appearance of his or her model by eye. The best advice must be to formulate in advance the questions – they may be qualitative rather than numerical – which the model study is designed to answer. Analysis of these key questions may well reveal that specific daylight factors are unimportant, and that more may be learned by studying a model under real sky conditions, facing alternately towards and away from the sun, than by leaving the overcast sky convention to dictate a programme of expensive measurements which may turn out to be irrelevant.

2.3 Calculating the average daylight factor

The average *daylight factor df* is given by the following equation:

$$df = (T \times W \times \theta \times M) / [A(1 - R^2)] \text{ per cent} \qquad \text{equation (4)}$$

where T = *transmittance* of glazing material (clear single glazing = 0.82; clear double glazing = 0.70)
W = net area of glazing material
θ = vertical angle of sky seen from centre of window, Figure 9.1
M = maintenance factor, Table III
A = total area of interior surfaces: floor + ceiling + walls, including windows
R = area-weighted average *reflectance* of interior surfaces

2.4 Shaping a window

Increasingly the prime function of a window is as much to provide a view as to illuminate the interior. In principle the analysis of view presents no great problem. A straight line can be drawn from the eye of an occupant to an object of regard outside the building. If the straight line passes through a window opening, in both plan and section, then the object will be visible; if not it may be necessary to alter the shape or position of the window. In practice, occupants move around, and the indoor end of the straight line moves with them; a good view from the back of a room will be harder to achieve than a view from just inside the window. The choice of desirable objects of regard is usually easier in reality than in theory; but it is a choice that needs to be made consciously and deliberately if the window is to be optimised.

The skyline plays a key role. Ideally the view of the skyline should not be interrupted by the window head. Should this be impracticable, some direct view of the sky remains desirable, if only to reveal the clarity or cloudiness of the local weather.

But the need for a view interacts with other aspects of the environment. A direct view of the sky can be a source of discomfort ('glare'), especially when the patch of sky is close to the direction of the sun. On the other hand, the daylight factor at the back of a room depends largely on the amount of sky directly visible, see Section 1.2. Thus there is a potential conflict between the imperatives of view, comfort and uniform daylighting. This conflict can be resolved only by prioritising. The relative importance of the three factors will largely determine the right shape and position for each window.

3 WINDOW DESIGN

3.1 A sequence for window design

We return to equation (4) for the average daylight factor, in Section 2.3. Inspection of the expression suggests a natural sequence for window design decisions.

Stage 1

The first item to be fixed in the equation is the angle θ defined by the position of exterior obstructions. This depends mainly on the

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Table III Maintenance factors for natural lighting (Tregenza, Stewart and Sharples, 1999)

		Slope of glazing					
		Vertical		Inclined		Horizontal	
Room function	**Exposure**	**Rural/ suburban**	**Urban**	**Rural/ suburban**	**Urban**	**Rural/ suburban**	**Urban**
Residential	**Driving rain exposure**	0.98	0.95	0.94	0.88	0.88	0.76
Private rooms and communal areas, few occupants, good maintenance, no smoking.	**Normal exposure**	0.96	0.92	0.92	0.84	0.88	0.76
	Heavy snow exposure	0.96	0.92	0.88	0.76	0.84	0.68
	Sheltered by overhang	0.88	0.76				
Commercial, educational	**Driving rain exposure**	0.98	0.95	0.94	0.85	0.88	0.70
Rooms used by groups of people, areas with office equipment or with some smoking	**Normal exposure**	0.96	0.90	0.92	0.80	0.88	0.70
	Heavy snow exposure	0.96	0.90	0.88	0.70	0.84	0.60
	Sheltered by overhang	0.88	0.70				
Polluted and heavily used interiors	**Driving rain exposure**	0.92	0.90	0.76	0.70	0.52	0.40
Swimming pools, gymnasia, heavy industry or heavy smoking	**Normal exposure**	0.84	0.80	0.68	0.60	0.52	0.40
	Heavy snow exposure	0.84	0.80	0.53	0.40	0.36	0.20
	Sheltered by overhang	0.52	0.40				

spacing and massing of surrounding buildings. The block layout is effectively fixed quite early in the design process, well before fenestration has been thought about. Access, prospect, privacy, site utilisation and microclimate are some of the formative factors at this stage. Because these will act as constraints on the daylight factor, the determination of the angle θ is identified as the first stage in window design. Some relevant criteria and design aids were listed in Table I.

Stage 2

A side-lit room may be too deep to be satisfactorily daylit. This outcome was discussed in Section 2.1. It occurs when the *no sky line* seriously encroaches on the *working plane*, or when equation (3) indicates that the natural lighting at the back of the room will look unacceptably dim.

If the room is indeed too deep for stand-alone natural lighting, the average daylight factor will not be a useful design criterion. Instead the windows should be optimised mainly for view and for thermal performance and, if daylight linked controls, as in Section 5.2, are contemplated, for the dimming and extinction of the row of luminaires closest to the window wall. Unless the room survives the two tests in Stage 2 the designer should proceed straight to Stage 4, omitting Stage 3 of this window design sequence.

Stage 3

The window area W is estimated by inverting equation (4):

$$W = df \times A(1 - R^2)/(T \times \theta \times M)$$

At this point there is the familiar conflict between visual and thermal considerations. The average daylight factor *df* is proportional to the window area *W,* but so is the winter heat loss through the windows, and so (other things being equal) is the daily mean solar heat gain. Passive solar design, harnessing both daylight and solar gain, may optimise by reducing heat loss through the glazing. Other approaches to design must face and resolve a three-way conflict: daylight versus heat loss and summer heat gain. It is important to resolve these pressures on the window area at this stage, before proceeding to Stage 4 which is concerned with optimising window shape and position for each window.

Stage 4

By this stage either the window area is established and the average daylight factor settled in Stage 3, or the room has been identified in Stage 2 as too deep for stand-alone natural lighting. In either case the shape and position of the windows have yet to be finalised, but the completion of the design is obviously simplified by the prior decisions in Stages 2 and 3.

The competing claims of view, visual comfort and daylight uniformity were reviewed in Section 2.4 above. They centred on the visibility of the skyline. The avoidance of glare required as little visible sky as possible. A good view implied a good sight of the skyline itself but no additional access to the sky. Uniform daylighting mandated as much sky as possible visible from the depths of the room. The conflict must be resolved, in Stage 4 as in Stage 3, by identifying and balancing the relevant priorities.

Also in Stage 4 the possible advantages of multilateral fenestration may merit review. Windows in more than one wall may improve the natural lighting in two respects: by increasing the area of sky seen from the worst-lit parts of the room, and by reducing the brightness contrast between the sky and the window walls. In a naturally ventilated building they will also promote cross-ventilation, mitigating summertime overheating.

Applicability

Obviously the above idealised sequence is remote from the reality of window design. The results of applying it slavishly window-by-window would be a chaotic elevation, maybe unbuildable. A formal design sequence should provide a safety-net for architects in trouble. They can retrace their steps and recognise false turns if need be. The key to good natural lighting design is to identify significant crunch points: What is the most important or the most

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Table IV Circuit efficacies

Lamps	Circuit efficacy (lumens per watt)
Filament lamps	
60 W general lighting service (GLS)	10 lm/W
150 W linear halogen	15 lm/W
T8 fluorescent tubes	
58 W triphosphor with conventional ballast	77 lm/W
58 W triphosphor with high-frequency ballast	98 lm/W
58 W multiphosphor with conventional ballast	54 lm/W
58 W multiphosphor with high-frequency ballast	68 lm/W
Compact fluorescent	
18 W four-limb, high-frequency	60 lm/W
Metal halide	
400 W MBI-T	85 lm/W
70 W CDM	100 lm/W
High-pressure sodium	
250 W SON-T	102 lm/W
250 W SONDL-T (improved colour)	82 lm/W
100 W "White" SDW-T	42 lm/W
"White" Light-emitting diodes (LED)	
1100 lumens	53 lm/W
2000 lumens	56 lm/W

demanding room on a given facade? Design its windows properly. Repeat variants of the solution up and down the elevation. Then the windows will do their job, both as external visual elements and as components of the interior environment.

4 ELECTRIC LIGHTING – ENERGY EFFICIENCY

4.1 Lamp efficacy

The *efficacy* of an electric lamp is defined as its *luminous flux (lumens)* divided by the electric power consumed (watts). Efficacy is expressed in lumens per watt (lm/W). Lamp manufacturers specify the lumen output of a lamp as that of a clean lamp once its output is reasonably stable. For fluorescent and other discharge lamps this condition is said to be reached after 100 hours of normal running.

Note that lamp manufacturers normally express lamp efficacy as lumens per lamp watt, whereas Part L of the Building Regulations specifies lumens per circuit watt including power consumed by control gear. Some representative *circuit efficacies* are listed in Table IV.

4.2 Luminaires

The term *luminaire* covers a lighting fitting complete with control gear and suspension where applicable. The *light output ratio* (LOR) of a luminaire is the proportion of *luminous flux (lumens)* from the lamps which emerges from the luminaire. The LOR for a bare lamp would be 1.00. Other things being equal, a luminaire having a high LOR is more efficient than one with a lower LOR. Typical values are listed in Table V.

Table V Light output ratios for typical luminaires

Luminaire	Light output ratio (LOR)
Bare lamp	1.0
Open reflector	0.8
Pendent or surface-mounted diffuser	0.65
Louvered luminaire	0.6
Recessed diffuser	0.5

The *luminaire efficacy* is the *luminous flux* output from the luminaire, divided by the electric power consumed, including losses in control gear. Luminaire efficacy, like *lamp efficacy*, is measured in lumens per watt (lm/W).

Luminaire efficacy = lamp efficacy × LOR

The *flux fraction ratio* (FFR) of a luminaire is the ratio of the flux (*lumens*) emerging in directions above the level of the luminaire, to the flux directed below the level of the luminaire. For a downlight the FFR is zero; for an uplighter, infinity.

With an FFR greater than 0.8, the ceiling may be more brightly lit than the working plane. With an FFR less than 0.1, the ceiling may look dark; so low-FFR luminaires work best when the ceiling, floor and table top all have a reasonably high *reflectance.* The FFR has a significant effect on the character of the lit environment. See Table VI.

Table VI Effects of luminaire light distribution on the atmosphere in a room

Flux fraction ratio FFR	Spread of downward light: light Tight	Medium	Widespread
0 to 0.1	Concentration on task in hand.	Dark ceiling may look oppressive.	Danger of glare?
0.1 to 0 8	Well-mannered, formal.	Safe, characterless?	Welcoming, expansive.
Over 0.8	Dignified.	Safe, relaxing.	Relaxing.

4.3 Building regulations – dwellings

In new dwellings, and in existing dwellings where major refurbishment is undertaken, at least 75 per cent of luminaires in regularly used rooms (i.e. other than cupboards, wardrobes and storage spaces) must use lamps with a *circuit efficacy* greater than 45 lumens per watt, and emitting over 400 lumens. Filament lamps fall well short of the circuit efficacy requirement.

Any fixed lighting must satisfy one or other of the following sets of requirements:

Either

> lamp wattage must not exceed 100 lamp-watts per fitting, and must be automatically extinguished if the area becomes unoccupied, or when daylight is adequate;

or alternatively

> *Lamp efficacy* must be greater than 45 lumens per circuit watt, luminaires must be controllable manually, and automatically extinguished when daylight is adequate.

4.4 Building regulations: non-domestic buildings

The following requirements apply to general lighting in offices, industrial or storage spaces, classrooms, seminar rooms and conference rooms. They apply to new buildings and to buildings where substantial refurbishment is undertaken.

The average initial *luminaire efficacy* must be not less than 55 luminaire lumens per circuit watt. The circuit wattage for each luminaire may be multiplied by the control factors in Table VII. To derive the average luminaire efficacy, divide the total luminaire output (lumens) by the total circuit wattage adjusted by control factors.

In other spaces the average initial *lamp efficacy* should be at least 55 lamp lumens per circuit watt; for display lighting, at least 22 lumens per circuit watt.

Electric lighting energy consumption must be metered separately from other electrical supplies, either by kWh meters in dedicated lighting circuits or in the lighting controls of a lighting or building management system, or by automatically logging energy consumed by the lighting.

Lighting controls should be tailored to the nature and use of each space.

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Table VII Luminaire control factors

Output control	Control factor
(a) Photocell switching or dimming control in a daylit space.	
(A daylit space is an area within 6 m of a window wall at least 20 per cent glazed, or below rooflights with a glazing area at least 10 per cent of floor area).	0.9
(b) Occupancy detection.	
Lighting extinguished automatically when occupants leave, subject to safety considerations. Lighting switched on manually by occupants,	0.9
(c) (a) and (b) together.	0.85
(d) None of the above	1.00

5 LIGHTING CONTROLS

Five families of electric lighting controls may be distinguished as follows.

5.1 Constant illuminance control

Dimmable high-frequency fluorescent *luminaires* can be linked to indoor photocells set to sustain a fixed target *illuminance.* Otherwise a clean installation of new lamps would provide a substantially higher illuminance, missing an opportunity for energy savings. As time passes the controls will gradually pass additional power to the lamps, to compensate for light losses due to dirt and deterioration. When the lamps are fully loaded the time is overdue to alert the maintenance staff to clean the luminaires. This system has an additional advantage when the room changes from one use to another which permits a lower task illuminance: the setting can be adjusted to maintain the reduced lighting level.

5.2 Daylight linking

One or more rows of luminaires along a window wall may be linked to either interior or exterior photocells which monitor day light levels and adjust the electric lighting accordingly, preferably by top-up (dimming) rather than by automatic daylight-linked on-off switching The latter may be resented by occupants unless they understand and fully accept the purpose and value of the provision. Note that high-intensity discharge lamps, and most compact fluorescent lamps, are unsuitable for dimming. Control zones should be parallel to the main windows. Daylight linking can be combined with the occupancy detection system, Section 5.5.

5.3 Manual switching

Manual switches should be close to the luminaires they control. A bank of unlabelled switches invites indiscriminate switching. As a rule of thumb, the number of switches in a space should be not less than the square root of the number of luminaires. Thus twelve luminaires would require at least four switches. Options include low-voltage switching, pull-cords and remote 'wireless' switches such as ultrasonic or infrared; or a telephone signal to an energy-management system.

Manual switching is particularly suitable for a cellular office or consulting room, or for work stations which are occupied only intermittently.

5.4 Time switching

Electric lighting is switched off automatically at a control panel at the same time each day, perhaps to coincide with work breaks, e.g. at midday. It is better to switch half the lights at first, the rest 10 minutes later. A manual override then permits users to relight the lamps they still need. This system shares the responsibility for energy saving with the occupants, whose understanding and cooperation should be assured in advance.

There are several alternative methods for implementing a synchronised or staggered switch-off:

- low-voltage wiring to a relay in each lighting circuit
- a mains-borne signalling system
- a one-second interruption of the mains supply to each luminaire, causing latching relays to switch off.

In each case pull-switch or other manual overrides should be provided, for occupants to switch lamps straight back on if needed.

Time switching is particularly suitable for a hotel lounge, a restaurant, a shop, a corridor or an atrium.

5.5 Occupancy-linked switching

The aim of occupancy-linked lighting controls (presence detectors) is to operate the lighting when, but only when, somebody is there to make use of it. Some units beep or flash a warning signal just before lights are turned off, so that an undetected occupant can wave an arm and avoid being left in the dark. Fluorescent lamps require a time delay before switching off, as repeated switching shortens lamp life. Occupancy-linked discharge lamps with long restrike times should be supplemented by separate background lighting.

Occupancy detectors are suited to daylit spaces, and may be combined with daylight sensors, Section 5.2. Presence detectors can double as part of a security system. At night or at weekends they can activate an alarm instead of working the lights. They can also assist security patrols at night.

Occupancy detectors may be triggered by air movement, by a flapping curtain, or by events in a corridor outside the monitored space. Ultrasonic detectors seem more prone than passive infrared detectors to these extraneous stimuli. The sensitivity of some units can be adjusted to minimise such failings, at the price of their effective surveillance area. But the best arrangement is always to insist on manual-on/automatic-off occupancy controls with a manual override.

The best applications are where occupancy is infrequent or unpredictable, e.g. private offices, conference rooms, lecture rooms, toilets, warehouse storage aisles, photocopy rooms, and bookcase lighting in libraries.

6 SIZING AN OVERALL LIGHTING INSTALLATION

The sizing of overall lighting installations for working interiors and for floodlighting is nowadays left to computers. However the choice of target lighting levels remains in the hands of the specifier. The Building Regulations do not mandate target lighting levels. Wise choices may offer opportunities for appreciable savings in energy and in costs. Table VIII lists some recommendations from the Lighting Code of the Society of Light and Lighting (SLL), part of the Chartered Institution of Building Services Engineers. In many cases, especially in residential or public areas, a critical visual task is hard to identify and the *illuminance* should be chosen to provide the right atmosphere for getting together or for relaxing. Especially where this is the case, listed values of standard maintained illuminance should be treated as a point of departure, not as a target. If a designer seeks a subdued atmosphere a lower value would be right; if a livelier ambience is envisaged, a higher illuminance would be justified.

Table VIII Standard maintained illuminance recommendations

Location	Illuminance
Walkways Corridors	50 lux (can range from 5 to 100 lux)
Machine and turbine halls	100 lux (can range from 20 to 200 lux)
Classrooms	200 lux
General offices	300 lux (500 lux for adult education)
Technical drawing	200 to 500 lux
CAD work stations	750 lux 500 lux
General inspection and precision assembly	200 to 1000 lux
Minute assembly	2000 lux

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7 DISPLAY LIGHTING

The effectiveness of display lighting depends as much on the skill of the person responsible for aiming it as on the good intentions of the specifier. The latter would be well advised to consider who is likely to take responsibility for the lighting once his or her back is turned. It may well be a caretaker, a shop assistant or a clerk of works, with no training in display lighting techniques. If so, any track lighting is likely to become poorly positioned and wrongly aimed. Fixed lighting, perhaps above egg-crate louvers, may well be preferable. The following notes relate mainly to track lighting, but the same principles apply to fixed lighting.

In a space where visitors are free to move around it is virtually impossible to light vertical surfaces without shining light straight into somebody's eyes. To remedy this, start from the principal entrance and plan a route through the exhibits. Run lighting track across, not along, this route. Arrange spotlights to shine over the shoulders of visitors following the preferred route. At each point along the route, make sure that the next stopping point is attractively lit, to encourage circulation in the right direction. Visitors moving the opposite way will face darker surfaces and will have to brave the dazzle of spotlights planned for their more accommodating brethren. They may take the hint.

Track lighting should preferably be 2.5 to 3 m high. Lower mounting would invite glare, tampering, discomfort from heat radiated from the lamps, and the shadows of visitors thrown on exhibits. Higher mounting would make aiming more difficult, and spotlights might remain unadjusted month after month.

Effective display lighting depends as much on darkness as on illumination. Objects will stand out only if they look significantly brighter than their surroundings. Brightness has two aspects:

- *Illuminance:* to appear noticeably brighter the illuminance on a surface should be at least three times the background illuminance; to stand out strongly would require a ratio of 10:1 or more.
- *Reflectance:* if an object has a lower reflectance than its background it will respond much less to an increase in illuminance; spotlighting may well be inappropriate, or the profile of the beam may need careful trimming to the profile of the target.

The overall pattern of light and shade deserves careful consideration. To pick out a single focus of attention is simple and always effective. To highlight two objects risks an impression of disunity. To spotlight more than three requires skill and invites confusion. Aim for a simple and clear hierarchy of illuminance.

The lighting of paintings, notice-boards, chalk-boards, etc. must meet two constraints:

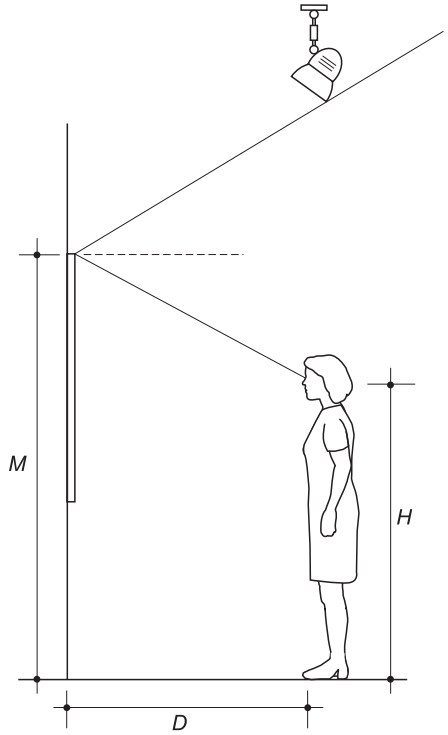
- It must not produce shiny reflections, which reduce legibility
- It must provide reasonably even illumination over the target surface.

In Figure 9.11, the closest distance from which an observer can comfortably regard the picture as a whole is equal to the length of the picture's corner-to-corner diagonal. This fixes the distance D, which shows the best position for a luminaire. If it were mounted closer to the target surface, the foot of the target would look dimly lit compared with the top. If it were further back, a visitor would see shiny reflections.

In conclusion, the Golden Rule for successful spotlighting is 'Light the objects, not the people'. The positioning of luminaires should be constrained as much by the need to avoid glare and distraction as by the need to reveal an illuminated object.

8 VISUAL DISPLAY TERMINALS

The front surface of a visual display terminal (VDT) acts as a partial mirror. Screen visibility is impaired when shiny reflections



9.11 *The geometry of picture lighting. M = height of top of tallest picture frame, H = eye level of short adult, say 1.5 m.*

approach or exceed the brightness of the luminous pixels. Side windows present a double problem. If operators face a window they may be distracted because the outside scene is brighter than the VDT. If their backs are to the window they will pick up its reflection in the VDT screen. The face of the VDT should ideally be at right angles to the face of the window. If there are windows on two adjacent walls this remedy may fail, and solid partitions might be considered.

In a private office the choice of luminaire is seldom critical; a ceiling-mounted fitting would not normally be reflected in the display screen. In an open-plan office the choice is more restricted.

If the height of the ceiling is greater than 2.5m, uplighters containing metal halide or high-pressure sodium lamps, possibly integrated into the office furniture, should be suitable. If the ceiling height exceeds 3.5m, one might consider *direct-indirect lighting*, suspended uplighters or column-mounted uplighters.

For ceiling heights below 2.5 m the best solution is a modular VDT luminaire providing a suitable illuminance (perhaps 2–300 lux) on the desk, with restricted light sideways to reflect in the screen. This combination of low *flux fraction ratio* and lateral constraint can result in an unsympathetic luminous environment, see Table VI. Consider wall hangings or pictures, perhaps with wall-washers, to brighten up the walls.

9 GLOSSARY

Altitude
An angle in a vertical plane, measured upward in degrees from the horizontal. The solar altitude is the altitude of the sun above the horizon.

Azimuth
An angle in plan, also called the bearing. The solar azimuth is usually measured from due north.

Circuit efficacy
The *luminous flux (lumens)* emitted by a lamp or *luminaire*, divided by the *circuit wattage*. See also *lamp efficacy* and *luminaire efficacy*.

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Circuit wattage
The power consumed by the lamps in an electric lighting system, by their control gear, and by associated equipment for power factor correction.

Daylight factor
Equal to the *illuminance* (lux) at a point indoors, expressed as a percentage of the simultaneous horizontal illuminance under an unobstructed overcast sky outside, see Section 2.1.

Direct-indirect lighting
Provided by a luminaire designed to combine the lighting characteristics of an uplighter and a downlight. It provides upward and downward illumination, sometimes in variable proportions, but little or no light sideways.

Efficacy
Luminous flux output (lumens), divided by the electric power consumed (watts). See also *lamp efficacy* and *luminaire efficacy*.

Flux
See *luminous flux.*

Flux fraction ratio
Equal to the upward *luminous flux* from a *luminaire*, divided by the downward flux.

Heliodon
Figures 9.8, 9.9. A physical simulation of the changing geometrical relation between the earth and the sun. The heliodon incorporates seasonal and hourly changes. A model of a building is mounted on a rotating platform whose tilt from the vertical corresponds to the geographical latitude of the building's location.

Illuminance (E)
The degree of concentration of light, in *lumens* per square meter (lux), striking a surface. Illuminance is measured by a special light-meter – an illumination photometer; photographic lightmeters are unsuitable.

Lamp efficacy
The *efficacy* of an electric lamp, i.e. the *luminous flux (lumens)* emitted by an electric lamp, divided by the wattage consumed by the lamp. It is known as the lamp circuit efficacy if power consumed by the electric circuit is included.

Light output ratio (LOR)
The *luminous flux (lumens)* emitted by a *luminaire*, expressed as a fraction of the flux emitted by the lamp(s) inside the luminaire. The LOR is sometimes known as the 'luminaire efficiency'.

Lumen
See *luminous flux.*

Luminaire
A lighting fitting complete with control gear and suspension where applicable. In North America but not usually in the UK the term includes associated lamps.

Luminaire efficacy
The *efficacy* of a luminaire, i.e. the *luminous flux (lumens)* emitted by a *luminaire*, divided by the wattage consumed by the lamp(s) in the luminaire. It is known as the luminaire circuit efficacy if power consumed by the electric circuit is included.

Luminous flux (φ)
The rate in lumens at which light energy is emitted from a source or received by a surface. For a given illuminance E lux, the flux striking a surface will be proportional to the area A (m^2):

$$\varphi = E \times A \text{ lumens} \qquad \text{equation (5)}$$

Hence 1 lux = 1 lumen per square metre.

Lux
See *illuminance.*

Maintenance factor (MF)
The ratio of the *illuminance (lux)* of a lighting system, or, in the case of natural lighting, the *daylight factor*, after a given interval, expressed as a fraction of the illuminance or daylight factor when the same installation was clean and newly commissioned. See Table III for maintenance factors for natural lighting.

No-sky line
The dividing line, Figure 9.2, in a room between the area which is exposed to a direct view of the sky, and the area which receives no direct daylight at all.

Probable sunlight hours
The long-term average number of hours per year when direct sunlight is visible from a given point. Long-term weather conditions are taken into account.

Reflectance (R)
The proportion of incident light which a surface reflects. A perfectly white surface would have a reflectance of 1.00, a perfectly black surface would have zero reflectance. Table IX gives some values for typical surfaces.

Sky factor
The horizontal *illuminance* (lux) at a given point due to light received directly through an unglazed window opening from a sky of uniform brightness, expressed as a percentage of the horizontal illuminance under an unobstructed vault of the same sky. See Section 1.5. Zero *reflectance* is ascribed to interior and exterior surfaces.

Table IX Reflectance of some familiar surfaces

Surface	Reflectance
White emulsion paint on plaster	0.80
Pink plaster	0.65
Cork tiles	0.20
Red quarry tiles	0.10
Black chalkboard	0.05
Painted surfaces, (with BS 4800 colour code)	
White 00 E 55	0.85
Light grey 00 A 01	0.68
Mid grey 00 A 05	0.45
Dark grey 10 A 11	0.14
Black 00 E 53	0.05

Skylight indicator
Figure 9.4, for checking the daylight potential of new buildings and daylight protection for existing buildings. It provides an estimate of *the vertical sky component* on a built-up site. The centre of the semi-circular indicator corresponds to the position in plan of the reference point. Its base should run along the plane of the window wall. Radial distances correspond to the ratio (distance of obstruction on plan)/(height of obstruction above *reference* point). Each little cross stands for a vertical sky component of 0.5 per cent. Count how many crosses fall within the outline of the sky. Divide by 2. The answer equals the vertical sky component, expressed as a percentage.

Solar declination
At any moment the sun is precisely overhead at some point on the earth's surface. The latitude of this point depends on the season,

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and is known as the solar declination. Some values of solar declination are shown in Table II.

Sunlight availability indicator

Figure 9.5, for checking sunlight protection for existing buildings and sunlight potential for new buildings. It provides a measure of the *probable sunlight hours* on a built-up site. The centre of the indicator corresponds to the position in plan of the reference point. Radial distances correspond to the ratio (distance of obstruction on plan) / (height of obstruction above reference point). Align the south-point of the indicator with the south-point of the site plan. Each of the 100 dots on the indicator stands for 1 per cent of the annual probable hours of sunlight. Choose the indicator whose stated latitude (51.5°, 53.5° or 56°) is closest to the geographical latitude of the site. If a dot is closer to the centre than any obstruction in that direction, then sunlight from that dot is unobstructed (unless, of course, it comes from behind the facade). Count the unobstructed dots. The total is the percentage of probable sunlight hours. Littlefair (2011) recommends an annual exposure to at least 25 unobstructed dots, including at least five from beyond the equinox line.

Sun-on-ground indicator

Figure 9.6, designed for site planning, and shows the length and direction of shadows at the equinox. The Building Research Establishment has issued indicators for the following latitudes – 51.5°, 53.5° and 56° – each at scales of 1:100, 1:200, 1:500 and 1:1250. Place the point P of the indicator over a reference point at ground level on plan. Line the south point of the indicator with the south point on the plan. Parallel east-west lines on the indicator show the heights of obstructions which would just intercept direct sunlight at the time indicated. Hence one can estimate the hours of potential sunlight reaching any point on the ground at the equinox. Sunlight less than 10° above the horizon is ignored.

Sunpath indicator

Figure 9.7, for checking times and seasons when direct sunlight strikes a given reference point on a built-up site. It is aligned and scaled in the same way as the *sunlight availability indicator.* Choose the indicator whose stated latitude (51.5°, 53.5° or 56°) is closest to the geographical latitude of the site. If a point on one of the sunpath lines is closer to the centre than any obstruction in that direction, then the sunlight at that moment is unobstructed (unless, of course, it comes from behind the facade).

Transmittance (T)

The proportion of *luminous flux* in lumens striking the upper surface of a transparent or translucent sheet which emerges from the lower surface. The transmittance of clear window glass is taken as 0.82; double glazing 0.70.

Note: These values refer to diffuse incidence; figures from glass manufacturers usually refer to normal incidence, and are correspondingly higher.

Vertical sky component (SCv)

The *illuminance* in lux on a vertical element at a point due to direct light from the overcast sky vault, expressed as a percentage of the simultaneous horizontal illuminance under the whole unobstructed sky vault.

Working plane

The flat plane on which the visual task is located. In a corridor this would be at floor level. In a shop, at counter height. In an office 0.7 m, a factory or kitchen 0.85 m above floor level. Unless otherwise stated the working plane is assumed to be horizontal.

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10 Sound

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KEY POINTS:
- More detailed performance requirements available to the designer
- Performance criteria have been broadened and minimum standards raised
- Regulatory control in many areas is now proved through completion testing placing more emphasis on good design

Contents

1 Introduction
2 Fundamentals of acoustics
3 Reducing sound transmission from external sources
4 Reducing sound transmission through layout and design
5 Reducing sound transmission through a structure
6 Permissible noise levels within a building
7 Sound insulation performance parameters
8 Sound insulation performance criteria
9 Specifying airborne and impact insulation from laboratory test data
10 Reverberation criteria
11 General guidance on the acoustics of performance spaces
12 Bibliography

1 INTRODUCTION

There are three main areas for consideration when designing buildings for good acoustics:

1 The control of sound break-in from external noise sources; most commonly from transportation, industrial and/or commercial (pubs, clubs, etc.) activities.
2 The control of sound transmission through a building; most commonly from building users (voices, TV, stereo, footfall, living activities) but can also include control of sound from building services (fixed plant, ventilation systems).
3 The acoustic quality of a room; most commonly the level of reverberation (echo) in a room.

The consideration of acoustic design during the early stages of a project can substantially reduce the potential for costly remedial works. Equally important is the correct use of the most appropriate design parameters and criteria. This chapter aims to provide a base upon which the designer, architect or specifier can start to identify the most suitable design parameters and criteria for each of the three areas outlined above.

2 FUNDAMENTALS OF ACOUSTICS

The following section gives a narrative explanation of sound, sound transmission and sound control. More mathematical explanations of these processes can be found in the building acoustic text books listed in the bibliography.

2.1 Creating sound

Imagine a tuning fork. When the fork is struck the prongs vibrate. As the prongs vibrate the air particles around the prongs are pushed away. These air particles in turn push the air particles next to them and so on thereby creating a wave motion through the air. This *forced wave* through the air is what our senses interpret as sound in the inner ear (Figure 10.1).

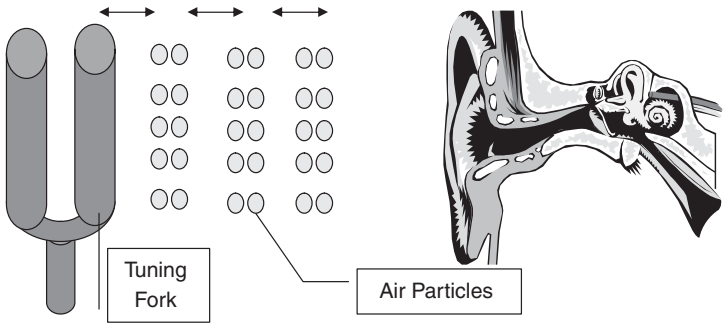
In all instances we will have a source (e.g. the tuning fork), a path (the air) and a receiver (normally a person) (Figure 10.2).

2.2 Sound transmission

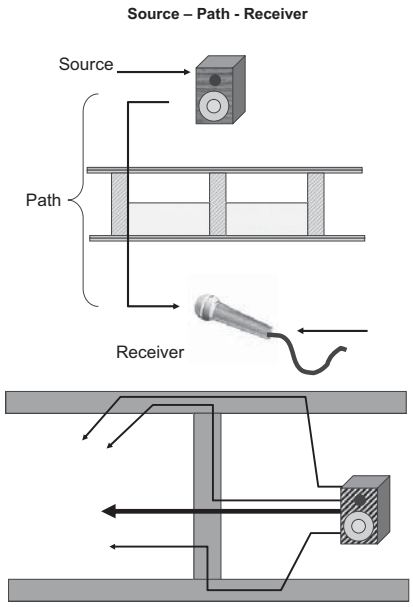
Forced particle motion forms wave patterns and so allows sound to carry through the air. This wave motion allows noise to diffract, propagate and curve like any other wave motion which is why sound can be heard round corners or through small gaps in a structure. We can reduce the effects of sound by reducing the noise at source, altering the sound transmission path or by changing the acoustics of the room where the listener is located.

The first option, reducing noise at source, is normally not a consideration for most noises affecting a building as they normally emanate from sources outwith the designer's control (motorway traffic, the activities of a neighbour etc.). The exception to this would be from noise sources associated with the design of the building (fixed plant, services, ventilation). Here the selection of suitable equipment and plant will reduce the likelihood of noise complaint.

The second option, altering the sound transmission path, is the most readily used method of reducing sound from a source. This can be seen in the use of heavy double glazed windows to reduce road traffic noise or the specification of a twin stud partition instead of a single stud partition within buildings. By varying and altering



10.1 *How sound is created*



10.2 *Source–path–receiver*

the materials and properties of a façade, floor or wall we can alter the sound path and alter the way that sound is transmitted.

The third option is to alter the acoustics of the space or room in which the receiver is situated. While this will have a limited effect on the annoyance of noise from external sources, more importantly it does have the effect of altering the acoustic environment within a room. This is equally important when considering things such as speech intelligibility or suitable listening environments.

2.3 Reverberation time

Acoustic absorption occurs when sound comes into contact with an acoustically porous material. In a bedroom the carpet, curtains, bed and bedding are all acoustically absorbent and so have the effect of reducing the reverberation time (echo) within a space. This can make the room sound quieter than a 'live' room or a room with lots of hard reflective surfaces, such as the bathroom. Hard smooth surfaces within a room will increase the reverberation time (echo) within a space. The size or volume of a space will also have an effect on the reverberation time.

We can measure this effect in a room by creating an interrupted sound (a sudden bang or burst of noise) and measuring the time it takes this noise level to fall by 60 dB. Alternatively if we know the properties of the room (its volume, the area of each surface in the room and its absorption coefficient) we can calculate the reverberation time in a room using the Sabine formula.

$$T = \frac{0.16}{S\acute{\alpha} + xV}$$

where T = Reverberation Time (seconds)
V = room volume in m^3
$S\acute{\alpha}$ = total surface absorption in m^2
x is the coefficient related to the sound attenuation of air

Total surface absorption is calculated by adding together the separate areas of absorption.

$$S\acute{\alpha} = S_1\acute{\alpha}_1 + S_1\acute{\alpha}_1 + S_2\acute{\alpha}_2 + S_3\acute{\alpha}_3 + ... + S_5\acute{\alpha}_5$$

where S_1 is the area in m^2 and d_1 is the absorption coefficient of the material.

Table I Absorption coefficients

	Frequency					
	125	**250**	**500**	**1000**	**2000**	**4000**
Smooth unpainted concrete	0.01	0.01	0.02	0.02	0.02	0.05
Plaster on solid wall	0.04	0.05	0.06	0.08	0.04	0.06
Plasterboard on frame 100 mm cavity	0.08	0.11	0.05	0.03	0.02	0.03
Plasterboard on frame, 100 mm cavity with mineral wool	0.30	0.12	0.08	0.06	0.06	0.05
6 mm glass	0.10	0.06	0.04	0.03	0.02	0.02
Double glazing, 2–3 mm glass, 10 mm air gap	0.15	0.05	0.03	0.03	0.02	0.02
22 mm chipboard, 50 mm cavity filled with mineral wool	0.12	0.04	0.06	0.05	0.05	0.05
Acoustic timber wall paneling	0.18	0.34	0.42	0.59	0.83	0.68
Plaster on lath, deep air space	0.20	0.15	0.10	0.05	0.05	0.05
Curtains hung in folds against solid wall	0.05	0.15	0.35	0.40	0.50	0.50
Raised computer floor, steel-faced 45 mm chipboard 800 mm above concrete floor, no carpet	0.08	0.07	0.06	0.07	0.08	0.08
Wooden floor on joists	0.15	0.11	0.10	0.07	0.06	0.07
Linoleum or vinyl stuck to concrete	0.02	0.02	0.03	0.04	0.04	0.05
5mm needle-felt stuck to concrete	0.01	0.02	0.05	0.15	0.30	0.40
Medium pile carpet on sponge rubber underlay	0.50	0.10	0.30	0.50	0.65	0.70
Solid timber door	0.14	0.10	0.06	0.08	0.10	0.10
50mm mineral wool (96 kg/m^3) behind 25% open area perforated steel.	0.20	0.35	0.65	0.85	0.90	0.80
Plaster decorative panels, ceilings	0.20	0.22	0.18	0.15	0.15	0.16
Seating, slightly upholstered, unoccupied	0.07	0.12	0.26	0.42	0.50	0.55
Empty plastic or metal chairs (per chair) in m^2 units	0.07	0.00	0.14	0.00	0.14	0.14
Fully upholstered seats (per item) in m^2	0.12	0.00	0.28	0.00	0.32	0.37
Water surface, e.g. swimming pool	0.01	0.01	0.01	0.01	0.02	0.02

Table I lists the expected absorption coefficient of some common materials. These values can be used in the Sabine formula to help calculate the reverberation time within a room. By altering the selection of ceiling and wall finishes the most advantageous reverberation time can be calculated long before a room is ever built or the materials selected for use.

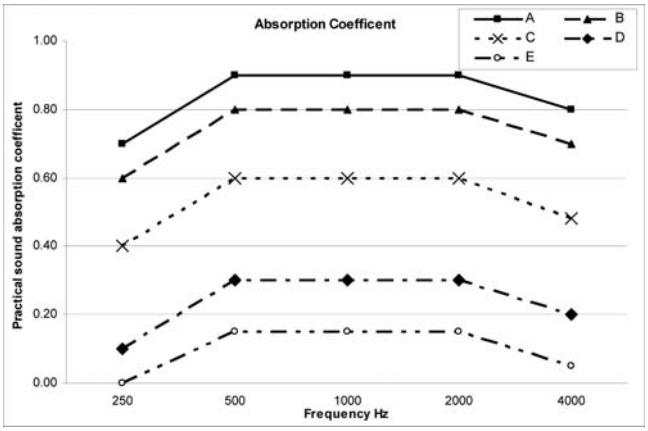
The acoustic absorption characteristics detail can also be rated into different classifications in line with the guidance given in BS EN ISO 11654:1997, *Acoustics – Sound Absorbers for Use in Buildings – Rating of Sound Absorption*. This allows the designer to specify a classification of material rather being forced into giving a prescriptive specification.

Figure 10.3 details the absorption classifications that are normally associated with absorbent materials specified in the UK. They run from Class A materials (those with the highest levels of acoustic absorption) to Class E materials (those with the lowest levels of acoustic absorption).

Classification of a material against the absorption coefficient graph shown in Figure 10.3 may not be suitable for all material types, e.g. panel absorber will tend to perform better at particular frequencies. This means that while a panel absorber can provide good average levels of absorption it may be limited across the frequency band. Therefore BSEN ISO 11654 also allows for the average absorption coefficient of a material to be used as a method of defining its absorption classification. This is detailed in Table II where $\acute{\alpha}_w$ is the average acoustic absorption of the material.

By detailing appropriate materials we can achieve a required reverberation time (T) within a room. For this reason the

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10.3 *BS EN ISO 11654 absorption classifications*

reverberation time of a room is normally used as the performance criteria when designing rooms for good speech intelligibility or suitable listening environments.

The reverberation time (T) of a room is normally specified for the space when unoccupied. It is important to note that for rooms with volumes greater than 200 m^3 the use of the Sabine formula becomes less reliable. It is therefore always preferable to seek professional advice when detailing or designing for good room acoustics in large or complex spaces. However there is no reason why the designer cannot provide a performance criterion for the reverberation time within a room.

3 REDUCING SOUND TRANSMISSION FROM EXTERNAL SOURCES

In the UK the level of noise at which disturbance from particular noise sources is likely to occur within a dwelling can be found in planning documents such as Planning Policy Guideline 24 (England) or Planning and Noise 1 (Scotland). In addition to the planning guidelines there are other guidance documents that can be used when assessing noise within non-domestic builds. In all instances we are concerned with the level of noise break in from external sources which are outwith the control of the building owner or occupier.

Such documents set the maximum noise level (L_{Aeq}) that can be measured within a room when unoccupied or not in use.

L_{Aeq}: The L_{Aeq} level is effectively the average measured noise level over a defined period of time ($L_{Aeq\ 16hours}$, $L_{Aeq\ 8hours}$, etc). The 'A' in the L_{Aeq} parameter means that the noise level has been weighted so that it is akin to the subjective noise level that the average person would hear.

For most transportation sources it is suggested that external average noise level of $L_{Aeq(16hour)}$ 55 dB during the daytime and $L_{Aeq(8hour)}$ 45dB during the night time are set as target levels, however, as can be seen from Table III these levels are likely to be below the normal noise level in many urban and suburban areas.

Table II BS EN ISO 11654 Absorption classifications for average absorptions values

Sound absorption	Class α_w
A	0.90, 0.95, 1.00
B	0.80, 0.85
C	0.60, 0.65, 0.70, 0.75
D	0.30, 0.35, 0.40, 0.45, 0.50, 0.55
E	0.25, 0.20, 0.15
Not classified	0.10, 0.05, 0.00

Table III Likely external ambient noise levels

Source	A weighted sound pressure level L_{Aeq} (dB)
Urban area close to motorway	70–90
20m from the edge of a busy motorway (110km/h)	78
Urban area close to main road	65–75
20m from the edge of a busy main road (50km/h)	68
Suburban area remote from main road	55–65
On a road parallel to a busy main road and screened by buildings for traffic	58
Parkland within a large town or city	55–60
Secluded country location	35–45

L_{Amax}: In addition to the average noise level the other parameters that may need to be controlled would be the maximum noise level (L_{Amax}) or the highest single noise event, such as would be associated with a sudden increase in noise such as a train passing by.

L_{A90}: For some noise sources, such as industrial noise affecting a dwelling, it is common to attempt to control noise in line with the background noise level (L_{A90}). This is the underlying noise level or the average noise level which is exceeded for 90 per cent of the measurement period. This allows for noise to be assessed against the quiet periods or lulls in average noise levels to ensure that a disturbance is not created, i.e. the periods between vehicles passing by a dwelling will result in quiet passages of time where the noise under consideration (industrial noise) may not be masked by other events (road traffic noise) and so cause a disturbance.

3.1 Control of external noise levels

The permissible level of noise outside a building can differ greatly depending on the nature of the development or even the policy of the local authority. As a starting point guidance issued by the World Health Organisation suggests external free-field levels of below $L_{Aeq\ (16hrs)}$ 50–55 dB as being suitable to avoid serious disturbance or annoyance during the daytime with more recent European guidance suggesting maximum external free-field levels outside a dwelling of $L_{Aeq\ (8hours)}$ 40 dB as being suitable to avoid noise disturbance at night. However in many instances (city centre, some urban and suburban areas) a different approach may be suitable.

Table IV defines some of the standard noise criteria applied in a range of cases. External noise is normally considered an issue for residential properties but can be a requirement for outdoor workspaces or education spaces. It should be noted that the requirements of different local authorities can differ greatly and so consultation with Planning and Environmental Health should always be sought when designing for the control of external noise levels, particularly for dwellings.

Noise from entertainment sources (bars, clubs, pubs) is not normally required to be controlled outside the nearest residential property as in most cases noise from these sources is associated with night time use and sleep disturbance within a property. Control levels for such noise will again differ from one local authority to another and so they should always be consulted either when building dwellings next to an entertainment source or when introducing a new source of entertainment noise.

3.2 Distance attenuation

The more distant a building is from a noise source the quieter the level of noise from the source will be within the building. This will depend upon whether the noise source is considered as a *point source*, such as individual items of fixed plant or as *a line source*, such as noise from a railway line or motorway. If a house were located 20 m from a railway line or a road this would be considered a line source and so the level of noise would reduce by 13 dB. If the house were 20 m from a point source (a lawn mower or aeroplane)

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Table IV Suitable external noise levels

Noise source and receiver description	Method of control	Performance criteria Maximum noise level at the receptor
New **Industrial noise** affecting existing residential properties or existing industrial affecting new residential	Noise levels should be controlled in relation to the pre-existing background noise level L_{A90} dB	–10 dB below the background = positive indication that complaints are unlikely Around +5 dB higher than the background level = Moderate likelihood of disturbance + 10 dB higher than the background level = likelihood of complaint significant
New **office development plant noise** affecting existing residential properties	Noise levels should be controlled in relation to the pre-existing background noise level L_{A90} dB	–5 dB below the background –10 dB below the background if noise source is tonal.
Construction noise affecting existing residential and commercial activities	Noise levels should be controlled to a maximum ambient level and operating times on site are restricted	≥L_{Aeq} 75 dB 8am–6pm Mon–Friday 8am–12am Saturday Restricted activity at other times
Road, rail,* affecting new residential developments	Noise levels should be controlled for private amenity spaces (e.g. rear gardens, balconies)	≥L_{Aeq} 55 dB 7am–11pm ≥L_{Aeq} 45 dB 11pm–7am
Airport noise, affecting new residential developments	Noise levels should be controlled for private amenity spaces (e.g. rear gardens, balconies)	≥L_{Aeq} 57 dB 7am–11pm ≥L_{Aeq} 48 dB 11pm–7am

*For rail noise sources it is also expected that during the night time period maximum individual noise events should not ***regularly*** exceed $_{LAmax}$ 82 dB.

the level would be reduced by 26 dB relative to the measured noise level at the source.

As a general rule of thumb the difference between line source and point source attenuation is:

- –3 dB reduction in noise level for each doubling of distance from a line source
- –6 dB reduction in noise level for each doubling of distance from a point source

3.3 Acoustic barriers

Noise can be further reduced by the construction of an acoustic barrier. An acoustic barrier can be as simple as a close boarded fence or earth bund. By breaking the direct line of sight between a noise source and the receiver (a person or a building) we reduce the level of sound because we are increasing the distance the sound has to travel between source and receiver (i.e. the sound has to go over the top of the barrier).

The level of attenuation for an acoustic barrier will be dependent on the following factors.

- The height of the barrier: the higher the barrier the greater its expected performance.
- The type of noise source: barriers are more effective for stationary noise sources such as fixed plant than for a moving source such as vehicles.
- The height of the noise source: the higher the source the higher the barrier will have to be to break the line of sight.
- The height of the receiver: the higher the receiver is the higher the barrier will have to be to break the line of sight.
- The distance between the source and the barrier: it is always preferable to place the barrier as close to the source as possible.
- Where this cannot be achieved the next best option is to position the barrier as close to the receiver as possible.
- The worst position for a barrier is half way between the source and the receiver.
- The mass of the barrier: generally the minimum surface mass of any acoustic barrier should not be less than 5 kg/m^2.

The calculation of the attenuation offered by an acoustic barrier can be complicated but a good rule of thumb is to assume a 5 dB reduction for a partial barrier effect and 10 dB for a full barrier effect (see Table V). For example a 2 m barrier is likely to provide 10 dB reduction from road traffic at ground floor level and 5 dB reduction at first floor level.

Table V Basic sound reduction levels from acoustic barriers

Full barrier (full break in line of sight from source to receiver)	–10dB
Partial barrier (partial break in line of sight from source to receiver)	–5dB

Higher levels of acoustic insulation can be provided by acoustic barriers, however to achieve this they normally have to be significantly higher. If a reduction of more than 10 dB from an external noise source is required then it is likely that a barrier with an effective height greater than 2 m would be required.

3.4 Angle of view

The orientation of a building or a noise sensitive room away from a noise source can also reduce the level of noise disturbance experienced. Where a room directly overlooks a noise source (road, railway line etc.) the design is entirely dependent upon the distance from the source or the inclusion of an acoustic barrier for attenuation. If the room is angled away from the source then there is an expected reduction in noise due to the angle of view between the receiver and the source. Table VI outlines the expected reductions in sound levels at 500 Hz and 1000 Hz dependent on the angle of view from source to receiver.

3.5 Façade attenuation

The final method for reducing noise within a building from external sources is through the specification of the building envelope.

If we take the glazing element to be the dictating factor in the acoustic insulation of a façade it can be used as the means by which façade insulation can be specified.

It is commonly accepted that for some noise sources (commercial noise and industrial noise) internal noise levels within an affected building should be calculated in relation to an open window. In many other instances (transportation noise in particular) the assessment of internal noise levels can be calculated with closed windows. A wide range of acoustic performance data is published by most glazing manufacturers and will normally detail frequency performance levels along with average or single figure values. When assessing the acoustic performance of a glazing unit it is best to base any assessment on the R_{TRA} criteria. This is the reduction (R) in noise level provided by the glazing unit when adjusted for a traffic noise spectrum (TRA). Table VII details the expected insulation values for some typical glazing specifications. In addition it shows expected levels of reduction (D_w) from open windows dependent on the source noise.

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Table VI Angle of view correction

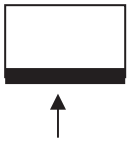
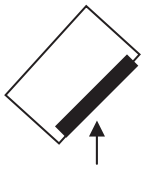
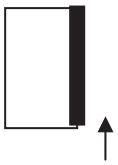
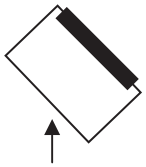
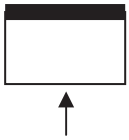
Building orientation		Sound attenuation (dB) 500 Hz	1000 Hz
0°		0	0
45°		1	1
90°		6	6
135°		15	17
180°		17	19

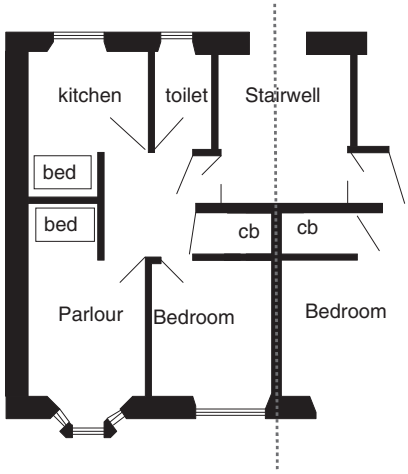
Table VII Insulation values for open and closed glazing units

Open windows – expected D_w for windows with a free open area of 0.05 m^2	D_w dBA
Road traffic noise	12–18
Railway noise	12–18
Aircraft noise	14–19
Amplified music	15–20
Closed windows – expected R_{TRA} dB insulation values for typical glazing types	
Glazing type	**R_{TRA} dB**
4 mm float glass/12 mm cavity/4 mm float glass	25
6 mm float glass/12 mm cavity/6 mm float glass	26
6 mm float glass/12 mm cavity/6.4 laminate glass	27
10 mm float glass/12 mm cavity/4 mm float glass	29
6 mm float glass/12 cavity/7 float glass	31
10 mm float glass /12 mm cavity/6 mm float glass	32
6 mm float glass/12 cavity/11 mm float glass	33
10 mm float glass/12 cavity/6.4 mm laminate glass	34

4 REDUCING SOUND TRANSMISSION THROUGH LAYOUT AND DESIGN

Consideration of the layout of a building interior can either enhance or reduce its suitability in controlling noise. It is generally good practice to locate noise sensitive activities away from noisy activities. An example of this process in action can be seen in the design of the traditional Glasgow tenement flat popular at the turn of the century. While not perfect it is clear that the design has taken cognisance of the limitations of the building fabric, the expected use of each space and the number of occupants within the flat. Of equal importance is the understanding that the occupants of such flats would be living compatible lifestyles, a luxury not often afforded to modern designers.

Quiet and noisy areas between dwellings are grouped together with bedrooms in one flat backing onto bedrooms in the other (Figure 10.4). The parlour and kitchen locations are next to the mass 600mm masonry wall where acoustic insulation would be better. Habitable spaces are located away from the stairwell by cupboards and double entrance lobbies helping to further reduce stairwell noise. The party wall between the bedrooms (denoted by the grey line) is a relatively poor single brick wall but it was considered that this would be acceptable because it separates two quiet spaces where the occupants live compatible lifestyles.



10.4 *Traditional tenement flat layout Glasgow circa 1890*

The following should be considered in order to reduce noise issues from building users:

- Avoid placing noise sensitive activities next to rooms with higher levels of noise.
- Avoid detailing services (such as SVP or HVAC) through noise sensitive spaces
- Avoid placing rooms with heavy service demands or high activity above quiet rooms (e.g. kitchens above sleeping areas).
- Locate external bin areas away from noise sensitive rooms.
- Avoid locating lift shafts in areas where they directly back onto noise sensitive rooms.
- Place plant rooms and building services in as remote a location as practical from a noise sensitive area.
- Fire doors in communal corridors should be located away from the entrance doors to dwellings or noise sensitive rooms.
- Try to avoid locating rooms with high occupancy rates at the end of corridors where there are noise sensitive rooms along the corridor in order to reduce possible disturbance from foot traffic in a corridor.

5 REDUCING SOUND TRANSMISSION THROUGH A STRUCTURE

Sound transmission through a structure is the passage of the sound pressure wave from the air, into the structure, through the structure and then out the other side. Low frequency noise pushes the whole structure causing the sound pressure wave to be transmitted by the surface of the wall or floor. As we move up the

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frequency range the wavelength of the sound gets shorter and so instead of being able to force the whole partition into motion the sound finds paths through the structure. Finally sound will also find ways of transmitting through small gaps or voids within the structure or through weaker flanking elements such as adjoining walls or service runs.

There are six key factors in the reduction of sound through a building structure. By taking cognisance of these six issues when specifying a partition, be it a floor, wall, roof or external cladding element, it can be possible to determine which construction type is likely to provide the best performance.

5.1 Stiffness of a structure

The stiffness of a partition affects how it will transmit sound particularly at low frequencies and also some higher frequencies. Materials will naturally resist any force against them such as a sound wave and the greater the stiffness or rigidity the better a material will be at reducing the transmission of low frequency sound.

Cast in-situ concrete decks can provide a very high level of acoustic insulation between floors despite the apparently slim section of concrete slab. The profiles, while adding mass to the structure, also act as stiffeners to the floor structure. Increased dwangs or noggins in a timber floor help improve the stiffness of a floor. Similarly timber floors with heavy deafening or pugging also help to improve stiffness in the floor as well as mass.

5.2 Isolation of a structure

Separating (or isolating) the different elements of a structure can break the sound transmission paths like a break in a circuit board. Isolation also reduces forced transmission by creating large cavities between surfaces. Finally the more materials sound has to transmit through the more energy is lost.

Isolation is particularly important for the acoustic insulation of floors against impact sound. Impact resistant mats, isolated floor battens and floating floor systems all help to isolate a structure from impact sound. They will also have an effect on the transmission of airborne sound as will twin stud or twin leaf wall systems, or independent ceiling or wall lining systems.

5.3 Mass of a structure

The more mass a material or structure has the more difficulty the sound pressure wave has in forcing it into vibration. For most materials mass is the defining factor in acoustic performance. For every doubling of mass in a structure or material we should see a 6 dB improvement in acoustic insulation. However this will only be noticed at the mass controlled frequencies. This normally occurs at the mid range of frequencies.

The reason why some single leaf brick walls can provide similar levels of acoustic insulation to a metal or timber stud partition with multiple linings is the substitution of isolation (i.e. the isolation of the two plasterboard layers by the frame) for increased mass (the inherent mass of the brick or block work).

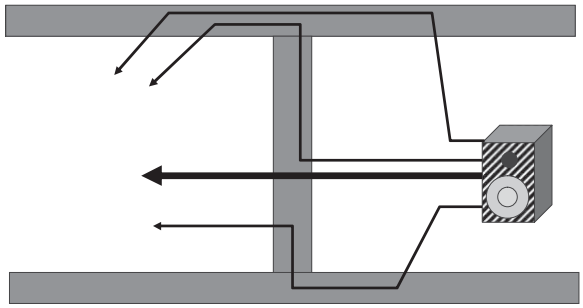
5.4 Absorption within a structure

By adding absorbent materials to the cavities within a partition we can increase the amount of sound that is absorbed within the cavity and so reduce the amount of sound that can be transmitted. This is normally achieved by adding acoustically porous materials such as mineral fibre quilt. The inclusion of such materials can improve the acoustic insulation of a partition by between 3 and 6 dB.

5.5 Flanking sound affecting a structure

Sound always takes the path of least resistance. Flanking sound transmission relates to noise which is transmitted into an adjoining room or space but which does not come directly through the separating partition. It is possible for there to be at least 12 possible flanking transmission paths between two rooms separated by a simple wall construction (flank via the walls, floor and ceiling).

Flanking transmission can be a particular problem with masonry supported timber floors where there is a strong structural connection between flats due to continuous masonry walls running up through a building (Figure 10.5).



10.5 *Flanking paths through a separating wall*



10.6 *Service penetration at wall head where no detailing has been issued to site*

5.6 Completeness of a structure

Without a complete structure sound can leak through any gaps or holes in the same way that water would leak through the cracks in a dam. In addition to gaps or holes in constructions incompleteness of a structure or weaknesses in a structure will also have a similar effect. In some instances this can be a result of poor workmanship (badly finished joints) but it can equally be attributed to poor detailing (e.g. wall head details or detailing of service penetrations, Figure 10.6).

6 PERMISSIBLE NOISE LEVELS WITHIN A BUILDING

It often falls to the lead designer on a project to outline suitable performance parameters and criteria for permissible noise levels within a building. The required levels will depend upon the client's requirement, the expected use of the building and the types of room within a building. Defining the most suitable parameter to use is the first task of any design process. There are two main performance parameters that should normally be applied: the Ambient Noise (L_{Aeq}), outlined in Section 3, and/or the Noise Rating (NR) parameter. In addition the maximum noise level (L_{Amax}), outlined in Section 3, is often applied.

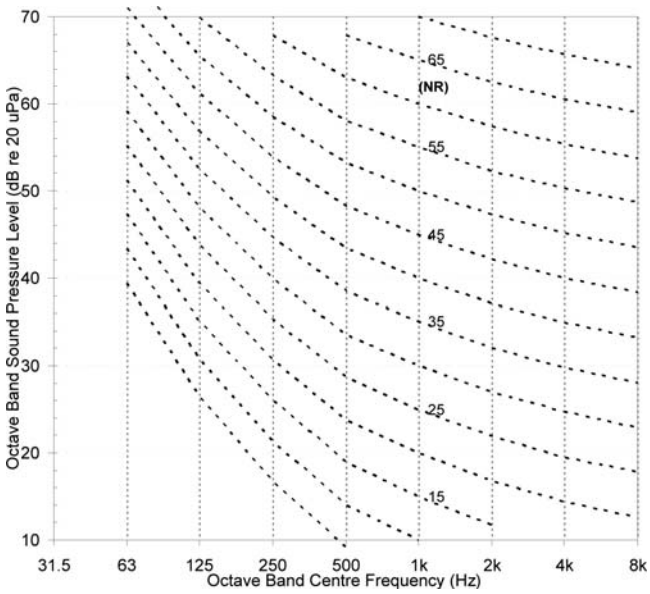
6.1 Noise rating curves

NR is the noise rating curve. This is applied to noises which may cause disturbance but which emanate from a steady noise source or a tonal noise source (e.g. fixed plant and equipment). The NR criterion sets a maximum noise limit for each frequency band rather than setting a maximum average noise level as is the case with the L_{Aeq} parameter. Most noise sources are made up of noise across a

range of frequencies. Deep or rumbling noises represent low frequency noise while sharp or piercing noises represent higher frequency noise. Fixed noise sources such as plant and machinery are known for having high levels of noise at a particular frequency and so it is important to have a performance parameter that can set a maximum level at each frequency band. If an average noise level were set, such as the L_{Aeq} criterion, then it could be possible for noise from say a fan to meet an L_{Aeq} criterion but still be perceived as disturbing. This is because it would have a high level of noise at one particular frequency but a lower level of noise at other frequencies which would have a great effect on the average noise level. Figure 10.7 details the NR curves.

6.2 Guidance on performance criteria by room type

Table VIII details suitable ambient noise levels and suitable NR levels for a range of building types and room types. The guidance given in the table is an amalgamation of current performance criteria from the most relevant guidance documents (Building Bulletin 93, HTM08-01, BS8233, CSDG2007, BCO Specification Guide 2009 BREEAM).



10.7 *Noise rating curves*

Table VIII Suitable maximum ambient noise levels and NR levels

Type of building/room	Maximum L_{Aeq} dB*	Maximum NR
School		
Nursery school playrooms	35	30
Nursery school quiet rooms	35	30
Primary school; classrooms, class bases, general teaching areas, small group rooms	35	30
Secondary school; classrooms, general teaching areas, seminar rooms, tutorial rooms, language laboratories	35	30
Open-plan teaching area	40	35
Open-plan resource area	40	35
Music classroom	35	30
Small practice/group room	35	30
Ensemble room	30	25
Performance/recital room	30	25
Recording studio	30	25
Control room for recording	35	30
Small lecture room (<50 people)	35	30
Large lecture room (>50 people)	30	25
Classroom designed specifically for use by hearing impaired students (including speech therapy rooms,	30	25
Study room (individual study, withdrawal, remedial work, teacher preparation)	35	30
Libraries – quiet study areas	35	25
Libraries – resource areas	40	35
Science laboratories	40	35
Drama studios	30	25
Design & Technology – resistance materials, CAMCAD		
Areas	40	35
Design & Technology – electronics/ control, textiles, food, graphics, design/ resource areas	40	35
Art rooms	40	35
Assembly halls, multi-purpose halls (drama, PE, audio/visual presentations, assembly, occasional music)	35	30
Audio-visual, video conference rooms	35	30
Atria, circulation spaces used by students	45	40
Indoor sports hall	40	35
Dance studio	40	35
Gymnasium	40	35
Swimming pool	50	45
Interviewing/counseling rooms, medical rooms	35	30
Dining rooms	45	40
Kitchens	50	45
Office, staff rooms	40	35
Corridors, stairwells	45	40
Coat and changing areas	45	40
Toilets	50	45
Hospital	40 Day	30
Single bed/on-call room	35 Night	
Children & older people (single bed)	40 Day 35 Night	30
Children & older people (multi-bed)	45 Day 35 Night	30
Consulting room	40	35
Examination room	40	35
Treatment room	40	35
Counseling/bereavement room	40	35
Interview room	40	35
Operating theatre suite	40	40 (50 Laminar flow)
Nurseries	40 Day 35 Night	30
Birthing room	45	40
Laboratories	45	40
Dirty utility/sluice	55	40
Clean utility	55	40
Speech and language therapy	30	25
Snoezelen/multi-sensory room	30	25
Multi-faith/chapel	40	35
Corridor (no door)	55	40
Atrium	55	40
Dining	50	40
Public/staff toilets (non cubicles)	55	45
En suite toilets (non cubicles)	45	40
Waiting (large > 20 people)	50	40
Waiting (small ≤ 20 people)	50	40
Main kitchen	55	50 (55 at extract hood)
Ward kitchen, pantry	50	40
Storeroom	n/a 45 Day	n/a
Rest room	35 Night	30
Locker/changing room	55	40
Large training/seminar (>35m²)	35	30
Small training/seminar(≤ 35m²)	40	35
Lecture theatre	35	30
Library/archiving room	40	35
Single-person office	40	35
Multi-person office (2–4 people)	40	40
Open-plan office (≥ 5 people)	45	40
Boardroom	35	30
Large meeting room (> 35m²)	35	30
Small meeting room (≤ 35m²)	40	35

(continued)

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Table VIII (continued)

Type of building/room	Maximum L_{Aeq} dB*	Maximum NR
Offices**		
Cellular office	40	35
Speculative offices	43	38
Open plan office	45	40
Entrance lobbies	45	40
Circulation spaces	45	40
Toilets	50	45
Loading bays	60	55
Underground parking	60	55
Drafting rooms	≤45–55	≤40–50
Staff room	≤35–45	≤30–40
Meeting room	≤35–40	≤30–35
Executive office	≤35–40	≤30–35
Industrial		
Heavy engineering	≤70–80	≤55–75
Light engineering	≤65–75	≤45–65
Warehouses	≤65–75	≤45–65
Commercial laboratories	≤45–55	≤40–50
Garages	≤65–75	≤45–65
Loading bays	≤60–75	≤55–60
Workshops	≤50–60	≤60–70
Canteen	≤50–55	≤45–50
Commercial		
Hotel bedrooms	≤30–35	≤20–25
Department store	≤50–55	≤35–45
Retail unit	≤50–55	≤35–45
Underground parking	≤60–70	≤55–65
Café	≤50–55	≤35–45
Commercial kitchens/laundries	≤ 55–65	≤ 40–50
Restaurant	≤40–55	≤35–40
Reception rooms	≤35–40	≤30–35
Public house	≤40–45	≤35–40
Night club	≤40–45	≤35–40
Ball room	≤35–40	≤30–35
Banquet hall	≤35–40	≤30–35
Cinema	≤30–35	≤30–35
Commercial recording studio	≤20–25	≤15–20
Civic & Amenity		
Library	≤40–50	≤35–45
Museum	≤40–50	≤35–45
Church/religious (serious liturgical music)	30	20
Church/religious (small)	35	25
Court rooms (with public address)	40	35
Court rooms (no public address)	30	25
Magistrates/judge retiring, judges chambers	40	35
Interview rooms	40	35
Committee rooms	40	35
Custody areas	45	40
Video conferencing	30	25
Concert halls	≤25–30	≤20–25
Theatre	≤25–30	≤20–25
Toilets	≤45–50	≤40–45
Washrooms	≤45–50	≤40–45
Control centres	L_{A90} between 30–35	≤25–30
Public baths/swimming pools	≤50–55	≤45–50
Domestic		
Living rooms	≤30–40	≤25–35
Bedrooms	≤30–35	≤20–25

*BB101 allows for a +5dB increase to the ambient noise levels where natural ventilation is part of the design with the exclusion of designed for the hearing impaired.
**a +5dB increase in ambient levels can be allowed in naturally ventilated office buildings

6.3 Maximum or impulsive noise levels

The control of sudden noise events is also worthy of consideration in building design. This is normally described by the parameter L_{Amax}, the A-weighted maximum noise level recorded during a measurement period although the $L_{A1,30min}$ parameter is used for schools. These parameters should be considered when assessing noise sources which may include a sudden increase in noise levels or individual high noise events. Examples of this would be train pass-bys or bangs and knocks from industrial sources. These parameters are not normally used in isolation but in conjunction with the L_{Aeq} or even the NR criteria. It is generally only reasonable to enforce maximum parameters in situations where sudden noise events occur regularly and during the night time periods (11pm to 7am) although there are some exceptions. 'Regularly' is normally taken to mean more than twice in any single hour. Table IX defines some appropriate L_{Amax} and $L_{A1,30min}$ performance criteria to avoid disturbance.

Table IX Suitable internal $_{LAmax}$ levels

Type of building/room	$L_{Amax(f)}$ dB
Bedroom	45 (night time)
Teaching spaces with a maximum ambient noise level of L_{Aeq} 35dB (see Table VII)	55dB ($L_{A1,30min}$)
Single person ward, multi-bed ward	45 (night time)
Operating theatres	50 (day and night)
Open plan/speculative offices	55dB (60dB when naturally ventilated)
Cellular offices	50dB (55dB when naturally ventilated)

7 SOUND INSULATION PERFORMANCE PARAMETERS

Detailing the correct performance parameter for separating partitions has become a more complex task since the advent of new guidance documents such as Approved Document E, Building Bulletin 93 and Health Technical Memorandum 08–01. This is because different terms are used to define acoustic insulation. For example airborne laboratory tests on a sample partition are normally defined as the R_w value (the weighted sound reduction) while testing on site in Scotland the $D_{nT,w}$ term is used (difference in transmitted sound) and in England and Wales the $D_{nT,w} + C_{tr}$ term is used (the difference in transmitted sound adjusted using a C traffic noise weighted adaptation term).

It is also important to know whether airborne sound insulation or impact sound has been measured. As a general rule any parameter which starts with 'D' or 'R' ($D_{nT,w}$ R_w, D_w etc.) will be an airborne sound test while any parameter which starts with an 'L' ($L'_{nT,w}$ L_{nw}, ΔL_w) will be an impact sound test.

Note: Simply stating a dB requirement for the acoustic insulation of a partition is inadequate as it does not describe the method by which the partition is to be assessed and can lead to substantial differences in actual performance (e.g. the difference in on site performance between specifying a partition with a D_{nTw} of 50 dB compared to a partition with a $D_{nT,w+}$ C_{tr} of 50 dB can be more than 10 dB). Therefore it is necessary to state the performance parameter ($D_{nT,w}$ R'_w, etc.) as well as the performance criteria (45 dB, 50 dB etc). The most commonly used parameters are listed in Table X outlining what they mean and where they are used.

8 SOUND INSULATION PERFORMANCE CRITERIA

The level of insulation required is set as a performance criterion and stated in dB. For example if we were to be undertaking sound

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Table X Sound insulation performance parameters

Building type	Regulations/guidance used	Performance parameter
Residential	England and Wales – A.D.E	Airborne – $D_{nT,w} + C_{tr}$
		Impact – $L'_{nT,w}$
	Scotland – Section 5	Airborne – $D_{nT,w}$
		Impact – $L'_{nT,w}$
	Northern Ireland – Technical	Airborne – $D_{nT,w}$
	Booklet G	Impact – $L'_{nT,w}$
	Eire – Technical Document E	Airborne – $D_{nT,w}$
		Impact – $L'_{nT,w}$
Schools	BB93 (new version)	Airborne – $D_{nT,(Tmf,max)\,w}$
		Impact – $L'_{nT,(Tmf,max)\,w}$
The $T_{mf,max}$ adjustment used in the schools document emphasises the importance of controlling of reverberation		
Hospitals	HTM 08-01	Airborne $D_{nT,w}$
		Impact $L'_{nT,w}$
Offices	British Council for Offices	Airborne D nT,w
		Impact
	BS8233/BREEAM	Airborne D_w
		Impact
The D_w is a simple measurement of the difference between the source and receiving room values when measured on site. Acoustic insulation is not often considered when designing office accommodation; however it can be a real issue particularly in areas where confidentiality is important.		
Hotels/care	England and Wales	Airborne $D_{nT,w} + C_{tr}$
Homes/student accommodation	ADE	Impact $L'_{nT,w}$
	Scotland	Airborne $D_{nT,w}$
	S8233	Impact $L'_{nT,w}$
	Ad Hoc Hotel Chain	D_w
		Various mainly $D_{nT,w}$
Hotels, care homes and student accommodations in England and Wales and Scotland are covered under the building regulations. Most hotel chains also apply their own performance parameter either in line with previous experience of what is suitable or what is used in the hotel chains home country e.g. French hotel chains tend to use the $R'_w + C$ parameter.		
Cinema	UK	$D_{nT,w}$
	Ad hoc cinema operators	+ a minimum performance at 100Hz.
	levels	
The performance for cinema walls usually requires very high levels of insulation across the frequency range. A minimum performance criterion is also normally given for one of the low frequency bands; usually 100Hz.		
Civic amenity	UK Ad Hoc	Airborne D_w
	Courts Standards and Design Guidance 2007	Impact $L'_{nT,w}$
Manufacture	UK – BS EN ISO 140 Lab	Airborne R_w
Data	Test	Impact ΔL_w
The R_w value relates to the laboratory performance of a partition. The ΔL_w value is the test of an impact isolation material on a standard concrete floor in a laboratory. It is the improvement over the base construction when overlaid with the isolation material.		
Enhanced	Robust Details	Airborne $D_{nTw} + C_{tr}$
Performance	BREEAM	Impact $L'_{nT,w}$
Criteria	Code for Sustainable Homes	
	Ecohomes	
Used primarily in residential or residential type buildings (e.g. student accommodation). Code and Ecohomes still expect testing to use the C_{tr} adjustment even when tested outside England & Wales.		

insulation testing in England and Wales we know that the performance parameter is $D_{nT'w+Ctr}$ (as shown previously in Table IX) but if we were testing in Northern Ireland the performance parameter is $D_{nT,w}$. As these parameters determine the way in which the result is calculated the resultant dB level is likely to be different, i.e. if we test a blockwork wall and calculate the insulation value using the $D_{nT,w+Ctr}$ parameter we may get a dB level of 45 but if it were calculated using the $D_{nT,w}$ parameter we may get a dB level of 52dB.

Because of the different ways that airborne and impact sound measurements are conducted there is a difference in how we determine what is a good result for airborne sound insulation than for impact sound insulation; in short:

- Airborne sound insulation values are always set as *minimum* performance levels.
- Impact sound insulation values are always set as *maximum* performance levels.

Therefore *for airborne sound insulation the higher the result the better* while *for impact sound insulation the lower the result the better*.

8.1 Residential performance criteria

Table XI details the performance criteria for the British Isles. It is generally the case that the regulations for England and Wales are adopted in the Channel Islands and the Isle of Man.

Guidance for internal partitions is only relevant for the regulations in England and Wales and Scotland.

Regulations for Northern Ireland show a previous test evidence method whereby test data from lab reports or other site reports can be submitted as evidence that a structure is suitable.

8.2 Acoustic lining systems performance

When selecting suitable acoustic lining systems, such as Bonded Resilient Coverings, Floating Floor Treatments (batten, cradle or deck overlay systems) or Resilient Ceiling Bar systems in domestic

Table XI Sound insulation requirements for dwellings

Type of Building Room	Walls		Floors	
	Mean Value	Individual Value	Mean Value	Individual Value
England & Wales Approved Document E 2003 Amended 2004 – Performance standards for separating walls, floors and stairs that have a separating function[*]				
Dwelling houses and flats – Purpose Built	N/A	$D_{nT,w}+C_{tr} \geq 45dB$	N/A	$D_{nT,w}+C_{tr} \geq 45dB$ $L'_{nT,w} \leq 62dB$
Dwelling houses and flats – Formed by a material change of use	N/A	$D_{nT,w}+C_{tr} \geq 43dB$	N/A	$D_{nT,w}+C_{tr} \geq 45dB$ $L'_{nT,w} \leq 64dB$
Rooms for Residential Purpose	N/A	$D_{nT,w}+C_{tr} \geq 43dB$	N/A	$D_{nT,w}+C_{tr} \geq 45dB$ $L'_{nT,w} \leq 64dB$
England & Wales Approved Document E 2003 Amended 2004 – Laboratory Values for new internal walls and floors within dwelling houses, flats and rooms for residential purpose				
Purpose built or formed by a material change of use	N/A	$R_w \geq 40dB$[#]	N/A	$R_w \geq 40dB$[#]
Scotland Section 5 Noise 2010 Performance standards for separating walls and floors and stairs that have a separating function, Dwelling houses, flats and residential purpose				
New build	N/A	$D_{nT,w} \geq 56dB$	N/A	$D_{nT,w} \geq 56dB$ $L_{nT,w} \leq 56dB$
Refurbishment	N/A	$D_{nT,w} \geq 53dB$	N/A	$D_{nT,w} \geq 53dB$ $L_{nT,w} \leq 58dB$
Scotland Section 5 Noise 2010 Laboratory Values for new internal walls and floors within dwelling houses, flats and rooms for residential purpose				
Purpose built or formed by a material change of use	N/A	$R_w \geq 43dB$[#]	N/A	$R_w \geq 43dB$[#]
Northern Ireland Technical Booklet G/G1 1990/1994 Performance standards for separating walls and floors and stairs that have a separating function, Dwelling houses, flats and residential purpose				
New Build	$D_{nT,w} \geq 53dB$	$D_{nT,w} \geq 49dB$	$D_{nT,w} \geq 52dB$ $L_{nT,w} \leq 61dB$	$D_{nT,w} \geq 48dB$ $L_{nT,w} \leq 65dB$
Conversion Previous Test Evidence Method (Site Data option)	N/A	$D_{nT,w} \geq 49dB$	N/A	$D_{nT,w} \geq 48dB$ $L_{nT,w} \leq 65dB$
Conversion Previous Test Evidence Method (Lab Data option)	N/A	R_w 53dB	N/A	
Eire Technical Guidance Document E 1997 Performance standards for separating walls and floors and stairs that have a separating function, Dwelling houses, flats and residential purpose				
New Build & Change of use/ Conversions Tests in at least 4 Pairs of rooms	$D_{nT,w} \geq 53dB$	$D_{nT,w} \geq 49dB$	$D_{nT,w} \geq 52dB$ $L_{nT,w} \leq 61dB$	$D_{nT,w} \geq 48dB$ $L_{nT,w} \leq 65dB$
New Build & Change of use/ Conversions Tests in at least 8 Pairs of rooms	$D_{nT,w} \geq 52dB$	$D_{nT,w} \geq 49dB$	$D_{nT,w} \geq 51dB$ $L_{nT,w} \leq 62dB$	$D_{nT,w} \geq 48dB$ $L_{nT,w} \leq 65dB$

[*]The requirements of ADE can also be met by adopting the Robust Details Scheme

[#]Internal partition requirements in ADE are only for partitions which separate rooms for sleeping purposes from other rooms and so exclude walls between bedrooms and circulation spaces, and bedrooms to their own en-suite. In Section 5 the requirement applies to any partition which forms a room for sleeping purposes with the exception of en-suites attached to the bedroom.

buildings manufacturers should prove that their systems can meet minimum standards based on laboratory data.

In this instance the ΔL_w or ΔR_w parameters are used. This is the level of improvement a system has achieved when tested on a base timber or concrete floor under laboratory conditions. Regardless of whether it is an impact (ΔL_w) or airborne (ΔR_w) result the Δ character means that the higher the value the better the performance. The minimum requirement for each lining system is listed below:

- Bonded Resilient Coverings on concrete floors – ΔL_w 17dB
- Floating Floor Treatments on concrete floors – ΔR_w 5dB; ΔL_w 22dB
- Floating Floor Treatments on timber floors – ΔR_w 17dB; ΔR_w+Ctr 13dB; ΔL_w 16dB
- Resilient Ceiling Bars on timber floors – ΔR_w 16dB; ΔR_w+Ctr 14dB; ΔL_w 16dB

8.3 Enhanced performance criteria (domestic)

Many new housing developments are built under the BREEAM Ecohomes or Code for Sustainable Homes (CforSH) credit system. CforSH supersedes Ecohomes, however it is still widely used in some parts of the UK (e.g. Scotland). In order to gain credits it is necessary to provide a higher level of acoustic insulation than that outlined in the building regulations. Regardless of where in the UK a dwelling is constructed the airborne performance parameter outlined for England and Wales is always applied ($D_{nT,w}+C_{tr}$).

For the Code for Sustainable Homes credits are dependent upon 10 per cent of the site being tested and performance levels which exceed the basic pass rate as detailed in Table XII.

Ecohomes credits are dependent upon the level of testing undertaken and the improvement over the basic requirements of Approved Document E. To gain more than two credits the minimum required

Table XII Code for sustainable homes – credit system

Credits	Improvement on Approved Document E Levels (dB)	
	Airborne $D_{nT,w}+C_{tr}$	Impact L'
1	**+3**	–3
3	+5	5
4	+8	8

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rate of testing is increased. The amount of testing required is also affected by the number of plots on site and the number of different dwelling types (flats, houses).

Table XIII details the required testing and improvement over the minimum requirement needed to gain the relevant credits. It should be noted that the volume of testing requirements under the Ecohomes systems is substantial in comparison to the requirements under CforSH.

Under both the CforSH and the Ecohomes scheme it is possible to gain credit points without testing on site if the Robust Details scheme is adopted and the relevant constructions are used. In order to gain multiple credits the correct Robust Detail partition must be specified. Details of the number of credits that can be achieved for each partition type can be found on the Robust Details website (www.robustdetails.com).

In Scotland, Section 7 applies a gold, silver and bronze rating scheme. A 4 dB improvement beyond the standard achieves gold, a 2 dB improvement beyond the standard achieves silver and meeting the standard achieves the bronze rating.

8.4 Performance standards for dwellings in other countries

Table XIV details the performance criteria set in other countries for sound insulation in dwellings as of May 2004 taken from COST TU0901 and *Architectural Acoustics* (Cavanaugh et al., 2010).

8.5 School performance criteria

The guidance offered in this section is based on the performance criteria set out in Building Bulletin 93. Table XV details the $D_{nT(Tmf,max),w}$ airborne sound insulation requirements for school developments.

Table XVI details the impact sound insulation requirements for schools. The impact requirement for each room listed in Table XV would be for the floor above the room in question so that the room is protected from impact sound to the prescribed level.

Table XIII Summary HEA2 credit requirement of Ecohomes 2006

No. credits	Approximate no. tests required	Sound insulation performance
1	~ 50% plots	As ADE
2	~ 50% plots+ 2	As ADE
3	~ 50% plots + 2	3 dB improvement over ADE
4	~ 50% plots + 2	5 dB improvement over ADE

8.6 School performance criteria – corridor/circulation space walls

For schools it is accepted that the level of sound insulation for corridor walls separating rooms from circulation spaces which have doors or glazing in them would not be testable on site. Therefore a performance criterion based on laboratory performance should be set. This means that laboratory test data can be used as evidence that a partition specification is suitable for use.

For all rooms to circulation spaces except music rooms the minimum requirement would be R_w 40dB for the wall and R_w 30dB for the door set. For music rooms to circulation spaces the minimum requirement would be R_w 45dB for the wall and R_w 35dB for the door.

8.7 Hospital performance criteria

The guidance offered in this section is based on the performance criteria set out in Health Technical Memorandum 08-01.

Impact sound insulation – Guidance for impact insulation given in HTM08-01 is limited and recommends that the aim should be to avoid locating heavy traffic areas above sensitive spaces such as wards.

The performance requirement set is a maximum $L'_{nT,w}$ of 65dB.

Airborne sound insulation – Table XVII details the D_{ntw} airborne sound insulation requirements for hospital developments.

Locating rooms adjacent to one another which will result in a partition which requires a $D_{nT,w}$ of 57dB should be avoided.

Table XIV Domestic sound insulation requirements in other countries (May 2004)

Country	Airborne performance parameter	Multi-storey house (dB)	Terraced house (dB)	Impact performance requirement	Multi-storey house (dB)	Terraced house (dB)
Austria	$D_{nT,w}$	≥ 55	≥ 60	$L'_{nT,w}$	≤ 48	≤ 46
Australia	$D_{nT,w}+C_{tr}$	≥ 45	≥ 45	$L'_{nT,w}+C_I$	≤ 62	–
Belgium	$D_{nT,w}$	≥ 54	≥58	$L'_{nT,w}$	≤ 58	≤ 50
Czech	R'_w	≥ 52	≥ 57	L'_{nw}	≤ 58	≤ 53
Denmark	R'_w	≥ 52	≥ 55	L'_{nw}	≤ 58	≤ 53
Estonia	R'_w	≥ 55	≥ 55	L'_{nw}	≤ 53	≤ 53
Finland	R'_w	≥ 55	≥ 55	L'_{nw}	≤ 53	≤ 53
France	$D_{nT,w}+C$	≥ 53	≥ 53	$L'_{nT,w}$	≤ 58	≤ 58
Germany	R'_w	≥ 53	≥ 57	L_{nw}	≤ 53	≤ 48
Hungary	R'_w	≥ 52	≥ 57	L'_{nw}	≤ 55	≤ 47
Iceland	R'_w	≥ 52	≥ 55	L'_{nw}	≤58	≤ 53
Italy	R'_w	≥ 50	≥ 50	L'_{nw}	≤ 63	≤ 63
Latvia	R'_w	≥ 54	≥ 54	L'_{nw}	≤ 54	≤ 54
Lithuania	$D_{nT,w}$ or R'_w	≥ 55	≥ 55	L'_{nw}	≤ 53	≤ 53
Netherlands	I_{luk}	≥ 0	≥ 0	I_{co}	≤+5	≤ +5
New Zealand	STC	≥ 55	≥ 55	IIC	≤ 55	–
Norway	R'_w	≥ 55	≥ 55	L'_{nw}	≤ 53	≤ 53
Poland	R'_w+C	≥ 50	≥ 52	L'_{nw}	≤ 58	≤ 53
Portugal	$D_{n,w}$	≥ 50	50	L'_{nw}	≤ 60	≤ 60
Russia	I_b	≥ 50	–	I_y	≤ 67	–
Slovakia	R'_w	≥ 52	≥ 52	L'_{nw}	≤ 58	≤ 58
Slovenia	R'_w	≥ 52	≥ 52	L'_{nw}	≤ 58	≤ 58
Spain	$D_{nT,w}+C_{100-5000}$	≥ 50	≥50	$L'_{nT,w}$	≤ 65	≤ 65
Sweden	$R'_w+C_{50-3150}$	≥ 53	≥ 53	$L'_{nw}+C_{50-3150}$	≤ 56	≤ 56
Switzerland	$D_{nT,w}+C$	≥ 54	≥ 54	$L'_{nT,w}+C_I$	≤ 50	≤ 50
USA*	STC	≥ 48–55+	≥ 48–55+	IIC	≤ 55–48+	–

*USA guidance for federal housing, state guidance may differ.

+performance requirement dependent on grade of existing background level (Grade 1 [34–50dBA] =1 STC55 ICC48; Grade 2 [40–45dBA] STC52 IIC 52; Grade 3 [55dBA] STC48 IIC 55)

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Table XV Airborne $D_{nT(1m,max),w}$ sound insulation requirements for schools (BB93)

	Toilets	Coat and changing areas	Corridors, stairwells	Office, staff rooms	Kitchens	Dining rooms	Interviewing/counselling rooms, medical rooms	Swimming pool	Gymnasium	Dance studio	Indoor sports hall	Atria, circulation spaces used by students	Audio-visual, video conference rooms	Assembly halls, multi-purpose halls (drama, PE,audio/visual presentations, assembly), occasional music)	Design & Technology - resistance materials, CAMCAD areas	Design & Technology - Electronics/control, textiles, food, graphics, design/resource areas	Art rooms	Drama studios	Science laboratories	Libraries - resource areas	Libraries - quiet study areas	Study room (individual study, withdrawal, remedial work, teacher preparation)	Classroom designed specifically for use by hearing impaired students (including speech therapy rooms	Large lecture room (>50 people)	Small lecture room (<50 people)	Control room for recording	Recording studio	Performance/recital room	Ensemble room	Small practice/group room	Music classroom	Open-plan Resource area	Open-plan Teaching area	Primary school; classrooms, general teaching areas, small group rooms, language laboratories	Secondary school; classrooms, general teaching areas, seminar rooms tutorial/	Nursery school; classrooms, class bases,	Nursery school quiet rooms	Nursery school playrooms
Nursery school playrooms	45	55	55	50	55	55	55	55	55	55	55	50	55	55	50	50	55	55	50	50	55	55	55	55	55	55	55	55	55	55	55	50	50	55	55	55	55
Nursery school quiet rooms P school; classrooms, classbases, gen	45	55	55	45	55	55	40	55	55	55	55	45	45	55	45	45	55	55	45	45	40	40	45	45	45	55	55	55	55	55	55	45	45	45	45	40	
teach areas, small group S school; class, gen teach areas, seminar/	45	45	55	45	55	55	45	55	55	55	55	45	45	55	45	45	55	55	45	45	45	45	50	50	45	55	55	55	55	55	55	45	45	45	45		
tutorial, language lab	45	55	55	45	55	55	45	55	55	55	55	45	45	55	45	45	55	55	45	45	45	45	50	50	45	55	55	55	55	55	55	45	45	45			
Open-plan Teaching area	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40	40	50	50	40	40	45	45	50	50	45	50	55	55	55	55	55	40	40				
Open-plan Resource area	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40	40	50	50	40	40	45	45	50	50	45	50	55	55	55	55	55	40					
Music classroom	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	55	55	55	55	60	60	55	55	60	60	60	55	55					
Small practice/group room	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	55	55	55	55	60	60	55	55	60	60	60	55						
Ensemble room	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	55	55	55	55	60	60	55	55	60	60	60							
Performance/recital room	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	60	55	55	55	60	60	55	55	60	60								
Recording studio	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	60	55	55	55	60	60	55	55	60									
Control room for recording	45	55	55	50	55	55	55	55	55	55	55	50	55	55	50	50	55	55	50	50	55	55	55	55	55	55											
Small lecture room (<50 people)	45	55	55	45	55	55	45	55	55	55	55	45	45	55	45	45	55	55	45	45	45	45	50	50	45												
Large lecture room (>50 people)	50	55	55	50	55	55	45	55	55	55	55	50	50	55	50	50	55	55	50	50	45	45	50	50													
Classroom designed specifically for use by hearing impaired students (including speech	50	55	55	50	55	55	45	55	55	55	55	50	50	55	50	50	55	55	50	50	45	45	50														
Study room (individual study, withdrawal, remedial work, teacher preparation)	45	55	55	45	55	55	40	55	55	55	55	45	45	55	45	45	55	55	45	45	40	40															
Libraries - quiet study areas	45	55	55	45	55	55	40	55	55	55	55	45	45	55	45	45	55	55	45	45	40																
Libraries - resource areas	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40	40	50	50	40	40																	
Science laboratories	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40	40	50	50	40																		
Drama studios	50	55	55	50	55	55	55	55	55	55	55	50	55	55	50	50	55	55																			
Design & Technology - resistance materials, CAMCAD areas	45	45	45	50	45	45	55	45	50	50	50	50	55	55	50	50	45																				
Design & Technology - Electronics/control, textiles, food, graphics, design/resource	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40	40																					
Art rooms	40	50	50	40	50	50	45	50	50	50	50	40	45	50	40																						
Assembly halls, multi-purpose halls (drama, PE,audio/visual presentations, assembly)	45	55	55	50	55	55	55	55	55	55	55	50	55	55																							
Audio-visual, video conference rooms	45	55	55	45	55	55	45	55	55	55	55	45	45																								
Atria, circulation spaces used by students	40	50	50	40	50	50	45	50	50	50	50	40																									
Indoor sports hall	45	50	50	50	50	50	55	50	50	50	50																										
Dance studio	45	50	50	50	50	50	55	50	50	50																											
Gymnasium	45	50	50	50	50	50	55	50	50																												
Swimming pool	45	45	45	50	45	45	55	45																													
Interviewing/counselling rooms, medical rooms	45	55	55	45	55	55	40																														
Dining rooms	45	45	45	50	45	45																															
Kitchens	45	45	45	50	45																																
Office, staff rooms	40	50	50	40																																	
Corridors, stairwells	45	45	45																																		
Coat and changing areas	45	45																																			
Toilets	35																																				

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Table XVI Performance standards for impact sound insulation of school floors (BB93)

Type of room	Maximum impact sound pressure level $L'_{nT(Tmf,max),w}$ (dB)
Nursery school playrooms	
Science laboratories	
Design & Technology resistance material CAMCAD areas	
Atria, circulation spaces for students	
Indoor sports halls	
Gymnasium	65
Swimming pool	
Dining rooms; kitchens	
Offices. staff rooms	
Corridors, stairwells	
Coats and changing areas	
Toilets	
Nursery school quiet rooms	
Primary school, classrooms, class bases, general teaching areas, small groups	
Secondary school, classrooms, general teaching areas, seminar rooms, tutorial rooms, language laboratories	
Open plan teaching areas	
Open plan resource areas	
Small lecture rooms (fewer than 50 people)	
Study room (individual study, withdrawal, remedial work, teacher preparation)	60
Libraries	
Design & Technology electronic/control, textiles, food, graphics, design/resource areas	
Art room	
Assembly halls, multi-purpose halls (drama. PH. audio/visual presentations, assembly, occasional music)	
Audio-visual, video conference rooms	
Dance studio	
Interview/counselling rooms, medical rooms	
Music: music classroom, small practice/group room, ensemble room, performance/recital room, recording studio, control room for recording.	
Large lecture room (more than 50)	55
Classrooms designed specifically for use by hearing impaired students (including speech therapy rooms)	
Drama studios	

Note: Where it is not possible to meet the minimum acoustic absorption requirements (set out in section 10) then the level of insulation for the partitions in these areas should be increased by 3dB.

8.8 Hospital performance criteria – corridor/circulation space walls

The level of sound insulation for corridor walls separating rooms from circulation spaces which have doors or glazing in them would not be testable on site. Therefore a performance criterion based on laboratory performance should be set. Laboratory test data can be used as evidence that a partition specification is suitable for use. For all rooms to circulation spaces the minimum requirement would be R_w 40–45dB for the wall and R_w 30–35dB for the door set respectively.

8.9 Performance criteria for civic buildings

Guidance for many civic buildings will be ad hoc; however guidance is available in the Courts Standards and Design Guide 2007 (CSDG) document which outlines reasonable performance specifications for airborne and impact sound insulation. Table XVIII details the airborne insulation requirements while Table XIX details the impact requirements.

8.10 Performance criteria for other building types

Sound insulation in other building types is often not considered as an area of concern however in many cases sound transmission in offices, cinemas and other building types is important. Table XX outlines good practice for airborne sound insulation in a variety of building types. Performance standards given for office accommodation are taken from the BCO Specification Guide 2009.

8.11 Broadcasting

The guidance requirements for commercial recording studios and television broadcast studios are considered a highly specialised area and should be considered the remit of an acoustic consultant or specialist design consultant. Further guidance can be found in BBC Engineering's 'Guide to Acoustic Practice'.

9 SPECIFYING AIRBORNE AND IMPACT INSULATION FROM LABORATORY TEST DATA

9.1 Laboratory to site

It can often be difficult to find site performance data for a partition and so a designer may have to rely on test data gathered from laboratory testing. In most instances airborne and impact sound insulation is measured in a suppressed flanking laboratory. This type of laboratory reduces the effects of the other sound paths between the two test rooms (see Section 5.5) so that only the performance of the specimen partition is tested.

In order to assess if the laboratory performance of a partition is good enough to be used on site it is necessary to adjust the laboratory result. The level of adjustment required is partly based on the performance parameter that is used on site ($D_{nT,w}$, $D_{nT,w} + C_{tr}$ etc.) and the anticipated effects of flanking. For these estimations to be meaningful it is assumed that the partition specification used on site is identical to that tested in the laboratory and that a high level of workmanship has been undertaken on site.

9.2 Domestic performance conversions

The following rules of thumb are normally applied when converting site performance requirements to laboratory performance levels;

Site $D_{nT,w}$ = Lab R_w +5dB for masonry partitions
Site $D_{nT,w}$ = Lab R_w +7dB for light weight partitions
Site $D_{nT,w}+C_{tr}$ = Lab R_w +C_{tr} + 10dB for masonry partitions
Site $D_{nT,w}+C_{tr}$ = Lab R_w +C_{tr} + 15dB for lightweight partitions

9.3 Hospital performance conversions

For hospitals the HTM08-01 document suggests that additional care be taken when specifying partitions with relevance to room volume.

Figure 10.8 shows the relationship between on site performance ($D_{nT,w}$) and laboratory performance (R_w) in relationship to the room width. The minimum that should be added is taken to be +5dB for heavy constructions and +7dB for light constructions; however as the room width reduces, the level of insulation that a wall would have to provide under laboratory conditions increases in order to provide the required level of insulation on site.

9.4 School performance conversions

For schools projects the use of the $D_{nT(Tmf,max),w}$ parameter has broadly similar properties to the $D_{nT,w}$ parameter discussed in Sections 9.2 and 9.3. Note the use of the $T_{mf,max}$ parameter. This is a set maximum reverberation time to be used in the calculation of the result. If the correct reverberation time within a room is not achieved it will have an effect on the overall sound insulation performance of the partition.

While it is suitable to use the rules of thumb outlined in Section 9.2 (+5 and +7dB added to the R_w value depending upon the partition type) this will only be credible if the correct reverberation time in the receiving room is also achieved (see Section 10).

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Table XVII $D_{nT,w}$ Airborne sound insulation requirements for hospitals (HTM08-01)

Room type	Small meeting room (<35m2)	Large meeting room (> 35m2)	Boardroom	Open-plan office (≥ 5 people)	Multi-person office (2-4 people)	Single-person office	Library/archiving room	Lecture theatre	Small training/seminar (≤ 35m2)	Large training/seminar (>35m2)	Locker/changing room	Rest room	Storeroom	Ward kitchen, pantry	Main kitchen	Toilets (non cubicles)	Waiting (small ≤ 20 people)	Waiting (large > 20 people)	Toilets (non cubicles)	Dining	Atrium	Corridor (no door)	Multi-faith/chapel	Snoezelen/multi-sensory room	Speech and language therapy	Clean utility	Dirty utility/sluice	Laboratories	Birthing room	Nurseries	Operating theatre suite	interview room	Counseling/bereavement room	Treatment room	Examination room	Consulting room	Children & older people (multi-bed)	Children & older people (single bed)	multi-bed room	Single bed/on-call room
Single bed/on-call room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	47	47	47	47	47	52	52	47	47	47	47	47	47	47	47	47
multi-bed room	42	47	37	37	47	42	42	47	42	47	47	42	37	37	52	47	37	42	42	42	42	42	37	47	47	47	37	42	52	52	52	47	47	47	47	47	42	47	37
Children & older people (single bed)	47	47	47	47	47	47	52	52	47	47	47	47	42	42	52	47	42	42	42	42	42	42	42	52	52	52	47	42	52	52	52	47	47	47	47	47	47	47	47
Children & older people (multi-bed)	47	47	47	47	47	47	47	47	47	47	47	47	42	42	52	47	42	42	42	42	42	42	42	52	52	52	47	42	52	52	52	47	47	47	47	47	42	47	42
Consulting room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Examination room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Treatment room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Counseling/bereavement room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
interview room	47	52	52	42	42	47	47	52	47	52	42	47	42	42	52	47	47	47	42	42	42	42	42	52	52	52	42	47	52	52	52	47	47	47	47	47	47	47	47
Operating theatre suite	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Nurseries	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Birthing room	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Laboratories	42	47	47	37	37	42	42	47	42	47	37	42	37	37	52	37	37	42	37	37	42	42	37	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Dirty utility/sluice	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Clean utility	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Speech and language therapy	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Snoezelen/multi-sensory room	47	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Multi-faith/chapel	47	52	52	47	47	47	52	52	47	52	42	47	42	42	52	47	42	47	42	42	42	42	42	52	52	52	42	47	52	52	52	47	47	47	47	47	47	47	47
Corridor (no door)	42	47	47	n/a	37	42	42	47	42	47	37	42	37	37	52	47	37	42	37	37	42	42	37	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Atrium	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Dining	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Toilets (non cubicles)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Waiting (large > 20 people)	42	42	47	42	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Waiting (small ≤ 20 people)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Toilets (non cubicles)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Main kitchen	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Ward kitchen, pantry	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Storeroom	42	47	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Rest room	42	47	47	42	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Locker/changing room	42	42	47	37	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Large training/seminar (>35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Small training/seminar (≤ 35m2)	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Lecture theatre	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Library/archiving room	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Single-person office	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Multi-person office (2-4 people)	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Open-plan office (≥ 5 people)	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Boardroom	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Large meeting room (> 35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Small meeting room (<35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47

Room type	Small meeting room (<35m2)	Large meeting room (> 35m2)	Boardroom	Open-plan office (≥ 5 people)	Multi-person office (2-4 people)	Single-person office	Library/archiving room	Lecture theatre	Small training/seminar (≤ 35m2)	Large training/seminar (>35m2)	Locker/changing room	Rest room	Storeroom	Ward kitchen, pantry	Main kitchen	Toilets (non cubicles)	Waiting (small ≤ 20 people)	Waiting (large > 20 people)	Toilets (non cubicles)	Dining	Atrium	Corridor (no door)	Multi-faith/chapel	Snoezelen/multi-sensory room	Speech and language therapy	Clean utility	Dirty utility/sluice	Laboratories	Birthing room	Nurseries	Operating theatre suite	interview room	Counseling/bereavement room	Treatment room	Examination room	Consulting room	Children & older people (multi-bed)	Children & older people (single bed)	multi-bed room	Single bed/on-call room
Single bed/on-call room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	47	47	47	47	47	52	52	47	47	47	47	47	47	47	47	47
multi-bed room	42	47	37	37	47	42	42	47	42	47	47	42	37	37	52	47	37	42	37	37	42	42	37	47	47	47	37	42	52	52	52	47	47	47	47	47	42	47	37
Children & older people (single bed)	47	47	47	47	47	47	52	52	47	47	47	47	42	42	52	47	42	42	42	42	42	42	42	52	52	52	47	42	52	52	52	47	47	47	47	47	47	47	47
Children & older people (multi-bed)	47	47	47	47	47	47	47	47	47	47	47	47	42	42	52	47	42	42	42	42	42	42	42	52	52	52	47	42	52	52	52	47	47	47	47	47	42	47	42
Consulting room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Examination room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Treatment room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Counseling/bereavement room	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
interview room	47	52	52	42	42	47	47	52	47	52	42	47	42	42	52	47	47	47	42	42	42	42	42	52	52	52	42	47	52	52	52	47	47	47	47	47	47	47	47
Operating theatre suite	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Nurseries	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Birthing room	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Laboratories	42	47	47	37	37	42	42	47	42	47	37	42	37	37	52	37	37	42	37	37	42	42	37	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Dirty utility/sluice	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Clean utility	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Speech and language therapy	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Snoezelen/multi-sensory room	47	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Multi-faith/chapel	47	52	52	47	47	47	52	52	47	52	42	47	42	42	52	47	42	47	42	42	42	42	42	52	52	52	42	47	52	52	52	47	47	47	47	47	47	47	47
Corridor (no door)	42	47	47	n/a	37	42	42	47	42	47	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Atrium	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Dining	42	42	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	n/a	n/a	n/a	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Toilets (non cubicles)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Waiting (large > 20 people)	42	42	47	42	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Waiting (small ≤ 20 people)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Toilets (non cubicles)	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Main kitchen	52	52	52	52	52	52	57*	57*	52	52	47	52	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Ward kitchen, pantry	42	42	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Storeroom	42	47	47	n/a	37	42	42	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Rest room	42	47	47	42	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Locker/changing room	42	42	47	37	42	47	47	47	42	42	37	42	37	37	52	47	37	42	37	37	n/a	n/a	n/a	47	47	47	37	42	52	52	52	47	47	47	47	47	47	47	47
Large training/seminar (>35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Small training/seminar (≤ 35m2)	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Lecture theatre	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Library/archiving room	47	52	52	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Single-person office	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Multi-person office (2-4 people)	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Open-plan office (≥ 5 people)	42	47	47	42	42	47	47	47	42	42	42	42	42	42	52	42	42	42	42	42	42	42	42	47	47	47	42	42	52	52	52	47	47	47	47	47	47	47	47
Boardroom	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Large meeting room (> 35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47
Small meeting room (<35m2)	47	47	47	47	47	47	47	47	47	47	47	47	47	47	52	47	47	47	47	47	47	47	47	52	52	52	47	47	52	52	52	47	47	47	47	47	47	47	47

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Table XVIII $D_{nT,w}$ Airborne sound insulation requirements for court houses (CSDG 2007)

	Toilets	Witness Waiting Room	Defendants Holding Area	Cells	Public Areas	Restricted Circulation Areas	Advocates' Rooms	Assembly Areas	Offices	Multi-purpose Rooms	Waiting Areas	Usher Rooms	Jury Rooms	Conference Rooms	Consultation Rooms	Committee Rooms	Interview Rooms	Magistrates' & Judges' Retiring Chambers	Courtroom
Courtroom	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
Magistrates' & Judges' Retiring Chambers	50	50	50	55	50	48	50	50	50	50	50	50	55	50	50	50	50	50	
Interview Rooms	42	50	50	55	35	42	50	42	42	42	43	45	55	42	42	42	42		
Committee Rooms	42	50	50	55	42	42	45	42	42	42	42	45	55	42	42	42			
Consultation Rooms	42	50	50	55	35	42	45	42	42	42	42	45	60	42	42				
Conference Rooms	42	50	50	55	35	42	45	42	42	42	42	45	55	42					
Jury Rooms	55	55	55	55	50	50	55	50	55	55	50	45	53						
Usher Rooms	42	50	50	50	35	50	45	53	40	40	35	42							
Waiting Areas	42	50	50	55	35	42	45	35	35	35	42								
Multi-purpose Rooms	42	50	50	55	35	50	45	35	42	42									
Offices	42	50	50	55	35	50	50	35	42										
Assembly Areas	42	50	50	55	45	50	48	42											
Advocates' Rooms	42	50	50	55	45	50	50												
Restricted Circulation Areas	50	50	50	55	45	50													
Public Areas	42	50	50	55	50														
Cells	55	55	55	48															
Defendants Holding Area	42	50	50																
Witness Waiting Room	42	50																	
Toilets	42																		

Table XIX Performance standards for impact sound insulation of court buildings (CSDG 2007)

Room type	Maximum impact sound pressure level $L'_{nT,w}$ (dB)
Courtrooms/critical areas	50
Private offices/ conference	55
Public/non-critical areas	60

Table XX Sound insulation performance guidance for a variety of building types

Type of building/room	Airborne sound (dB)	Impact sound (dB)
Offices		
General office – general office (fitted out to Cat A Standard)	$D_{nT,w}$ ≥48dB	N/A
Private offices/meeting room to another space	$D_{nT,w}$ ≥50dB	$L'_{nT,w}$ ≤65dB
Commercial	$D_{nT,w}$ ≥65dB	
Cinema to cinema	(plus minimum D_{nT} of 35dB at 63Hz)B	N/A
Cinema to foyer/bar	$D_{nT,w}$ ≥55dB	N/A
Cinema to corridors/concourse (where doors are present)	R_w ≥71dB	N/A
Cinema to corridors/concourse (where no doors are present)	$D_{nT,w}$ ≥55dB	N/A
Cinema to projection room	$D_{nT,w}$ ≥55dB	N/A
Retail/commercial to dwelling	As outlined for separating partition in relevant building regulations*	

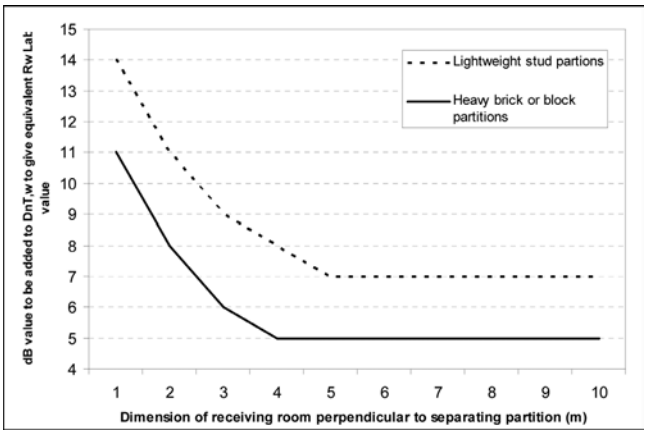
*It is normal for additional acoustic insulation to be required in such situations and is usually detailed during the planning phase.

9.5 Perception of sound insulation values

Table XXI details the perceived relationship between the level of sound insulation offered by a partition and how speech would be perceived in the adjoining room.

10 REVERBERATION CRITERIA

Two performance parameters are normally set when considering reverberation time in a room. Either the room must not exceed a maximum reverberation time or a minimum area of acoustically absorbent material should be specified within the room. For the second parameter described it is also normal to dictate the minimum level of absorption offered by the material.



10.8 *HTM08-01 Converting site performance requirements to laboratory performance requirements*

Table XXI Perceived relationship between sound insulation values and speech

Description	DnT,w
Talk at a normal level can be heard and followed in the room next door	30
Talk at a normal level can be heard and partly distinguished in the room next door	35
Talk at a normal level can be heard but words cannot be distinguished in the room next door	40
Talk at a normal level cannot be heard in the room next door	45
Loud speech can be heard through the wall but words cannot be distinguished	50
Loud speech cannot be heard through the wall	55
Loud shouting can be heard through the wall, but words cannot be distinguished	60

Wood Focus Oy

Table XXII Suitable maximum reverberation times

Type of building/room	Maximum reverberation time (second
School	
Nursery school playrooms	0.6
Nursery school quiet rooms	0.6
Primary school; classrooms, class bases, general teaching areas, small group rooms	0.6
Secondary school; classrooms, general teaching areas, seminar	
Rooms, tutorial rooms, language laboratories	0.8
Open-plan teaching area	0.8
Open-plan resource area	1.0
Music classroom	1.0
Small practice/group room	0.8
Ensemble room	0.6–1.2
Performance/recital room	1.0–1.5
Recording studio	0.6–1.2
Control room for recording	0.5
Small lecture room (<50 people)	0.8
Large lecture room (>50 people)	1.0
Classroom designed specifically for use by hearing impaired students (including speech therapy rooms)	0.4
Study room (individual study, withdrawal, remedial work, teacher preparation)	0.8
Libraries – quiet study areas	1.0
Libraries – resource areas	1.0
Science laboratories	0.8
Drama studios	1.0
Design & Technology – resistance materials, CAMCAD areas	0.8
Design & Technology – electronics/control, textiles, food, graphics, design/resource areas	0.8
Art rooms	0.8
Assembly halls, multi-purpose halls (drama, PE, audio/visual presentations, assembly, occasional music)	0.8–1.2
Audio-visual, video conference rooms	0.8
Atria, circulation spaces used by students	1.5
Indoor sports hall	1.5
Dance studio	1.2
Gymnasium	1.5
Swimming pool	2.0
Interviewing/counselling rooms, medical rooms	0.8
Dining rooms	1.0
Kitchens	1.5
Office, staff rooms	1.0
Corridors, stairwells	See Note
Coat and changing areas	1.5
Toilets	1.5
Offices	
Cellular office	1.0
Staff room	1.0
Meeting room	0.6
Executive office	0.6
Open plan office	0.8
Industrial	
Workshops	0.8
Canteen	1.0
Civic & Amenity	
Library	0.6
Court rooms (up to 500m³) with 50% room occupancy	<0.6 @ 125Hz-2kHz (+ 0.1sec)
Court rooms (over 500m³) with 50% room occupancy	1.0 @ 125Hz-2kHz (± 0.2sec)
Magistrates/judge retiring, judges' chambers	0.6
Control centres	0.4–0.75
Interview rooms (for recording)	0.3
Toilets	1.5
Public sports halls/games halls	2.0
Public gymnasium	2.0
Washrooms	1.5
Public baths/swimming pools	2.0
Domestic	
Living rooms	0.8
Bedrooms	0.6

Note: Corridors and stairwells can provide suitable reverberation time levels by applying a Class B absorbent ceiling to all areas.

10.1 Reverberation times

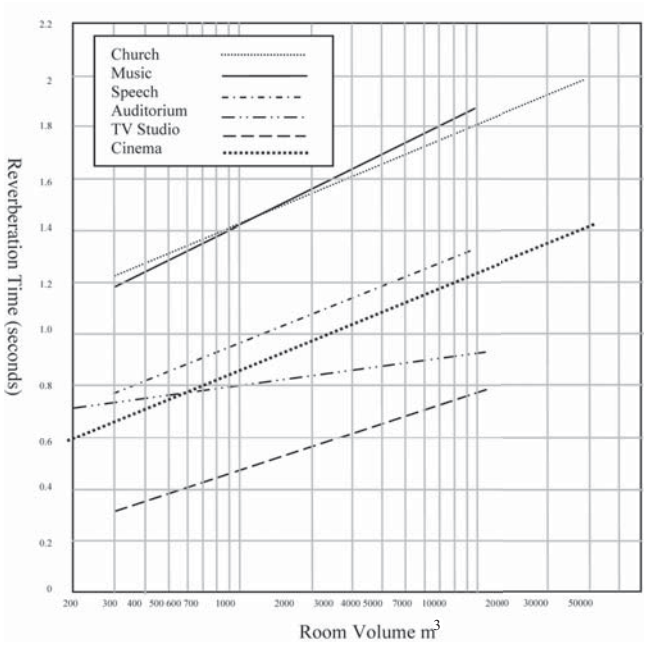
The reverberation time (RT), given in seconds, is normal consider as the average reverberation time for the frequency bands 500Hz, 1000Hz and 2000Hz. Table XXII details the required maximum reverberation times for a range of rooms. Instances where an alternative frequency range should be used are noted in the table.

10.2 Optimum reverberation times in performance spaces

For performance spaces, including churches, the optimum reverberation time will differ dependent upon the type of performance (speech, music), the type of building and the volume of the space. Figure 10.9 gives guidance values for reverberation times in some common performance spaces (Cavanaugh et al., 2010; BS 8233; Ballou, 2005).

These guidance levels show the optimum reverberation time dependent on room volume at the 500Hz frequency band width. Achieving these reverberation times will be dependent on specialist acoustic design. General guidance on this subject is given in Section 11.

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10.9 *Reverberation vs volume criteria in performance spaces (500Hz)*

10.3 Minimum area of absorption

The other performance parameter commonly used is to define the minimum area of absorption required for a space and to define the absorption classification of the material. This is used in hospital developments or in circulation spaces (e.g. in schools or stairwells in domestic developments).

The absorption classification of a material is defined in BS EN ISO 11654 at each frequency as the α_s and as a single figure value as the α_w. From this the classification of a material is rated from A–E, Class A absorbent material being the highest classification with the most absorption and Class E materials being the lowest classification with the least absorption. Table XXIII details the likely absorbent classification and area requirement for particular room types.

Table XXIII Recommended absorption requirements

Type of building/room	Recommendations for achieving suitable reverberation times in a space based on absorbent areas in a room
Schools (BB3)	
Entrance halls, corridors, hallways	Cover an area equal to or greater than the floor area with a Class C absorber Cover an area equal to or greater than the total stair tread, intermediate landings and top landing (excluding ground floor area) with a Class D absorber
Stairwells, stair enclosures	OR Cover 50% of the calculated area with a Class C absorber
Hospitals (HTM08–01)	
All rooms excluding unimportant rooms (e.g. storerooms) where cleaning, infection-control, patient-safety, clinical and maintenance requirements allow.	Cover an area equal to or greater than 80% of the floor areas with a Class C absorber
Rooms requiring optimum acoustic conditions (e.g. lecture theatres)	Specialist advice should be sought
Large areas such as Atria	Specification should be agreed on a case by case basis (see options in Table XXII)
Common areas in domestic developments (ADE)	
Entrance halls, corridors, hallways	Cover an area equal to or greater than the floor area with a Class C absorber Cover an area equal to or greater than the total stair tread, intermediate landings and top landing (excluding ground floor area) with a Class D absorber
Stairwells, stair enclosures	OR Cover 50% of the calculated area with a Class C absorber

11 GENERAL GUIDANCE ON THE ACOUSTICS OF PERFORMANCE SPACES

When designing performance spaces such as auditoria, theatres etc. it is always advised that a specialist in building acoustics is involved. However there are some basic guidance rules that the non-specialist designer should be aware of to allow them to begin the initial design.

- Halls for music performance required a minimum of 8m^3 per audience member.
- Halls for theatres or cinemas require a minimum of 4m^3 per audience member.
- Rectangular shaped halls with high ceilings are normally preferable, fan shaped halls normally provide poor acoustics for musical performances.
- Domes and barrel vaults can cause focusing and should be avoided or treated with additional absorption.
- Acoustic scattering treatments are recommended for side walls. Side-wall diffusion will increase the musical clarity
- A proscenium stage enclosure will benefit the balance and ensemble of orchestrations.
- Large overhangs or balconies will reduce the quality of sound reaching those seated below. The depth of an overhang should not exceed the height between the floor and the underside of the overhang.
- Shallow pitched roofs can cause flutter effects.
- Seating should be arranged to allow for a clear line of sight to the performance space for acoustic as well as visual reasons. This should help to ensure the same acoustics at each seat.
- Steeply raked seating should be avoided particularly for musical performance spaces.
- The walls, floor and ceiling around the performance space should preferably be acoustically reflective. Acoustic absorption in this area should be avoided.
- For music performance spaces the acoustic absorption provided by unoccupied seating should be as similar as possible to when the seats are occupied. Upholstered seating is best. Where tip-up seating is used it is preferable to upholster the underside of the seat.
- Background noise levels should be kept to a minimum. The acoustic performance of the building envelope is important when designing in noisy (city centre) areas.
- Plant and machinery should be as quiet as possible.
- See Figure 10.9 for advice on suitable Reverberation Times versus room volumes.
  - Concert Halls 8–12 m^3 per occupant
  - Opera Halls 4–6 m^3 per occupant
  - Theatres 2.5–4 m^3 per occupant
  - Churches 6–14 m^3 per occupant
  - Lecture Rooms 3–6 m^3 per occupant

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11 Fire

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KEY POINTS:
- *Consider from first principles how a fire can start*
- *Then how can it grow?*
- *Will it threaten life, property or both?*
- *How can it be fought?*
- *How will people escape?*
- *Only after considering all these points, refer to regulations*

Contents

1 Introduction
2 Components of fire
3 Principles of fire protection
4 Means of escape
5 Materials
6 Fire protection appliances and installations
7 Statutory requirements
8 Bibliography

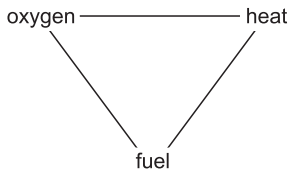
1 INTRODUCTION

When designing a building with fire safety in mind, particularly ease of escape, it is important not to forget the needs also for usability and security. If the fire measures are seen to be too onerous (for example, a multiplicity of fire doors) they will be circumvented (propped open) and their purpose will be frustrated. Fire escape doors are often weak points when it comes to unauthorised ingress, particularly in places of public assembly.

2 COMPONENTS OF FIRE

2.1 Combustion

Fire is combustion producing heat and light. Combustion will occur and continue if three factors are present: oxygen, heat and fuel. These are generally referred to as the combustion triangle, Figure 11.1.



11.1 *Triangle of fire*

2.2 Extinguishing

Fire can be extinguished by removing one corner of the combustion triangle:

- Starve or limit the fuel by removing it.
- Smother by limiting or stopping the further supply of oxygen.
- Cool by dissipating the heat faster than it is generated.

2.3 Source

A source of heat comes into contact with a combustible material (the fuel) which ignites and supports combustion while oxygen is present. The heat sources within a building are many – cooking, smoking, heating equipment, overheating/faulty equipment (particularly electrical).

2.4 Fuel

Three kinds of fuel have been identified:

- tinder, material ignitable by a match which will continue to burn after its removal;
- kindling, material which will ignite and burn if associated with sufficient tinder, but in which a match will not produce a continuing fire;
- bulk fuel, which needs kindling to cause to burn.

2.5 Flammability

The fuel may be present in the building structure, fittings and/or contents and can be in the form of solids, liquids or gases. Most organic materials will burn. Certain materials spontaneously combust and care is required in their storage, e.g. linseed oil, certain chemicals, grains. Certain industrial processes involving high levels of dust, e.g. printing, flour mills, can result in flash fires. Specialist advice should be sought in respect of these matters.

2.6 Risk

The initial source of heat cannot ignite most bulk fuels unless the fire is able to follow the tinder-kindling chain. Of course, this does not apply when the bulk fuel is itself highly combustible; but it does apply to elements of building construction and to many stored materials.

This leads to the point that fire risks in most buildings can be greatly reduced if measures are taken to avoid build-ups of tinder. Dust, waste paper, sawdust, rags, etc. are materials which will act as tinder; so will a number of man-made organic materials which are now coming under stricter control.

2.7 Smoke

This is formed when organic materials decompose by heat giving off tarry and sooty decomposed materials. It is likely that most smoke will be generated by the building contents.

2.8 Heat

This can be transmitted in three forms:

- Conduction – heat energy is passed from one molecule to the next. The conductivity of a material (which varies with the material) may affect the fire resistance of a component or structure. A steel member in contact with combustible materials may transfer the heat generating a fire or damage away from the original source.
- Radiation – heat is transmitted in straight lines without any contact between the radiating material and the target which may absorb or reflect the heat. The intensity reduces inversely as the square of the distance from the source of radiation. Combustible materials placed in close proximity to a radiant fire will ignite.

- Convection – only occurs in liquids and gases. The heated combustion gases become buoyant and rise through voids and shafts with the potential of causing ignition in other areas of a building.

3 PRINCIPLES OF FIRE PROTECTION

Note: specific recommendations relating to periods of fire resistance for specific uses, structural elements etc. are given in various codes only some of which are referred to here.

3.1 Potential problems

- Unrestricted growth and spread of a fire within a building that will cause extensive damage and may result in its collapse.
- Rapid spread of fire across surfaces within the building, ignition of adjacent fuels, means of escape prejudiced.
- Spread of fire, smoke and hot gases in a building through ducts, voids and shafts affecting the means of escape, access for firefighters and causing extensive damage to decorations and property.
- Spread of fire to adjacent buildings affecting life safety and property.
- Loss of contents, disruption of work, loss of trade/production.

3.2 Restriction

The aim of fire precautions within a building is to inhibit the growth and to restrict the spread of any fire. The influencing factors are:

- the size of building – area, height, volume;
- the layout and configuration within the building;
- the uses accommodated, and the requirements of the occupants;
- the construction materials, linings and claddings;
- the type of construction;
- the services installed;
- the furniture.

3.3 Precautions

The precautions are:

- protection of loadbearing structure to prevent untimely collapse, limitation of combustibility of key structural elements;
- adequate and appropriate provisions for means of escape;
- access for firefighters up to and through the building to reach the seat of the fire and promptly extinguish it;
- compartmentation and separation to restrict spread of fire, maintenance of these by protection of openings, fire stopping and cavity barriers within concealed spaces;
- safe installation and maintenance of services, heat-producing equipment and user equipment;
- separation of different uses to protect, for example, a risk to sleepers from commercial uses;
- enclosure of high risks with fire-resisting construction to protect adjacent areas;
- active fire-extinguishing installations to detect and/or contain fire in its early stages and restrict its spread and growth;
- limitation of flame spread by selective use of materials;
- fire-resisting external walls and/or space separation to prevent spread of fire to adjacent properties, protection of openings in external walls, limited flame spread across external walls and roofs, use of insulation with limited combustibility to restrict ignition and spread;
- the provision of natural or mechanical ventilation, smoke extraction and/or smoke control measures to facilitate means of escape and firefighting;
- management training and procedures for evacuation, maintenance of fire precautions, risk analysis, management policy.

3.4 Growth and spread

An analysis of the growth and spread of fire is explained in detail and substantiated by Malhotra in BRE publication BR 96 *Fire Safety in Buildings.*

3.5 Fire load and ignitability

The majority of a fire load within a building will be its contents, over which a designer may have no influence. Some types of occupancies have controls relating to the ignitability of furniture (domestic and assembly buildings under licensing legislation, hospitals and prisons under government directives), see Table I. Electricity, often cited as the cause of fires, while not itself a risk presents a potential hazard when brought into contact with combustible material; all new electrical installations should be installed in accordance with the current edition of the regulations of the Institution of Electrical Engineers and existing installations periodically examined and tested for potential risks.

3.6 Smoke

The limitation of smoke spread is considered mainly as an aspect of safe means of escape. Specific limitations of smoke production are not, to date, generally specified. There is no generally accepted test related to smoke emission. The production of toxic gases which accompanies all fires would be very difficult to specify.

3.7 Combustibility

While it would be possible to construct a totally non-combustible building, it is not practical and not required by legislation; although some codes do relate means of escape to a classification based on the 'combustibility' of a building. Non-combustible materials should be used where hazardous conditions are anticipated or there is a need to maintain the integrity of a structure for the maximum time, e.g. a compartment wall or floor, or an escape stair in a high building.

3.8 Fire resistance

The need for a degree of fire resistance within a structure may be dictated by Building Regulations (Table II), insurance or damage-limitation requirements. The prevention of untimely collapse allows evacuation, containment of a fire and therefore protection of adjacent areas, and access for firefighters. This is essential in high-rise buildings. Factors relating to the need for fire resistance are building height and size, occupancy and anticipated fire severity. While a specific period of fire resistance may be specified and an element constructed accordingly, it should not be assumed that the period will be attained; it may be longer or shorter due to, among other factors, interaction with other elements or non-maintenance, or more severe fire conditions than those anticipated in the test.

Guidance is also available in BS 5950 Structural use of steelwork in building. Part 8 Code of practice for fire resistant design.

3.9 Fire compartments

These are formed around areas of different uses or hazards, or to divide an area into a size in which it is considered a fire could be contained and dealt with by firefighters, and thereby protecting adjacent areas. The addition of automatic active measures such as sprinklers to contain and control the growth of a fire allows larger compartments or, in some cases, their omission. If the only consideration is life safety, it can be argued that if all persons can safely escape there is no need for compartmentation, and the potential exists for reduced fire resistance. This principle is often adopted in low-rise or single-storey buildings. However, in the case of high-rise or buildings with phased or staged evacuation, compartmentation is an essential part of the safety package. Flats and maisonettes are constructed such that every unit is a compartment; in the event of a fire it is only necessary initially to evacuate the unit on fire.

Effective compartmentation requires attention to detail. Openings, including those for ventilation and services, must be protected; where shafts perforate compartment floors 'protected shafts' should be detailed, see Table III.

3.10 Recommendations

Compartments within residential, institutional and health buildings require careful consideration as they form an essential part of the scheme for means of escape. All floors should be compartment floors. It is recommended that compartments do not exceed 2000 m^2 in multi-storey hospitals and 3000 m^2 in single-storey hospitals.

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Table I Classification of purpose groups (from Approved Document B, Table DI)

Title	Group	Purpose for which the building or compartment of a building is intended to be used
Residential (dwellings)	1(a)*	Flat or maisonette.
	1(b)**	Dwellinghouse which contains a habitable storey with a floor level which is more than 4.5 m above ground level.
	1(c)**	Dwellinghouse which does not contain a habitable storey with a floor level which is more than 4.5 m above ground level
Residential (Institutional)	2(a)	Hospital, home, school or other similar establishment used as living accommodation for, or for the treatment, care or maintenance of persons suffering from disabilities due to illness or old age or other physical or mental incapacity, or under the age of 5 years, or place of lawful detention, where such persons sleep on the premises.
(Other)	2(b)	Hotel, boarding house, residential college, hall of residence, hostel, and any other residential purpose not described above.
Office	3	Offices or premises used for the purpose of administration, clerical work (including writing, book keeping, sorting papers, filing, typing, duplicating, machine calculating, drawing and the editorial preparation of matter for publication, police and fire and rescue work), handling money (including banking and building society work), and communications (including postal, telegraph and radio communications) or radio, television, film, audio or video recording, or performance (not open to the public) and their control.
Shop and Commercial	4	Shops or premises used for a retail trade or business (including the sale to members of the public of food or drink for immediate consumption and retail by auction, self-selection and over-the-counter wholesale trading, the business of lending books or periodicals for gain and the business of a barber or hairdresser and the rental of storage space to the public) and premises to which the public is invited to deliver or collect goods in connection with their hire repair or other treatment, or (except in the case of repair of motor vehicles) where they themselves may carry out such repairs or other treatments.
Assembly and Recreation	5	Place of assembly, entertainment or recreation; including bingo halls, broadcasting, recording and film studios open to the public, casinos, dance halls; entertainment-conference, exhibition and leisure centres; funfairs and amusement arcades; museums and art galleries; non-residential clubs, theatres, cinemas and concert halls; educational establishments, dancing schools, gymnasia, swimming pool buildings, riding schools, skating rinks, sports pavilions, sports stadia; law courts; churches and other buildings of worship, crematoria; libraries open to the public, nonresidential day centres, clinics, health centres and surgeries; passenger stations and termini for air, rail, road or sea travel; public toilets; zoos and menageries.
Industrial	6	Factories and other premises used for manufacturing, altering, repairing, cleaning, washing, breaking-up, adapting or processing any article; generating power or slaughtering livestock
Storage and other non-residential†	7(a)	Place for the storage or deposit of goods or materials [other than described under 7(b)] and any building not within any of the purpose groups 1 to 6.
	7(b)	Car parks designed to admit and accommodate only cars, motorcycles and passenger or light goods vehicles weighing no more than 2500 kg gross.

*Includes live/work units that meet the provisions of paragraph 2.52 of Volume 2 of Approved Document B.
**Includes any surgeries, consulting rooms, offices or other accommodation, not exceeding 50 m^2 in total, forming part of a dwelling and used by an occupant of the dwelling in a professional or business capacity.
†A detached garage not more than 40 m^2 in area is included in purpose group 1(c); as is a detached open carport of not more than 40 m^2, or a detached building which consists of a garage and open carport where neither the garage nor open carport exceeds 40 m^2 in area.

Table II Minimum periods of fire resistance

Purpose group of building	Minimum periods of fire resistance (minutes) in a:					
	Basement storey[(5)] including floor over			Ground or upper storey		
	Depth (m) of a lowest basement			Height (m) of top floor above ground, in a building or separated part of a building		
	More than 10	Not more than 10	Not more than 5	Not more than 18	Not more than 30	More than 30
1 Residential:						
a. Block of flats						
– not sprinklered	90	60	30*	60**†	90**	Not permitted
– sprinklered	90	60	30*	60**†	90**	120**
b. Institutional	90	60	30*	60	90	120#
c. Other residential	90	60	30*	60	90	120#
2 Office:						
– not sprinklered	90	60	30*	60	90	Not permitted
– sprinklered[(2)]	60	60	30*	30*	60	120#
3 Shop and commercial:						
– not sprinklered	90	60	60	60	90	Not permitted
– sprinklered	60	60	30*	60	60	120#
4 Assembly and recreation:						
– not sprinklered	90	60	60	60	90	Not permitted
– sprinklered	60	60	30*	60	60	120#
5 Industrial:						
– not sprinklered	120	90	60	90	120	Not permitted
– sprinklered[(1)]	90	60	30*	60	90	120#
6 Storage and other non-residential:						
a. any building or part not described elsewhere:						
not sprinklered	120	90	60	90	120	Not permitted
sprinklered[(2)]	90	60	30*	60	90	120#
b. car park for light vehicles:						
i. open sided car park[(3)]	Not applicable	Not applicable	15* +	15* +[(4)]	15* +[(4)]	60
ii. any other car park	90	60	30*	60	90	120#

Single storey buildings are subject to the periods under the heading 'not more than 5'. If they have basements, the basement storeys are subject to the period appropriate to their depth.
$The floor over a basement (or if there is more than 1 basement, the floor over the topmost basement) should meet the provisions for the ground and upper storeys if that period is higher.
*Increased to a minimum of 60 minutes for compartment walls separating buildings.
**Reduced to 30 minutes for any floor within a flat with more than one storey, but not if the floor contributes to the support of the building.
#Reduced to 90 minutes for elements not forming part of the structural frame.
+Increased to 30 minutes for elements protecting the means of escape.
†Refer to paragraph 7.9 regarding the acceptability of 30 minutes in flat conversions.

Notes:
1. Refer to Table A1 for the specific provisions of test.
2. 'Sprinklered' means that the building is fitted throughout with an automatic sprinkler system in accordance with paragraph 0.16.
3. The car park should comply with the relevant provisions in the guidance on requirement B3, Section 11.
4. For the purposes of meeting the Building Regulations, the following types of steel elements are deemed to have satisfied the minimum period of fire resistance of 15 minutes when tested to the European test method:

(i) Beams supporting concrete floors maximum Hp/A = 230 m^{-1} operating under full design load.
(ii) Free standing columns, maximum Hp/A =180 m^{-1} operating under full design load.
(iii) Wind bracing and struts, maximum Hp/A ~ 210 m^{-1} operating under full design load.
Guidance is also available in BS 5950 Structural use of steelwork in building. Part 8 Code of practice for fire resistant design.

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Table III Maximum dimensions of multi-storey non-residential buildings and compartments (from Approved Document B, Table 12)

Purpose group of building or part	Height of floor of top storey above ground level (m)	Floor area of any one storey in the building or any one storey in a compartment (m²)	
		In multi-storey buildings	In single-storey buildings
Office	No limit	No limit	No limit
Assembly and recreation			
Shop and commercial:			
a. Shops – not sprinklered	No limit	2000	2000
Shops – sprinklered[1]	No limit	4000	No limit
b. Elsewhere – not sprinklered	No limit	2000	No limit
Elsewhere – sprinklered[1]	No limit	4000	No limit
Industrial[2]			
Not sprinklered	Not more than 18	7000	No limit
	More than 18	2000[3]	N/A
Sprinklered[1]	Not more than 18	14,000	No limit
	More than 18	4000[3]	N/A

	Height of floor of top storey above ground level (m)	Maximum compartment volume m³	Maximum floor area (m²)	Maximum height (m)[4]
		Multi-storey buildings	Single-storey buildings	
Storage[2] and other non-residential:				
a. Car park for light vehicles	No limit	No limit	No limit	No limit
b. Any other building or part:				
Not sprinklered	Not more than 18	20,000	20,000	18
	More than 18	4000[3]	N/A	N/A
Sprinklered[1]	Not more than 18	40,000	No limit	No limit
	More than 18	8000[3]		

Notes

[1] 'Sprinklered' means that the building is fitted throughout with an automatic sprinkler in accordance with paragraph 0.16.

[2] There may be additional limitations on floor area and/or sprinkler provisions in certain industrial and storage uses under other legislation, for example in respect of storage of LPG and certain chemicals.

[3] This reduced limit applies only to storeys that are more than 18 m above ground level. Below this height the higher limit applies.

[4] Compartment height is measured from finished floor level to underside of roof or ceiling.

In non-residential buildings floors over and generally within basements and any floor at a height of 30 m above ground level should be constructed as compartment floors.

3.11 Growth

To limit the growth of fire within the main structural elements is generally relatively easy provided that they do not contain large voids. The addition of linings and claddings can facilitate the rapid spread of fire beyond its area of origin. Flame can spread quickly in all directions and fixings are important. It has been found by experiment that the better the material is as an insulator, the greater the likelihood that flame spread will be more rapid and further.

3.12 Surface spread of flame

This is generally tested in accordance with BS 476 Part 7 1971, the results being classified 1 to 4 (Class 1 being very good, Class 4 very poor) on the basis of flame spread from the point of ignition. Class 0 is a classification defined for the purposes of recommendations under the building regulations (not a British Standard). Current codes vary in their recommendations but generally all escape routes and circulation spaces should have Class 0, all other areas other than small rooms Class 1.

3.13 Ventilation

Ventilation to release heat and control and/or dispel smoke from a fire will allow easier and rapid access by fire fighters to extinguish a fire. Its relationship to means of escape is outlined elsewhere.

Ventilation can be natural or mechanical. The latter is preferable as it is controllable, can be activated automatically and, when designed correctly, not influenced by wind, internal layout and configurations, outside temperature or stack effect. It does, however, add considerable cost, as it is necessary to safeguard its operation by using fans tolerant of high temperatures, protected wiring, fire and smoke dampers, automatic detection, secondary power supplies and monitoring. It may require sophisticated computerised controls.

3.14 Mechanical extraction systems

Opinions vary on the design of mechanical smoke extract systems, and the need or otherwise to incorporate fail-safe measures. It is necessary to determine if the system is for smoke extraction or smoke control. There is no generally accepted comprehensive code for mechanical smoke control systems; specialist advice should be sought.

3.15 Natural ventilation

Natural ventilation by the provision of open, openable or breakable vents is usually intended for operation by firefighters who will take into consideration aspects of wind etc. Openings should aggregate not less than 5 per cent of a total floor area within basements and areas of high or special risk, and 2.5 per cent above ground. If vents are not accessible, they should be permanent, open automatically or open by remote control.

3.16 Smoke reservoirs

The use of natural ventilation in large open areas such as single-storey factories, auditoria, exhibition halls and the like will necessitate the formation of smoke reservoirs to restrict the spread of smoke. See BRE publications Digest 260, *Smoke control in buildings: design principles* and BR 186 *Design principles for smoke ventilation in enclosed shopping centres.*

3.17 Access

Specific access for firefighters will allow their prompt action. Access is required up to, into and through a building. Various dimensional information is given in Table IV but it should be

Table IV Fire service vehicle access to buildings not fitted with fire mains (from Approved Document B, Table 19)

Total floor area of building (m²)	Height of floor of top storey above ground	Provide vehicle access to:	Type of appliance
up to 2000	up to 11	see paragraph 16.2	pump
	over 11	15% of perimeter	high reach
2000–8000	up to 11	15% of perimeter	pump
	over 11	50% of perimeter	high reach
8000–16,000	up to 11	50% of perimeter	pump
	over 11	50% of perimeter	high reach
16,000–24,000	up to 11	75% of perimeter	pump
	over 11	75% of perimeter	high reach
over 24,000	up to11	100% of perimeter	pump
	over 11	100% of perimeter	high reach

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remembered that fire equipment is not standardised; it is also constantly changing, giving many variations in sizes and weights.

If a building is provided with a fire main, access is required to within 18 m of the inlet to a dry riser or the access to a firefighting shaft containing a wet riser. The setdown point should be within sight of the dry riser inlet or shaft access.

No appliances should have to reverse more than 20 m. Dead-end roads should be provided with hammerhead turning spaces if longer than this, see Tables IV, V and VI and Figures 11.2 to 11.5.

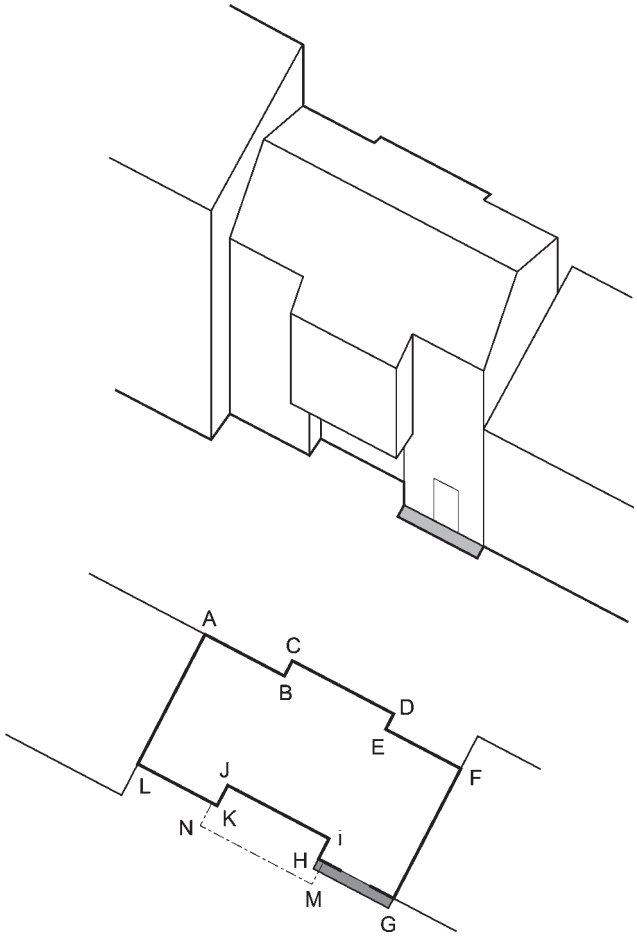
3.18 Firefighting shafts

Access into the building should be provided via a firefighting shaft. In the cases of all buildings and those with deep basements this should incorporate a firefighting lift to transport equipment and personnel at speed. In all cases it should include a staircase 1.1 m in width between walls or balustrades, ventilated or pressurised, entered from the floor areas via a lobby, both of which are separated from the remainder of the building by 2-hour fire-resisting construction. BS 5588 Part 5 details the technical and dimensional specification for a firefighting shaft. The criteria for the provision and number of shafts in any particular building are set out in that part of the BS 5888 series relating to the specific use or within Building Regulations. A firefighting lift can be one normally used for passengers; it should not be one used as a goods lift, see Figures 11.6 and 11.7.

Table V Typical vehicle access route specification (from Approved Document B, Table 20)

Appliance type	Minimum width of road between kerbs (m)	Minimum width of gateways (m)	Minimum turning circle between kerbs (m)	Minimum turning circle between walls (m)	Minimum clearance height (m)	Minimum carrying capacity (tonnes)
Pump	3.7	3.1	16.8	19.2	3.7	12.5
High Reach	3.7	3.1	26.0	29.0	4.0	17.0

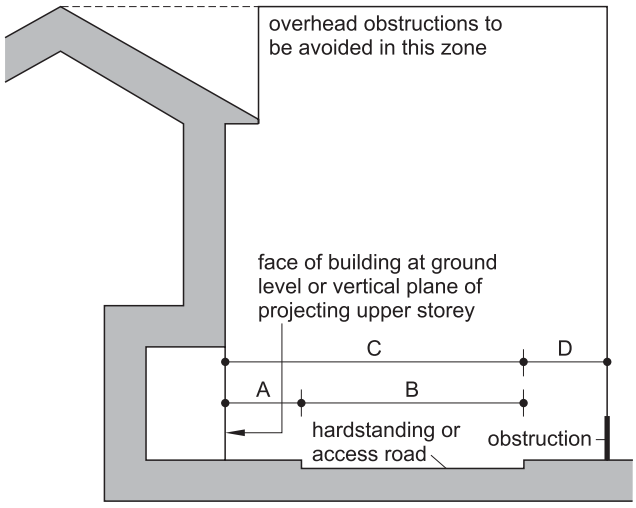
Notes:
(1) Fire appliances are not standardised. Some fire services have appliances of greater weight or different size. In consultation with the Fire Authority, Building Control Authorities and Approved Inspectors may adopt other dimensions in such circumstances.
(2) Because the weight of high-reach appliances is distributed over a number of axles, it is considered that their infrequent use of a carriageway or route designed to 12.5 tonnes should not cause damage. It would therefore be reasonable to design the roadbase to 12.5 tonnes, although structures such as bridges should have the full 17 tonnes capacity.



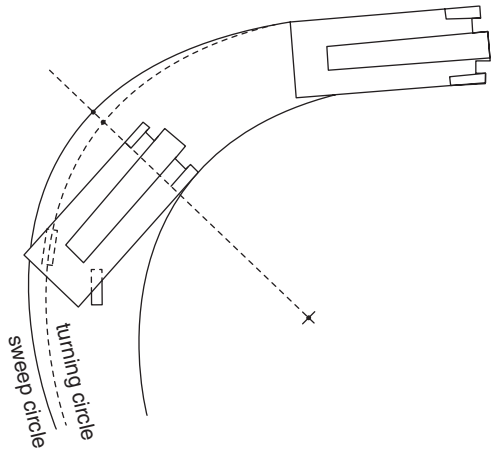
11.2 *Example of building footprint and perimeter. The building is AFGL where walls AL and FG are shared with other buildings. The footprint is the maximum aggregate plan perimeter found by the vertical projection of any overhanging storey onto a ground storey: i.e. ABCDEFGHMNKL. The perimeter for the purposes of the table is the sum of the lengths of the two external walls taking account of the footprint, i.e. (A to B to C to D to E to F) + (G to H to M to N to K to L). If the dimensions of the building require vehicular access by the table, the shaded area illustrates a possible example of 15% of the perimeter. Note that there should be a door into the building in this length. If the building has no walls common with other buildings, the lengths AL and FG would be included in the perimeter. From Approved Document Part B 2006*

Table VI Dimensions required for fire appliances (see Figure 11.3)

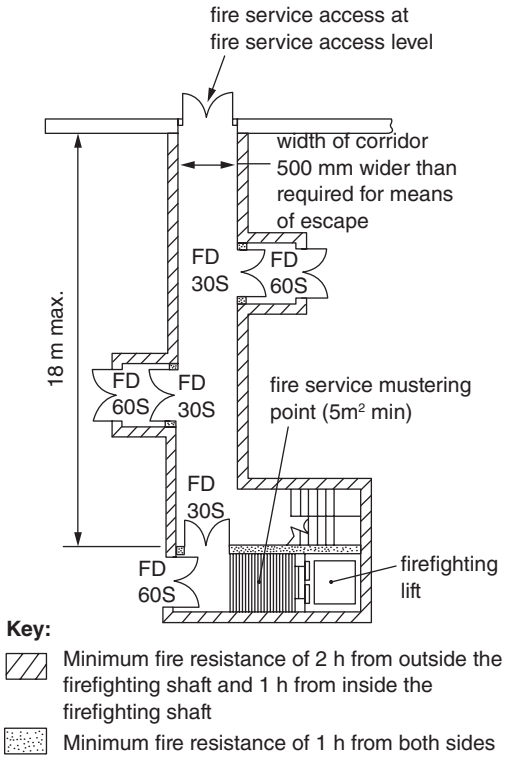
Dimension	Description	Type of appliance	
		Turntable ladder	Hydraulic platform
A	Maximum distance of near edge of hardstanding from building	4.9m	2.0 m
B	Minimum width of hardstanding	5.0m	5.5 m
C	Minimum distance of further edge of hardstanding from building	10.0m	7.5 m
D	Minimum width of unobstructed space for swing of appliance platform	NA	2.2m



11.3 *Relationship between building and hardstanding or access roads for high-reach fire appliances. For key, see Table VI. From Approved Document Part B 2006*



11.4 *A pumping appliance (drawing not to scale) Max length 8.5 m, max height 3.3 m, max width 2.3 m, max weight 13.21 ts, on front axle 5.5 ts, on rear axle 6.1 ts, max wheelbase 3.81 m, rear wheel track 2 m, ground clearance 229 mm, roadway width required 3.66m, turning circle 16.75 m, sweep circle 18.3 m*



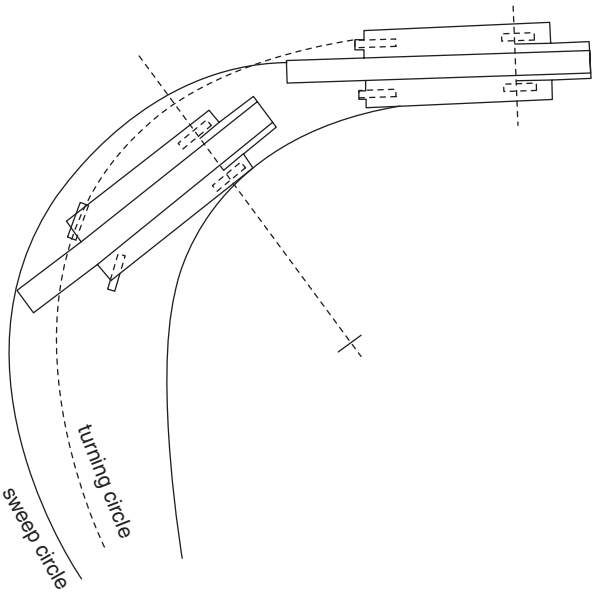
11.6 *Typical firefighting shaft layout at fire service access level, access via a corridor*

3.19 Spread

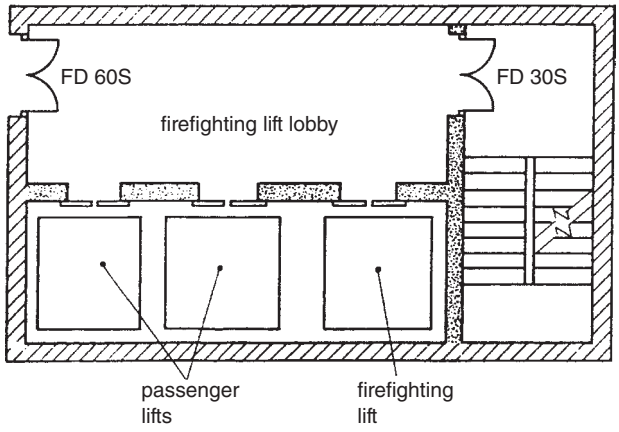
The spread of fire to adjacent buildings can be prevented by:

- clear space
- fire-resisting walls
- external walls of limited combustibility and limited surface spread of flame, and/or
- roof coverings resistant to penetration of fire.

If precautions are taken within a building to limit a fire's growth and spread, it can be assumed that its effects on an adjacent building are reduced. Openings in an external wall or walls having no fire resistance present weaknesses to an adjoining building by radiation and convection. If property protection in addition to life safety is a consideration, then all buildings should be considered as being of equal risk.



11.5 *A hydraulic platform and turntable ladders (drawing not to scale) max length 10 m, max height 3.5 m, max width 2.5 m, max width with jacks out 4.4 m, laden weight 16.25 t, av. weight front axle 6 t, av. weight rear axle 10 t, max wheelbase 5.33 m, rear wheel track 2 m, min ground clearance 229 mm, road width required 6m, turning circle 21.5m, sweep circle 24.5 m. The overhang of the booms on the headrest do not exceed 1.83 m from foremost part of the vehicle. Turntable ladders and hydraulic platforms ('cherry-pickers') are fitted with four ground jacks as stabilisers, for which the working load is normally less than 7.5 t*



11.7 *Passenger lifts within the firefighting shaft. Firefighting lobbies should have a clear floor area of not less than 5 m². The clear floor area should not exceed 20 m² for lobbies serving up to four lifts, or 5 m² per lift for lobbies serving more. All principal dimensions should be not less than 1.5 m and should not exceed 8 m in lobbies serving up to four lifts, or 2 m per lift in lobbies serving more*

If life safety is the only factor, then residential, assembly and recreational uses are at greater risk from external fire sources and warrant additional safeguards. It is generally assumed that only one compartment is involved in a fire and as such the risk emanates only from its external enclosures.

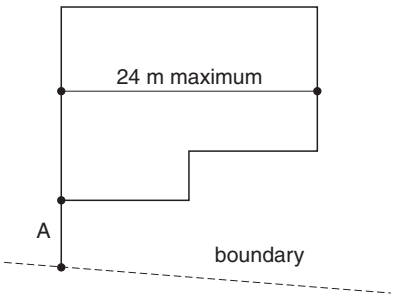
3.20 Protection

Methods generally used for determining the necessary degrees of protection are based on acceptable percentages of 'unprotected areas' (openings, non-fire-resisting walls, combustible claddings and insulation) having regard to heat radiation exposure from a

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Table VII Unprotected areas for small residential buildings. See Figure 11.8 (from Approved Document B, Vol 1, Diagram 22)

Minimum distance (A) between side of building and relevant boundary (m)	Maximum total area of unprotected areas (m^2)
1	5.6
2	12
3	18
4	24
5	30
6	no limit



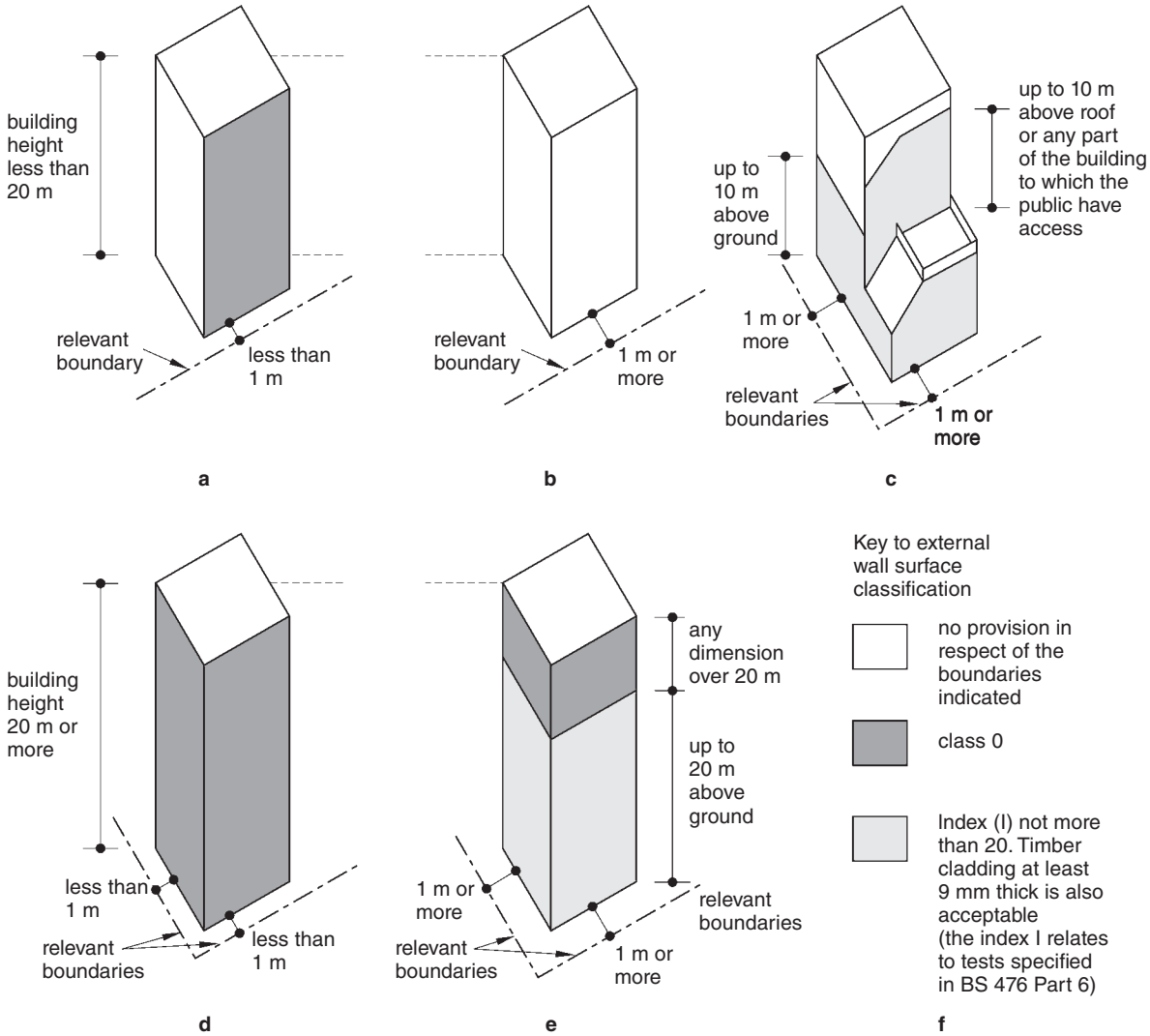
11.8 *Permitted unprotected areas in small residential buildings*

Table VIII Permitted unprotected areas in small buildings or compartments (from Approved Document B, Table 15)

Minimum distance between side of building and relevant boundary (m)		
Purpose groups Residential, Office, Assembly and Recreation	Shop and Commercial Industrial, storage and other Non-residential	Maximum total percentage of unprotected area (%)
(1)	(2)	(3)
n.a	1	4
1.0	2	8
2.5	5	20
5.0	10	40
7.5	15	60
10.0	20	80
12.5	25	100

Notes:
n.a. 1/4 not applicable.
(1) intermediate values may be obtained by interpolation.
(2) For buildings which are fitted throughout with an automatic sprinkler system, meeting the relevant recommendations of BS 5306 Part 2, the values in columns (1) and (2) may be halved, subject to a minimum distance of 1 m being maintained.
(3) In the case of open-sided car parks in purpose group 7(b) the distances set out in column (1) may be used instead of those in column (2).

known use. The basis of the necessary calculations is set out in BRE document BRE 187 *External fire spread: building separation and boundary distances*; Approved Document B makes recommendations in relation to small buildings or compartments, both residential in Table VII and Figure 11.8 and non-residential in Table VIII.



11.9 *Provisions for external surfaces of walls. a Any building. b Any building other than as shown in c. c Assembly or recreational building of more than one storey. d Any building. e Any building. f Key to external wall surface classification*

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3.21 Cladding

Combustible claddings and insulation present a risk, especially in tall buildings. While claddings and their supports are not always required to be fire-resisting, insulation at a height exceeding 15 m is recommended to be of limited combustibility, Figure 11.9.

Table IX Limitations on roof coverings* (from Approved Document B, Table 16)

Designation† of covering of roof or part of roof		Minimum distance from any point on relevant boundary			
National class	**European class**	**Less than 6 m**	**At least 6 m**	**At least 12 m**	**At least 20 m**
AA, AB or AC	BROOF(t4)	•	•	•	•
BA, BB or BC	CROOF(t4)	○	•	•	•
CA, CB or CC	DROOF(t4)	○	•(1)(2)	•(1)	•
AD, BD or CD	EROOF(t4)	○	•(1)(2)	•(1)	•(1)
DA, DB, DC or DD	FROOF(t4)	○	○	○	•(1)(2)

Notes:

*See paragraph 14.8 for limitations on glass; paragraph 14.9 for limitations on thatch and wood shingles; and paragraphs 14.6 and 14.7 and Tables 18 and 19 for limitations on plastic rooflights.

†The designation of external roof surfaces is explained in Appendix A. (See Table A5, for notional designations of roof coverings.)

Separation distances do not apply to the boundary between roofs of a pair of semidetached houses (see 14.5) and to enclosed/covered walkways. However, see Diagram 30 if the roof passes over the top of a compartment wall. Polycarbonate and PVC rooflights which achieve a Class 1 rating by test, see paragraph 15.7, may be regarded as having an AA designation.

Openable polycarbonate and PVC rooflights which achieve a Class 1 (National class) or Class C-s3, d2 (European class) rating by test, see paragraph 10.7, may be regarded as having an AA (National class) designation or BROOF(t4) (European class) classification.

- • Acceptable.
- ○ Not acceptable.

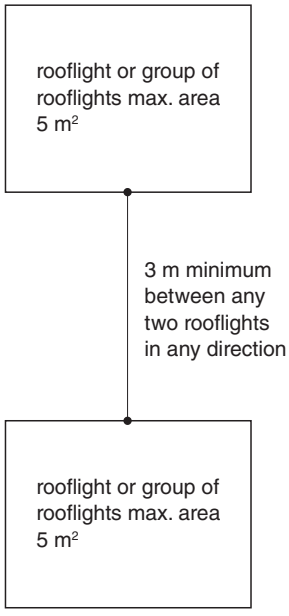
[1]Not acceptable on any of the following buildings:

a. Houses in terraces of three or more houses.
b. Industrial, storage or other non-residential Purpose Group buildings of any size.
c. Any other buildings with a cubic capacity of more than 1500 m^3.

[2]Acceptable on buildings not listed in Note 1, if part of the roof is no more than 3 m^2 in area and is at least 1500 mm from any similar part, with the roof between the parts covered with a material of limited combustibility.

3.22 Roof coverings

Roof coverings (not structures) in close proximity to boundaries should have limited flame spread and penetration to fire. The performance of coverings is designated by reference to BS 476 Part 3 which classifies the results on the flame spread and time taken to penetrate: AA being the best (specimen not penetrated within one hour, no spread of flame), DD the worst (penetrated in preliminary flame test, extensive and continuing spread of flame). The addition of a suffix 'x' denotes one or more of dripping from the underside, mechanical failure, development of holes. Approved Document B sets out specific classification recommendations relating to distances from the boundary, see Table IX together with recommendation for plastic rooflights, Figure 11.10 and Table X.



11.10 *Limitations on spacing and size of plastic rooflights having a Class 3 or TP(b) lower surface: see Table IX. Note: the surrounding roof covering should be of limited combustibility for at least 3 m*

4 MEANS OF ESCAPE

4.1 General

There are numerous codes and guides relating to means of escape from various uses, some of which, as they have evolved, have overlapped and derived different recommendations for the same matters. Occasionally, they include matters outside those of life safety. Generally, means of escape is the provision of safe routes for persons to travel from any point in a building to a place of safety.

4.2 Fire engineering

At the time of writing, various aspects of fire safety, particularly the basis on which adopted standards and practices are founded, are under review. However, there is nothing to stop an alternative, innovative or unorthodox approach to means of escape being adopted. Fire-engineering solutions may be used where the established practices are unsuitable; methods such as smoke control and automatic detection and suppression can be used to evolve a package of safety measures for a specific user and building design requirements. It should be noted that a change in specific user may require a reassessment of the fire safety provisions.

4.3 Tailored solutions

Whatever method is adopted, the means of escape must be tailored to the individual occupancy and building. Where a project is speculative a judgement must be made as to the necessary provisions for means of escape: to assume the worst case may not be feasible, although it will result in a level of provision acceptable for the majority of occupancies. In the case of designs such as atria, persons should be at no greater risk than those in a nonatrium building.

4.4 Basic principles

The aim is to make provision such that escape can take place unaided. The occupants of some buildings, however, will not be able to achieve this. There are certain basic principles and provisions accepted as necessary for the provision of minimum means of escape. These are:

- Exits and escape routes of adequate number and width within a reasonable distance of all points in the building
- An alternative means of escape (in the majority of cases)
- Protected escape routes where necessary
- Lighting and directional signage
- Readily openable exit doors
- Smoke control to safeguard escape routes
- Separation of high or special risks

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Table X Plastics rooflights: limitations on use and boundary distance (from Approved Document B)

Minimum classification on lower surface	Space which rooflight can serve	Minimum distance from any point on relevant boundary to rooflight with an external designation of: AD BD CD (National class) or E_{ROOF}(t4) (European class) CA CB CC or D_{ROOF}(t4) (European class)	DA DB DC DD (National class) or F_{ROOF}(t4) (European class)
Class 3	a. Balcony, verandah, carport, covered way or loading bay, which has at least one longer side wholly or permanently open b. Detached swimming pool c. Conservatory, garage or outbuilding, with a maximum floor area of 40m²	6m	20m
	d. Circulation space (except a protected stairway) e. Room	6m	20m
		Minimum distance from any point on relevant boundary to rooflight with an external surface classification of:	
		TP(a)	**TP(b)**
1. TP(a) rigid	Any space except a protected stairway	6m	Not applicable
2. TP(b)	a. Balcony, verandah, carport, covered way or loading bay, which has at least one longer side wholly or permanently open b. Detached swimming pool c. Conservatory, garage or outbuilding, with a maximum floor area of 40m²	Not applicable	6m
	d. Circulation space (except a protected stairway) e. Room	Not applicable	6m

- Access for fire brigade to attack the seat of a fire swiftly for protection of life
- Audible/visual warning of fire and active measures
- First aid fire appliances
- Instruction of action to be taken in the event of a fire and evacuation procedure.

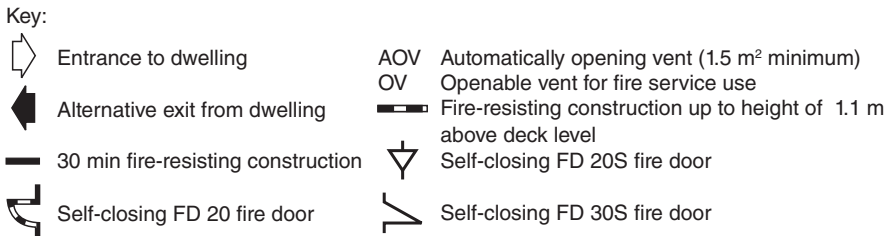
The last three items are additional to structural provision for means of escape. However, some procedures for evacuation and the life safety systems associated with certain designs of building, e.g. atria and shopping malls, and certain uses, e.g. hospitals, necessitate the utilisation of active measures to provide effective means of escape-pressurisation/depressurisation of escape routes to control smoke, automatic detection by heat and smoke detectors, etc.

4.5 Flats and maisonettes

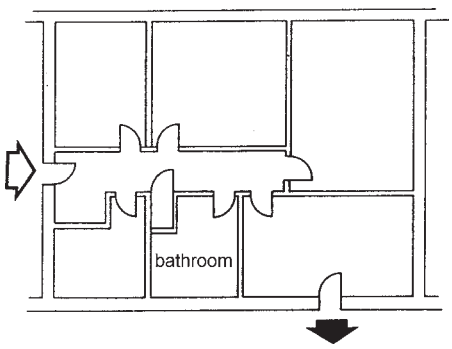
The concept for escape from flats and maisonettes differs from that of other uses. This is based on the high standard of compartmentation and separation recommended in Approved Documents Part B, in particular B3 *Internal Fire Spread (structure)*. Major factors are difficulties in alerting the population of the block to a fire (fire alarms in this situation being a potential source of acute nuisance), and also in ensuring that everyone in fact is evacuated.

4.6 Containment

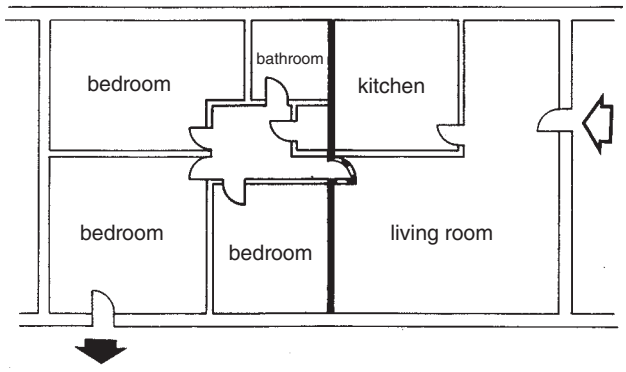
Each residential unit is a separate fire compartment, and it is considered only necessary initially to evacuate the unit on fire. Consequently the necessary width of escape exits and routes may be minimalised. The spread of fire and smoke is controlled under the principles of smoke containment. As it has been shown that most fires are containable within the room of origin, the current edition of BS 5588 Part 1 (*Code of practice for residential buildings*) and Approved Document B have reduced the recommendations relating to fire separation within the unit from those previously given. The travel distance, any alternative means of escape and the layout dictate the level of internal protection necessary, which influences the common area protection, see Figures 11.11 to 11.35.



11.11 *Key to following drawings 11.12 to 11.35*

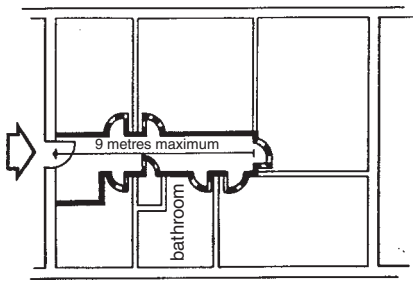


11.12 *Flat with alternative exit and where all habitable rooms have direct access to an entrance hall*

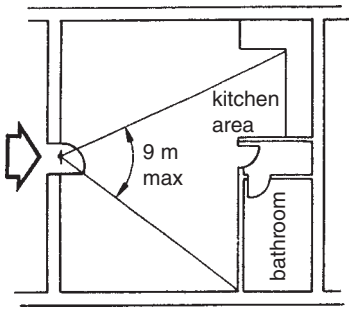


11.13 *Flat with alternative exit and where all habitable rooms do not have direct access to an entrance hall. The fire-resisting partition separates living and sleeping accommodation*

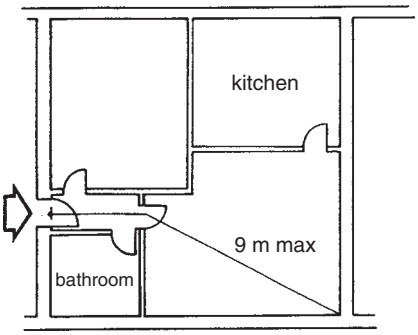
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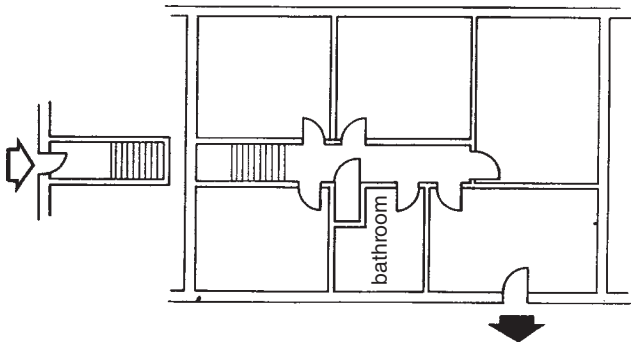
11.14 *Flat with a protected entrance hall and restricted travel distance. If the partitions between bathroom and adjacent rooms have 30 minutes fire resistance, then the partition between it and the entrance hall need not be fire-resisting and its door need not be a fire door. The cupboard door need not be self-closing*



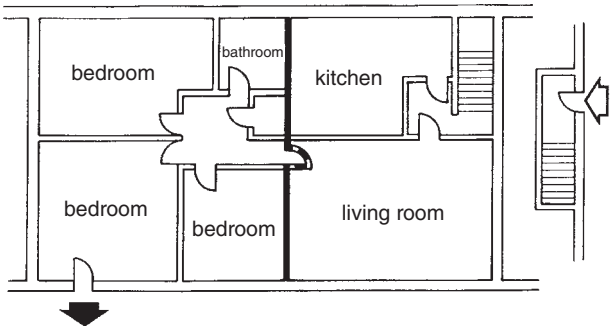
11.15 *Open-plan flat (bed-sitter) with restricted travel distance*



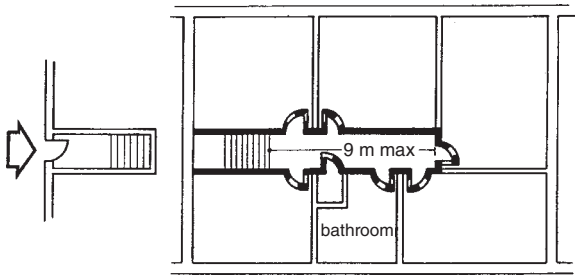
11.16 *Flat with separate habitable rooms and restricted travel distance*



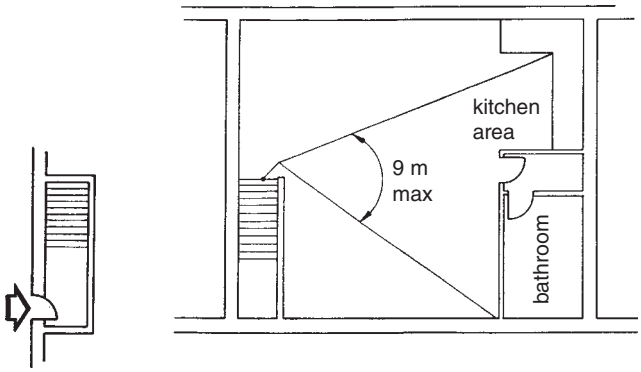
11.17 *Flat entered from above or below with an alternative exit and where all habitable rooms have direct access to an entrance hall*



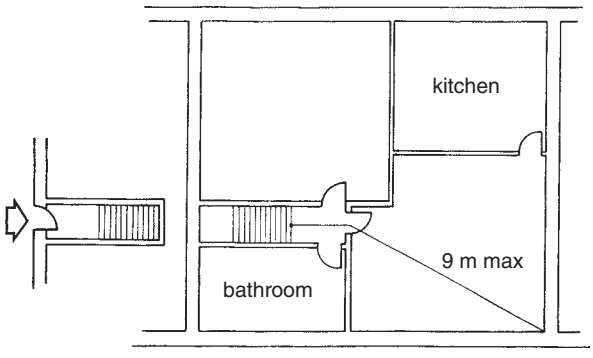
11.18 *Flat entered from above or below with an alternative exit and where all habitable rooms do not have direct access to an entrance hall. The fire-resisting partition separates living and sleeping accommodation*



11.19 *Flat entered from below with a protected entrance and restricted travel distance. If the partitions between bathroom and adjacent rooms have 30 minutes fire resistance, then the partition between it and the entrance hall need not be fire-resisting and its door need not be a fire door. The cupboard door need not be self-closing*



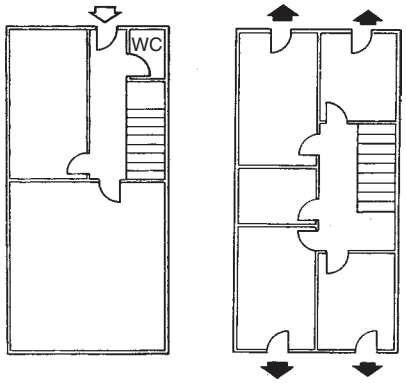
11.20 *Open-plan flat (bed-sitter) entered from below with a restricted travel distance*



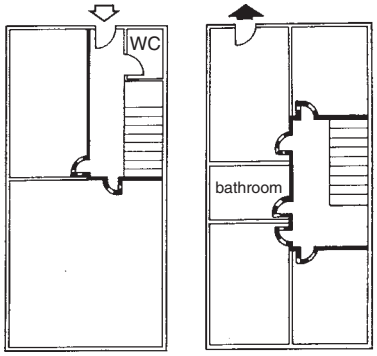
11.21 *Flat with separate habitable rooms entered from below with a restricted travel distance*

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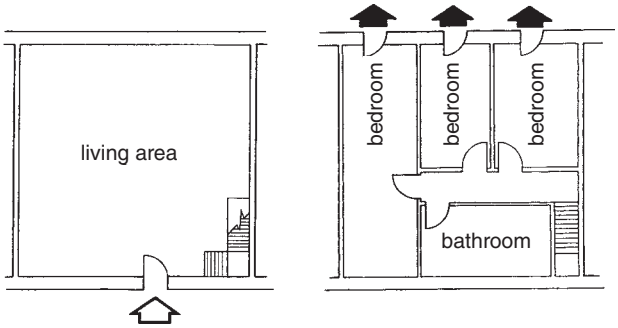
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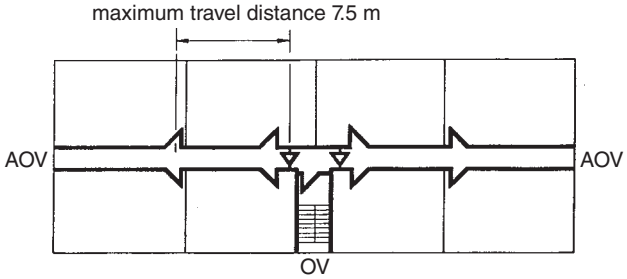
11.22 *Maisonette with alternative exits from each room not on the entrance floor level*



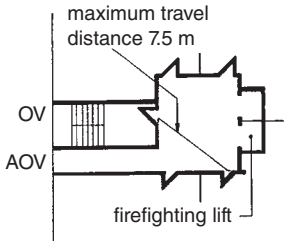
11.23 *Maisonette with protected entrance floor and landing. If the partitions between bathroom and adjacent rooms have 30 minutes fire resistance, then the partition between it and the entrance hall need not be fire-resisting and its door need not be a fire door*



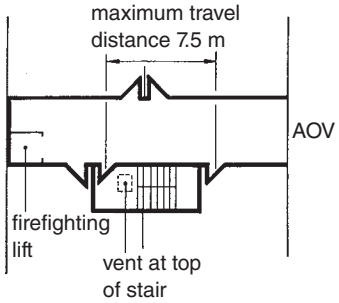
11.24 *Open-plan maisonette*



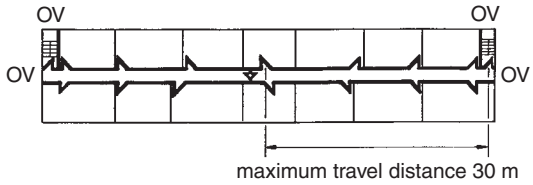
11.25 *Common escape routes in single stair buildings more than 11 m high with corridor access dwellings. Where all dwellings on a storey have independent alternative means of escape, the maximum travel distance may be increased to 30 m. Where a firefighting lift is required, it should be sited not more than 7.5 m from the door to the stair. The openable vents (OVs) to the stairway may be replaced by an openable vent over the stair*



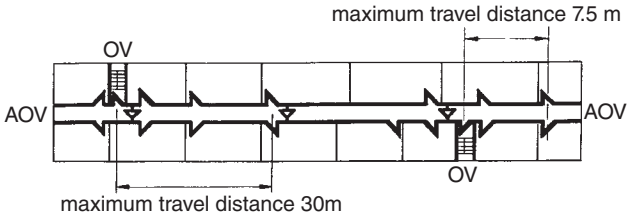
11.26 *Common escape routes in single stair tower blocks more than 11 in high, with the stair adjacent to an external wall. See riders to Figure 11.25*



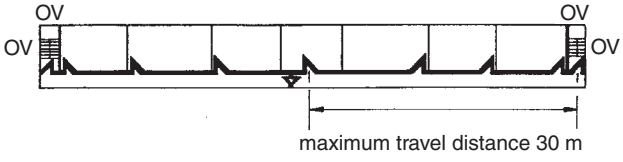
11.27 *Common escape routes in single stair tower blocks more than 11 m high with internal stair. See riders to Figure 11.25*



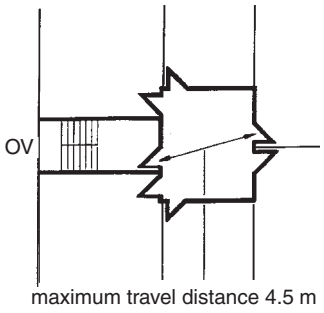
11.28 *Common escape routes in multi-stair buildings with corridor access dwellings and no dead-ends*



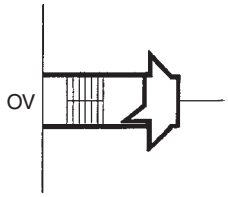
11.29 *Common escape routes in multi-stair buildings with corridor access dwellings and with dead-ends. The central fire door may be omitted where the maximum travel distance does not exceed 15m*



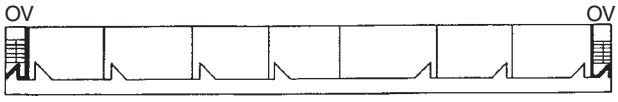
11.30 *Common escape routes in multi-stair buildings with corridor access dwellings on one side only*



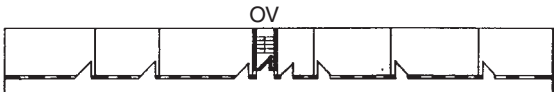
11.31 *Common escape routes in small single-stair buildings*



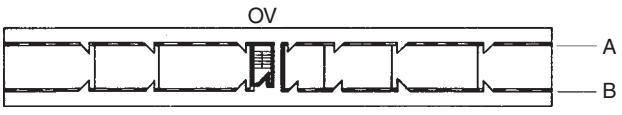
11.32 *Common escape routes in small single-stair buildings with not more than two dwellings per storey. The door between the stair and lobby should be free from security fastenings. Where the dwellings have protected entrance halls, the separation between the stair and the dwelling entrance doors is not necessary*



11.33 *Common escape routes in balcony/deck approach multi-stair buildings*



11.34 *Common escape routes in balcony/deck approach single-stair buildings*



11.35 *Common escape routes in balcony/deck approach single-stair buildings with an alternative exit from each dwelling. One of the external enclosures A or B must be fire resisting*

4.7 Offices and shops

Parts 2 and 3 of BS 5588 (*Fire precautions in the design, construction and use of buildings*) deal with offices and shops respectively.

4.8 Number of exits and escape routes

In order to determine the number of exits from a room or storey, their occupancy must be established. This may be known, or it can be assessed by the use of recognised space factors for specific uses. These are only indicators and can be varied. These numbers will also affect the width of escape routes. In existing buildings the width of doors, stairways, passages etc., if not to be altered, will dictate the numbers of people that can be accommodated, see Tables XI, XII and XIII:

$$\text{Occupancy} = \frac{\text{Area of room or storey (m}^2\text{)}}{\text{Floor space per person (m}^2\text{)}}$$

Table XI Floor space factors[1] (from Approved Document B, Volume 2, Table C1)

	Type of accommodation[2][3]	Floor space factor m²/person
1	Standing spectator areas, bar areas (within 2 m of serving point) similar refreshment areas	0.3
2	Amusement arcade, assembly hall (including a general purpose place of assembly), bingo hall, club, crush hall, dance floor or hall, venue for pop concert and similar events and bar areas without fixed seating	0.5
3	Concourse, queuing area or shopping mall[4][5]	0.7
4	Committee room, common room, conference room, dining room, licensed betting office (public area), lounge or bar (other than in 1 above), meeting room, reading room, restaurant, staff room or waiting room[6]	1.0
5	Exhibition hall or studio (film, radio, television, recording)	1.5
6	Skating rink	2.0
7	Shop sales area[7]	2.0
8	Art gallery, dormitory, factory production area, museum or workshop	5.0
9	Office	6.0
10	Shop sales area[8]	7.0
11	Kitchen or library	7.0
12	Bedroom or study-bedroom	8.0
13	Bed-sitting room, billiards or snooker room or hall	10.0
14	Storage and warehousing	30.0
15	Car park	Two persons per parking space

Notes:

[1]As an alternative to using the values in the table, the floor space factor may be determined by reference to actual data taken from similar premises. Where appropriate, the data should reflect the average occupant density at a peak trading time of year.

[2]Where accommodation is not directly covered by the descriptions given, a reasonable value based on a similar use may be selected.

[3]Where any part of the building is to be used for more than one type of accommodation, the most onerous factor(s) should be applied. Where the building contains different types of accommodation, the occupancy of each different area should be calculated using the relevant space factor.

[4]Refer to section 4 of BS 5588-10:1991 Code of practice for shopping complexes for detailed guidance on the calculation of occupancy in common public areas in shopping complexes.

[5]For detailed guidance on appropriate floor space factors for concourses in sports grounds refer to 'Concourses' published by the Football Licensing Authority (ISBN: 0 95462 932 9).

[6]Alternatively the occupant capacity may be taken as the number of fixed seats provided, if the occupants will normally be seated.

[7]Shops excluding those under item 10, but including – supermarkets and department stores (main sales areas), shops for personal services such as hairdressing and shops for the delivery or collection of goods for cleaning, repair or other treatment or for members of the public themselves carrying out such cleaning, repair or other treatment.

[8]Shops (excluding those in covered shopping complexes but including department stores) trading predominantly in furniture, floor coverings, cycles, prams, large domestic appliances or other bulky goods, or trading on a wholesale self-selection basis (cash and carry).

Table XII Floor space factors for assembly buildings (from BS 5588: Part 6, Table 3)

	Description of floor space	Floor space per person (m²)
1	Individual seating	0.4 to 0.5
2	Bench seating	0.3[1]
3	Dance area	0.5
4	Ice rinks	1.2
5	Restaurants and similar table and chair arrangements around a dance area	1.1 to 1.5
6	Bars without seating and similar refreshment areas	0.3
7	Standing spectator areas	0.3
8	Exhibition	1.5[2]
9	Bowling alley, billiard or snooker hall	9.5
10	Museum/art gallery	5.0
11	Studio (radio, television, film, recording)	1.4

[1]If the number and length of benches is known, a factor of 450 mm per person should be used.

[2]Alternatively, a factor of 0.4 m² may be used over the gross area of gangways and other clear circulation space between stalls and stands.

Note. These floor space factors are for guidance only and should not be taken as the only acceptable densities. Where the number of seats is known this should be used in preference to the floor space factors.

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Table XIII Capacities of exits in shopping complexes other than from malls (from BS 5588 Part 10, Table 3)

Maximum number of persons	Width (mm)
50	800
110	900
220	1100
240	1200
260	1300
280	1400
300	1500
320	1600
340	1700
360	1800

1. Other values of width for a maximum number of persons greater than 220 may be obtained by linear interpolation or extrapolation.
2. For the purposes of this table, the width of a doorway is that of the leaf or leaves, and the width of a passage is between the sides at shoulder level (that is about 1.5 m above finished floor level).

Table XIV Widths of escape routes and exits (from Approved Document B, Table 4)

Maximum number of persons	Minimum width mm
50	750
110	850
220	1050
more than 220	5 per person

4.9 Occupancy

Once the occupancy factor for an area is known the number of exits must equate to the necessary total width of escape required, although a minimum number of exits is specified within Approved Document B and Part 6 of BS 5588 (assembly buildings). Not less than two exits should be provided, except in the case of an occupancy of less than 50, or a small storey with a limited travel distance ('dead end').

4.10 Capacities

The capacities of exits are given in various tables. Most recommendations equate to approximately 40 persons passing through a unit width of 500 mm in 2 1/2 minutes. While not all exits need be of equal width, they should be evenly distributed to provide alternatives. Where there are two or more exits, it is assumed that fire may affect one of them, therefore the largest exit should be discounted. Hence the total number of exits = calculated number +1, see Table XIV.

4.11 Travel distances

Alternatively, the number of exits may be determined by recommended travel distances, i.e. the actual distance to be travelled to the nearest exit, having regard to obstructions such as partitions. The distances currently recommended are historical, based on experience and accepted practice. They are not sacrosanct, but should be shorter rather than longer. Extension of travel distances may be justified where compensatory factors such as smoke control systems or early warning of fire is provided. Only one exit need be within the travel distance, alternatives may be at any distance, see Tables XV to XVIII.

4.12 Alternative means of escape

A person should be able in most circumstances to turn their back on a fire and walk to an alternative exit. If escape is in one direction only, an exit or alternative escape route should be near enough for people to reach it before being affected by heat and smoke. The Scottish Building Regulations and the Home Office Guide for

Table XV Limitations on travel distance (from Approved Document B, Volume 2, Table 2)

Purpose group	Use of the premises or part of the premises		Maximum travel distance[1] where travel is possible in: One direction only (m) M	More than one direction (m)
2(a)	Institutional		9	18
2(b)	Other residential:			
	a. in bedrooms[2]		9	18
	b. in bedroom corridors		9	35
	c. elsewhere		18	35
3	Office		18	45
4	Shop and commercial[3]		18[4]	45
5	Assembly and recreation:			
	a. buildings primarily for disabled people		9	18
	b. areas with seating in rows		15	32
	c. elsewhere		18	45
6	Industrial[5]	Normal Hazard	25	45
		Higher Hazard	12	25
7	Storage and other non-residential[5]	Normal Hazard	25	45
		Higher Hazard	12	25
2–7	Place of special fire hazard[6]		9[7]	18[7]
2–7	Plant room or rooftop plant:			
	a. distance within the room		9	35
	b. escape route not in open air (overall travel distance)		18	45
	c. escape route in open air (overall travel distance)		60	100

Notes:
[1]The dimensions in the Table are travel distances. If the internal layout of partitions, fittings, etc. is not known when plans are deposited, direct distances may be used for assessment. The direct distance is taken as 2/3rds of the travel distance.
[2]Maximum part of travel distance within the room. (This limit applies within the bedroom (and any associated dressing room, bathroom or sitting room, etc.) and is measured to the door to the protected corridor serving the room or suite. Sub-item (b) applies from that point along the bedroom corridor to a storey exit.)
[3]Maximum travel distances within shopping malls are given in BS 5588: Part 10. Guidance on associated smoke control measures is given in a BRE report *Design methodologies for smoke and heat exhaust ventilation* (BR 368).
[4]BS 5588: Part 10 applies more restrictive provisions to units with only one exit in covered shopping complexes.
[5]In industrial and storage buildings the appropriate travel distance depends on the level of fire hazard associated with the processes and materials being used. Higher hazard includes manufacturing, processing or storage of significant amounts of hazardous goods or materials, including: any compressed, liquefied or dissolved gas, any substance which becomes dangerous by interaction with either air or water, any liquid substance with a flash point below 65°C including whisky or other spirituous liquor, any corrosive substance, any oxidising agent, any substance liable to spontaneous combustion, any substance that changes or decomposes readily giving out heat when doing so, any combustible solid substance with a flash point less than 120° C, any substance likely to spread fire by flowing from one part of a building to another.
[6]Places of special fire hazard are listed in the definitions in Appendix E to Approved Document B.
[7]Maximum part of travel distance within the room/area. Travel distance outside the room/area to comply with the limits for the purpose group of the building or part.

Table XVI Maximum travel distances in assembly buildings (from BS 5588: Part 6, Table 2)

Available direction of escape	Areas with seating in rows (m)	Open floor areas (m)
(a) In one direction only	15	18
(b) In more than one direction	32[1]	45[2]

[1] This may include up to 15 m in one direction only.
[2] This may include up to 18 m in one direction only.

Table XVII Maximum travel distances in shopping malls (from BS 5588: Part 10, Table 1)

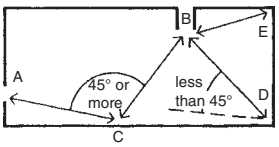
Available direction of escape	Uncovered malls (m)	Covered malls (m)
(a) In one direction		
(1) malls at ground level	25	9
(2) malls not at ground level	9	9
(b) In more than direction		
(1) malls at ground level	not limited	45
(2) malls not at ground level	45	45

Table XVIII Maximum travel distances in shopping complexes other than in malls (from BS 5588: Part 10, Table 2)

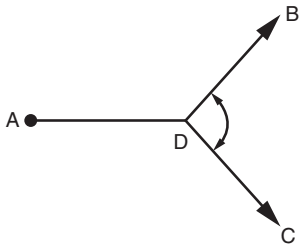
Accommodation	Maximum part of travel distance within room or area		Maximum travel distance to nearest storey exit	
	Escape in one direction only (m)	Escape in more than one direction (m)	Escape in one direction only (m)	Escape in more than one direction (m)
Accommodation other than the following list	18	45[1]	18	45[1]
Engineering services installation rooms Boiler rooms Fuel storage spaces Transformer, battery and switchgear rooms Rooms housing a fixed internal combustion engine	9	18	18	45[1]

Notes:
[1] This may include up to 18 m with escape in one direction only.

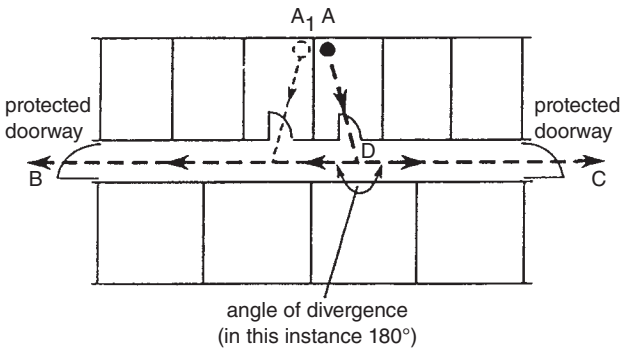
premises requiring a fire certificate recommend that the angle of divergence should be not less than 45° plus 2 1/2° for every metre travelled in one direction, see Figures 11.36, 11.37 and 11.38.



11.36 *Alternative escape routes are available from C because angle ACB is at least 45°, so that either CA or CB should be less than the maximum travel distance given in Table XV. Alternative routes are not available from D because angle ADB is less than 45°, so that DB should not exceed the distance for travel in one direction. There is also no alternative route from E. From Approved Document Part B, Volume 2, Diagram 11*



11.37 *Alternative escape routes in principle, A being the point of origin and D the point of divergence of alternative routes. Angle BDC = 45° + 2 1/2° for each metre travelled from A to D*



11.38 *Alternative escape routes in practice*

4.13 Width of escape routes and exits

An escape route should be as wide or wider than an exit leading to it, and should be of uniform width. The width of a final exit should equate to the route or routes it serves. This may comprise the total number of persons descending a stair plus a ground-storey population plus those ascending from a basement.

4.14 Measuring width

Unfortunately to date there is no agreed method of measuring width. In addition to means of escape, access for the disabled may be a consideration with specific details for projection of handrails. The variations should be accommodated by measuring an absolute clear width with no allowances for the projection of handrails, door thickness, etc., except door furniture with a maximum intrusion of 100 mm. The safe and rapid use of a stair is dependent on all persons being within reach of a handrail, therefore no staircase should exceed 1.4 m in width unless additional central handrails are provided.

4.15 Evacuation

The capacity and therefore the width of a stair differ from that of a horizontal escape route being influenced by the rate of descent and the standing position on the stairs. The width necessary is also influenced by the type of evacuation – total or phased – the stair having to accommodate only the population of a phase in the latter instance.

Total evacuation: on the raising of the alarm the total population moves to evacuate the whole of the building in a single phase.

Phased evacuation: on the discovery of a fire the alarm is given in the following manner. The fire floor and the floor above are given the signal to evacuate immediately, all other floors are given the alert signal to stand by to evacuate. If the fire is extinguished no further evacuation is necessary; if not, the next two floors immediately above the initial phase are evacuated; and so progressively in separate phases of two floors up the building to the top. Evacuation then proceeds down the building, starting with the floors nearest the fire, until it is complete or the fire extinguished. As the population of only two floors are evacuated at a time, the stair width dimensions can be decreased.

4.16 Additional measures

As people remain in the building during the fire-phased evacuation, it can take place only if additional protective measures are incorporated:

- All compartment floors with openings through them protected to maintain compartmentation.
- All stairs protected by lobbies or corridors of fire-resisting construction.
- A fire alarm system incorporating a personal address system operated from a central control point from where occupants can be instructed and orderly evacuation directed.
- An automatic sprinkler installation (although this may not be necessary in a low-rise building with, say, three phases of evacuation which would be complete within 30 minutes).

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4.17 Phased evacuation

Phased evacuation is not generally accepted for any basements, assembly, hotel, recreational and similar buildings, and, to date, the majority of shops. However, in the case of mixed user and large complexes total evacuation may not be necessary or prudent and enforcing authorities should be consulted at an early stage.

4.18 Stairs

Where two or more stairs are provided, it is reasonable to assume that one will not be available for use due to fire or smoke unless a sufficiently high degree of protection is afforded. If a stair is approached through a lobby, or protected by a pressure-differential smoke control system, it can be assumed that it will be available. Where such protection is not provided, a stair should be discounted (number of stairs required = calculated number plus 1). Each stair should be discounted in turn, to ensure that the capacity of the remaining stairs in total is adequate, see Tables XIX and XX.

Table XIX Minimum widths of escape stairs (from Approved Document B, Table 6)

Situation of stair	Maximum number of people served[1]	Minimum stair width (mm)
1a. In an institutional building (unless the stair will only be used by staff)	150	1000[2]
1b. In an assembly building and serving an area used for assembly purposes (unless the area is less than 100 m²)	220	1100
1c. In any other building and serving an area with an occupancy of more than 50	Over 220	See Approved Document
2. Any stair not described above	50	800[3]

Notes

[1]Assessed as likely to use the stair in a fire emergency.

[2]BS 5588-5 recommends that firefighting stairs should be at least 1100 mm wide.

[3]In order to comply with the guidance in the Approved Document to Part M on minimum widths for areas accessible to disabled people, this may need to be increased to 1000 mm.

Table XX Capacity of a stair for basements and for total evacuation of the building (from: Approved Document B, Table 7; also BS 5588: Part 6, Table 5)

No. of floors served	Maximum number of persons served by a stair of width:								
	1000 mm	1100 mm	1200 mm	1300 mm	1400 mm	1500 mm	1600 mm	1700 mm	1800 mm
1	150	220	240	260	280	300	320	340	360
2	190	260	285	310	335	360	385	410	435
3	230	300	330	360	390	420	450	480	510
4	270	340	375	410	445	480	515	550	585
5	310	380	420	460	500	540	580	620	660
6	350	420	465	510	555	600	645	690	735
7	390	460	510	560	610	660	710	760	810
8	430	500	555	610	665	720	775	830	885
9	470	540	600	660	720	780	840	900	960
10	510	580	645	710	775	840	905	970	1035

Notes:

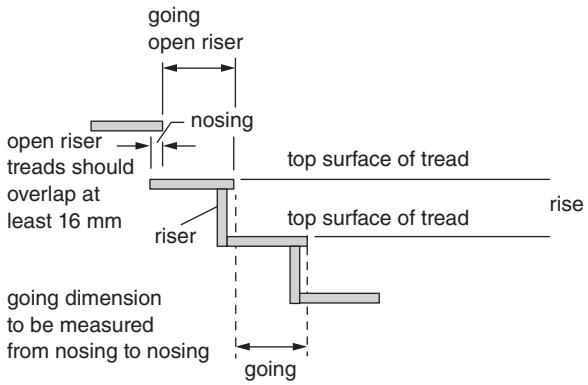
The capacity of stairs serving more than 10 storeys may be obtained by using the formula in para **419**.

This table can also apply to part of a building.

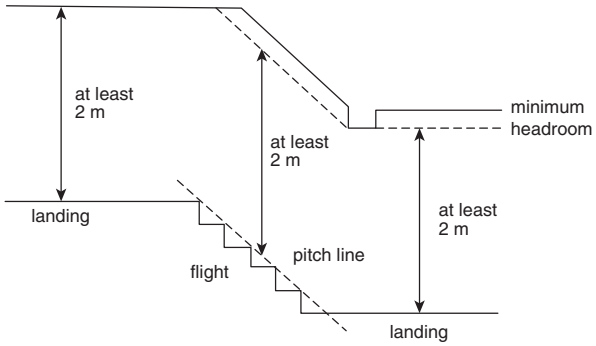
4.19 Stair design

Stair design should accord with Approved Document K or BS 5395, *Stairs, ladders and walkways*, see Figures 11.39, 11.40 and 11.41, and Table XXI.

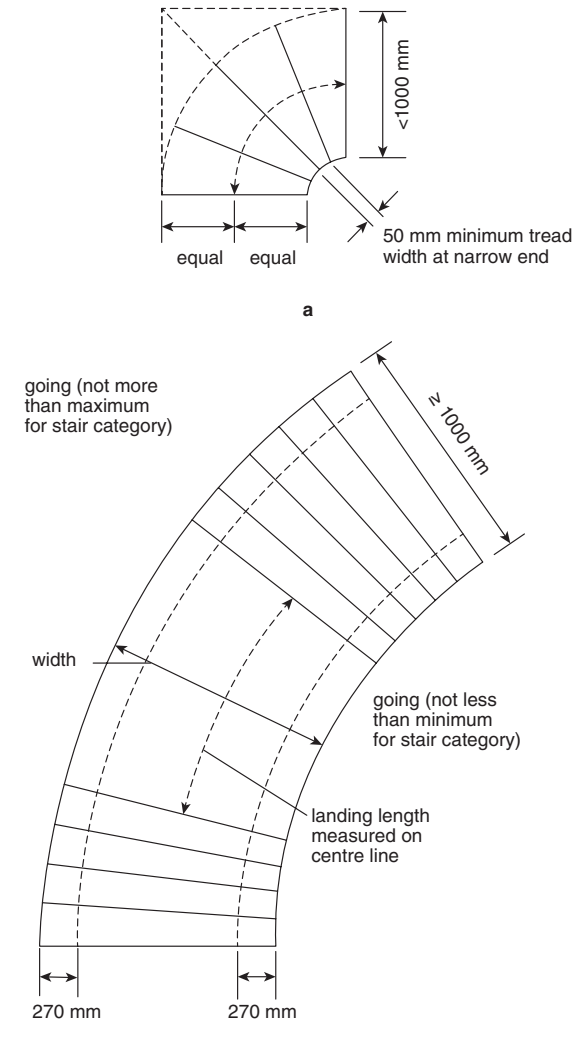
For buildings over 10 storeys Approved Document B recommends the use of the following formula to assess the capacity of stairs:



11.39 *Measuring rise and going on staircases*



11.40 *Measuring headroom on staircases*



11.41 *Measuring tapered treads. a Stair width less than 1 m. b Stair width equal to or greater than 1 m*

Table XXI Rise and going (from Approved Document K, Table 1)

	Maximum rise (mm)	Minimum going (mm)
1 Private stair	220‡	220*
2 Institutional and assembly stair	180‡	280†
3 Other stair	190‡	250

*The maximum pitch for a private stair is 42°.
†If the area of a floor of the building is less than 100 m², the going may be reduced to 250 mm.
‡For maximum rise for stairs providing the means of access for disabled people reference should be made to Approved Document M: Access and facilities for disabled people.

$$P = 200w + 50(w–0.3)(n–1)$$

where

P is the number of people that can be accommodated

w is the width of the stair in metres

n is the number of storeys in the building

Where phased evacuation is envisaged, the minimum widths in Table XXII may be adopted.

Table XXII Minimum aggregate width of stairs designed for phased evacuation (from Approved Document B, Table 38)

Maximum number of people in any storey	Stair width[1] (mm)
100	1000
120	1100
130	1200
140	1300
150	1400
160	1500
170	1600
180	1700
190	1800

[1]Stairs with a rise of more than 30m should not be wider than 1400 mm unless provided with a central handrail (see para 4.6). As an alternative to using this table, provided that the minimum width of a stair is at least 1000 mm, the width may be calculated from: [(P × 10) – 100 mm] where P = the number of people on the most heavily occupied storey.

Small buildings occupied by a limited number of persons and satisfying the criteria for travel distance and a single exit can have a single stairway, see Tables XXIII and XXIV.

Table XXIII Maximum permitted distances of travel in small shops (from BS 5588: Part 2, Table 6)

	Maximum travel distance (m)	Maximum direct distance (m)
Ground storey with a single exit	27	18
Basement or first storey with a single stairway	18	12
Storey with more than one exit/stairway	45	30

*See footnote to 9.2.3 in BS 5588.

Table XXIV Capacity of a stairway for an office building permitted to be served by a single stairway (from BS 5588: Part 3, Table 6)

Maximum number of persons per storey	Width of stairway (mm)
50	900
more than 50	1100

4.20 Population

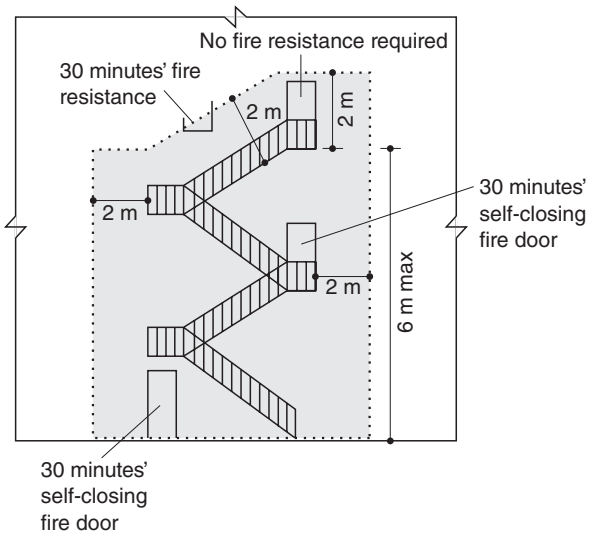
The recommended widths assume a uniform distribution of population. If any floor within a building has a higher population, e.g. a conference room or restaurant, extra or wider stairs necessary to accommodate the increased population should extend down to the final exit.

4.21 Independent escape

Separate stairs should be provided for use by residential or assembly occupancies independent of any other use. Where a totally independent escape can be provided from these higher risk uses, e.g. using an access deck or walkway, it is reasonable that some stairs may be shared.

4.22 External stairs

The use of external stairs should be avoided if possible, due to the psychological effect of using unfamiliar external stairs at high levels and the effects of bad weather. The width and design of external stairs is the same as for internal ones. External stairs are not considered suitable for use by the general public, nor for hospital or similar uses. They should only be used as an alternative escape unless they are the only stair, see Figure 11.42.



11.42 *Enclosure of escape stairs and ramps, not drawn to scale. The shaded area should have not less than 30 minutes fire resistance*

An external escape route should be protected against the accumulation of ice and snow. This may be in the form of an enclosure, partial shielding or trace heating

4.23 Escape routes

Recommendations related to means of escape are generally based on a 30-minute period of fire resistance. Higher periods may result by reason of the need to maintain compartmentation or provide firefighting shafts.

Escape stairs, other than external, should be enclosed by fire-resisting construction to protect against the effects of smoke, heat and fire, and to retard the progress of fire and smoke affecting escape routes. Escape routes should lead to final exits.

4.24 Lobbies or corridors

Additionally, lobbies or corridors of fire-resisting construction should be provided to give additional protection to stairs in the following positions:

- between a floor area and stair in all buildings over 20 m in height at all levels;
- between a stair and a basement storey as the stair is at greater risk from heat and smoke;
- between a stair and an enclosed car park;

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- between a stair and a higher risk area, e.g. a boiler room;
- between a stair and a floor area in a single-storey building other than a small shop (see BS 5588 Part 2) to protect the stair from smoke;
- in assembly buildings to protect the public and performers – where an opening occurs in a proscenium wall, and between stage and dressing-room corridors;
- where phased evacuation is used;
- where a stair is not discounted.

4.25 Enclosure

Escape routes do not necessarily have to be enclosed; in some situations this would create great problems – open-plan offices, exhibition halls, warehouses, factories.

4.26 Dead-end corridors

Where a corridor dead-end situation exists, the escape route must be protected against fire, heat and smoke by fire-resisting construction, as it may be necessary to pass the room on fire to reach the exit, see Figure 11.43.

4.27 Corridors

Where a corridor connects escape routes, it should be protected against the ingress of smoke. To be effective, the construction should be from structural floor to structural floor or imperforate suspended ceiling. The corridors should also be subdivided by cross-corridor doors to inhibit the progress of smoke. These doors do not necessarily require fire resistance. Their purpose is to make it possible to take an alternative means of escape, not to subdivide the corridor at given intervals. Corridors exceeding 12 m should be subdivided (not subdivided at 12 m intervals), see Figure 11.44.

4.28 Lighting and directional signage

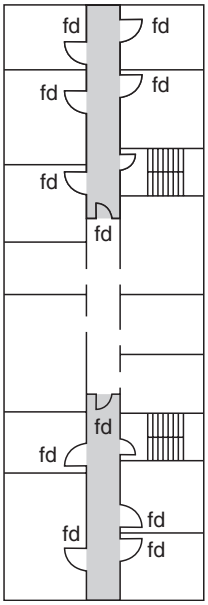
General artificial lighting should be provided for persons to move about a building effectively and safely.

4.29 Emergency lighting

This should be provided in those areas necessary for escape purposes in case the artificial lighting fails. It may be a maintained system (continuously illuminated in conjunction with the general lighting) or be non-maintained, only coming into operation on the failure of the general lighting. Maintained systems are usually provided in areas with large numbers of the public unfamiliar with their surroundings, and where darkened situations may be common.

Escape lighting should be provided in:

- areas occupied or used by the public
- windowless accommodation
- escape routes, including internal corridors without borrowed light
- basements



11.43 *Dead-end corridors continued past stairway*

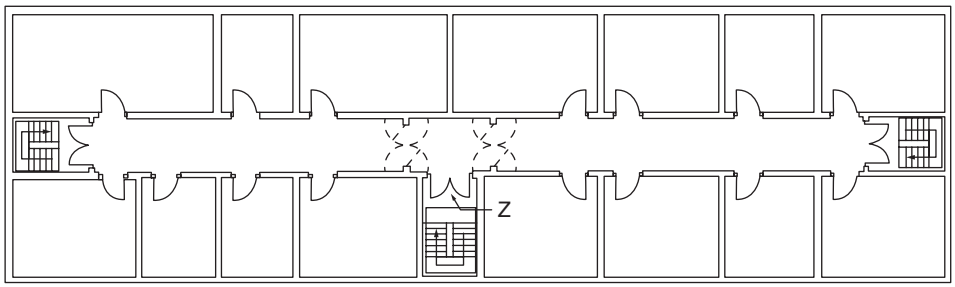
- areas used outside normal daylight hours
- rooms containing essential equipment.

4.30 Signs

These are required to indicate the way to exits, and the exits themselves. Preferred colours, sizes, typeface and graphics are set out in BS 5499. The criterion is that signs should be distinguishable against their background and surroundings and be of a size that can be read at the required distance. If the use of the building warrants it, the signs may have to be in more than one language. Signs should also be provided to indicate fire doors, and those that should be kept locked shut. In public assembly areas, signs are usually internally illuminated; elsewhere it is normally sufficient for escape lights to be positioned so as to illuminate a sign.

4.31 Fastenings

Fastenings on exit doors should allow exit without the use of a key or other device. Unless careful consideration is given to fastenings security may be undermined. The degree of security required will depend on the use of the building and user requirements. Access into a building is not required for escape purposes: re-entry into a floor area is neither necessary nor desirable. Fastenings that prevent a person entering a floor area from a staircase are acceptable. This is often a necessity to prevent theft in offices, factories and hotels and the like. The use of electronic fastenings and the use of card systems or similar to gain entry are acceptable provided that on the raising of the



11.44 *Corridors connecting alternative exits. Doors to central stairway should be at position Z, doors may also be required across the corridors*

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fire alarm or failure of the electrical system all locks 'fail-safe' in the unlocked position. However, consideration should also be given to the possibility of criminals setting off a false fire alarm in order to circumvent security arrangements.

Panic bolts and latches are most suitable where there are large numbers of persons. Turnbuckle locks with lever handles are commonly used where no public is involved. These may not be suitable in some institutional buildings, or places used predominantly by the elderly or disabled who may find a small turnbuckle difficult to operate; appropriate door ironmongery should be fitted in these circumstances.

4.32 Smoke control

If a smoke control system is for life safety purposes, it is essential that its initiation is automatic on the detection of smoke; and if mechanical, that it remains operational at all times by the use of duplicate equipment and secondary power supplies etc. Specialist advice should be sought regarding the type, design and installation of a life safety system.

The measures required to protect a means of escape from the effects of smoke will depend on the escape scheme adopted. Where escape is over a reasonable travel distance, the enclosure of the routes by partitions constructed to resist smoke, i.e. to maintain their integrity, should be adequate. Some smoke will enter escape routes, but should not reach a level to make their use untenable in the time it takes to reach an exit.

As described earlier, the addition of lobbies will retard the entry of smoke. Ventilating the lobbies will further dilute the smoke and hopefully direct it away from the escape route. It is also possible to protect escape routes from the ingress of smoke by the use of pressure differentials to retard the movement of smoke whereby fans, ducts and vents are used to create different pressures between the fire and protected area (pressurisation or depressurisation). Any such system should be designed and installed with the recommendations of BS 5588 Part 4.

4.33 Mechanical ventilation

These systems should not adversely affect a means of escape by perforation of enclosures without adequate protection, or by directing smoke into escape routes. Systems should have regard to BS 5720 and BS 5588 Part 9.

4.34 Ancillary accommodation

Service areas such as boiler and switch rooms should include provision in accordance with Tables XXV and XXVI.

4.35 Escape for people with disabilities

Escape for disabled people should be provided from all buildings to which they have access. BS 5588 Part 8 gives guidance on means of escape for them. Buildings designed particularly for use by persons with disabilities will require specific additional facilities and protection to escape routes depending on the disability. In any case,

Table XXV Maximum permitted part of travel distance in certain areas of ancillary accommodation (from BS 5588: Part 3, Table 8)

Areas of ancillary accommodation	Cross-reference	Maximum part of travel distance within the room (m)	
		For escape in one direction only, or in directions less than 45° apart that are not separated by fire-resisting construction	For escape in more than one direction in directions 45° or more apart, or in directions less than 45° apart but separated by fire-resisting construction
1 Higher fire risk areas other than items 2, 3, 4 and 5	11.6	6	12
2 Transformer and switchgear rooms	12.2		
3 Boiler rooms	14.6.2		
4 Some fuel storage spaces	14.7		
5 Room housing a fixed internal combustion engine	14.8		

Table XXVI Structural fire protection of areas of ancillary accommodation (from BS 5588: Part 3, Table 9)

Area of ancillary accommodation	Cross-reference	Structural fire protection: the area of ancillary accommodation should be separated from other parts of the building by:
1 Storage area not greater than 450 m² (see notes 1 and 2)	18	
2 Repair and maintenance workshops and reprographic rooms (see note 1)	20	Robust construction having a minimum standard of fire resistance of 30 min (see note 3)
3 Kitchens (separately or in conjunction with an associated restaurant/canteen)	21	
4 Transformer, switchgear and battery rooms, for low voltage or extra low voltage equipment	12.2	
5 Loading bays	18	
6 Storage areas greater than 450 m² (see notes 1 and 2)	18	
7 Service installation rooms other than those covered by items 4 and 10 to 14 inclusive		Robust construction having a minimum standard of fire resistance of 60 min (see note 3)
8 Car parks within or adjoining an office building and not greater than 450 m² in area	19	
9 Car parks within or adjoining an office building and greater than 450 m² in area	19	
10 Boiler rooms (see note 4)	14.6	Robust construction having a minimum standard of fire resistance equivalent to that required of the elements of construction of the building and in no case less than 60 min (see note 3)
11 Fuel storage spaces (see notes 4 and 5)	14.7	
12 Transformer and switchgear rooms for equipment above low voltage	12.2	
13 Rooms housing fixed internal combustion engines	14.8	
14 Any higher fire risk area other than items 10 to 13	11.6	

Notes

[1]Not higher fire risk areas.
[2]Other than refuse storage.
[3]Any openings in the required constriction should be protected by doors having a similar standard of fire resistance.
[4]Other than oil fired boiler installations and oil storage.
[5]Other than liquefied petroleum gas storage.

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controlled escape by effective management is vital and assistance should be available.

The Building Regulations require access for disabled persons to the majority of buildings; therefore a number of factors to facilitate their escape will exist – additional width escape routes to accommodate wheelchairs, position and height of guarding on stairs and ramps. Also, in some cases lifts, if adequately protected, may be used by them in the event of fire. It may be necessary to construct protected refuges adjacent to lifts and stairs for those in wheelchairs and with limited mobility to await the use of a lift or assistance to evacuate the building.

When assessing escape arrangements for disabled people it is important not to consider only those that are in wheelchairs. Among others, blind people need help to find the exits, and deaf people require audible warnings to be duplicated by visual ones.

4.36 Fire safety management

This is the prevention and control of a fire, and the maintenance of the fire safety facilities. The understanding and maintenance of these is essential, particularly in a large or complex building; therefore the occupier/management should have comprehension of the safety measures incorporated into the design of the building. This means that the designer must supply all relevant information in a fire safety manual. Details should include:

- the basis on which the means of escape was planned;
- the type of management structure and staff responsibilities envisaged;
- operational details of mechanical and electrical systems;
- record drawings of active and passive protection measures.

5 MATERIALS

5.1 General

The materials forming a building should be chosen having regard to the safety of the structure and occupants. The adequacy of their resistance or their ability to sustain load for any particular period may necessitate their protection to prevent the premature failure of the structure by collapse or failure of loadbearing capacity. Additional resistance may be achieved by protective coverings, casings or membranes.

5.2 Form of construction

Fire resistance relates to the form of construction, not the material, and is stated in terms of performance in relation to British Standards methods of test:

- loadbearing capacity (resistance to collapse);
- integrity (resistance to fire penetration);
- insulation (resistance to transfer of excessive heat).

5.3 Loadbearing capacity

The criterion *loadbearing capacity* has replaced stability. In line with international practice, under BS 476 Part 22, non-loadbearing elements are assessed only for integrity and insulation. Loadbearing elements are tested in accordance with Part 21. BS 476 Part 8 is still often referred to, although superseded in 1987 by Parts 20, 21, 22 and 23. When tested specifications are used, the construction must replicate that tested in total. Consideration of products or systems having an Agrément Certificate issued by the British Board of Agrément or a product complying with a European Technical Approval (refer to the EEC Construction Products Directive) may be of use.

5.4 Ease

Regard should be given to the ease of acquiring the required fire protection, ease of construction, and durability. Although the last is not required under the Building Regulations, a material should be 'fit for the purpose'. There are several terms used in Approved Document B issued in support of the Building Regulations specifically relevant to materials and their choice.

5.5 Flame spread

Restriction of the spread of flame across the surface of a material is an important factor of fire safety, as it affects fire growth and spread, and means of escape. The surface spread is referred to in terms of class classification in accordance with BS 476 Part 7 1971 and reference to Class 0. Flame spread can be reduced by the application of chemicals in the form of a surface application or pressure impregnation. In the latter case mechanical damage to the surface exposing a substratum will not be detrimental to the material. Materials chosen for low spread of flame properties may later be compromised by inappropriate painting.

5.6 Steel

Exposed steel can lose strength very quickly when exposed to fire, buckling and collapsing in as little as 10 to 15 minutes. The actual temperature at which it starts to lose strength depends on the type of steel, whether it is in tension or compression, and its restraint if any. Encasing the steel insulates it against temperature rise. Protection can be in the form of concrete, fire-retardant boards, fibrous sprayed or intumescent coatings, or suspended ceilings. Water cooling has been used to protect columns.

5.7 Aluminium

Some forms fail structurally at quite low temperatures but it has good properties for flame spread.

5.8 Concrete

This loses its crushing strength in fire, see Table XXVII. The heat of the fire also affects the strength of steel reinforcement. Adequate concrete cover is essential, and may require the addition of mesh reinforcement to restrict spalling; this is caused by the reinforcement expanding with heating.

5.9 Clay masonry, brickwork

As a form of ceramic clay performs well at high temperatures albeit some expansion may take place. Any steel in clay can expand causing failure and should be protected.

5.10 Timber

This performs better than steel in a fire. It is a low conductor of heat; it progressively chars, protecting itself with a charcoal layer. The charring rate can be assessed, and the ability of the residual timber to sustain the required loads calculated – see BS 5268 Part 4 Section 4.1 *Method of calculating fire resistance of timber members*. Timber studwork with plasterboard can easily achieve 30 minutes' fire resistance, one hour with additional protection. Existing timber floors can be upgraded to improve their fire resistance by the addition of soffit protection and insulation – see BRE Digest 208, *Increasing the fire resistance of existing timber floors*.

5.11 Asbestos

This is no longer used in its basic form for health reasons.

Table XXVII Behaviour of concrete in fire

Temperature (°C)	Permanent loss of compressive strength as demonstrated by crushing test
250	5%
600	64%
1200 and above	collapse

Table XXVIII Provisions for fire doors (from Approved Document B, Table B1)

Position of door	Minimum fire resistance of door in terms of integrity (minutes) when tested to BS 476-22[1]	Minimum fire resistance of door in terms of integrity (minutes) when tested to the relevant European standard[3]
1 In a compartment wall separating buildings	As for the wall in which the door is fitted, but a minimum of 60	As for the wall in which the door is fitted, but a minimum of 60
2 In a compartment wall:		
a. If it separates a flat from a space in common use;	FD 30S[2]	E30 Sa[2]
b. Enclosing a protected shaft forming a stairway situated wholly or partly above the adjoining ground in a building used for Flats, Other Residential, Assembly and Recreation, or Office purposes;	FD 30S[2]	E30 Sa[2]
c. enclosing a protected shaft forming a stairway not described in (b) above;	Half the period of fire resistance of the wall in which it is fitted, but 30 minimum and with suffix S[2]	Half the period of fire resistance of the wall in which it is fitted, but 30 minimum and with suffix Sa[2]
d. enclosing a protected shaft forming a lift or service shaft;	Half the period of fire resistance of the wall in which it is fitted, but 30 minimum	Half the period of fire resistance of the wall in which it is fitted, but 30 minimum
e. not described in (a), (b), (c) or (d) above.	As for the wall it is fitted in, but add S (2) if the door is used for progressive horizontal evacuation under the guidance to B1	As for the wall it is fitted in, but add Sa[2] if the door is used for progressive horizontal evacuation under the guidance to B1
3 In a compartment floor	As for the floor in which it is fitted	As for the floor in which it is fitted
4 Forming part of the enclosures of:		
a. a protected stairway (except as described in item 9); or	FD 30S[2]	E30 Sa[2]
b. a lift shaft (see paragraph 5.42b); which does not form a protected shaft in 2(b), (c) or (d) above.	FD 30	E30
5 Forming part of the enclosure of:		
a. a protected lobby approach (or protected corridor) to a stairway;	FD 30S[2]	E30 Sa[2]
b. any other protected corridor; or	FD 20S[2]	E20 Sa[2]
c. a protected lobby approach to a lift shaft (see paragraph 5.42)	FD 30S[2]	E30 Sa[2]
6 Affording access to an external escape route	FD 30	E30
7 Sub-dividing:		
a. corridors connecting alternative exits;	FD 20S[2]	E20 Sa[2]
b. dead-end portions of corridors from the remainder of the corridor	FD 20S[2]	E20 Sa[2]
8 Any door within a cavity barrier	FD 30	E30
9 Any door forming part of the enclosure to a protected entrance hall or protected landing in a flat;	FD 20	E20
10 Any door forming part of the enclosure		
a. to a place of special fire risk	FD 30	E30
b. to ancillary accommodation in care homes (see paragraph 3.50)	FD30	E30

Notes:
[1]To BS 476-22 (or BS 476-8 subject to paragraph 5 in Appendix A).
[2]Unless pressurization techniques complying with BS EN 12101-6:2005 Smoke and heat control systems – Part 6: Specification for pressure differential systems – Kits are used, these doors should also either:
(a) have a leakage rate not exceeding 3 m^3/m/hour (head and jambs only) when tested at 25 Pa under BS 476 *Fire tests on building materials and structures,* Section 31.1 *Methods for measuring smoke penetration through doorsets and shutter assemblies, Method of measurement under ambient temperature conditions; or*
(b) meet the additional classification requirement of Sa when tested to BS EN 1634-3:2001 *Fire resistance tests for door and shutter assemblies,* Part 3 – *Smoke control doors.*
[3] The National classifications do not automatically equate with the equivalent classifications in the European column, therefore products cannot typically assume a European class unless they have been tested accordingly.

5.12 Protective board, plasterboard, mineral fibre boards

This is used to protect structural members and form fire-resisting enclosures on suitable frames. Some forms of construction and systems can achieve in excess of 2 hours' fire resistance when constructed correctly. Care is necessary when cutting for services, etc. to maintain the fire resistance. There are many proprietary systems utilising protective boards on timber and metal frames.

5.13 Glass

Plain glass (also depending on whether it is toughened or laminated) offers negligible fire resistance. Wired glass can achieve a 1 hour standard of fire resistance in terms of integrity but with little insulation. Recent developments have resulted in plain glass giving 15 minutes' insulation. Insulating fire-resisting glazing can achieve in excess of 2 hours; the size of glazing panels may be restricted.

5.14 Plastics

Thermosetting harden when heated and thermoplastic soften on heating. Plastics often fall from their supports, making an assessment of their action in fire difficult under test conditions. The material may not burn, but can drip flaming droplets and spread fire. See Approved Document B regarding the acceptable use of thermoplastic materials for ceilings, rooflights and lighting diffusers.

5.15 Doors and shutters

These can be wooden, glass, metal or composite, see Table XXVIII. Some can achieve a fire resistance in excess of 4 hours. They are tested with regard to their integrity and insulation; most do not require insulation. Shutters are generally held open and close on the actuation of a fusible link, or automatically following detection of heat or smoke. Doors are designated according to their performance in minutes in terms of their integrity. Doors forming part of a protected enclosure (stair, lobby or corridor) for means of escape should have not less than a 30-minute standard of fire resistance. Additionally these doors should be able to resist the passage of smoke at ambient temperatures; these are generally denoted by the suffix 'S', i.e. FD30S.

Most door sets require the addition of an intumescent strip to attain a 30-minute standard of fire resistance. The seal intumesces at high temperature swelling to seal any imperfections of fit or gaps and thereby protecting the edges of the door to maintain its integrity. The ambient temperature seal, which may be in the form of a brush, retards the passage of smoke around the door when the fire is at a lower temperature but possibly producing large quantities of smoke. Various codes require 'S' doors in different situations. To be effective for means of escape doors must be self-closing. Where a door is in constant use it may be acceptable to use a hold-open device (usually electromagnetic) to avoid it being wedged open or damaged.

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5.16 Materials for fire stopping and cavity barriers
These must effectively close a concealed cavity, and stop spread of fire and smoke around a service or element, by sealing an imperfection of fit. The material must be capable of sustaining movement, including expansion, be adequately fixed and, in the case of barriers, have fire resistance. Materials include intumescent mastics, fire-protective boards, cement mortar, gypsum plaster and glass fibre; there are numerous proprietary systems.

5.17 Intumescent coatings
These are formed of differing materials with varying characteristics and foam on exposure to heat to form a protective coating. They can be used to improve fire resistance and reduce surface spread of flame. If adopted the following points should be considered:

- The intumescent system must be compatible with the material to be protected.
- The system must suit site conditions by virtue of the necessary mode of application, and in accordance with that tested and achieving the required standard. This includes atmospheric conditions.
- Not all are suitable in areas of high humidity.
- Protection against mechanical damage may be necessary.
- The possible damage of the protection by secondary fixings, follow-on trades or water damage.

6 FIRE PROTECTION APPLIANCES AND INSTALLATIONS

6.1 General
Fire protection appliances and installations are increasingly forming a part of an overall fire protection system. Active extinguishing systems are often installed to compensate for inadequate structural protection, or to facilitate an innovative concept or design which would be hampered by protective construction or division by fire walls.

6.2 Systems
The following brief descriptions give an indication of some of the appliances and systems available and their application. The adoption of any particular system requires careful consideration – the nature of the risk, effectiveness of protection, reliability, ease of maintenance. Specialist advice should be sought. Reference should be made to the relevant British Standards – see Section 9. Although the use of a foreign system or component is not prohibited, the prior agreement and approval of any enforcing authority, insurer or water undertaker should be obtained.

6.3 Hand fire appliances: extinguishers, fire buckets, fire blankets
These are first aid appliance for use by general public. The extinguishing medium of hand-held extinguishers varies to suit the risk; they are colour coded for quick reference.

6.4 Hose reels
These are first aid appliance for use by occupants and firefighters, connected to a pressurised water supply.

6.5 Automatic sprinklers
These provide an automatically released water spray above a fire to contain its growth and inhibit its spread. There are various types and systems for specific areas, applications and risk categories. It should be noted that some systems are meant for property protection only, and that special provisions relate to life safety. Certain situations are not considered suitable for protection by sprinklers because of the potential water damage (art galleries, museums, historical libraries), the risk of accidental discharge or the unsuitability of water as the extinguishing medium for certain processes and materials. There may also be a need to provide large volumes for on-site water storage.

6.6 Water drenchers
A curtain of water, usually to protect the outside of a building or the safety curtain of a theatre.

6.7 Water spray projector systems
For fires involving oils or similar flammable liquids.

6.8 Hydrant systems (sometimes known as mains)
This is a rising main to deliver water for firefighting onto the floor of a building via landing valves. A wet rising main is a pipe permanently charged with water and is generally installed in buildings above 60 m in height, beyond the pumping capabilities of a fire service pumping appliance; it requires water storage. A dry riser is a pipe charged by a fire service pump at ground/access level; it can be at any height but is generally provided in a building over 18 m. Any horizontal section should not exceed 12 m in length unless the delivery of the required rate of water at each outlet can be proven hydraulically. Falling or dropping mains deliver water to low levels. Private hydrants are provided within the curtilage of a site where statutory hydrants are too distant or where the risk is such as to require large volumes of water immediately.

6.9 Foam installations
These are of limited application, generally for the extinction of flammable liquid fires. They may require space for on-site foam-making equipment. There are various forms; specialist advice will be needed. A foam inlet is a fixed pipe through which foam can be pumped to protect rooms containing oil fuel, oil fired boilers etc.

6.10 Gaseous and vaporising liquid installations
These can be:

Carbon dioxide to protect an enclosed area acting in the main by dilution of the atmosphere. Not suitable for all fires. Satisfactory for electrical, computer and telephone equipment, flammable liquids, some chemicals, libraries, archives, art stores, diesel engines and textiles.

Vaporising liquids (halogenated hydrocarbons). Because of the stated detrimental effects of halon on the atmosphere alternatives are being developed; the Building Research Establishment should be consulted for information on acceptable alternatives.

Dry powder installations are suitable for use on flammable liquid and metal fires. Clearance after use is a problem.

6.11 Automatic detectors
Note that their effectiveness is dependent upon the correct selection and siting – see the various Building Research Establishment reports.

Smoke detectors detect the presence of smoke by optical (obscuration) or ionisation methods and raise an alarm. Ionisation detectors are sensitive in the early stages of a fire when smoke particles are small, most suitable in a controlled environment such as a computer suite. Optical detectors react to the visible products of combustion and are the most effective.

Heat detectors detect heat at a pre-selected temperature or on a rapid rise in temperature. Use where smoke may be present as part of process or function but regard should be had to normal temperature of area where sited.

Radiation and ultraviolet detectors respond to distinctive flame flicker. Suitable for large open areas and can detect certain chemical fires.

Laser beam detectors: rising hot air affects laser beam being projected onto receiver by obscuration or movement. Suitable for covering large open areas but note that the receiver may be subject to building movement; beware of false alarms from falling objects or birds.

6.12 Fire alarms manual and automatic (as defined in BS 5839 Part 1)

The system must be carefully chosen to meet specific needs – property or life safety; special needs of those with impaired hearing or sight; public entertainment application (possibly muted alarms) or a specific evacuation procedure (two stage/phase evacuation).

6.13 System type

A manual system (gongs, handbells, etc.) is only to be used in exceptional cases for very small buildings or specific areas. An automatic system in which an alarm of fire can be initiated automatically by the breaking of a call point or by a detector is the more common form. The complexity of the evacuation may require a message relayed via a public address system, initial alarms and alert signals, or the provision of fire telephones. Modern systems can be highly technical, incorporating computers and other data-processing equipment; specialist advice should be obtained at an early stage in any design.

7 STATUTORY REQUIREMENTS

7.1 Legislation

The statutory requirements to provide fire precautions almost without exception relate to life safety and the diminution of fire, although in consequence a degree of property protection is achieved. Some counties and most major conurbations have local Acts or bylaws in relation to access for firefighting. Many large towns and cities have provisions relating to 'large' buildings. At the time of writing the legislation relating to fire is under major review, with a view to rationalisation and streamlining aimed at deregulation. This will involve the repeal of many Acts and Regulations where the Building Regulations have a similar requirement, and extension of existing fire safety legislation to encompass uses such as public entertainment currently dealt with under numerous statutes. A list of national legislation relating to fire is contained in Section 8.

7.2 Regional variations

The Building Regulations (England and Wales) are substantive; the Scottish Building Regulations are currently prescriptive (but are under review); the Building Regulations (Northern Ireland) are currently prescriptive.

7.3 Adoption

The fire safety aspect of the Regulations in England and Wales (Part B) applies to all buildings other than certain prisons. While there is an Approved Document of technical standards to Part B there is no obligation to adopt its recommendations. Provided that the substantive requirement is fulfilled any solution acceptable to the enforcing authority (or Approved Inspector) may be used. If a recognised code is used it is only necessary for the purposes of fulfilling the statutory requirement to adopt the recommendations pertaining to the requirement. However, care should be exercised, as any one recommendation may be reliant on the adoption of another. Section 9 details current codes and guides.

7.4 Requirements

The requirements for fire safety under the Building Regulations of England and Wales are as follows.

BI: Means of escape.

The building shall be designed and constructed so that there are means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times.

B2: Internal fire spread (linings)

(1) To inhibit the spread of fire within the building the internal linings shall

(a) resist the spread of flame over their surfaces; and

(b) have, if ignited, a rate of heat release which is reasonable in the circumstances

(2) In this paragraph 'internal linings' means the materials lining any partition, wall, ceiling or other internal structure.

B3: Internal fire spread (structure)

(1) The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.

(2) A wall common to two or more buildings shall be designed and constructed so that it resists the spread of fire between those buildings. For the purposes of this subparagraph a house in a terrace and a semi-detached house are each to be treated as a separate building.

(3) To inhibit the spread of fire within the building, it shall be subdivided with fire-resisting construction to an extent appropriate to the size and intended use of the building.

(4) The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited.

B4: External fire spread

(1) The external walls of the building shall resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building.

(2) The roof of the building shall resist the spread of fire over the roof and from one building to another, having regard to the use and position of the building.

B5: Access and facilities for the fire service

(1) The building shall be designed and constructed so as to provide facilities to assist firefighter in the protection of life.

(2) Provision shall be made within the site of the building to enable fire appliances to gain access to the building.

7.5 Application

B2, B3(1), (2) and (4), B4 and B5 apply to all buildings; certain prisons are exempt from the other requirements.

7.6 Advice

The Building Regulations relate to a building under construction, certain changes of use, and certain extensions and alterations. Once occupied the Fire Precautions Act may be applicable. To avoid any potential conflict, the Department of the Environment and the Home Office have issued an advice document to enforcing authorities on how the required consultation process should take place. The document, *Building Regulation and Fire Safety Procedural Guidance*, also provides a guide for an applicant through the approval procedure outlining the aims and varying responsibilities of the authorities concerned.

7.7 Statutory bar

Section 13 of the Fire Precautions Act 1971 imposes a 'statutory bar' on a Fire Authority preventing them making the issue of a fire certificate conditional on works to the means of escape approved under the Building Regulations, provided that such matters were shown on deposited plans, and circumstances have not changed.

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If such matters did not have to be shown the statutory bar does not apply.

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(These documents are available for purchase, but can be downloaded free of charge from the UK Government's Planning Portal website.)

British Standards

BS 476: Fire tests on building materials and structures

BS 5306: Fire extinguishing installations and equipment on premises

Part 2: Specification for sprinkler systems

Part 3: Code of practice for selection, installation and maintenance of portable fire extinguishers

BS 5446: Components for automatic fire alarm systems for residential premises

Part 1: Specification for self-contained smoke alarms and point type smoke detectors

BS 5449: Fire safety signs, notices and graphic symbols

BS 5588: Fire Precautions in the design, construction and use of buildings

Part 1: Code of practice for residential buildings

Part 5: Access and facilities for firefighting

Part 6: Code of practice for places of assembly

Part 7: Code of practice for the incorporation of atria in buildings

Part 8: Code of practice for means of escape for disabled people

Part 9: Code of practice for ventilation and air conditioning ductwork

Part 10: Code of practice for shopping complexes

Part 11: Code of practice for shops, offices, industrial, storage and other similar buildings

Part 12: Managing fire safety

BS 5839: Fire detection and alarm systems for buildings

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12 Flood-aware design

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DISCLAIMER
The information contained in this chapter is an introduction to flood risk only. The authors take no responsibility for the subsequent use of this information, nor for any errors or omissions it may contain. Professional advice should always be sought when considering any development, particularly where flood risk may be present.

KEY POINTS:
- *Urbanisation and changing weather patterns are increasing the frequency of flooding*
- *Flooding cannot always be prevented, so designing developments that work with and make space for water is becoming increasingly important*
- *The optimum solution to reducing and managing flood risk may require a combination of different design measures*
- *All development should seek to include sustainable drainage*

Contents
1 Introduction
2 Understanding flooding
3 Planning for flood risk
4 Reducing flood risk
5 Case study
6 Bibliography

1 INTRODUCTION
Flooding is a natural part of the weather cycle. Many people live in areas of high flood risk such as river systems, deltas and coasts, drawn by fertile land and waterway transport links. But throughout the world, flooding has had a devastating impact, at times destroying whole cities and communities.

As global warming influences the natural water cycle, a paradigm shift in our approach to the design of new and existing settlements is required. Coastal communities are increasingly threatened by rising sea levels and stormier weather, whilst inland towns and homes suffer from more intense rainstorms with worse and more frequent flooding.

As a result, the number of people at risk of flooding is rising, particularly in urban areas, where population rises, increased hard surfaces and changing weather patterns exacerbate the problem. According to the Environment Agency in 2014, over 5.5 million, or one in six, properties are at risk of flooding from all types of floods across England and Wales.

However, by better understanding the nature of flood-risk, cities and buildings can be better designed to manage and reduce the risk to people and property.

2 UNDERSTANDING FLOODING

2.1 Flood risk
Natural disasters appear to be occurring with both greater frequency and intensity around the globe. In part, this is a result of more people living in high-risk areas, particularly through urbanisation and unplanned development.

Floods are typically caused by:

- extreme weather events such as rainstorms, hurricanes or tsunamis, or variation such as rapid snow melt;
- man-made activities such as structural failure of man-made facilities such as dams or embankment.

Flood risk is commonly considered a combination of probability (likelihood of exposure to flooding) and consequence (the vulnerability of the receptor to being flooded). This is the likelihood of a flood occurring in any given year and the impact of that flood.

Reducing flood risk requires consideration of both factors. For instance, it is possible to reduce the probability of flooding by installing defences, but increase the consequence of a flood by building more homes behind the defences. However, if the homes are designed to be flood resilient then the consequence of them flooding is low and the overall risk reduced. Equally, it is possible to increase the probability of flooding by removing defences but reduce the consequence by relocating occupants and changing to natural wetlands.

2.2 Probability
The probability of flooding is described as the annual percentage probability of a flood occurring, such as 5 per cent. This is also described as 1 in 20 years, but this can be misleading as a 5 per cent probability flood could occur 3 years in a row and then not again for 60 years.

The probability of a flood also reflects the magnitude. A 1 per cent (1 in 100 year) flood will be bigger than a 5 per cent (1 in 20 year) flood; that is why it is less likely to occur. However, climate change is affecting the magnitude of floods and confusing this method of understanding. In the future, a 5 per cent probability flood could be more extensive, perhaps equivalent to a current 2 per cent flood.

2.3 Consequence
The consequences of flooding are usually measured in terms of the impact of flooding on the people or things that were flooded, the receptors. It is typically measured in terms of loss of life and financial costs, from both direct and indirect causes. The main consideration for the built environment is the vulnerability of the receptors. A hospital is likely to be considered to be more vulnerable than an office or workshop, due to the nature of its occupants and equally its role in society.

2.4 Sources of flooding
Flooding can occur from various sources, as outlined in guidance such as Technical Guidance to the National Planning Policy Framework:

- **River (fluvial)** flooding when excess water bursts the riverbanks, Figure 12.1. This occurs when the run off following a large rainstorm overwhelms the capacity of the river or artificial channel. The land around the river that is flooded is known as the flood plain and can extend for hundreds of metres, sometimes miles. This is the most common and well-known type of flooding.



12.1 *River flooding, Marlow 2014*

- **Coastal flooding** when sea-water is driven on to the land by storms, tsunamis and high tides. This occurs when seismic activity causes tidal waves or when meteorological events, such as hurricanes or storms, combine with strong winds and low pressure to cause sea levels to rise above expected peak levels. If these storm surges overwhelm or breach the sea defences they can have devastating consequences, particularly for communities in low-lying areas.
- **Pluvial, overland and sewer flooding** when drains are overwhelmed leading to rain ponding and flowing over the land, Figure 12.2. This occurs when excessive rain cannot be absorbed in the ground, and runs off hard (or water-logged) surfaces too quickly for the drains to discharge it. It is becoming more prevalent in urban areas, where green space has been paved over and where drainage systems are old and insufficient for the population. Sewer flooding occurs when too much rainwater enters the sewers causing the drains to become surcharged and spill over the land.
- **Groundwater flooding** when the below ground water rises above the surface of the ground. This typically occurs in winter months or in the rainy season and flooding can last for several months until the water level subsides in the summer months or dry season.
- **Failure of artificial systems** such as a dam failure, a burst water main or an embankment collapsing. If a collapse or breach occurs then this can result in fast flowing water, in unexpected locations, catching people unaware.

2.5 Climate change impacts

Climate change is likely to result in rising sea levels, more intense rainstorms and monsoons, higher peak wind speeds, stormier seas,



12.2 *Sewer flooding (source: Environment Agency)*

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higher waves and wetter winters. Today's extreme events could start to become the normal events, and tomorrow's extreme events could be far more extreme than we are prepared for. Sea level rise will put low-lying coastal communities at greater threat from storms. Intense rainstorms could regularly overwhelm our drains and sewers. Heat waves and drought could put undue stress on buildings and landscapes, and it could leave occupiers short of water.

The current consensus, according to the IPCC is that sea levels will rise by less than 1 m by the end of the century. However, it will not stop rising in 2100.

These changes create a challenge for planners, engineers and designers, demanding a paradigm shift in our approach to new and existing settlements.

3 PLANNING FOR FLOOD RISK

3.1 Guiding principles

Flood risk is one of the most well-recognised constraints to planning, typically indicated through flood zones. However, the status quo has been challenged by both changing weather patterns and through changing technology. Changing weather patterns are changing the extent of the flood zones. Changing technology is finding solutions to overcome the challenges of flooding, water shortage and other issues.

Strict policies on development restriction within the floodplain are advisable. This is not to say that the floodplain must only have the one use but that the use should be compatible with its primary function to provide space for rivers to expand and flow during times of flood. Once this is understood, and integrated into land use planning, there is an opportunity to use the floodplain productively as part of good town planning. For instance, when preserved as parkland it can provide amenity space for high-density development away from the floodplain, transport corridors, urban heat island reduction, buffers to storms and habitat.

There are different approaches to planning in flood risk areas in different countries around the world but many follow these principles:

- Assess the risk from flooding.
- Avoid building in areas at risk of flooding.
- If this is not possible, then identify less vulnerable uses that are compatible with the level of flood risk.
- Design the development to be resilient to flooding (see Section 4.5) without increasing flood risk.
- Ensure, where possible, that there is a means to evacuate to safety/higher ground.

Following these principles may result in a mixture of uses that matches different levels of flood risk, often with public space along higher risk areas such as riverbanks and coastal areas.

3.2 Location

Like spatial planning, designing for flood risk is developed at different scales from a national and regional level through to city planning. Detailed planning is developed from a neighbourhood level down to a building/plot level.

Understanding the location within a river or water catchment, particularly in combination with an understanding of the topography can help with preliminary assessment of flood risk and the appropriate solutions. For instance in low-lying areas flooding can be extensive and long lasting and the water may take a long time to drain away after a flood. In hilly areas the onset of flooding can be rapid and unexpected.

Typically, the upper catchment of a river is set within hillier land and often (though not always) the lower catchment of a river is within low-lying land along the coast. Though there are examples of low-lying upper catchments and of mountainous lower catchments the characteristics described above are more common.

3.3 Flood zones

Flood zones are used to indicate areas of high to low flood risk, typically based upon probability of flooding. The Environment Agency publishes online maps indicating the Flood Zones in England and Wales. These flood zones indicate the areas that could be at risk of flooding from rivers or the sea but ignoring the presence of defences. The maps also indicate flood defences and the areas that benefit from them. The Scottish Environment Protection Agency (SEPA) and the Rivers Agency in co-operation with the Department of the Environment (DOE) publish similar maps for Scotland and Northern Ireland respectively.

In England, the Flood Zones are defined as follows:

- Flood Zone 1 is considered low probability and is defined as areas with less than 0.1 per cent (1 in 1000) annual chance of flooding from rivers or the sea.
- Flood Zone 2 is considered medium probability and is defined as areas with between a 1 per cent and 0.1 per cent (1 in 100 to 1 in 1000) annual chance of river flooding and between a 0.5 per cent and 0.1 per cent (1 in 200 to 1 in 1000) annual chance of flooding from the sea.
- Flood Zone 3 is considered high probability and is defined as an area with a greater than 1 per cent (1 in 100) annual chance of river flooding and a greater than 0.5 per cent (1 in 200) annual chance of flooding from the sea.
- Flood Zone 3b is also considered high probability. This zone includes areas where water must flow or be stored in times of flood. It is often (but not explicitly) considered to be land that has a greater than 5 per cent (1 in 20) annual chance of river flooding.

The area of land that would be affected by the 1 per cent (1 in 100) annual chance of flooding is used in many countries to define the floodplain. The 1 in 100 flood level is sometimes referred to as the design flood level on the basis that floor levels should be set above this level.

The Environment Agency also publishes interactive online maps should typically indicating the probability of flooding taking into account defences for various flood sources. For rivers, seas and surface water these are indicated as very low to high probability. The area of high probability is that with a greater than 3.3 per cent (1 in 30) chance and is similar to the extent of Flood Zone 3b, which is 5 per cent (1 in 20).

Therefore as a simple reference, the areas of high probability give some indication of the highest risk areas. However, it is very important that a site specific Flood Risk Assessment (FRA) taking into account all sources of flooding and local characteristics including topography is undertaken to determine risk to any given site.

None of these maps indicate how deep the floodwater can be or how fast it will flow but give a good idea of the likelihood an area may flood and importantly, the need to find out more information. A common sense approach to considering flood risk is to look at the topography of a site. Water follows the path of least resistance so it will typically channel in low valleys and pond in depressions. If a site is located on a hill it is not always safe to assume that it is not at risk of flooding as it could be within a local channel or depression.

A site specific Flood Risk Assessment (FRA) can provide a more detailed assessment of the hazard, to include depth and velocity of water as well as the character of the area whether it is urban or rural.

3.4 Planning policy

The English planning policy (National Planning Policy Framework (NPPF) 2012) sets out the need to apply a sequential test with regards to flood risk when considering sites for development. This test is carried out by local government, to determine if development can be located on sites with a 'very low' probability of flooding (Flood Zone 1). If there are not suitable sites for development or if there are other benefits of developing sites in flood risk areas, then sites in Flood Zones 2 and 3 can be considered for development so long as it can be demonstrated that development:

- provides wider sustainability benefits (such as enhancing a deprived area of a town or cleaning up contaminated land);
- will be safe for its users over the lifetime of the development (taking into consideration the effects of climate change), and it will not result in an increase in flood risk elsewhere, and ideally reduce flood risk overall.

Both the 'sequential test' and the second test, which is referred to as the 'exception test', provide a good principle to follow for all development in the UK and beyond.

Key considerations for planning individual development sites to reduce the risk from flooding are:

- planning the site to locate the most vulnerable uses in the lowest risk areas;
- provide safe access and escape routes.

Even where flood defences are provided it is also important to consider residual risk of flooding should defences be breached or overtopped.

3.5 Use and vulnerability

The English planning policy identifies vulnerability according to five categories, with the aim to protect the most vulnerable users and to ensure that key infrastructure that is required to help during floods is protected:

1. Less vulnerable – which includes shops, offices, warehouses.
2. More vulnerable – which includes dwellings and residential institutions, hospitals.
3. Highly vulnerable – basement flats, caravans and mobile homes, police, fire and ambulance stations and telecoms centres which would be needed during a flood.
4. Water compatible – includes flood defences, marinas, water based recreation.
5. Essential infrastructure – including essential transport links, primary electricity sub-stations and water treatment works.

The first three categories of less to more vulnerable uses are most relevant to architects and designers.

A more complete list of uses is given in the National Planning Policy Framework (NPPF) technical guidance. This document also provides a table to determine which of the vulnerability classifications are appropriate in which flood zone and in which flood zones development should not be permitted (see Table I).

4 REDUCING FLOOD RISK

4.1 Introduction

Planning by means of zoning according to high to low levels of risk is only a first step. Flooding may vary in depth, velocity and hazard even within one area. Different building technologies and uses may be more adapted to one flood hazard than another:

- Areas with low flood depths may be managed by variations in land levels to raise some areas above flood levels for say housing, compensated for by lowering other areas which may only be used for gardens.
- For areas potentially affected by deeper floodwaters, buildings may need to be elevated high above the ground or designed to float with the rising water.
- For areas with substantial flood risk, the solution may be for regional flood storage areas and wetlands to be provided.

Measures to reduce flood risk can be structural or non-structural:

- Structural measures include flood defences (soft and hard), building resilience, drainage systems including Sustainable Urban Drainage Systems (SuDS), temporary barriers.
- Non-structural measures include early warning systems, flood forecasting, land use planning, insurance, evacuation and recovery plans.

Table I Appropriate uses according to flood risk (based upon NPPF/PPS25) indicating which are required to pass the exception test in England

Use	Very low flood risk	Low flood risk	Medium flood risk	High flood risk
Less vulnerable uses • Shops and restaurants • Offices • Industry and warehouses • Agriculture and forestry • Water and sewage treatment	Yes	Yes	Yes	No
More vulnerable • Residential houses and flats • Residential institutions, hostels and prisons • Hospitals, health centres • Hotels, bars and nightclubs • Holiday lets or short let caravans	Yes	Yes	Maybe[1]	No
Highly vulnerable • Basement flats • Caravans and mobile homes for permanent residence • Police, fire and ambulance stations • Telecoms centres needed during a flood	Yes	Maybe[2]	No	No
Water compatible • Flood defences • Docks, marinas and ship building • Water based recreation • Amenity open space • Outdoor sports and recreation grounds	Yes	Yes	Yes	Yes
Essential infrastructure • Essential transport links • Primary electricity sub-stations • Sewage and water treatment works	Yes	Yes	Maybe[2]	Maybe[2]

1 Cells indicated as Maybe correspond to uses which are required to pass the exception test in England.
The general principle is to direct highly vulnerable uses towards lower flood risk areas.
2 For all sites in Flood Zones 2 or 3, or for sites with over 10 units proposed or with an area of over 1 hectare it is essential to carry out a site specific Flood Risk Assessment (FRA).

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For most architects, planners and engineers, it is the structural measures which will be most relevant. Measures are discussed in more detail in the *Cities and Flooding* guide by the World Bank (GFDRR and World Bank 2012).

Different measures are appropriate at different scales. These are introduced below.

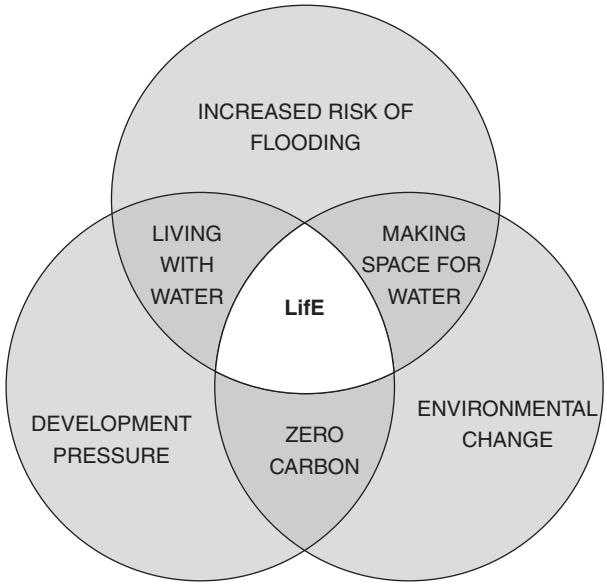
4.2 Planning and sustainability

Where flood risk exists on a site it should be seen as a design driver to lead to safe and responsible planning. There are opportunities to use areas at risk of flooding for beneficial functions to the development and the wider area. For instance, it is possible to use flood storage areas for recreation, helping to contribute to the amenity provision for a development. They may also be used for wildlife, increasing habitat and biodiversity. In some circumstances, flood storage areas can be used for renewable energy technology such as wind power, hydro electric, solar farms and tidal turbines. This is well illustrated by the Long-term Initiatives for Flood-risk Environments (LifE) approach (www.lifeproject.info) to development, in which flood risk is managed through the creation of parks, gardens, public squares and wetlands all designed to form an integral part of new sustainable development. This approach, which was developed with funding from Defra as part of the making space for water programme, is illustrated in Figure 12.3.

Examples of a new village blue/green along the River Wandle in Hackbridge, Figure 12.4, and a tidal flood storage lagoon, Figure 12.5, along the River Arun in Littlehampton show how making space for water to store flood water could enhance the public realm with generous public spaces, recreation areas (on land and water), wildlife walks and new habitat, as well as providing space for renewable power generation through Ground Source Heat Pump Arrays, and Wind and Tidal Turbines respectively.

4.3 Designing buildings for flood risk

There are a number of building design improvements that can be used to reduce the effects of flooding. Different approaches can be implemented, depending on whether they are added to an existing building or constructed as part of a new building.

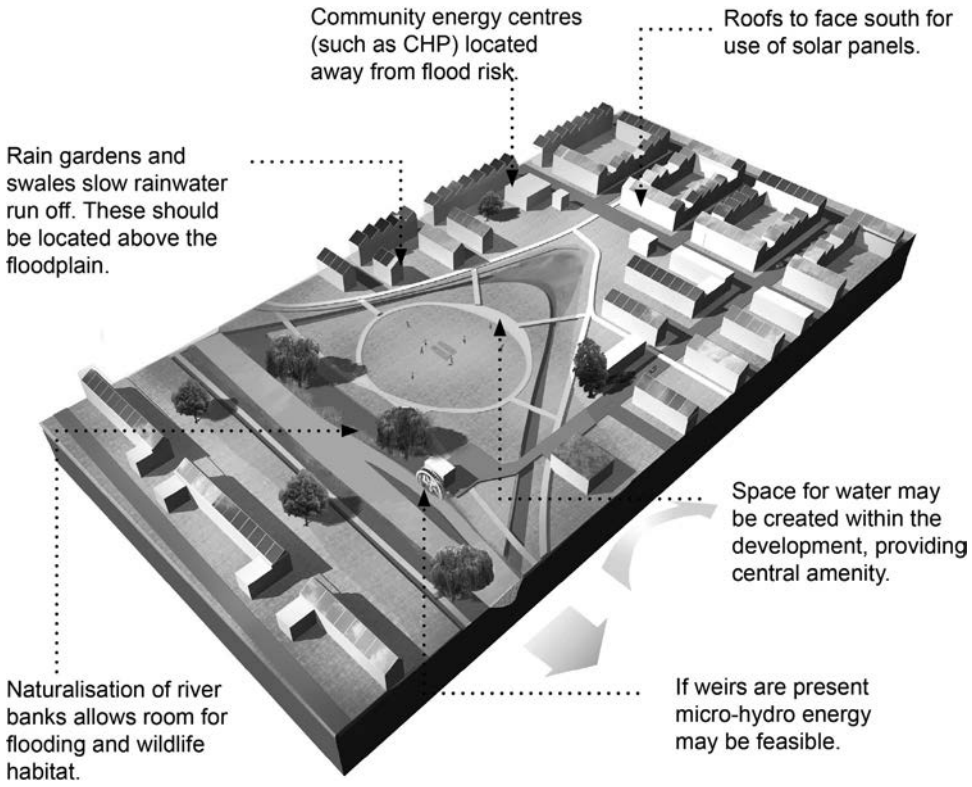


12.3 *LifE is an integrated design approach in which measures to make space for water also help reduce carbon emissions through sustainable (Zero Carbon, Passivhaus and Code Level 6) development*

There are four main approaches to tackling flood risk at a building level, Figure 12.6:

- Avoidance
- Resistance
- Resilience
- Floating

A coherent flood resilient masterplan may consist of a combination of the above building types, organised around urban landscape that uses soft and hard landscape that accumulatively mitigate flood risk across the site.



12.4 *The 'village blue/green' provides a flexible informal recreation area, with landscaped hollow designed to regularly accommodate floodwater and slow the flow downstream (source: Baca Architects)*

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4.4 Flood avoidance

Flood avoidance is the most usual building design measure with many examples of buildings on stilts or raised ground throughout the world.

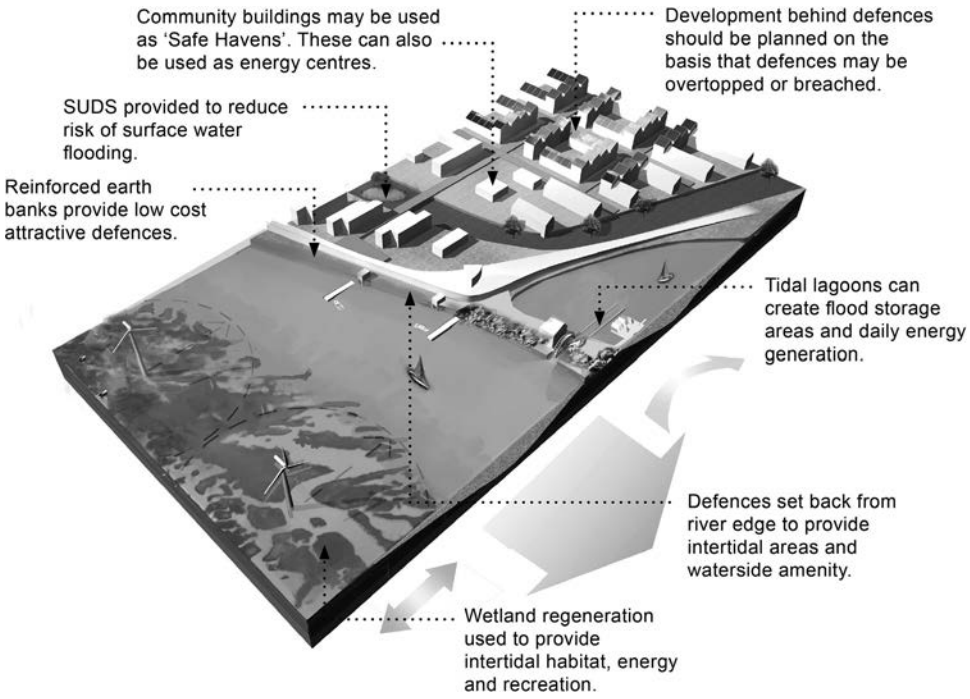
For flood avoidance to be effective, the ground floor level of the building must be set above the design flood level, including an allowance for climate change and tolerance (freeboard).

- For residential units the floor level is typically required to be set above the 1 per cent (1 in 100) flood level + 300 mm (climate change allowance) + 300 mm (freeboard).
- For commercial units, the floor level is typically required to be set above the 5 per cent (1in 20) flood level + 300 mm (climate change allowance) + 300 mm (freeboard).
- For residential car parking, the flood level is typically required to be set above the 1 per cent (1 in 100) flood level.
- For commercial car parking, the flood level is typically required to be set above the 5 per cent (1 in 20) flood level.

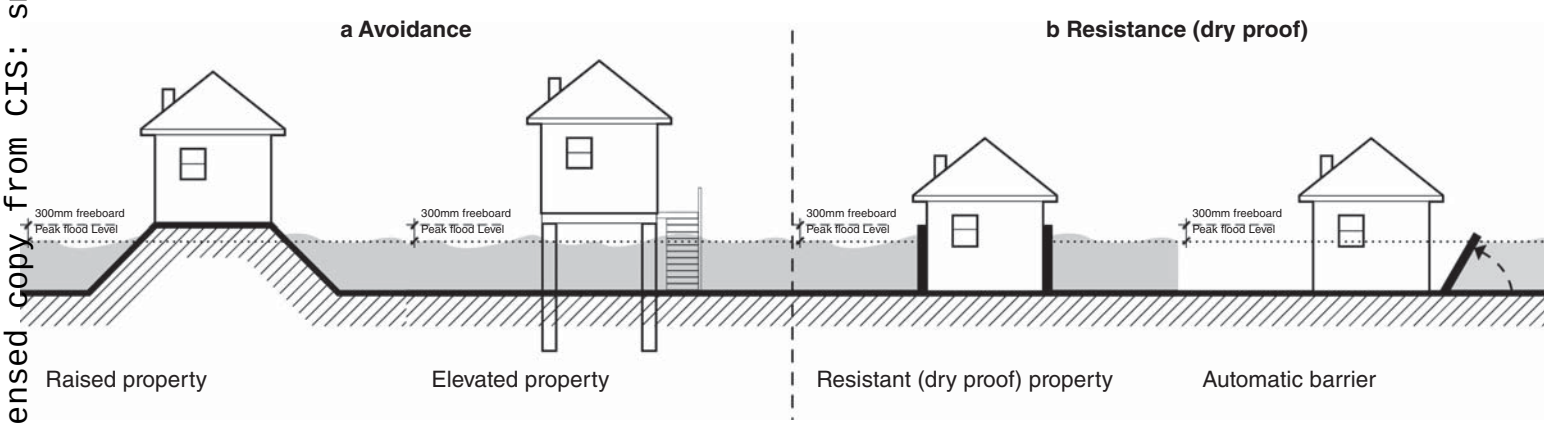
Though land raising may seem an obvious solution to reducing flood risk it is often not possible as raising the land would result in increasing the flood risk elsewhere. Where land raising is to be considered, the loss of flood storage would normally need to be compensated for by an area of excavation at the same level as the area of raising for it to be effective – this is referred to as level for level compensation. In areas with limited land level variation it is unlikely to be feasible.

Working with the natural topography of a site it may be possible to reduce the flood risk to areas by increasing the land level whilst compensating for the loss of flood storage by reducing levels elsewhere, see case study, Section 5.

Buildings may be elevated on stilts, columns or walls to raise the floor levels above the potential flood level. Buildings elevated on stilts or columns help to preserve space for floodwater where building raised on walls may still require compensation for loss of flood plain, unless there are adequate openings in the walls to allow water to pass through. An elevated building can result in



12.5 *Land at risk of flooding, could be elevated above future flood levels on spoil from the excavation of a new, 'tidal lagoon', flood storage area and wetlands (source: Baca Architects)*



12.6 *Different building measures to manage flood risk (© Baca Architects)*

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floor levels being set well above the ground level, requiring raised or stepped access routes, which may be at odds with level access for disabled users. It may also result in a disconnection between the floor and ground level, reducing natural surveillance of streets.

4.5 Flood resistance/dry proofing

Flood resistance and resilience measures are not normally acceptable for new buildings other than to manage residual flood risk (Figure 12.7). This is because it is safer to avoid flood risk rather than relying on flood defences to keep water out or allowing floodwater into a building that carries obvious health risks.

Flood resistance measures include flood defences, flood barriers, door guards and back flow drains with the purpose of preventing water from entering the property – hence keeping it dry.

Typically flood resistance measures are only effective for short duration shallow flooding (below 300 mm in depth or below 600 mm in depth depending on structural assessment). Tests have shown that floodwater may still infiltrate different building constructions designed to resist flooding though the duration of resistance may vary. There are examples of buildings designed to withstand greater depths of flooding, but these require heavy-duty water resisting construction such as tanking, waterproof concrete and steel flood doors.

For most cases it should be assumed that flood resistance measures will only be effective where predicted flood levels are no more than 300 mm above the surrounding ground level.

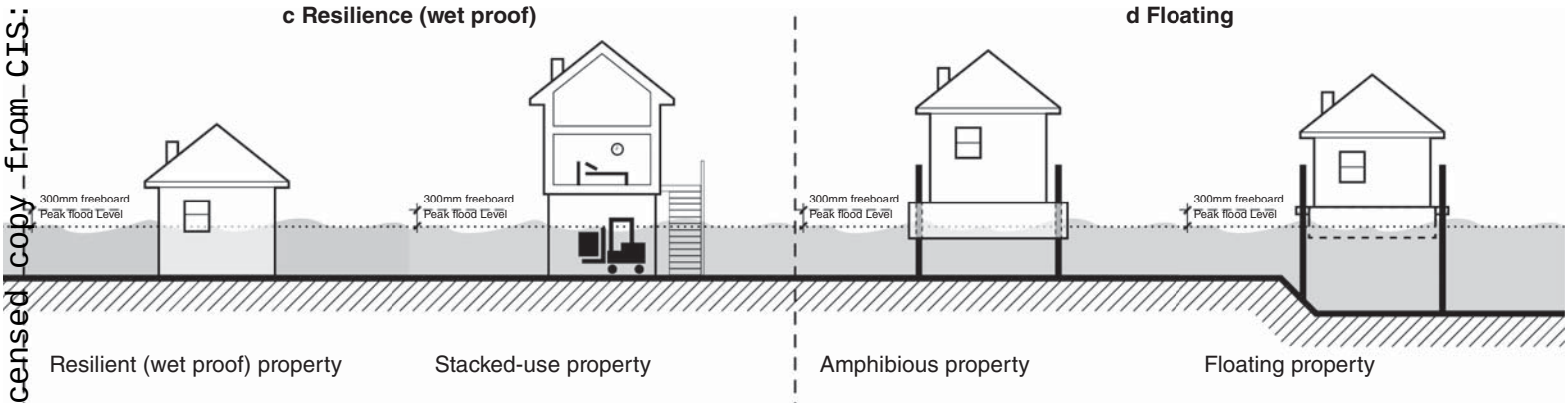
A flood proofing matrix is shown in Table II.

4.6 Flood resilience/wet proofing

Flood resilience measures or wet proofing involves constructing a building in such a way that although floodwater may enter the building, its impact is minimised, the structural integrity is maintained, and the time to clean up and use is minimised (Figure 12.8). It relies on using building materials that can survive being waterlogged without requiring repair or replacement according to the Communities and Local Government guidance *Improving the flood performance of new buildings*. Flood resilience measures are typically used where flood depths are greater than 600 mm.



12.7 *A new building at the BRE Innovation Park will show how different building techniques may be used to keep water out (resistance) as well as cope if water enters into the building (resilience)*

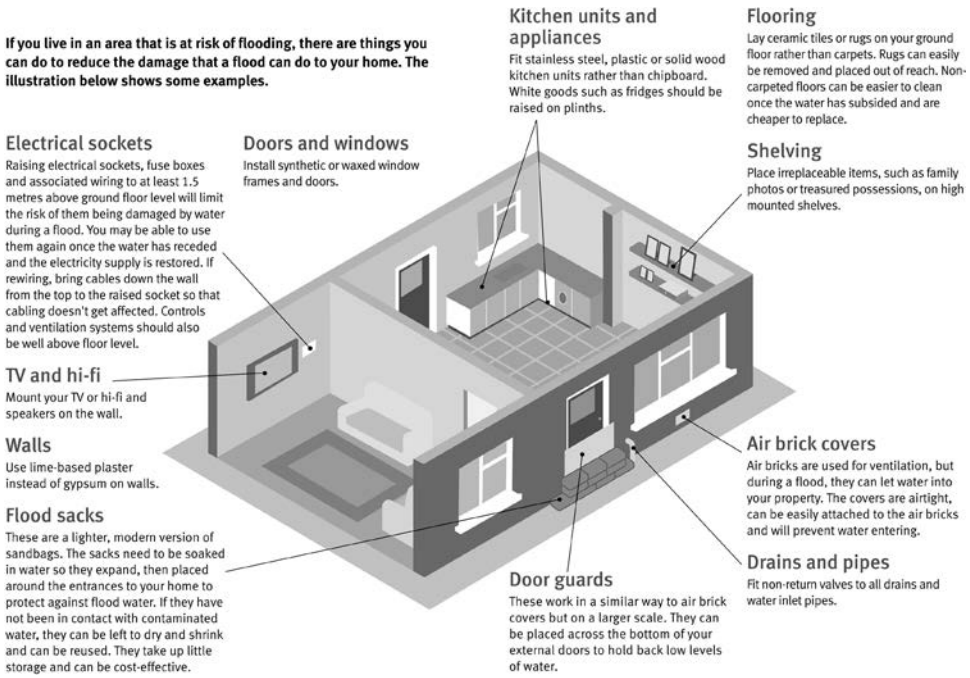


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Table II Application of flood proofing measures, based on flood depth, velocity and construction types

Flood Proofing Matrix		Measures								
		Elevation on foundation walls	Elevation on Piers	Elevation on posts or columns	Elevation on piles	Relocation	Walls and levees	Flood walls and levees with closures	Dry flood proofing/ resistance	Wet flood proofing/ resilience
Flood Characteristics										
Depth	Shallow (<1m)*	✓	✓	✓	✓	✓	✓	✓	✓*	✓
	Moderate (1-2m)*	✓	✓	✓	✓	✓	✓	✓	×	✓
	Deep (>2m)*	✓	✓	✓	✓	✓	×	×	×	×
Velocity	Slow (<1m/s)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Moderate (1-2m/s)	✓	✓	✓	✓	✓	✓	✓	×	×
	Fast (>2m/s)	×	×	✓	✓	✓	×	×	×	×
Subject to rapid/flash flooding		×	✓	✓	✓	✓	✓	×	×	×
Subject to ice and debris flow		×	✓	✓	✓	✓	✓	×	×	×
Site Characteristics										
Location	Coastal floodplain	×	✓	✓	✓	✓	✓	×	×	×
	Riverine floodplain	✓	✓	✓	✓	✓	✓	✓	✓	✓
Soil type	Permeable	✓	✓	✓	✓	✓	×	×	×	✓
	Impermeable	✓	✓	✓	✓	✓	✓	✓	✓	✓
Building Characteristics										
Foundation	Slab	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Sub-floor void	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Basement**	✓	×	×	×	✓	✓	✓	×	×
Construction	Concrete/masonry	✓	✓	✓	×	✓	✓	✓	✓	✓
	Wood/other	✓	✓	✓	×	✓	✓	✓	×	×
Condition	Excellent to good	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fair to poor	×	×	×	×	×	✓	✓	×	×

*Note: that the levels within this international guidance differ from that of English National Guidance (advice should always be sought from an expert)
(Source: GFDRR and World Bank 2012, adapted from USACE)



12.8 *Flood resilience measures (source: Environment Agency)*

Water resistance, impermeability, drying ability, rot avoidance, mould resistance and replacement are all key considerations for materials to provide resilience.

Resilience measures include:

- raise susceptible infrastructure above flood level (such as electric sockets and supply);
- non-return valves (fitted to drains);
- secure drainage (such as sealed drain covers and concrete man holes to prevent pollution and floatation);
- impervious/wash down materials (such as tiled floors, plastic doors, rendered masonry walls);
- solid core materials, (such as use of solid kitchen units instead of chipboard, or solid wall construction below potential flood levels);
- replaceable materials (such as horizontally fitting plasterboard where just the lowest boards can be replaced).

The purpose of these measures is to reduce the susceptibility of the building fabric to being inundated by water and if they are flooded to improve the ability to recover from inundation. Buildings need time to dry out thoroughly after being inundated to avoid the risk of mould, permanent damage and rot. This may be difficult with materials that form part of a composite structure and therefore

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solid materials or construction such as partitions may be preferable below flood levels.

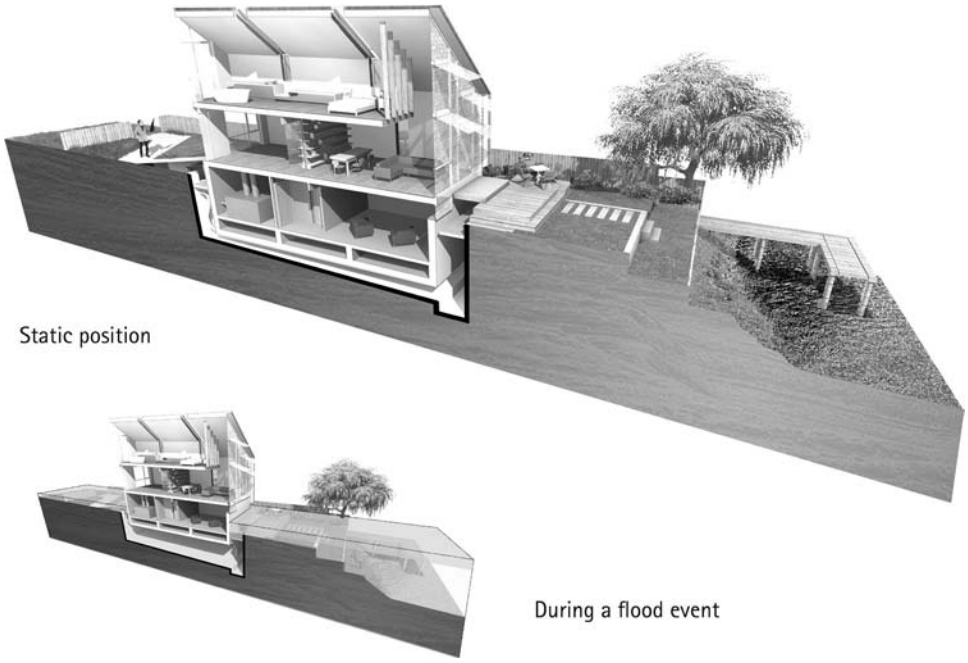
In addition to the flood depth, the velocity of floodwater and the potential for it to carry debris should be considered as high velocity flows and debris impact have the potential to cause scour and structural damage to foundations and superstructure.

4.7 Floating or amphibious structures

Floating or amphibious structures are unlikely to be an option for managing flood risk in most cases due to the need to site the building in water, which is often a high flood risk area, incompatible with the vulnerability of the use.

- source controls/interception devices (such as green roofs and rain water harvesting);
- infiltration devices (such as permeable paving);
- retention and detention devices (such as ponds, below ground storm tanks);
- conveyance devices (used to transfer water);
- constructed wetlands.

The aim of source controls, such as green roofs or water butts, is to intercept and slow the run off rate of water before it reaches the ground and other drainage devices.



12.9 *Amphibious house design (source: © Baca Architects)*

A floating building is, typically, a lightweight structure, which rests on a buoyant base or foundation designed to rise and fall with the level of the water. The benefit of this form of construction is that it can be designed to cope with significant flood depths and can respond to variable flood levels, beneficial where there may be uncertainity in predictions.

An amphibious structure, Figure 12.9, is a floating building set on or within the ground. It can rest on the ground, only floating when the water level rises. These types of construction require careful assessment, design and engineering to provide sufficient resistance to flood flows, debris and manage services.

4.8 Safe access and egress

With all of these building types it is important to provide safe access and egress in the event of a flood. This is particularly relevant for emergency vehicles, which are likely to be called upon during times of flood, and it is a key planning requirement.

Safe access and egress is not required to be dry but it is required to be safe. The Defra document *Flood Risk Assessment Guidance for New Development* (Defra 2005) identifies conditions for creating safe access and egress into developments.

4.9 Sustainable Drainage Systems (SuDS)

In addition to flood resilience measures, it is also important to mitigate flood risk through drainage control. Sustainable Drainage Systems provide the means to manage rainwater run off so that it emulates natural drainage systems. The various devices can be summarised as:

The aim of infiltration devices, such as permeable paving and underground soakaways, is to facilitate infiltration of rainwater into the ground. A soakaway is typically a stone filled circular chamber, shallow linear trenches or perforate pipes depending on the depth of the groundwater and permeability of the ground.

Permeable paving may be used in parking areas or paths to allow infiltration into the ground or into below ground detention tanks.

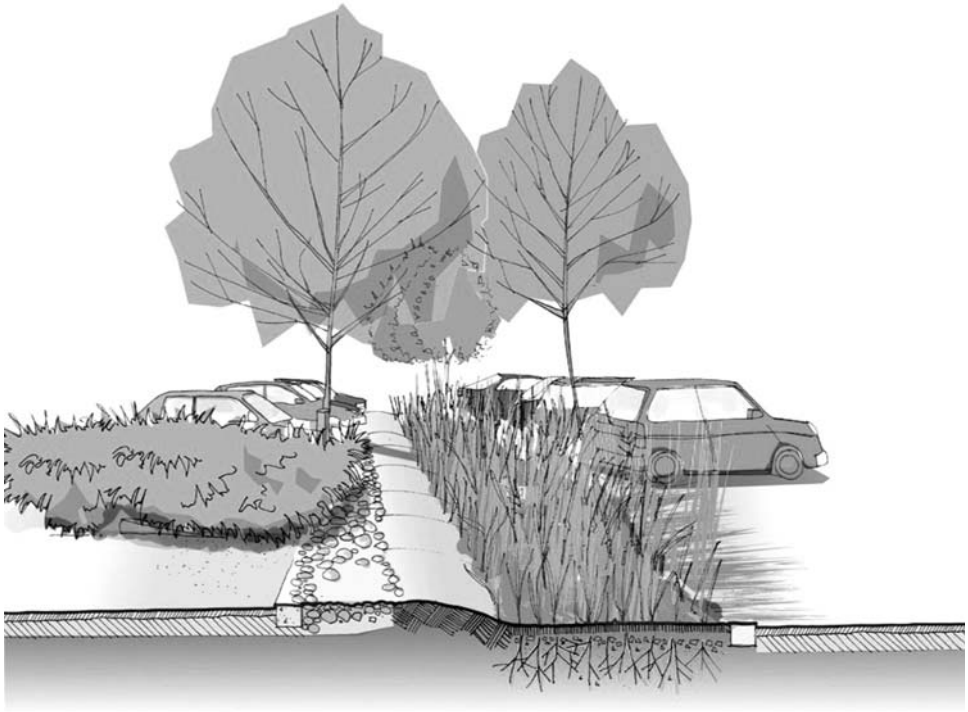
It is important that pollution control measures are used to intercept contaminants from vehicles or other sources, before they have the potential to pollute groundwater. Filter strips may be used between parking areas to control run-off (Figure 12.10).

Retention and detention devices are storm water storage facilities such as ponds or below ground cellular storage devices, which detain water during a storm before releasing via a controlled outflow. They need to be designed to remain (predominantly) dry at other times to provide effective storage during a storm.

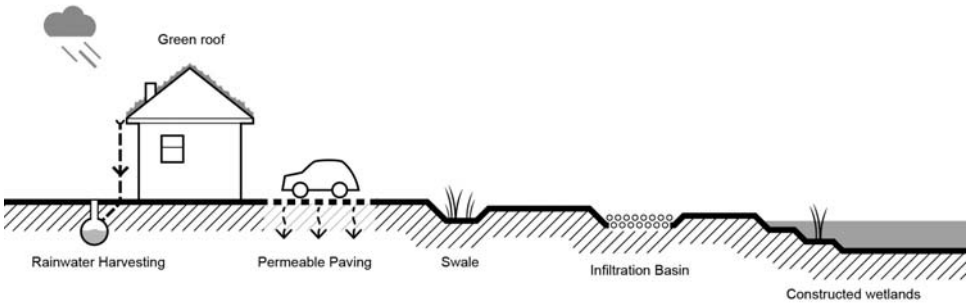
Conveyance devices, such as swales and filter strips, are channels (typically landscaped) that transfer water from one device into another such as the run-off from a roof into an infiltration pond.

Constructed wetlands, such as ponds and lakes, are neighbourhood and regional control measures that emulate the natural benefits of wetlands and are usually the last device in larger SuD systems.

Vegetated SuDS devices (such as green roofs, walls and planted swales) can also provide environmental benefits, such as cooling through evapotranspiration, habitat and visual enhancement. SuDS can enhance masterplanning through increasing the opportunity for landscaping, greater provision of amenity and better place making.



12.10 *A filter strip can be introduced between parking bays to manage run-off (© Baca Architects)*



12.11 *Sustainable drainage options (© Baca Architects)*

A sustainable drainage system typically comprises a range of these devices, which in combination help to detain run-off and release it slowly into watercourses or to ground, Figure 12.11.

SuDS can include below ground drainage as well as above ground drainage solutions. In contaminated areas or in areas with poor SuDS, options often rely on storage rather than infiltration.

Water Sensitive Urban Design (WSUD) is a term that was established in Australia to describe the integration of water cycle management within the planning and urban realm. Components of this are similar to those used in sustainable drainage but expand water management beyond drainage. Good design and planning should integrate water management and at all levels of development.

There is much guidance on sustainable drainage systems available from CIRIA and from many technical suppliers. To determine the type and scale of system required it is important to carry out ground investigations to understand the type of soil and geology. It is also important to undertake drainage calculations to determine the storage required and run off rates.

5 CASE STUDY – DEAL GROUND

Design: Baca Architects

5.1 Context

The Deal Ground site is located on the eastern outskirts of Norwich, and on the western boundary of the Norfolk Broads. The site lies within 1000 m of the Railway Station and about a mile to the Cathedral in the city centre but is cut off from this route by the River Wensum. The site is bordered by both the River Wensum and the River Yare.

The site was previously used for storage, manufacture and most recently light industry and is therefore considered to be brownfield land. The site also contained an unmanaged County Wildlife Site - Carrow Abbey Marsh.

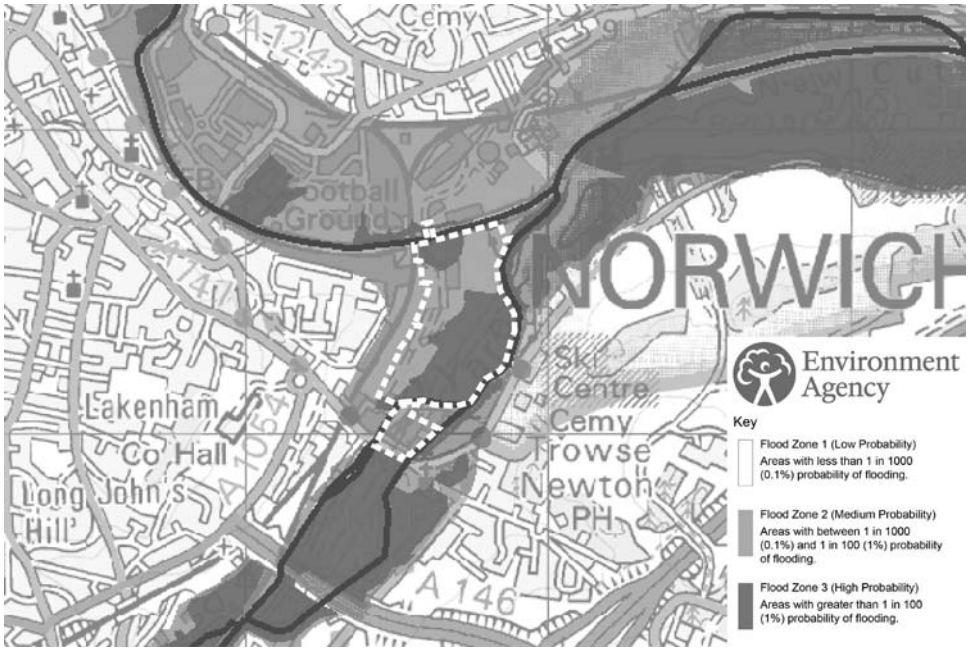
Baca Architects (working with a team of experts) were commissioned by Serruys Property to develop a masterplan for the redevelopment of the site that simultaneously managed flood risk.

5.2 Understanding flood risk

The main source of flood risk is from the rivers, Figure 12.12. They are tidally influenced at the site, but flood flows are dominated by fluvial effects. Surface water run-off from rainfall must also be considered. Due to the topography, this is limited to rainfall on the site and not run off from adjacent sites.

Environment Agency Flood Zone Maps indicated that the site lies within Flood Zone 2 and 3. A site specific Flood Risk Assessment was carried out. This involved on the ground topographical studies combined with LiDAR data where it was difficult to determine the land levels. 2D flood modeling was used to determine flood flow paths, water levels, duration, flood depths and velocities across the site.

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12.12 *Flood zones (source: Environment Agency)*

This indicated that:

- An area to the west of the site lies within Flood Zone 1.
- Approximately 37 per cent of the site lies within Flood Zone 2.
- Approximately 30 per cent of the site lies within Flood Zone 3a.
- Approximately 30 per cent of the site lies within Flood Zone 3b.

These flood zones were agreed with the Environment Agency and used to inform the choice of development.

5.3 Planning for flood risk (use and vulnerability)

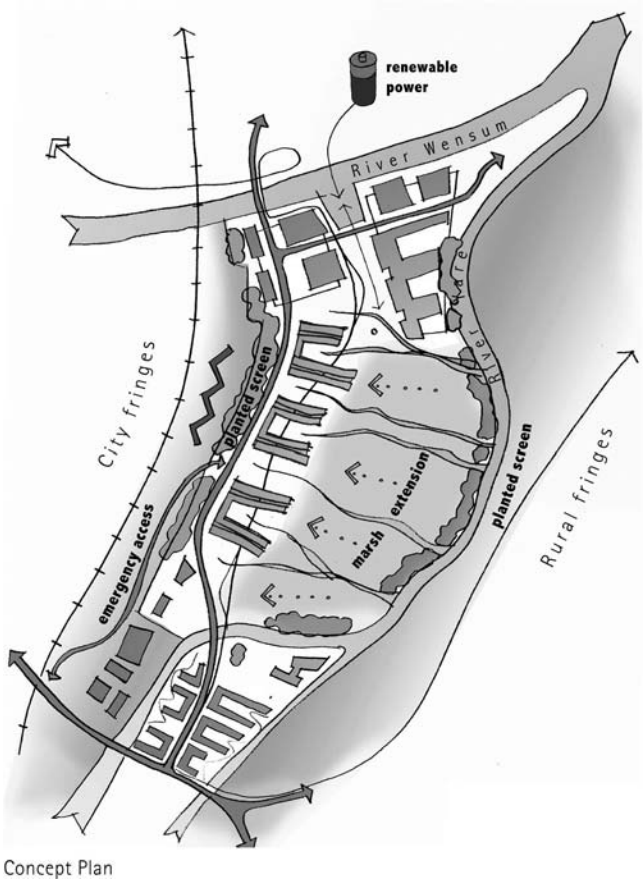
A masterplan that 'worked with water' was conceived, Figure 12.13, in which the marsh would be extended between development on higher ground, allowing flood water to flow around and (in some cases) under the buildings.

Development was located in the areas of least risk – Flood Zone 2, with some development located in an area of Flood Zone 3a. The County Wildlife Site is located in Flood Zone 3b therefore there was no development proposed in these locations.

The residential use proposed would be considered appropriate in Flood Zone 2 but would be required to pass the Exception Test where located in Flood Zone 3a. The restaurants and shops proposed in areas of Flood Zone 3a would be considered appropriate. Because the site is subject to flood risk it required a detailed FRA to demonstrate that the development would be safe over its lifetime and not increase risk elsewhere.

The redevelopment of the site would provide a number of sustainability benefits to Norwich and the area, which meant that if the flood risk could be managed over the lifetime of the development without increasing risk elsewhere it would be appropriate to redevelop. These benefits include:

- improved transport infrastructure, through the provision of a new cycle route, part of the Sustrans, national cycle network, two new bridges and improved public transport;
- environmental gains through habitat generation;
- management and enhancement of the County Wildlife Site, with better access;
- increased flood storage;
- provision of housing, including affordable housing;
- access to a further redevelopment site;
- an exemplar development, sympathetic to and enhancing the surroundings.



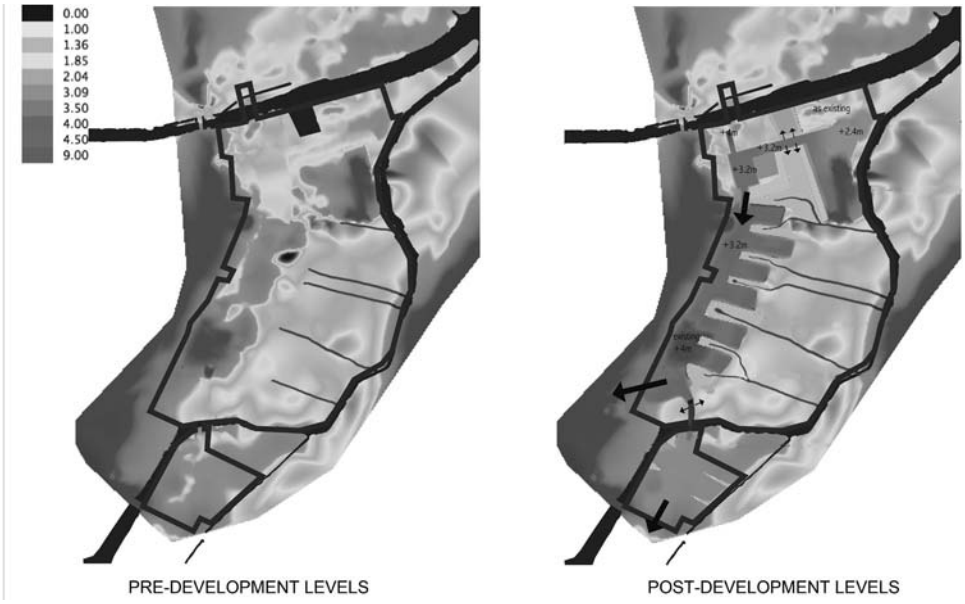
12.13 *Concept plan (© Baca Architects)*

5.4 Reducing flood risk

Because flood flows overland were found to be slow the critical concern was ensuring that the development was located above the peak flood levels.

The flood levels were not the same across the site, and the Environment Agency provided design flood levels generally based

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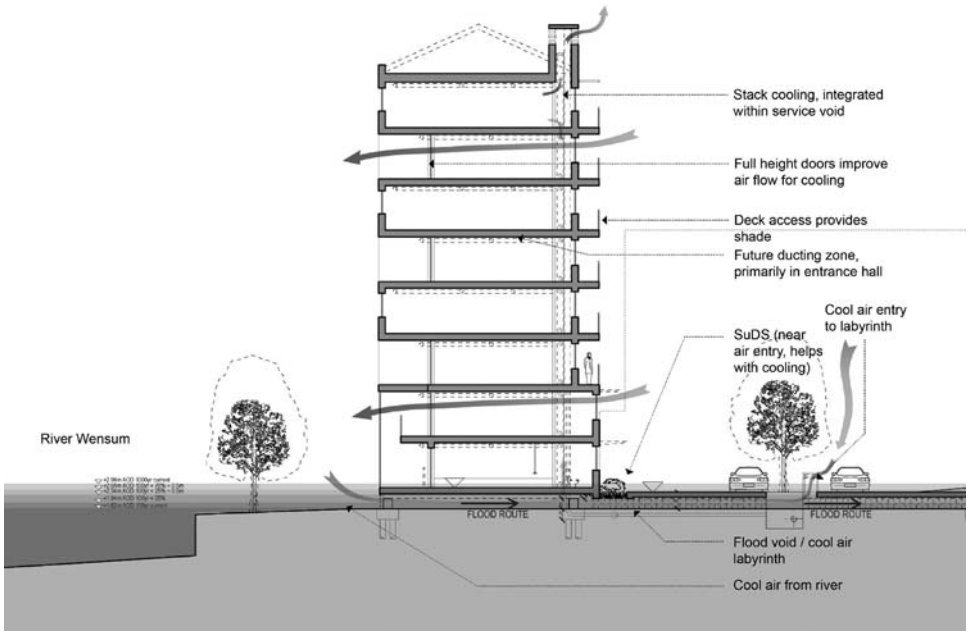
12.14 *Land level changes following development (source: Baca Architects & JBA Consulting)*



12.15 *Flood flows across the site during 1 in 1000 event (source: JBA consulting)*

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12.16 *Flood voids used for stack cooling (source: Baca Architects)*

upon the highest flood levels. Based on this guidance, the flood levels were as follows:

- 0.1% (1 in 1000) 3.09 m AOD
- 1% (1 in 100) + climate change 2.04 m AOD
- 1% (1 in 100) 1.85 m AOD
- 5% (1 in 20) 1.36 m AOD (for the May Gurney & middle of the Deal Ground), 1.24 m AOD (for the north of the Deal Ground).

The Environment Agency required the ground floor of the 'more vulnerable' residential uses to be located 300 mm above the 1 per cent (1 in 100) flood level including allowing for climate change, and the floors of the 'less vulnerable' commercial uses to be located 300 mm above the 5 per cent (1 in 20) flood level including allowing for climate change.

5.5 Design approach

The entire development adopts a non-defensive approach to flood risk management – meaning that there are no defences.

A combination of design measures has been used to create a comprehensive and an integrated flood risk management plan. These include:

- land raising, particularly below access roads;
- this is compensated by excavation of areas of corresponding height, increasing the overall flood storage, Figure 12.14;
- elevated building construction, raised on stilts, to the north of the site;
- flood resilient construction, elsewhere to cope with the risk of a flood exceeding the 1 in 100 + climate change level;
- sustainable drainage systems;
- safe access and escape through raised routes;
- flood warning and evacuation plan.

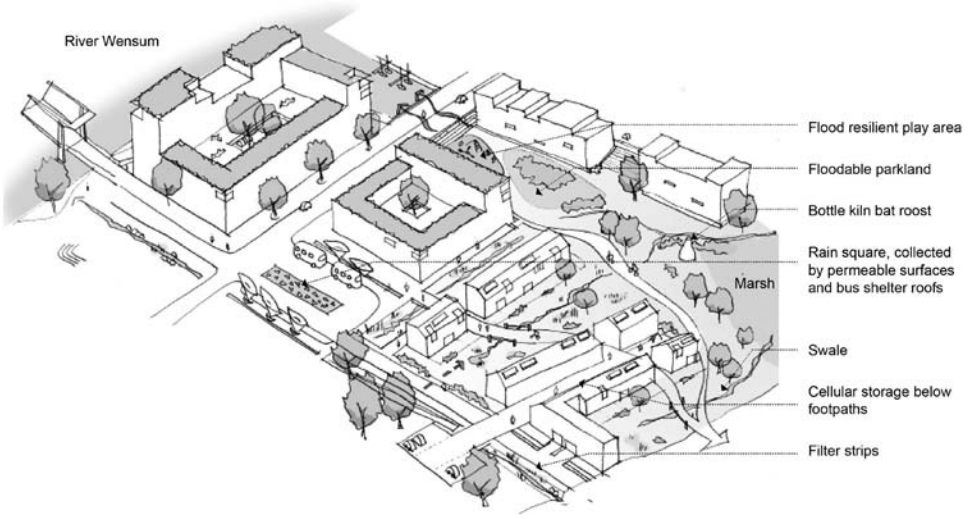
These measures have been integrated into the design, such that additional flood storage areas double as shared gardens, and local play areas. They have been designed between development areas to provide landscape features and separation between units. Two dimensional flood modeling was used to test the impact of the development on surrounding flood levels and to refine the scheme. Modeling during a theoretical 1 in 1000 probability flood, Figure 12.15 shows areas where the flood water passes beneath the buildings in flood voids.

The buildings and car parking along the River Wensum waterfront were all elevated without raising land levels to maintain the flood storage. In the following Climate Adaptive Neighbourhoods research carried out for the Technology Strategy Board, the cooling capacity of using the void beneath the buildings, Figure 12.16, to manage increased temperatures was calculated. In combination with a heavy building construction (also beneficial in providing flood resilience) and shading devices was found to tackle the overheating risk for future climate predictions up to 2080.

Infiltration systems would have been inappropriate because of the superficial geology on the site, high water table and previous uses on parts of the site. The system developed, Figure 12.17, combined the following:

- green roofs to apartment blocks;
- cellular storage below pedestrian streets;
- a 'rain square' detention basin;
- filter strips along road edges and parking areas to intercept run off;
- swales to channel water into drainage ditches;
- constructed wetlands in the form of extensions to the ditch system in the marsh.

This provides a robust system through the underground storage facilities combined with the environmental benefits of planted systems. An open storage facility within the proposed 'rain square', creates a demonstration of sustainable drainage systems in operation and educational facility, Figure 12.18.



12.17 *Sustainable Drainage System (SuDS)*



12.18 *Development located around an extension of the marsh (source: Atelier Pro)*

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13 Crime prevention design

Nick Hughes

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KEY POINTS:

- *Designing out crime is not an exact science; rather, it involves weighing up factors designed to minimise opportunities for criminals*
- *Consider Victim (or target), Offender and Location*
- *Designers of buildings should ask themselves: 'If I were to break into this building, how would I do it?'*

Contents

1 Introduction
2 Legislation and primary planning policy
3 Secured by Design
4 The principles of Crime Prevention Through Environmental Design (CPTED)
5 Access and movement
6 Surveillance
7 Layout and land use
8 Defensible space
9 Management
10 Parking
11 CCTV
12 Planting
13 Lighting
14 Security hardware
15 Planning companion guides and supporting documents

1 INTRODUCTION

CPTED is not an exact science; it is more a series of considerations that need to be weighed up in order to come up with a design that minimises the opportunity for criminals. CPTED can work on all levels from an individual property to a whole town or city. Whilst there is no definitive 'right answer', it is easy to spot the 'wrong answers' where CPTED has not been considered.

The 'Problem Analysis Triangle' explains why crime occurs. At the three apexes of the triangle are 'Victim (or target), Offender and Location.' It is the coincidence of these three in time and space that allows for a crime to take place. By working on the location, crime can be reduced even if there is still an offender and target present, such as a laptop by an open window. For example, a well-designed development with well-used and defined access routes, together with good surveillance from the houses opposite and the use of defensible space outside of the open window, might mean the offender feels s/he was less likely to get away with stealing the laptop.

Good CPTED has been proven to reduce the incidence of burglary, robbery and other crimes as well as anti-social behaviour (ASB). A 'Secured by Design' refurbishment of an affordable housing scheme in Glasgow resulted in a 75 per cent reduction in burglary (figures from Strathclyde Police). ASB manifests itself in many ways such as graffiti, fly tipping, drug taking, (underage) alcohol consumption and dog fouling. Good CPTED can reduce ASB and crime significantly, working as the antithesis of the 'Broken Windows Theory' (Wilson and Kelling), which can then lead to the increased legitimate usage of an area; this in turn increases surveillance and can create a sense of pride in an area and a stronger community spirit. This 'upward spiral' can continue, with safety and increased legitimate usage both positively influencing each other.

Conversely, poor design can create an environment in which those who commit crime and ASB feel at home. Legitimate users are then less likely to use the area and ASB and crime become the accepted norm, which in turn can lead to a downward spiral in which the seriousness of incidents can increase and go unchallenged by the local community.

Central to good CPTED is the early involvement of the local Crime Prevention Design Advisor (CPDA). CPDA is the more recent term for an Architectural Liaison Officer (ALO) but the difference is purely semantic. The local CPDA will have access to the local crime statistics and can speak to police colleagues to ascertain the specific problems in a given area. The introduction of various websites has made these statistics more accessible for the public but designers should not underestimate the advantage of having access to the knowledge possessed by local police officers. The term 'site-specific' is seldom more important than in the realm of CPTED. While good CPTED should be used regardless of the area, the level of security deemed necessary will vary greatly. Heights of fences, the location of parking provision and the required security ratings of locks and other hardware will all vary with location.

Sociological factors have a massive impact on crime rates and safety in a given area. What may be deemed necessary in terms of security will change with the demographics of the location; the level of required security depends on the likelihood of a crime happening in a given area.

In the world of policing, CPTED and crime reduction are closely related. Crime reduction has traditionally been split into 10 principles and there is overlap between these and the principles of CPTED. Indeed, one of the 10 principles is 'Environmental Design' – this essentially means CPTED. The most important distinction between the two is that CPTED is pro-active whereas crime reduction is reactive. Prevention is better than cure and a consideration at design stage of the themes to be discussed in this chapter can obviate retro-fit measures such as alley-gates, razor wire and the overreliance on CCTV. Having anticipated the potential crimes and ASB that may occur in and around a development, good CPTED makes the built environment less conducive for crime.

It used to be thought that by making the commission of offences harder in a certain location, crime, especially burglary, would be displaced to neighbouring areas. Research has disproved this assumption and there can even be a 'diffusion of benefits' (manifested as a reduction in burglary) to neighbouring areas. Research also shows that burglars tend to operate within a certain radius of their home and, when presented with less opportunity locally due to good CPTED, are not always willing to travel further afield to commit crime.

Good CPTED can make developments more sustainable. Taking the definition from *Our Common Future* (1987), sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. By reducing the opportunity for crime, CPTED aims to create safe and secure environments where, other factors allowing, residents can enjoy living and where community spirit can flourish.

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2 LEGISLATION AND PRIMARY PLANNING POLICY

- Circular 5/94 made crime reduction a material consideration in planning.
- Section 17 of the Crime and Disorder Act 1998 states: 'Without prejudice to any other obligation imposed upon it, it shall be the duty of each authority to which the section applies to exercise its various functions with due regard to the likely effect of the exercise of those functions on, and the need to do all it reasonably can to prevent, crime and disorder in its area.' The Local Authority, Police Authority and Fire Authority are included under this.
- Planning Policy Statement 1 (2005) states that design policies should ensure that developments, 'create safe and accessible environments where crime and disorder or fear of crime does not undermine quality of life or community cohesion'.
- Planning Policy Statement 3 states that the shared vision of the local planning authorities should develop design policies aimed at 'Creating places, streets and spaces which meet the needs of people, are visually attractive, safe, accessible, functional, inclusive, have their own distinctive identity and maintain and improve local character'.
- Planning Policy Statement 4 states: 'Local planning authorities should manage the evening and night-time economy in centres, taking account of and complementing the local authority's Statement of Licensing Policy and the promotion of the licensing objectives under the Licensing Act 2003. Policies should: set out the number and scale of leisure developments they wish to encourage taking account of their potential impact, including the cumulative impact, on the character and function of the centre, anti-social behaviour and crime, including considering security issues raised by crowded places, and the amenities of nearby residents.'

3 SECURED BY DESIGN

The term Secured by Design (SBD) is owned by the Association of Chief Police Officers (ACPO) and is the corporate title for a group of national police projects focusing on the design and security for new and refurbished homes, commercial premises and car parks as well as the acknowledgement of quality security products and crime prevention projects. It contains two key elements:

- Part 1 – Layout and design
- Part 2 – Physical security.

The local CPDA administers the developments that apply and ultimately decides if developments have reached the required standard. Developers can apply for compliance with both parts or just with Part 2. Early involvement of the local CPDA is vital and officers should be consulted at all stages from initial design through to handover to the end user.

4 THE PRINCIPLES OF CPTED

The principles overlap and it is difficult to neatly categorise all considerations. Other CPDAs may choose to put the principles into different categories although there is a general consensus over the themes and considerations outlined here. This is why the principles should all be considered together when designing a development.

5 ACCESS AND MOVEMENT

'Safer Places' defines the ideal as 'places with well-defined routes, spaces and entrances that provide for convenient movement without compromising safety'. The word 'permeability' is used to define the ease with which someone may move through an area, whether on foot or in a vehicle. The number of roads/paths and the ways in which they interconnect are at the heart of this issue. Due to the factors mentioned below, cul-de-sacs can prove to be very safe places to live providing that there is only one way in and out, and there are no paths or alleys leading out of the end. Cul-de-sacs with large numbers of houses or networks of cul-de-sacs leading off each other also work to counteract the inherent safety of the design.

Considerations in this topic are:

- Are all of the routes necessary? To and from where does it provide access, and is this access needed? The higher the number of routes, the fewer the average number of users for each route. A large part of personal safety is avoiding quiet routes so increasing the number of footpaths will inevitably result in some of them being underused and therefore potentially less safe. A balance needs to be struck between the need for easy movement and over-permeability. An excess of routes means that a criminal has a variety of escape routes and can come and go to the scene of a crime easily without passing the same house more than once. As the criminal does not want to be spotted or to arouse suspicion, the anonymity afforded by a large choice of exits suits their needs.
- Do the access routes divide users of different types? Having footpaths alongside roads rather than separated from them allows for more passive surveillance of the path by road users, thus (in theory) making them safer.
- Has access to the back of the property been minimised? The majority of burglaries involve entry from the rear, therefore public access should be restricted. Different research quotes the percentage of burglaries that involve rear access as anywhere from 55 to 80 per cent. The proliferation of alley-gating schemes across the country has been necessary due to the large number of older estate designs that incorporated rear lanes, often for coal delivery. Many of these lanes and alleys are not used by the residents but instead provide burglars with secluded and unobserved access to the rear of houses.
- Are the footpaths designed with safety in mind? Where they are not adjacent to roads, paths should be wide, straight and well over-looked. They should ideally be at least 3 m wide with a 2 m verge or mown strip on either side. There should be no possible hiding places, therefore trees or shrubs should be set well back from the path. Subways and underpasses should be avoided where possible. If this is not possible, they should be as short and wide as possible, well lit, with chamfered entrances.
- How legible and easy to navigate are the routes? Locals and visitors should be able to find their way easily. Signs should be clear and the routes should be easy to understand.

6 SURVEILLANCE

Surveillance can be split into two categories: formal and informal. Formal surveillance means a person or system is specifically there to keep watch on an area. A CCTV system or a security guard would be an example of this. Informal, or 'natural', surveillance is that which occurs as people go about their everyday business. People have not been asked or employed to keep watch but they oversee nearby people and places merely by their presence.

Sociological factors play a large role. The principle of safety through surveillance relies on the assumption that it acts as a deterrent because people who witness a crime may intervene or call the police. In reality, people may choose to turn a blind eye; just because a place is well populated does not necessarily make it safe. A crowded street with lots of people in close proximity may be the ideal environment for a pick-pocket, for example. Surveillance should therefore be seen as a vital part in the overall design rather than as a panacea.

The main considerations here are:

- Do blank walls face the public realm? All aspects of buildings fronting the public realm should have windows. A commonly used term for this is 'active frontages'. Windows are the obvious

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ways to offer the chance for surveillance and even if it is unlikely that someone may be looking out, a window may deter a criminal as there is at least a chance he may be seen. In order to generate the maximum amount of surveillance, thought should be given to the use of the room containing the window. The chance of seeing something from a bed/bathroom is lower than from a sitting room or kitchen. Frosted glass would also indicate that the room is likely to be a bathroom and therefore being observed is less likely.

- Is parking overlooked? Surveillance over parking is crucial unless the car park is secure with good access control. The issues with parking are discussed in their own section.
- Does planting reduce surveillance? Trees and bushes can block lines of sight (for CCTV cameras as well as for people) and can also provide hiding places. Careful thought should be given to the location of planting and to the maximum growth heights. What may start as a low shrub may grow into a large barrier to surveillance and a climbing aid for criminals. Some trees have high canopies that allow clear lines of sight underneath. Canopy heights should be no lower than 2 metres from the ground. Together with the use of shrubs with a maximum growth height of 1 metre, such trees still allow for a window of surveillance between 1 and 2 metres.
- How will it look in the dark? Lighting must also be considered when discussing surveillance. If the designer wants an area to be visible 24/7, then it must be lit to an appropriate standard.

7 LAYOUT AND LAND USE

Building type and usage, together with the nature of the boundaries between them and how they interact with each other and with the intervening spaces, are all vital considerations in good CPTED. The land uses and spaces within a development should all be considered together rather than fitting in the 'less important' (often meaning less profitable) features in the remaining space regardless of their suitability, as is often done with playgrounds or public open space.

Consider:

- How compatible are neighbouring uses? Consider whether segregating or mixing land use would be beneficial. There are pros and cons to each choice and consideration of local context is therefore important. Segregating uses might mean that traffic and noise associated with businesses do not disturb residents; but this may mean that there would be no local residents to act as a deterrent to commercial burglars overnight.
- Has the impact of possible 'crime generators' been considered? Crime generators comprise built environment elements that can act to increase crime. Out-of-scale facilities such as large shopping centres can have a detrimental effect on the local area. The increased traffic and daytime population of these areas can bring associated crime problems which work against the fostering of a local community spirit. 'Honey pots' are another potential crime generator. These are facilities such as pubs, takeaways or convenience stores that encourage people to congregate and loiter in an area, thus potentially causing ASB and disturbance to local residents. Care should be taken when deciding where to position such places within a development so as to minimise disruption while maximising legitimate usage. Consider grouping them together to minimise the proliferation of negative impacts.
- How many faces of a building front the public realm? The number of such faces should be minimised to improve security and reduce access. For residential properties, it is generally safer to have gardens flanked by other gardens, with just the front of the property facing the public realm. Side access should be gated as close to the building line as possible.
- What boundary treatment option has been chosen? Using the 'onion peeling' principle of crime reduction, intruders should be stopped as far from the interior of the building as possible. Rather than letting people have access to the shell of the building itself, stopping them at the boundary is preferable. The standard height of boundaries to the rear and side of residential properties is 1.8 metres; local crime statistics may suggest higher boundaries are required. Gates should be the same height as the boundary to either side. There are many options for boundary treatments:
  - Wooden fencing is cheap but can be flimsy and lack longevity. If using featherboard fencing, ensure that the horizontal rails are on the inside to avoid creating a makeshift ladder for intruders. The addition of a trellis to the top of fencing adds height and acts as deterrent as it breaks noisily if climbed. Thorny plants trained along a trellis are a further deterrent.
  - Walls are sturdy but can attract graffiti. Consider using coping stones or angled bricks on the top to deny handholds to those trying to climb in. Low walls at the front of houses may be used as seats so consider angled bricks or another topping to prevent this.
  - Hedges can be cheap and attractive but may require maintenance and could potentially be breached using secateurs. Some thorny varieties can provide excellent protection.
  - Railings and metal fences allow surveillance and can be very strong but can look too imposing or institutional. Weldmesh or expanded metal fencing is generally considered to be a preferable option to 'pallisade' style fencing.

8 DEFENSIBLE SPACE

This term, coined by Oscar Newman, is a fundamental concept of CPTED. Defensible space describes the area over which one feels a sense of ownership or responsibility, whether individual or collective. At the micro scale, this may be a back garden. At the macro scale this may be a park that is part of the identity of a city of which the city's inhabitants are proud. The theory is that if an individual or group has (or feel they have) ownership and responsibility for an area, then someone who does not share this (perceived) ownership stands out and is less welcome – especially if misbehaving. People feel the right to challenge others who do not belong in their defensible space.

By clearly defining space and giving it a use and ownership, those who own it are more likely to take care of it, especially if that group is small.

Front gardens are an example of defensible space. There is an implied permission to access the front door to deliver a letter but no right-minded person would argue that they had the right to sit therein to eat their lunch. Contrast this with houses that front directly on to the pavement. Members of the public have a free right of access right up to the building line and the resident could not legitimately ask pedestrians to move.

Blocks of flats have traditionally had undefined areas of public space between them, over which residents have no control. Demarcating that space and assigning it to different blocks would be a way of improving control in the hope that residents would take care of it if they felt it was theirs. Whilst this does not always happen in practice, it is usually an improvement on any indistinct space that existed previously. Linking back to the idea of anonymity mentioned in the section on Access and Movement, criminals are more likely to be denied anonymity and to feel that they stand out in an area with clear ownership over which someone obviously takes pride.

The boundaries to such space need not be high and may comprise merely a line of low plants or a change of texture/colour of the pavement or road. A sign may suffice or a high fence may be needed. The main principle is that it becomes clear to the outsider that this space is not for free roaming.

Points to consider are:

- Is there a buffer between the private and public realm?
- Is the intended use for each area clear, such as a car park, playground, garden etc.?

- Are the boundaries between the different areas clear? Could anyone reasonably claim they thought they were in a fully public area when they were not?
- How many people 'own' or have shared responsibility for a space? The higher the number, the lower the sense of individual responsibility felt by each member of the group (in theory).
- Has the appropriate boundary been chosen? Does it need to be visually permeable or would a solid wall or fence be better? How high should it be? Could the boundary be symbolic rather than a physical barrier?
- Have local people been consulted and involved in the design of areas for their use? Consultation can help to foster a feeling of ownership among users; this approach has had particular success for youth facilities. Community murals are another example of where involving local people in a project can help to engender pride in the result. Murals are often left relatively graffiti-free in comparison to nearby blank walls.

9 MANAGEMENT

Good CPTED should ensure that a new development will deter criminal activity. If, however, no thought is given to ongoing maintenance and management then design work may go to waste as the area deteriorates over time. Linking back to the 'broken windows theory', quickly addressing minor issues can prevent them becoming serious as it sends out a clear message as to what will be tolerated in the area. In order to be sustainable, ongoing management must be considered. Points to consider are:

- If management is needed, who will pay for it? Will a residents' committee or management company be needed?
- What quality are the materials, products and finishes? Consider how long everything should last. Using cheaper products may eventually lead to problems.
- Will plants need maintenance such as cutting and watering? Is there access for maintenance vehicles.
- Will roads be adopted? If not, then there are many issues to consider such as lighting, road repairs, refuse collection etc.
- Are there sufficient bins to minimise littering, thus preventing excessive street cleaning?

10 PARKING

The best CPTED option is to accept parking as part of the design challenge and to make appropriate allowance for the safe and secure parking of vehicles. Individual integral garages tend to be the safest, followed by 'in-curtilage' parking (i.e. on a drive/parking space on the residential plot), on-street parking visible from the house, followed by remote car parks. In the case of the last option, gated parking courts can vastly increase the security. It should be borne in mind, however, that if people park in a rear court, they tend to enter the house from the rear for convenience; this often means rear garden gates are left unlocked and the back of house becomes used as the front.

Convenience plays a big role in people's decision of where to park; few people want to walk far to their car. This can clearly be seen at work in many newer estates where parking courts are ignored in favour of 'fly parking' in front of houses on roads not designed to accommodate it. Consider:

- What type of parking (on-street, parking court etc.) should you select? A mixture of types may work best and will depend on many things including topography, the likely occupant and proximity of local services.
- Is the parking option safe and convenient? If it is not both of these things then many will choose not to use it.
- Are the spaces allocated or not? Research by Jenks and Noble (1996) indicates that more spaces are needed if a high number of them are allocated.
- If not parked in garages, can residents' cars be seen from houses? Trees and shrubs can hinder surveillance. Car ports are often a 'worst of both worlds' option; they do not allow for surveillance yet are not secure and can act as impromptu shelters.
- Is the car park lit to appropriate standards (BS 5489 and BS EN 13201)? Lighting helps with surveillance and makes people using the car park feel safer.
- Is the car park easy to navigate with separate spaces for vehicles and pedestrians? Clear signage and different ground colours can be useful in this regard.
- If the car park is underground, could it be a target for terrorism? Counter-terrorism security advisors (CTSAs, contactable through the local constabulary) can advise on these issues. Vehicle borne explosive devices are even more lethal if detonated beneath a building rather than outside it. The use of the building above (e.g. as government offices) or the potential for large numbers of casualties (e.g. under a shopping centre or stadium) may indicate a higher vulnerability and necessitate 'hostile vehicle mitigation' or mean that an underground car park is not suitable.
- Is CCTV necessary?

11 CCTV

Per capita, there are more CCTV cameras in the UK than in any other country in the world. As the UK is not the safest country in the world, it follows that CCTV is not the answer to all problems of security. It does have an important part to play in improving security but should not be relied on in isolation. The single most important question is 'Why is the system there?' If designers cannot answer this question, they should ask why CCTV is being installed. An 'Operational Requirement' should be the starting point for a new system. Many systems provide images of poor quality and of no use for investigating crime. Many also do not comply with the Data Protection Act. CCTV may act as a deterrent but to be effective in this regard, someone should be watching the pictures live and be in a position to call the police. A well-designed system considered at design stage can be an excellent crime reduction tool.

Consider the following:

- Will images be monitored or will they merely be looked at retrospectively if something occurs?
- Are fixed cameras sufficient or are 'pan, tilt, zoom (PTZ)' cameras needed? PTZ cameras would be more suited to a monitored system, enabling an operator to track a person/vehicle.
- How many frames per second (FPS) will each camera record? Twenty-five FPS is broadcast standard. The higher the number, the smoother the image transition and the lower chance of missing something. All of the images need to be stored and the higher the frame rate, the more storage is required. Multiply the frame rate by the number of cameras by the amount of time the images are stored for (usually 31 days) and data storage requirements quickly mount.
- How close-up does the image need to be? 'Identification quality' images used to secure convictions usually require the person to fill the frame. This means that only a small field of view is covered by the camera. If the purpose of the camera is merely to see if someone is present in a part of a site, then a much larger field of view will suffice. Designers must know what they want from each camera.
- Does the camera need to function in all light conditions?
- Can images be exported easily, e.g. to a disc for police after an incident?

12 PLANTING

Planting can hinder or help a CPDA. Again, this should be part of the design process rather than considered as an after-thought. Consider:

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- Will the plant block surveillance, street light or a CCTV camera? Remember: maximum 1 metre growth height for shrubs and minimum 2 metre canopy height for trees.
- Is the species suitable for the location? What size and shape will it be when fully grown?
- Will it act as a climbing aid? Expensive fences can be made redundant by running them alongside an easily climbable tree.
- Will the plant offer a hiding place?
- Will the plant require ongoing maintenance and who will pay for this?
- Can thorny plants be used to enhance security, especially around boundaries? Species such as berberis, pyracantha and brambles all help deter intruders.
- Can shrubs be used to help create buffer zones? Low planting against a wall helps keep people a certain distance away so could prevent access for graffiti. It could also reduce access to a vulnerable ground floor window.
- Can planting be used as a means of marking out (defensible) space? A line of low shrubs may stop people cutting across the corner of an unfenced front garden.

13 LIGHTING

The CPDA can provide some advice but a qualified lighting engineer will be needed for developments of any significant size. Good lighting has been proven to reduce the fear of crime but has a less proven effect on actual crime. Reducing fear of crime can, however, lead to increased legitimate use of an area, which can in turn make the area safer. Lighting facilitates surveillance and can be essential for CCTV and road safety.

Footpaths should be lit to the same standard as the adjacent road so that pedestrians are not in shadow. Uniformity is vital and lighting schemes should achieve an even spread of light so as to avoid pooling and shadowing, unless there is a specific reason not to. To work out the uniformity, divide the average lux into the minimum lux and express this as a percentage; 25 per cent is the minimum; 40 per cent and above is the usual aim. Lighting should be in accordance with BS EN 13201 and guidance on lighting design is given in BS 5489.

Points to consider are:

- Why is lighting needed? If the area or building gets no use during the hours of darkness then what is the use in lighting it? It may just facilitate criminal activity. If no one can overlook the area, no increased surveillance is facilitated by the lighting.
- Has light pollution been minimised? The light should be trained to where it is needed and prevented from spilling. 'Security' lights activated by PIR sensors can irritate neighbours and dazzle road users.
- How will the light be activated? Some turn on automatically in low lights, whereas others are activated using a switch or a PIR sensor. Energy efficient lights illuminated all night are the preferred security option over PIR-activated types and are usually cheaper to run than bright lights that turn on and off in reaction to movement.
- What type of 'bulb' will be used? High pressure sodium, metal halide and LEDs are all options. The 'colour' of the light is important. Clear daylight is represented as 100 on the colour rendering index and allows for excellent differentiation between colours. Low pressure sodium on the other hand gives a very orange light under which many colours appear similar.
- What housing will be used and at what height? Bollard lighting can be vulnerable to vandalism, can be a reversing hazard and can fail to illuminate the faces of anyone approaching; it therefore becomes difficult to judge if people appear friendly or not.

14 SECURITY HARDWARE

The 'Secured by Design' scheme goes into great detail on this topic. The 'New Homes 2010' document is the guide used by CPDAs. Much hard CPTED work can be negated by fitting inferior hardware. Doors, windows, gates, fences and the locks and bolts used to secure them are essential elements of a development. Compliance with Part 2 of SBD is all about using the right hardware and this alone can hugely reduce the risk of burglary.

If additional security is needed such as roller shutters, then it is easier and cheaper to design this in at the start rather than installing them later. Other design features may assist the burglar in bypassing hardware. Walls, porches, flat roofs etc. may facilitate access to first floor windows that are more likely to be left open or unlocked. Designers should imagine how they would break into the building they are designing.

15 PLANNING COMPANION GUIDES AND SUPPORTING DOCUMENTS

Below is a list of reference material. This list draws from the introduction to the booklet *The Compendium of Crime Prevention and Reduction in the Planning System* compiled by Thames Valley Police (http://www.thamesvalley.police.uk/compendium-intro.pdf). The compendium is an excellent guide and index to the advice on CPTED contained within the listed documents:

Better Places to Live by Design A Companion Guide to PPG3, Commission for Architecture and the Built Environment, 2001.

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For more information on Wilson and Kelling's 'Broken Window Theory', see, for example, http://www.theatlantic.com/magazine/archive/1982/03/broken-windows/304465/?single_page=true.

More information on Oscar Newman and defensible space can be found at http://www.defensiblespace.com/start.htm.

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14 Agricultural buildings

John Weller, Rod Sheard, Frank Bradbeer and others

CI/SfB: 26, 565

KEY POINTS:
- *Farming is an industry subject to continual change*
- *Animal welfare and concern about pollution is leading to legislative constraints, both domestic and European*

Contents

1 Introduction
2 Farm animals
3 Farm machinery
4 Dairy cattle housing
5 Beef cattle and calf housing
6 Sheep housing
7 Pig housing
8 Poultry housing
9 Crop storage and effluent produced
10 Equestrian design
11 Building legislation
12 Bibliography

1 INTRODUCTION

1.1 The agricultural economy

Agriculture in the UK and also in the rest of Europe (particularly in the West) is becoming big business. Small farms and small farmers are becoming increasingly rare; marginal land is coming out of production. Owners of hitherto agricultural land are seeking other revenue-earning uses such as golf courses.

1.2 Planning

Buildings, irrespective of the enterprise, should be planned in terms of their functions for storage, processing or production. Food, like other industrial processes, should be designed for materials handling and flow-line production. Superimposing linear buildings within or over traditional courtyard forms is both a visual and a tactical problem.

Stock housing produces effluents. Farm waste management is an essential part of the building design and increasingly subject to statutory control. Wastes should normally be recycled, provided that this is done safely.

1.3 Building functions

Depending on managerial philosophy, building functions may be specialist, semi-specialist or flexible in their form. Farmers tend to equate flexibility with general-purpose layouts and with low capital investments; this can be a false equation. The loss of quality control, often difficult to evaluate, makes most 'cheap umbrellas' poor performers for specific end products.

The demand for flexibility reflects two factors – lack of confidence in stable markets and the rapidity of technical change. UK food production is essentially controlled by EU policy (via CAP, the Common Agricultural Policy), which aims at market stability. Technical change is liable to continue, although expansion of power demand may become more selective.

1.4 Stock housing and storage requirements

In simple terms, most storage requirements are those of containers: cylinders, bins and bunkers. Wide-span portals are suitable for some layouts for cattle, bulk storage and general farm machinery. Compact and insulated 'boxes' of low profile are best for calves, pigs or poultry. They may include total or partial environmental control. In contrast, 'kennels' are cheaply framed, semi-open, mono-pitch structures suitable for some cattle and pig layouts.

1.5 Construction and procurement

Most buildings are partially or wholly prefabricated, or are purchased under package deals. Standard frames can be obtained 'off the shelf' and infilled by 'self-build'.

Performance specifications are rare. Overall costs are lower than for most buildings of similar type, partly due to lower standards being demanded (see BS 5502, *Buildings and Structures for Agriculture*, in its many parts).

1.6 Lifespan of buildings

Most pre-1960 buildings are inefficient for modern production and many traditional buildings are redundant. A few are suitable for casual storage, administration, isolation units or spare boxes. The issue of redundancy is not easy to resolve. Some historic barns have been dismantled and relocated. Tourism, recreation and craft work are all encouraged in rural areas. A tenth of all farms have some tourist income. In upland areas, it may be the principal source of income. Farm planning should allow for alternative uses for buildings and land.

The normal economic life for farm buildings is ten years, though some are depreciated over five. This is a major design constraint. Some estates may permit a longer term of 20–60 years, especially for 'umbrella' enclosures. Grants are available for all except plastic, cheap tents and for factory farms (i.e. without supporting land). EU grants are more generous but require carefully prepared development proposals.

The moving, alteration or demolition of historic farm buildings may be subject to listed building legislation. Some unlisted structures are also subject to listed building consent because they are curtilage structures to a listed farmhouse or manor house: the demolition of an unlisted but curtilage building usually requires listed building consent even if their alteration and repair does not.

1.7 Appearance

Farm building appearance, especially since many are exempt from control and since most are cheap compared to other building types, is a contentious issue. Simple forms, good colour, defined planes and coordinated fittings such as vent pipes and flues, combined with careful siting and landscaping, make buildings acceptable. However, large roof surfaces are likely to conflict with vernacular buildings and can, near rising land, become dominant. Component design is often poor and unrelated to the basic structure. Surrounds to buildings, including yards, tanks, fences, etc., are often more unsightly than the buildings.

1.8 Criteria

Farm management in relation to resources of land area and terrain, climate, soil, capital, etc. is such that every farm building problem is different, despite prefabrication, package deals and BS 5502. In many enterprises, it is difficult to establish a good design brief.

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The basic layout, Figure 14.1, shows the relationships between the elements of the farm and the main service road. Figure 14.2 shows a typical farm.

2 FARM ANIMALS

Average sizes and weights of animals are shown in Figure 14.3. Width of animal given is normal trough space allowed (i.e. about two-thirds of overall width). Length given is normal standing (not fully extended).

3 FARM MACHINERY

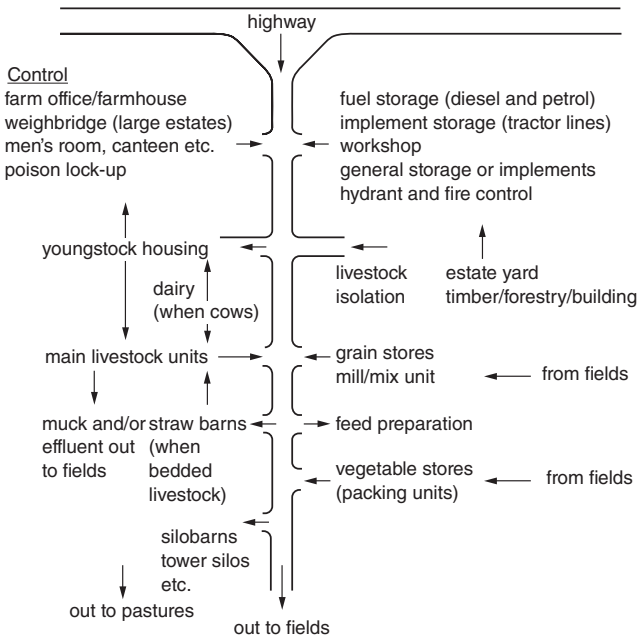
Average sizes and weights of tractors and other machinery are given in Figure 14.4.

4 DAIRY CATTLE HOUSING

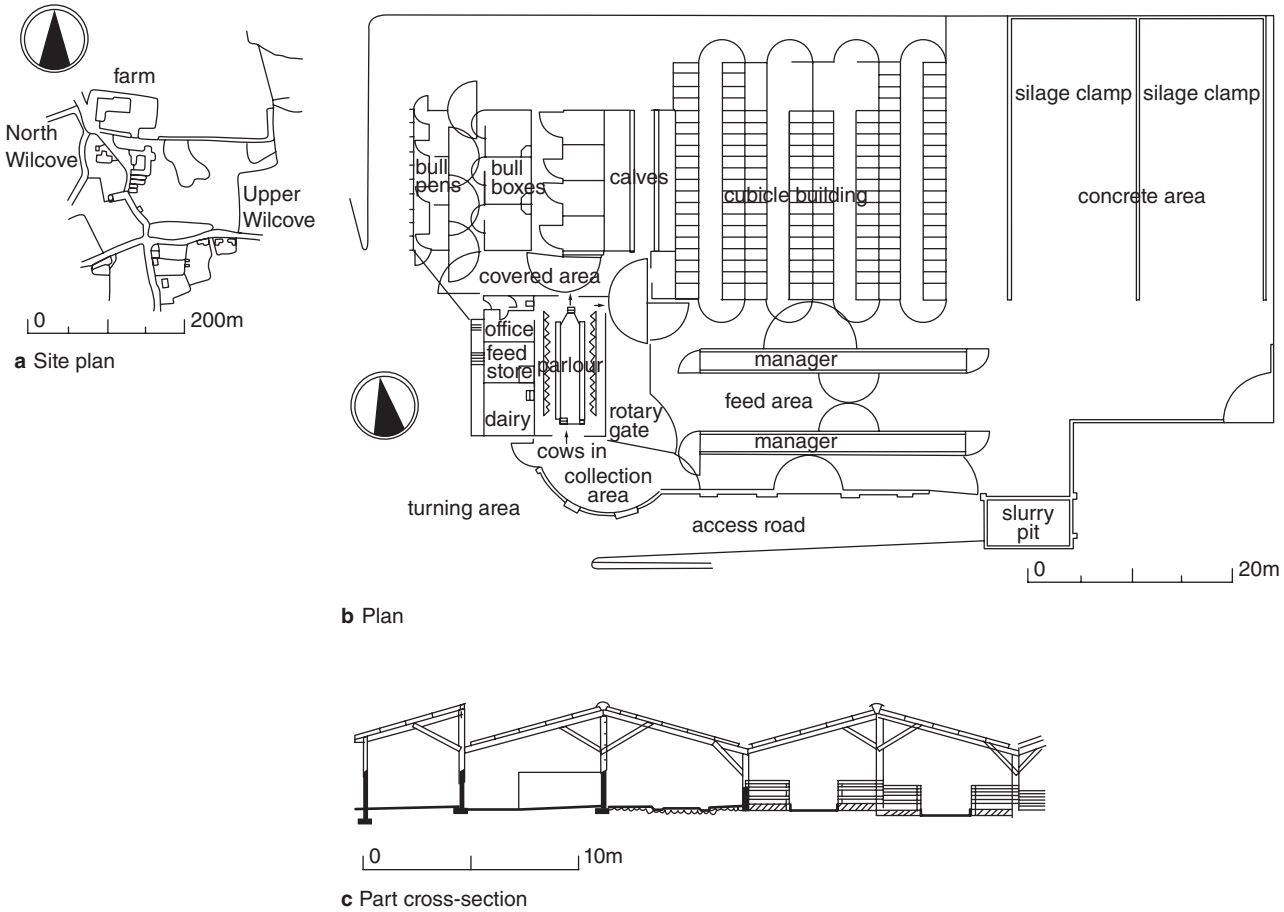
Table I gives dimensions for cattle housing; examples suitable for a 120-cattle unit are shown in Figures 14.5 and 14.6. A typical cubicle house is 27 m wide × 55 m long plus 10 m turn area at one end plus a 4 m road. A 'kennel' has the same basic dimensions but the roof is lower and is held by the cubicle division and the passage is not completely roofed, as Figure 14.7. Various systems of milking parlour are shown in Figure 14.8. Rotary parlours are now considered obsolete, and the current favourite is the herring-bone, Figure 14.9.

5 BEEF CATTLE AND CALF HOUSING

Straw-covered and slatted yards for beef cattle are shown in Figures 14.10 and 14.11. A calf house illustrated in Figures 14.12 and 14.13 is a 'general-purpose' straw-covered yard for cattle (700 mm/head for manger for adults, 500 mm for yearlings).

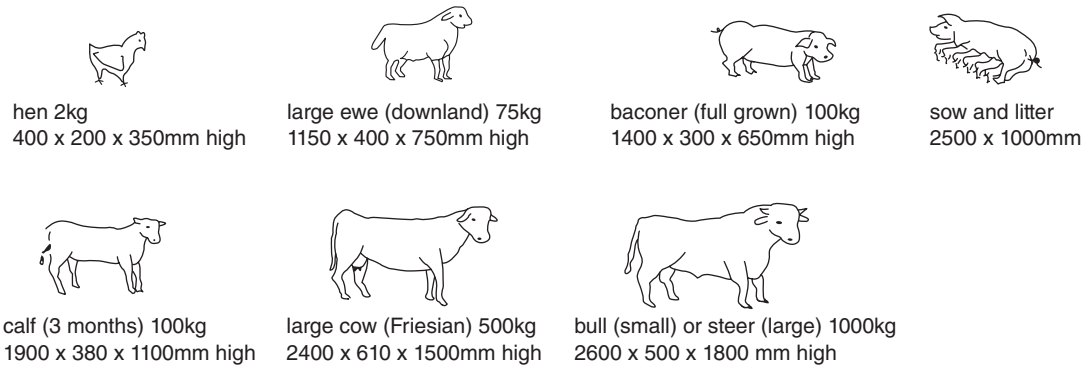


14.1 *Basic layout, mixed arable and stock farm. Although the arrangement shown has been stylised, in fact farms are usually linear to the main service road*

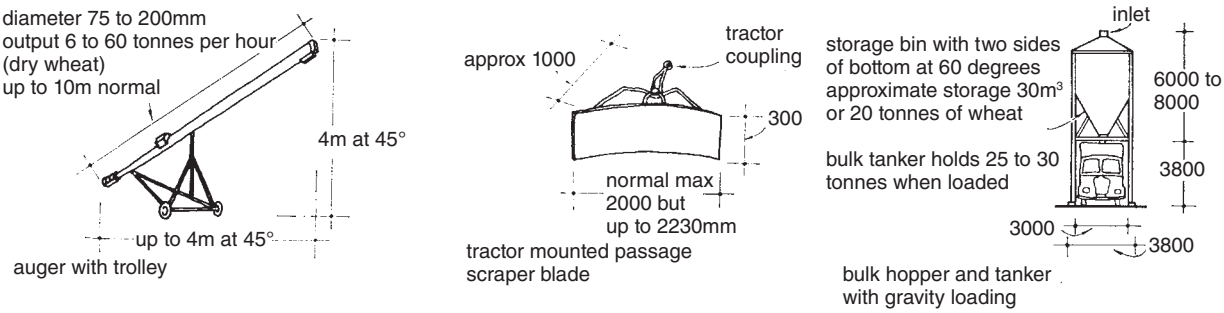


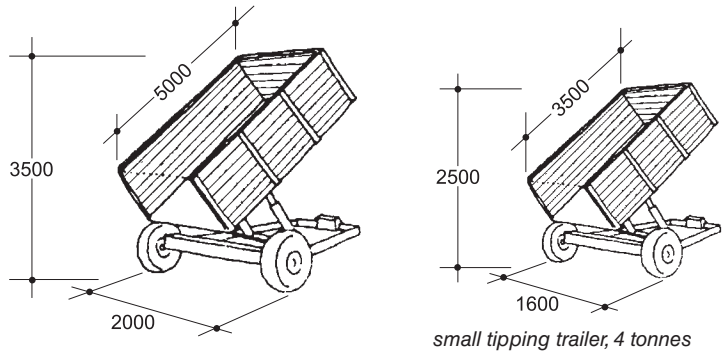
14.2 *Typical farm: Wilcove*

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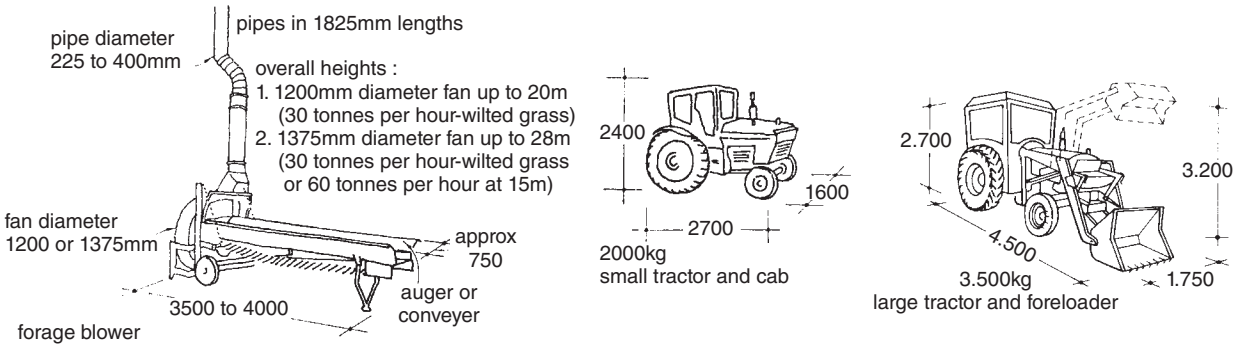
14.3 *Farm animals: average size and weights*

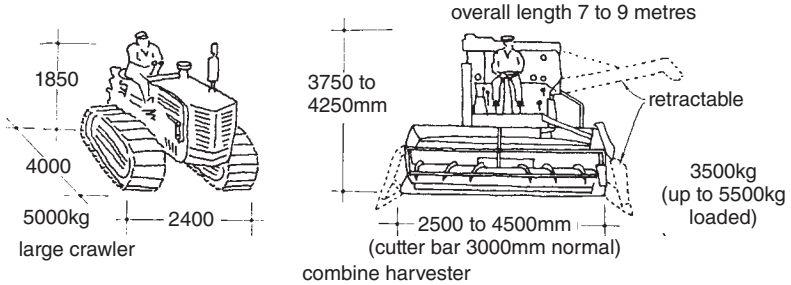




large tipping trailer, 7 tonnes load

small tipping trailer, 4 tonnes load



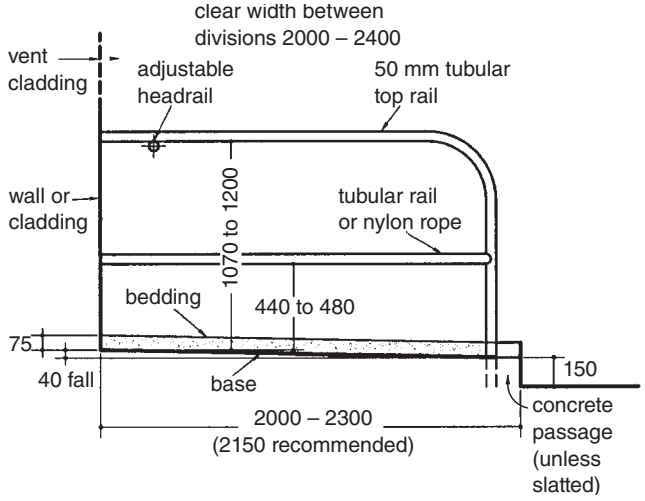


14.4 Farm machinery: average weights and sizes

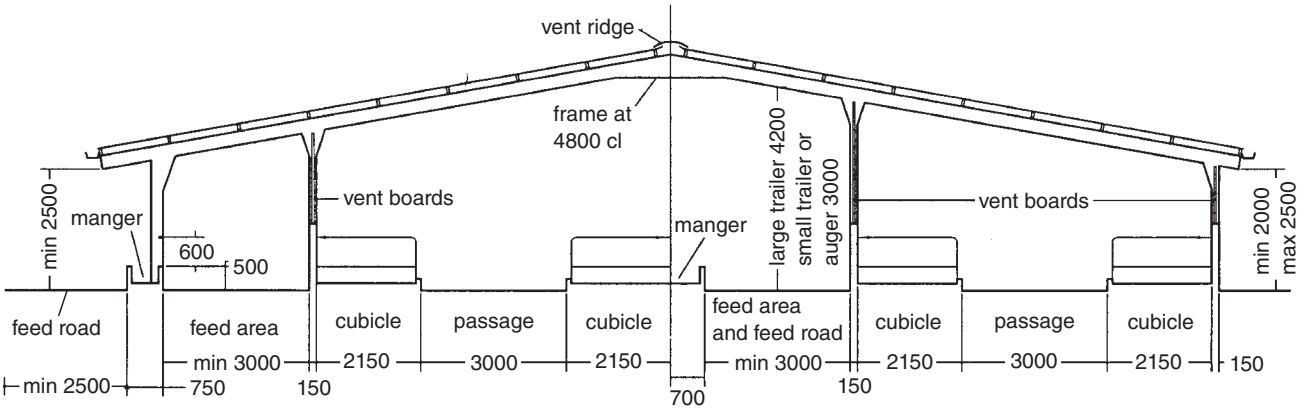
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Table I Dimensions of cattle housing

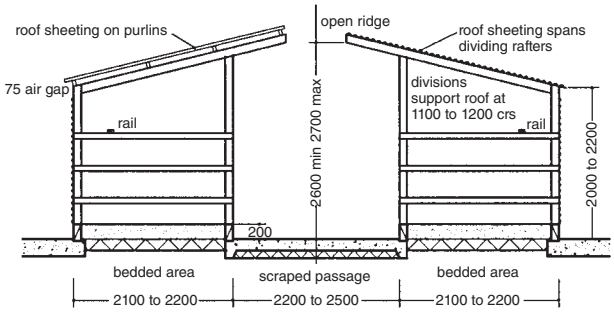
	Dimensions of cubicles (m)					Dimensions of cowsheds (m)			
Mass of cow (kg)	Length including kerb	Length behind trough	Minimum clear width between partitions	Length of standing without trough	Length of standing behind 0.75 to 0.9 wide trough	Clear width between stall divisions of a two-cow standing	Gangway width	Minimum width of feed passage (if any)	Longitudinal fall along gangway and dung channel
350–500	2.00	1.45	1.00	2.00	1.45	2.00	Single range: 2.0	0.9	1%
500–600	2.15	1.60	1.10	2.15	1.60	2.15			
600–650	2.30	1.80	1.15	2.30	1.80	2.40	Double range: 3.0		
650–700	2.30	1.80	1.15						
700–800	2.50	2.00	1.20						



14.5 *Section showing cubicle division: dimensions for Friesian cows*

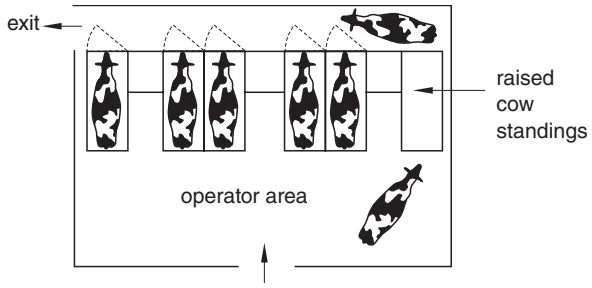


14.6 *Alternative sections of cubicle house showing perimeter feeding to left of centreline, centre feeding to right*

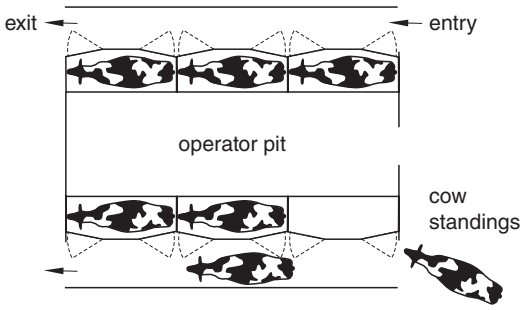


14.7 *Section through kennel for beef or dairy cattle*

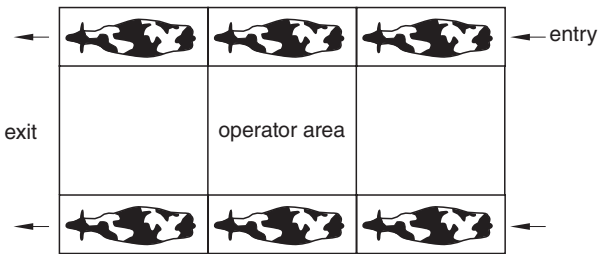
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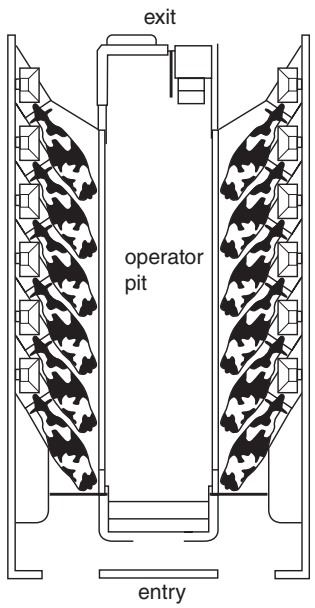
a *abreast*



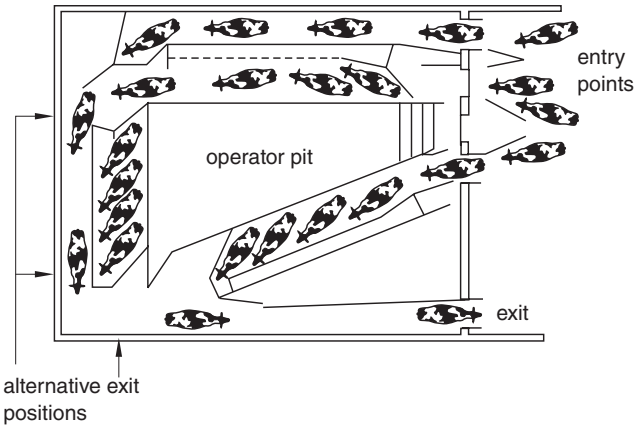
b *tandem*



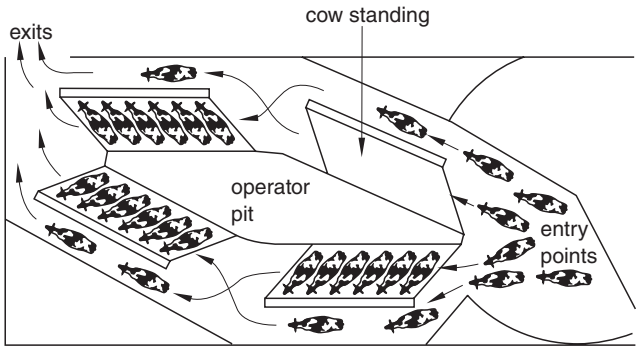
c *chute*



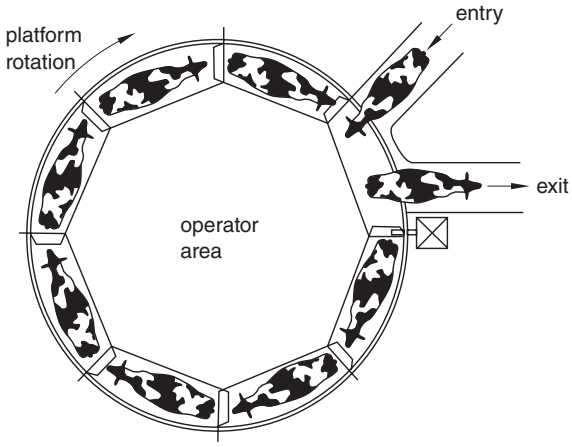
d *herringbone*



e *trigon*



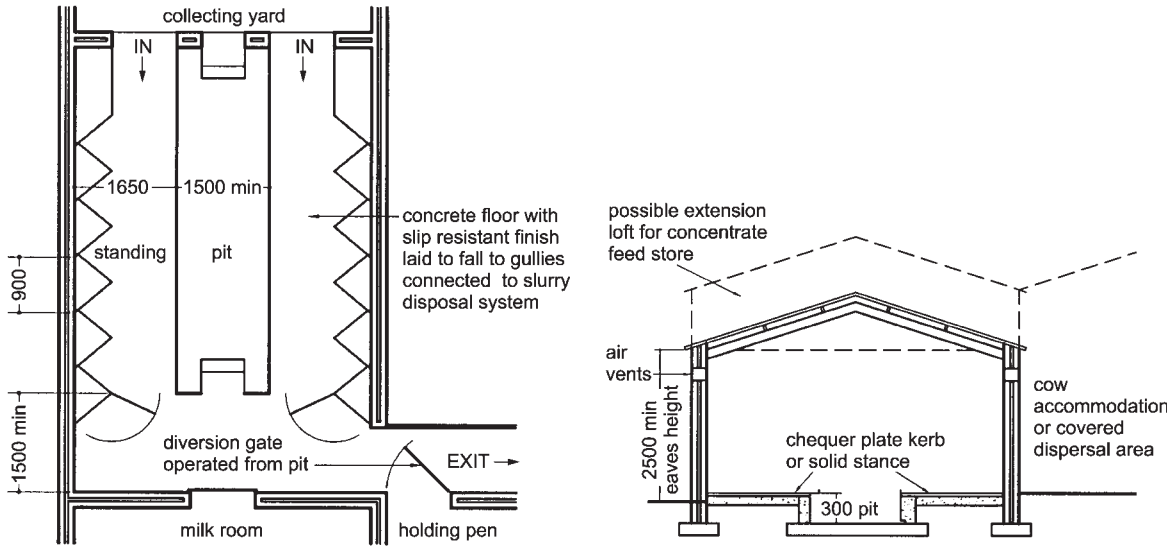
f *polygon*



g *rotary*

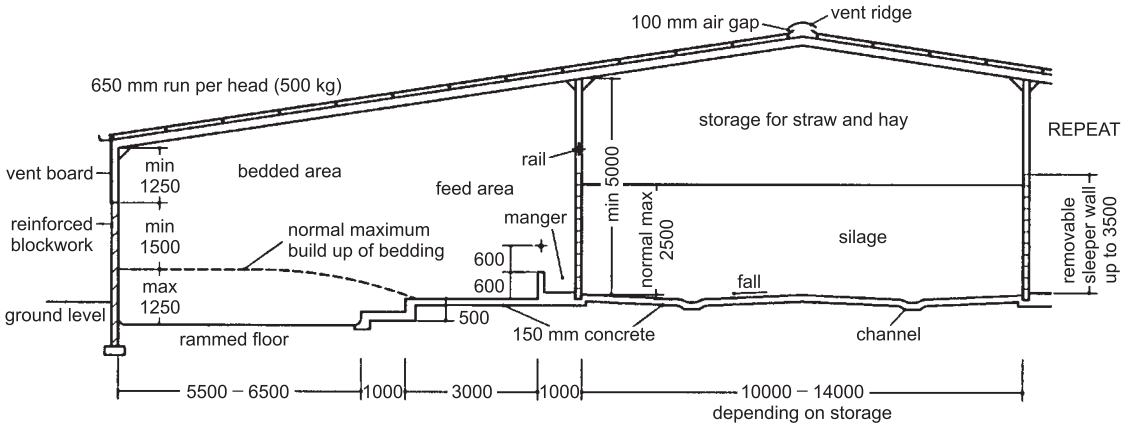
14.8 *Milking parlour systems*

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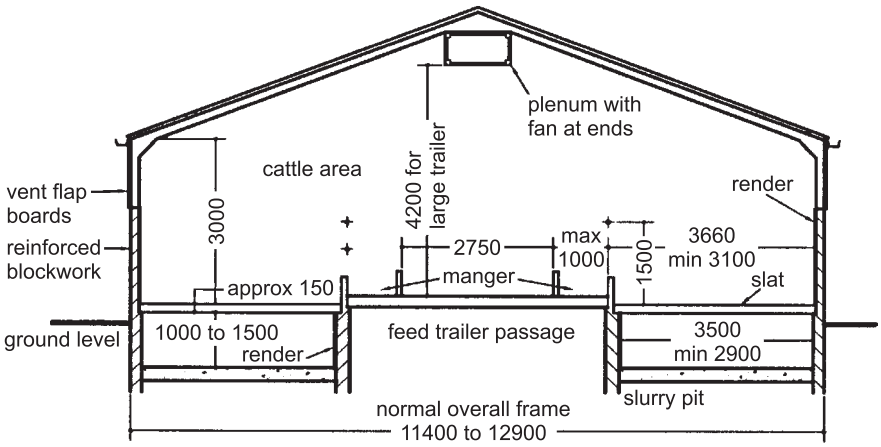


a *plan* **b** *section*

14.9 *Herringbone system milking parlour*

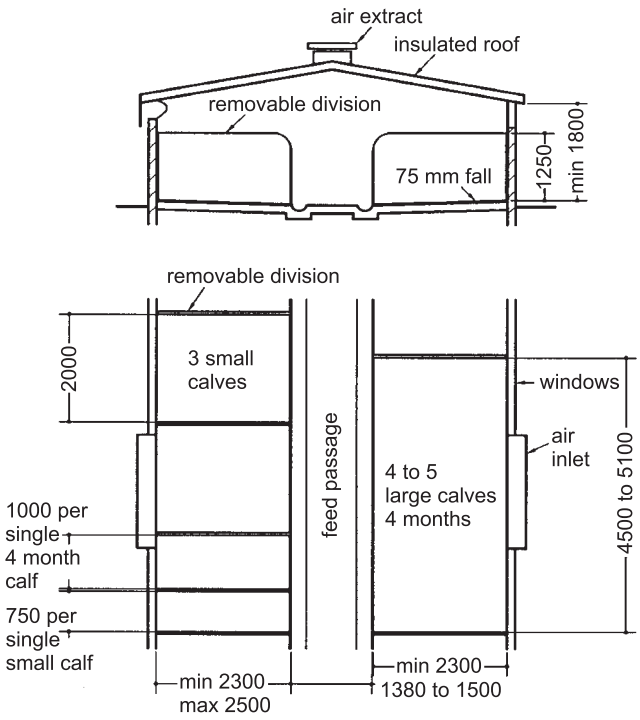


14.10 *Section through straw-covered yard for beef cattle with easy feeding*



14.11 *Section through slatted yard for beef using self-unloading trailers. Note: fully slatted yards are not approved by Brambell Committee*

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14.12 *Plan and section of calf house*

6 SHEEP HOUSING

Required dimensions are given in Table II. A section through sheep housing is shown in Figure 14.14. A dipping tank suitable for large breeds is shown in Figure 14.15.

7 PIG HOUSING

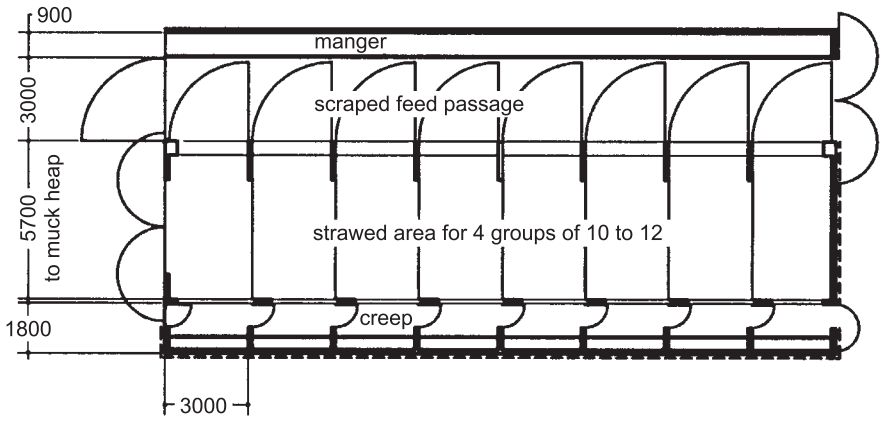
Table III covers the dimensional requirements. Three types of fattening house are shown in Figures 14.16–14.18, and two types of farrowing house in Figures 14.19 and 14.20.

8 POULTRY HOUSING

Dimensions are given in Table IV. Rearing, fattening and egg houses are shown in Figures 14.21–14.25 and a pole barn for fattening turkeys in Figure 14.26.

9 CROP STORAGE AND EFFLUENT PRODUCED

Some typical feed and produce stores are shown in Figures 14.27–14.34. Table V indicates the scope of manure likely to be produced.

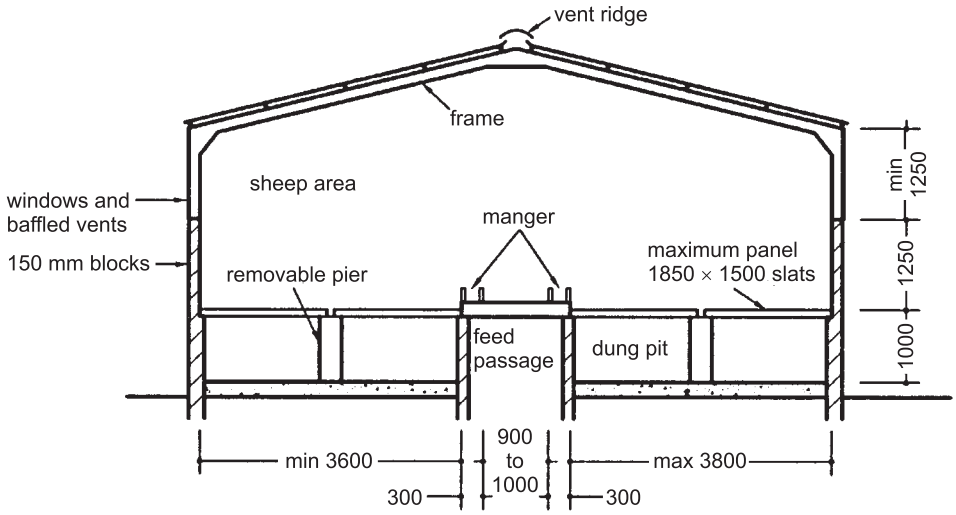


14.13 *Plan of general purpose straw-covered yard for cattle*

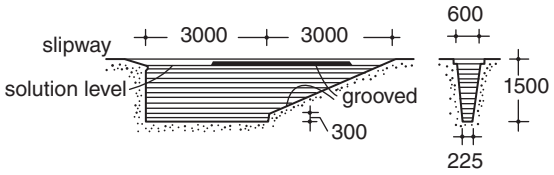
Table II Sheep housing

		Area per animal (m²)		Length of trough (mm) depending on feeding system		
Type of sheep	**Age or mass**	**Perforated floor**	**Solid floor with straw**	**Compounds/ concentrates**	**Ad lib hay/silage**	**Big bale silage, self-feed**
Pregnant ewes	45–60 kg	0.8	1.0	400	175	100
	60–75 kg	0.9	1.2	460	200	150
	75–90 kg	1.1	1.4	500	225	150
Ewes with lambs	Individually penned	–	2.2			
	Groups, 45 kg ewe	1.0	1.3	420	175	100
	Groups, 68 kg ewe	1.4	1.7	460	200	150
	Groups, 90 kg ewe	1.7	1.8	500	225	150
Lambs	Individually penned	–	2.1			
	Group housed	–	1.5			
	Creep area at 2 weeks	–	0.15			
	Creep area at 4 weeks	–	0.4			
Hoggs	20–30 kg	0.5	0.7	300	125	100
	30–40 kg	0.6	0.8	350	150	100
	40–50 kg	0.8	0.9	400	175	100

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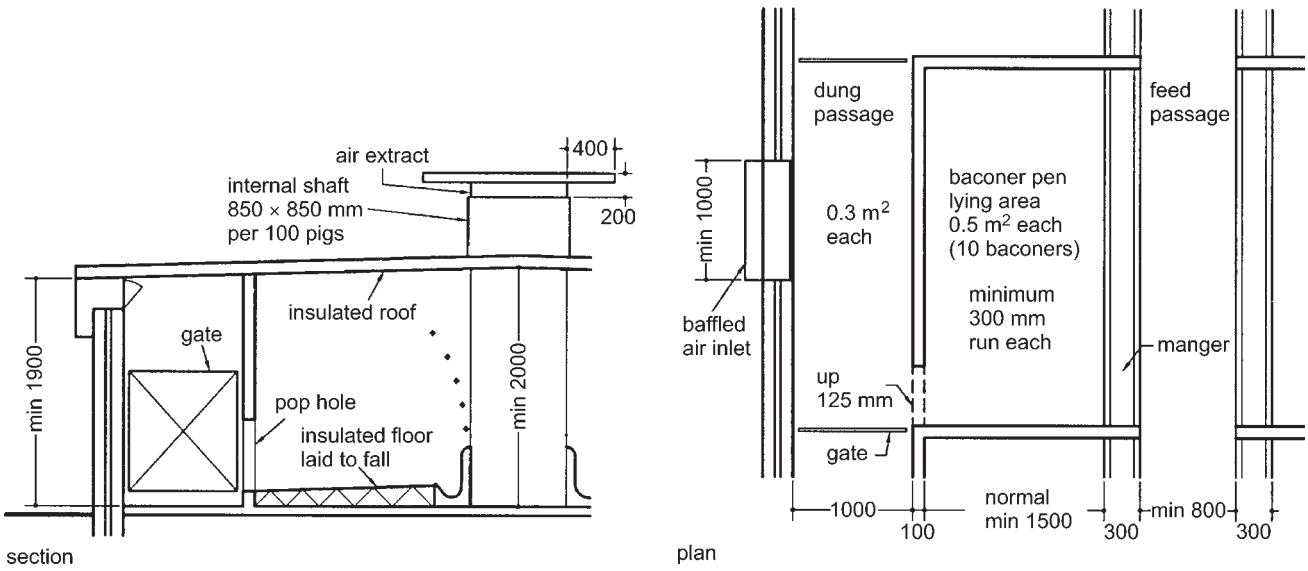
14.14 *Sheep housing, manger run per head: fattening lamb 300 mm ewe and lamb 400 mm yearling 500 mm*



14.15 *Sections through dipping tank for large breed ewes. Allow 2.25 litres of solution per head*

Table III Pig housing: dimensions required for 10 animals

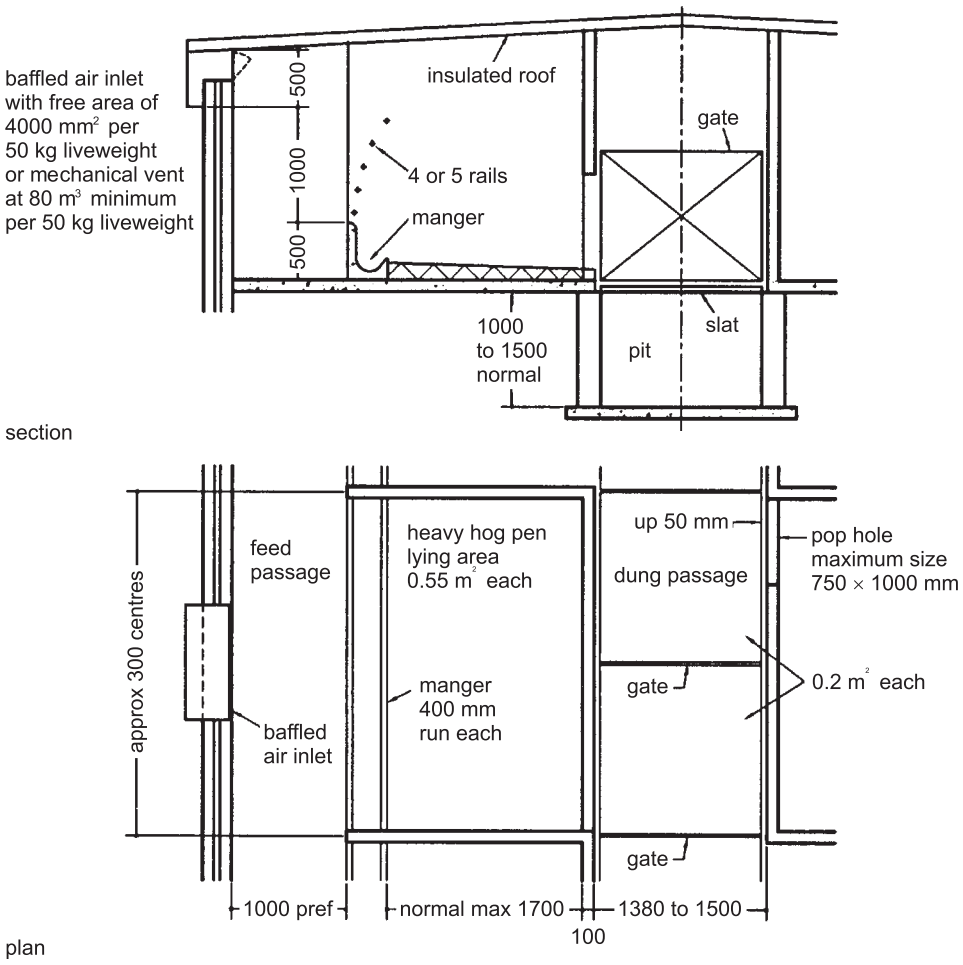
Typical age (days)	Mass (kg)	Type	Lying area (m²)	Min dung area (m²)	Total (m²)	Trough length (mm)	Lying pan depth (mm)
0	1.5	Piglets			1.3/litter	500	
20	5	Early weaners			1.75/litter	500	
35	9	Weaners	0.7	0.3	1.0	600	1170
65	20	Weaners	1.5	0.6	2.1	1750	860
115	50	Porkers	3.5	1.0	4.5	2250	1560
140	70	Cutters	4.6	1.6	6.2	2750	1280
160	85	Baconers	5.5	2.0	7.5	3000	1840
185	110	Heavy hogs	6.7	2.3	9.0	4000	1680
210	140	Overweight	8.5	3.0	11.5	5000	1700
–		Dry sows	15.0	5.0	20.0		3000
–	–	In-pig sows	15.0	5.0	20.0		3000
–	–	Boar		8.0/boar	500/boar		



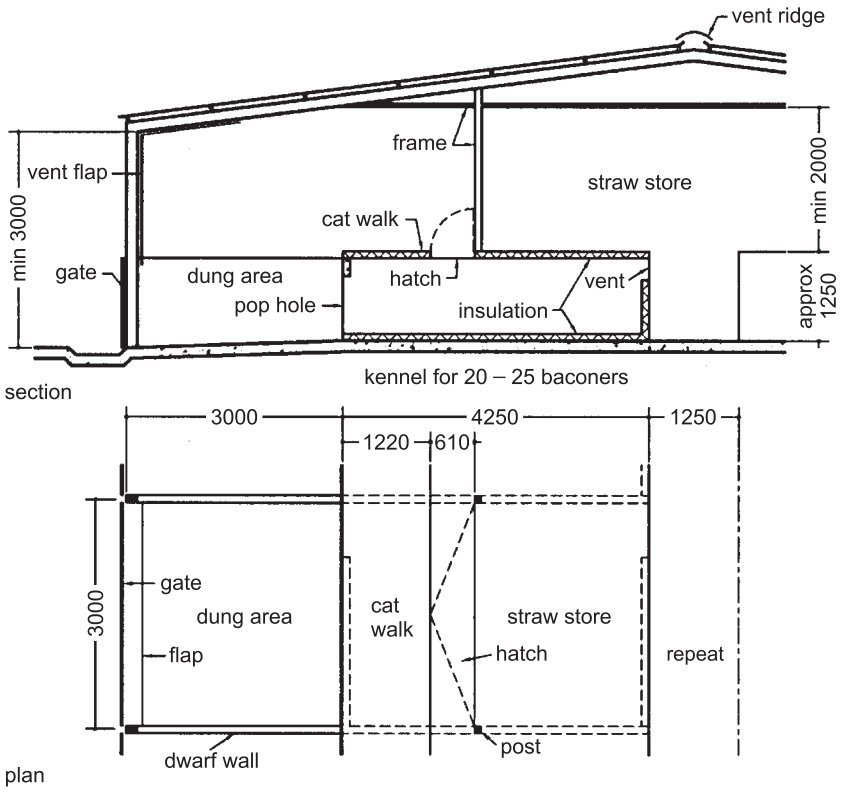
14.16 *Plan and section of fattening house with side dung passage*

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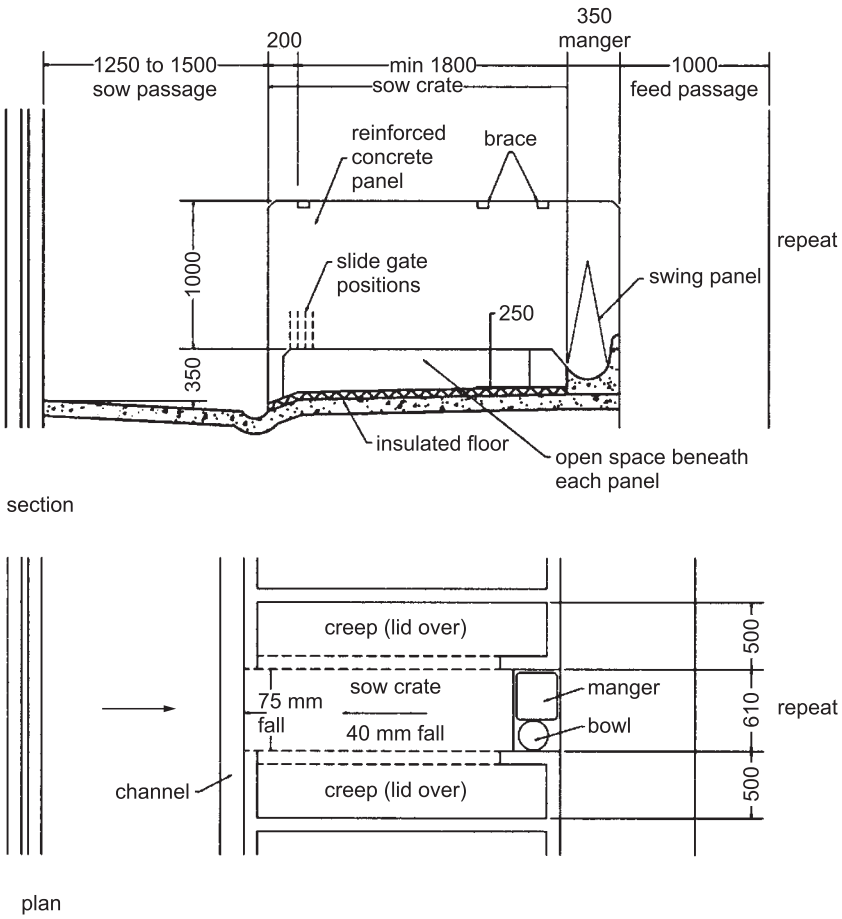
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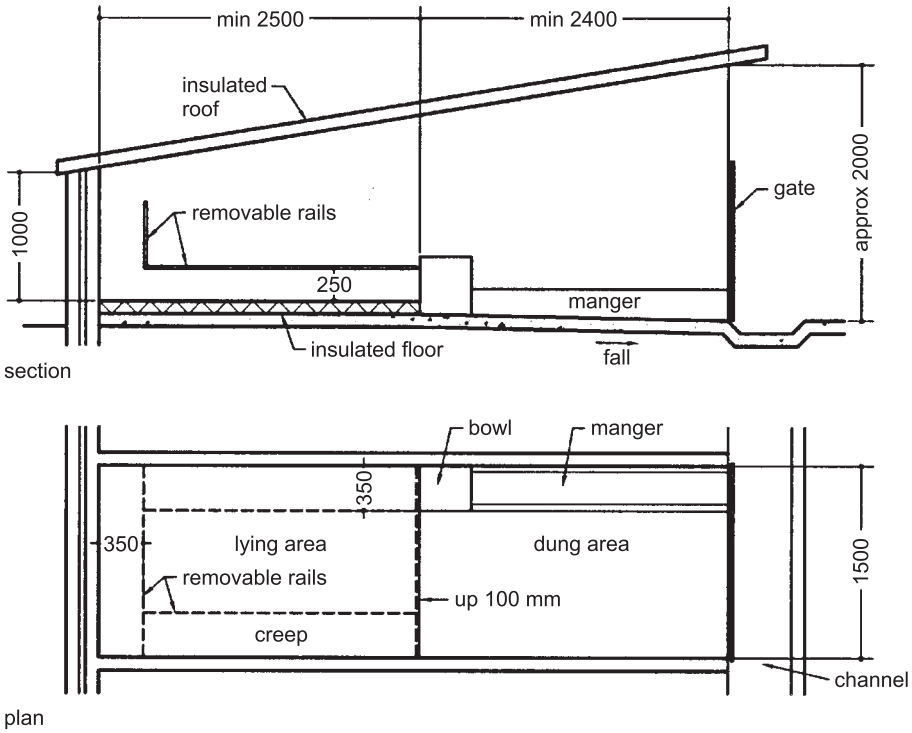
14.17 *Plan and section of fattening house with centre slatted dung passage*



14.18 *Plan and section of fattening house with straw-covered system and floor feeding*



14.19 *Plan and section of permanent crate farrowing house*

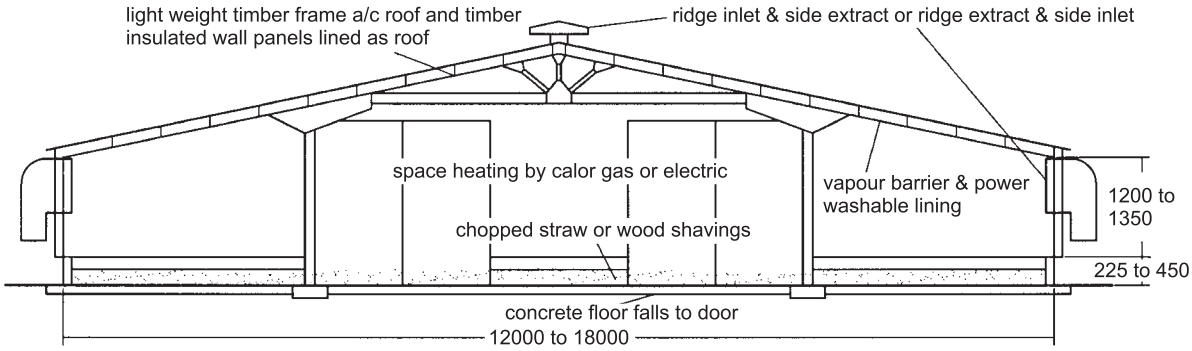


14.20 *Plan and section of Soleri open front farrowing house*

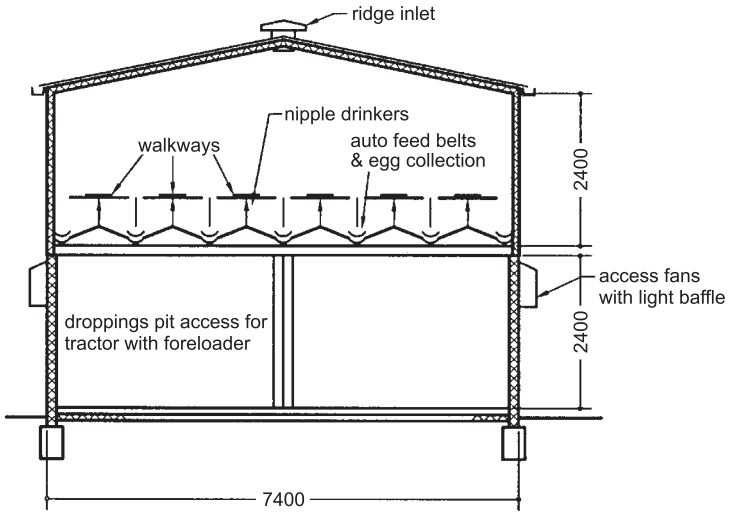
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Table IV Poultry housing

System	Species/cage numbers	0–4 weeks	4–8 weeks	9–16 weeks
Battery or tier brooder and cooling cage	One hen in cage	0.1	0.1	0.1–0.43
	Two hens in cage	0.075	0.09	0.1–0.43
	Three hens in cage	0.055	0.09	0.1–0.43
	Four hens in cage	0.043	0.09	0.1–0.43
Floor rearing on litter	Layers	0.025	0.09	0.18–0.28
	Broilers		0.09	
	Turkeys	0.09	0.14	0.37–0.46
Part wire or slatted floor rearing	0.015	0.09	0.09–0.14	
	Ducks	0.09	Free range	
Trough length (mm)	Birds in cages	100		
	Layers	30	40	60
	Broilers	30	50	75
	Turkeys	36	73	73
	Ducks	55	122	Free range



14.21 *Section through poultry broiler and rearing house. Roof insulated with minimum 25 mm rigid polyurethane or equivalent. Stocking density 10 birds/m², RH 60%, temperature 30°C*

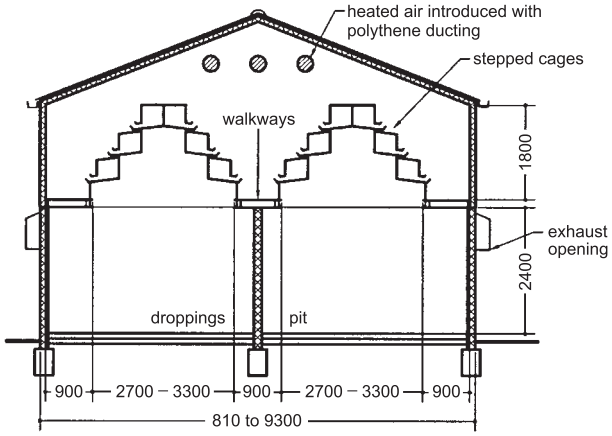


14.22 *Section through flat deck deep pit battery house. Roof insulated with minimum 25 mm rigid polyurethane or equivalent. Stocking at 100 mm trough per bird in multibird cages for light hybrids, 125 mm for heavier birds. RH 60%, temperature 20–25°C. If falls to 12° does not harm output but increases food conversion ratio*

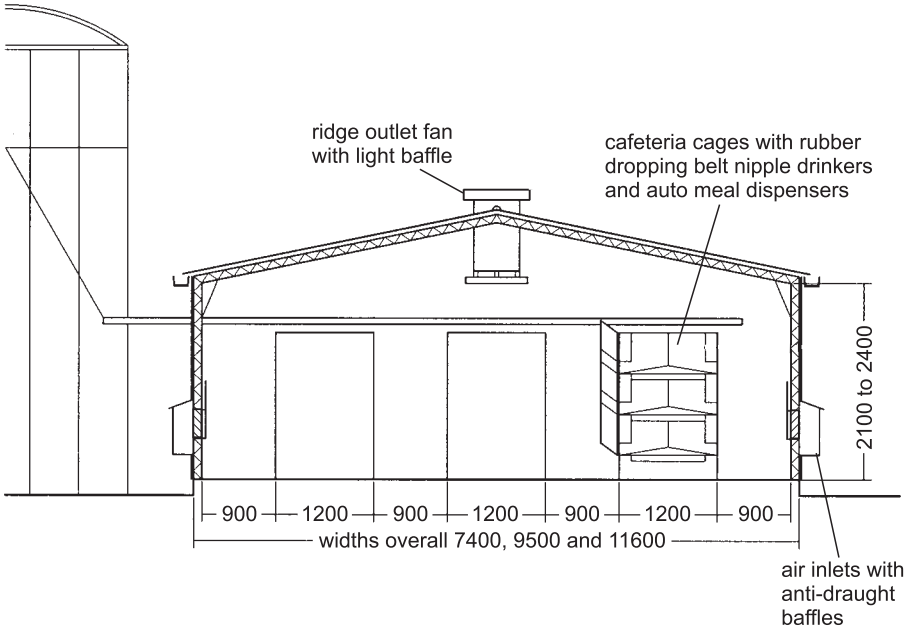
Table V Average production of effluent

		Production per head per week					
		Mass (kg)	Output (l)	Volume (m³)	Total solids (kg)	BOD (kg)	BOD population equivalent
Man	Adult	75	10	0.01	0.57	0.41	1.0
Cow	Dairy	450	250	0.25	21.20	4.20	10.2
Cow	Large dairy	550	380	0.38	32.22	6.13	14.8
Calf	3-month	100	200	0.20	19.05	2.54	6.2
Pig	Porker	50	38	0.04	3.00	1.20	2.0
Pig	Baconer	95	51	0.05	3.50	1.40	3.4
Pig	Wet-fed	95	100	0.10	3.50	1.40	3.4
Pig	Farrow sow	110	75	0.08	3.60	1.45	3.6
Poultry	Adult layer	2.25	3.75	0.005	1.27	0.09	0.13
Sheep	Adult ewe	75	35	0.04	3.81	0.70	1.7
Silage	30% dry matter	Tonne	3.20	0.001	–	–	–
Silage	20% dry matter	Tonne	37.00	0.04	–	–	–

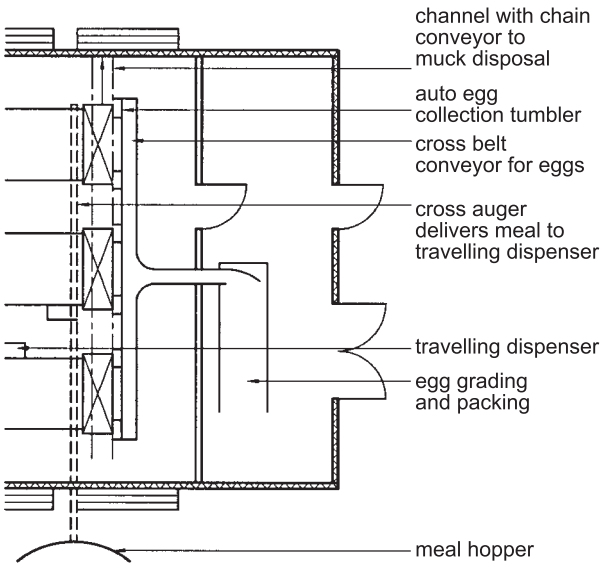
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14.23 *Section through California cage deep pit battery house. Roof insulated with minimum 25 mm rigid polyurethane or equivalent*



14.24 *Section through cafeteria cage battery house*



14.25 *Plan of end of cafeteria cage battery house showing gear*

10 EQUESTRIAN DESIGN

10.1 Horse riding today

Facilities for keeping horses are mainly constructed for recreational riding, equestrian sport and breeding purposes. The use of horses for commercial haulage is unusual nowadays, and together with police or military facilities there is likely to be a specific brief.

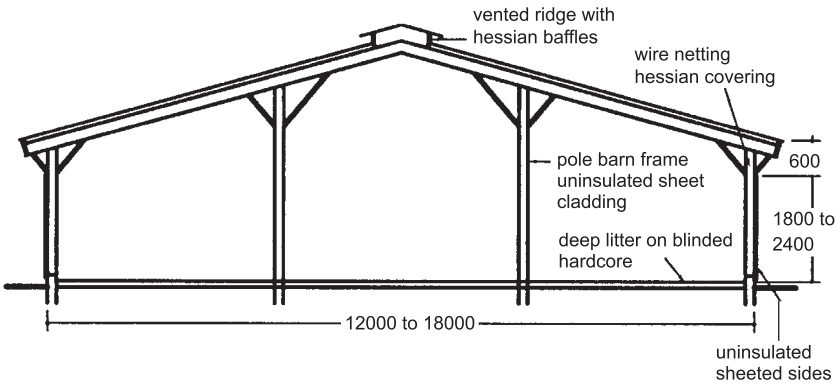
10.2 Planning elements in private stables

Private stables range from a stable for one horse to large complexes to accommodate a thousand horses or more, complete with full health and training facilities. The principal elements remain the same, Figure 14.35, and are based on the physical and psychological requirements of the horses.

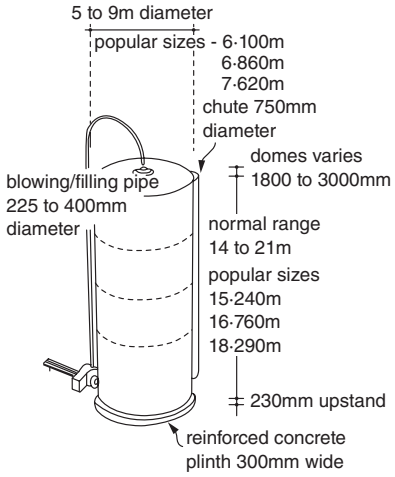
1 Boxes

- Loose boxes
- *Sick box/boxes (50 per cent larger)
- *Utility box/boxes

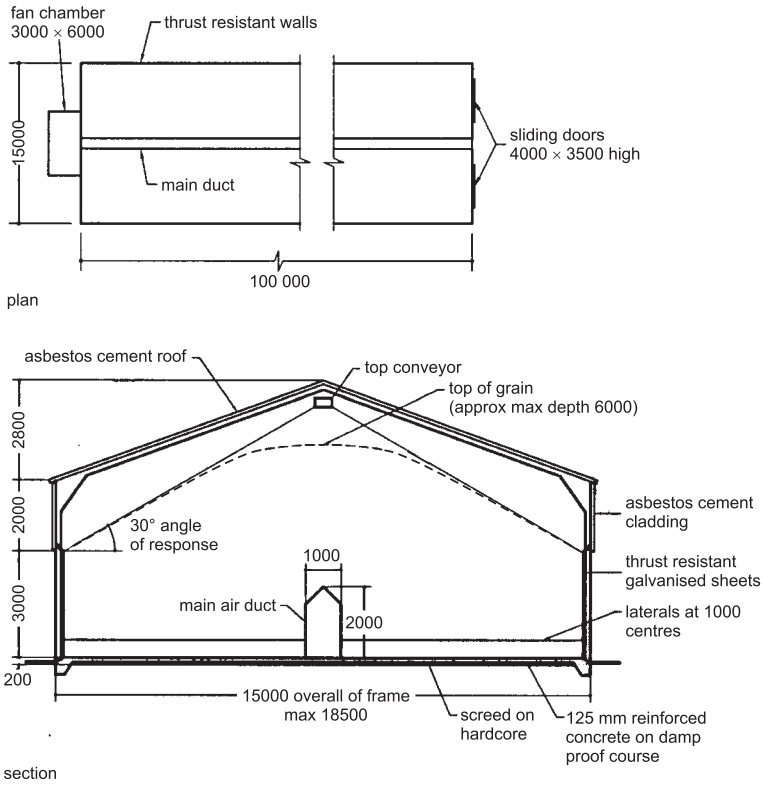
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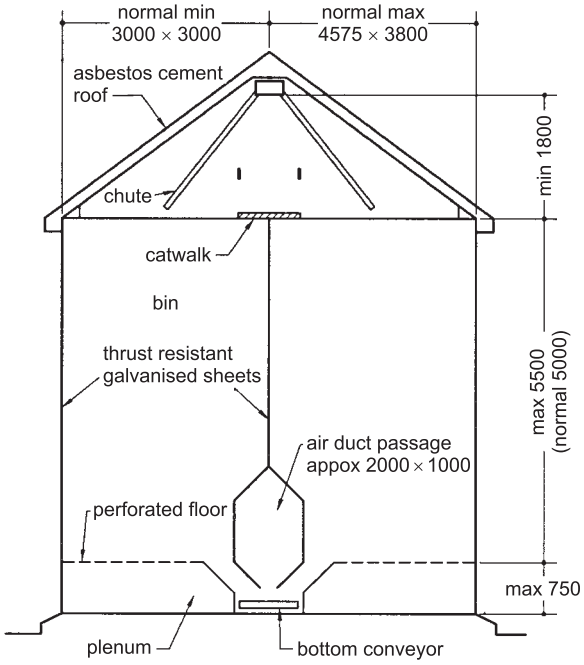
14.26 *Section through pole barn for fattening turkeys. Stocking density 30 kg/m2*



14.27 *Tower silo for wilted grass with 40–50% dry matter. Wet grass is stored in towers of 6 m diameter × under 12 m height*

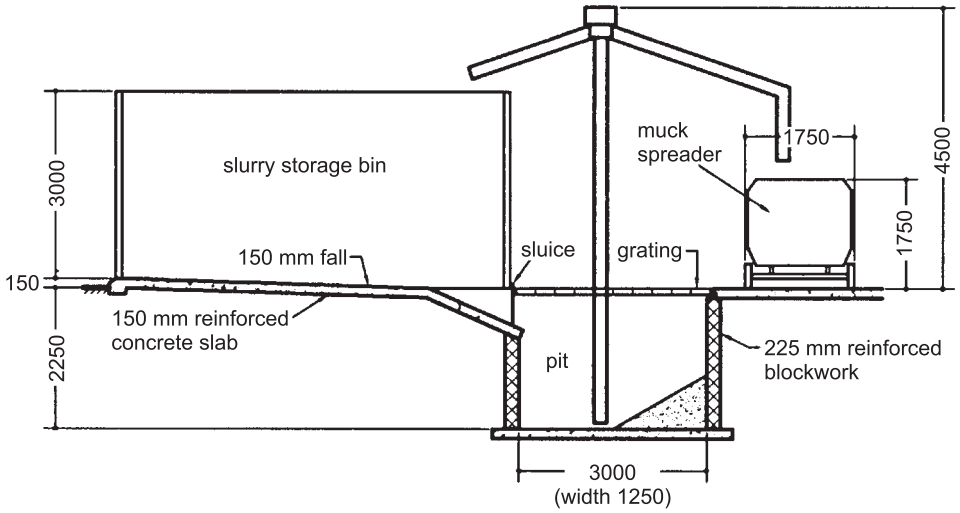


14.28 *Plan and section of storage for food grain, showing lateral system for 1200 tonnes storage*

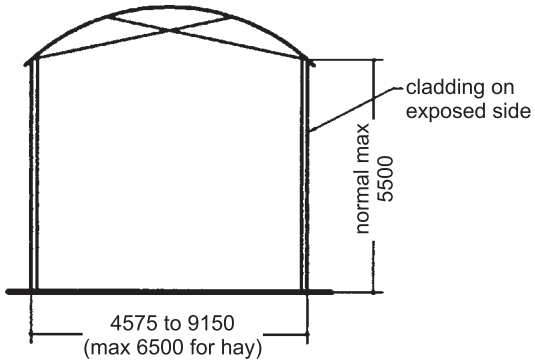


14.29 *Grain drying and storage: section through a nest of bins (square or rectangular) with roof. A bin 4.575 × 3.8 × 5m holds 60 tonnes of wheat*

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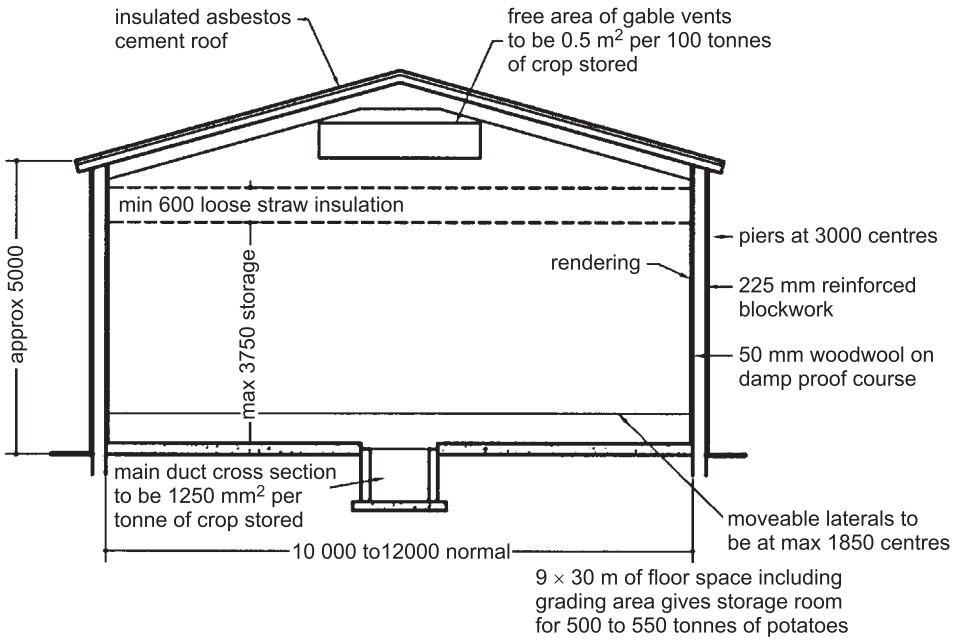


14.30 *Section through above-ground slurry storage*



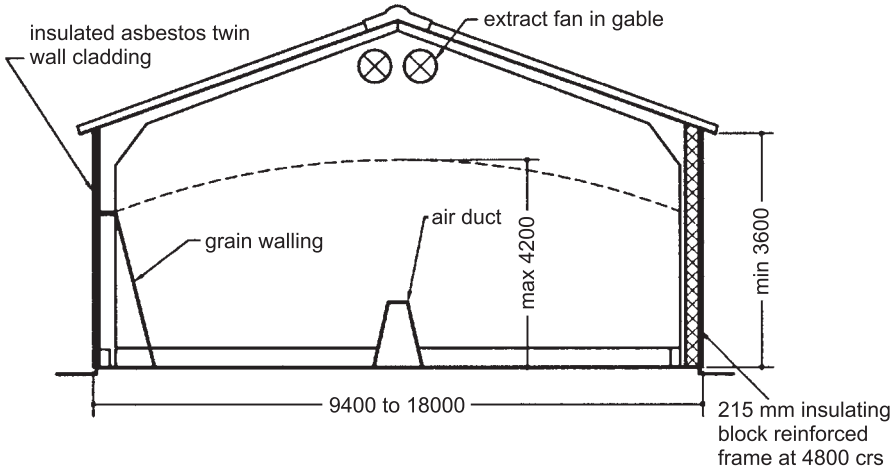
14.31 *Section through Dutch barn for bale storage. The capacities of a 4.575 m bay at 6.5 m span and 5.5 m high are:*

wheatstraw–12 tonnes
barleystraw–14 tonnes
hay–27tonnes

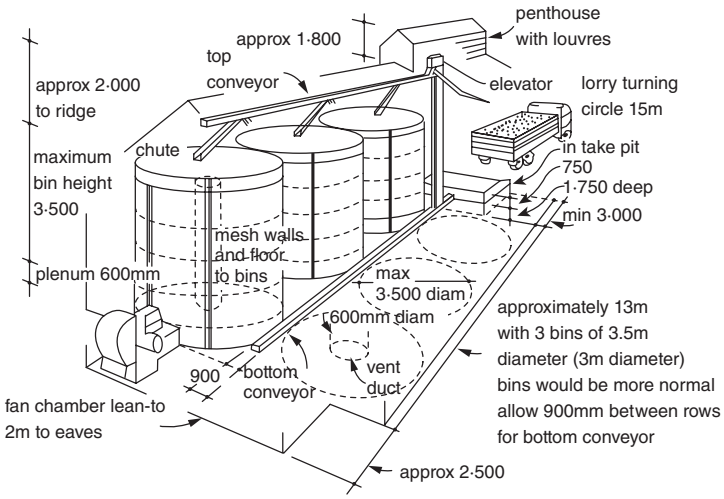


14.32 *Section through floor storage for potatoes. 9 × 30 m of floor space stores 500–550 tonnes. Movable laterals maximum 1.85m centres. Free area of gable vents 0.5m²/100 tonnes stored, main duct cross-section 1250 mm²/tonne*

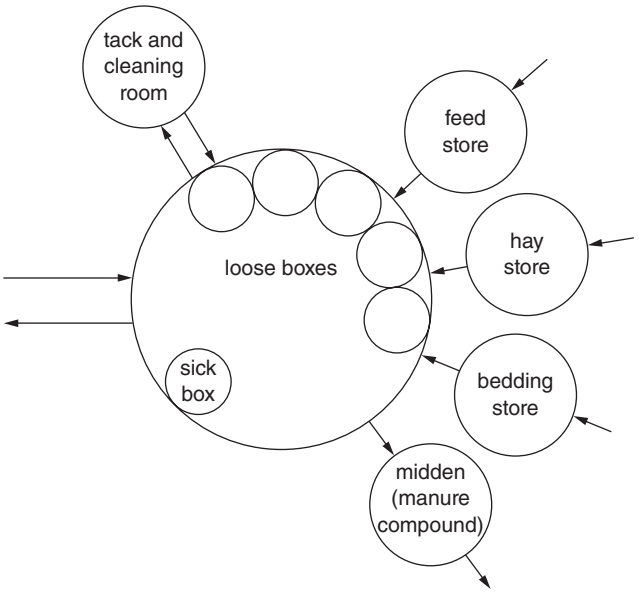
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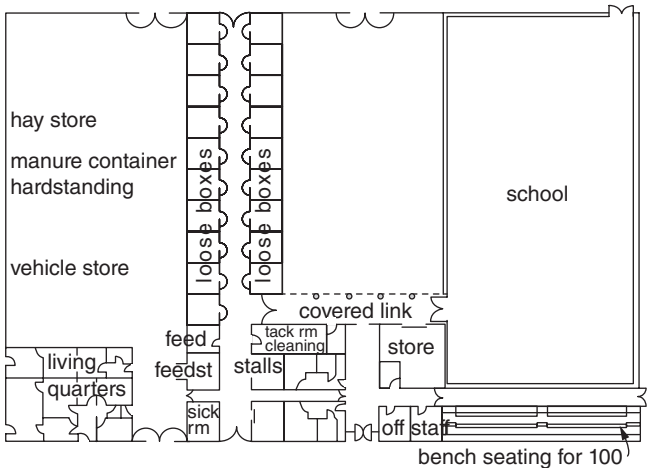
14.33 *Section through radial flow bins in a barn for grain drying and storage. The air duct delivers 400m³/h.t to dry and 100m³/h.t to store. Air temperature above 0°C, RH 75%*



14.34 *Onion store*



14.35 *Relationships between elements of the plan*



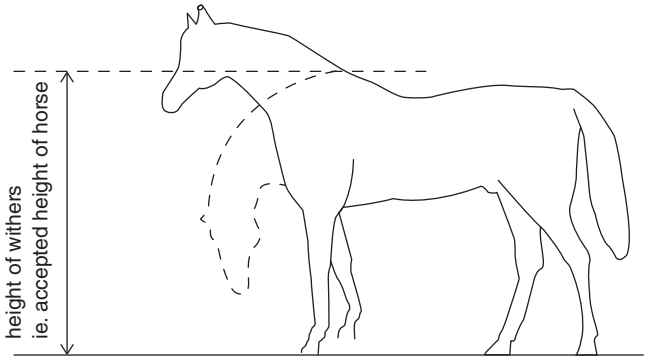
14.36 *Plan of Porter's Field Riding School, Leyton*

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Table VI Common breeds of horses and ponies, with heights in hands and equivalent metric measure, Figure 14.37
(1 hand = 4 inches, 12.2 hands = 12 hands + 2 inches)

Breed	Height in hands	Height in mm	Breed	Height in hands	Height in mm
Horses			**Ponies**		
Cleveland bay	16	1625	Connemara	14.2	1475
Clydesdale	16	1625	Dartmoor	12	1220
Morgan	14–15	1420–1525	Exmoor	12.2	1270
Percheron	16–16.3	1625–1700	Fell	13.1	1345
Shire	17	1725	Highland	12.2–14.2	1270–1475
Suffolk	16	1625	New Forest	14.2	1475
Tennessee Walker	15.2	1575	Shetland	39–42 inches	990–1065*
Thoroughbred	16	1625	Welsh	12	1220

*Shetland ponies are always described in inches.

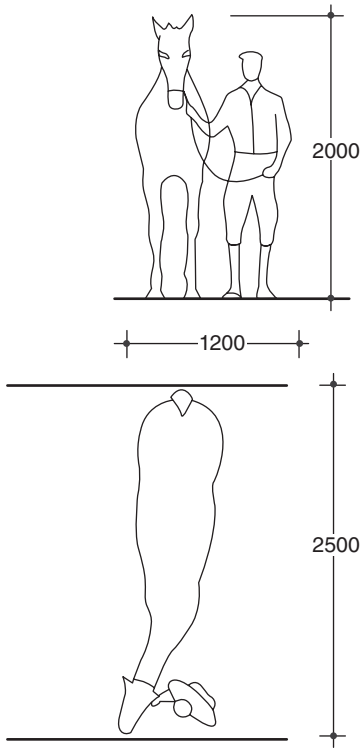


14.37 *Measurement of the height of a horse at the withers. Traditionally the height was measured in hands (4 inches), but a hand is equivalent to a decimeter (100 mm) within the limits of accuracy attainable. Table VI gives the heights of a number of breeds of horses and ponies*

Table VII Typical dimensions of horse or pony and rider, Figure 14.39

Dimension	Thoroughbred	New Forest pony	Welsh pony
A	1600	1450	1200
B	550	500	415
C	900	815	675
D	1620	1470	1215
E*	2450	2225	1840
F	1625	1475	1220

*Assuming that the rider is in proportion to the horse or pony



14.38 *The led horse. a Front view. b Plan*

2 Stores
- Feed
- Hay
- Bedding
- Equipment (wheelbarrows, mowers, etc.)

3 Housekeeping
- Tack room
- *Cleaning room
- *Drying room
- Staff lavatories/showers
- *Staff rest room
- *Office
- *Vet room

4 External facilities
- Midden
- *Washdown area
- Trailer parking
- Staff parking
- *Carriage store

5 Health/exercise
- Sand roll
- Lungeing yard
- Treadmill
- Weighing machine/weigh bridge
- Equine pool

*In many cases, the accommodation will not require these items because of their small-scale activities.

A typical plan is shown in Figure 14.36.

10.3 Dimensional criteria

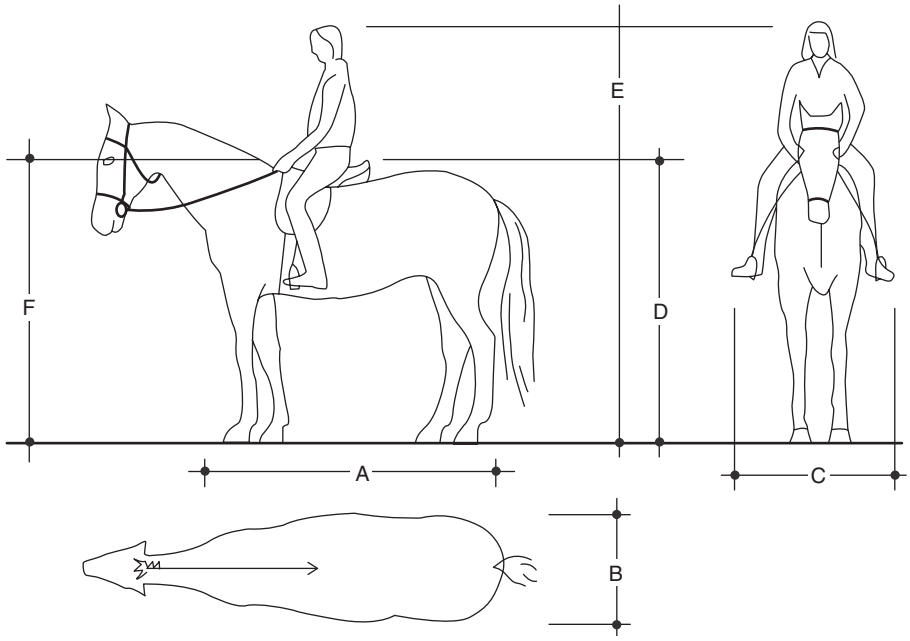
Dimensionally standardised criteria may be applied:

- The size of the horse, with and without rider, Figures 14.37–14.39, Tables VI and VII.
- Stabling and care of the horse, Figures 14.40–14.43.

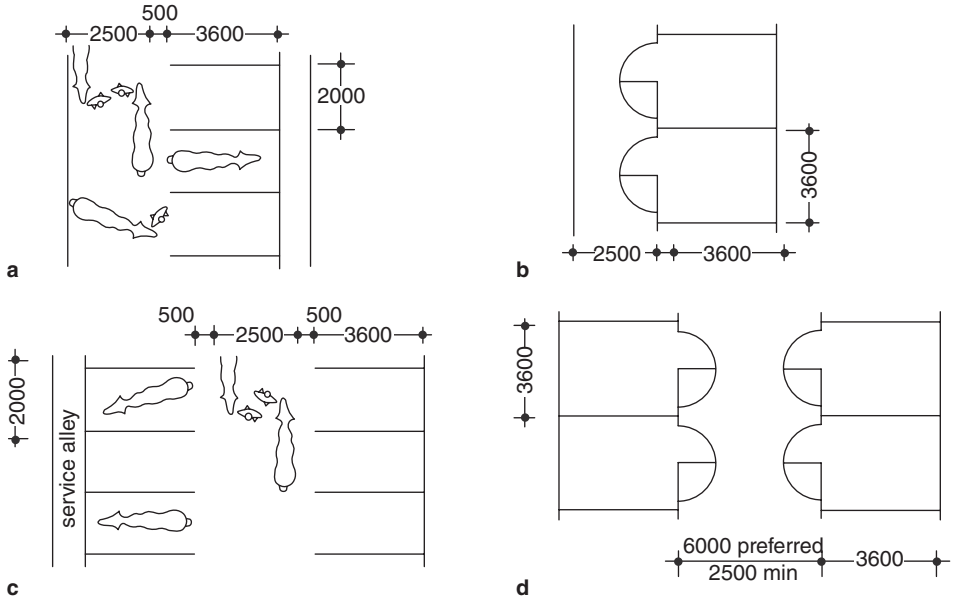
Section
Plan
Tack rooms, Figure 14.44.

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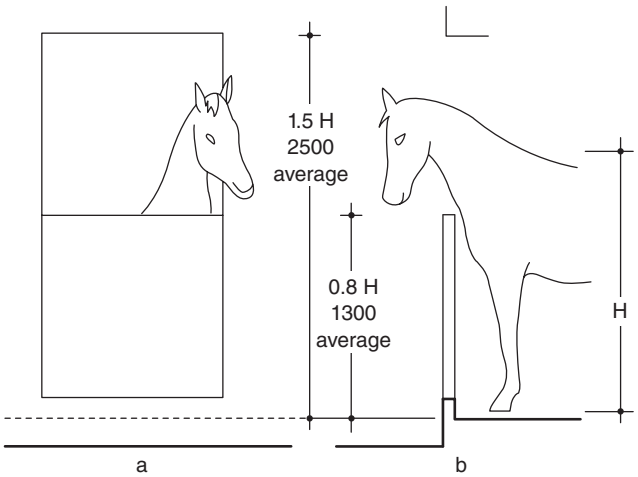
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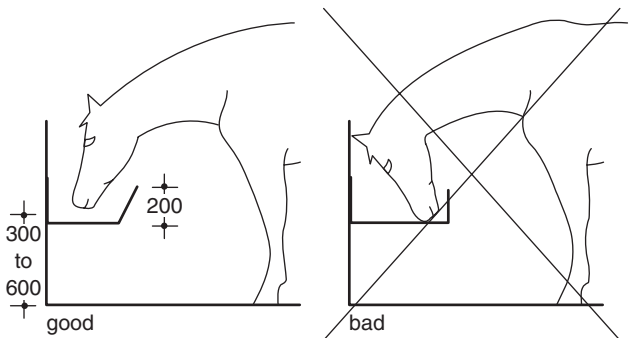
14.39 *Dimensions of the horse and rider, see Table VII*



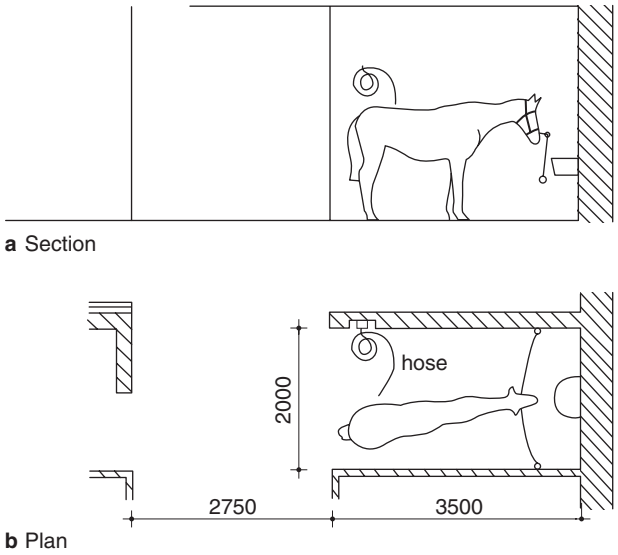
14.40 *Arrangements of stables. a Stalls on one side. b Loose boxes on one side. c Stalls on both sides. d Loose boxes on both sides: doors should not be directly opposite one another*



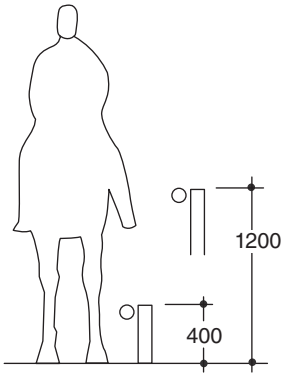
14.41 *The stable door. It is essential for the horse's mental wellbeing for it to see out – horses are inclined to be very inquisitive! H is the height at the withers (see 14.37). a Front view. b Section*



14.42 *Height of the manger*



14.43 *Veterinary box 'Stallapotheke'*



14.45 *Rails for the outside school*

- Schooling, Figure 14.45 and 14.46
- The dressage arena, Figure 14.47
- Polo, Figure 14.48
- Transportation, Figures 14.49–14.51

10.4 Stabling and environmental conditions

The principal requirements can be identified as follows:

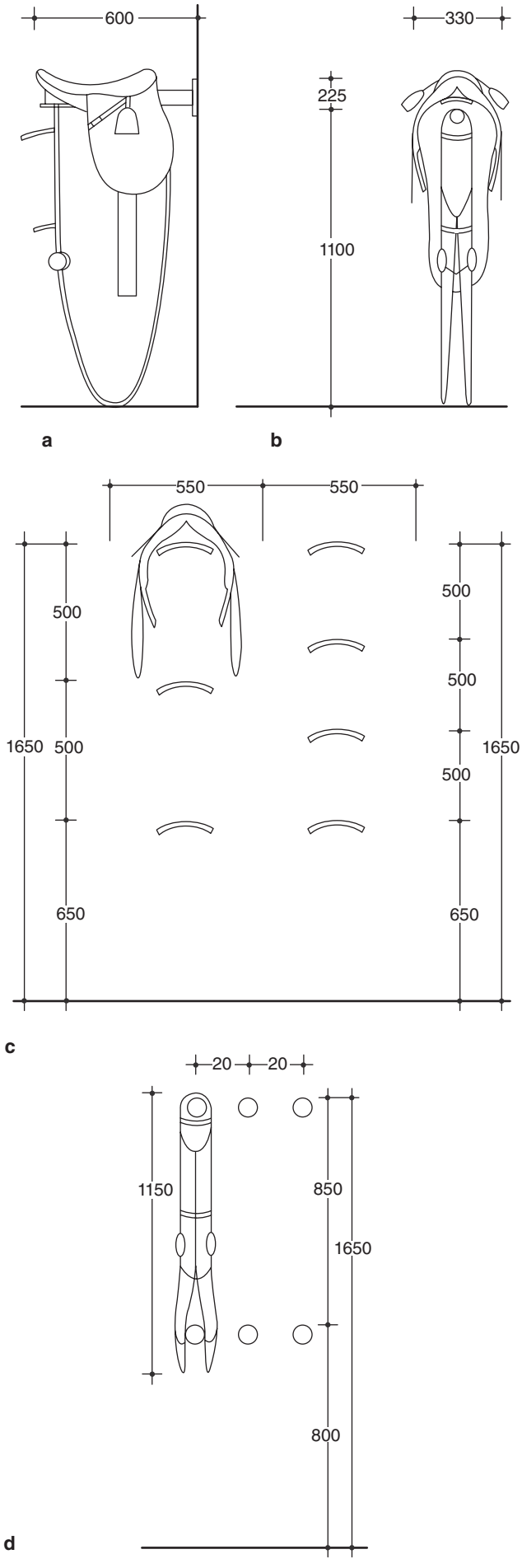
1 Dryness and warmth
2 Adequate ventilation without draughts
3 Adequate supply of water and good drainage
4 Good daylight and good artificial light.

Siting

- On well-drained ground.
- Avoid the tops of hills and hollows.
- Protected from severe prevailing winds.
- Avoid sites hemmed in without free circulation of air.

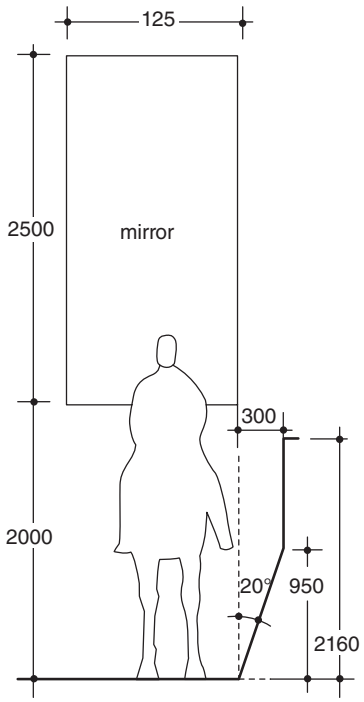
Temperature

The stable should moderate extremes of exterior conditions. Therefore a degree of air circulation is helpful and adequate ventilation essential. However, care should be taken to avoid draughts.

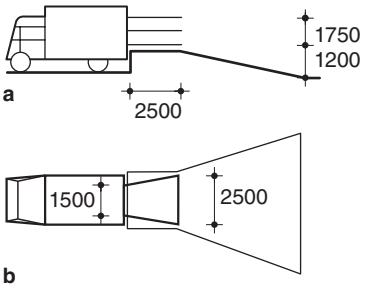


14.44 *Tack rooms. a Saddles and bridles together, side view. b Saddles and bridles, front view. c Saddles only. d Bridles only, when kept separate*

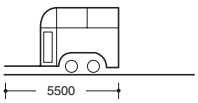
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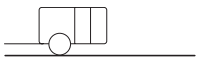
14.46 *Indoor school: batten to walls and arrangement of mirror tilted to give self-vision*



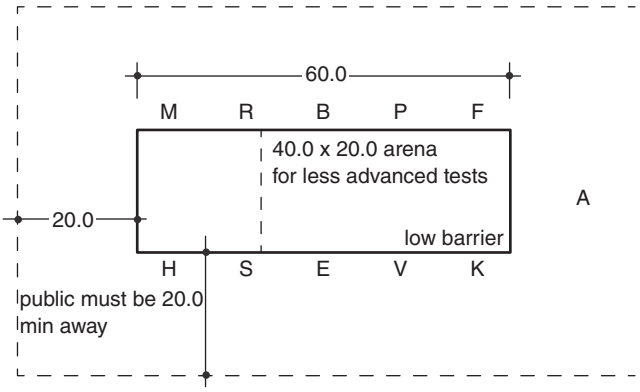
14.49 *Ramp for loading horses into horse-boxes or trailers. a Section. b Plan*



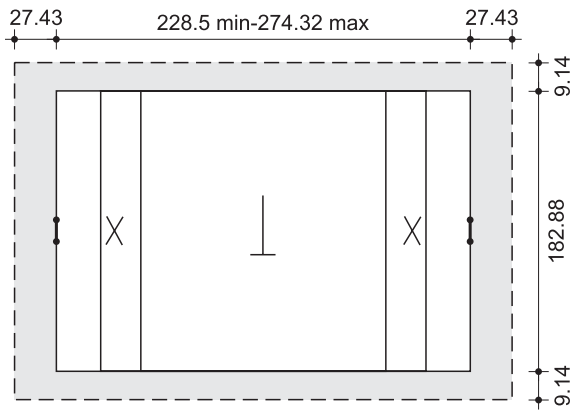
14.50 *Large trailer*



14.51 *Small trailer*



14.47 *Dressage arena*



14.48 *Polo*

Size
Unless a particularly small breed is kept the standard dimensions should be adhered to.

Noise
Sudden noise may startle horses and disrupt sleep during the night, therefore relationship to public roads or urban developments requires careful consideration.

10.5 Detailed stabling design

Floor
The floor should be impervious to moisture, hard wearing, nonslip, easily cleaned and protect the horse from any ground moisture. Selection of floor finish can vary from dense concrete, granolithic concrete or engineering brick-laid herringbone pattern to proprietary rubber mats and seamless rubber flooring.

Walls
The walls should be smooth for cleanliness and, wherever possible, free from projections. It is preferable that masonry walls are protected up to at least 120 mm by stout timber or plywood panelling on battens. Masonry should be painted white or a light shade to encourage cleanliness. Horses are gregarious animals and therefore it is normal for the partitions to be solid up to 1200–1500 mm and have a metal grille up to 2100 mm above floor level.

Ceilings
The ceiling should not be less than 3050 mm high and care should be exercised in the choice of materials to avoid the build-up of condensation.

Fire resistance
In large installations, the fire resistance of the structure and the location of fire separation barriers should be carefully considered bearing in mind the difficulty of evacuating frightened horses and the often rural location.

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Doors and windows
Doors to loose boxes should be positioned to one side of the box to allow the horse to keep clear of the draught when the upper half is left open. Doors to two adjoining boxes should not be placed next to each other. The door should open back to 180° and any exposed edges be protected with a galvanised steel capping to avoid 'crib biting'. There should be no sharp arisses and a minimum clear width of 1200 mm. Windows should, where possible, be fitted at high level. Any low-level windows should have Georgian wired glass and a steel protective grille.

Fittings
Usually, these will consist of a manger, drinking water receptacle and two tie rings. The exact position of these items will depend to some extent on the management of the stables, and to whether automatic replenishment is incorporated. Tie rings are generally fixed between 1525 and 1800 mm in order to avoid a horse dropping a leg over the tie.

Services
An exterior quality plug socket will be required (one per six stalls maximum) for portable equipment. This should be sited outside the stall. Artificial lighting should provide illumination to both sides of the horse switched from outside the stalls.

Drainage
The floor should be laid to a fall of between 1:80 and 1:60 to a gulley outside the stall or loose box. Channels may be formed to enhance drainage. Good housekeeping is the key to drainage and all gullies should be equipped with a removable perforated bucket to collect bedding and feed that may wash down the gulley.

Midden
The midden must be arranged so that effluent does not run away into groundwater. There should be a gulley and an adjacent water supply to enable regular periodic cleaning. For hygiene reasons, it should be sited away from the stables.

11 BUILDING LEGISLATION

Town and Country Planning Act 1990
General Development Order 1988 amended and extended 1991

Many farm buildings and developments are no longer classed as permitted development under planning law. Details of all schemes have to be sent to the local planning authority together with a fee. The authority will rule in each case whether further information needs to be submitted for formal planning approval before work can commence.

Particular developments normally requiring formal planning approval include:

- buildings for non-agricultural purposes;
- dwelling houses;
- conversions of farm buildings to commercial or industrial or residential use;
- buildings not designed for agriculture, e.g. containers, lorry bodies, etc.
- buildings exceeding 465 m^2 – in any 2-year period within 90 m – includes yards and slurry lagoons;
- buildings 12 m and over in height;
- buildings 3 m and over in height within 3 km of an airfield;
- buildings within 25 m from the metalled part of a classified road;
- livestock buildings within 400 m of a 'protected building';
- caravan sites for which special rules apply;
- holiday cottages;
- recreational pursuits of a recurring nature, e.g. adventure games, canoeing, hang-gliding, windsurfing, water skiing, need consent if exceeding 28 days per year;
- farm shops: permission is needed for shops if produce is not derived from the farm involved and for new buildings to be used as shops. Particular care is required over access, parking and advertising signs.

The Building Regulations 2000
Many agricultural building are exempt from the Building Regulations 2000 – but not all. The following extract from the Regulations details the buildings that are exempt – all others are subject to Building Control and details must be submitted to the Local Authority before work commences.

Schedule 3 – Exempt Buildings and Works
Regulation 9 – Greenhouses and Agricultural Buildings

1 A building used as a greenhouse unless the main purpose is for retail packing or exhibiting.
2 a A building used for agriculture which is:

i. Sited at a distance not less than one and a half times its own height from any building containing sleeping accommodation, and
ii. Provided with an exit which may be used in the case of fire which is not more than 30 m from any point within the building (unless the main purpose for which the building is used is for retailing, packing and exhibiting).

b In this paragraph, 'agriculture' includes horticulture, fruit growing, seed growing, dairy farming, fish farming and the breeding and keeping of livestock (including any creature kept for the production of food, wool, skins or fur or for the purpose of farming the land).

Other relevant legislation
The Environmental Assessment Regulations, 1988
Health and Safety at Work Act, etc., 1974
Control of Substances Hazardous to Health Regulations, 1988 (COSHH)
Electricity at Work Regulation, 1989
The Noise at Work Regulations, 1989
The Food Safety Act, 1990
The Food Hygiene (HQ) Regulation, 1990
Code of Practice for the Control of Salmonella
The Environmental Protection Act, 1990
The Code of Good Agricultural Practice for the Protection of Air
Control of Pollution Act 1974 – Water Act 1989
The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations, 1991
The Code of Good Agricultural Practice for the Protection of Water July, 1991
The Welfare of Livestock Regulations
The Building Standards (Scotland) Regulations, 1988

12 BIBLIOGRAPHY

BS 5502 Code of practice for the design of buildings and structures for agriculture.
Published in separate parts as follows:

Part 0: 1992 Introduction
Part 11: 2005 Guide to regulations and sources of information
Part 20: 1990 Code of practice for general design considerations
Part 21: 1990 Code of practice for the selection and use of construction materials
Part 22: 2003 Code of practice for design, construction and loading
Part 23: 2004 Code of practice for fire precautions
Part 25: 1991 Code of practice for design and installation of services and facilities
Part 30: 1992 Code of practice for control of infestation

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Part 32: 1990 Guide to noise attenuation
Part 33: 1991 Guide to the control of odour pollution
Part 40: 2005 Code of practice for the design and construction of cattle buildings
Part 41: 1990 Code of practice for design and construction of sheep buildings and pens
Part 42: 1990 Code of practice for design and construction of pig buildings
Part 43: 1990 Code of practice for design and construction of poultry buildings
Part 49: 1990 Code of practice for design and construction of milking premises
Part 50: 1993 Code of practice for design, construction and use of storage tanks and reception pits for livestock slurry
Part 51: 1991 Code of practice for design and construction of slatted, perforated and mesh floors for livestock
Part 52: 1991 Code of practice for design of alarm systems and emergency ventilation for livestock housing
Part 60: 1992 Code of practice for design and construction of buildings for mushrooms
Part 65: 1992 Code of practice for design and construction of crop processing buildings
Part 66: 1992 Code of practice for design and construction of chitting houses
Part 70: 1991 Code of practice for design and construction of ventilated on floor stores for combinable crops
Part 71: 1992 Code of practice for design and construction of ventilated stores for potatoes and onions
Part 72: 1992 Code of practice for design and construction of controlled environment stores for vegetables, fruit and flowers
Part 74: 1991 Code of practice for design and construction of bins and silos for combinable crops
Part 75: 1993 Code of practice for the design and construction of forage stores
Part 80: 1990 Code of practice for design and construction of workshops, maintenance and inspection facilities
Part 81: 1989 Code of practice for design and construction of chemical stores
Part 82: 1997 Code of practice for design of amenity buildings

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15 Auditoria

Ian Appleton and Stefanie Fischer

CI/SfB 52

Ian Appleton is a partner in The Appleton Partnership. Stefanie Fischer, who contributed the section on cinema design with input from Ron Inglis of Mayfield Arts and Media, and Richard Boyd, technical director, BFI Southbank, is a principal of Burrell, Foley Fischer LLP

KEY POINTS:

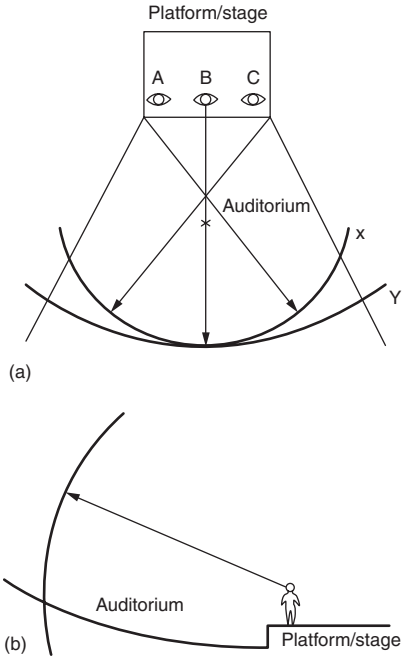
- *Each member of an audience should clearly see a performance, screen or speaker, as well as clearly hearing speech, music or sounds*
- *Auditorium design must consider audience comfort, fire safety, acoustic quality, sound insulation, sound systems, lighting, receptive atmosphere and access to technical equipment*
- *Stage and audio-visual technologies are constantly evolving*

Contents

1 Introduction
2 Seating
3 Auditorium design
4 Theatre
5 Studio theatres
6 Concert hall
7 Conference halls
8 Cinemas
9 Multi-purpose auditoria
10 Support facilities
11 Facilities for people with a disability
12 Legislation

1 INTRODUCTION

The three-dimensional volume of an auditorium is conditioned by the need for all members of the audience to be able to see the whole of the platform or stage; and to hear the actor, singer, musician or speaker, Figure 15.1. Seating density, floor rake and seating layout are partly determined by this, partly to give the audience an appropriate level of comfort and essentially to ensure a means of escape in an emergency, such as a fire, within the time required by safety considerations and by legislation.



15.1 *Visual and aural limitations: a Plan: for a performer at centre stage B there is an arc Y beyond which visual and aural perceptions are impaired. However, for performers nearer the sides of the stage at A and C produce more restrictive curves X. b Section: Similarly, visual and aural limits in section also set an arc centred on the performer*

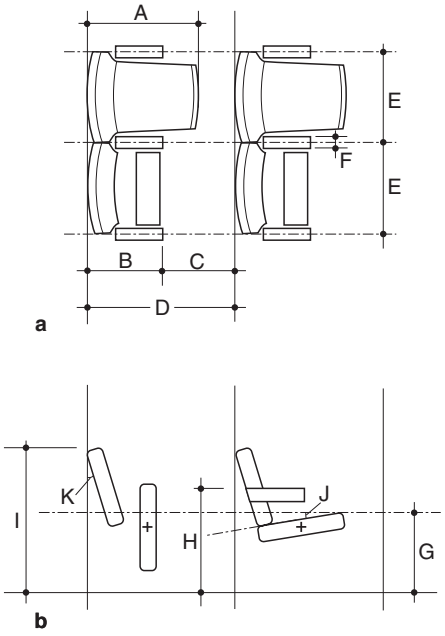
2 SEATING

2.1 Design of the auditorium seat

The aim is to provide an appropriate standard of comfort. The range of human body dimensions is wide; while in most auditoria a single size of seat is provided, Figure 15.2 and Table I. Tolerance levels vary: young people can tolerate simple seating found less comfortable by older people. Those attending concerts of classical music seem to expect more comfort than those watching drama. Seats are generally designed for the average person expected to use it; this varies according to age and nationality. Minor variation is achieved by the upholstery and adjustment of the back and seat pan material when the seat is occupied: otherwise the seat selection is a common size within the whole, or part of, the auditorium layout. The best able to be achieved is in the order of 90 per cent of the audience within an acceptable range of comfort.

2.2 Working dimensions

Seat width: the minimum dimension as stipulated by legislation is 500 mm with arms and 450 mm without. For seats with arms a width of 525 mm is the least for reasonable comfort.



15.2 *Auditorium seating: definitions of terms and dimensional information (to be read in conjunction with Table I): a Plan. b Section*

Table I Dimensions of auditorium seats

Dimension	Description	Minimum	Maximum	Drawn as
A	Overall seat depth	600 mm	720 mm	650 mm
B	Tipped seat depth (same as length of arm)	425	500	450
C	Seatway (unobstructed vertical space between rows)	305		400
D	Back-to-back seat spacing	760		850
E	Seat width for seats with arms	500	750	525
	Seat width for seats without arms	450		
F	Armrest width	50		50
G	Seat height	430	450	440
H	Armrest height	600		600
I	Seatback height	800	850	800
J	Seat inclination from horizontal	7°	9°	7°
K	Back inclination from vertical	15°	20°	15°

Seat height: 430–450 mm.
Seat inclination: an angle to the horizontal of 7–9°.
Back height: 800–850 mm above floor level (may be increased for acoustic reasons).
Back inclination: angle to the vertical of 15–20°.
Seat depth: 600–720 mm for seat and back depth overall, reducing to 425–500 mm when the seat is tipped. The seat depth varies and depends on thickness of upholstery and backing and if the rear of the seat contains the air-conditioning. For a modest seat with arms, the dimensions can be as low as 520 mm deep, 340 mm when tipped. The ability of the seat to tip, activated silently by weight when not occupied, allows a clearway (which is a critical dimension) to pass along a row while limiting row to row distance. Where space is severely limited such as in studio theatres, an especially slim seat, Figure 15.3 can be used.
Arm rests: 50 mm minimum width, with the length coinciding with the tipped seat to avoid obstructing the clearway; the height about 600 mm above floor level; the upper surface may be sloped or not.

2.3 Supports

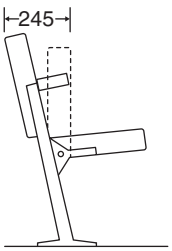
The permanent fixing of a seat can be:

- side supports shared by adjacent seats, Figure 15.4;
- a pedestal or single vertical support, Figure 15.5;
- cantilevered brackets fixed to riser (if of sufficient height) and shared by adjacent seats, Figure 15.6;
- a bar supporting a group of seats with leg or bracket support, Figure 15.7.

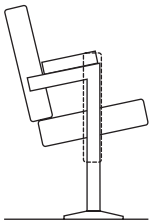
2.4 Other factors

Acoustics: upholstery to satisfy the acoustic requirements, usually the level of absorbency when unoccupied, especially the case with music, Figure 15.8.

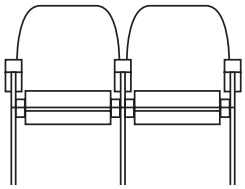
Ventilation and heating: for air supply or extract under a seat, allow space in floor or riser to receive grille, Figure 15.9.



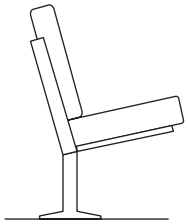
15.3 *A slim 'studio theatre' seat for use when space is limited*



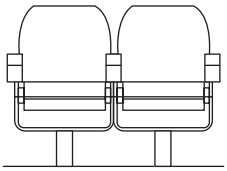
15.4a *Tip-up seat*



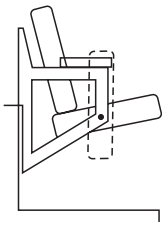
15.4b *Fixed seating with side support off floor or tread*



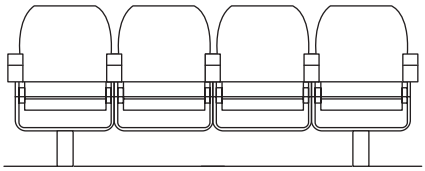
15.5a *Fixed continuous upholstered bench seating*



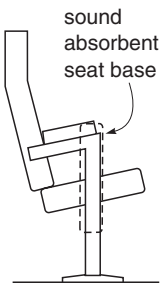
15.5b *Fixed seating with pedestal support off floor or tread*



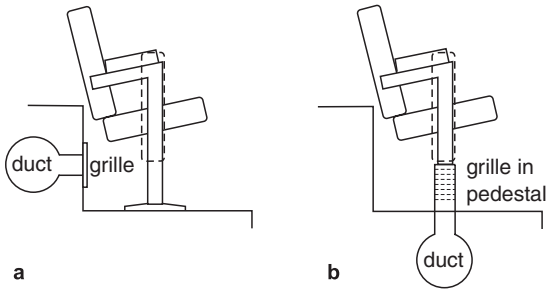
15.6 *Fixed seating with cantilevered support off high riser without overlap of riser*



15.7 *Fixed seating with bar support off floor or tread*



15.8 *Acoustic control seating (for when unoccupied)*



15.9 *a Ventilation grille below seat in riser or floor. b Ventilation grille incorporated into pedestal*

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Upholstery: thickness of padding should provide comfort and avoid fatigue, but not encourage excessive relaxation; material of padding and finish must satisfy fire regulations.

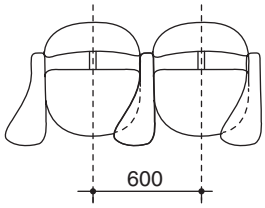
2.5 Writing surface

Conference use may require a writing surface for note-taking. The writing surface may be:

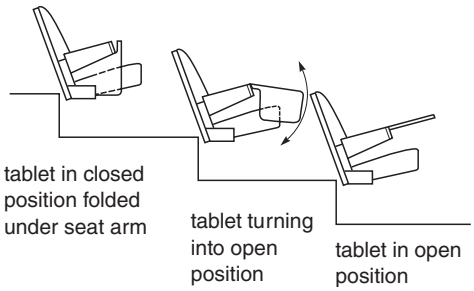
- a tablet fixed to each seat, Figure 15.10;
- a removable tablet;
- a tablet pivoted to slide away vertically, Figure 15.11;
- a writing shelf on the back of the row in front, which can be fixed in position, hinged or retractable, Figure 15.12;
- a fixed table with loose seat;
- a fixed table with fixed pivoting or sliding seat, Figure 15.13.

Table seating has the advantage that delegates can pass behind the row of seats, and assistants can sit behind the delegates.

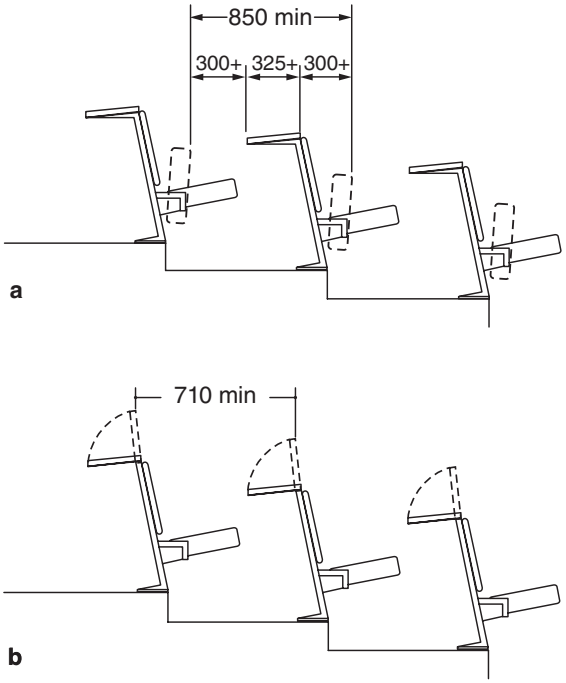
In a theatre or concert hall where there is occasional conference use every other row of seats can be used with temporary tables, Figure 15.14.



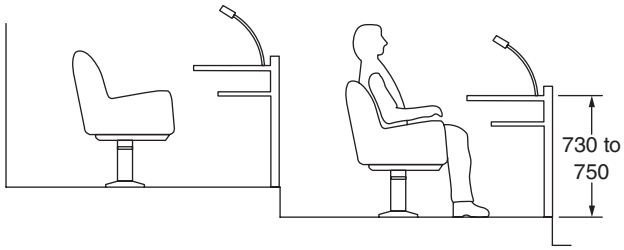
15.10 *Fixed tablet arm*

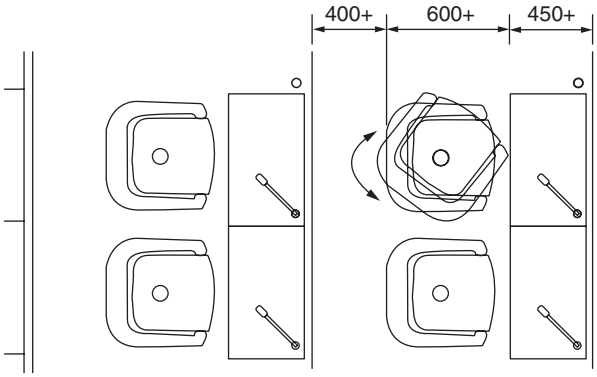


15.11 *Folded writing tablet under seat arm*

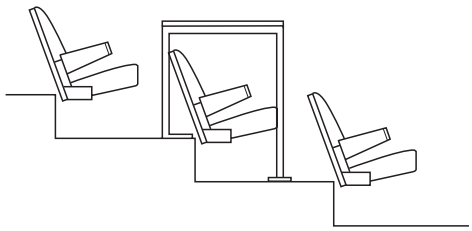


15.12 *a Fixed writing surface and tip-up seat. b Fixed seat and tip-up writing surface*





15.13 *Fixed writing surface, individual pivoting seats, section and plan*

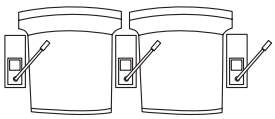


15.14 *Table added to every other row of fixed seating in theatre or concert hall for occasional conference use*

2.6 Wired services

These may be required for conference use. They can be incorporated into the arm of the seat, Figure 15.15 or into the rear of the seat or table in front. Further details will be found in Section 7.4.

For music, drama and cinema there may be provision for earphones for people with hearing impairment, or this facility may be provided by an induction loop.



15.15 *Controls and microphone in seat arm*

3 AUDITORIUM DESIGN

3.1 Audience requirements

As stated above, every member of the audience should be able to see and hear clearly whatever is happening on every part of the stage or platform. This is an ideal rarely (if ever) totally attainable in practice. However, a clear view for everyone of the main part of the stage or platform is normally achievable in modern auditoria. Where an existing building is undergoing renovation, further compromises may well be necessary for some seats.

The greater the encirclement of the audience of platform or stage, more people can be accommodated within the aural and visual limitations up to 180° encirclement. With a full encirclement, the distance from platform or stage should be restricted to six rows.

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3.2 Visual limitations

Visual limitations determine the maximum distance from platform or stage at which the audience is able to appreciate the performance and for the performers or speaker to command an audience. This distance varies according to function type and the scale of the performance:

- For drama it is essential to discern facial expression, and the maximum distance should be 20 m measured from the setting line of a proscenium stage or geometric centre of an open stage.
- For opera and musicals discerning facial expressions is less critical and the distance can be 30 m.
- For dance the audience needs to appreciate the whole body of dancers and facial expression: the distance should not exceed 20 m.
- For full symphonic concerts acoustic conditions predominate.
- For chamber concerts acoustic conditions also predominate but visual definition assists achieving an intimate setting.
- For conference speaker and lecturer there are two scales: discerning facial expression, restricted by 20 m; larger scale where facial expression is not regarded as critical.
- For slide, video, television, overhead projector and other projections, visual limitations are determined by their respective technologies.

3.3 Aural limitations

This refers to the distances across which speech, singing and music can be clearly heard without the need for amplification, and beyond which they cannot. For drama, opera and classical music amplification is deprecated; but it is acceptable for variety and pantomime and essential for rock music.

For amplified sound the auditorium requires a dead acoustic with no reflected sound from the platform or stage and limited or no reverberation; loudspeakers are positioned to provide full and even coverage of the audience.

The volume and quality of the unamplified sound is dependent on the volume, shape, size and internal finishes of the auditorium, and on its resultant reverberation time. It is therefore not possible to lay down limits as for visual appreciation. Even experts in acoustics find that their predictions are not always borne out in practice, although they should be consulted and their advice followed wherever possible. It has been found feasible to improve the acoustic of existing auditoria, for example, the famous ‘flying saucers’ in the hitherto notorious Royal Albert Hall.

3.4 Levels in the auditorium

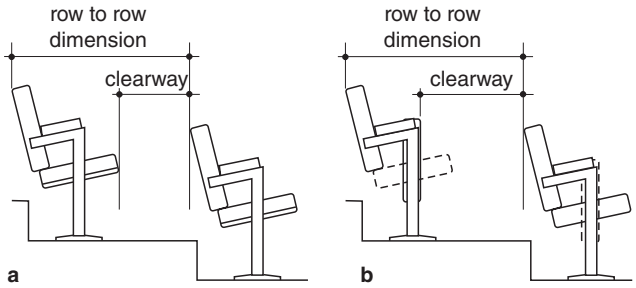
With a single level only, the pitch of the rake requires particular attention to achieve a sense of enclosure. The Greek amphitheatre is the exemplar.

Seating capacity within aural and visual limitations can be increased by the addition of one or more balconies within the overall permissible volume of the auditorium. Similarly, boxes, side galleries and loges can be added to the side walls, especially in the case of the proscenium format.

3.5 Number of seats in a row

With traditional seating the maximum number is 22 if there are gangways at both ends of the row, and 11 for gangway at one end. Thus in all but the smallest auditorium the gangways divide the seating into blocks.

Rows with more than 22 seats are permitted if the audience is not thereby imperilled. The term ‘continental seating’ is used for rows of seats with an increased back-to-back dimension extending the width of the auditorium with exits at both ends. This arrangement is usually only appropriate to proscenium stage, platform or cinema.



15.16 *a Row to row dimension and clearway with fixed seating. b Row to row dimension and clearway with tipped-up seating*

3.6 Row-to-row spacing

Spacing is controlled by the clearway between the leading edge of the seat (in an upright position, if tippable) and the rear of the back of the seat in front, Figure 15.16. For traditional seating the minimum clearway for people to pass along the row is 300 mm and this dimension increases with the number of seats in a row. For continental seating the clearway is not less than 400 mm and not more than 500 mm. Legislation also dictates the minimum row-to-row dimension at 760 mm: this is usually not adequate and the minimum should be 850 mm for traditional seating.

3.7 Gangways

As gangways are essential escape routes, their widths are determined by the number of seats served. The minimum is 1100 mm. They can be ramped up to 10 per cent, but only 8.5 per cent if likely to be used by people in wheelchairs. If the seating rake is steeper, gangways must have steps extending the full width and these must have consistent treads and risers in each run. This means that the row-to-row spacing and row rise should be compatible with a convenient gangway tread and riser; and this in turn means that the shallow curve produced by sightline calculations should be adjusted to a straight line.

3.8 Seating geometry

Seating is usually laid out in straight or curved rows focused towards the platform or stage. Further forms are the angled row, straight row with curved change of direction and straight rows within emphasised blocks of seats, Figures 15.17 and 15.18.

3.9 Seating density

Seats with arms and tippable seat can occupy a space as small as 500 mm wide (less for seats without arms) with a row-to-row dimension of 760 mm; but can be as large as 750 mm wide by 1400 mm, Figure 15.19. The area per seat therefore varies between 0.38 m^2 and 3.05 m^2. Increased dimensions reduces seating capacity. Minimum dimensions as laid down by legislation offer a low standard of comfort and should not be taken as a norm, but the social cohesion of the audience may be lost if the standards are too high.

In conference halls where writing space is required, lower densities are inevitable, Figure 15.20.

3.10 Sightlines for a seated audience

For every member of the audience to have an uninterrupted view of the platform or stage over the heads in front and clear of overhangs the section and plan of the auditorium need to conform to certain limitations set by vertical and horizontal sightlines.

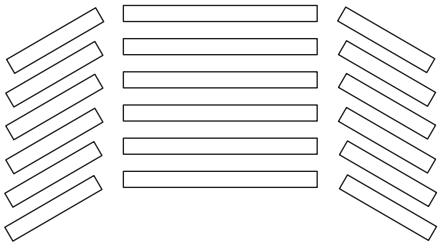
Vertical sightlines, Figure 15.21, may be calculated by establishing:

P Lowest and nearest point of sight on the platform or stage for the audience to see clearly.

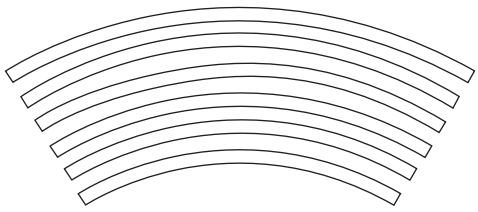
HD Horizontal distance between the eyes of the seated members of the audience, which relates to the row spacing and can vary from 760 mm to 1150 mm and more.



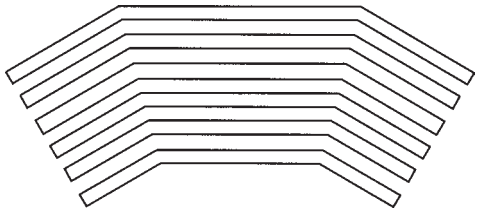
a *Straight rows on flat or sloping floor*



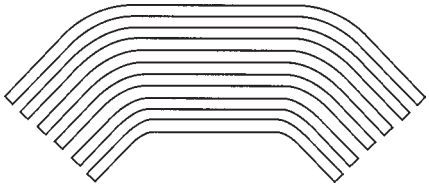
b *Straight rows with separate angled side blocks on flat or sloping floor*



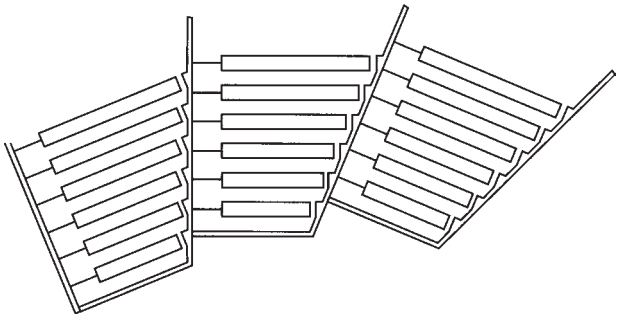
c *Curved rows on flat or sloping floor*



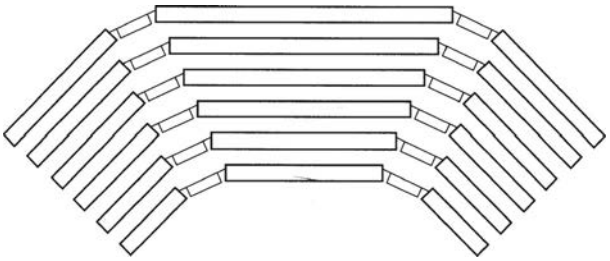
d *Straight and angled rows on flat or sloping floor*



e *As d but with curves at change of angle*

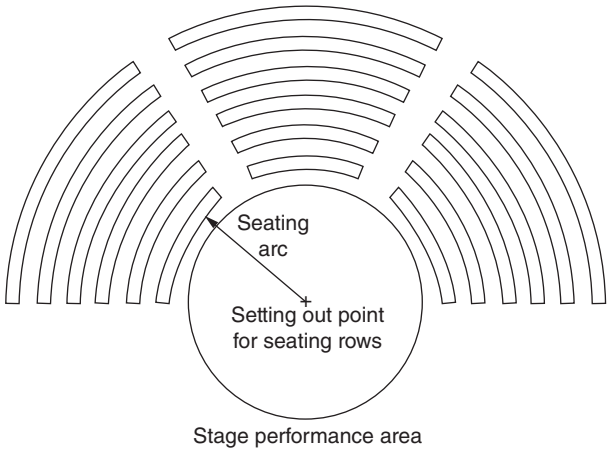


f *Separated stepped blocks focused on stage*

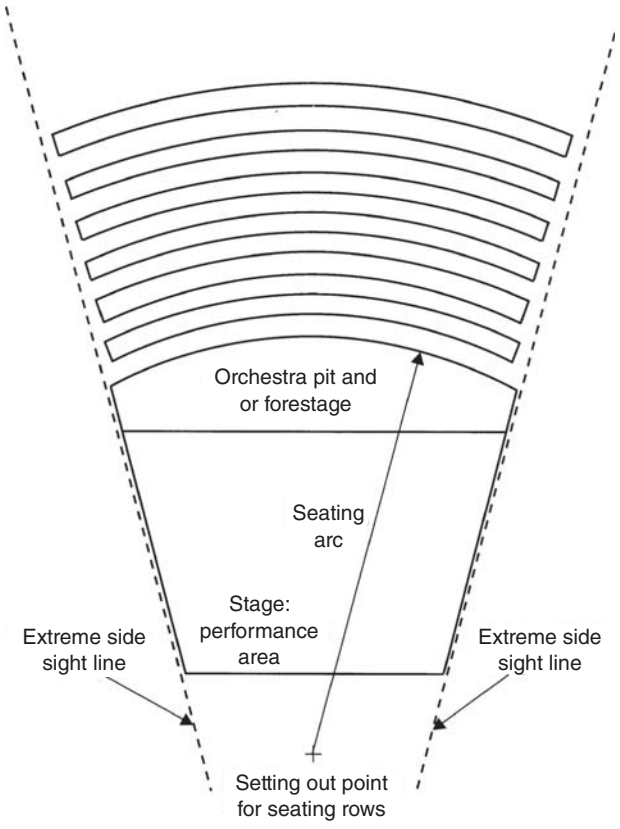


g *Straight stepped rows and separated angled side blocks*

15.17 *Alternative auditorim seating arrangements*



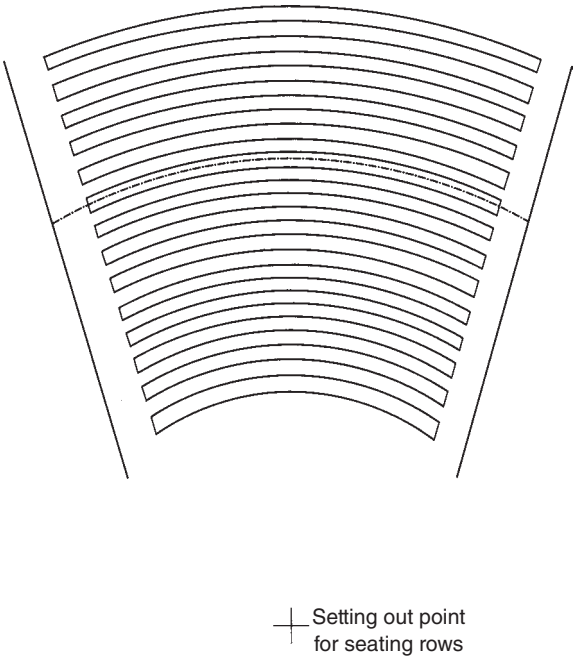
a *Open stage and theatre-in-the-round layouts*



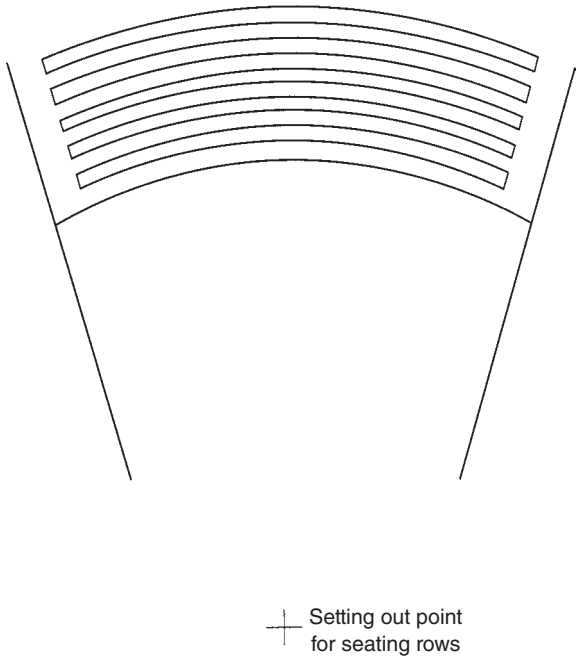
b *Proscenium layout*

15.18 *Setting-out of auditorium seating rows*

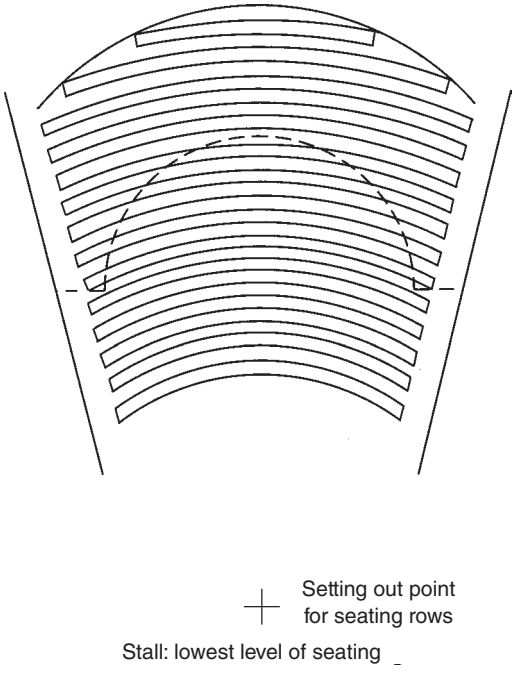
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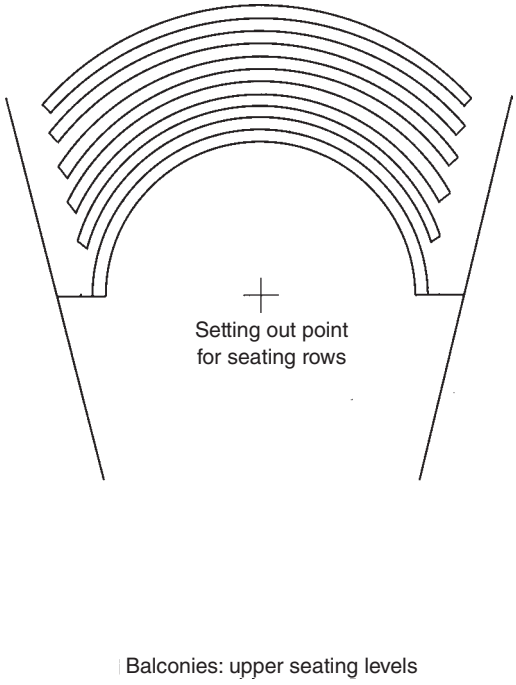
c *Proscenium and end stage layout 1: stalls*



d *Proscenium and end stage layout 1: balcony*



e *Proscenium and end stage layout 2: stalls*



f *Proscenium and end stage layout 2: balcony*

15.18 *Setting-out of auditorium seating rows (contd.)*

EH Average eye height at 1120 mm above the theoretical floor level: the actual eye point will depend on seat dimensions.

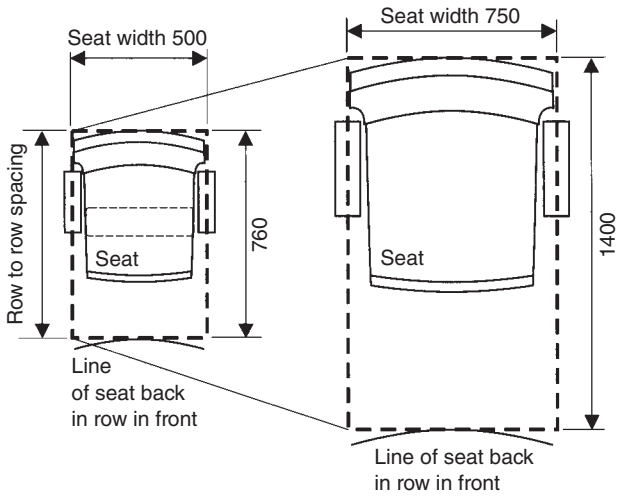
E Distance from the centre of the eye to the top of the head, taken as 100 mm as a minimum dimension for the calculations of sightlines. For assurance that there is a clear view over the heads of those in the row in front this dimension should be a least 125 mm.

D Front row of seats: the distance from point P to the edge of the average member of the audience in the front row. The relationship is shown in Figure 15.21.

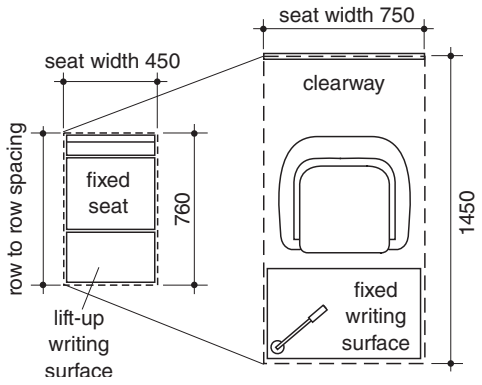
The longitudinal section is a parabolic stepped floor as a theoretical rake produced by the sightline calculation. This gives every member of the audience similar viewing conditions. This may be reduced to a single angle or series of angles.

When applied as described the rake will also be steep. This is satisfactory for a single tier of seating with no balconies and is especially appropriate for open-stage formats. If a balcony or balconies are introduced, the rake of the lower bank of seats can be reduced, assuming vision to be every other row allowing for point P being seen between heads in the row in front. The vertical distance between point from eye to top of the head for calculation purposes can be reduced to 65 mm if seats are staggered. This is particularly applicable with the design of a large auditorium where, within the visual and aural limitations, the aim is to maximise the seating capacity. This implies a balance between sightlines, height of

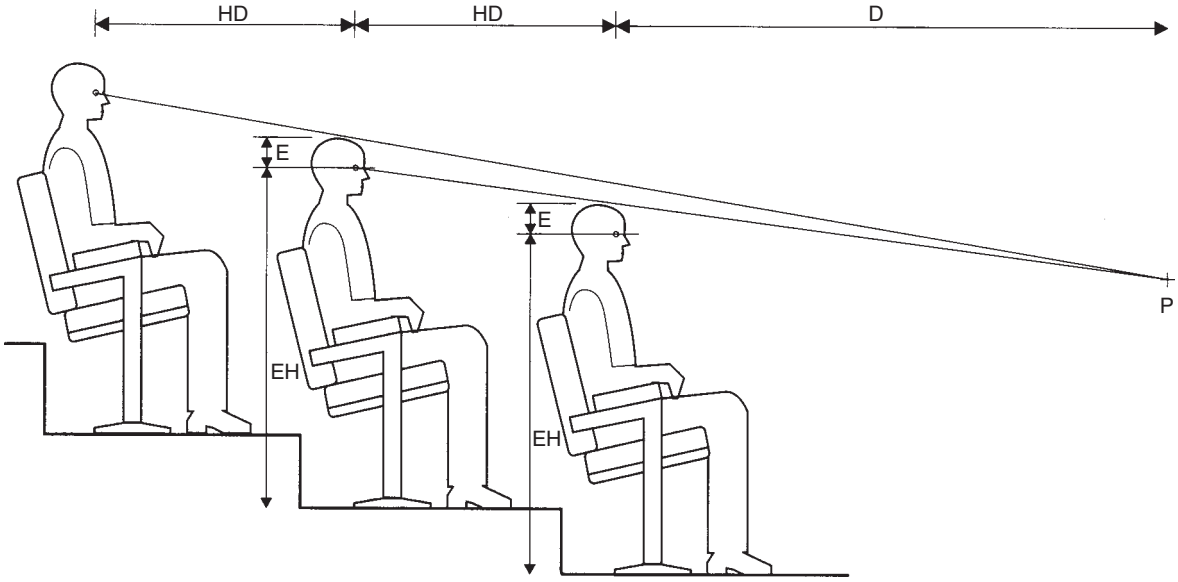
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15.19 *Seating density, from 0.38m² to 1.05m² per person*



15.20 *Seating density in conference halls, from 0.34 m² to 1.09m² per person*



15.21 *Graphic representation of vertical sightlines, P lowest and nearest point on stage clearly visible by audience, HD horizontal distance between eyes in successive audience rows, EH average audience eye height above floor, E height between eye and top of head, D distance from eye of person in front row to P*

auditorium and seating capacity. Reducing the accumulative height of the lower level of seating allows more height for balconies.

With the smaller auditorium, especially with the audience partially or wholly surrounding the stage and a limited number of rows of seats, an increased height of the rake to the seating encourages a sense of enclosure of the stage, while providing good sightlines. Figure 15.22 shows how the eye position relates to the seat and the stepped floor.

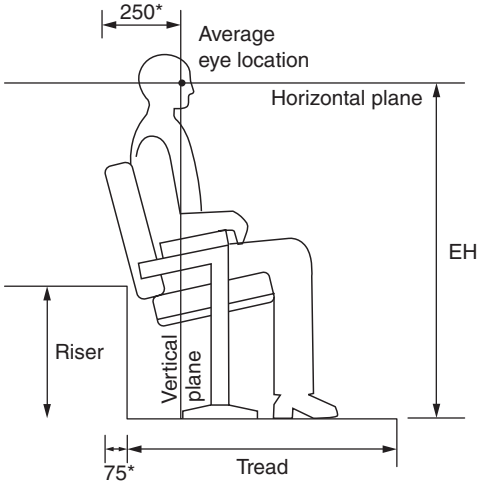
Cross-gangways

With *cross-gangways* the line of the auditorium rake must continue so that the audience can see the performance area above the gangway as below. With stepped rows there requires a handrail to the upper side of the gangway and, if a steep rake, a handrail to the lower side. See Figure 15.23.

Horizontal sightlines

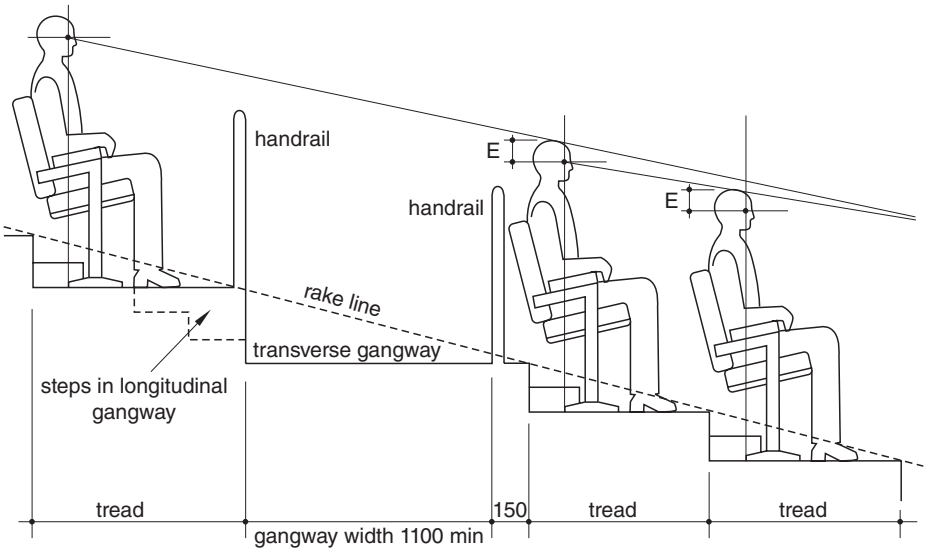
Given a particular size and shape of the platform or stage, horizontal sightlines limit the width of the seating area in the auditorium. This is more critical with the proscenium stage and with film, video and slide projection.

Without head movement, the arc to view the whole platform or stage on plan is 40° from the eye, Figure 15.24. Debatable is an

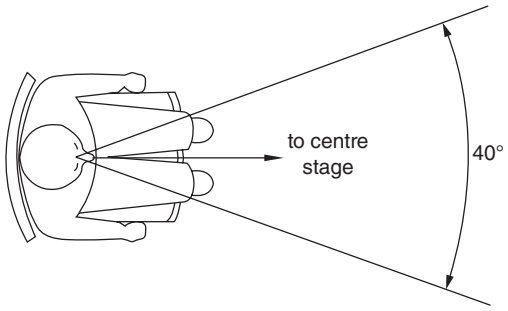


15.22 *Position of eye in relation to seat and stepped floor. Dimensions vary according to upholstery thickness, and inclinations of both seat and back. Working dimensions are starred**

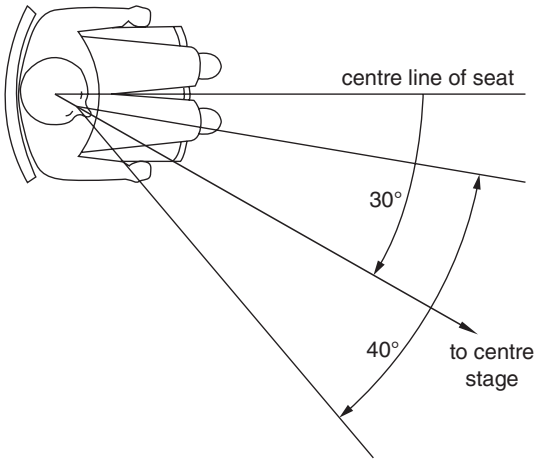
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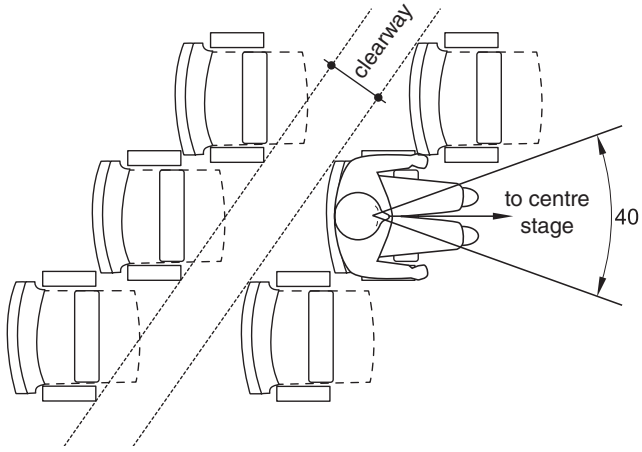
15.23 *Sightlines at transverse gangway; the angle of the rake line is constant*



15.24 *The angle of horizontal vision for a stationary head is 40°*



15.25a *The maximum comfortable amount the head can be turned from the seat centreline is 30°*



15.25b *Where the head angle would exceed 30°, the seats may be angled within the row*

acceptable head movement, where the seat is focused away from the platform or stage, such as with side galleries requiring the head to be turned by the member of the audience, Figure 15.25.

The horizontal sightline of the performer may also need consideration, Figure 15.26.

3.11 Wheelchair location

Regulations require a minimum of six places for wheelchair users, or 1/100th of the audience capacity, whichever is the greater. Their location as discrete areas can be at the rear, front, side or within the seating, Figure 15.27. Wheelchairs can be centrally positioned by forming a bay off a cross-gangway.

A wheelchair user should be able to sit with a party of friends not in wheelchairs, Figure 15.28. Sightlines from the wheelchair should be checked, as should the sightlines of those audience members behind. Some wheelchair users can transfer into auditorium seats.

3.12 Means of escape

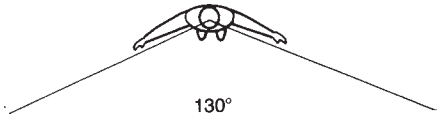
The aim is for all in the auditorium to be able to escape to a place of safety within a set period of time. The escape route is from the seat, along the clearway and gangway, and through exit doors immediately, or through an enclosed corridor, to the place of safety.

Travel distance

The maximum travel distance from seat to exit within the auditorium is determined by the need to evacuate from each level of the auditorium within 2½ minutes. For traditional seating the maximum travel distance is 18 m measured from the gangway, for continental seating 15 m from any seat.

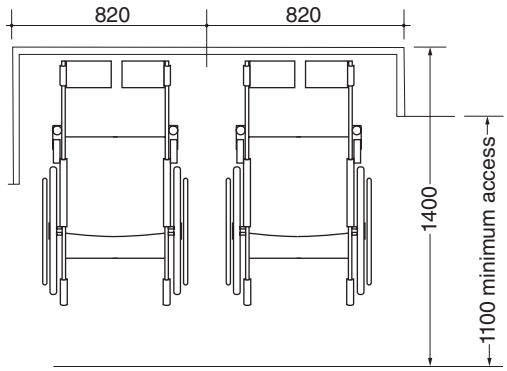
Exits

From each level of the auditorium two separate exits must be provided for the first 500 seats with an additional exit for each further

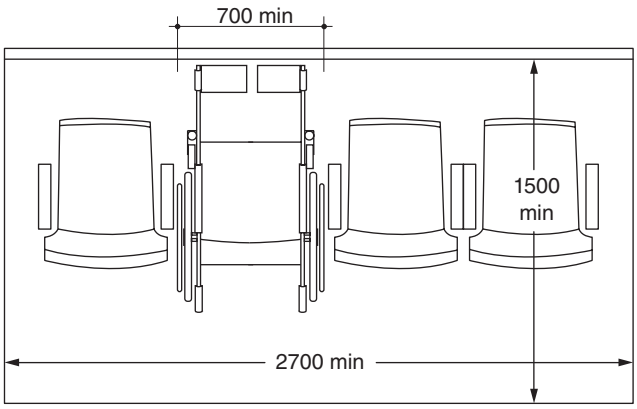


15.26 *Horizontal sightlines of the performer*

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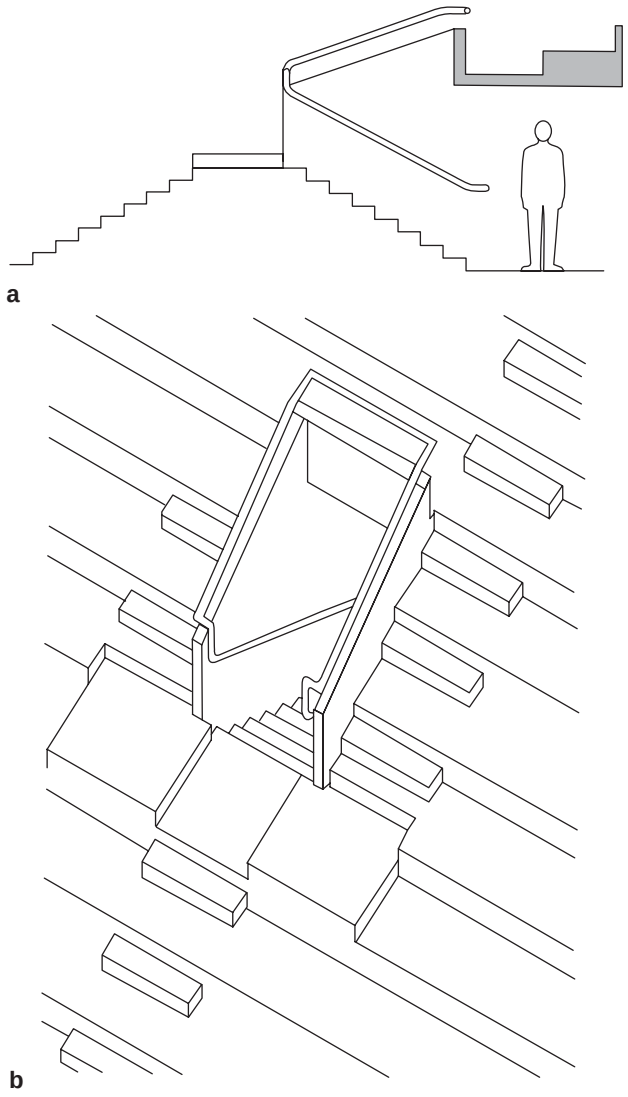
15.27 *Designated wheelchair area, required dimensions*



15.28 *Plan of a box designed for a wheelchair plus loose chairs*

Table II Total exit widths required by legislation

Numbers of people	Minimum total exit width (m)
up to 200	2.2
201–300	2.4
301–400	2.8
401–500	3.2
501–750	4.8
751–1000	6.4
1001–2000	14.4
2001–3000	20.8



15.29 *Audience vomitory: a public entrance to and exit from the auditorium through a seating block as distinct from through the side or rear walls: a Section. b Axonometric view*

250 seats. Table II gives the minimum total of exit widths required by legislation. Each exit from the auditorium must lead directly to a place of safety.

Exit routes

The route must be a consistent width the same as the exit. There must be no bottlenecks and all doors within the route must open in the direction of escape. Routes within the building should have fire-resistant enclosures. There are special requirements for all doors opening onto fire escape routes.

Stairs

Staircase flights should have at least two risers and not more than 16. All treads should be 275 mm and risers 180 mm.

Ramps

Wheelchair users should be provided with flat or ramped escape routes which may be separate from other routes. Ramps should not be longer than 4.5 m or steeper than 8.5 per cent.

3.13 Circulation

While gangway lengths and widths are calculated as part of the fire escape route, they also provide the circulation through the auditorium, with possible additional gangways from the audience entry points to individual rows and seats.

3.14 Entry points

The audience can enter the auditorium from the foyer at the rear, at the sides of the seating or from vomitories within the seating banks, Figure 15.29; and the entry points need to connect directly with the gangways. There should be a threshold space at the entry points for ticket check, programme sales and for members of the audience to orientate themselves.

Sometimes, particularly in theatre-in-the-round, performers make their entrances from within the audience area, Figure 15.30.

3.15 Handrails

Balcony handrails, Figure 15.31, are specified by legislation covering height, width and structure: they must also not interfere with sightlines.

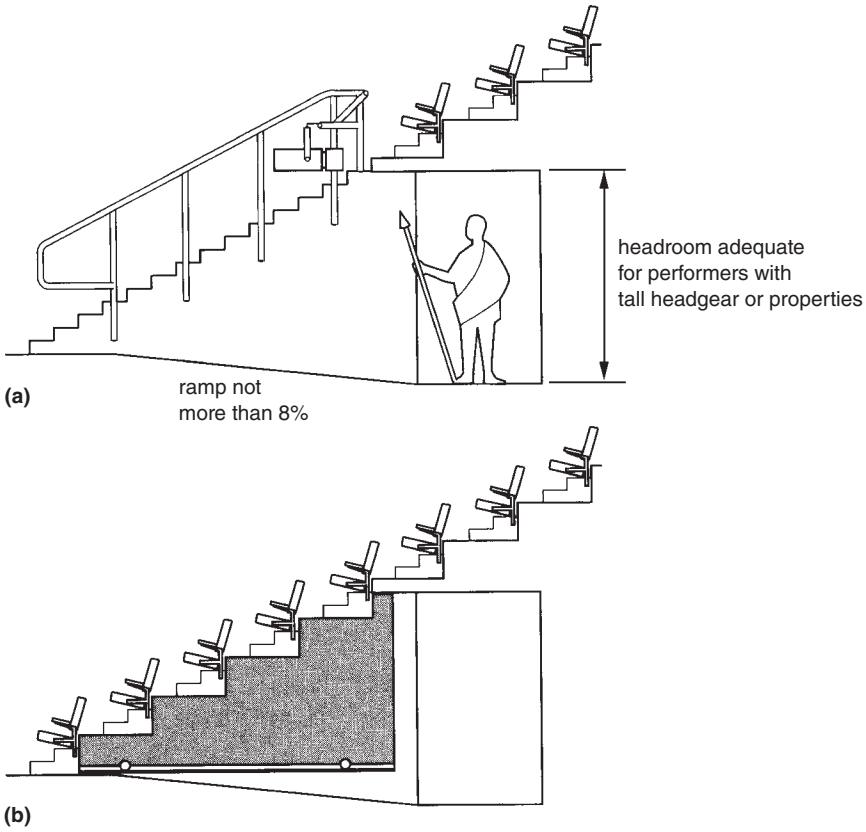
Handrails will also be required to stepped gangways:

- adjacent to enclosing wall;
- if there is a drop at the side.

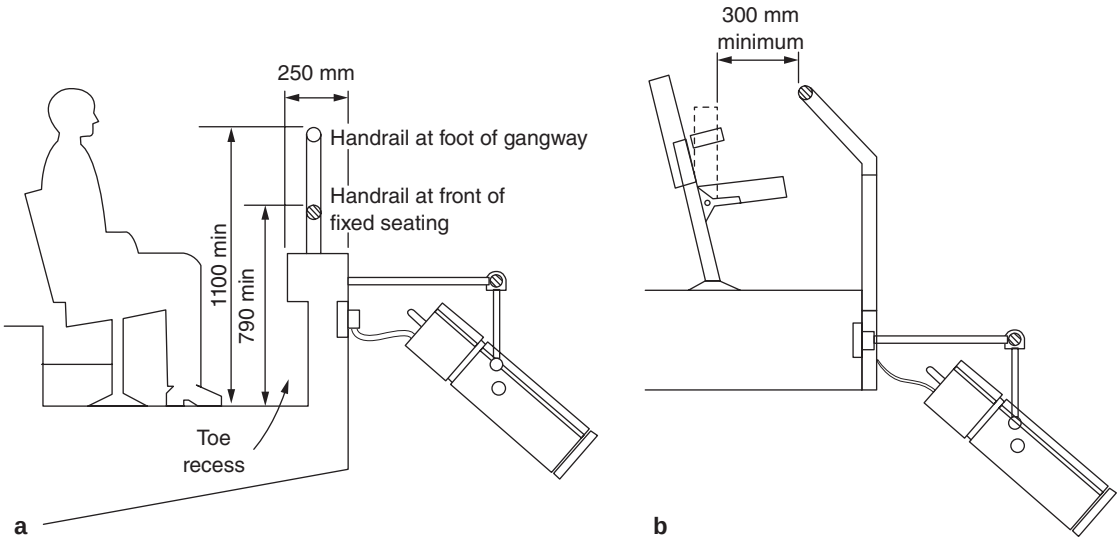
They are also needed:

- at landings;
- at the rear of rostra;
- where there is a drop of more than 600 mm.

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15.30 *Performers' vomitory: access to the stage through a block of seating, usually in an open stage or theatre-in-the round format. a Section. b Section showing removable seating in place when vomitory not required*



15.31 *The minimum balcony handrail height (BH) is set by legislation at 790 mm in front of fixed seating and 1100 mm at the ends of gangways. Balcony fronts are used to support performance lighting and need socket outlets connected to stage lighting controls: a Traditional balcony front incorporating shelf below handrail and adequate legroom. b Simpler front for side galleries with minimum clearway allowing the audience to lean on the handrail. This front is removable as part of a flexible auditorium*

Where the rake of a gangway is above 25° the ends of the rows should have a loop rail, Figure 15.32.

Rails are usually 900 mm above pitch line and 1200 mm above landings, with infill panels that are solid or have no gap greater than 100 mm.

3.16 Floors

The floor of the auditorium is an acoustic factor in the success of an auditorium. Some venues now dispense with carpets as plain wooden floorboards offer a better acoustic for orchestral music. Consideration should be given as to whether the auditorium floor should be flexible to account for acoustic variability.

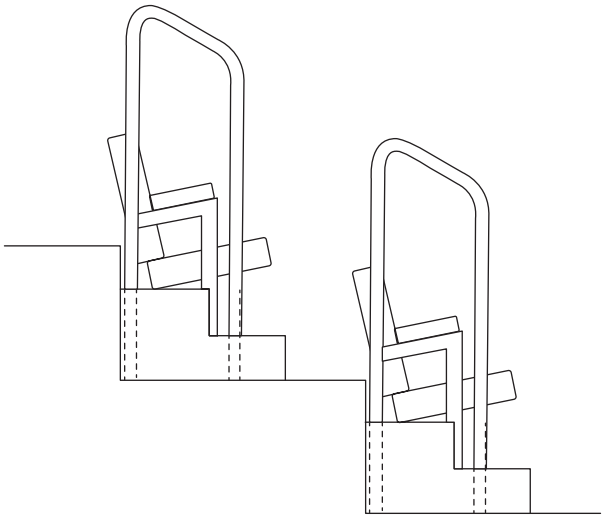
3.17 Latecomers

A waiting area at the rear of the auditorium either within the auditorium or in a separate enclosed space with viewing panel and tannoyed sound, or elsewhere with a closed-circuit television facility.

3.18 Attendants

Legislation dictates a number of attendants present at public events, each requiring a seat in the auditorium.

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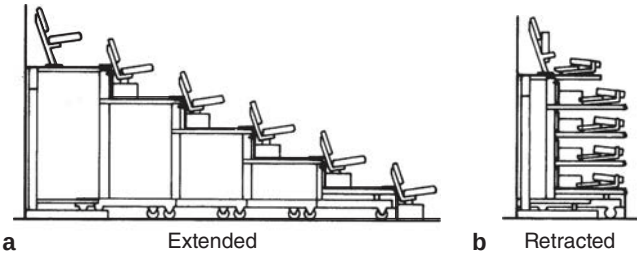


15.32 *Loop guardrail at the end of a row where the rake is steep*

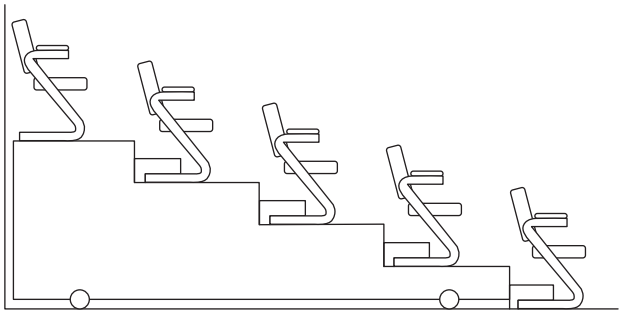
3.19 Adaptation

Relevant for multi-purpose auditoria where different formats or uses are combined or part of the raked seating will require to be moved. This can be achieved by forming structure off a flat floor, and methods include:

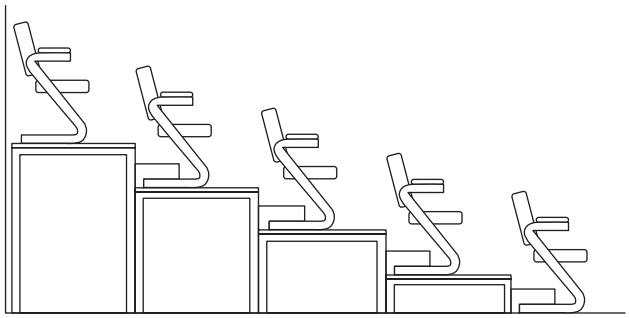
- Bleacher seating, Figure 15.33: telescopic structure with tip-pable upholstered seating with backs, able to be retracted into the depth of a single and highest row; rows are straight and the extended structure is a simple rectangular block, which places a discipline on the seating layout.
- Rostra, Figure 15.34: complete raked units with either permanent or removable seats, on wheels or air palettes for ease of movement into storage areas when not in use.
- Sectional rostra, Figure 15.35: a set of boxes able to be built up to form raked units with removable seats; storage requirements less than complete rostra.
- Kit of parts, Figure 15.36: scaffolding or equivalent set of components able to form raked levels to receive seating; the most flexible system, efficient storage requirements, but labour intensive.
- Hydraulic lifts, Figure 15.37: mechanical method of raising sections of the flat floor to form a rake floor to receive seating.
- Loose seats, Figure 15.38, secured in position when required for performances, can be used with functions requiring a flat floor.



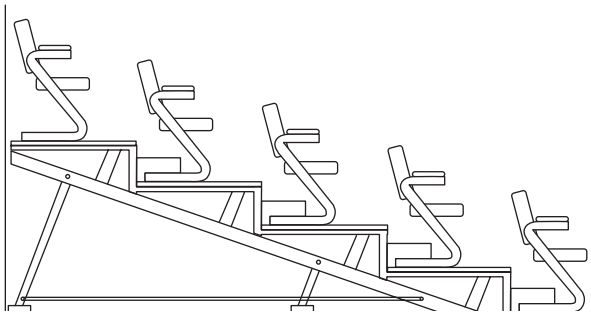
15.33 *a Bleacher seating: one of a number of proprietary systems of permanently installed retractable systems. The length of seating in a single unit is limited to 6 m. For tip-up seats with arms the minimum riser height is 250 mm. b Bleacher seating retracted*



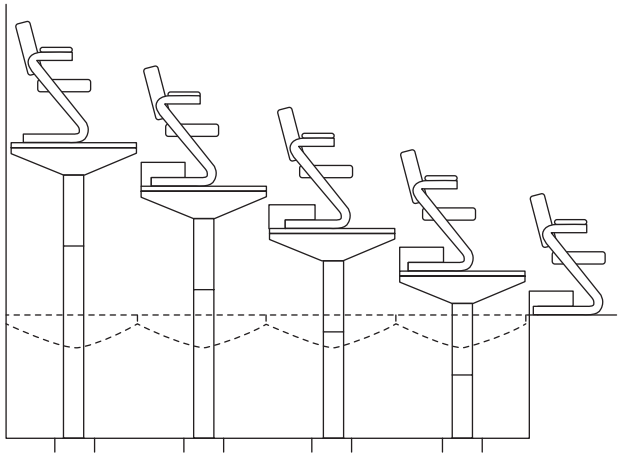
15.34 *Large units on brakable casters or air cushions*



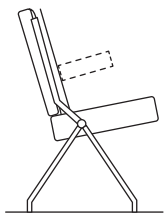
15.35 *Rostra: a set of metal or timber units built up to form a stepped floor on a flat base. Seats are secured onto floor or riser. Each rostrum unit collapsible for storage*



15.36 *Proprietary scaffolding-type system*



15.37 *Floor sections that can be raised and lowered hydraulically*



15.38 *Loose seating, capable of removal. May or may not have arms, and be stackable. Needs to be firmly fixed down when in public use*

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Following a number of failures of such flexible spectator facilities, legislation has been tightened up and official inspections are often necessary whenever seating arrangements are changed. This means that it is not usually possible to stage a series of different events within a short space of time.

3.20 Sound insulation from outside noise sources

The standards are expressed as Noise Rating (NR). To achieve the appropriate rating auditorium design may require:

- isolation of the auditorium structurally;
- sound locks to all doors at point of entry;
- services acoustically sealed;
- noise reduction to air conditioning/heating/ventilation system.

3.21 Air conditioning, heating and ventilation

The design depends on the internal standards required in the auditorium, the thermal insulation of the enclosure and on the external climatic conditions. Ventilation needs to provide fresh air at a rate of change to achieve comfort conditions: rates are set down by legislation and include a proportion of recycled conditioned air which vary locally. A common condition is a minimum air supply per occupant of 8 litres per second, 75 per cent of outside air and 25 per cent recirculated.

Extract ductwork can be at ceiling level and under balconies with supply below the seating.

Plant should be remote from auditorium to avoid noise transmission.

3.22 Lighting

There are six different requirements for auditorium lighting.

Performance lighting

For theatre, opera and dance performance lighting is an integral part of the staging of productions, with lighting positions not only on the stage but also within the auditorium at ceiling level, on side and rear walls and balcony fronts. Further details are given in Section 4.11.

For classical music and serious jazz sufficient lighting for the performers to see their music and the conductor (if any), and for them to be seen by the audience is usually all that is required. Similar lighting is required for the platform at conferences.

Pop music requires as complex lighting as for drama and opera – perhaps even exceeding that with elaborate effects.

House lighting before and after performance and during intervals

Illumination is needed to enable the audience to move around, find their seats and read programmes; decorative lighting to emphasis architectural features. This form of lighting will also be required during conferences.

House lighting during performance

For cinema lighting is only for exit signs and escape routes. For the latter, small lights just above floor level have advantages in not obscuring the screen and being most effective in smoke-logged conditions.

For theatre a slightly higher level of illumination may be used, particularly if the performance demands a contrast with a time of almost total darkness. For classical music it is now usual to have sufficient lighting for near-normal vision and following scores.

Pop music may nowadays require house lighting as sophisticated as performance lighting, with strobe and laser facilities.

Certain lighting is required during performances to ensure safety in emergency, particularly the statutory exit signs. Other lighting may be required to come on automatically in emergency situations; this may work off a separate protected supply. Alternatively, each item can incorporate a battery and be programmed to come on when a failure in the mains supply is detected.

House lighting at other times

It should not be forgotten that the seating area will also require a working level of lighting for cleaning, maintenance and probably during rehearsals and auditions.

Front-of-house lighting

Escape routes have to be adequately lit at all times, during performances as well as before and after. Foyers, bars and ticket offices require careful lighting design to enhance their attraction.

Backstage lighting

Corridors are escape routes for the performers and service staff, and must be kept illuminated whenever the building is occupied. Dressing rooms and workshops will have normal lighting for such facilities, and may be fitted with proximity detectors to ensure that lights are not left on when the rooms are unoccupied.

3.23 Fire protection

Fire precautions should be discussed with the local fire authority and with fire insurers. Means of escape have already been covered in Section 3.12. However, it is important to consider four other factors.

Preventing fires occurring

- Non-combustibility of materials including finishes and seating.
- Protection of electrical circuits.
- Care with lighting.
- Separation of hazardous processes such as scene-painting.

Detecting them early when they do occur

- Smoke and heat detectors backstage, in auditorium and all voids.
- Alarms connected to the automatic detector system and central indicator panel, and possibly direct link to local fire station. These should be visual (flashing light) in auditorium and not audible.

Preventing them spreading

- Enclosing walls and floors to be fire-resistant.
- Self-closing firedoors to openings.
- Either a safety curtain to the stage area or special on-stage precautions.

Facilitating extinguishing

- Hose-reels.
- Portable extinguishers.
- Automatic sprinkler systems backstage (not allowed over seating areas).

3.24 Ceiling zone

Functional requirements cover:

- Acoustics: profiled reflector panels and possible adjustable diffusers. For non-amplified music, reflectors also over concert platform.
- Lighting: bridges for access and support for auditorium lighting, working lights and emergency lighting as well as performance lighting.
- Ventilation: air ducts and plenums, diffusers, noise attenuation and monitoring equipment, supporting hangers and means of access for servicing.
- Production requirements: for operas, dance musicals and drama, a grid and pulley suspension for suspending scenery over forestage, including access by technicians.
- Fire control: detection system in voids and fire dampers in ducts.
- Structure: support for roof, ducts, lighting bridges, etc.

4 THEATRE

4.1 Range

Theatre covers productions of drama, opera, ballet, musicals, variety and pantomime, 15.39.

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4.2 Types

Theatre structures are enormously varied and much alteration work is done in theatres during their working lives. This work usually includes upgrading or modernising the stage equipment, and improving the seating quality. The reasons are market driven: equipping to take larger or more complex productions, enabling more productions within a given time and labour-saving measures. Front-of-house improvements are made to attract greater attendance through increased facilities and comfort.

Theatres and studio spaces, which for these purposes also include 'fringe' venues formed out of existing buildings, also see themselves as fitting into a particular bracket, for example small, medium or large scale. These categories are determined by a sliding scale involving seating capacity, size of stage, backstage accommodation and even geographical location. The intended scale of use should be apparent in any brief, or should be clarified. It will need to be reflected in the design proposals.

Medium-scale theatres would normally be considered as those with perhaps less than 1000-seat capacity, without a significant array of stage machinery, but provided with proper fly suspension systems and orchestra pit facilities suitable for taking smaller productions with cast not normally exceeding 20–25 individuals.

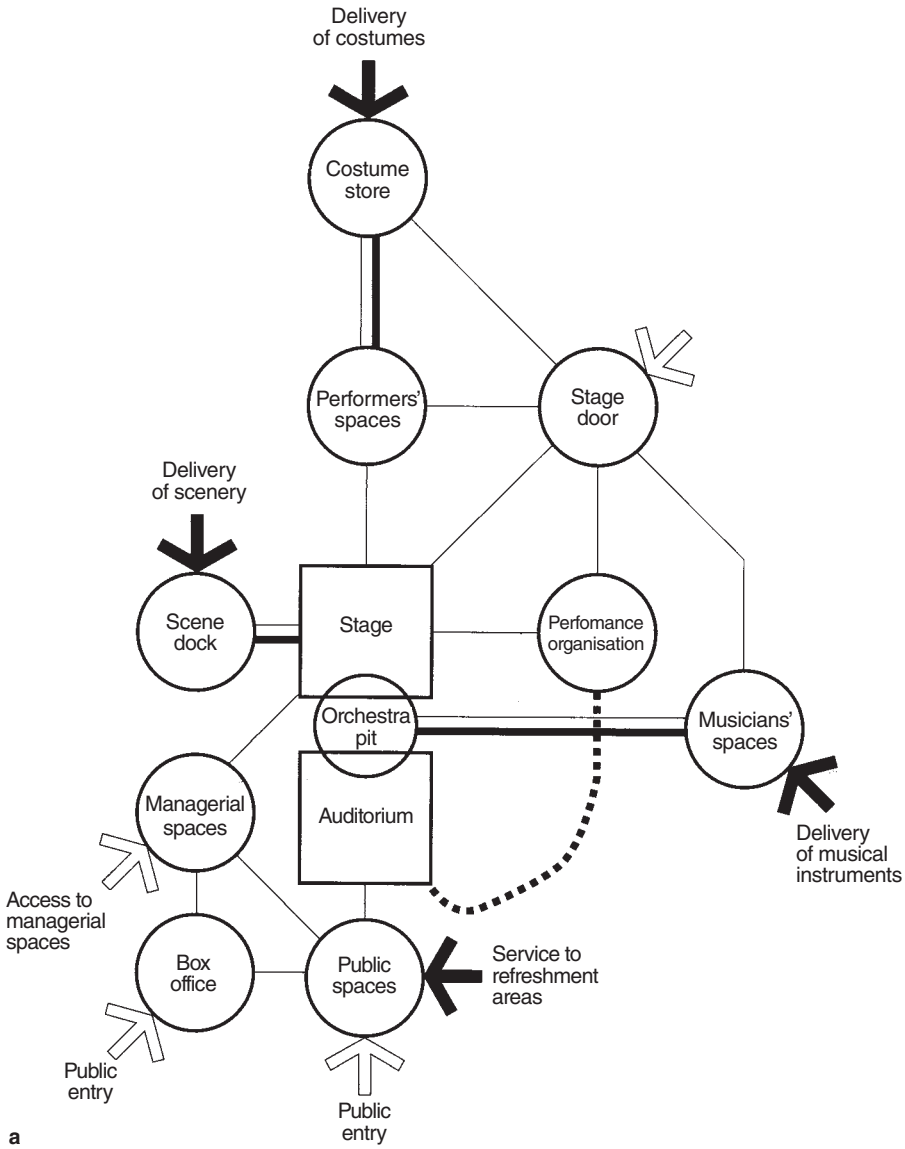
4.3 The proscenium

For most opera, dance and musicals, the formats are restricted to the proscenium and end stage. The proscenium form is a conventional arrangement placing the audience facing the stage, viewing the performance through an architectural opening. Scenery on the stage can be developed as a major design element. The traditional position is for the orchestra to be located in a pit between audience and stage, with the conductor in a pivotable location controlling orchestra and singers. The auditorium formats, Figure 15.40, include the horseshoe, fan with or without balconies, and courtyard. The latter consists of shallow balconies of no more than three rows around three sides of the auditorium. The end stage is similar to the proscenium format but without the architectural opening, placing audience and performance in the same space and suitable for small-scale productions.

For drama there is a wider range of formats: the initial distinction is between the proscenium format and open stage forms.

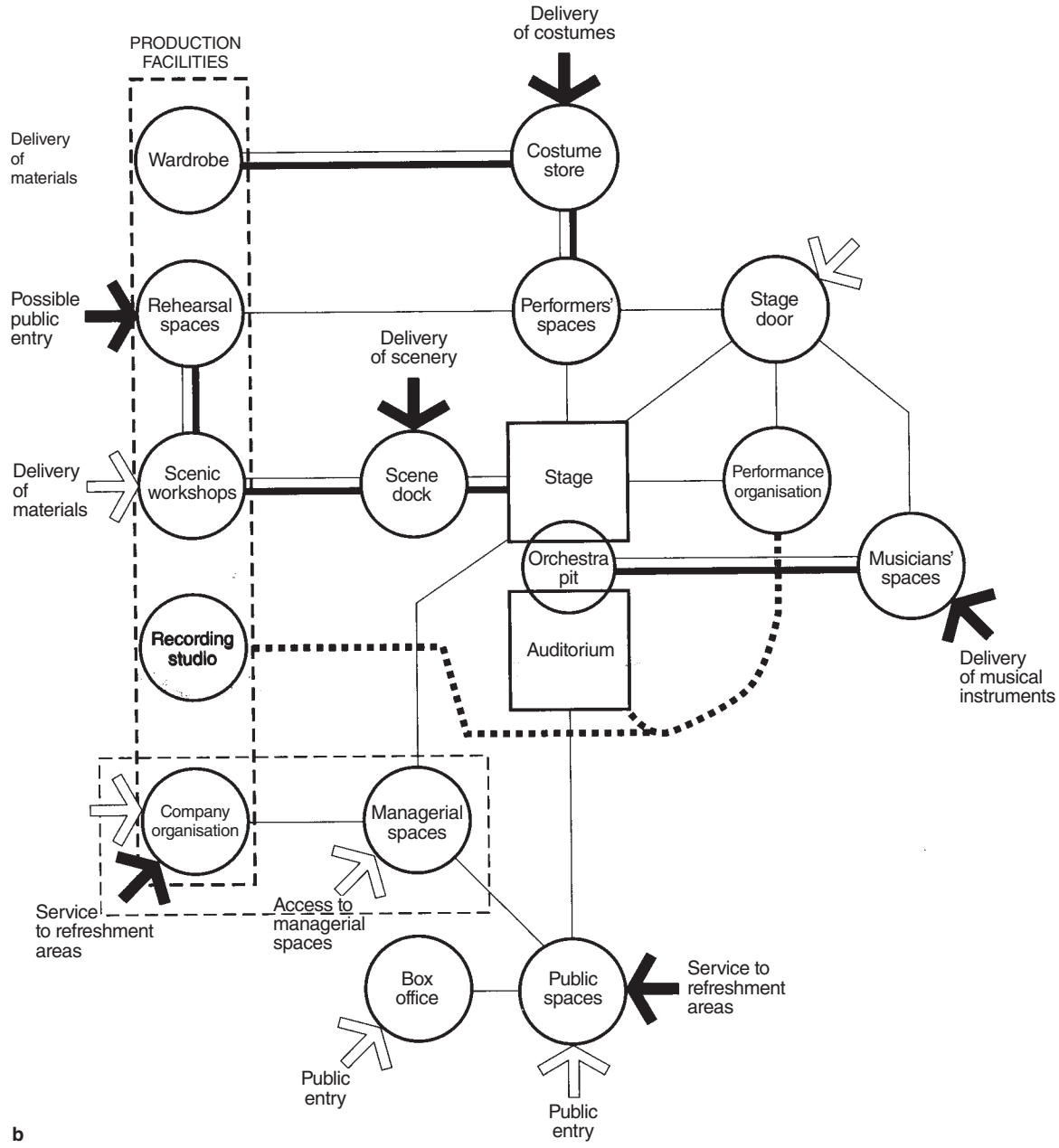
The proscenium format is outlined above. There are five variations of open stage formats, Figure 15.41:

- End stage
- Fan-shaped
- Thrust stage
- Theatre-in-the-round
- Transverse stage.

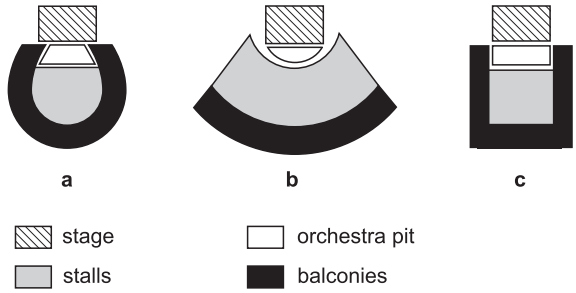


15.39 *Relationship diagrams for buildings for opera, musicals, dance and drama. If for drama only, the orchestra pit and musicians spaces may not be required: a Where the building serves only touring companies or with a resident company whose production facilities are elsewhere. b Where production facilities are needed*

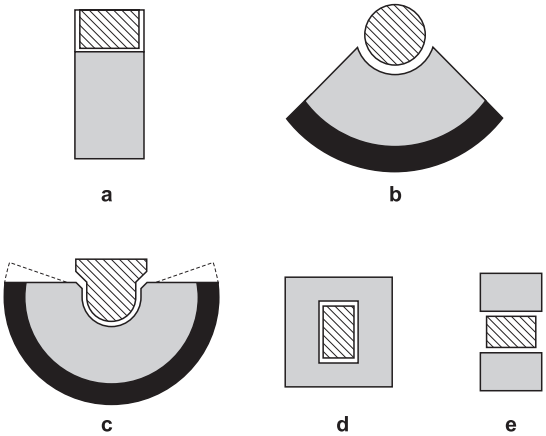
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15.39b



15.40 *Auditorium formats for opera, dance and musicals on proscenium stages: a Horse-shoe form, shallow rear and side balconies. b Fan shape with 90° arc, with or without rear balcony. c Shallow rear and side balconies*



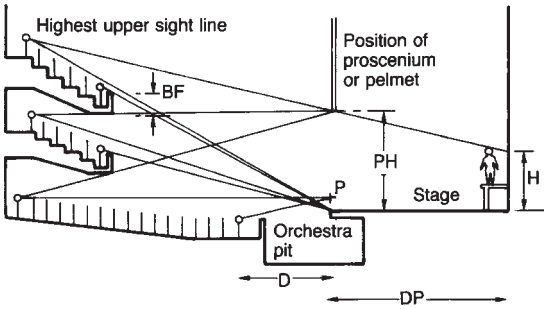
15.41 *Auditorium formats for drama on open stages: a End stage. b Fan shape, 90° arc with or without rear balcony. c Thrust stage, 180° + arc, with or without rear balcony. d Theatre-in-the-round. e Transverse: audience on sides of stage*

The viewing criteria in the auditorium will depend on the performance volume on stage, 15.42.

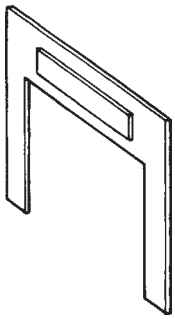
4.4 Stage

Stage refers to the main performance area and its associated fly-tower, side and rear stages and orchestra pit if these are provided. The stage floor is a vital part of the working system. It is essential that access can be made to the underside of the stage floor, and that

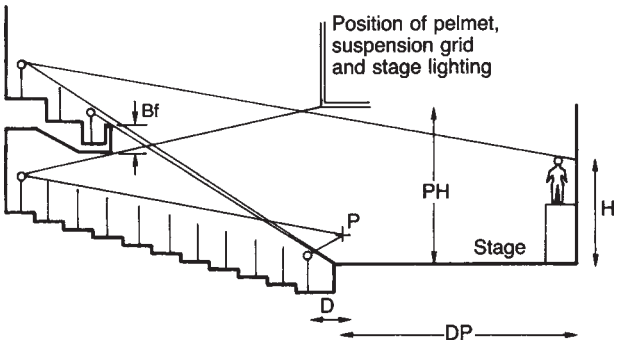
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15.42a *Vertical sightlines for proscenium stage*



15.42b *Subtitle panel over proscenium opening: needs to be visible to whole audience. These are increasingly essential for opera, and when drama is performed in a language foreign to most of the audience*



15.42c *Vertical sightlines for open stage*

it be constructed of such material that screws, nails etc. can be used with relative ease.

4.5 Proscenium stage without flytower

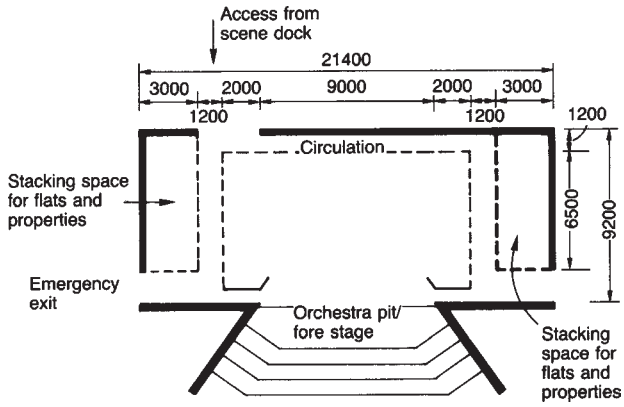
For the smaller auditorium without a flytower, suspension of scenery, curtains, pelmets, borders and lighting barrels above the stage, Figure 15.43, is necessary. Lines can be fitted to pulleys hung on a grid, with flying from a side gallery above the stage, or from the stage level. Side stages are required for stacking spaces for flats, properties and rostra, as well as circulation routes within the stage.

4.6 Proscenium stage with flytower

The dimensions and shape of the performance area are determined by the recommended proscenium opening as in Table III. A wider opening can be reduced by screens or curtains, so that an all-purpose stage should be sized for opera. Ideally, the depth of the performance area front to rear should be equal to the proscenium opening.

Raised stage

The height of the stage can be between 600 mm and 1100 mm with a straight, angled or curved front edge. The floor to the performance area, in part or total, may be a series of traps, that is modular sections usually 1200 mm square which can be removed selectively.



15.43 *Stage layout and dimensions for a medium-size theatre without flytower*

Table III Widths of proscenium opening in metres for various types of performance

	Small scale	Medium scale	Large scale
Drama	8	10	10
Opera	12	15	20
Dance	10	12	15
Musical	10	12	15
All-purpose	12	15	20

Side and rear stages

Sizes should relate to the size of the performance area. These areas may need to hold sets as on the performance area, with circulation all round. The clear height required is to be the highest scenery plus 1 m.

Stage basement

The space under the stage should be fully accessible with a minimum headroom of 4.5 m.

Safety curtain

In the case of fire on the stage it must be separated from the auditorium, with the proscenium opening being closed off by a safety curtain. The normal form is a rigid curtain suspended immediately behind the proscenium opening and dropping on the stage from the flytower, Figure 15.44. The fire seal must continue below stage level.

Examples of existing fly-tower stages are shown in Figures 15.45–15.48.

4.7 Stage machinery

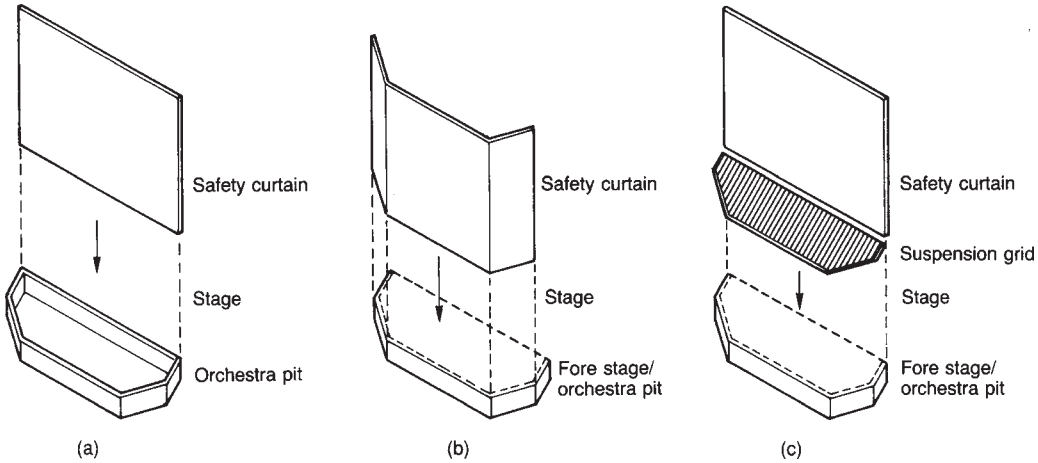
Large dedicated buildings such as opera houses require an amount of stage machinery to be installed:

Bridges are long lifts which span the width of the proscenium opening, giving a rise and fall facility over the main acting area. They are driven by screw jacks, scissors, chain or hydraulic systems.

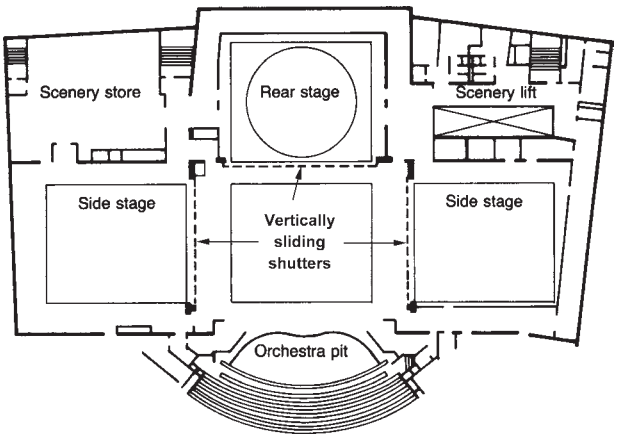
Revolving stages require to be set into the stage floor to provide a flush fit surface, but this can sometimes be organised to coincide with the system of lifts and bridges.

Wagon stages are large pallets capable of taking an entire set which may be moved into place behind the proscenium fully built, thereby saving labour during the performance period. If wagon stages are used, sound separation shuttering needs to be provided around the stage area to shut off the off-stage areas where work is going on to the wagon stages. Depending on the flying configuration, up to three wagon stage positions (left, right and upstage) may be involved in an immediate off stage situation. It is also possible to mount revolves in wagon stages. Much larger installations have in fact extended the wagon principle so that they are used as a system of gigantic palletised storage to store up to a dozen or more sets fully erected in large spaces below the stage, provision being made to have them lowered below the stage surface.

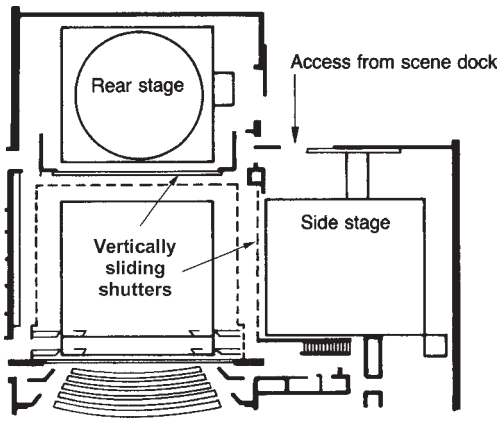
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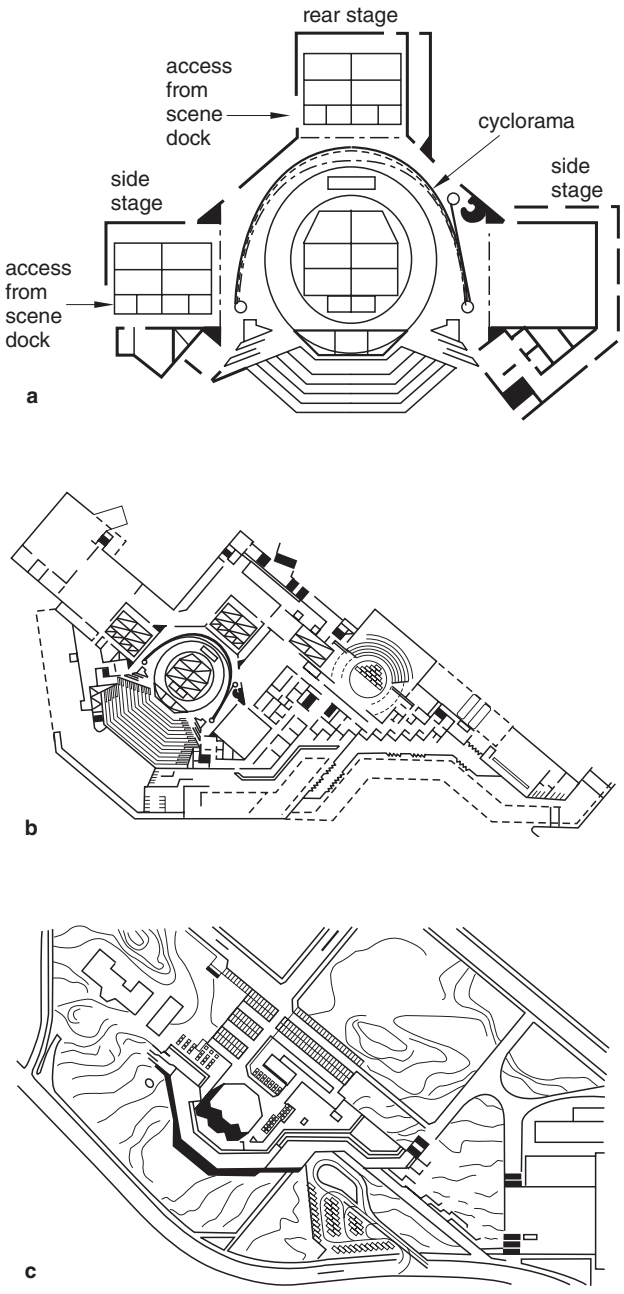
15.44 *Safety curtains, essential for a proscenium stage: a Simple flat design. b Cranked design for when orchestra pit is covered to make a forestage. c Flat design where scenery and properties on forestage are fully incombustible*



15.45 *Opera House, Essen: stage layout for a proscenium stage with a flytower for opera and dance*



15.47 *Lyttleton Theatre, Royal National Theatre, London: proscenium stage with flytower for drama*



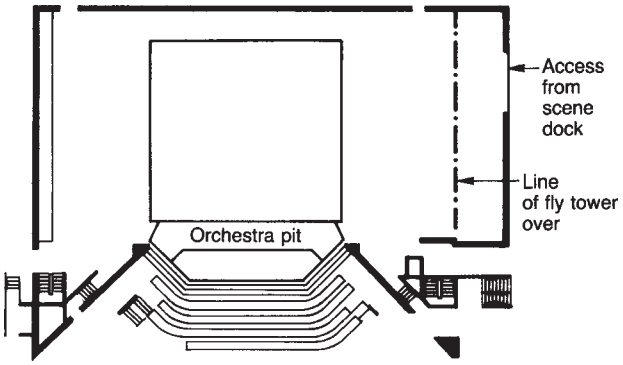
15.46 *Civic Theatre, Helsinki: a proscenium stage with flytower for drama and dance: a Stage layout. b Plan at entrance level. c Site plan*

4.8 Flytower

Where there is a space dedicated for use as a stage, then it is essential to provide this with means of suspension overhead. This suspension is to be used for both scenic and lighting instruments.

The grid above the stage from where the suspensions come should provide clear walking space above for personnel to move about over the floor area. The received wisdom is to place the pulleys supporting the suspension bridge at the high point with the walking grid space below it. The key to overhead suspension is the load and the frequency of suspension points. Multi-use, intensively used venues will have bars suspended every 200 mm with load capacity up

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15.48 *Theatre Royal, Plymouth: stage for touring opera, dance, musicals, drama and concerts*

to 500 kgf per bar. Less intensively used installations may have bars 300 mm apart and, depending on the nature of the performance to be given, the load capacity may come down to 350 kgf per bar.

It is essential that the means of suspension can be lowered to the floor. Depending on the frequency of usage, this suspension system can either be winched, or in smaller installations be operated using rope hand lines. In the theatre, all items suspended overhead are 'flown'. The space above the stage is referred to as the 'flys'. The greater the height over the stage is usually considered the better, offering greater flexibility for designers both of scenic and lighting disciplines. Where the scenic suspension system is raised considerably above the stage it can then be described as a flytower.

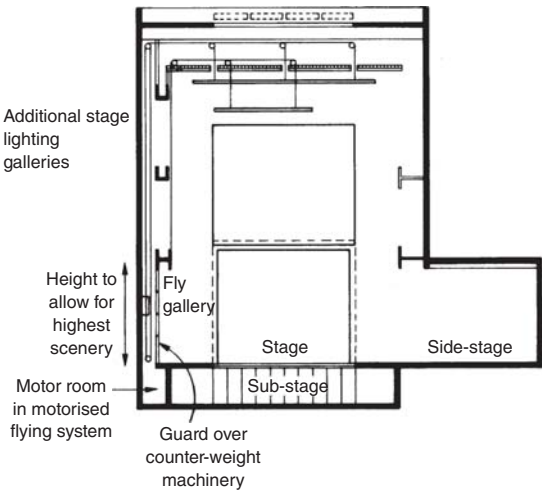
Conventionally the clear height of the flytower was 2½ times the proscenium height. Nowadays greater heights are usually demanded, with a minimum of 2½ times the proscenium height to the underside of the grid and a clear 2 m above the grid.

There are different means of suspension: the main ones are counterweight and hydraulic systems.

Counterweight systems

A 'cradle' laden with weights travels up and down special places vertically either side of the stage. There are two types:

- Single-purchase counterweights where the travel distance is equal to the height of the grid above the stage, Figure 15.49: a continuous vertical wall running higher than the grid is required for the guides.
- Double-purchase counterweights where the distance travelled by the counterweights is halved in relation to the distance of the suspension, Figure 15.50. This allows the operation to occur from a gallery above the stage level: an extra loading gallery is necessary between the flying gallery and grid.



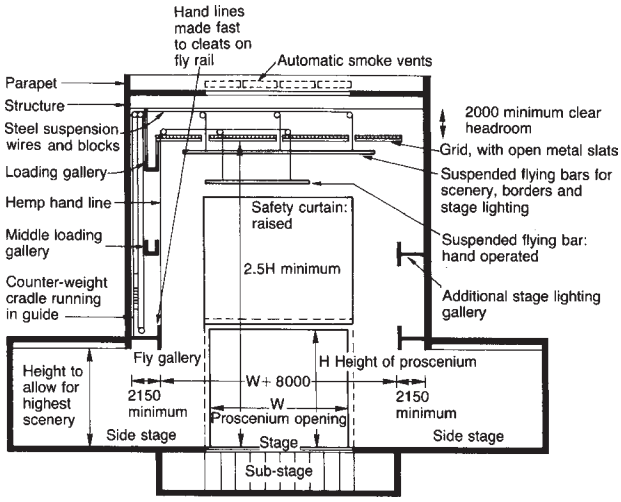
15.49 *Section through flytower showing single-purchase flying system permitting only one side stage*

Hydraulic systems

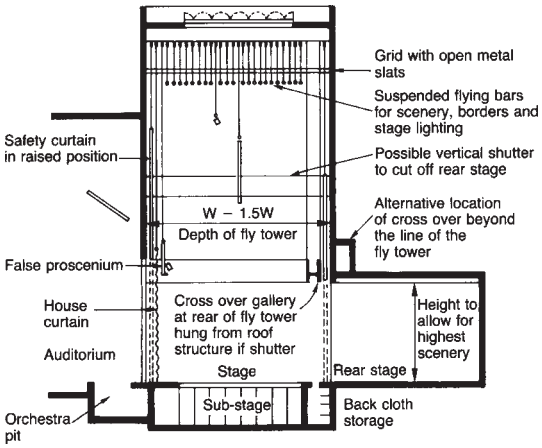
These obviate the need for space for the cradles by containing the entire system at the very highest point in the building, opening up the possibility of side stages on either side.

It is important to locate flyfloors either side of the flytower to provide horizontal access above the nominal height of the scenery.

This is used by technicians to locate and control horizontal movement of vertically suspended components. If the building is likely to have dedicated usage by a single-occupancy user, then certain suspension positions may be dedicated for lighting systems, in which case a special provision may be made for horizontal access by personnel to reach these positions as well as their raise and lower facility. It will also be possible to feed the necessary electrical supply from directly above the position in a self-monitoring system which caters for the vertical movement. Figure 15.51 shows a flytower stage with a rear stage.



15.50 *Section showing double-purchase flying system and side stages*



15.51 *Cross-section showing rear stage*

An automatic smoke vent is required at the top of the flytower: regulations require the cross-sectional area of the vent to be a particular proportion of the stage – usually 10 per cent.

4.9 Orchestra pit

A limiting factor is for the conductor to be seen both by the singers and dancers on the stage, and by the musicians in the pit. The audience needs a balance of performance from stage and orchestra.

Allow 3.3 m^2 average per player, 5 m^2 for the piano, 10 m^2 for tympani and percussion, and 4 m^2 for the conductor. The conductor's eye level must not be lower than stage level when seated on a high stool. To minimise the gulf between stage and audience, the

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pit can extend under the stage front for a distance no greater than 2 m.

For opera, the pit requires to hold a maximum of 100 musicians, 60 for musicals, 60–90 for dance. The numbers can be less with touring companies. The pit should be horizontally reducible, with the floor level vertically adjustable.

Where there is a multi-use facility orchestra lifts, Figure 15.52, are common. These can provide:

- a fore stage when elevated;
- two or three extra rows of seating when level with the auditorium floor;
- the orchestra pit when in the down position.

4.10 Open-stage formats

End stage

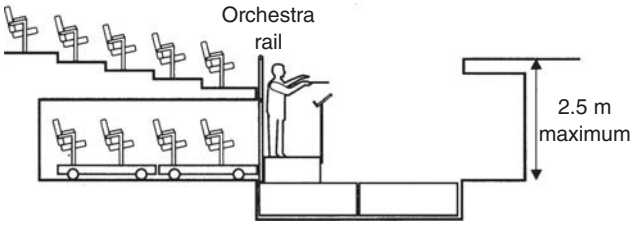
For dance and opera, the minimum performance area is 10 m × 10 m, for drama 10 m × 8 m. Modest side stages with masking are necessary for the storage of scenery as well as performers' entrances. Orchestra pit can be formed between stage and auditorium.

90° fan

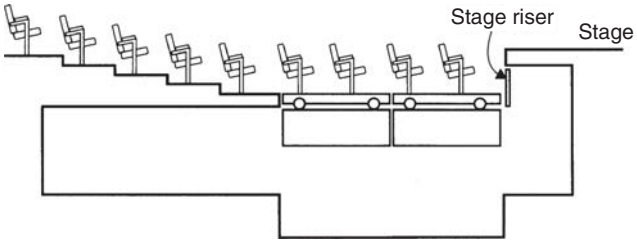
Dimensions vary, based on a circle or faceted circle, with diameters ranging from 8 to 11 m, Figure 15.53.

Thrust stage

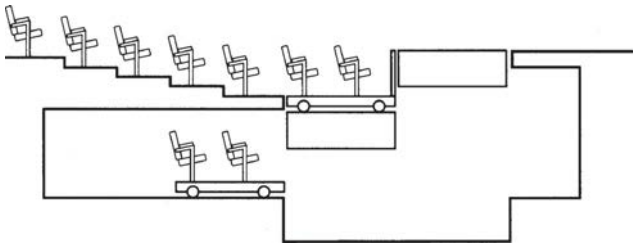
The performance area as a peninsula projecting from rear setting, Figure 15.54.



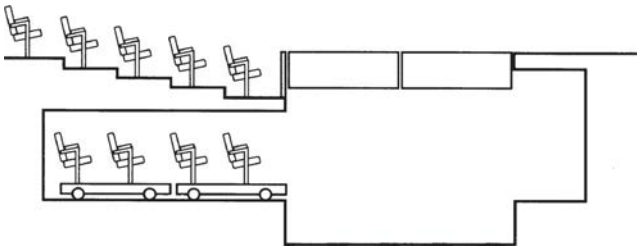
a Lift in lowest position with seat waggons in store under fixed seating



b Lift partially raised for maximum additional seating

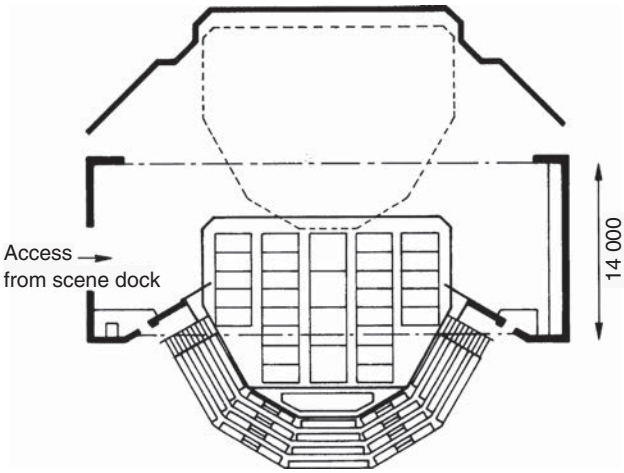


c Half lift raised for seating and half fully raised for stage extension

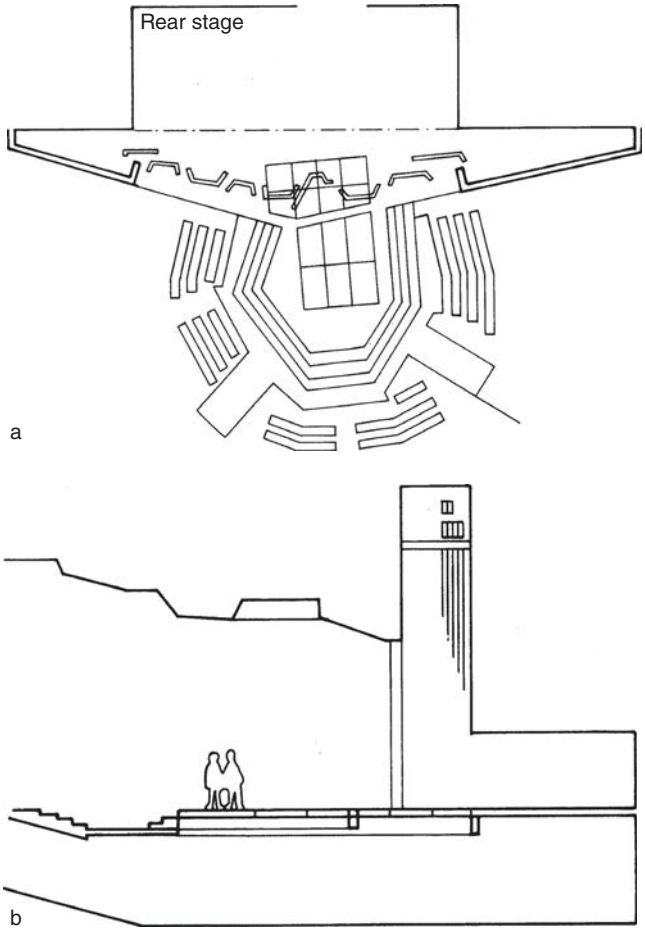


d Lift fully raised for maximum stage size

15.52 *Orchestra pit lifts*



15.53 *West Yorkshire Playhouse, Leeds: plan of a stage where the audience encircles it by 90°. This theatre has a single-purchase flying system and a retractable wagon stage*

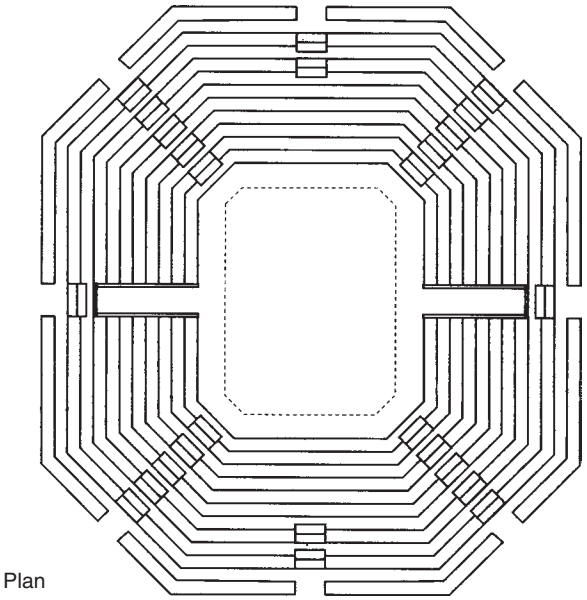


15.54 *Tyrone Guthrie Theatre, Minneapolis: thrust stage with steps at the edge permitting performers to access from various parts of the auditorium. The stage has traps, a rear stage and a backcloth flying system: a Plan. b Section*

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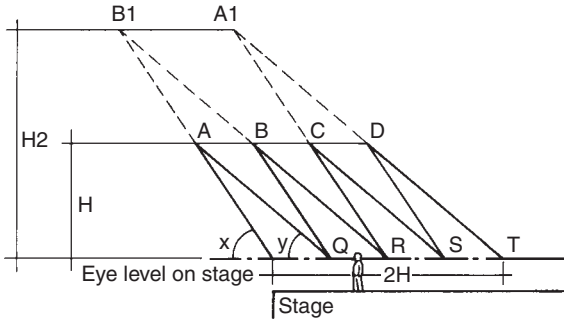
Theatre-in the-round

The performance area can be circular, square, polygon, rectangular or elliptical, Figure 15.55. The performers' entry can be combined or separate from the public access.



15.55 *Theatre-in-the-round with a rectangular performance area and performers entering at stage level from vomitories. The audience enters from rear of seating*

The stage is usually not raised, but can be 300–750 mm with 600 mm a favourite dimension. The minimum clear height over the stage including scenery suspension grid and stage lighting is 6.5 m. The whole or part of the performance area can receive traps as previously described, with one 'grave' trap 1200 × 2400 mm as a minimum. If there are traps a basement will be needed with access for the performers and minimum ceiling height of 4.4 m.



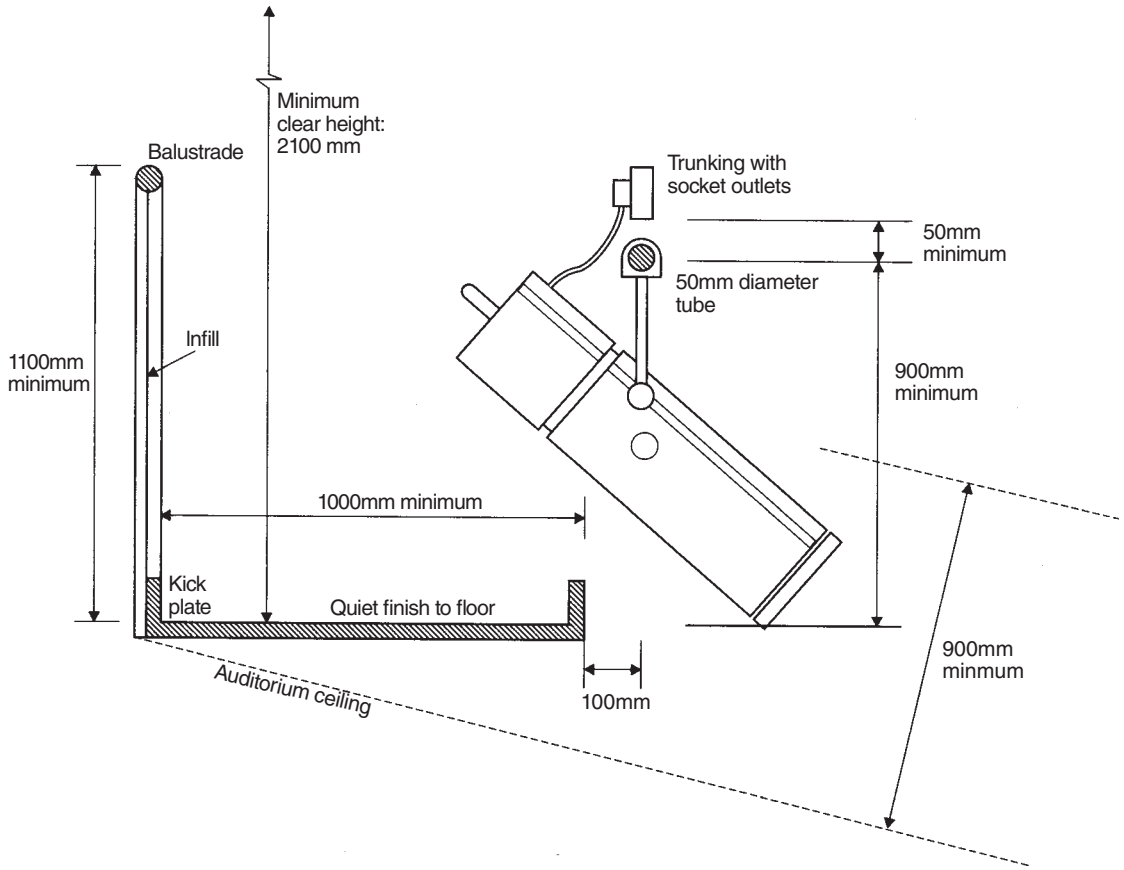
15.56 *Method of locating theoretical positions of spotlights. Spots at A will light a performer at stage edge at 55° in section, about 45° to 50° after crossing, but as the performer moves in from the edge the angle decreases. At Q it is only 40° in section, about 35° after crossing and this is the minimum. Another lighting position B must be provided to cover the area Q to R within the same range of angles, and then C and D to light areas R to S and S to T*

4.11 Auditorium lighting positions

There are three main factors governing these positions.

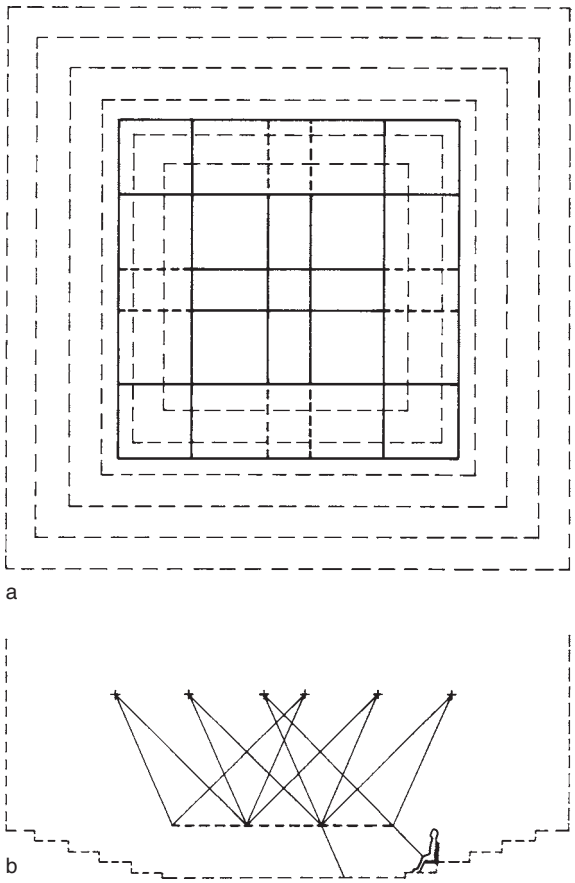
Ease of access is dependent upon the intended use of the auditorium. For intensively used auditoria, staff will require almost daily access to the instruments and this should be provided in such a way that they are not required to use loose ladders in order to carry out their functions. The access needs to be to the rear of the instrument with ample room for the staff to reach around the instrument to the front and also sufficient free space for the instrument to be readily demountable should repair be required.

Location. Over a third of the total number of instruments in a modern rig are likely to be located in the auditorium area (front of house), Figure 15.56. The desired angle is normally between 42° and 44° at an angle to a horizontal plane emanating at the stage front. Lanterns are required at a high angle either side as well as across the main front area of the stage. Depending on auditorium design, lanterns are either housed on bridges which cross the auditorium, Figure 15.57 or are



15.57 *Auditorium lighting bridge at ceiling level*

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15.58 *On thrust and theatre-in-the-round stages virtually all the lighting comes from overhead to avoid glare in the eyes of the audience: a Plan. b Section*

attached to the auditorium structure itself. Provision for instruments on the auditorium side of the proscenium arch in a vertical plane is also recommended. Lighting design for theatre-in-the-round is particularly complex, Figure 15.58.

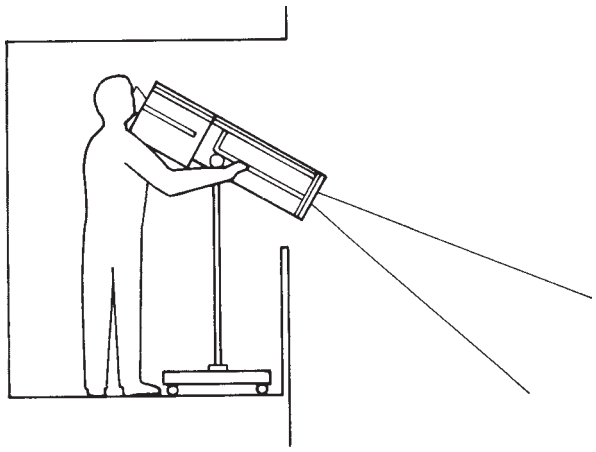
Integrity of design. Many people consider lanterns and their relevant bulky cabling and paraphernalia to be unsightly in the context of formal auditorium design and therefore steps need to be taken to provide housings for the instruments such that they are not normally in the view of the majority of the audience. However, auditoria which carry a 'high tech' design ethic will find it just as acceptable to place lanterns in exposed positions, provided they are sympathetically arranged as they then become part of the design integrity. When considering lighting positions, account must be taken of the lanterns themselves intruding into the audience's line of sight, as well as providing a safe means of suspension.

Follow spots

These are an integral part of much musical, ballet and operatic work. An operator directs a movable beam of light onto one or more performers during the course of the performance, Figure 15.59. Depending on the intended usage of the building, the provision of specific chambers at least 2m square for this work should be located behind or over seating. The angle of the position to the stage should be around 45° or more, because the whole point of follow spotting is to isolate what is being lit in this way.

A pair of instruments located in a high central position allows the individual operators easy contact, especially if they are separated by glass from the auditorium area. Provision should be considered for two further spotlight positions, either side of the auditorium, at a similarly high angle.

It must be noted that the position should be so that the lantern can reach most of the main acting area of the stage. Sometimes the lanterns are situated within the auditorium on specially constructed



15.59 *Follow spot, minimum size for equipment and operator 1.5 m × 2 m*

platforms at the expense of a number of seats. Provision has to be made for barricading the follow spot position from the audience.

Follow spots as instruments are becoming increasingly powerful and correspondingly larger. Some are more than 2 m in length. Therefore, the overall size of the proposed auditorium will be a factor in determining the size of the follow spot situation. Its position should allow for the instrument, the instrument to swing, and the operator to stand either behind or beside the instrument while this activity is going on. A place for the operator to sit and a local means of isolating the instrument should also be catered for.

4.12 Spaces associated with the audience area

Lighting control room

This is a room centrally at the rear of the auditorium fully enclosed and sound-proofed with an observation window and space for the lighting control console and for the operator who needs to sit by the console and view the performance through the observation window which has an unrestricted view of the stage, Figure 15.60. There should also be space for an assistant, a worktop for plans and scripts. A minimum size would be 3 m wide, 4.5 m deep and 4.4 m high.

Dimmer rooms

Space is required for the dimmer racks which are the direct means of control for all of the stage lighting instruments. The racks also contain the individual fusing for each stage lighting circuit. Mains cabling runs from the dimmer room to all outlets of the stage lighting installation, and also to the house lights, but the connection between the dimmer racks and the lighting control itself is not a mains voltage line.

The dimmer room should be placed so that quick access may be achieved either from the lighting control position or from the stage area. The dimmer room will also normally contain the mains isolation for the stage lighting system. In large installations which have a three-phase supply, each single-phase installation should be physically separated.

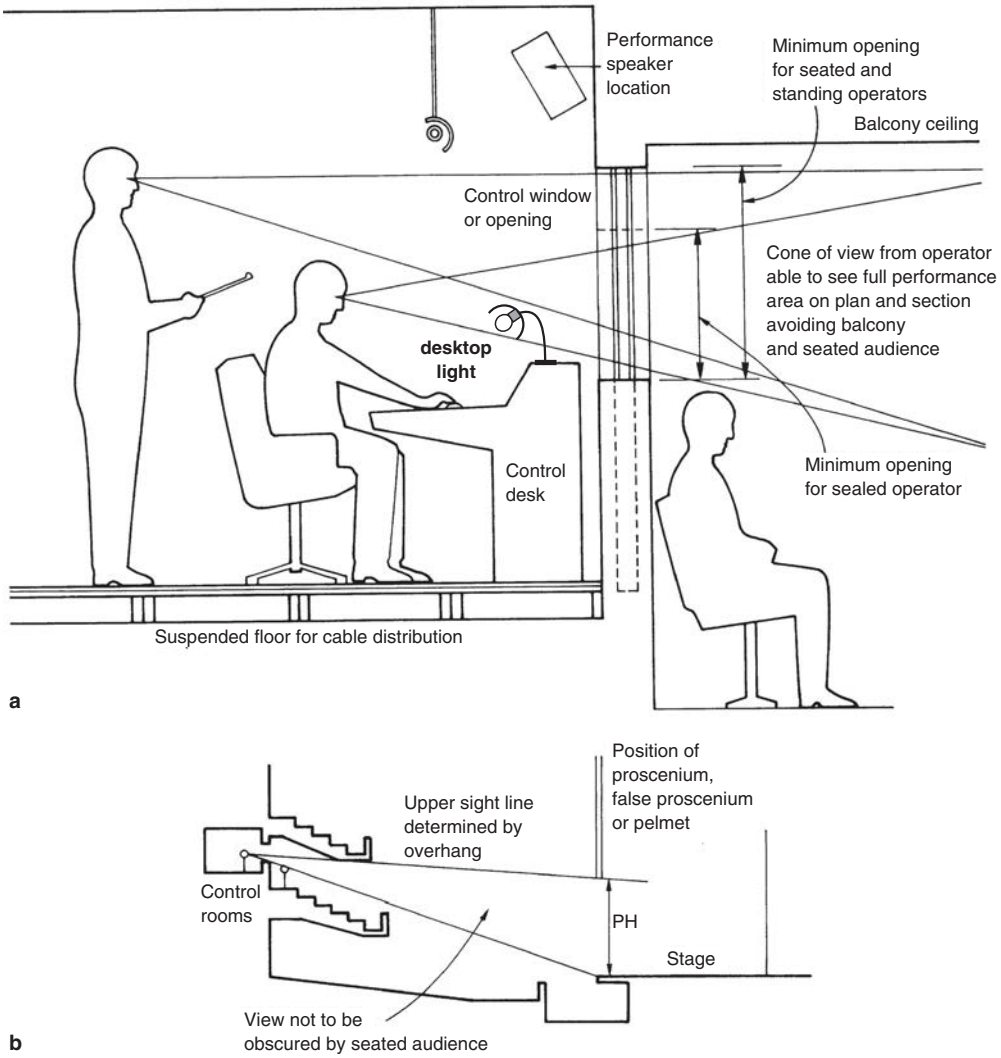
Sound control room

An open enclosure in a representative position within the auditorium. The operator requires an interrupted view of the performance area as well as being able to hear the performance. The room contains a control desk, equipment racks, monitor loudspeakers and worktop for scripts. The minimum size is 3 m wide, 4.4 m deep and 4.4 m high.

Auditorium sound-mixing position

This is for the mixing of amplified sound from the stage by an operator who requires to hear the same sound as the audience. The area requires to be flat, set within the seating area: minimum area of 2 m × 2 m, with mixer pad sound control desk and protective barrier.

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15.60 *Control room with direct view of the stage: a Section. b Vertical sightlines*

TV, radio and recording control room
This is a separate soundproof control room, with observation window and clear view of the stage. It will accommodate announcers, and staff for balancing and directing transmissions and recording. A minimum area of 2 m × 2 m, but should be larger.

Observation room
Those associated with production may need to check activities on the stage from a room at the rear of the auditorium, with a clear view of the stage through an observation window, minimum area, 2 m × 2 m.

4.13 Stage-related spaces

Quick change
Separate rooms immediately off the stage, each with two make-up positions and hanging rails.

Properties room
This is a store room, opening directly off a side stage for properties for use during a performance. It requires a sink with hot and cold running water.

Scene dock
At the same level as the stage for storage of scenery.

Loading bay
For the delivery of scenery and properties into the scene dock. Allow for more than one pantechnicon to reverse.

Scenery
A repair and maintenance area at the side of the stage to maintain scenery and properties in use on the stage.

Piano store
For a grand piano when not in use. A separate room kept at a temperature similar to stage conditions; minimum area 4.5 m × 3.5 m.

Lighting equipment
Requires direct access off the side stage for chandeliers, hand properties, etc.

Sound equipment
Storage and maintenance space for such items as microphones, speakers, stands and so on.

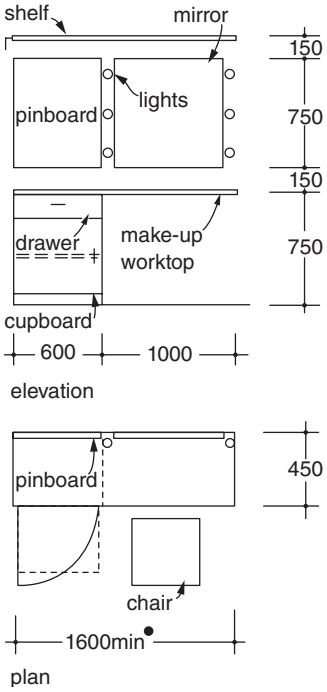
Stage manager
Located stage left (facing the audience). Control equipment includes public address, safety curtain and/or drencher release, flytower vent release, and communication with lighting and sound technicians, fly gallery, conductor, etc. as well as cueing performers.

4.14 Spaces for actors, singers and dancers

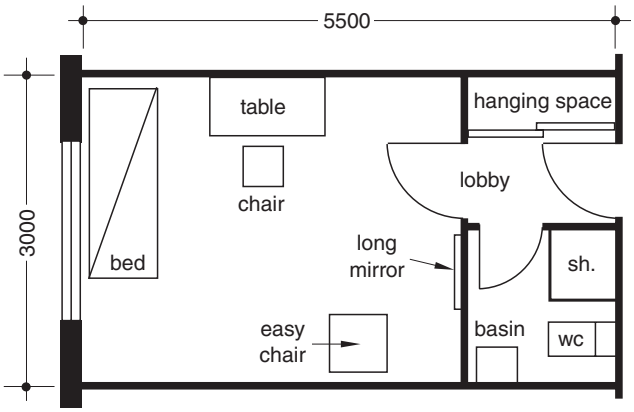
Dressing rooms
Arrangements are illustrated in Figures 15.61 to 15.69 covering single shared and communal occupancy rooms.

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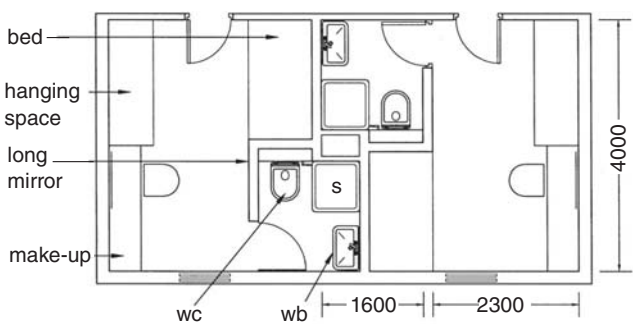
Green room with kitchen and servery: 3.4 m² per occupant.
Laundry for repair and maintenance of costumes, 20 m² minimum.
Costume store, including skips and rails
Costume delivery.
Specialist make-up room: 10 m² minimum per person.
Pre-performance practice room(s) (singers): 15 m² minimum.
Pre-performance dance studio (dancers): 1000 m² minimum.
Physiotherapy room (dancers): 15 m² minimum.
Wig store and hairdresser's room: 5–10 m².
Waiting area for visitors and dressers.
Offices: children's supervisor, company manager, touring manager, etc. 10 m² minimum per office.
Toilets.
Performers' assembly areas: at points of entry to stage.



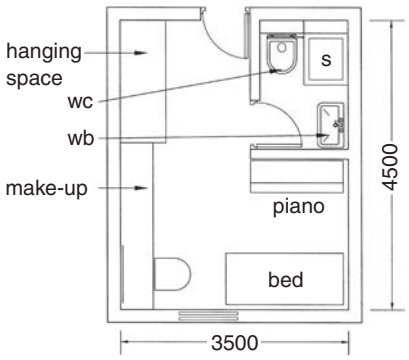
15.61 *Single dressing room: a Elevation. b Plan. Dimension marked • is minimum; a greater length is desirable to allow space for flowers, etc*



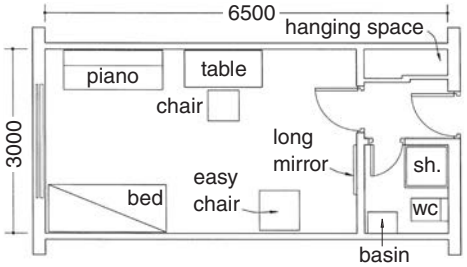
15.62 *Single dressing room with en-suite WC and shower*



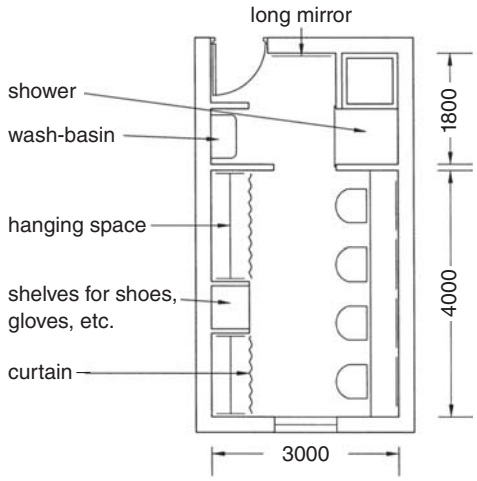
15.63 *A pair of single dressing rooms each 14.4 m²*



15.64 *Single dressing room with piano, area 15.7m²*



15.65 *Single dressing room with piano and en-suite WC and shower*



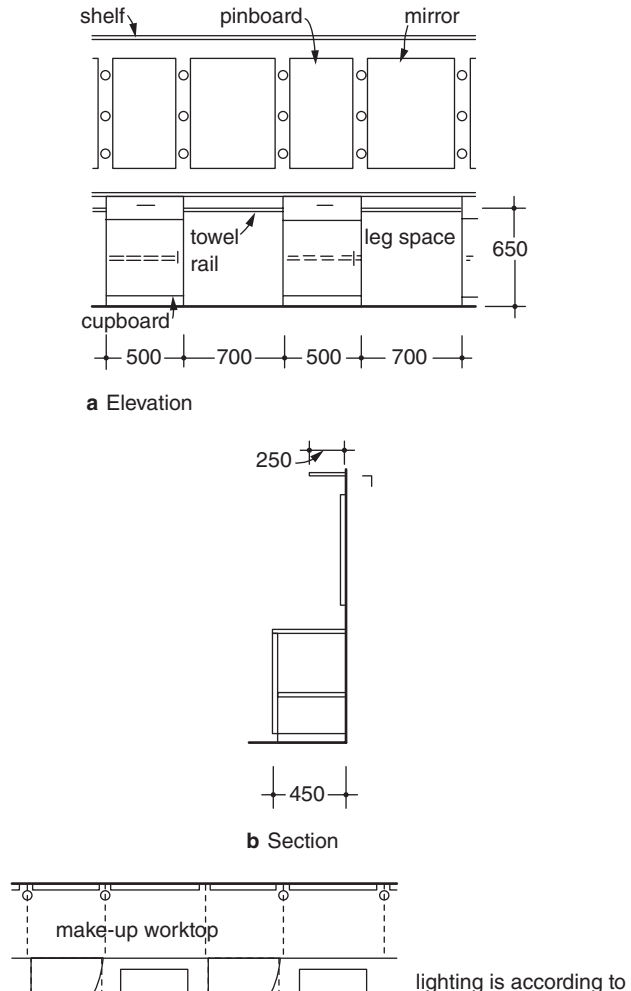
15.66 *Dressing room for four, area 17.4m²*

4.15 Spaces for musicians

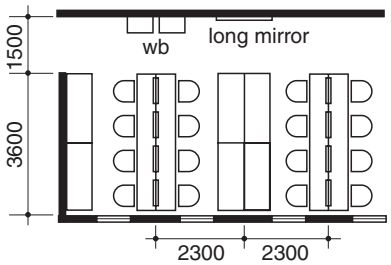
- Changing rooms: at least two rooms.
- Musical instruments store: large instruments and their cases.
- Pre-performance practice room(s).
- Musicians' common room: 3.4 m² per occupant.
- Conductor's room.
- Offices: orchestra manager, tour manager, etc.
- Musicians' assembly area: at point of entry to orchestra pit.

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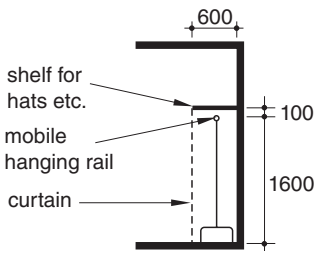
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15.67 *a–c Shared dressing room*



15.68 *Communal dressing room, area of each bay 8.3 m²*



15.69 *Section through hanging space*

5 STUDIO THEATRES

5.1 Introduction

Studio theatres, by definition, do not contain moving stage machinery. They usually have some form of mobile or movable seating either to provide for different layouts or to clear the space for other uses at different times.

There are a number of well-developed, flexible seating systems offering great variety and compliance with normal seating regulations, with a foldaway and mobile facility. However, bleacher seating systems demand a dedicated space into which the seating can be concertinaed when not in use. There is a significant point load factor under the supporting wheels. Bleacher seating arrangements do not offer flexible layout possibilities.

5.2 Access

Studio theatres should have different access points, allowing for seating and performer flexibility. A passage around allows performers to access any entrance. In all cases it is assumed that audience circulation and amenities are located adjacent to designated exits which should have immediate access to further doors on the outer side of the passage leading to the regulatory place of safety. Provision for drapes to be hung and moved around the walls offers the potential for varying the acoustic as well as the colour of the space. Either the walls or the drapes should be black.

Height is a key factor.

5.3 Lighting grid

One of the great selling points for the studio theatre is the speed and ease with which one can move from one production to another. Frequently this is serviced by having a grid made up of 50 mm OD tubing over the whole space from which lighting instruments can be hung in any location. It is doubly advantageous if this can be organised in such a way that there are walk gantries with lighting tubes either side, allowing the personnel to effect all the lighting changes without the use of access equipment and ladders, thereby allowing for completely different functions to be carried out at floor level simultaneously. If the gantry is not possible then it is essential that all of the lighting grid can be accessed from below by a mobile access system. From a desirable lighting point of view, the head of the instrument should not be less than 4 m above the nominal floor level.

6 CONCERT HALL

6.1 Introduction

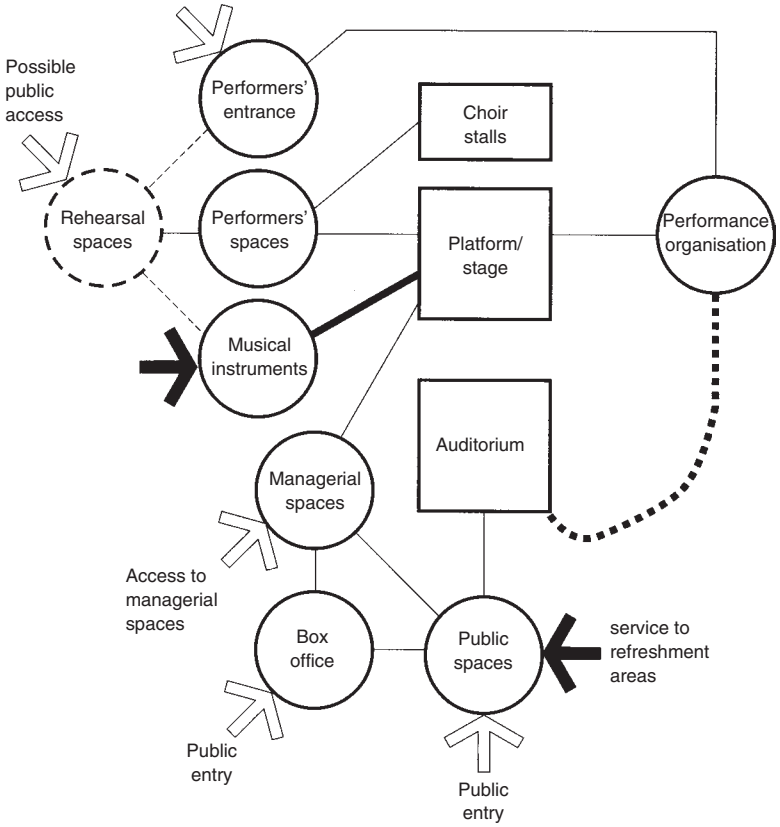
A relationship diagram for a concert hall is shown in Figure 15.70. For orchestral and choral classical music in concert hall or recital room there are three broad categories of relationships between audience and platform, Figure 15.71:

- Audience focused towards the orchestra and choir on the platform, with or without choir stalls, in a single direction, Figure 15.71a;
- Audience on three sides semi-surrounding the platform, Figure 15.71b;
- Audience surrounding the platform, Figure 15.71c.

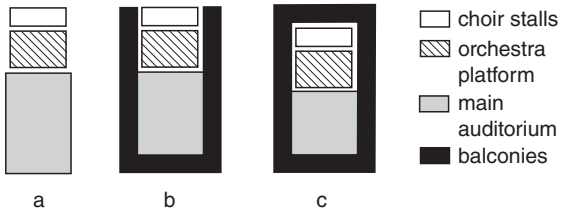
Types of single-direction relationship include the rectangular box as in the diagrams shown, variations on the rectangular box and the fan-shaped auditorium, Figure 15.72. The rectangular box is a simple well-established form. It allows full cross-reflection of audience, is central to the platform and receives a good sound balance. The fan-shaped auditorium is a particular variation on the rectangular box but suffers from the lack of side- and cross-reflection. Other shapes, Figure 15.73, include the coffin and elliptical.

6.2 Viewing conditions

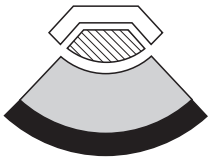
For vertical sightlines see Figure 15.74.



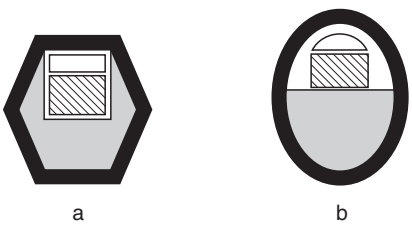
15.70 *Relationship diagram for buildings for orchestral and choral classical music with choir stalls, and for jazz and pop/rock music without choir stalls*



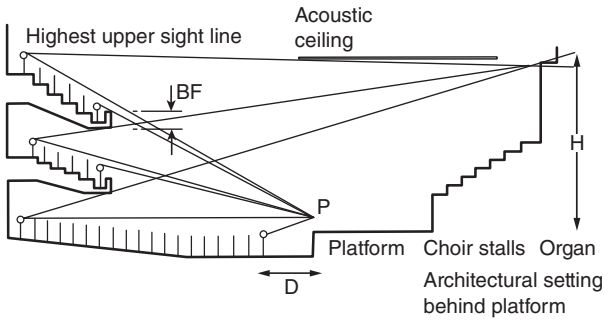
15.71 *Relationships between audience and platform in various rectangular formats: a Single direction. b Audience partially surrounding the platform. c Audience surrounding the platform. With or without rear and side balconies*



15.72 *90° fan shape, with or without rear and side balconies, in single direction relationship*



15.73 *Orchestral and choral music formats for audience surrounding the platform. With or without rear and side balconies: a Coffin. b Elliptical*



15.74 *Vertical sightlines through auditorium with concert platform. These need to include choir stalls, architectural setting behind the platform as well as the conductor, soloists and orchestra. However, acoustic requirements of direct and reflected sound may override sightline parameters*

6.3 Platform design

The music components include orchestra platform, choir stalls and organ, Figure 15.75.

Platform design relates to orchestra size:

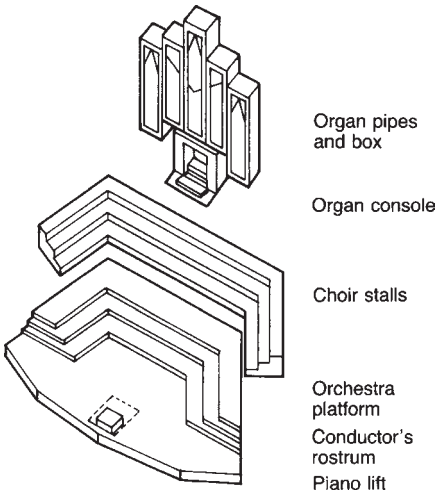
- Symphony orchestra and choir
- Symphony orchestra, 80–120 musicians
- Chamber orchestra, 40–50 musicians
- Small ensemble

For a chamber orchestra, the platform can be 6 m deep, 9 m wide and 900 mm high, for a full orchestra an area of 12 m × 12 m, with a platform height of 1000 mm. Various configurations are shown in Figure 15.76 and a section in Figure 15.77.

6.4 Areas for individual musicians

- Violin players and small wind instruments 1000 × 600 mm; the horns and bassoons, 1000 × 800 mm.

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15.75 *Components of the platform for classical music*

- 1200 mm tiers for string and wind players, including cellos and double base.
- Tiers up to 2 m for percussion or concert grand piano: 2.75 m × 1.6 m.
- Choir: 0.38 m^2 minimum per singer in choir stalls with seats. The longitudinal section can be flat and stepped transversely, rising from the conductor's rostrum.

6.5 Associated spaces

- Lighting and control room
- Dimmers
- Television and radio transmission and recording control room
- Follow spot
- Observation room.

See also Section 6.8.

6.6 Platform-related spaces

- Piano store
- Storage of musical instruments
- Delivery of musical instruments
- Access for deliveries
- Parking provision for touring vans
- Offices
- Technicians' changing
- Electrical workshop
- Electrical store.

6.7 Performers' spaces

- Changing rooms: not more than 20 people per room, 3.5 m^2 each
- Single rooms, 15.62, 19 m^2
- Single room with piano, 15.65, 23.5 m^2
- Single room with space for auditions 40 m^2
- Shared rooms 2 m^2 per occupant.

6.8 Associated spaces

- Conductor's green room
- Pre-performance practice room(s)
- Orchestra assembly area
- Choir assembly area
- Musicians' common room
- Orchestra manager's office
- Other offices (e.g. tour manager)
- Toilets.

7 CONFERENCE HALLS

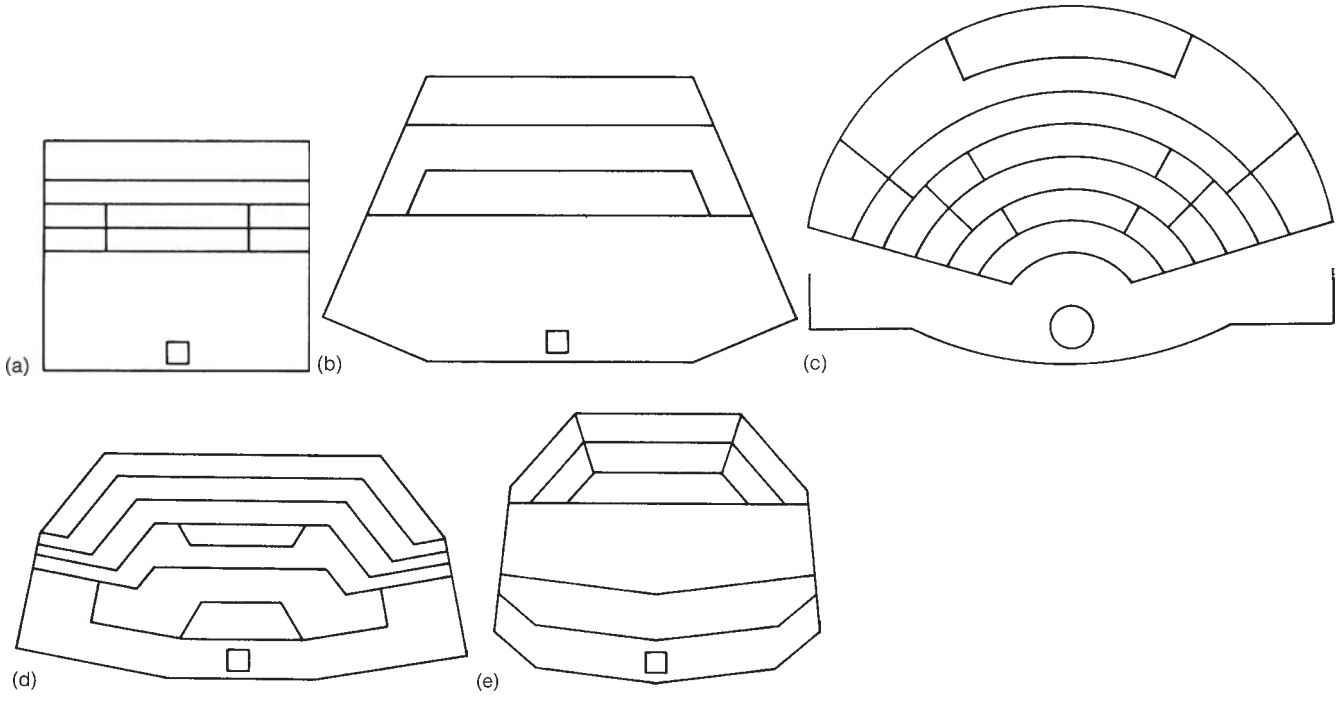
7.1 Relationships

Figure 15.78 shows the relationships between the parts of a conference suite.

7.2 Formats

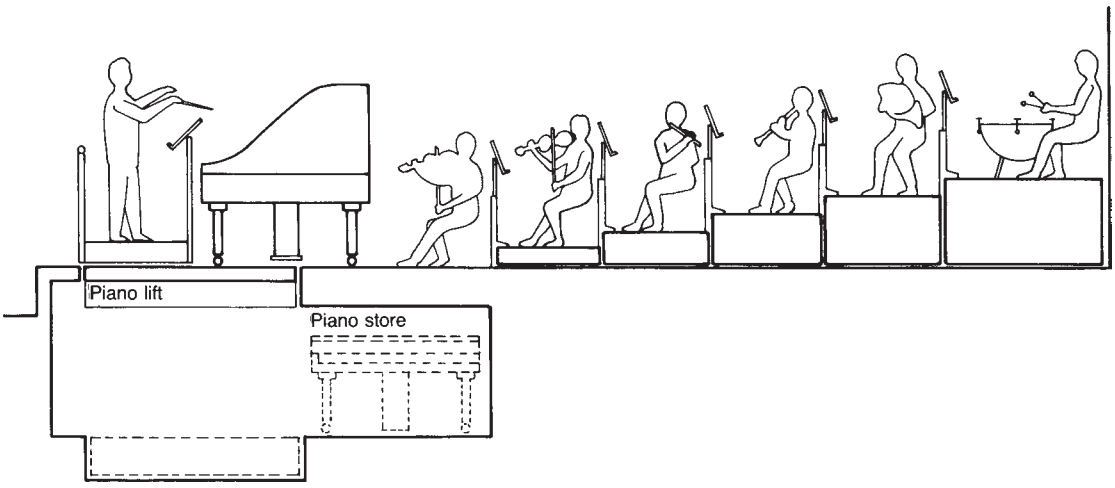
Formats depend on use:

- Traditional lecture theatre formats with the audience focused towards a platform on which is provision for a speaker or speakers, possibly served by a range of audio-visual aids, Figure 15.79. The speaker is the controlling point with audience in a receptive role. Slide, film and video projection limit the extent of encirclement of the platform.
- Participation by each member of the audience which suggests the debating formats of semi-circle, *U*-shape and circle, controlled

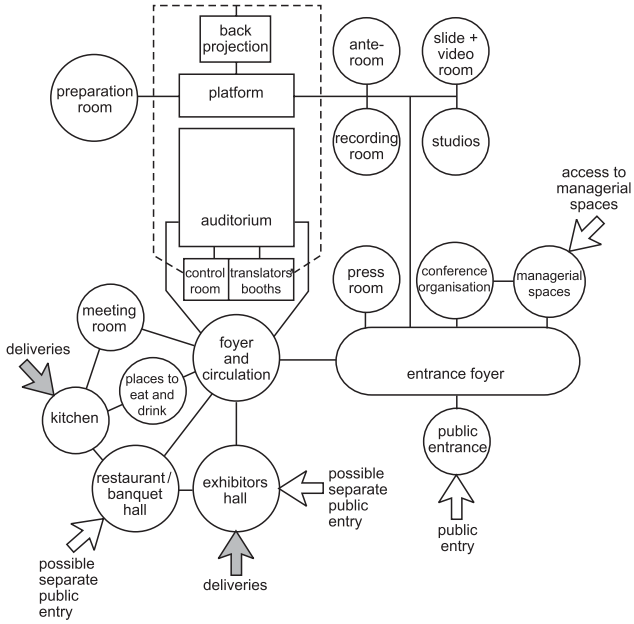


15.76 *Platform designs, each on multi-levels: a Rectangular. b Trapezoidal. c Semi-circular. d Wide shallow plan. e Design for a small orchestra*

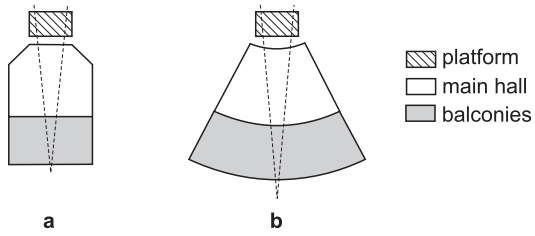
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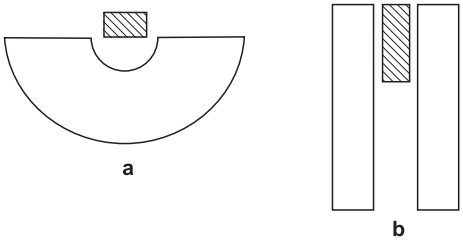
15.77 *Section through an orchestra platform showing piano store and lift*



15.78 *Relationship diagram for conference hall*



15.79 *Conference hall formats for lectures requiring projection facilities: a Rectangular with or without rear balcony. b 60° fan with or without rear balcony*



15.80 *Conference hall formats for debating: a Fan with 180° arc (US Senate). b Audience in two facing banks (House of Commons)*

by a chairperson, with little or no audio-visual aids, Figure 15.80. The need for equal distribution and viewing of all delegates' facial expressions implies a single row only. However, it is possible to have up to six rows where delegates can still be aware of the spoken contribution of each.

The plan shape of the conference hall can be:

- Rectangular
- Fan-shaped, with angles of 135°, 90° or 60°. The last is best for screening
- Hexagonal
- Circular
- Oval, or
- Coffin.

7.3 Functional requirements

With the lecture format the functional requirements include:

- The audience needs to see and hear the speaker, chairperson and panel of speakers in the various positions on the platform.
- They need a clear view of screens, chalkboard and other visual displays: each has its own physical requirement.
- Acoustic clarity of sound listening to speaker and to reproduced sound.
- Adequate presentation and viewing of any demonstrations.

With the debating format:

- Awareness of the whole audience by every member
- The audience able to hear all speakers and chairperson
- A clear view of the chairperson.

An example of a facility used only for lecturing is shown in Figure 15.81.

7.4 Audience facilities

Seating design for conference use is covered earlier in this chapter in Section 2.5. In fully equipped conference halls each person in the audience may be provided with:

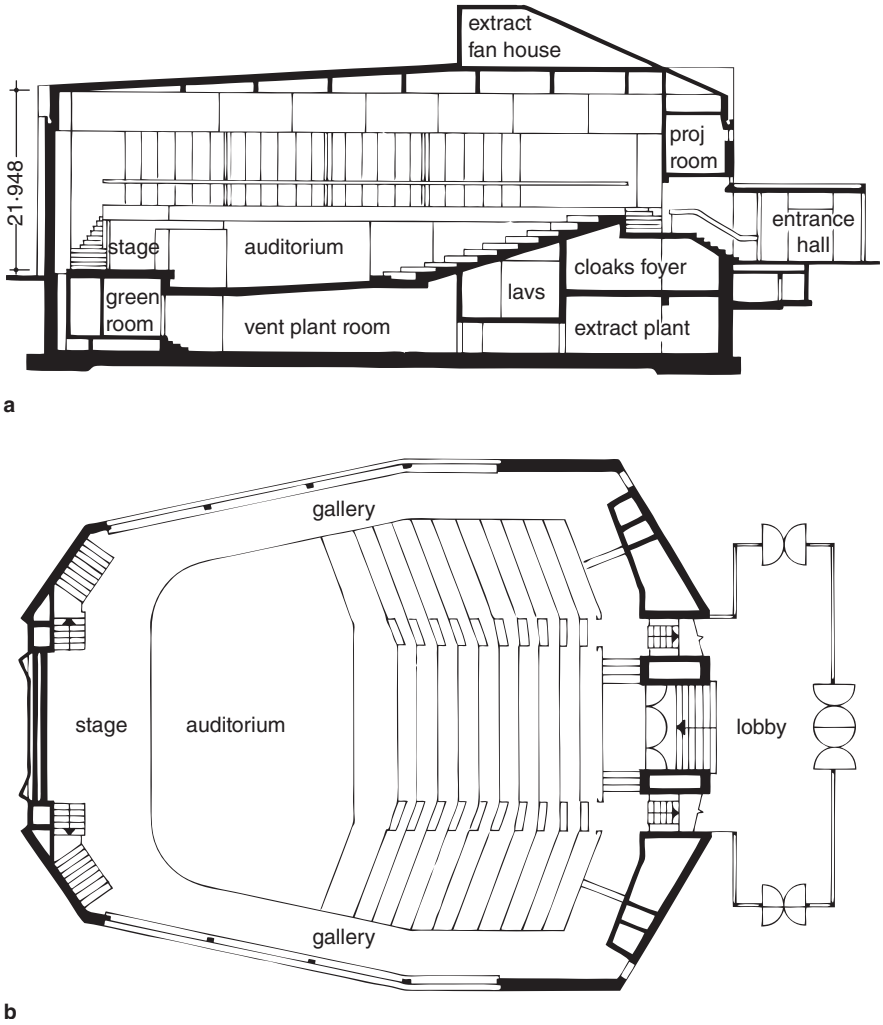
- voting buttons: yes, no and abstain
- simultaneous translation headphones
- headphones for the hard of hearing
- small individual light.

The following is normally provided to be shared by two adjacent participants:

- microphone controlled by the chairperson from the platform
- button for 'request-to-speak'.

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15.81 *Lady Mitchell Hall, Cambridge. A large lecture theatre for 450 students. Architects: Casson, Conder and Partners: a Longitudinal section. b Plan of auditorium*

7.5 Platform

Height depends on hall capacity and sightlines:

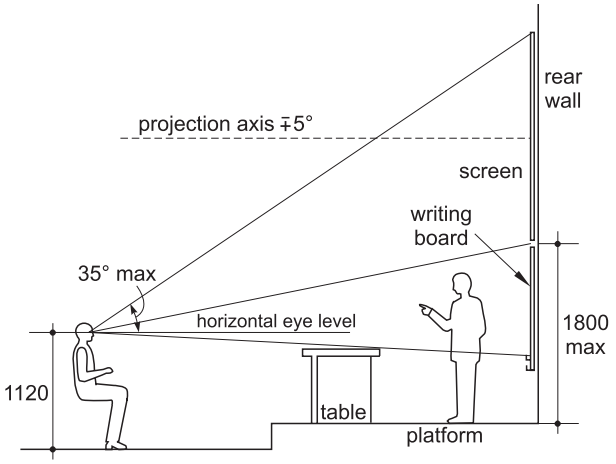
- 300 mm up to 150 seating capacity
- 600 mm 150–300
- 750 mm over 300.

Steps are required from the auditorium to provide ease of access for speakers onto the platform at ends of gangways and front rows. Ramps may also be needed for wheelchair users.

Size and shape depends on extent of audio-visual aids, lectern, demonstration table, panel table and other equipment as well as sightlines and size and shape of auditorium.

The platform may need to accommodate only a single speaker at one time, with no (or limited) audio-visual aids as the least provision, Figure 15.82. In other cases it will require to allow for scientific demonstrations, a panel of speakers with or without a lectern, or major presentations as with commercial, political and institutional organisations. For major political conferences there can be as many as fifty people to accommodate on the platform.

The setting about the platform can be an architectural setting common to all types of presentations or a shell in which complete new settings can be constructed for each conference.

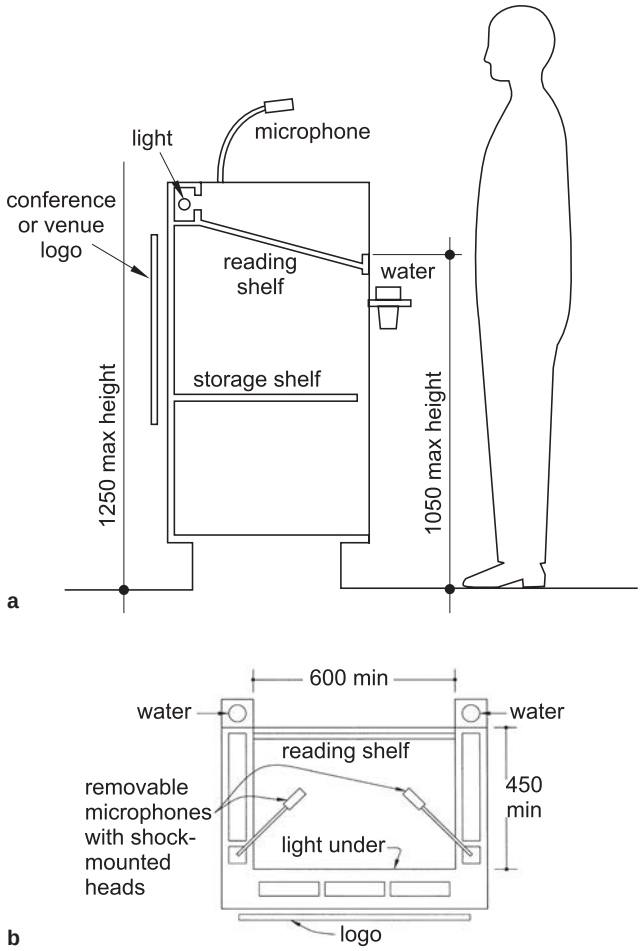


15.82 *Section through lecture theatre showing platform and front wall arrangements*

7.6 Lectern

This is the normal position for the speaker. The lectern, Figure 15.83, should have:

- a top sloping at 15° large enough for two A4 sheets;
- an adjustable screened light to illuminate script;
- a mounted microphone with switch;
- a jack point for lapel microphone;
- a microphone connection to simultaneous interpretation and/or recording systems;
- a level surface for pencils and glass of water and jug;
- controls for dimming house lights;



15.83 *Lectern: a Section. b Plan*

- controls for remote operation of projectors and screens;
- a manual or motorised raise and lower device for lectern stand;
- a hand-operated light pointer;
- a teleprompter screen (autocue);
- a clock;
- remote cueing;
- possibly red, yellow and green lights visible to both speaker and audience to indicate time available to speaker;
- a shelf below the top for brief-case, demonstration items, etc.
- for presentations using laptop images to be operated by a speaker, horizontal table 900 mm high, adjacent to the lectern, would be necessary.

7.7 Other platform facilities

The chairperson may introduce speakers from the lectern or a separate position elsewhere on the platform, with or without a lectern. It is usual for the chairperson to remain in a prominent position on the platform during speaking, questions and discussion, unless slides or films are shown on a screen behind their seat. Anyone on the platform in that case will move to a reserve seat in the body of the hall.

Control panel

It is common to have a separate panel operable by the chairperson. Alternatively, it could be duplicated at the lectern. This panel might incorporate:

- a buzzer to the projection room;
- a telephone link to the projection room;
- remote operation to black out windows (if any);
- house lights dimmer;
- separate lighting over platform;
- a teaching board light.

For the chairperson only:

- control for red, yellow and green lights on lectern;
- clock and/or timer;
- panel showing 'request-to-speak' indicators;
- on/off control for individual audience microphones;
- voting numbers display (see Section 7.4);
- control of large audience voting number panel.

Demonstration bench

A 'laboratory' fully serviced bench on the platform for the scientific demonstrations, with the supply of electricity, gas, water and drainage. The bench should be able to be wheeled off the platform if it is to be used for non-demonstration presentations, with plug-in services: the bench can be stored in the adjacent side preparation room.

Panel table

For discussion and presentations by a panel of speakers and a chairperson, a long table, parallel to the front edge of the platform, is a recognised format, with a chair and microphone for each panellist, and possibly simultaneous translation earphones. The table should be at least 750 mm deep, allowing 1 m length for each person. The name and details of each panellist may be mounted on the front edge of the table or on a stand in front of each. The lectern may or may not be used.

Rear and side walls of platform

Either a permanent enclosure with all or some of the following (see further details see Section 7.9ff):

- chalkboards
- projection screens
- space for conference name, logo and setting
- clock
- fixed lectern, overhead projector, table
- fixed or mobile demonstration table.

Curtains, masking, sliding panels may be incorporated to cut off sections of side and rear walls when not in use. Alternatively, there may be a shell with rear and side walls and equipment constructed for a particular conference: similar to theatre open stage with suspension over platform for setting and lighting.

An easily visible place is needed for a person to stand to translate the speaker's words into sign language.

7.8 Translators' booths

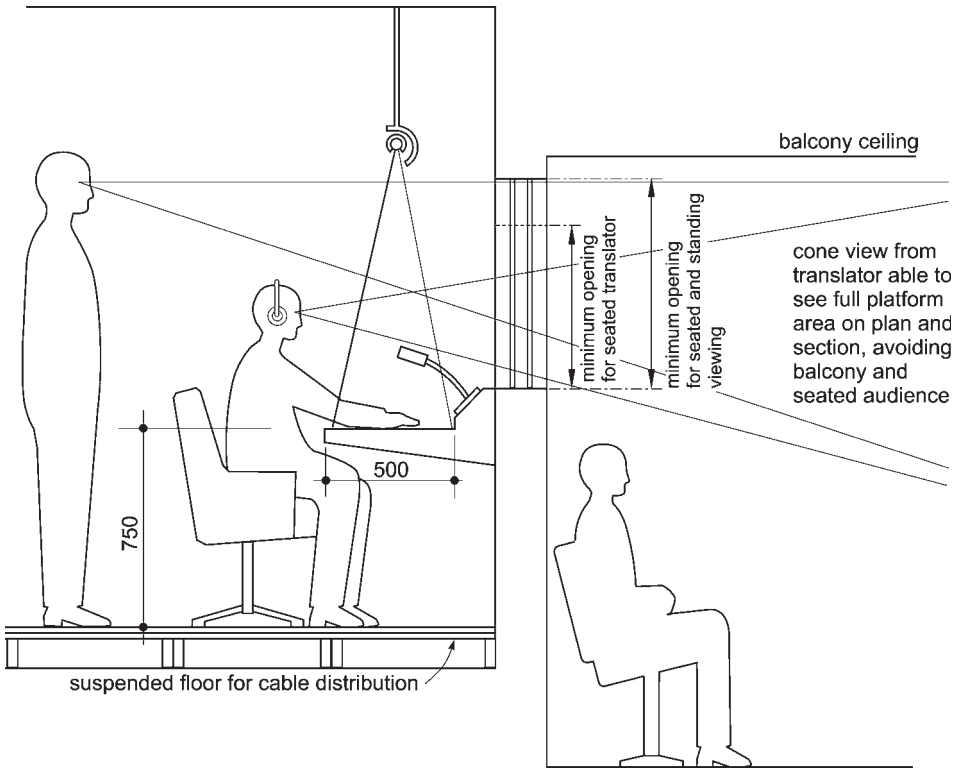
Conferences with international audiences will probably require simultaneous interpretation by translators in booths of those speaking in various languages.

Booths need to be located at the rear or perhaps the side of the auditorium with an unobstructed view by the translator of the speaker, chairperson, projection screens and chalkboards as well as any visual display, Figure 15.84. The booths are soundproofed, with the translator listening to the speech on headphones.

Booths should be located side by side with acoustic isolation and small connecting windows. They should open off a corridor giving discreet but secure access from the public areas. Booth interior should have absorbent material to walls, floor and ceiling, in dark matt colours.

Each booth needs to be able to accommodate two or three seated persons, minimum size 6.5 m wide and 6.4 m deep. The soundproof observation window can be full width of the booth, 800 mm high, and may be inclined to avoid acoustic reflections on either side. The translators need a clear working surface 500 mm wide in front of the window for scripts, notes, microphone, channel-selection buttons, indicator lights, etc.

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15.84 *Section through translators' booth at rear of auditorium*

Translators' ancillary rooms
A common room for translators should be located near the booths. This should have easy chairs, tables, telephones, cloakroom and toilets.

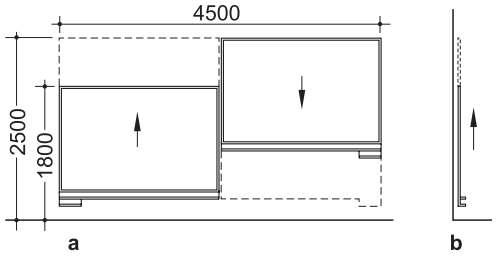
Simultaneous translation systems in the auditorium
Available methods are:

- Induction loop: magnetic field transmission generated by a conductor looped around auditorium. Conference delegates have portable receivers.
- Infra-red: modulated light signals radiated from a number of sources. Delegates have portable receivers.
- Hard-wired: cable within underfloor trunking connected to panels in arm rest or back of each seat for heavily used conference facilities.

7.9 Audiovisual facilities

Writing boards
Conventional chalkboards are now uncommon as they have now been superseded by overhead projectors for which material can be pre-prepared. Where they are used they would be a black or white chalkboard, fixed to a rear wall or moveable. The audience viewing angle is critical to avoid glare and reflections. The visibility tends to be restricted to twelve rows. Chalk and pen channel to be incorporated, with a ledge for an eraser.

Boards can slide vertically or horizontally to increase writing surface within a restricted space, Figure 15.85, or they can revolve vertically or horizontally, if made of a rubber or plastic material.



15.85 *Writing boards: vertically sliding: a Elevation. b Section*

The extent of chalkboard may be nominal, 1 m × 3.5 m for limited use by a speaker, or, in the case of the presentation of complex and mathematical formulae, a board extending the full width of the platform.

Small conference rooms are often equipped with whiteboards which are written or drawn on using special felt-tipped pens. These are permanently mounted on a wall, and have a ledge beneath for the pens and the eraser.

Flipcharts
Commonly used in small conferences and seminars, particularly in debating format. A1 size portrait orientation on a board 750 × 900 mm on a loose easel with ledge at 900 mm above platform. A storage space for this and for the pens etc. is useful. Sometimes they are fixed to a rear wall; good visibility is restricted to twelve rows.

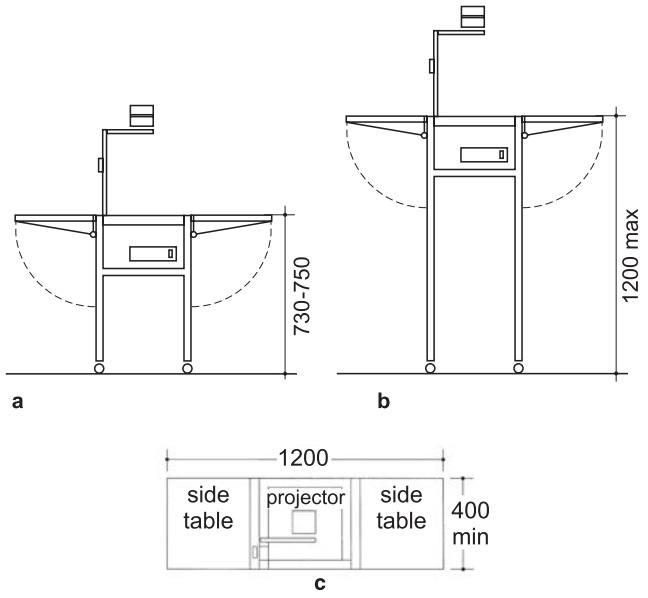
Overhead projector
Figure 15.86 shows a projector on a stand. The image surface is 250 × 250 mm for writing on or for prepared images. A surface beside the projector is needed for the prepared acetate sheets and pens. The lecturer can be standing or seated. The projector may be located at a lower level in front of the platform to assist sightlines from the front auditorium rows to see the screen over the projector and speaker.

The screen needed to receive the image should be tipped forward to an angle of 20–25° to the vertical to avoid 'keystone' distortion, Figure 15.87; the distance from the projector to the screen equals the screen width. Such screens are available that can be swung or rolled away when the main projection screen is used.

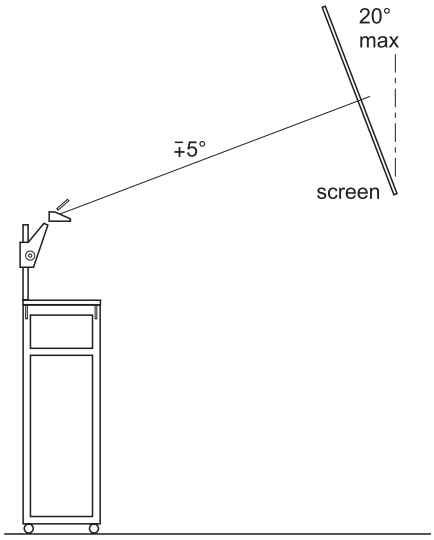
Projection room
A projection room, Figure 15.88, may or may not be needed. Its advantages are that:

- The operator and operations will not disturb the audience.
- Noise is reduced or eliminated.
- The equipment and the media are more secure from interference and theft.
- It is easier to lift the projection beam over the heads of the audience.

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15.86 *Overhead projector: a Elevation of a projector on a table for a seated speaker. b Elevation of a projector on a table for a standing speaker. c Plan of either*



15.87 *Overhead projector screen: tilting helps to avoid the keystone effect*

The equipment needs to be grouped near the axis of the screen(s). It is more convenient for it to be on loose mobile stands, and the beam should be above the heads of a standing audience. Each port should be provided with a separate black-out shutter. The room should have separate extract ventilation and should open off a ventilated lobby.

Lighting control room

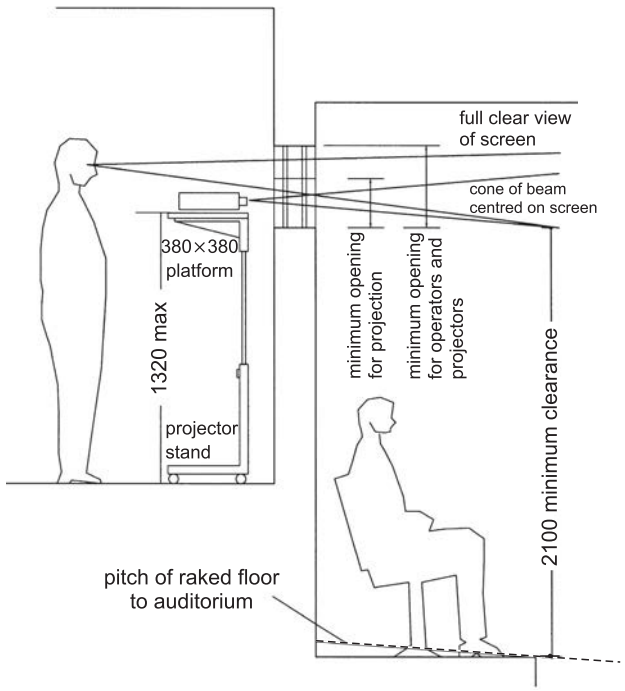
This is a limited requirement for conferences, but lighting control could be incorporated into a projection room at the rear of the auditorium, minimum size 2 m × 3.5 m. In some cases a dimmer room may be needed (see Section 4.10).

Sound control room

In this case an open room preferably at rear of the auditorium adjacent to the lighting control room, minimum size 2 m × 3.5 m. Here the amplified sound from one or more speakers can be mixed and balanced. The sound control desk may alternatively be situated within the auditorium.

Screens

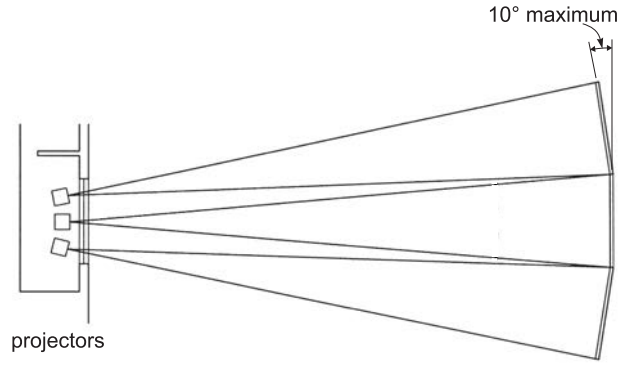
Increasingly, back-projection screens are being used. In this case the projection room will be behind the platform rather than behind the audience. Back projection for video, film and slide requires wide-angle lenses but allows more freedom for speaker. Where conventional screens are used, they will be mounted above the heads of seated people on the platform. If multiple slide projection is to be used, a wide-screen format is necessary. Sometimes the side screens are angled up to 60°; this tends to limit seating positions with good visibility. Where wide flat screens are used curtains should be provided to reduce the width of these for film and video projection.



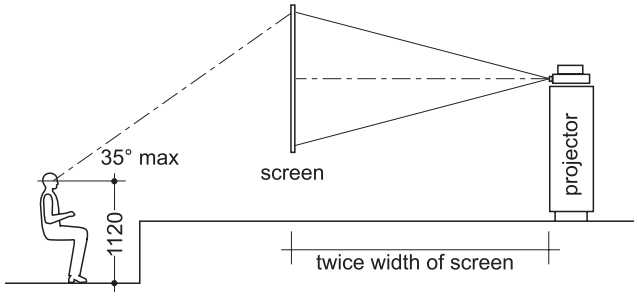
15.88 *Section through projection room at rear of auditorium (projecting slides)*

Slide projection

One, two and maybe more projected images from 35 mm slides, Figures 15.89–15.91, able to be used individually or simultaneously;

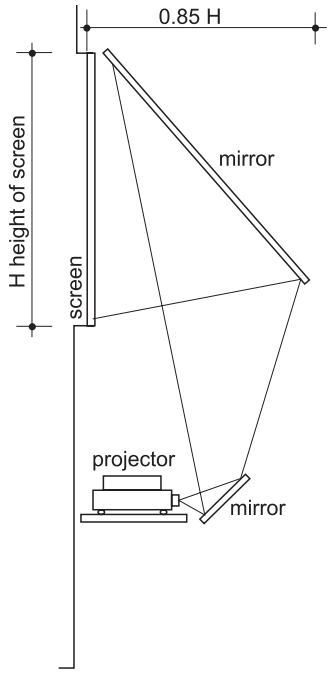


15.89 *Slide projection: multi-screen presentation*



15.90 *Back projection for slides and 16 mm film*

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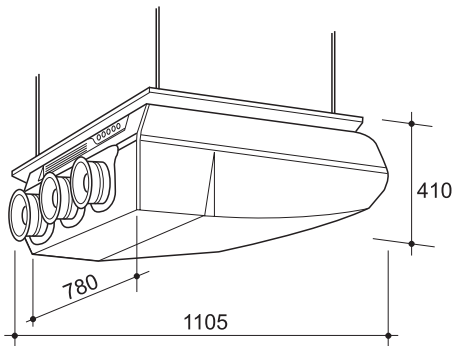


15.91 *Back projection of slides using mirrors*

the usual type of projector is the carousel. High-intensity projectors allow some light in auditorium for note taking. Screen areas for projecting slides should be square, as slides may be in portrait or landscape format. For three-screen projection the side screens are sometimes angled as much as 30° from the centre screen.

Video, DVD, data and other projection

Projectors are now usually mounted at high level in the auditorium, Figure 15.92, on stands or behind the screen. Close-range projectors can produce pictures up to 3 m high; they should be 3.5 to 3.6 times the picture width from the screen. DVDs, for example, may be loaded in a projection room, or from some position on the platform.



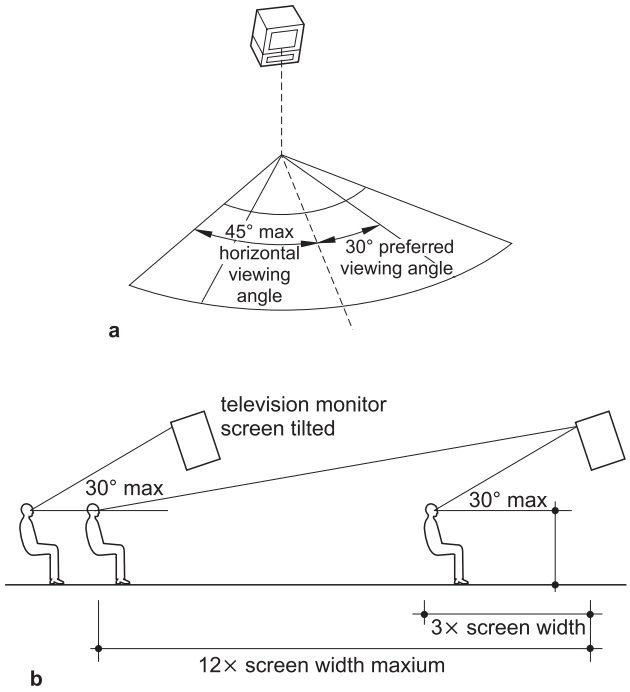
15.92 *Video projector mounted at high level in auditorium*

For a large screen a long-range projector is used producing a picture up to 7.5 m high. It should be housed in a projection room, with room for control and back-up equipment consisting of racks for VCR equipment, monitor screens, off-air times and ancillary control unit.

For small conference and seminar rooms, conventional TV sets can be used, Figure 15.93. Sometimes a number of these each serving a section of the audience are suspended at high level in a larger conference facility, but this is a somewhat primitive arrangement.

Film projection

Where films are used they are rarely greater than 35 mm and are usually 16 mm: 8 mm is now uncommon as video has taken its place. Films can be projected from a position within the seating



15.93 *Television viewing: a Horizontal angles. b Vertical angles*

area, but care must be taken that the beam is not interrupted by standing or sitting members of the audience. It is preferable to use a projection room where the beam can be at a higher level, although here the video projector must be avoided (more details in Section 8.2).

Television and film cameras

Conferences are frequently televised and recorded. Speakers and demonstrations are often projected oversize on screens both within the main conference hall and in overflow venues. Cameras are usually mobile, but require suitable floor surfaces.

A room may be required for recording and editing purposes, but this may not need direct vision of the conference, and could in fact be a remote studio.

Voting panel

This is a panel indicating electronically the numbers voting by pressing buttons at each seat, mounted above the platform and controlled by the chairperson.

7.10 Platform: associated spaces

- Ante-room: reception and waiting areas for conference chairperson and speakers, with lounge, changing facilities and toilets; sound and light lobby onto platform; access for guests from public areas.
- Preparation room: preparation of scientific and other demonstrations in room immediately off the platform.
- Slide and video room: viewing room for speakers, to sort and check slides, inspect videos and films, check overhead projector material.
- Studios: television, film and still photography preparation.
- Recording room: separate facility with tape-recording equipment linked to the auditorium and platform amplification system for the recording of the conference proceedings.

7.11 Conference organisation offices

- Offices with desks and chairs
- General office, with desks and chairs, fax machines, telephones, photocopier, computers, typewriters, intercom, translations, secretarial work.

7.12 Press room

- General room: desks and chairs, telephones, fax machines, computers
- Television and radio interview rooms.

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Table IV Film type and application

Type	Projection	Application	Quality	Light source/screen size
35 mm	Usually permanent installation. Portable versions possible.	Multiplex, independent and specialist cinemas, arts centres, high quality lecture halls, TV	Excellent – a world standard for commercial cinema	Usually high pressure Xenon lamps. 1 Kw–7 Kw lamps. Older projectors may use carbon arc lamphouses. Long throw and large screen sizes require higher power lamps
70 mm	Usually permanent installation. Equipment will also project 35 mm	Mainly specialised cinemas and venues	Excellent – normally used for prestigious films	High pressure Xenon lamps
2 K and 4 K High definition digital cinema (D-Cinema)[1]	Usually permanent installation occupying similar space to 35 mm projectors. Smaller semi-portable projectors available for small/ mid-size auditoria	Multiplex, independent and specialist cinemas, arts centres, high quality lecture halls, TV	Excellent – rivals or exceeds 35 mm film quality	High pressure Xenon lamps. Certain models require high levels of ventilation. 1 Kw–12Kw lamps
3D D-Cinema	As above	As above	Excellent	As above but with increased demands on lamp power and ventilation
1 K and 1.3 K High definition digital cinema (E-Cinema)	Portable or semi-portable projectors offering a lower quality image	Specialist cinemas, arts centres, lecture halls.	Very good – this standard is widely used by cinemas in Asia and South America. It is not considered acceptable for major Hollywood films.	Lamps usually rated below 1 Kw, consequently ventilation requirements are modest.
LCD/Data projectors	Portable projectors	Film clubs, lecture halls, conferences, business meetings	Varies from poor to satisfactory. Not acceptable for public cinema applications	Lamps usually rated below 1 Kw.

Note: [1]2 K and 4 K refer to the number of horizontal pixels produced by the digital projector (2048 and 4096 respectively). 2 K projectors are considered to be the minimum quality standard for feature films by the major Hollywood studios.

8 CINEMAS

8.1 Types of film and method of projection

Cinema projection is traditionally film based but is increasingly being supplemented or completely replaced by high definition digital projection technologies. Film projection in cinemas normally uses 35 mm film but can also use 70 mm (mainly for larger cinemas with wide screens) or 16 mm (generally for smaller or specialised cinemas). Large formats such as IMAX use special film projection systems to produce very wide and tall screen images. Digital projection systems are capable of replicating a similar range of screen formats to film projection at comparable or superior quality levels. Both film and digital projection systems can be adapted to produce 3D images. The various film and digital projection types are shown in Table IV.

8.2 Methods of projection

There are three methods of film projection:

- Direct projection from the rear of the auditorium onto the screen. The most common method by far.
- Indirect projection, where the film projection requires one or more mirrors. This method is used where lack of space or structural difficulties make direct projection difficult to achieve. Mirror projection requires a powerful light source and the screen cannot be wider than 9 m.
- Rear projection. Not possible with curved screen, but may be applicable for the smaller auditorium. For this method the picture needs to be reversed, for which mirrors are an economic solution.

8.3 Auditorium design

Functional requirements include:

- Every member of the audience requires an unobstructed view of the whole picture area on the screen, without visual and physical discomfort and picture distortion.
- Picture sharpness and luminance need to be uniform and satisfactory, and sound reproduction needs to be distortion free.
- Integration of seating for members of the audience with mobility disabilities.

8.4 Viewing conditions

Viewing criteria are shown in plan, Figure 15.94, and section, Figure 15.95. The size and shape of the screen must be related to the shape and rake of the auditorium floor. Seating rake is less critical than for concert halls and theatres as the screen can be elevated and sound comes from overhead speakers.

Seating arrangements

Few new auditoria are designed with galleries or balconies (unless the auditorium is required for other forms of performance). Steeply tiered stadia seating offers an opportunity for good sightlines onto a large screen relative to audience numbers.

In small auditoria, stadia seating may be arranged in a single tier in order to optimise seating capacity. In order to provide a choice of seating for members of the audience with mobility disabilities access should be provided for wheelchair users to the front and rear row.

In larger auditoria, access may be provided onto a cross aisle with steeply tiered stadia seating to the rear of the cross aisle and a gentle rake to the front rows. A choice of seating position for members of the audience with mobility disabilities can be on the cross aisle or in the front row.

Seating types

To meet expectations of comfort, seat centres are generally at least 550 mm. Seat tier widths are governed by expectations of comfort, choice of seat type and statutory requirements for minimum clear seatways.

The design of modern multiplexes has established an expectation in cinema-going audiences that seat tiers should be at least 1100 mm wide. This is wide enough to accommodate most comfortable models of cinema seats. With tip-up seats 1000 mm can be acceptable. Accommodating comfortable fixed cinema seats or small sofa style seats may require increases in the width of the tiers to 1200 mm.

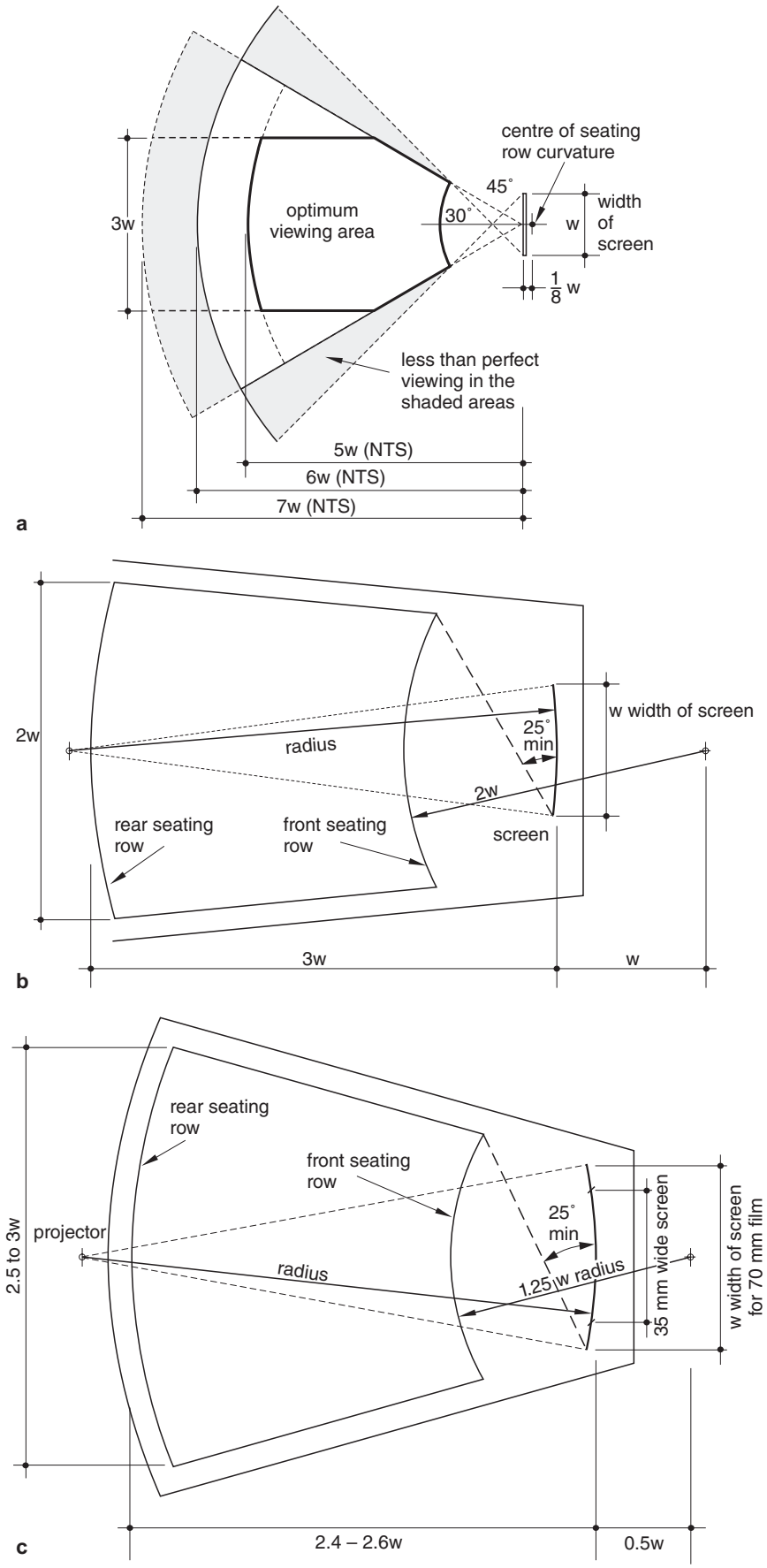
To accommodate ‘premium’ armchair or sofa style seats offering extra comfort, seat tiers of up to 1500 mm wide may be required. A requirement to accommodate cup holders, bottle holders or small tables will influence the choice of seat, seat centres and seat tier widths.

In multi-use auditoria with a flat floor regularly used for cinema screenings, retractable seating systems with straight and curved rows and comfortable cinema style seats are available.

Aisle arrangements

The maximum number of seats permitted in a row is not only governed by viewing criteria but statutory requirements. The aisle arrangement and clear seatway are critical factors. The maximum

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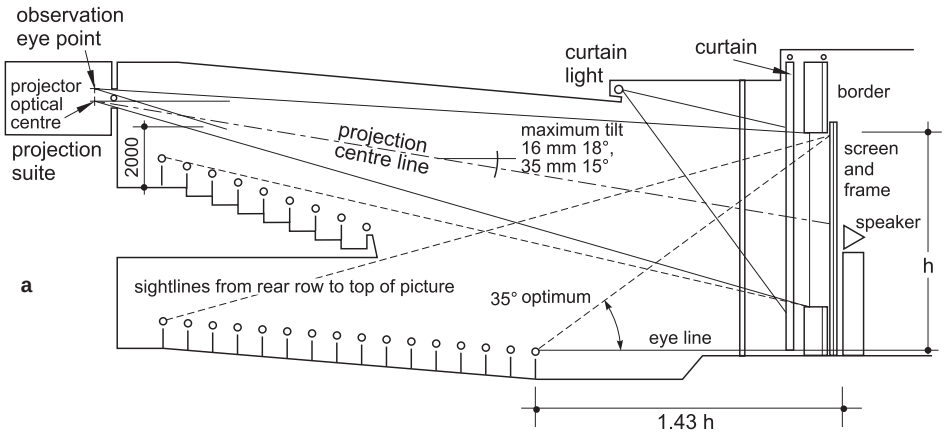


15.94 *Projection criteria for various formats: a 16mm film. b 35mm film. c 70mm film*

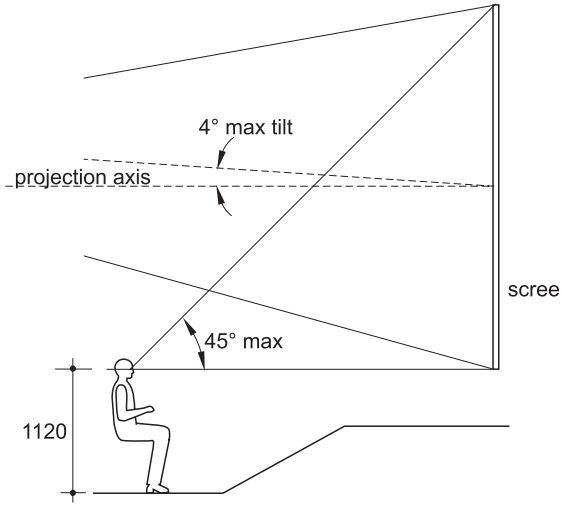
number of seats permitted in a row with a single aisle is 12, irrespective of the seatway width.

A single centre aisle is not favoured as it occupies seat positions with the best viewing conditions, as well as splitting the audience. An off set single aisle provides a more cohesive seating arrangement for the audience as a whole and provides an opportunity to accommodate seats for couples in the shorter row. The provision of two side aisles enables the numbers in a single row to be increased.

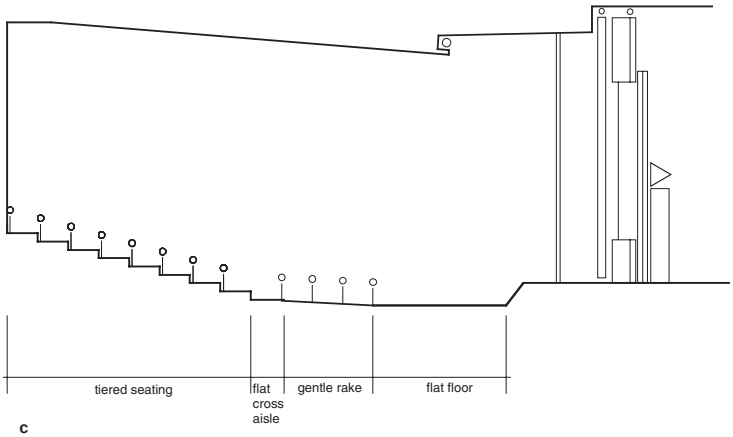
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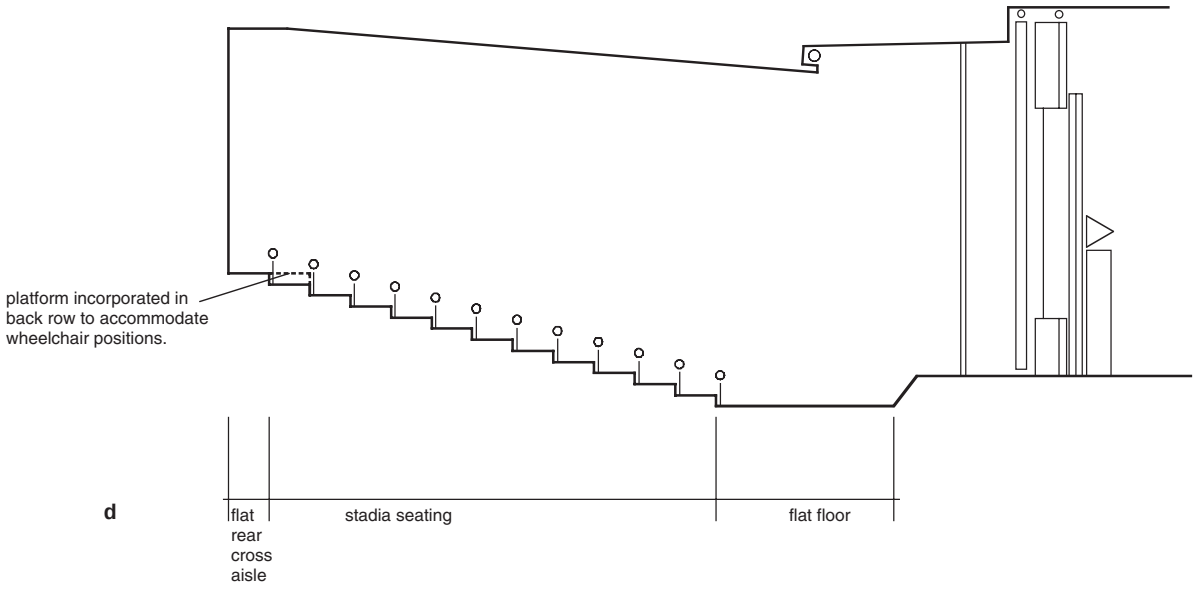
15.95a *Vertical sightlines: a 16 mm and 35 mm*



15.95b *Vertical sightlines:70 mm film. Seating options*



15.95c *Vertical sightlines: tiered seating*



15.95d *Vertical sightlines: stadia seating*

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It is good practice to avoid entrances at the screen end of the cinema, so as to avoid disturbance by latecomers.

8.5 Acoustics for films

The sound track is an integral part of the audience experience and the quality of sound reproduction has vastly improved. Cinemas are now equipped with stereophonic sound systems which require acoustically dead auditoria; the ideal is a zero reverberation time. Hence all finishes – floor, walls, ceiling and seats – need to be sound absorbent. Side walls should not be parallel, and a fan shape is preferred. The auditorium should be structurally and enclosure-wise insulated from external noise. A suitable ambient noise standard for cinemas is NR30 to NR35. The volume per occupant should be at least 1.25 m^3 for large cinemas and 5 m^3 per person for small auditoria.

8.6 Access

The design of the auditoria should optimise the experience of going to the cinema for all members of the audience.

Mobility disabilities

A choice of position for wheelchair users should be provided, integrated within the main body of seating. Suitable positions on a level surface may include the front row, cross aisle or back row. It should be possible for a wheelchair user to sit next to a companion, whether another wheelchair user or not.

Visual impairment

Space should be provided for a guide dog at the end of a row. Facilities for screening films with audio description run off a CD for 35 mm film with professionally produced audio description synchronised with the film. Audience members pick up head sets from the box office which run off one of the channels on the infra red system. Digital Cinema servers have additional channels which provide audio descriptions.

Low level lighting on stepped or raking aisles, with the light source located out of the line of vision of the screen is an aid to all members of the audience.

Aural impairment

Facilities may include inductive loops and/or infra-red systems. Ideally both systems should be installed to cater for different types of hearing impaired user. A system of superimposing a subtitle (soft title) by use of the video projecting onto a projected 35 mm image is also available for the profoundly deaf. This system is incorporated into a single digital cinema projector.

8.7 Lighting

The different types of lighting which need to be provided within a cinema auditorium are:

- *House lights*. These are the decorative lights which set the ambience of the auditorium when the audience enters and are gradually dimmed before the screening.
- *Curtain lights*. These highlight the screen curtains/screen surface prior to the screening and often have coloured gels.
- *Primary lighting*. These are mains powered and provide a low level of lighting during screenings, equivalent to the level of lighting provided by the secondary emergency lighting in the event of mains failure. It is essential that they are no brighter than required to meet statutory requirements in order to avoid distractions during screenings.
- *Secondary (emergency) lighting*. These are powered by a central battery or local battery packs and provide a low level of illumination in the event of mains failure.
- *Illuminated emergency exit signs*. These are dual fed, that is mains powered and powered by a central battery or local battery packs and remain illuminated during screenings and in the event of mains failure and an emergency. It is bad practice to locate exits and hence illuminated emergency exit signs within the same plane or in close proximity to the screen. Illuminated exit signs should be selected to minimise disturbance through light spillage during screenings.
- *Cleaners' lights*. House lights that are energy efficient may double up as cleaners' lights. Alternatively separate cleaners' lights are installed. These need to be controllable from the projection room and the ushers' position in the event of an emergency (other than mains failure) for example a medical emergency. Regard needs to be given to lamp life and ease of changing the bulbs when considering the location and specification of all light fittings within a cinema auditorium.
- *Speakers' lights*. In auditoria used for awards ceremonies and panel discussions before or after screenings or for conference use, speakers' lights should be provided.

8.8 Interiors

It is good practice to avoid light colours and reflective surfaces within a cinema auditorium, to avoid distraction during screening.

It is good practice for the lighting design and colour scheme on the approaches to the auditorium to assist members of the audience adjust to lighting levels within the auditorium.

8.9 Screens

Shape

Film and digital projectors may be required to project material in a variety of width-to-height ratios. Typical ratios for commercial cinemas are 1:1.66, 1:1.85 and 1:2.39. Specialist cinemas and lecture halls may require ratios as low as 1:1.33 (described as 4:3 in video terminology) for archive, independent or television material. High definition television normally uses a 1:1.78 ratio (16:9 for video).

Size

The largest 35 mm screens will usually be less than 18 m in width. 2 K digital cinema projectors can now illuminate a picture size in excess of 25 m.

Curvature

For uniform focus a large screen should be curved to keep its surface equidistant from the centre of the lens.

Luminance

Screens may have a matt white surface or a special high reflectivity surface which is particularly suitable for larger screens where the luminance needs to be enhanced. Some 3D projection systems require a high reflectivity silver surface although these are unsatisfactory for conventional 2D projection.

Position

The centre of screen should be on the central axis of the auditorium seating

Masking

Mechanically adjustable black masking to the sides and top of the screen is normally provided to contain the picture surface and obtain maximum apparent brightness. The masking is usually wool serge on metal rails, and the gear should be fixed at floor level for ease of maintenance. Movement is remotely controlled from the projection room.

Unmasked screens

Unmasked screens are used in many multiplex cinemas and some specialised cinemas. They are most suitable when used with digital projection systems which can produce a 'clean' picture edge.

Construction

Screen material is either PVC or metallised fabric, held by cord lacing to hooks on a metal lattice frame. Generally cinema screens are perforated to allow high quality sound reproduction from the speakers positioned behind the screen. Different sized perforations

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are available. Digital cinema projection and small auditoria usually require smaller size perforations. Unperforated screens may be used in specific circumstances such as lecture halls.

Temporary screens
In some multi-use auditoria screens may require to be easily and conveniently removed. A flat screen up to 6 m wide can be incorporated into a proscenium stage of a theatre form either housed, when rolled, in the stage or flown in the flytower. Curved screens could be flown, but take up much valuable space in the flytower; or they could be stored at the rear of the stage if fitted with rollers or castors for ease of movement.

Speaker installation
The speakers need to be located behind the screen, firmly fixed to the platform or screen frame. One speaker is needed for monophonic sound; for multi-channel and stereophonic sound from 35 mm film, three speaker units are necessary: one centrally placed and the others equidistant from it to the left and right. 70 mm sound production requires five symmetrically placed about the horizontal axis of the central speaker.

A sub-woofer low-frequency speaker is usually located centrally behind the cinema screen. Surround sound systems are widely used in cinemas and require a number of small or mid-size wall-mounted units on the left, right and rear auditorium walls.

Platform
The back of the screen frame, including the speaker, needs to be covered with heavy felt to absorb sound. Alternatively the entire wall surface behind the screen and speaker frame can be covered with black tissue faced insulation. The screen is set over a platform with a forestage, carpeted with black carpet to prevent reflection of sound and light. The forestage edge can be vertical, splayed or stepped. Some theatres now build baffle walls behind the screen which incorporate the theatre stage loudspeakers.

Stage for speakers
In cinemas used for speeches or panel discussions before or after screenings, awards ceremonies or occasional lecture or conferences it should be possible for all audience members to have a clear view of the speakers' panels' faces.

Usually this will require the provision of a raised stage in front of the screen, although with steeply tiered stadia seating this may not be necessary.

AV and IT provision at the speakers' position, linked back to the projection room, needs to be considered. It is also useful to incorporate within the design of the cinemas a reasonable sized pipe such as a drain pipe so that A/V lines can be added on an ongoing basis from the projection box to behind the screen area.

Access to the stage for speakers or panel members with mobility disabilities needs to be considered.

8.10 Projection suite

A projection suite provides space for all the image projection and sound reproduction equipment in a cinema. Contemporary cinema design aims for a single projection suite to cover all the auditoria. Most cinemas provide automated systems which allow complete performance to be screened with minimal staff input. Specialised cinemas and lecture halls rely less on automated systems.

Digital cinema systems remove the need for film preparation and storage equipment and film transport systems therefore may require smaller projection suites.

Projection suites should be secure from access by the general public.

Digital projection
Digital cinema projectors have approximately the same footprint as 35 mm projection. 2 K and 4 K projectors can achieve image widths up of 25 m.

A single projector can be used for 3D projection, but has to produce approximately twice the light output as used for 2D projection. This could, in larger auditoria, reduce the standard picture size; two projectors can be used to increase the luminance in the largest theatres. To achieve 3D in 4 K projection two projectors will be required. Some 3D equipment is fitted to the lens on 2 K projectors and requires approximately 500 mm from the projection lens to the porthole glass for installation and removal.

There are two types of 3D glasses in use, the disposable and reusable. It should be taken into account that glasses should be easy to distribute and to collect. The reusable glasses are expensive and security issues should be taken into account. Facilities will be required to wash, dry and store the glasses.

A standard digital projection system is comprised of the following:

- A projection head, lamphouse and rectifier. These are usually housed together in a single module.
- Digital cinema film server and storage system can be rack mounted with the theatre's sound processor and amplification system or in some cases under the projector's lamphouse. The film server will require an ADSL or IDSN connection to download security keys for diagnostic tests.
- In some theatres there may be a requirement to play alternative content, which includes/definition any image that is not high and digital cinema. This may comprise of corporate PowerPoint presentations, live concerts, DVDs, Playstation type gaming or other video formats.

Additional equipment may include:

- Multimedia playback box, digital to analogue sound interface, audio delay, DVD playback, satellite dish and transcoder for live events and downloading digital cinema content, space for HD disc player/VR playback, monitor.

Digital cinema projectors require venting at approximately 600/650 cfm. Projection boxes should be cooled to approximately 21°C.

9 MULTI-PURPOSE AUDITORIA

9.1 Requirements

Multi-purpose auditoria refers to an approach where compatible activities are combined within one volume. An example, Figure 15.96, covers a single form with a modest level of flexibility while combining opera, dance, musicals and drama, as well as concerts, conference and film shows. This is a multi-purpose proscenium stage with flytower and a flexible proscenium zone; the seating in the auditorium can remain constant.

9.2 Physical restraints

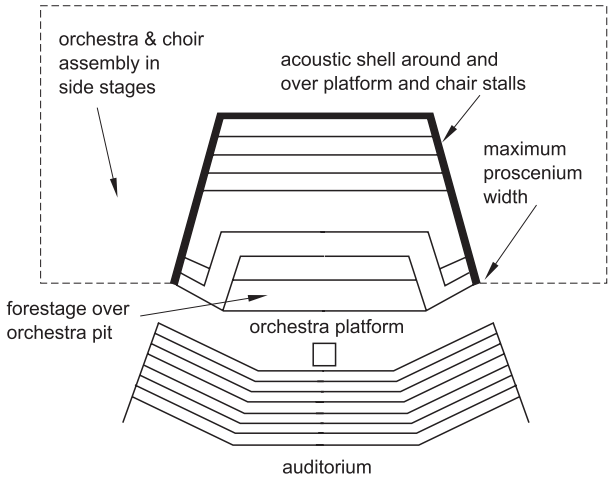
Problems can arise in combining different types of production in a single auditorium. Required volumes and reverberation times differ for speech and for music. To adjust the volume, arrangements to lower the auditorium ceiling can be incorporated into the design. Temporary alterations to the surface treatment of walls and ceilings can alter reverberation times, as can electronic 'assisted resonance'.

10 SUPPORT FACILITIES

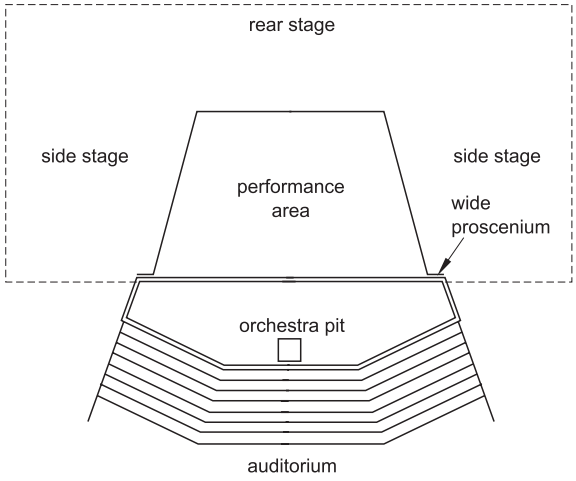
10.1 Entrance doors and lobbies

These require:

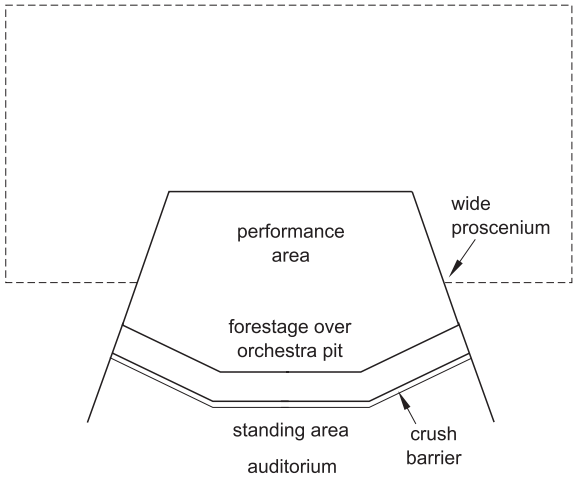
- Ease of access from car parking and public transport
- Canopy: to provide shelter at entrance
- Provision for posters and other information
- Draught lobby
- Automatic sliding doors



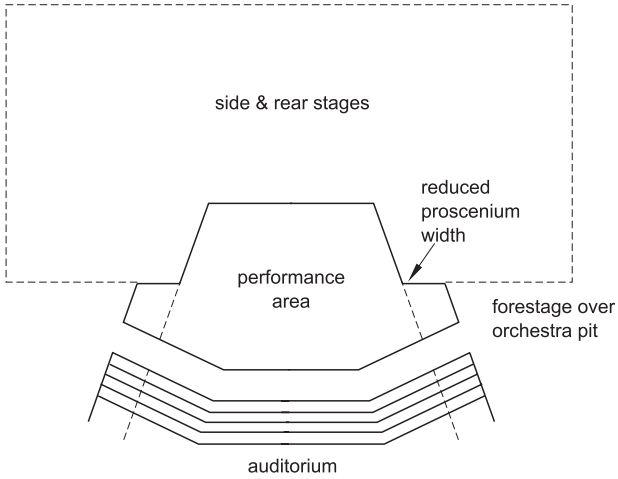
a *For orchestral and choral music*



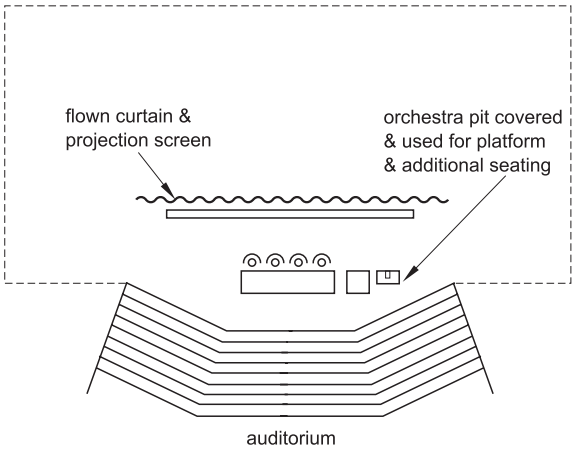
b *For opera, dance and musicals*



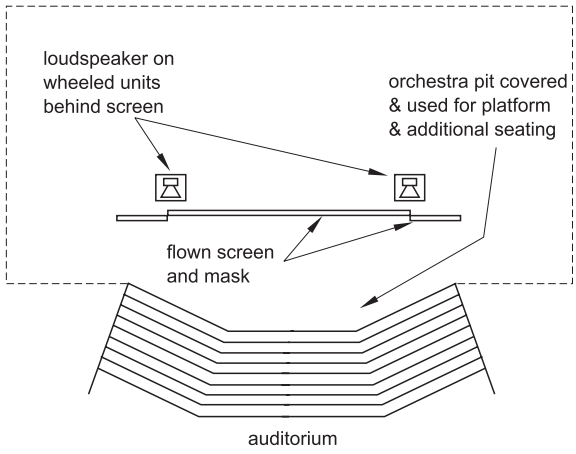
c *For jazz, pop and rock music*



d *For drama*



e *For conferences*



f *For cinema*

15.96 *Multi-use stage with flytower and flexible proscenium usable in the following ways*

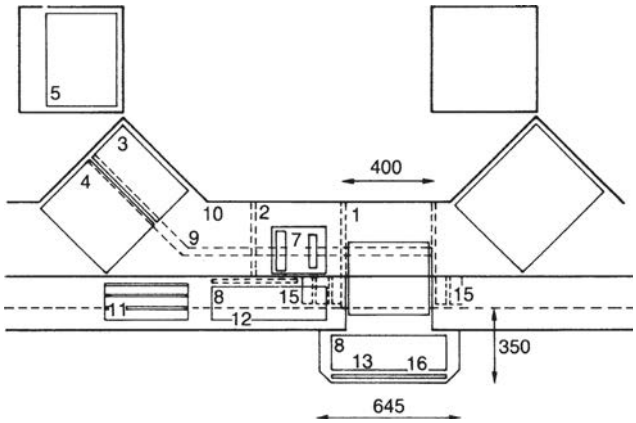
10.2 Entrance foyer

Box office, Figure 15.97 (in theatre, concert hall, cinema): counter for the sale of tickets; computer ticket dispenser
Registration (conference hall): counter or table
Reception and information: counter
Cloakroom (not usual in cinema): attended or unattended
Creche: at least 6.5 m^2 per child
First-aid room: bed, washhand basin
Toilets: see Chapter 2
Foyer and circulation: table, chairs, display stands
Performance area: within foyer or separate area
Space and display for exhibitions: see Chapter 29
Auditorium lobbies: barriers to sound and light at entry points into the auditorium; the level of lighting should assist adaptation to and from dark auditorium and the brighter foyer lighting, as with a cinema.

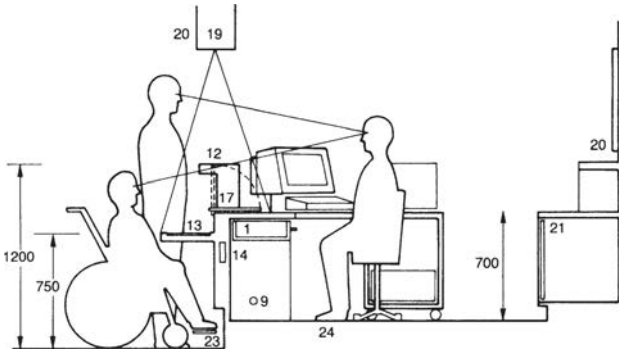
10.3 Places to eat and drink

- Coffee bar
- Licensed bar

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a *Plan*



b *Section*

15.97 *Box office. KEY: 1 stationery drawer, 2 till drawer, 3 keyboard, 4 VDU, 5 mobile ticket printer, 7 telephone, 8 seating layout plans, 9 footrest, 10 writing space, 11 leaflets, 12 upper customer counter, 13 lower customer counter, 14 cable trunking, 15 pigeon holes for tickets and messages to be collected, 16 cheque writing upstand, 17 counter flap, 19 counter lighting, 20 display, 21 storage, 24 raised floor*

- Cafeteria
- Restaurant
- Banquet room
- Private room
- Associated spaces: bar store, cellar, kitchen, storage, staff rooms, manager's offices, delivery, refuse.

See Chapter 34.

10.4 Sales

- Shops and merchandise outlets: display cases, shelving; office, storage, security; see Chapter 35.
- Kiosk and other food outlets: display cases, shelving, microwave oven, stockroom (confectionery, drinks, etc.) with possible refrigerator; security.

10.5 Meeting rooms

Break-out rooms, sponsors' rooms; equipped for receptions, and small group lectures, discussions and workshops.

10.6 VIP rooms

Reception rooms for distinguished visitors; lounge and toilets.

10.7 Exhibition hall

Displays including trade exhibitions; storage, deliveries, possible separate public entrance, see Chapter 29.

10.8 Art gallery

Permanent and/or temporary exhibitions, see Chapter 29.

10.9 Office services

Conference halls: access by delegates to fax machines, telephones, photocopiers, translators, secretarial work, see Chapter 30.

10.10 Outdoor areas

Gathering area at front doors; associated with foyer and places to eat and drink as external terraces; store for outdoor furniture; landscaping.

10.11 Signage

- External: name of venue, current and future events.
- Internal: direction signs to the various public attractions.

10.12 Managerial spaces

Administrative offices

- Offices: functions may include policy, house management, accounts, personnel, marketing, press and publicity, development and community programmes, clerical work; see Chapter 30.
- Associated spaces may include boardroom, storage, strong room, office services and equipment, entrance and reception, toilets.

Box office: room for postal and telephone bookings, storage of sales records and accounts; access to changing, relaxation and toilet facilities.
Men's and women's staff rest rooms: lockers, lounge chairs, refreshments and toilets.
Sales and trays store: refrigerator for ice cream, shelves for confectionery, programmes, documents and other items for sale or distribution; storage of sales trays; table; washhand basin; located directly off the public areas.
Maintenance workshop, office and store: for the maintenance of the building fabric, equipment, emergency services, external works.
Cleaners' stores: central storage of materials and equipment; cupboards with sink, cleaning materials and equipment throughout building.
Security control room: surveillance monitors, fire-detection systems, alarms, service monitors, paging systems, locking devices.
Refuse: external provision for dust-bins, well ventilated and easily cleaned.
Catering facilities: the scale of the operation may justify the inclusion of catering facilities for all staff.

10.13 Production spaces

For those opera, dance, musical and drama companies which initiate their own productions, the following spaces are required:

- Offices for the functions of artistic policy, direction, production development, instruction, design, production organisation, business management, development programmes and clerical work.
- Associated spaces may include boardroom, library, music room, audition room, working conference room, model-making facilities, dark room, general storage, office services, refreshment areas, toilets, entrance and reception.

10.14 Rehearsal spaces

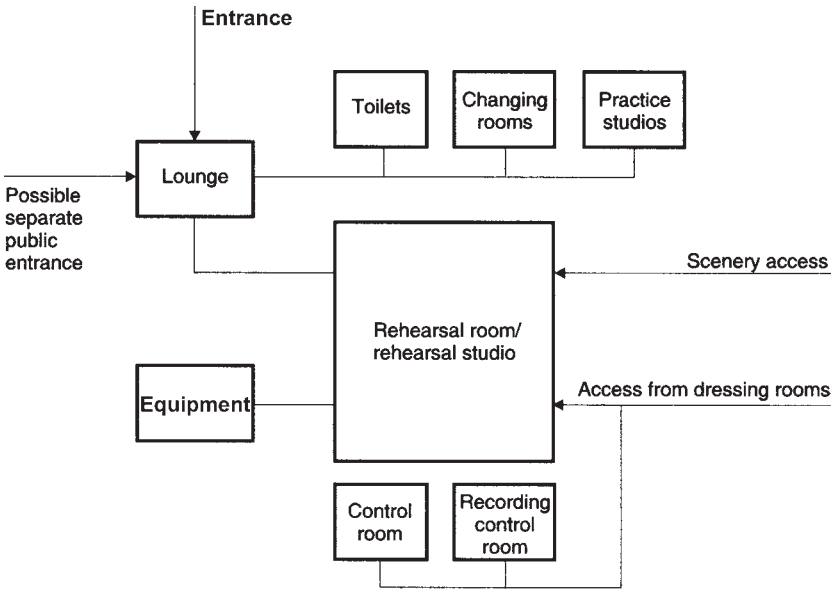
A relationship diagram for a rehearsal suite is shown in Figure 15.98.

- Rehearsal room or rehearsal studio able to accommodate largest performing area on the stage plus 2 m on three sides and 3 m on one long side as a minimum.
- Practice studios for individual or small group practice, for example for dancers, Figure 15.99.
- Associated spaces may include lounge, changing rooms, toilets, storage of equipment.

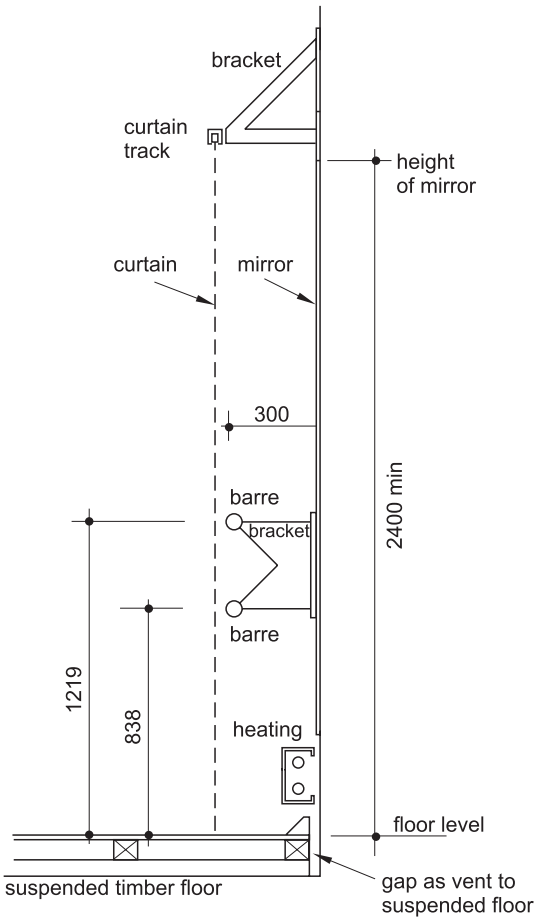
10.15 Scenery workshops

The substantial facilities required where the manufacture and maintenance of scenery is involved is well illustrated in Figure 15.100.

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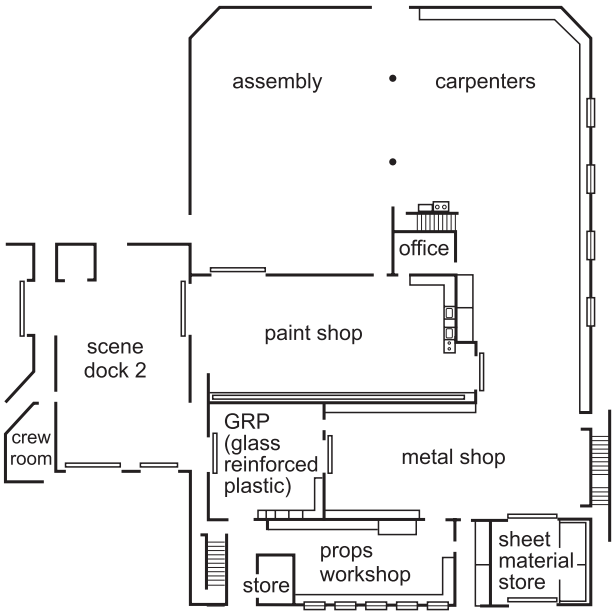


15.98 *Relationship diagram for a rehearsal room or studio*



15.99 *Section through wall barres in rehearsal studio for dance practice*

Offices: for head of carpentry workshop, head of paint shop, and head of property department.
Carpentry workshop: for the construction of scenery; power-operated tools (such as woodworking machine, mortise, circular and bandsaws and lathes); benches for carpentry, assembly and canvassing; storage of raw materials such as timber, sheet materials, rolls of materials, nails and screws and so on, including polystyrene sheets which may require a separate fire-resistant enclosure



15.100 *Plan of workshops in the West Yorkshire Playhouse, Leeds*

Paint shop: for the painting of scenery, the method of painting backcloths and flats (flat on the floor, on mobile frame or fixed frame and gantry), and three-dimensional pieces: the extent of benches for mixing paints and other preparation and cleaning brushes; storage requirements for raw materials such as paints and fire-proofing, and equipment such as brushes and spray equipment. Paints may require to be stored in a fire-proof enclosure.
Metalwork shop: the use of metal in the preparation of scenery; provision for welding, cutting and fabricating metalwork items; benches, welding screens and bending machinery; storage of raw materials such as sheets, tubes and bars, bolts, nuts and screws.
Trial assembly area: area for the erection of a trial assembly of the set under construction, the size of the performing area of the stage.
Property department: worktops and storage of raw materials. Two separate workshops may be required: one for polystyrene and fibre-glass work with associated fire-resistant requirements and extraction of toxic gases, the other for work with other materials.
Delivery and storage of raw materials to the carpentry workshop, paint shop, metalwork shop and property department, including unloading bay and parking of delivery vans and lorries.
Storage of scenery and properties for re-use.

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10.16 Layout of workshops

A level floor is required through unloading bays, workshops, scenery store and stage, giving a clear, broad passage of movement of scenery onto the stage. Where a change of level is unavoidable a lift will be inevitable but is not recommended. If touring companies are anticipated, passage from the unloading bay to the stage should be direct without interfering with the workshops.

The paint frame and backcloth storage should be placed so that the rolled backcloths can be moved horizontally into position under the flytower or grid with the painted surface facing the audience. The large doors or roller shutters required for the movement of scenery should not also be used for people. The minimum dimensions of the openings should be determined by the maximum size of scenery expected.

The carpentry shop should be isolated from the paint shop to avoid noise and sawdust penetration, and both areas should be acoustically insulated from the stage. Scenery storage located between workshops and stage acts as a sound barrier.

10.17 Wardrobe

Space is required for:

- making and fitting of performers' costumes;
- making and fitting associated items such as wigs;
- storing, repairing and cleaning costumes;
- making millinery and accessories;
- dyeing cloth and spraying materials;
- storing rolls of cloth and pattern paper;
- storing small items such as sewing materials, dyestuffs;
- delivery of raw materials including unloading bay and parking of delivery vans;
- office for costume supervisor.

Performers require easy access to the wardrobe for fitting costumes, while the distribution of finished costumes for, and their cleaning during, a production suggests a location close to the dressing rooms.

10.18 Recording studio

For sound effects and music. An isolated space, with control room. Associated areas may include a library of tapes and discs, entry lounge and lobby. Further details may be found in Chapter 40.

10.19 Common facilities

Provision for resting, changing, refreshment, toilets and showers.

10.20 Transport

Van or vans for the collections and delivery of goods, with parking spaces within the curtilage of the site.

11 FACILITIES FOR PEOPLE WITH A DISABILITY

Access:

- Dedicated car parking spaces at public and staff entrances.
- Drop-off points at entrances.
- Wheelchair users use main entrance.
- External and internal ramped access, handrails and lifts comply with Building Regulations.
- Unrestricted access to all levels and non-public areas (it may not be feasible to provide access for people in wheelchairs to access such areas as the grid over a stage, or lighting walkways over an auditorium).
- Dedicated wheelchair spaces in auditorium seating areas.
- Accessible toilets complying with Building Regulations.
- Box office reception desk and information counter with accessible height and width.

Facilities for people with sensory impairment:

- Induction loop system or infra-red hearing provision in auditorium.
- Induction loop system in box office, reception desk and information counter.
- Visual fire alarm system.
- Braille/large print/tactile signs.
- Audio description provision.
- Facilities for guide dogs.

12 LEGISLATION

Local authorities have a responsibility for licensing places of public entertainment. It is essential that contact be made with the appropriate local authority before plans are too far advanced. Before taking any decision they would normally consult the fire authority and the Health and Safety Executive as well as their own safety officer.

The areas of particular concern will be inflammability of materials, seating layout, emergency lighting levels, escape routes, signage and building services. Reference BS5499 and BS5588.

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16 Civic buildings

David Selby, Martin Sutcliffe and Neil Sansum

CI/SfB: 314, 317, 372, 373, 374

Updated with David Selby (town halls) and Martin Sutcliffe and Neil Sansum of BDP (law courts)

David Selby is a senior partner at Hopkins Architects. Martin Sutcliffe is chairman and Neil Sansum is an architect director at BDP Bristol.

KEY POINTS:

- *Flexibility is needed to accommodate likely future change*
- *Value-for-money is a major design criterion*
- *The need for security while ensuring full access to those entitled is an increasing design challenge*

Contents

1 Town halls
2 Law courts
3 References

1 TOWN HALLS

1.1 Introduction

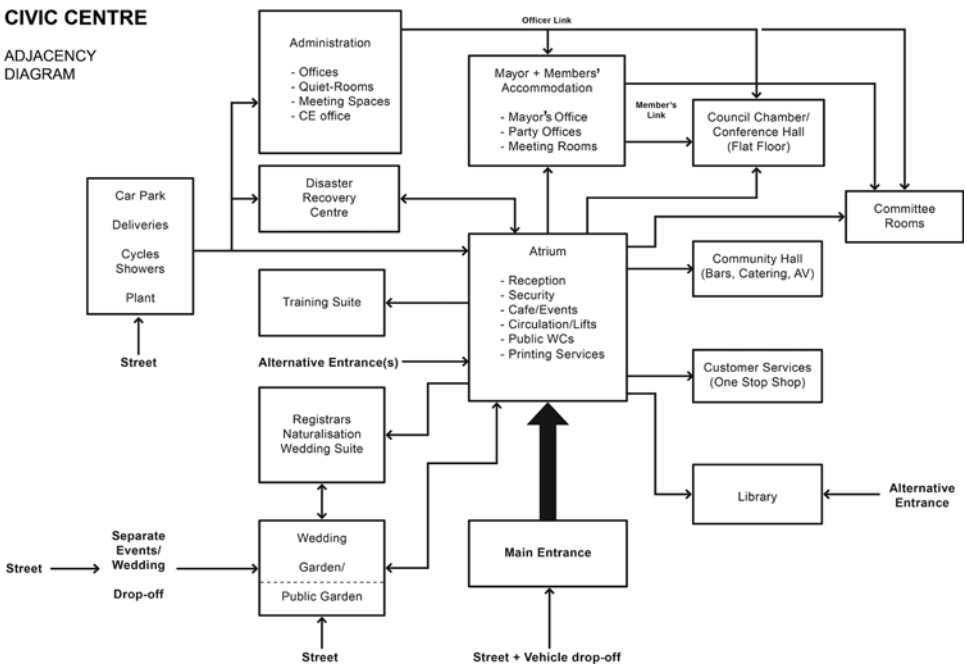
The concept of the town hall as a local civic and community focus has a continuing importance for communities. Local authorities are however significantly reviewing their modus operandi and the physical needs of their buildings.

A developing direction in the design of town halls is towards a flexible, modern facility that delivers high quality services to the public. Local authorities are consolidating their property portfolios in order to achieve greater efficiencies operationally and in terms of building stock. The name civic centre is considered as a more appropriate description or title, and even more fashionable expressions such as 'The Hub' or 'The Cube' have been adopted where the association with an outdated concept of local authority administration is no longer desired.

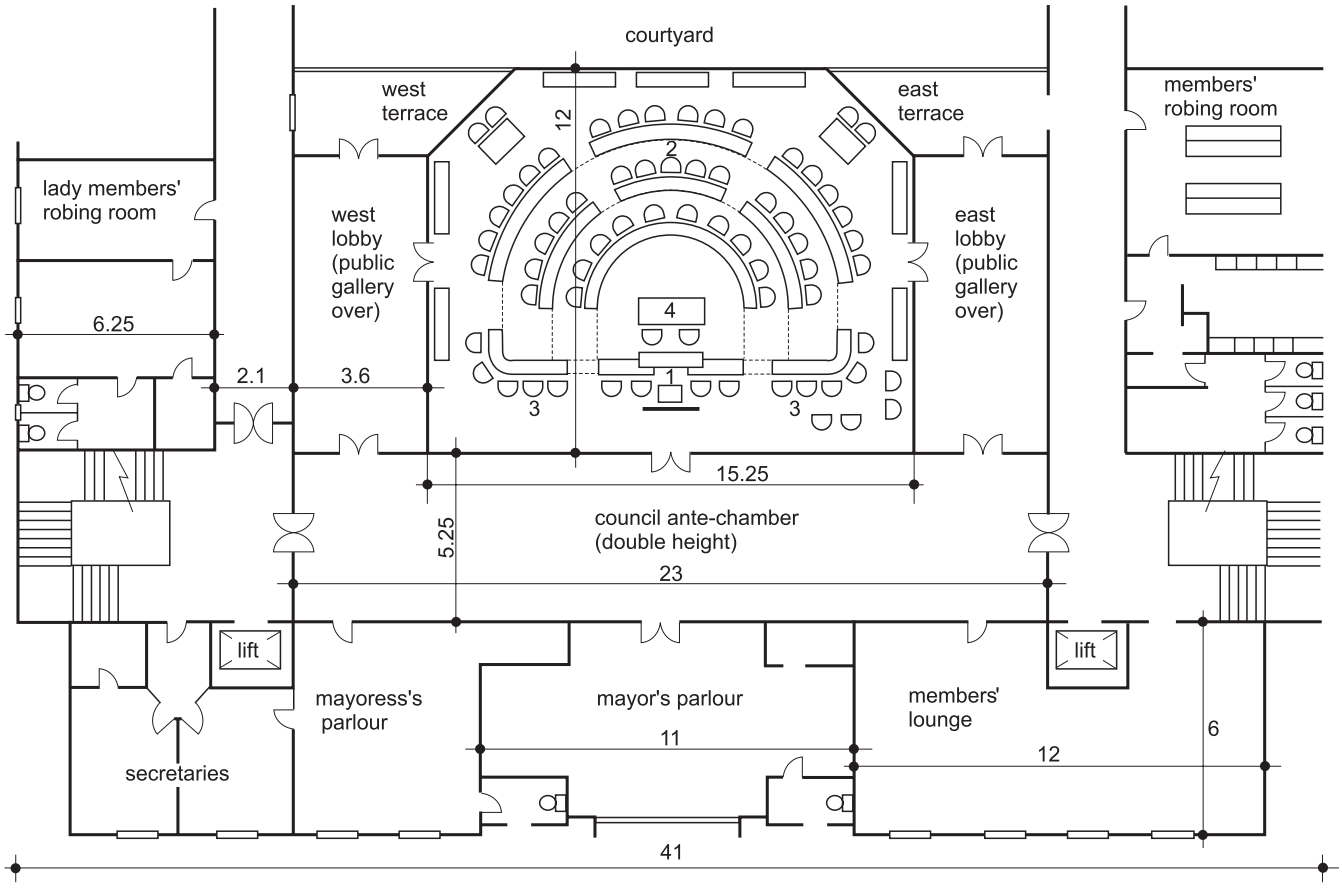
Although many of the key spatial requirements are similar to the traditional town hall model the emphasis has changed from the corridors of power to a building that provides services and facilities for the community, see Figure 16.1. The nature of the spaces has arguably become more demanding in terms of flexibility and therefore more generic rather than bespoke to a location.

Although local authorities may have different requirements, the new town hall or civic centre is likely to require the following principal components:

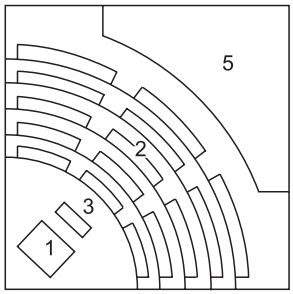
- members' accommodation
- council chamber
- community hall
- committee rooms and meeting rooms
- offices
- reception
- customer services
- library
- events spaces.



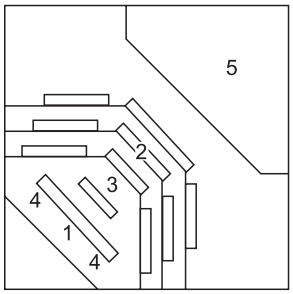
16.1 *Relationship diagram for civic centre functions (Hopkins Architects)*



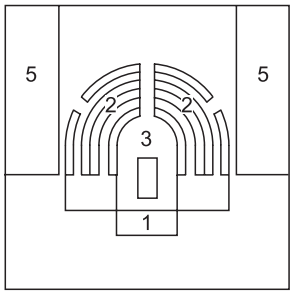
16.2 *Hammersmith Town Hall's Council Chamber suite is an example of a triple-tiered horseshoe configuration*



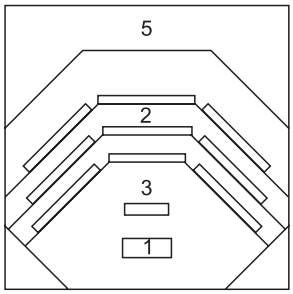
a *Approximately 300 seats in a five-tiered quadrant*



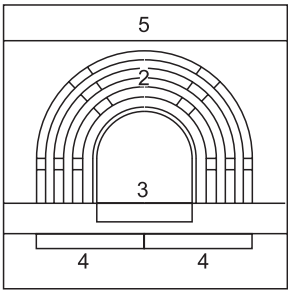
b *Approximately 60 seats in a three-tiered quadrant*



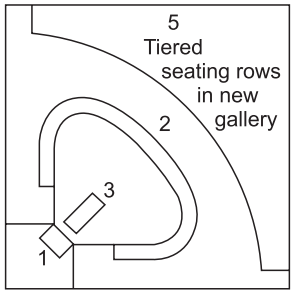
c *Approximately 30 seats in a two-tiered horseshoe*



d *Approximately 100 seats in a three-tiered segment*



e *Approximately 60 seats in a three-tiered horseshoe*



f *Approximately 30 seats a level*

16.3 *Council chamber, various layout types (1= mayor, 2 = ordinary members, 3 = officers, 4 = committee clerks, 5 = press and public)*

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1.2 Members' accommodation

Traditionally, the town hall was a place where the facilities accorded to the decision-making role of elected councillors were celebrated by a very high quality of traditional finishes setting those areas above others in terms of importance and status.

More recently, however, where members' facilities are provided in new accommodation the standard of finishes and furniture is required to match that of the council's offices or administration areas in order that members are not seen to have a higher standard of finishes or be enjoying lavish benefits associated with their elected position. Instead, members' offices are modern, flexible and deliberately non-specific to party colours.

1.2 Council chamber

The function of the council chamber as a space for council meetings continues and is likely to continue as long as the current format for local democracy exists. Their traditional forms are mostly segmental or horseshoe, see Figures 16.2 and 16.3.

Council meetings are held on a monthly basis and may be supplemented by youth parliament and other quasi-democratic meetings or presentations. For the remainder of the year the chamber is available for other potential uses, most of which would not require the tiered seating (see Figure 16.4) and public galleries so common in historic town halls but rather favouring a flat-floored space with flexible furniture, which can then be used for various functions or conferences that can be a source of potential revenue to the council.

The character of the civic chamber as a traditional oak-paneled room with all the allusions of grandeur attributed to outdated civic notions is not something that is prized by forward-looking councils. However, allusion to the civic nature of the room can be accommodated by a modern system of paneling utilised also for its acoustic performance. This space may be renamed. At Brent, for example, the civic chamber and its associated meeting and committee rooms are known as Conference Hall and Board Rooms.

1.3 Civic suite

In support of the civic functions of the council, meeting spaces and committee rooms are required in proximity to the civic chamber. These are to provide spaces serviced with audio-visual and catering for the needs of the council in conducting its business through committees. When not required for this use they can be let for community/private/corporate use.

1.4 Committee rooms

Local government business is conducted principally through numerous committees and sub-committees. Meeting rooms of various sizes are required; these (including the council chamber) are often available for letting by outside organisations, producing useful additional revenue for the council. For this reason, if for no other, they should be well designed and fitted out.

1.5 Community hall

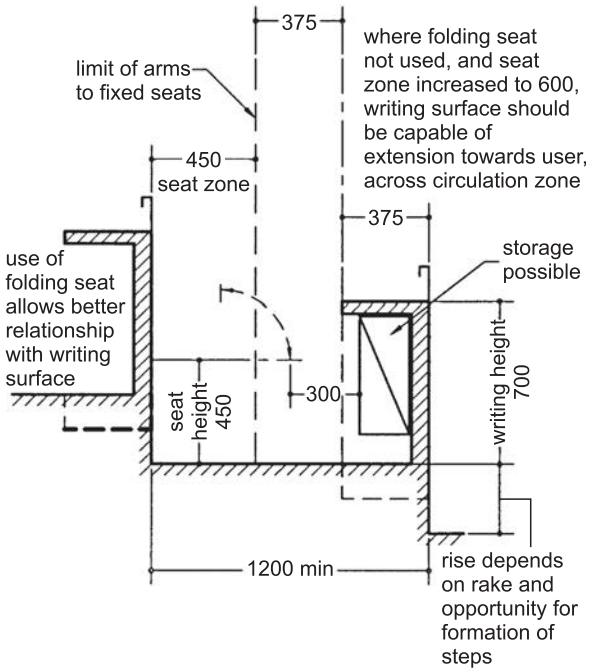
A central feature of the community function of the town hall/civic centre is the community hall. This is a space essentially for the use of the community but also for corporate events. It might accommodate large-scale weddings, concerts, pantomimes, plays, dances and banquets.

1.6 Offices

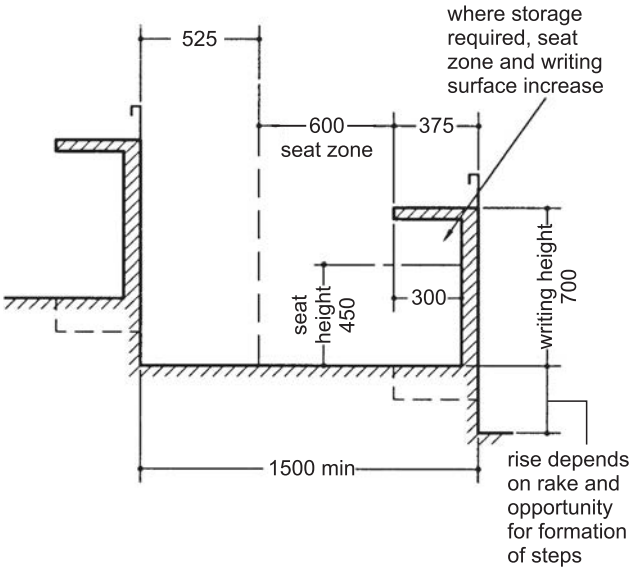
These can account for the bulk of accommodation within the town hall/civic centre as local authorities consolidate resources and departments in order to better deliver public services 'under one roof'. This breaks down the traditional 'silo' thinking of separate departments to encourage integrated delivery.

Administration areas within local authorities are now recognised as being as demanding as commercial office requirements (see Chapter 30). Smart desking and new ways of working are becoming accepted and have benefits in terms of space utilisation and efficiency. A ratio of 10 employees per 8 or even 7 desks is not unusual.

Flexible open plan areas with fixed island desking are punctuated with quiet rooms, breakout spaces, staff storage lockers, business support units for printing, re-cycling, storage and wet support areas for tea points.



a *Section through fixed seating at 600 to 750 mm centres. Number of seats in a row limited to avoid disturbance*



b *Section through moveable seating at 750 to 900 mm centres*

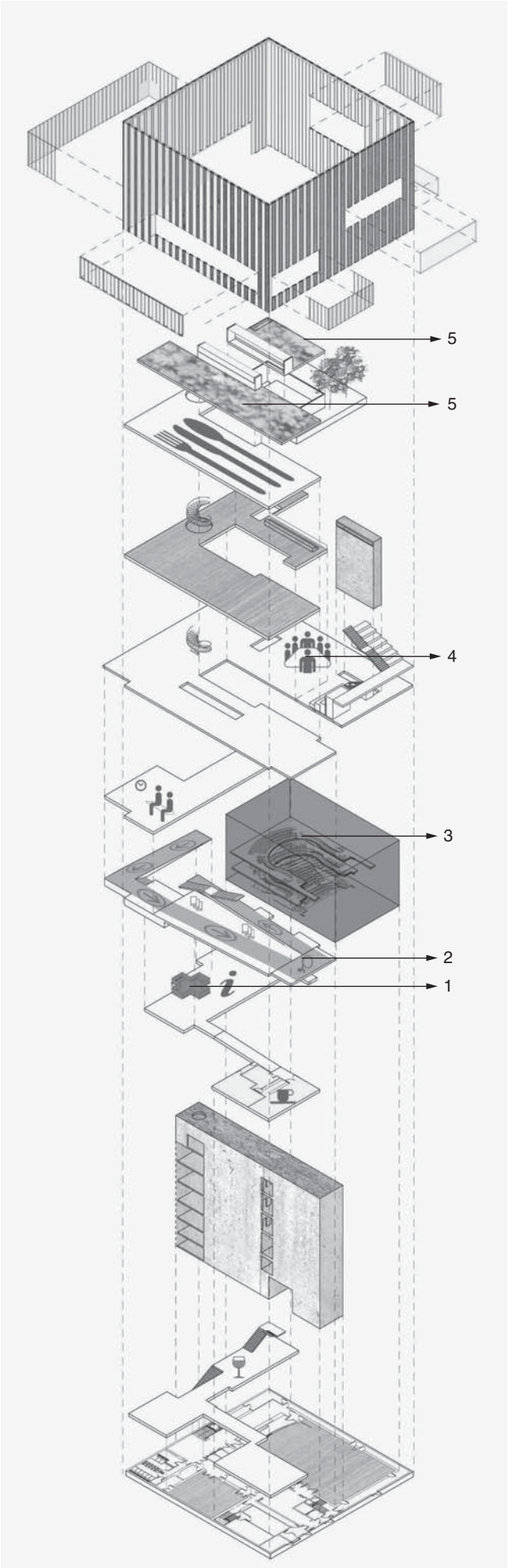
16.4 *Council chamber seating*

1.7 Public reception and information

A large entrance or atrium space is required for the public to arrive and orientate. People will be met by 'meeters and greeters', who will answer any immediate questions and give directions to departments as appropriate. A large reception desk is required with space for several receptionists, some potentially in wheelchairs, who will receive the public, provide information or coordinate meetings.

1.8 Customer services

Also known in some local authorities as a 'one-stop shop', this is a large space consisting of a seating/waiting area, queuing system



16.5 *Axonometric of the CUBE civic centre in Corby, designed by Hawkins Brown. Key: 1 entrance foyer information desk; 2 library ramp; 3 theatre auditorium; 4 Council chamber; 5 roof terrace and restaurant*

and large number of desks manned by council staff to answer queries and provide information to the public on all matters (planning, building control, council tax, education, social services, leisure). Additionally, a series of rooms for confidential consultations are required with alternative staff exits if necessary for security and escape reasons.

1.9 Cash facility

The need for cash transactions is diminishing as more and more are dealt with online. Dedicated cashier stations are generally no longer required.

1.10 Library

Public libraries (Chapter 27) are often incorporated into town halls/civic centres in order to benefit from the proximity with other services and facilities (Figure 16.5).

The nature of the public library has changed to more of an internet café and indeed many have informal seating and a café facility. Books are displayed face-on rather than end-on and study tables with Wi-Fi are mixed in. Children's book areas are linked and not separated.

1.11 Events spaces

With a growing emphasis on mixing up civic and community functions, the scope for impromptu or even scheduled performance events in visible areas within the town hall suggests that reception and circulation spaces can double-function as 'given' or 'found' spaces for such uses thereby animating the potentially otherwise institutional character of this area.

1.12 Case study – Brent Civic Centre

Introduction

London Borough of Brent commissioned Hopkins Architects to design a multi-purpose civic centre on a site close to Wembley Stadium. The aim was to house civic, public and administrative facilities within one building including office space for 2000 staff. It was also conceived as a new community hub for the public to meet within the newly landscaped Arena Square. There is also a wedding garden for guests attending wedding parties in the community hall.

Size

Brent Civic Centre totals 39,683 sq m. Of this, 14,154 sq m is public/civic space, 18,073 sq m administrative, and 7,456 sq m basement.

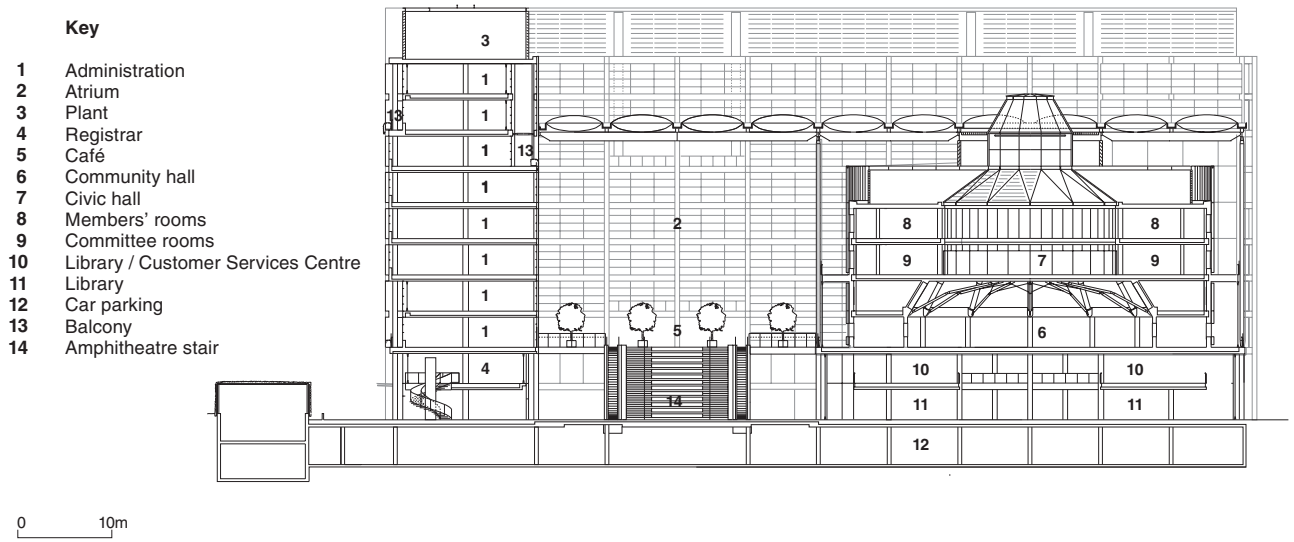
Layout

The building's spaces are arranged around a 31 m high, naturally lit foyer and atrium (Figure 16.6). This houses a large public amphitheatre and wide civic steps as well as the circular civic drum containing a multi-purpose, a library (1211 sq m), customer services centre (768 sq m) and 26 m diameter community hall (1177 sq m) (Figure 16.7).

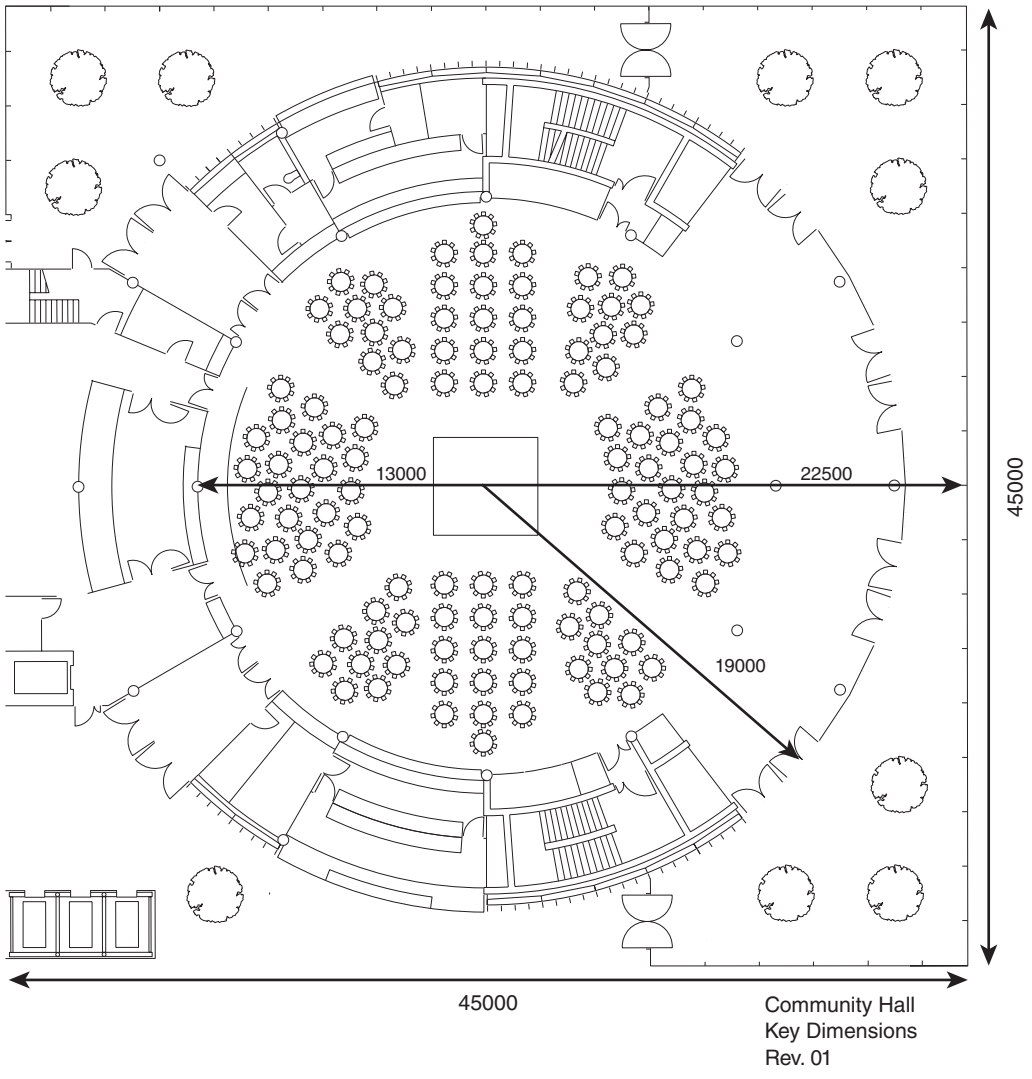
The chamber (284 sq m), on level three, can be reconfigured to suit a variety of civic and public uses (Figure 16.8 a, b, c). There is also an atrium foyer and civic hall lobby (473 sq m) and committee rooms (407 sq m).

Two glazed office wings provide open-plan and flexible administrative space to the rear of the site, included at a ratio of 7 seats to every 10 staff to reflect anticipated occupancy levels.

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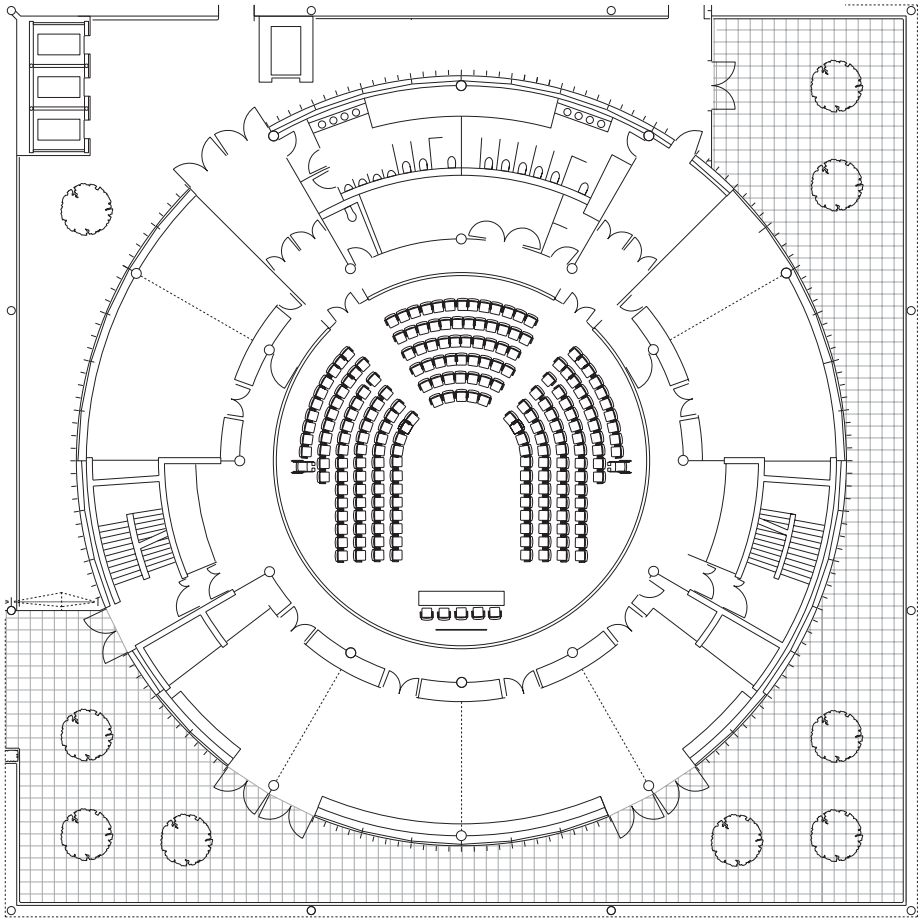


16.6 *Section looking north of Brent Civic Centre in north London, designed by Hopkins Architects*

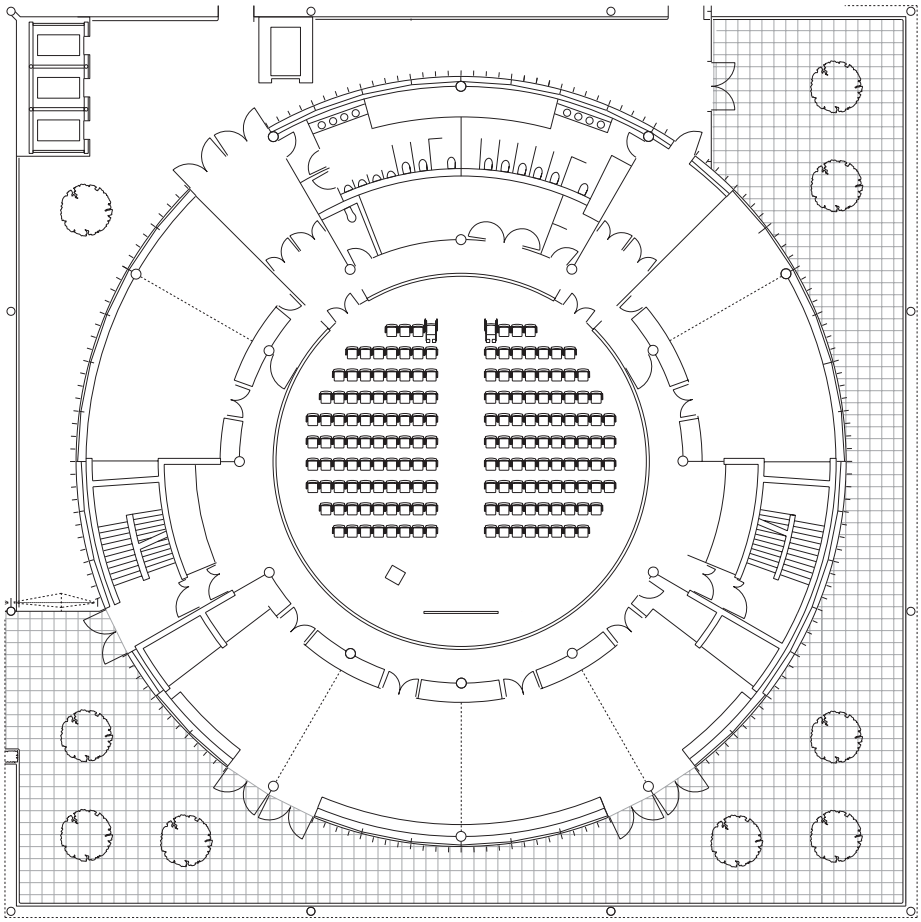


16.7 *Community hall, designed to be configured for a variety of uses including boxing matches, as shown here*

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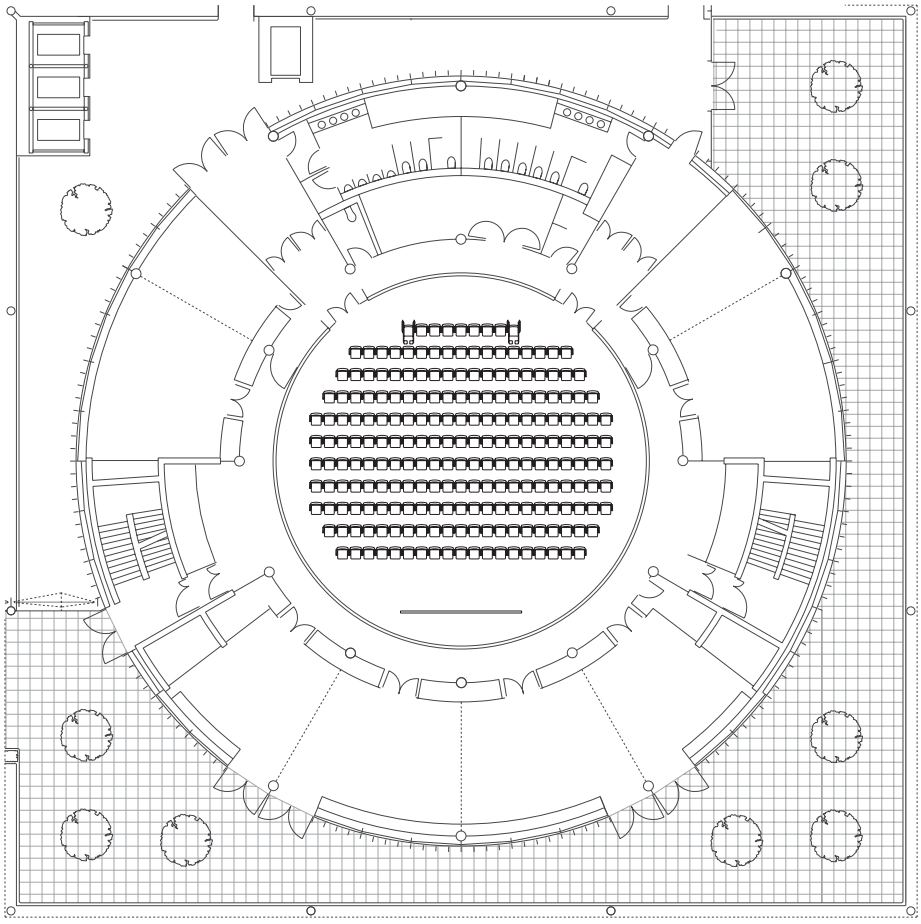


16.8a



16.8b

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16.8a–c *Brent Civic Centre civic chamber, shown configured for, a, council meetings; b, conference use; c, as a cinema*

Building performance
Brent Civic Centre has a BREEAM 'Outstanding' rating and was the first of its building type to have achieved this. As such, it attained a 33 per cent reduction in carbon emissions due to a combination of solar shading, natural ventilation, high-performance façade, and combined cooling, heating and power.

2 LAW COURTS

2.1 Background

The judicial system of England and Wales is in direct line of descent from that established by William I nearly a thousand years ago, subsequently modified by Magna Carta and many other reforms. Courthouses are the visible manifestation of one of the most fundamental sets of principles upon which our society is based.

How this is to be expressed in architectural terms is the particular challenge facing the designer of a courthouse. He or she will have to consider the contextual and environmental constraints that apply to any urban structure, especially those on prominent sites in town centres. Planning problems posed by the specific requirements for a courthouse must also be addressed, such as the four segregated circulation routes (for judge, jury, defendant in custody and public), the servicing of the many and varied spaces within a complex layout and the need for flexibility to accommodate future developments in information technology. Although courtrooms built 200 years ago are still able to cope, the law is constantly evolving and both the courtrooms and the ancillaries need to be receptive to inevitable change.

2.2 Court system

HMCS (Her Majesty's Court Service) has existed in various forms for over 900 years. Following the Courts Act 1971 it was given the task of running a new system covering all courts above the level of Magistrates' Courts. It is directly responsible for:

- the Court of Appeal
- the Royal Courts of Justice
- the High Court
- the Crown Court
- the County Court.

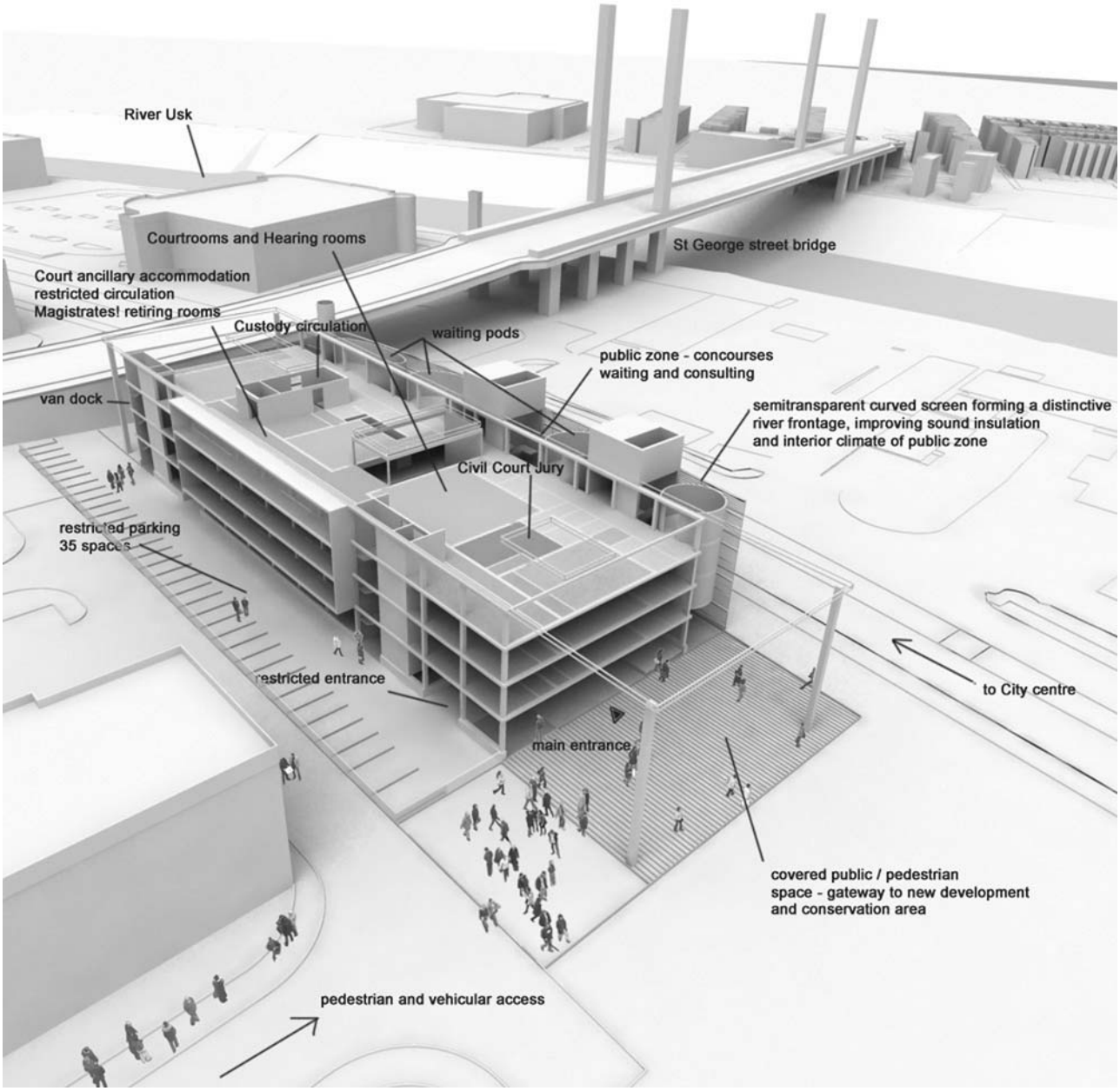
The Crown Court is a national court which sits at different centres. Practically all its work is concerned with cases committed for trial or sentence from the Magistrates' Courts, or appeals against their decisions. Cases for trial are heard before a judge and jury. Centres are classified as first, second or third tier according to the nature and complexity of the court business.

Magistrates' courts were traditionally local courts but are increasingly organised regionally. Some are part of larger combined courts such as Newport Law Court, which combines County and Magistrates Courts (Figure 16.9).

2.3 The courtroom

The Crown Court sits in a courtroom, the design of which will always be subject to the continuous adjustments dictated by changes in attitudes to child witnesses, the need to protect witnesses and jurors from possible intimidation and developments in technology.

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16.9 *Newport Law Court, in South Wales, designed by Feilden + Mawson, with clear delineation of public, court and court ancillary zones. Gross internal area: 9100m²*

The courtroom is the primary workspace and focal point in a courthouse, which is developed around it. It is the only place where all parties in a case are likely to meet. Of paramount importance is the need to segregate judge, jury, defendant and others in the courtroom and within the courthouse. Segregated circulation routes are provided so that the judge, jury and defendants (if in custody) make their way to the courtroom without meeting each other or any other users such as members of the public.

The exception is the magistrates court in which there is no jury, so therefore no need to provide space for jury seating or circulation (see case study in Section 2.15).

In all other courts, dedicated entrances are provided for:

- judge
- jury
- defendants in custody
- public, witnesses and defendants on bail.

Some prosecution witnesses have to be protected from intimidation; a separate secure waiting room for them is often situated with its entrance off the vestibule provided between the public entrance and the courtroom itself. An alternative arrangement has a separate access from the secure waiting area into the courtroom adjacent to the witness box.

The public enter the court behind or to the side of the public seating at the rear of the courtroom; neither public nor witnesses pass areas dedicated to other participants (e.g. jury or defendants in custody) on entering or leaving the courtroom.

2.4 Relationships within the courtroom

Courtroom layout incorporates specific and well-defined relationships between the various participants by means of carefully arranged sightlines, distances and levels. There are four main elements in Crown Court cases:

- judge
- jury

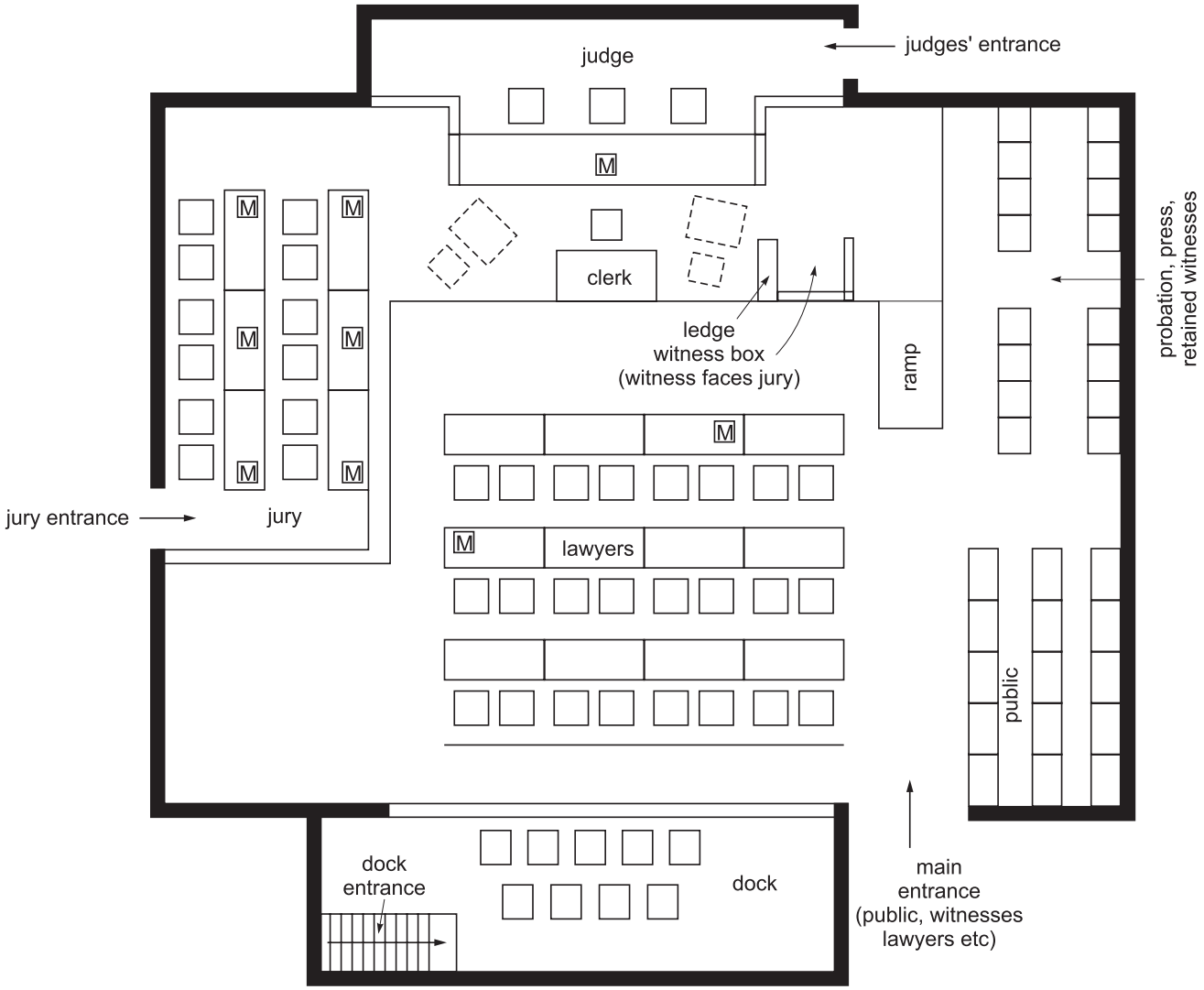
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- witness
- counsel (barristers and solicitors).

Defendants do not take part except as witnesses. Each element must be closely related, and be able to see and hear each other clearly at all times without mechanical or electrical aids, and without excessive turning from side to side. The basic positioning of the occupants is shown in Figure 16.10.

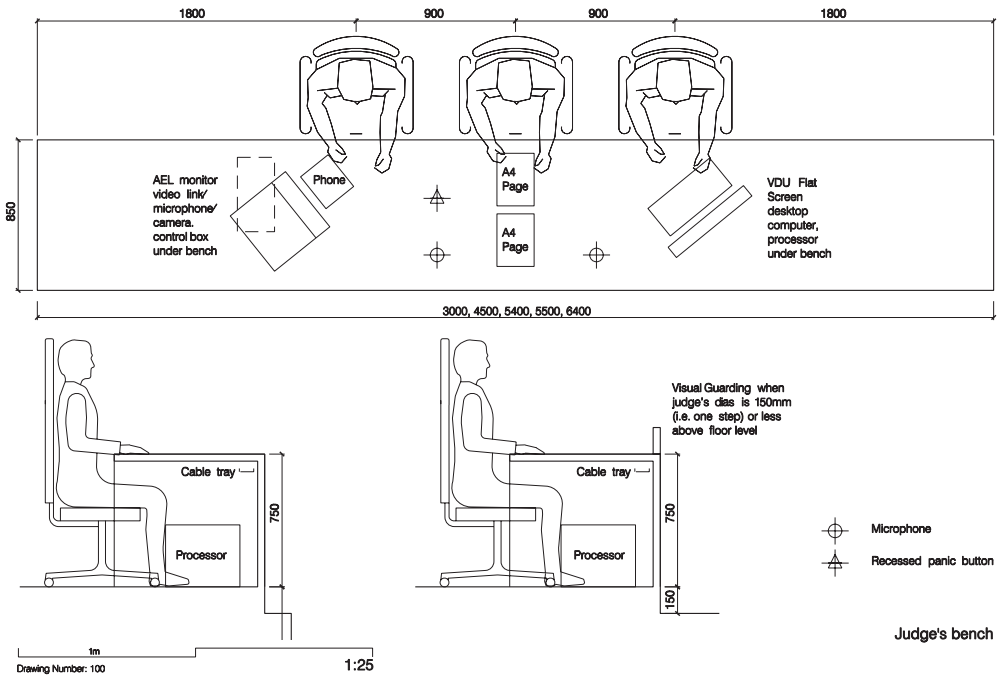
The theory behind these relationships can be summarised as follows:

- *The judge or magistrate.* Presides over the courtroom, should be able to observe the whole of it, to see clearly the principal participants as well as the defendant in the dock and, when called, the antecedents and probation officers. The judge or magistrates' bench is always elevated, usually by 450 mm (Figure 16.11).
- *The court clerk*. Administers the case and needs to keep a watching eye over the court. He or she often advises the judge and should be able to stand up and speak to the judge without being overheard.
- *The exhibit table*. This is in front of the counsel benches for the display of exhibits put forward for evidence.
- *Counsel*. These are barristers and solicitors who represent the defendant or prosecution. They need to be able to see the jury, judge and witness to whom they address their remarks. The barrister at each end of the front bench should be able to keep every jury member and the witness on the stand within about a 90° angle to obviate too much turning to ensure that the judge, the other main party, shall have at least a part face view. The counsel benches are wide enough to hold the large, and numerous, documents and books that are often in use.
- *The defendant*. The defendant is assumed to be innocent until proved guilty and current practice is to reduce any prison-like appearance of the dock by lowering the barriers enclosing it as much as possible compatible with security. Defendants sit in separate fixed seats and if they are thought to be a security risk may sit in an enclosed glazed cubicle within the court. The dock is controlled by a dock officer and situated at the back of the courtroom.
- *The jury*. This comprises twelve members of the public whose duty it is to reach a verdict based on the evidence presented. The jury sits opposite the witness stand and must be able to see the defendant in the dock, as well as the judge and counsel. Jurors must have a writing surface and a place to put documents.
- *The witness*. The witness waits outside the courtroom and when called gives evidence from the witness stand near to the judge's bench. They stand facing the jury who must be able to observe his or her face. The witness is questioned by the barristers and occasionally by the judge. If the judge directs that a witness should be retained, he or she can wait seated within the courtroom.



16.10 *Standard Crown Courtroom*

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16.11 *Judge's Bench. Source: Court Standards Design Guide, Ministry of Justice*

- *The shorthand writer*. This official keeps a transcript of the trial and consequently must be able to see and hear everyone who speaks.
- *Probation and antecedents officers*. These give evidence from their seats after the jury has reached a verdict. This evidence is used to assist the judge in passing sentence.
- *The press*. These are not party to the proceedings, but they should be able to see the participants.
- *The public*. These are in court to see that 'justice is done'. They are placed at the near end of the courtroom and have a general view of the proceedings, but with the minimum possible direct eye contact with the jury to reduce the risk of intimidation. A public gallery over the jurors is the most effective method of eliminating possible intimidation; but access to such a gallery and the increase in height of the courtroom has to be considered. The glass screen between the public and the dock is partially obscured to prevent members of the public from seeing the defendant(s) (and vice versa) while seated.

2.5 The courtroom environment

The design of Crown Court rooms should reflect the quiet dignity of the law rather than its power. A fully accessible (Figures 16.12, 16.13), well-detailed, comfortable and quiet courtroom with efficient and simply managed ventilation, lighting and acoustics is the ideal.

- **Youth court –** Magistrates' courts often contain a court appropriate for juveniles, where magistrates and defendants and legal teams can sit around the same table. These courts should have their own circulation routes which can be kept separate to that of any other courts operational that day in the building.
- **Ventilation** – Well-balanced environmental conditions within the courtroom are essential to the smooth running of the court. They keep the participants comfortable and interested, and avoid distractions. The current trend, supported by most users, is for natural ventilation with openable windows. This will subject the courtroom to wider temperature fluctuations; but this can be minimised by integrated automatic control systems.

  Mechanical assistance (or in extreme cases full air conditioning) will be necessary where there would be unacceptable noise intrusion; or where the courtroom cannot have the height to induce air flow by the natural stack effect. It is normally more economical and energy-efficient to have separate air handling units for each courtroom, managed by time switches and occupancy sensors.
- **Lighting –** Daylight is provided if possible; but direct sunlight must be controlled and security risks avoided. The controlled use of daylight alone improves environmental comfort, but when it becomes for any reason insufficient, artificial lighting will be required. A combination of uplighters and downlighters reduces glare and contrast, and enhances the character of the courtroom. Lighting levels and colour should ensure correct colour rendering, and that all participants, exhibits and written evidence can be clearly seen without strain or dazzle.
- **Acoustics –** The acoustics and noise levels should ensure that the proceedings can be heard in all parts of the courtroom while avoiding distraction and annoyance from movement by the public, press or others. There may be a need for reflective or absorbent surface treatment to walls and ceilings.
- **Communications –** The courtroom should accommodate data connections and telephones for the legal teams and judiciary, with cabling concealed within a raised floor. Screens to show testimony from witnesses outside the courtroom should also be incorporated.

2.6 Functional relationships outside the courtroom

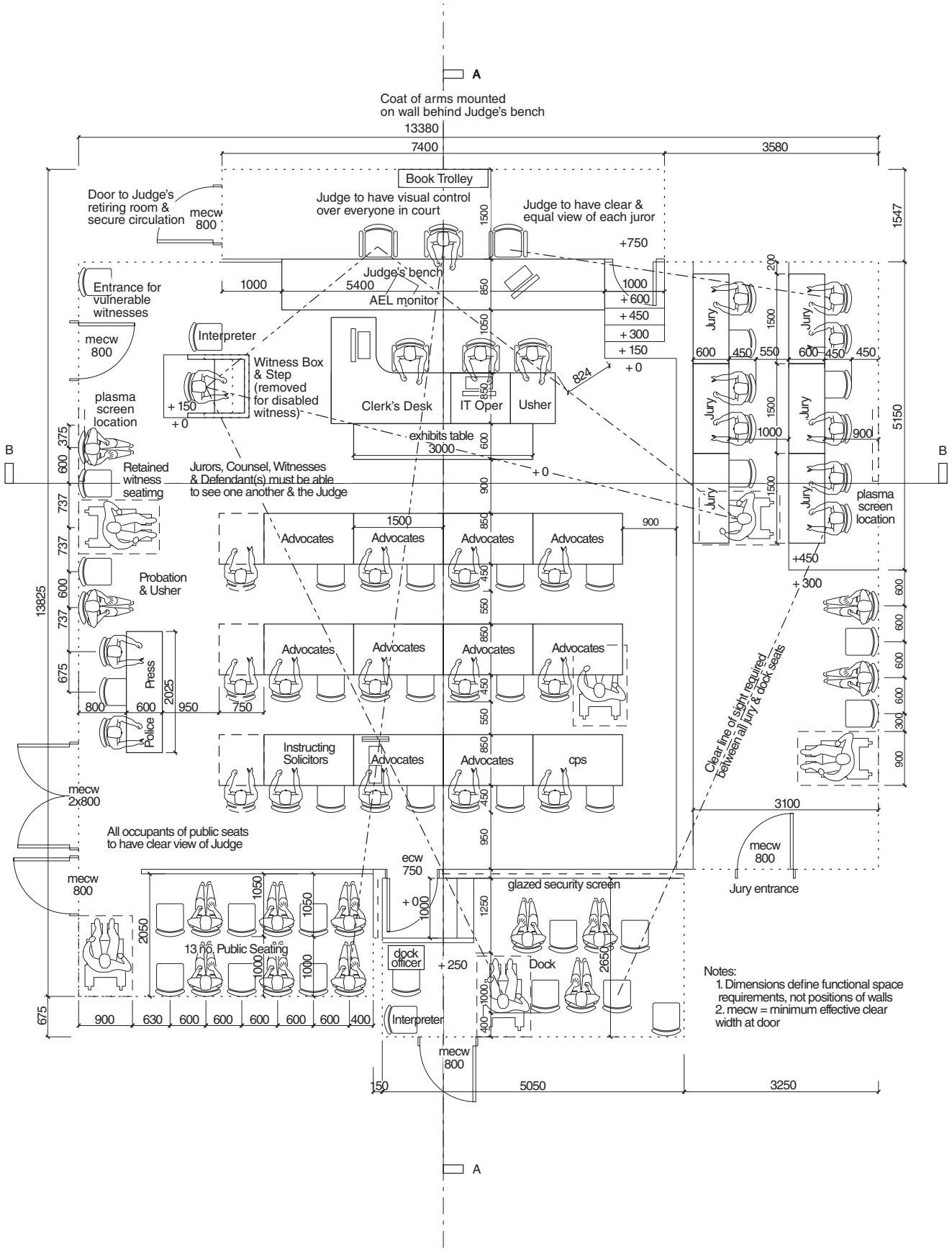
Courthouse accommodation is divided into areas, each with its own self-contained circulation. Movement between areas is limited and restricted. Even those who need to move freely can only enter certain restricted areas by passing through manned control points or other secure doors. The relationship and pattern of movement between the elements is shown in the functional relationship diagram in Figure 16.14.

2.7 Judiciary

The judiciary (judges, recorders, etc.) arrive at the court building and enter through a manned or otherwise restricted entry directly into their own secure area of the building. This contains the judges' retiring rooms and all areas devoted to judicial use.

The only other users of this area in 'working hours' are the staff, i.e. ushers, court clerks, security staff and invitees, i.e.

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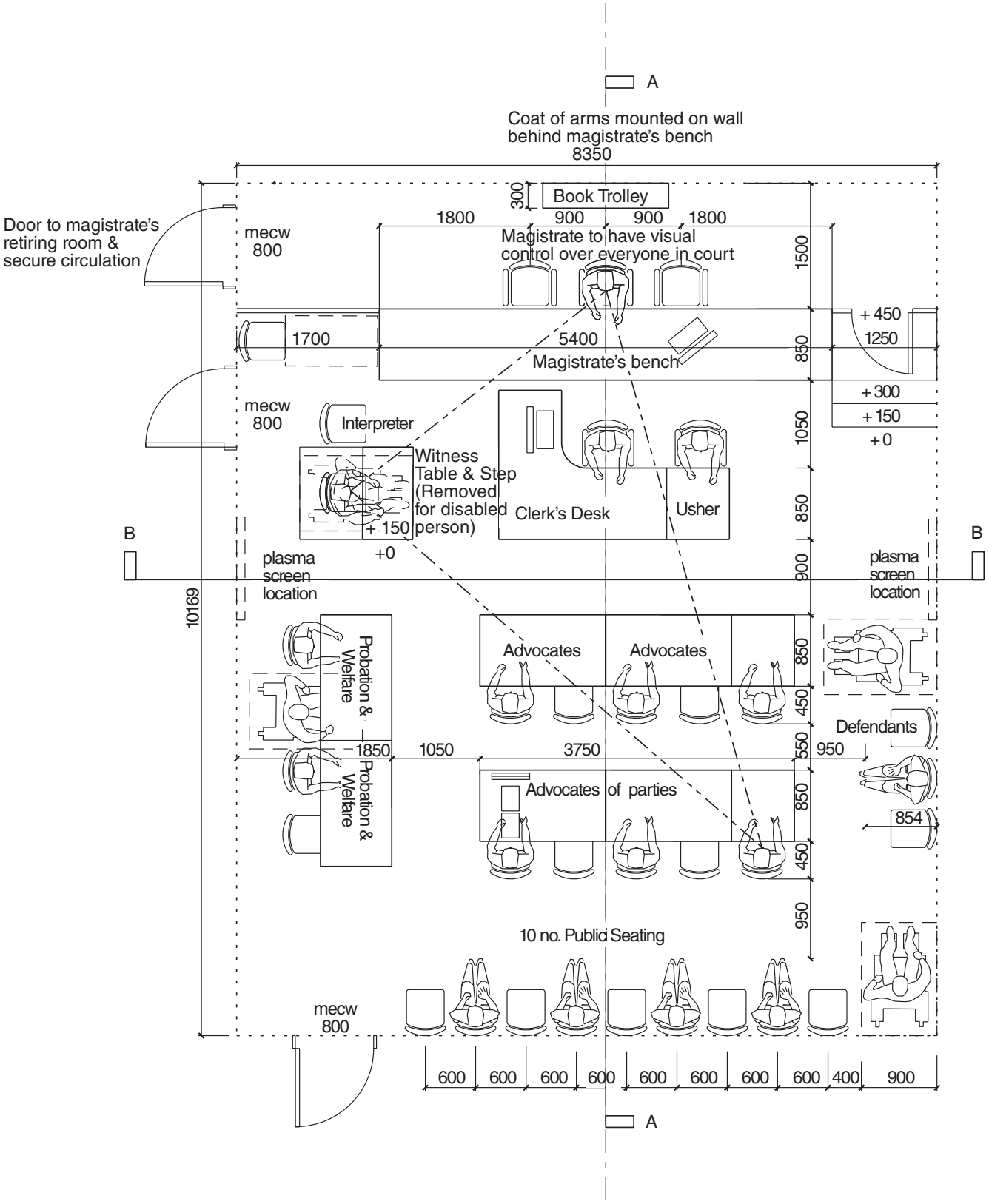
16.12 *DDA compliant standard criminal court, 14.4m x 13.5m, 172m². Source: Court Standards Design Guide, Ministry of Justice*

legal representatives, guests and some members of the public invited to a judge's room. Invitees will always be escorted, and access for all will be either via the judges' entrance into court or through staff areas. Each entrance will be via a self-locking, secure door.

2.8 Jurors

Persons, the number depending on the number and size of trials programmed, are summoned to the court building. They enter through the main public areas until they reach the reception area to the jury assembly suite where they are booked in.

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16.13 *DDA compliant standard criminal court, 10.2m x 8.4m, 84.9m². Source: Court Standards Design Guide, Ministry of Justice*

They then wait in the lounge or dining area where refreshments are available until called upon to form a jury panel. The period of waiting is variable and can be all day. Highest usage is before courts sit, and during lunch periods.

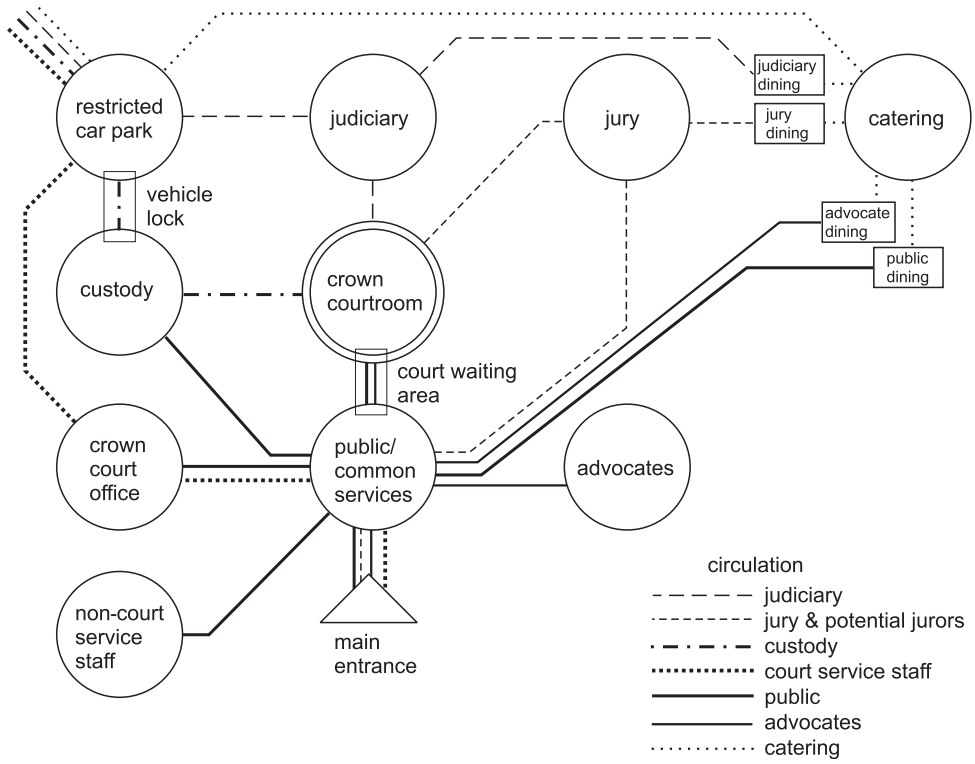
Egress from the assembly area, other than back past reception, is into jury-restricted circulation, which leads to court and jury retiring rooms. These should be adjacent or close to related court rooms, and all capable of supervision by one jury bailiff.

Once jurors have entered the jury assembly suite they remain there, in court or in the jury retiring room, until sent home at the end of the day, or on dismissal.

2.9 Defendants

The custody area (see Chapter 18, 3.5) is a self-contained compartment within the court building designated for the temporary use of prison governors in the discharge of their duties to the court to

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16.14 *Functional relationship diagram for a courthouse*

produce and retain prisoners in custody. It consists of the following principal parts, each separate from its neighbour and all non-custody uses:

- the custody core;
- the vehicle entrance;
- the visitors' entrance;
- the courtroom entrance;
- three independent secure connecting routes from custody core to vehicle dock; courtroom entrance; and visitors' entrance.

While courts are sitting, the custody area is staffed and administered by prison officers. A principal or senior officer is in charge, supported by number of officers according to the number of courts and the level of risk. Some officers have fixed duties, for instance dock officer and cells officer, but the remainder are on escort duties.

Custody areas are designed and constructed to contain defendants, and to produce them to the court. Containment requires the meticulous and consistent application of passive security measures. Confinement and attendance at court for defendants is stressful, and this is compounded by natural frustration and anxiety. The designer must:

- give careful attention to all aspects of the design from the overall plan and its approaches, down to fixtures, fittings, fixings, finishes, alarms and communications.
- devise a layout that will achieve maximum control, make the best use of staff resources and maintain an acceptable level of safety and security.
- use the building fabric and the facilities within it to provide a secure envelope.
- deny the public direct view or contact with defendants while they are inside the custody area, except during authorised visits.

2.10 Public

The public areas with their associated circulation form the central core or axis from which most non-judicial functions of the court building radiate.

Except for the judiciary and specified car park users, all users enter the building by the main entrance door where space and facilities for security checks are provided. The arrival concourse contains the information/enquiry point and the Cause List display, both of which should be clearly seen on entering.

Public circulation then leads to court waiting areas. These may be combined with associated circulation to form concourses off which are located the courtrooms and consultation/waiting rooms. Waiting areas should be visually interesting, preferably with external views. All furniture should be fixed.

Public circulation also gives access to private and semi-private accommodation occupied by Court Service (CS) staff, non-CS staff, the Probation Service, custody visits and to refreshment facilities. Access must also be available to the Crown Court Office counters. Direct access from the arrivals concourse to the jury assembly area is desirable.

2.11 Advocates

Advocates enter the court building by the main entrance, reaching their suite via the public circulation. This is the area reserved for solicitors and barristers preparing for court, combining lounge/study/retiring room for relaxation and quiet study in comfortable conditions, and for assembly, discussion, robing, etc. The lounge and robing room should if possible be contiguous otherwise direct access should be provided.

The suite has easy access to courtrooms via the public concourse where advocates meet clients, and to the advocates' dining room. The advocates' clerks' room is closely related and shares the same private 'advocates' circulation.

2.12 Crown Court office

The Crown Court office is occupied by executive and administrative staff engaged in the general administration of Crown Court business.

The general office counter must be conveniently located to allow easy access for the public and for the legal profession; payment of expenses to jurors and witnesses may be made here.

There should be separate circulation to other staff areas and for direct access to the judges restricted circulation by ushers. Within

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16.15 *North Somerset Courthouse*

the Crown Court offices, accommodation is provided for some more specialised groups:

- court clerks who are responsible for business in specific courtrooms and who spend part of their day in court;
- ushers who spend part of their time in court and also attending to judge and/or jury but will also do minor clerical work;
- listing staff who are responsible for the planning and programming of the court timetable (lists of cases).

2.13 Non-courts service users

Non-courts service users includes police, Crown Prosecution Service, Probation Service and shorthand writers, concerned with the running of the court.

The police area consists of two sections:

- *The Police Liaison Unit*. This is the suite of offices for police staff attached to the courts and providing antecedents, etc. Included is a room where police witnesses can assemble and change if necessary.
- *The Police Law and Order Unit*. This suite of offices is for police who maintain security or 'Law and Order' in the building.

The Crown Prosecution Service is responsible for the prosecution of defendants in court. It needs an office for law clerks to perform casework arising during the progress of the case, and to consult with members of the legal profession and witnesses.

The Probation Service, as attached to a Crown Court, will be active where persons have been made subjects of probation orders or inquiry reports at court, although they may do some paperwork on other cases. The probation suite is a separate individual unit and, where night reporting facilities are required, must be able to operate in isolation while full security to the remainder of the court building is maintained.

Shorthand writers are usually hired directly or via a service firm to take notes and transcribe court proceedings.

2.14 Catering

Catering within Crown Courts involves self-service facilities for advocates, jurors, public and court staff, together with waitress service from a sideboard or servery for the judiciary. The catering area should be sited on one floor with easy access for all court users, maximising usage and minimising operating costs. Multilevel catering areas should be avoided as less convenient and more expensive to operate.

2.15 Case study – North Somerset Courthouse, Worle, Weston-super-Mare

Architect: BDP

Introduction

A new courthouse was required as part of a rationalisation of magistrate courts in North Somerset. BDP's brief was to provide five courtrooms and associated facilities in a building that embodied the gravitas of the British legal system. Alongside the court building are offices for Avon and Somerset Area Probation Office. The project was procured as part of the Avon & Somerset Courts PFI Project for HM Courts Service.

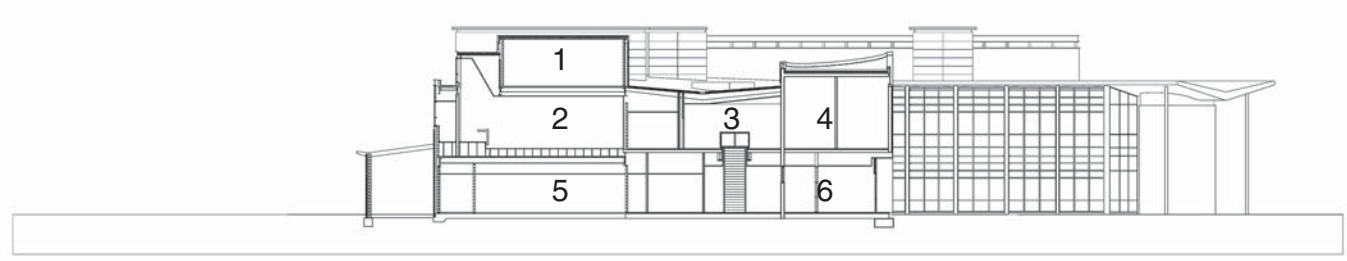
Site

The greenfield site was an edge-of-town location close to low-rise housing and a supermarket.

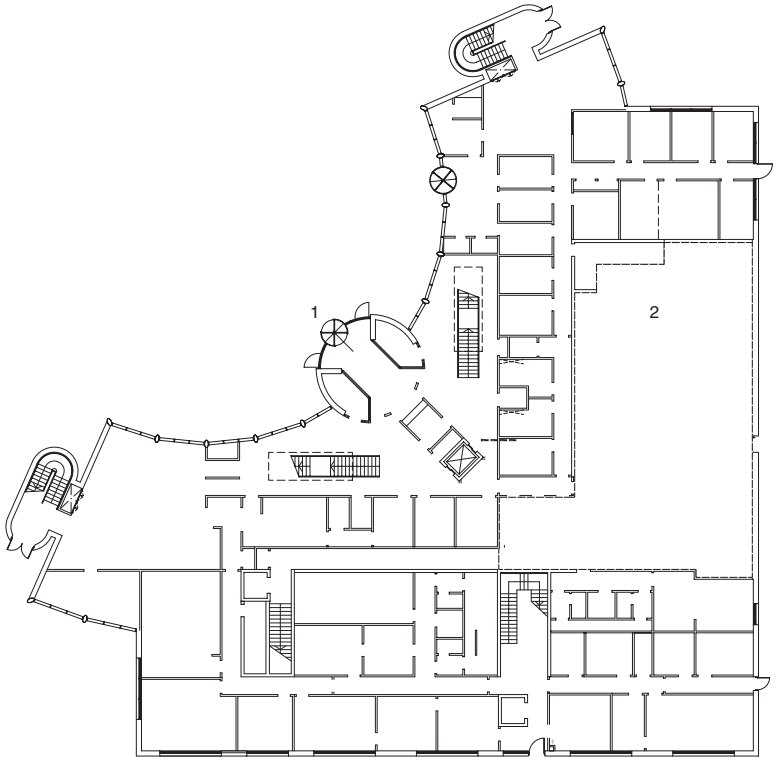
Design

The courthouse is organised as an L-shaped orthogonal block containing the courtrooms behind a softer, curved form containing the court halls. This sweeps around the front of the building to create a butterfly shape to give a strong visual identity (Figure 16.15).

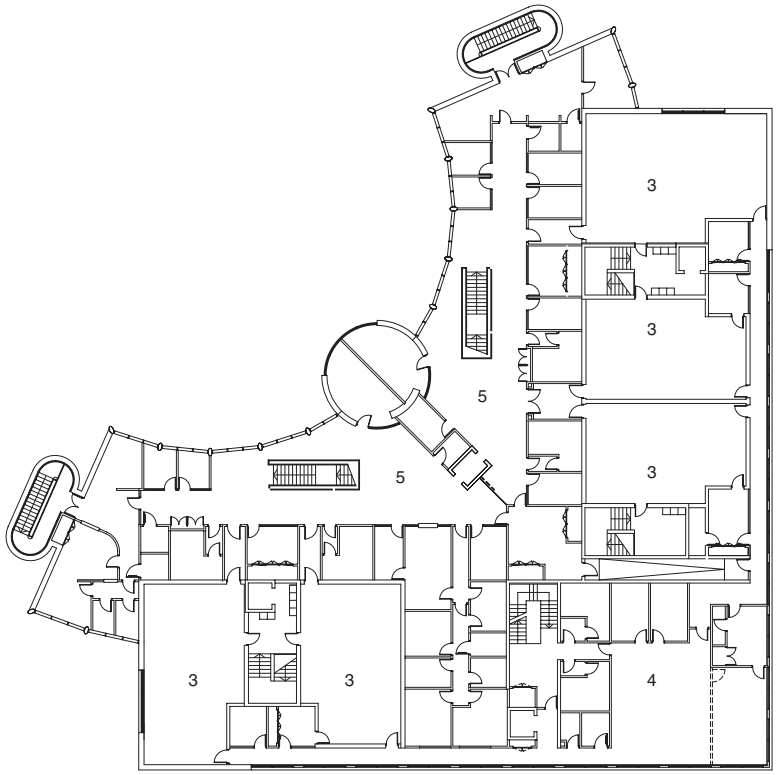
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16.16 *Section of North Somerset Courthouse. Key: 1, Plant; 2, Court; 3, Courthall; 4, Café; 5, Custody Suite; 6, Entrance*

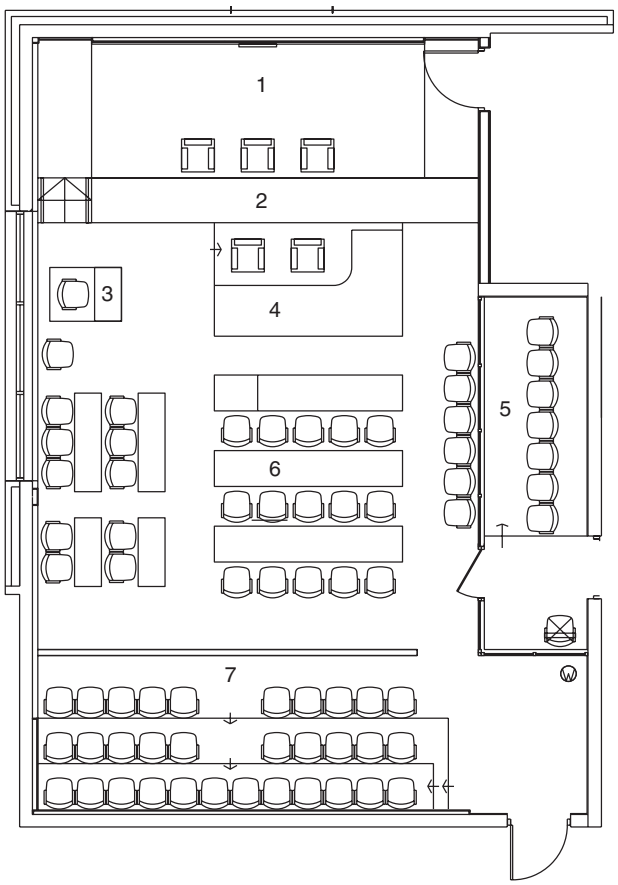


16.17a *Plans of North Somerset Courthouse. Key: 1, Entrance; 2, Custody suite; 3, Courtrooms; 4, Magistrates' quarters; 5, Courthalls*



16.17b

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16.18 *Typical courtroom A: Key: 1, Magistrates; 2, Magistrates' bench; 3, Witness box; 4, Clerk's Bench; 5, Dock; 6, Lawyers; 7, Public gallery*

The courtrooms are located on the first floor with the custody suite on the ground floor. The core challenge was achieving the separation of circulation needed for members of the public, the judiciary, and the defendants.

At Worle, the public circulation and waiting area is positioned to the front of the building served by two staircases. The custody suite contains male, female and juvenile cells and associated legal and officers' facilities, control room, van dock and assembly area. This suite is served by dedicated stair and lift cores to the courtrooms, one to every two courts.

A number of small interview rooms are positioned off the first floor public waiting area as well as toilets and a kitchen. Seating is robust and fixed and toilets have low-level lighting to deter intravenous drug use. A separate staircase and waiting area is provided to segregate accommodation for youth and children's court cases.

Five courts are positioned to the rear of the building on either side of the central magistrates' and courts staff area. They range from approximately 80–100 sq m each. Of these, Court 1 has full height security glazing to the dock while Courts 2, 3, 4 have half height, non-secure screens. Court 5, as a family court, has neither.

The magistrates' bench is raised 450 mm at the rear to provide security and authority, with separate access for judiciary. The room is timber-paneled to provide a warmer, less intimidating atmosphere. Two courts at the corners have side windows to let in natural light. In the others, clerestory windows are incorporated into a double-height space above the magistrate's bench.

3 REFERENCES

Ministry of Justice (2010) *Court standards and design guide*.

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17 Community centres

Jim Tanner

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CI/SfB 532

KEY POINTS:
- There is a need for a community facility in most areas
- Existing centres are often inadequate

Contents
1 Introduction
2 Planning and design
3 Elements of the plan
4 Bibliography

1 INTRODUCTION

1.1 Briefing

By their nature community buildings must serve a variety of functions among which are:

- meetings
- child care (crèche, day nursery, pre-school playgroup)
- children's activities (scouts, guides)
- concerts and plays
- dances
- parties and receptions
- exhibitions
- sporting and leisure activities
- adult education.

The client, such as a church or a local authority, may have its own specific requirements; but the financial viability of community facilities usually depends on letting them out to other organisations. At the briefing and planning stage it is wise to consider activities which could or should be accommodated.

1.2 Space requirement and arrangement

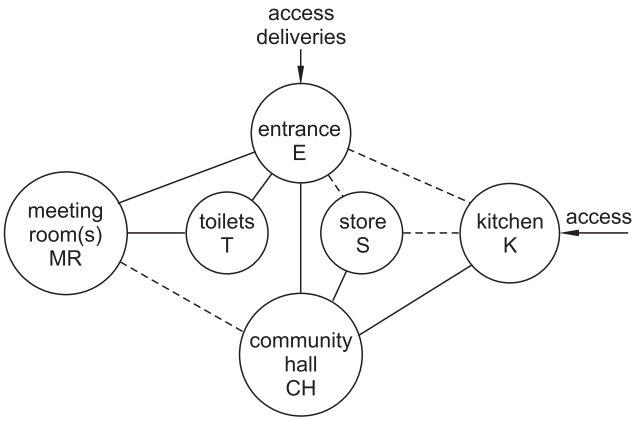
The following points should be borne in mind:

- Meetings can range from committee meetings of half a dozen people to public meetings with an audience of a couple of hundred. If this range is anticipated then accommodation should include one or two smaller meeting rooms as well as the main hall.
- Child care and children's activities invariably require storage for furniture and equipment. If Scouts use the facilities on a regular basis, for example, they are likely to need permanent storage for camping equipment, such as tents and poles, and cooking as well as games equipment.
- Some indoor sporting activities such as badminton, require generous space provision. See Chapter 38. These are likely to dictate the dimensions of the hall.

2 PLANNING AND DESIGN

2.1 Relationships

The principal plan elements and their relationship to each other illustrated in Figures 17.1, 17.2 and 17.3 are typical examples of the type.



17.1 *Elements of the plan of a community centre*

2.2 Space requirements

Table I gives recommended floor areas for various functions and activities.

2.3 Design

Community centres are multi-purpose buildings. Needs and priorities will often conflict; the skill of the designer in consultation with the client, statutory authorities and specialists must be exercised so that a balance is struck. All the following factors should be considered.

2.4 Structure and construction

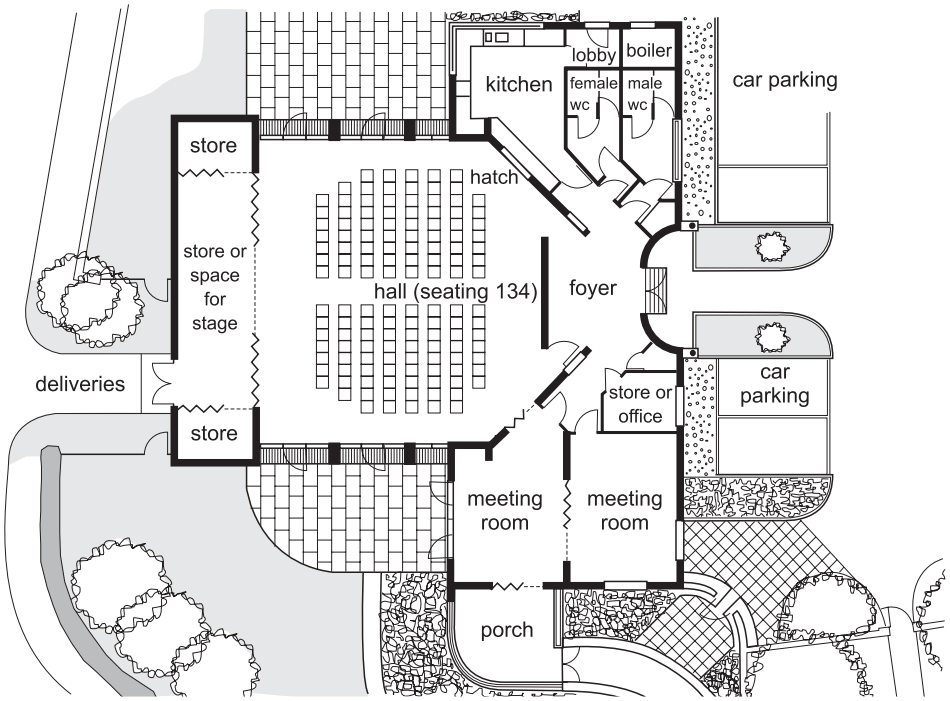
Most new-build self-contained community centres are domestic in scale. The most economic forms of construction are those used in domestic building: solid ground floors, masonry load-bearing walls and lightweight flat roofs or framed pitched roofs. Alternative forms of construction are only occasionally justified: for a difficult site or when only a short-life building is required. In the latter case, it is worth considering proprietary off-the-peg buildings. The appearance of such a building is not always aesthetically pleasing, but there are exceptions. Where the community facilities are to be accommodated in a larger building also used for other purposes, structure and construction will be determined by the wider considerations.

2.5 Materials and finishes

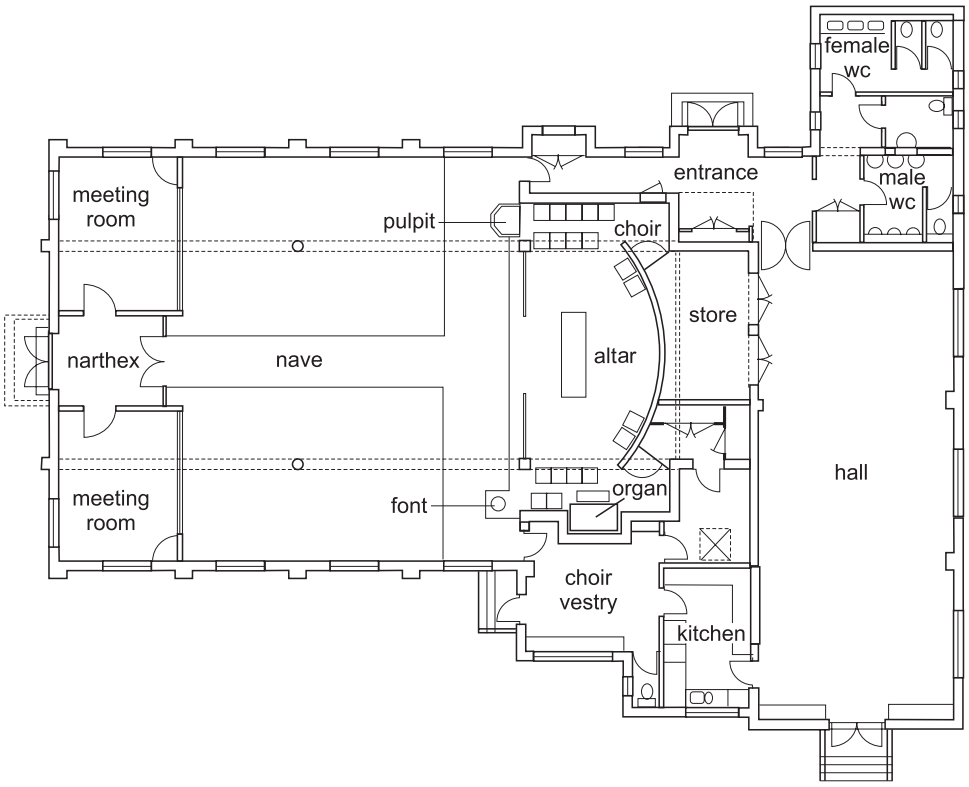
For self-contained community centres it is worthwhile designing for minimum maintenance, as upkeep funds are always limited. Choice of finishes should be influenced by the following considerations.

Nature of use may dictate forms of construction and finish which are non-standard. For example, when regular provision for dancing (particularly classical ballet) or indoor sport such as badminton or gymnastics is required, the floor should provide some resilience and specialist advice should be sought.

Durability: Some uses, particularly sporting activities, can be exceptionally hard on surface finishes. The main hall may



17.2 *Church centre for St James's Church, Finchampstead. Architects: Nye, Saunders & Partners*



17.3 *Community centre for St Francis Church, Westborough: an example of an addition to an existing building. Architects: Nye, Saunders & Partners*

need to be equipped with retractable bleacher seating as used in sports centres and educational buildings. Pulling out and stacking back such seating creates localised loading and wear. Resilient floors are particularly vulnerable. The manufacturers of the seating and of the floor finishes should be consulted at an early stage.

Safety: Users of a community centre range from small children to elderly and disabled people. Finishes should be chosen with a view to safety, all floors, ramps and steps should be non-slip. Projections, sharp corners and angles should be avoided.

Cleaning: Community facilities get heavy use and limited operating budgets. The building should be easy to clean.

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Table I Minimum floor areas for various activities

Function	Area per person (m^2)
Main hall:	
Closely seated audience	0.46 (based on movable seats, usually armless, 450 mm centre to centre; with fixed seating 500 mm centre to centre will increase to 0.6 m^2)
Dances	0.55 to 0.9
Dining	0.9 to 1.1
Crèche, day nursery or pre-school playgroup	0-2 years 3.75 2-3 3 3-5 2.5
Children 5–8 years (out of school and holiday schemes, open access projects)	2.5
Meeting rooms	2.25 up to 4 people 2 6 people 1.55 8–12 people 1.25 20 people

2.6 Means of escape

Care in planning and signposting the means of escape in case of fire is especially important because:

- the users, such as audiences at occasional concerts and meetings will not be familiar with the building layout.
- small children are likely to be present in a crèche or day care centre.
- elderly and disabled people may use the centre.
- facilities for leisure or educational purposes may be used by people with learning difficulties.

Early consultation with the local fire authority is essential.

2.7 Licensing

A licence will be required for certain uses and these invariably have conditions attached.

2.8 Noise

A community centre is more likely to generate than to suffer from high noise levels. They are commonly used at night and at the weekend, and are often situated within residential communities. They must therefore be designed to avoid nuisance. Where uses take place simultaneously, sound separation will be necessary between a noisy activity such as a dance and one requiring relative quiet such as a lecture.

The basic principles of acoustic design should be applied:

- orientation, e.g. location of entrances, exits and windows relative to adjoining buildings;
- layout;
- shape of rooms;
- double glazing, only viable in association with mechanical ventilation;
- sound-absorbent finishes, balanced with requirements of durability and cleanability;
- landscaping, including trees, to contain external noise.

Unless unavoidable, noise-producing spaces should not be located alongside quiet spaces. Absorbent surfaces may have to be concentrated at ceiling level or provided by means of drapes and wall hangings. Management can also play a significant part in controlling noise and this should be discussed with the client at an early stage.

2.9 Security

Community centres are more than usually vulnerable to break-ins and vandalism as they do not have resident caretakers or 24-hour surveillance, are not continuously occupied, are visited by a large number of people, contain expensive equipment and are isolated from other buildings. Requirements for security can conflict with those of means of escape, so it is important to consult with experts and local authorities.

2.10 Child care

Table II is a checklist of design considerations where creches, day nurseries or playgroups use the facility.

Table II Requirements for child care

Item	Comment
Child care: (crèche, day nursery, playgroup)	
Regulation	Child care for children in their early years (generally defined as under 8) usually comes within the Children Act 1989 (see Section 3) and local authorities are responsible for approving and registering facilities. Many of these authorities provide published requirements and guidance on standards
Staffing ratios	0–2 year olds 1:3 2–3 year olds 1:4 3–5 year olds 1:8 (minimum staff 2)
Outdoor play	A safe area with easy access from the building is a usual requirement
Catering	The Pre-school Playgroups Association recommends that children and adults should sit together during meals and consequently separate dining accommodation for staff is not required

2.11 Disabled people

There are statutory regulations relating to access for disabled people. These apply not only to those using wheelchairs but also include people with visual and auditory impairments and those using other types of walking aids. All these have difficulties with steps and changes of direction, and the design of entrances, circulation spaces and toilets should take this into account.

2.12 Legislation

This is constantly changing. Table III gives some current examples but is not exhaustive. The local authority will advise on the latest requirements. It is particularly important to ensure full conformity if the public are going to be charged for admission.

Table III Legislation

Legislation	Comment
Licensing Act 2003	Legislation requires that a licence is obtained for premises which are to be used, regularly or occasionally for the following purposes: • Public music or public music and dancing • Public performance of plays • Cinematograph exhibitions to which the public are admitted on payment • Cinematograph exhibitions for children who are members of a cinema club • Indoor sports entertainment Statutory requirements must be satisfied in terms of means of escape in case of fire and other safety considerations. Administered by the local authority
The Children Act 1989	Covers requirements for premises used by children in, for instance, day nurseries, playgroups, crèches, out-of-school clubs, holiday play schemes, adventure playgrounds and open-access projects. Administered by the local authority

3 ELEMENTS OF THE PLAN

3.1 Entrance

This should be large enough to accommodate an influx of people, such as prior to a meeting or concert. Signposting should be clear

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as many will be unfamiliar with the building. Unless there is a separate goods entrance, it should allow for bulk delivery of food and drink, display material and equipment. Consider the arrangement of the doors, the durability of surfaces and easy accesses to both the kitchen and the hall.

3.2 Hall
For sports purposes refer to Chapter 18. A rectangular shape is likely to be suitable for a wider range of uses than a square or any other shape. If black-out is required, pay special attention to size and location of windows; mechanical ventilation may be needed.

3.3 Meeting rooms
If more than one, make them different sizes. Alternatively, have one space that can be divided using sliding folding doors, although some of these do not provide adequate sound insulation. At least one meeting room should have direct access to the hall.

3.4 Toilets
Separate toilets will be needed for men, women and disabled people. There may also be a need for smaller toilets for little children. Unisex baby-changing facilities should be provided. If considerable sports usage is expected, showers will be necessary for each sex.

3.5 Kitchen
There should be little need for more than a domestic kitchen. If catered functions are expected, provide space for setting out and final preparations.

3.6 Storage
A separate store should be provided for each main use:

- kitchen
- sports
- seating and other furniture
- crèche/kindergarten
- Scouts.

The kitchen store should be directly accessible from the kitchen, the others from the hall. Storage space should be as generous as space and budget will allow.

3.7 Furniture
Refer to trade catalogues, and seek specialist advice.

4 BIBLIOGRAPHY
PPA Guidelines, published by the Pre-School Playgroups Association

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18 Emergency services

Michael Bowman

Including fire stations by Michael Bowman MA (Cantab) Dip. Arch. Dip. Cons (AA) RIBA

Michael Bowman is the senior design manager for the London Fire Brigade

KEY POINTS:

- *Many of these functions are tightly controlled by regulation*
- *The need for security against attacks from people both inside and outside while ensuring full access to those entitled makes design increasingly difficult*
- *Each Fire and Rescue Authority will have a detailed brief for the design of new fire stations including retained fire stations*
- *Fire stations are unique buildings and are 'Sui Generis' in planning terms. Their location will be determined by the attendance times that the fire and rescue service is required to meet within their 'fire ground'. Noise and lighting nuisance may need to be mitigated either by the design of the site or by management of these activities*

Contents

1 Fire stations
2 Ambulance stations
3 Police stations
4 References

1 FIRE STATIONS

1.1 Introduction

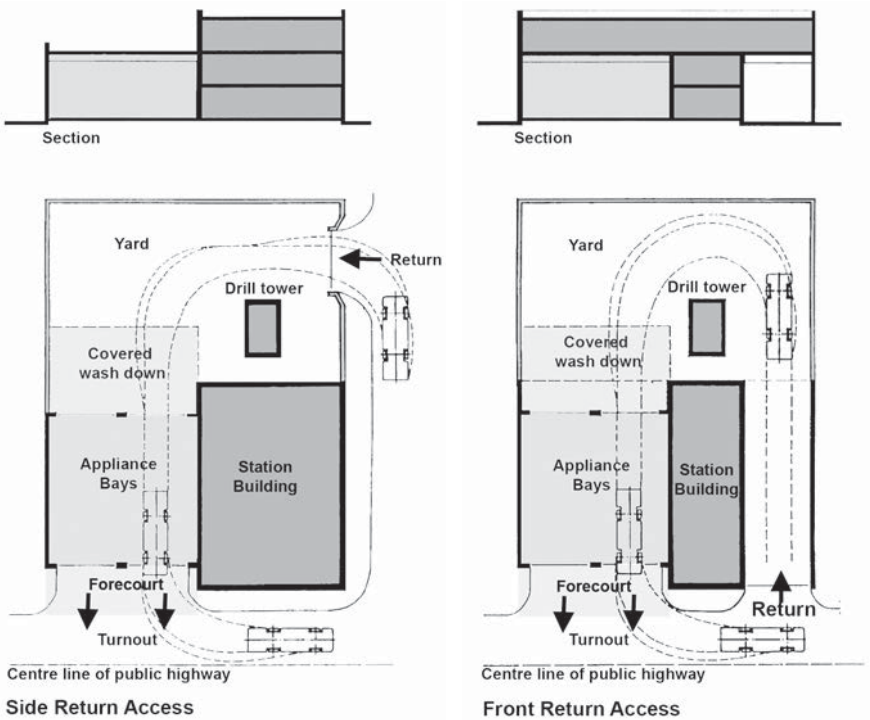
Fire stations must accommodate firefighting appliances and their crew to enable them to efficiently carry out their duties as set by the national, regional and metropolitan authorities that manage the fire and rescue services.

Each Fire and Rescue Authority will have a detailed brief for the design of new fire stations including retained fire stations. Full time firefighters typically work a 48 hour shift system over 8 days. Retained firefighters work a Retained Duty System and may have full time employment outside the fire service. The Retained Duty System requires the firefighters to live and work close to the fire station they serve. Full time firefighters operate a duty system of four watches of equal numbers identified by colours which work in sequence – RED, BLUE, GREEN and WHITE. Each 24 hours consists of a day duty and a night duty to cover the whole period. Each watch works 2 consecutive day duties, rests the next day and then works 2 consecutive night duties. The watch then has 4 days off duty. There are 'stand easy' intervals throughout the watch periods. The following is a guide for the design of a full time community fire station.

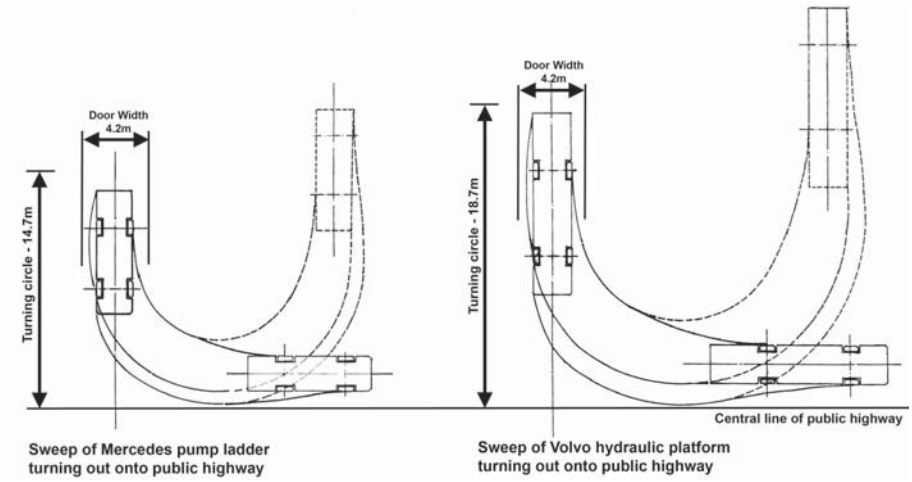
1.2 Planning

Fire stations are unique buildings and are 'Sui Generis' in planning terms. Their location will be determined by the attendance times that the fire and rescue service are required to meet within their 'fire ground'. The activities of training and appliances turning out to answer emergency calls can cause nuisance to neighbours by noise, vibration and external lighting. This nuisance may need to be mitigated either by the design of the site or by management of these activities.

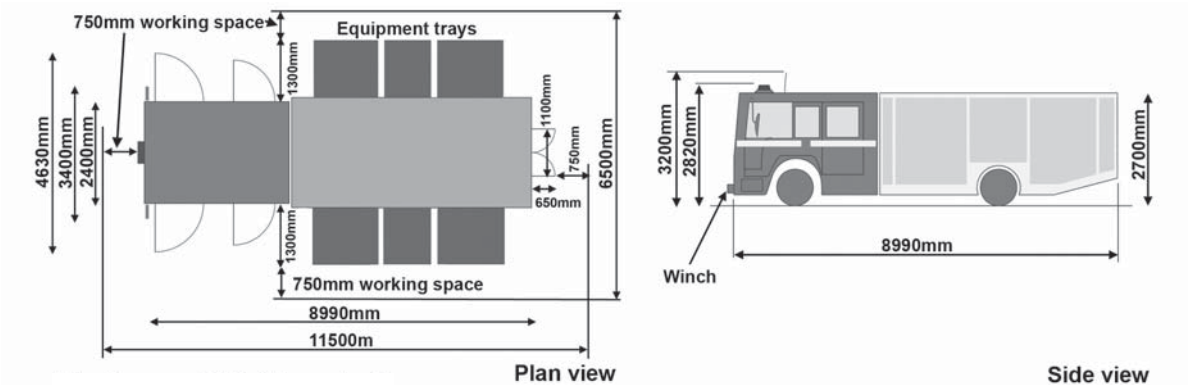
Radio and wireless communication is a vital part of the service's infrastructure and there must be good reception at the site. If the station is close to residential properties care must be taken that the position of the drill tower does not interfere with residents' TV reception.



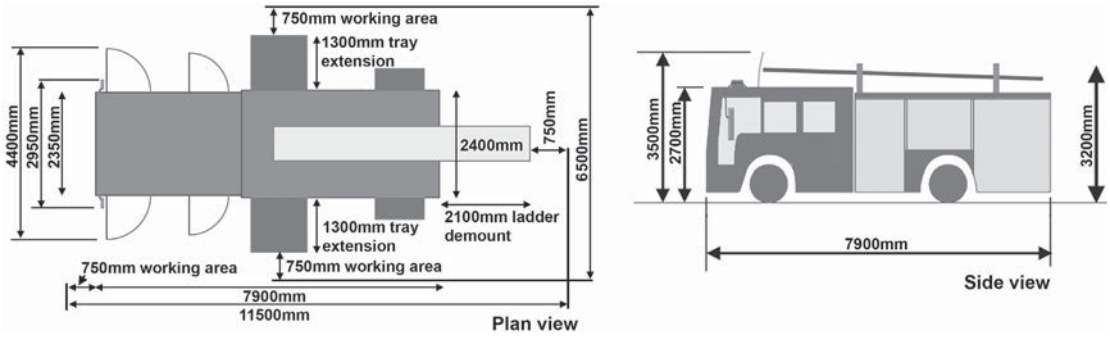
18.1 *Site layout for 2 bay fire station*



18.2 *Appliance turnout*



18.3 *Fire rescue unit (Mercedes)*



18.4 *Pump ladder (Mercedes)*

1.3 Egress/turnout

In an emergency the primary consideration is to get the fire fighting appliance onto the road quickly. A workable vehicular circulation pattern is therefore fundamental to the success of the station design, Figure 18.1. The turnout route of each appliance should not be interrupted by other traffic or returning appliances and maximum visibility is required. Appliances must be able to turn out without crossing the crown of the road. A forecourt will normally be necessary to achieve this.

A forecourt of 9 m depth will allow appliances to pull clear of the bay doors and turn out onto the highway without crossing the crown of the road. With this depth of forecourt a clear sightline to the edges of the site should be possible from a line 5 m back from the pavement. On restricted sites the forecourt may have to be reduced in depth or even omitted altogether. The vehicle turning circles illustrated in Figure 18.2 indicate the critical space requirements.

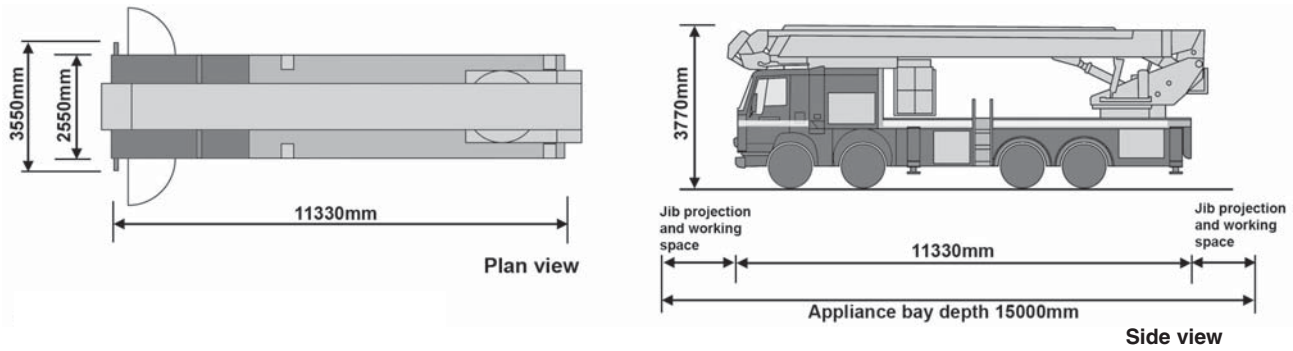
1.4 Ingress/return

The returning appliances should be able to navigate a clear sweeping approach from the return access to the covered wash down area, stopping on the centre line of its respective appliance bay.

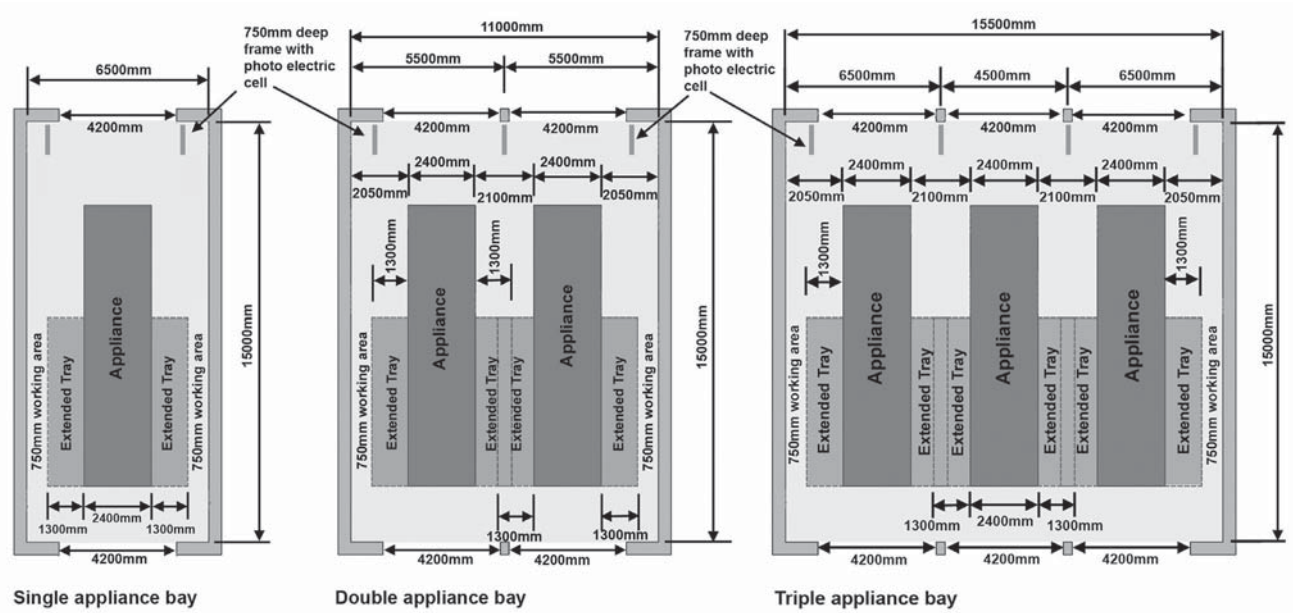
1.5 Appliances and their appliance bays

Fire and Rescue Services deploy various appliances which undertake specific tasks. Such appliances include urban search and rescue units, water tanker and bulk foam units, command support and incident response units. The fire rescue unit (Figure 18.3) is an important strategic appliance. The most common appliances are pumps, pump ladders (Figure 18.4) and aerial ladder platforms (Figure 18.5). As well as accommodating the turnout and return sweep of these vehicles the appliance bays must allow sufficient working space for their maintenance and re-equipment. Some appliances have equipment trays that extend up to 1300 mm from the sides of the vehicles.

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18.5 *Aerial ladder platform (Volvo)*



18.6 *Appliance bay dimensions*

A single appliance bay 15 m deep and 6.5 m wide will accommodate any appliance that the Fire and Rescue Services currently deploy. Multiple appliance bays need a width of 5.5 m as the appliances can share the working space between them. Doors should give a clear width of 4.2 m and a clear height of 4.2 m. Doors are operated on electric controls with photo electric cells and close automatically after the appliance has left (Figure 18.6).

1.6 The station building

Rooms and areas of a community fire station can be grouped into six main categories:

A: Operational – rooms and spaces that are essential to the operational readiness and performance of the service.
B: Training – spaces that contribute to the firefighters' skill and professionalism acquired through regular training.
C: Control and administration – accommodation for the station's communications, administrative duties, incident records and public advisory duties.
D: Amenity – accommodation for ancillary support activities.
E: Services – provision for engineering plant and controls.
F: Community engagement – rooms where emergency services can meet with residents and businesses and advise on fire risk, smoke detectors, extinguishers etc. Local communities can also use this facility for local community purposes.

Table I gives recommended areas for 2, 3 and 4 bay stations.

Security is vital as the station will be unmanned when all firefighters are attending calls. All external doors and all doors off appliance bays should be able to be locked. The community facilities must be separate from the rest of the station and be accessible without compromising the station's security. The station office should oversee the appliance bays, the reception area and the forecourt.

All finishes, fixtures and fittings must be robust, easy to clean and be easily maintained. Figure 18.7 shows the necessary relationships for the rooms detailed in Table I.

Other rooms may be accommodated within a fire station building depending on the Fire and Rescue Service's strategic planning. Such rooms include: fire safety office, borough manager's office, fire investigation offices etc.

Firefighters will descend to the appliance bays either via a staircase or the pole house. Pole drops are always of one storey only. For descents of more than one storey the pole house will discharge onto a landing and the firefighter will then enter a second pole drop for a further storey. A diagram of a typical pole house is shown in Figure 18.8.

1.7 Training facilities

Firefighters will acquire their skills at specialist training centres. The maintaining and improvement of existing skills is carried out at the fire station, space permitting. The yard should be able to accommodate a deep lift pit (underground water tank) and a road traffic collision (RTC) area of at least 30 m^2 for training purposes. The configuration of the training tower will depend on the local requirements. Standard training towers are typically 5–6 storeys high. A three storey training tower with training roof is a suitable alternative where planning constraints limit the height of buildings.

Training lectures are given in the lecture room and the gym provides for maintaining physical fitness. The training tower

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Table I Accommodation schedule for 2, 3 and 4 bay fire stations

Accommodation		Area (m²)			Notes
		2 Bay*	3 Bay**	4 Bay***	*max. watch strength 15 **max. watch strength 21 ***max. watch strength 23
A	**OPERATIONAL**				
A1	Appliance Bays	165	233	300	
A2	Covered Wash Down	99	140	180	9m deep across all bays
A3	Slide Poles	7	7	7	Extra drops needed if more than 2 storeys
A4	Fire Gear (Uniform) Store	32	40	42	4 peg spaces per watch strength
A5	Operational Equipment Store	12	12	12	Close to appliance bays
A6	Operational Equipment Cleaning	8	8	8	Close to appliance bays
A7	Drying Room	10	10	10	Close to appliance bays
A8	Breathing Apparatus (BA) Room	15	15	15	Close to appliance bays
A9	Forecourt	–	–	–	Provides easy turnout on to highway
A10	Personal Protective Equipment (PPE) Store	6	6	6	For gas tight suits etc.
A11	Dry Cleaning Store	2	2	2	For collection/delivery of uniforms
A12	Specialist Equipment Store	20	20	20	For kit bags with specialist gear
A13	Drying Room for personal items	4	4	4	May be combined with A7
A14	Toilet (Men)	2	2	2	For firefighters in fire gear
A15	Toilet (Women)	2	2	2	For firefighters in fire gear
B	**TRAINING**				
B1	Yard	–	–	–	For training and return access. Should include a road traffic collision (RTC) area.
B2	Deep Lift Pit	–	–	–	Below ground water tank for training
B3	Drill Tower and Training Roof	–	–	–	Height and configuration dictated by training regime
B4	Fuel Storage/Pump	–	–	–	Not required at all stations
C	**CONTROL AND ADMINISTRATION**				
C1	Station office	30	36	42	Oversees reception and appliance bays. Includes call out equipment
C2	Reception/waiting	12	12	12	
C3	Station Manager's Office	15	15	15	
C4	Watch Manager's Room	15	15	15	
D	**AMENITY**				
D1	Fire fighters' Lockers and Changing Area	56	80	88	Area split into rooms to accommodate up to 6 watch members
D2	Shower Rooms	5no. × 4m² = 20m²	7no. × 4m² = 28m²	8no. × 4m² = 32m²	Each room has shower, wc and whb
D3	Firefighters' Rest Area	84	120	138	Area split into rooms to accommodate up to 6 watch members
D4	Lecture/TV room	45	60	65	
D5	Lecture Storage	10	10	10	
D6	Quiet Study Room	10	10	10	
D7	Gymnasium	35	42	42	
D8	Kitchen	30	30	30	
D9	Dining Area	35	45	50	
D10	Cleaner's Store	2	2	2	
D11	Consumables Store	2	2	2	
D12	First Aid Room	15	15	15	
E	**SERVICES**				
E1	Electrical Intake and distribution	3	3	3	
E2	Standby Generator	12	12	12	
E3	Plant Room	15	15	15	May be larger depending on servicing strategy
E4	Bins/recycling	4	4	4	May be larger depending on recycling regime
E5	Gas meter	–	–	–	On ground floor
E6	Comms. room	15	15	15	
E7	Water meter	–	–	–	On ground floor
F	**COMMUNITY ENGAGEMENT**				
F1	Meeting Room	45	45	45	Must be accessible without public having to access operational areas of the fire station
F2	Kitchenette	6	6	6	
F3	Accessible wc	4	4	4	
F4	Toilet (men)	2	2	2	
F5	Toilet (women)	2	2	2	
F6	Meeting Room Store	5	5	5	
Total		**913**	**1136**	**1291**	
Total including 30% circulation (excepting bays and wash down)		**1108**	**1365**	**1534**	Main circulation routes should be a minimum of 1500mm wide

illustrated in Figure 18.9 allows a 135 (13.5 m) ladder to be pitched to the third floor opening. The upper storeys allow training scenarios for Aerial Ladder Platforms.

1.8 Staffing

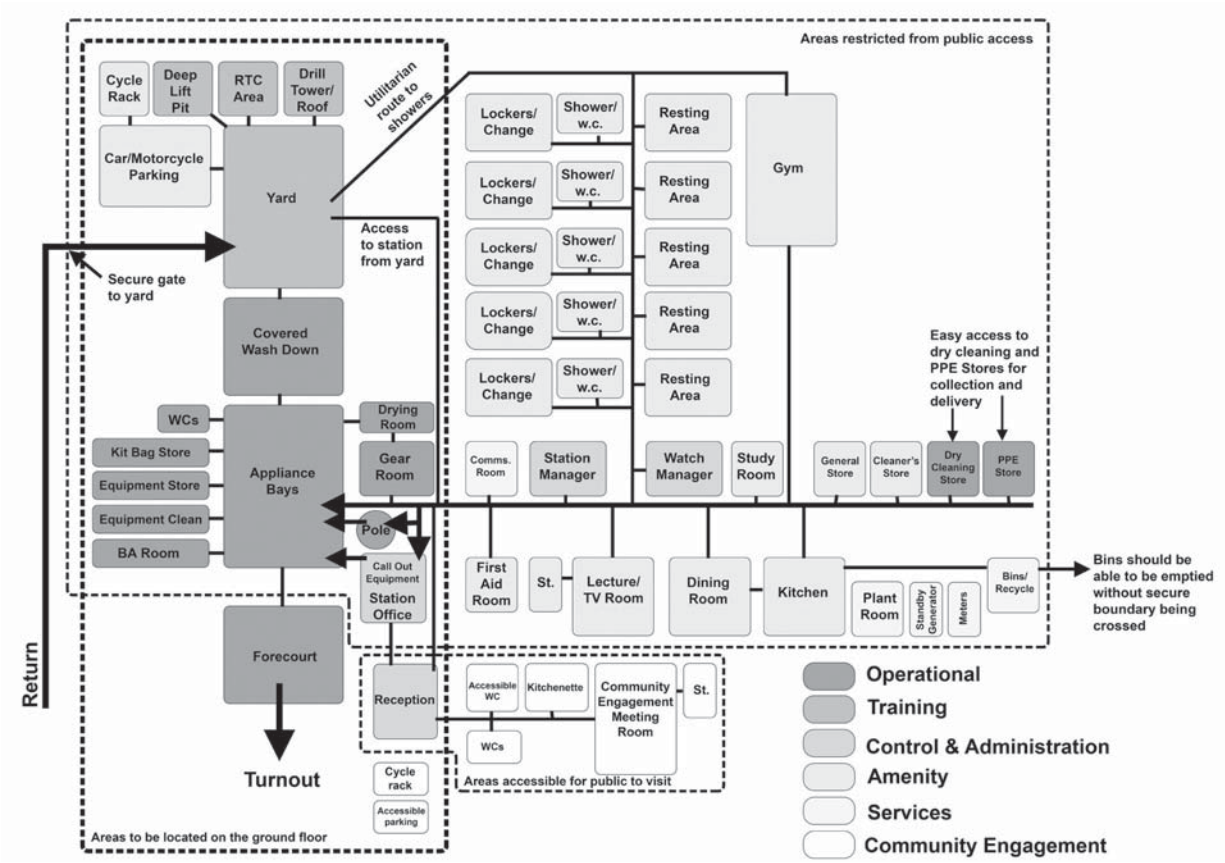
The fire station is staffed by the station manager and the watch members. Each watch comprises a watch manager and the crews for each of the appliances. As there are four watches there must be four sets of fire gear and four lockers per watch member. The watch strength will depend on the types of appliances deployed at the station. The watch strengths given in the accommodation schedule above assume the following deployment scenarios:

- bay station – pump ladder and fire rescue unit – watch strength 15.
- bay station – pump ladder, pump and fire rescue unit – watch strength 21.
- bay station – pump ladder, pump, fire rescue unit and an aerial ladder platform – watch strength 23.

1.9 Working practices

For the relationship of spaces in and around a fire station to succeed they must address the working practices of the firefighters. The

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18.7 *Relationship diagram (with thanks to Building Design Partnership)*

practices can be grouped into seven routines which can be divided into wet-dirty and clean-dry (Table II).

The mobilisation procedure demands that the firefighters move at speed through the building to the appliance bays. It is essential that circulation routes are generously sized to permit this movement to be undertaken safely. In particular junctions must be eased so that they do not become collision points. Main circulation paths should have a minimum width of 1500 mm and be well illuminated.

Routine a – mobilisation

The mobilisation of a crew originates from a central mobilising control centre. The system is fully computerised so that when a 999 call reveals an identifiable address the computer flags up the risk and recommends to the control officer the location of the resources that shall be mobilised to meet the predetermined attendance (PDA) requirements. If there are no overriding circumstances the mobilisation signal is sent.

A central control computer is aware of the operational status of every front line appliance. Each appliance is equipped with a mobile data pack which informs the control centre of its operational status indicated in Table III.

The command to mobilise is received by equipment located either in the station office or a watch room and simultaneously the mobilisation bells sound throughout the station. The firefighters proceed to the appliance bay as quickly as possible while the duty firefighter attends the call out equipment. He then operates the appropriate coloured dispatch lights which tell the assembled crew which appliances are to attend the incident. The crews not dispatched assume their normal duties about the station.

On return from an incident the appliance proceeds to the external covered wash down area where equipment in need of cleaning, repair or replacement is attended to. The appliance is then moved into its ready position in the appliance bay. The firefighters then attend to their own needs and should be able to gain access to their lockers and shower facilities without passing through clean/dry accommodation.

Routine b – training and drill

On station training is a combination of external physical activity and lectures and private study. Training is carried out in duty time and can be interrupted by a call out. The location of these spaces therefore must not hinder a crew's ability to achieve normal call out requirements. Training is carried out by every watch and entails the practice of those skills already acquired and also to check that operational equipment is in full working order.

Routine c – cleaning and maintenance of operational equipment

Station personnel are responsible for the working performance of the many items of operational equipment in their care. They must ensure that such items receive the required standard of cleaning and periodic maintenance. This work is carried out in the breathing apparatus room, operational equipment cleaning room and the operational equipment store (work bench area). All these rooms require easy access from the appliance bays.

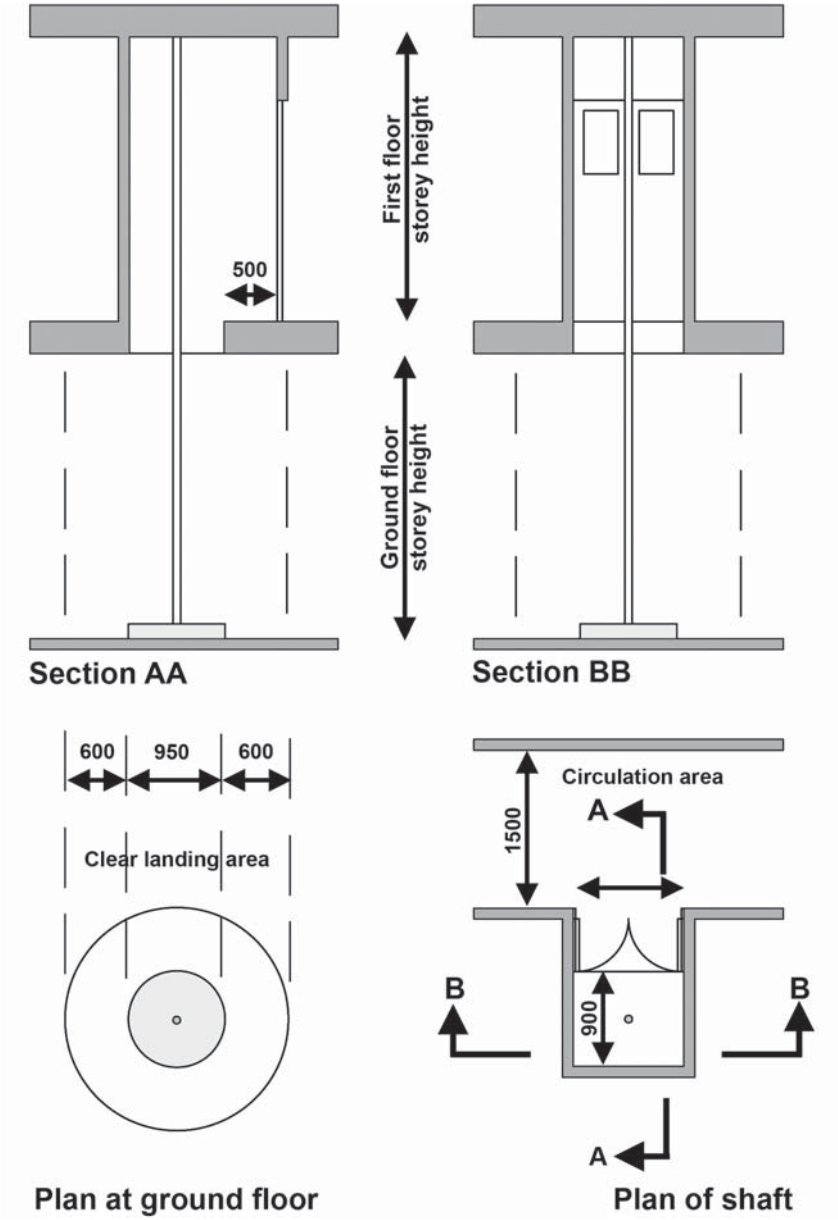
Routine d – administration

Administrative duties for a Fire and Rescue Service will include logging incident reports and managing operational policy notes, records, training and personnel issues. Each watch will have a staff member attached to administrative duties. These duties are carried out within the station office. Confidential matters will be dealt with by the station manager or watch manager within their private rooms.

Routine e – public interface

A community fire station needs to be designed to create an environment for firefighters to engage effectively with the local community and to provide facilities able to be used by the community and

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18.8 *Pole house layout*

which are accessible and welcoming. Members of the public visit fire stations for many different reasons. Visitors and events include:

- open days
- organised school visits
- local commerce
- local politicians
- local community groups
- charity organisers
- fire safety – education
- fire safety – legislative
- sports organisations.

Visiting members of the public are met at reception and escorted to their appointment. Visitors' names are entered into the station's day book. The public should not be allowed unaccompanied access around the station. Rooms to which the public will require access from the reception area are normally limited to the community engagement facilities.

Routine f – stand easy/recreation
The inclusion of a fully equipped gymnasium at fire stations provides the firefighter with the means to achieve and maintain the high level of fitness that their job demands. Television viewing is provided in the lecture room. Rest areas can be used during 'stand easy' periods.

Routine g – arrival for duty
On arrival for duty firefighters go to the locker rooms and change into their basic operational uniform. At the same time there will be firefighters preparing to come off duty using the locker rooms and showers. Firefighters will then proceed to the fire gear room to collect their individual fire gear; helmet, boots, uniform etc., and proceed to the appliance bay. Their fire gear is placed at the side of or on to the appliance. At watch changeover there is a roll call in the appliance bays where firefighters receive briefing and deployment instructions from the watch manager. Following the roll call all equipment is examined, checked and restored. Firefighters then go to the dining area for a short break before taking up their normal working routines or those allocated at roll call.

1.10 Special training facilities

Specialist training facilities may be attached to the fire station or have their own site. A typical local training centre for Breathing

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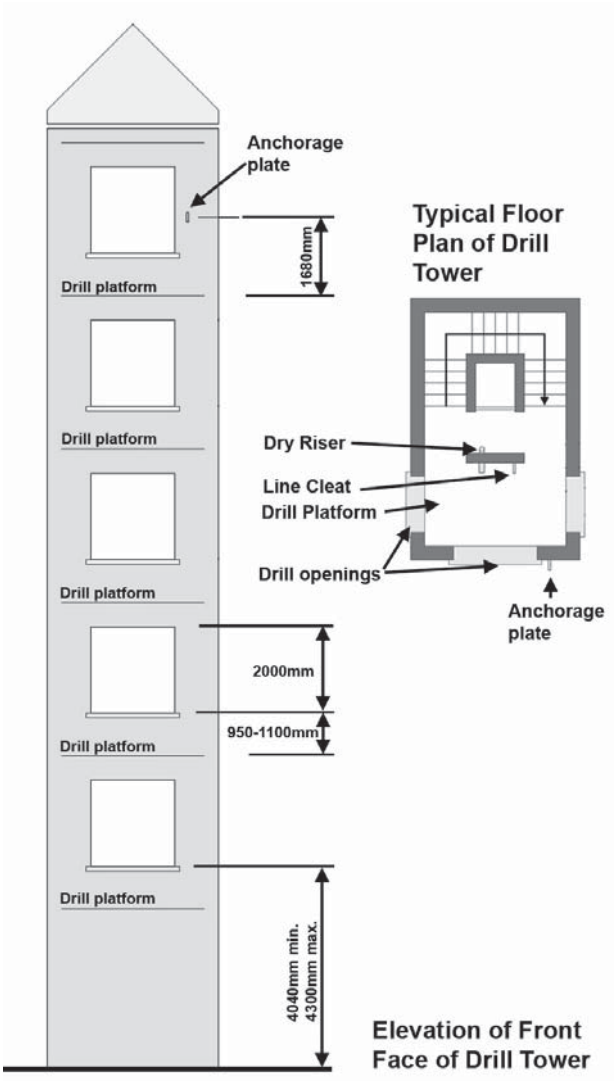
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Table II Working practices and spatial types

Routine	Routine type
a Mobilisation – call out	Wet–dirty
b Training and drill	Wet–dirty
c Cleaning and maintenance	Wet–dirty
d Administration	Clean–dry
e Public Interface	Clean–dry
f 'Stand easy'	Clean–dry
g Arrival for duty	Clean–dry

Table III Status hierarchy

STATUS 1	Readiness
STATUS 2	Proceeding to incident
STATUS 3	Attending at incident
STATUS 4	Mobile from incident
STATUS 1	Return to station/readiness
STATUS 0	Crew/appliance is incapable of further operational duty (injury etc.)



18.9 *Training tower*

Apparatus and real fire training may comprise the accommodation shown in Table IV.

If the local training centre shares its site with an operational fire station some of the above accommodation may be omitted and the station's facilities be shared with the local training centre.

Table IV Accommodation schedule for local training venue

Accommodation	Area (m^2)	Notes
Reception area	12	
Trainers' office	25	3 workstations
Lecture room	50	
Lecture room store	10	
Dining area	45	
Kitchenette	8	
Fire gear store	20	30 peg spaces for operational clothing
Drying room	15	30 rack spaces for operational clothing
Locker area (men)	20	20 locker spaces
Locker area (women)	20	20 locker spaces
Trainers' lockers (men)	10	10 locker spaces
Trainers' lockers (women)	10	10 locker spaces
Shower rooms (unisex)	$10 \times 4m^2 = 28$	Each room has shower, wc and whb
Breathing apparatus (BA) Chamber	200	Provides multiple scenarios for BA training. Rooms can be filled with smoke and be heated to high temperature. Specialist facilities will provide Real Fire Training scenarios.
BA control room	10	Controls smoke, temperature and any 'real fire' in the chamber. Also monitors trainers and trainees within the chamber.
BA maintenance room	55	Classroom for training in the maintenance of BA equipment.
BA storage room	20	For storage of BA cylinders
External areas	–	Area must accommodate drills for 2 to 4 pumping appliances, drill tower/training roof, deep lift pit and road traffic collision area.
Total	558	
Total including 30% circulation	725	

1.11 Further Information

The Department for Communities and Local Government (CLG) publish advice in their *Design Guide Achieving Design Quality in Fire and Rescue Service Buildings*. This is available for downloading from the CLG website (www.gov.uk/government/organisations/department-for-communities-and-local-government).

2 AMBULANCE STATIONS

2.1 Introduction

Ambulance stations are either control stations or their satellites. The control stations contain larger store areas and a divisional office, and may have dining, recreation and activity areas. On-site sleeping accommodation is no longer required. Satellite stations have from two to six ambulances and deal only with accident and emergency calls. They do not require dining or recreation facilities, as off-duty time is spent off the premises, but a rest room will be needed for waiting and relaxing between calls.

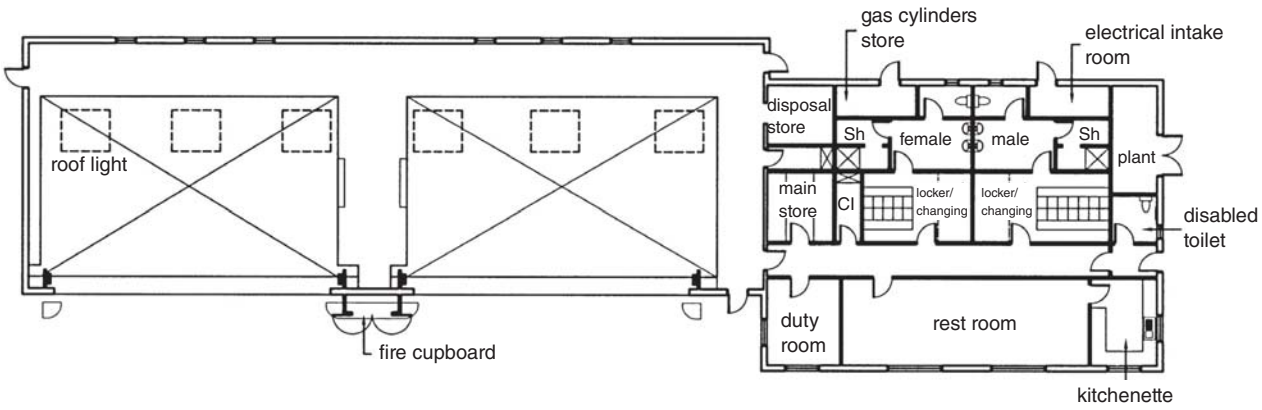
Because drugs may be stored on the premises all doors need to be lock controlled.

Like the police, more and more control equipment such as faxes, trackers and radios are in the ambulance, permitting greater use of these facilities with no need to return to base. However, to provide adequate hospital cover, ambulances are stationed there for half-hour periods.

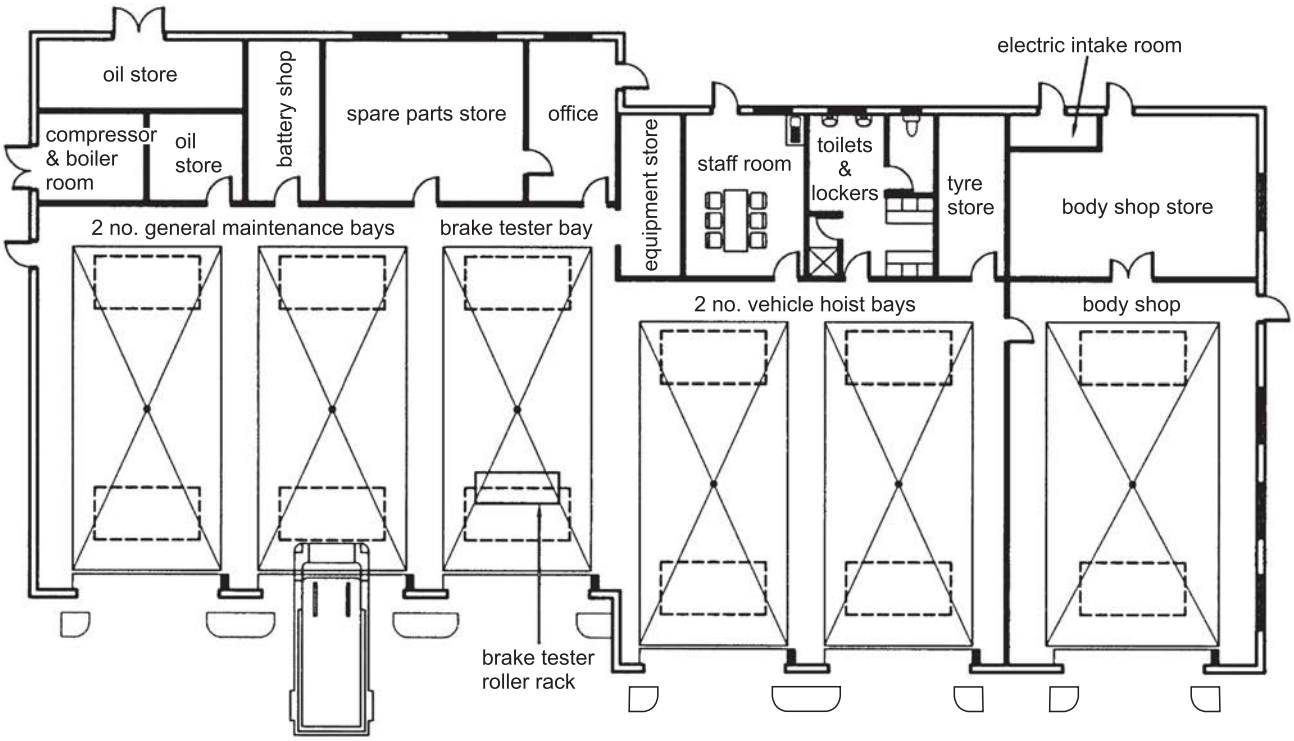
2.2 Function

Apart from accidents and emergencies, the larger stations also cover:

- patient transfer
- hospital to hospital
- home to hospital for consultancy
- taxi service.



18.10 *Layout of an ambulance station with six vehicles*



18.11 *Layout of a workshop for servicing ambulance vehicles*

2.3 Organisation

Regions are split into about four divisions with a central control. Each division normally consists of about six larger stations and twelve satellites, varying according to population density. All accident and emergency calls are received at central control.

2.4 Provision for vehicles

In small stations with less than seven ambulances, vehicles will be reversed onto their parking bays. The station will have an easy-to-open individual exit door to each bay (Figure 18.10). Larger stations use echelon parking with in-and-out access. There must be sufficient space behind the parked ambulance to permit easy removal of equipment.

Large stations require a fuel loading bay, but not the smaller stations. The current trend is towards using petrol rather than diesel, for smoother running and fewer fumes. A vehicle wash-down is required for each station.

2.5 Vehicle workshops

Vehicle maintenance is carried out in separate workshop buildings (Figure 18.11), covering at least six stations. It does not need to be on the same site as an ambulance station.

A workshop normally caters for up to six vehicles at a time, so front access only is required. Larger workshops are designed for echelon parking with a through-access system. All workshops will be capable of carrying out day-to-day maintenance and repairs, including the equivalent of MOT testing, standard servicing and body repairs. They are not expected to replace engines or crankshafts or do heavy repairs. Finishes must be robust and durable and floor surfaces non-slip.

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2.6 Duty rooms

Duty rooms should be close to the garage, have adequate wall space for maps and natural lighting and ventilation. Staff in the rest room must be able to see what is happening in the duty room, so it should be adjacent with a glazed screen between.

2.7 Lockers and changing facilities

Lockers and changing facilities are linked to showers and toilets. In the smaller stations unisex toilets and showers are acceptable. Elsewhere they should be designed to facilitate adjustment when the male/female ratio changes.

2.8 Toilets for disabled users

A toilet for wheelchair users and other disabled people is needed although the ambulance operatives themselves need to be fully able-bodied.

2.9 Stores

The main store needs to be a secure facility close to the garage. It will accommodate the following in a single area or in separate stores:

- linen such as blankets, sheets, pillowcases and towels;
- medical supplies such as first-aid dressings, bandages and splints;
- paramedic equipment such as defibrilators and resuscitators;
- spare items to replace equipment normally stored in the ambulance;
- trolleys, stretchers, etc. belonging to de-kitted vehicles;
- expendable items and documents, log books and files.

A separate store within the main store is required for drugs. This is separately lockable and alarmed to the duty room.

Blankets should be kept well ventilated and heated.

Dirty blankets, linen and contaminated clothes are temporarily kept in containers in a disposal store until they can be sent to a laundry. This disposal store should be near the ambulance parking, but away from clean stores and other clean areas. The same place can also be used for storing general refuse awaiting removal. Medical materials including used needles must be in separate containers for special disposal.

The gas store holds entonox and oxygen in small cylinders for use by paramedics. This store must be warm and well ventilated with easy access to the ambulances.

2.10 Laundries

Some regions still require a small blanket laundry in the larger stations. However, due to health and safety legislation, with stringent regulations relating to temperature controls, cleanliness and hygiene, there is a strong move towards using contract cleaning companies instead.

3 POLICE STATIONS

3.1 Introduction

The police aim to foster public goodwill; their buildings should be as pleasing and friendly to the visitor as possible compatible with essential security requirements.

The Home Office has produced most detailed and comprehensive guides covering legislative requirements, cost and design. New stations should be based on the Home Office *Police Buildings Design Guide* (2010), modified to suit the individual local requirements.

3.2 Organisation

Over the last few years there has been radical change in organisation. Some forces still maintain divisions and subdivisions; others have gone over to regions and areas. Some police forces collaborate with others to provide support services for their joint use. Regional crime squads come under this heading.

Because so much of the work has become extremely technical and specialised, many of the specialities are accommodated away from the custody and public departments.

The different levels of the organisation require different building types:

1 Headquarters buildings with control extending over a force area;
2 Divisional HQs;
3 sub-Divisional HQs, which may be located separately or may be combined.

Headquarters buildings and police stations are all based on the same principles, and only vary according to need. A facility like a custody suite or communications centre is located in the most suitable place regardless of the rank of the building.

3.3 Siting

Stations should be near public transport, readily available both to the local inhabitants and easily found by strangers. They no longer need to be near magistrates' courts. However, when they are, they should be totally separate with no shared facilities.

In busy shopping centres and high streets, police posts with direct communications to their headquarters are proving popular with both police and public, who provide information there that might never be otherwise obtained. The authorities are even considering having police posts in supermarkets.

3.4 Design of the station

The zoning diagram (Figure 18.12) is a guide to circulation.

The public area must be designed with an awareness of the dangers posed by explosives and people with weapons. It should still try to maintain a pleasing and welcoming atmosphere. It must be easily accessible from the police area. Access and toilet accommodation for disabled people is essential.

The reception counter should be located to permit officer-on-duty supervision of the building entrance. A security screen between counter area and waiting is desirable in some circumstances, so that only a limited number can enter at a time. This provides both privacy and security. Where there is no screen a privacy booth in or on the counter is desirable.

Waiting areas are provided with seating and notice boards for posters on road safety and crime prevention, etc.

The public interview area is entered off the waiting area. Interview rooms should be large enough to take several people at a time and are fitted with taping equipment.

The victim examination suite should be adjacent to the public entrance and is for interviewing and medical examination of assault, child molestation or rape victims. It must be pleasantly designed in order to reduce stress (Figure 18.13).

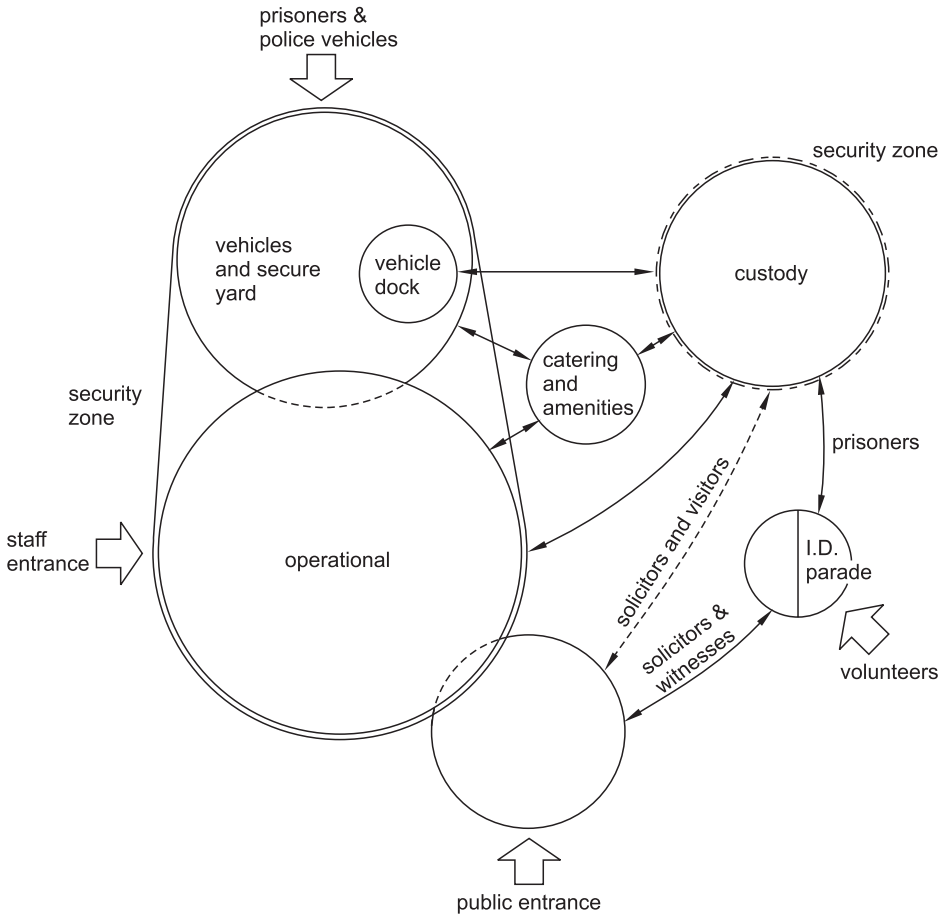
Found property

This is an area accessible only to the police for storing unclaimed stolen property and items handed in by the public or found by the police. No live animals are kept there, although some stations do have special facilities for animals.

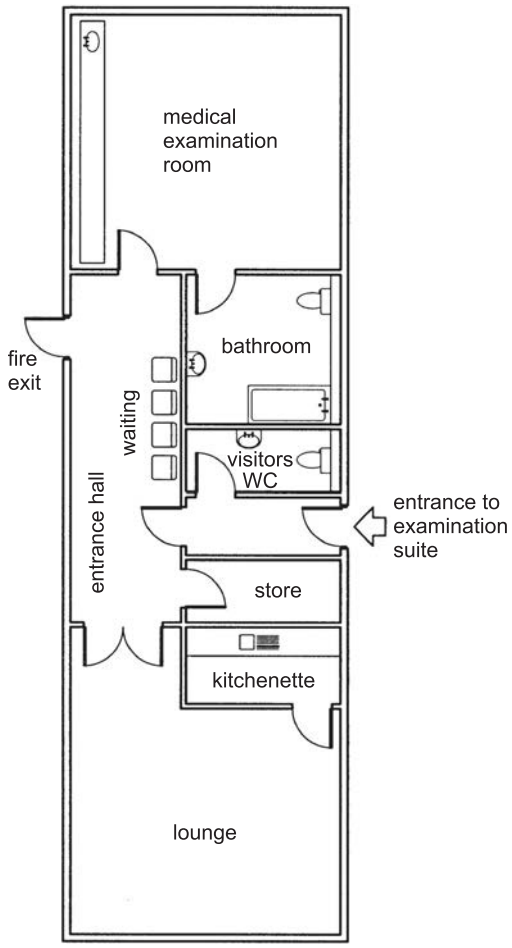
People seeking lost property enquire for it at the reception counter, so this should have easy access to the found property store. Its size will depend on local requirements. Some forces use warehouses due to the very large quantities that are collected. Where no large store or warehouse is available, bulky items such as bicycles are usually stored in out-buildings.

Assembly room, lockers, changing and drying rooms

They should be located close to the police entrance. Showers and toilets should be adjacent to the lockers and to the drying areas which should be operational in summer as well as winter.



18.12 *Relationship and zoning diagram for a large police station*



18.13 *Plan of a victim examination suite*

Report writing room
These should be adjacent to the assembly room. Booths and acoustic treatment are advisable.

Communications and control are central to the police function. Workload is extremely heavy and the working environment should be designed to mitigate stress (Figure 18.14). The control room deals with force or area-wide facilities including VHP radio, and has direct access to police resource information and criminal records. Communications rooms are principally used for message transfer and receipt of information.

The location and design of the central control room should be such as to frustrate any deliberate attempt to dislocate its vitally important functions by physical or electronic attack. Its vehicular access must ensure an uninterrupted road in an emergency; but no parking should be allowed within 15 m of its perimeter.

Major incident room
A force will on occasions need to work on serious crimes requiring extensive investigation, civil emergencies or major incidents. Accommodation with easy communication connections will be required for temporary use by CID, traffic or uniformed branches; when not so required, it will be designated for an alternative function such as a gymnasium.

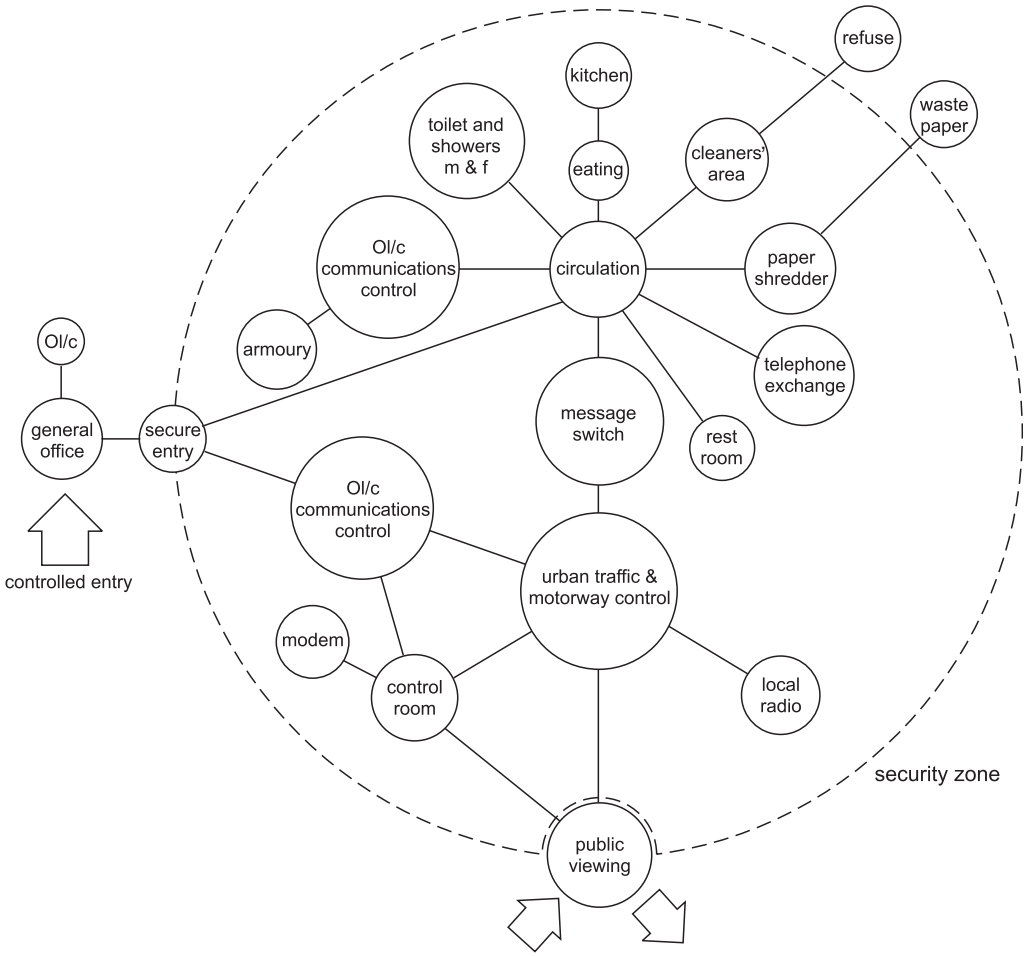
Criminal justice office
This is for documentation of cases to be brought before the courts.

Criminal Investigation Department (CID)
In some cases CID would have their own unit separate from the police station.

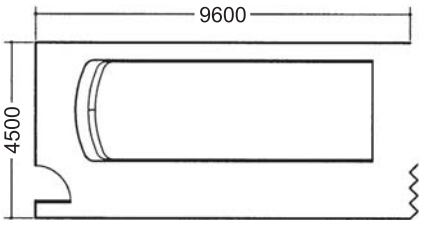
Operational group provides office accommodation for:

- beat patrols
- uniformed section
- operational control
- general administration.

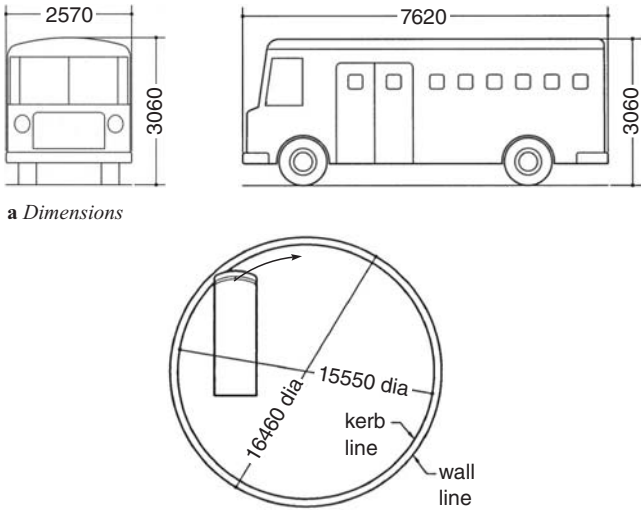
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18.14 *Relationship diagram of a Control Room suite*



18.15 *Plan of a prisoner transport vehicle dock*



a *Dimensions*

b *Turning circles*

18.16 *A vehicle for transporting prisoners*

Administration covers general administration as opposed to operational dependent administration and activities.

Traffic includes accommodation for motor patrols, traffic wardens, garages and workshops.

Garages and workshops may be on the same site as the station, or be a separate unit with attached accommodation for motor patrols depending on the size of the area and the number of vehicles. It is preferable not to have this unit in a busy city centre where it would add to congestion, and also hinder police cars quickly reaching the scene of an incident. If the police area includes motorways the unit should be sited near an access point, or even within a motorway service area.

The police car is becoming more 'high tech', with built-in computers in addition to two-way radios. It is becoming an office in its own right, so that there is less need for the occupants to report in person to a police station.

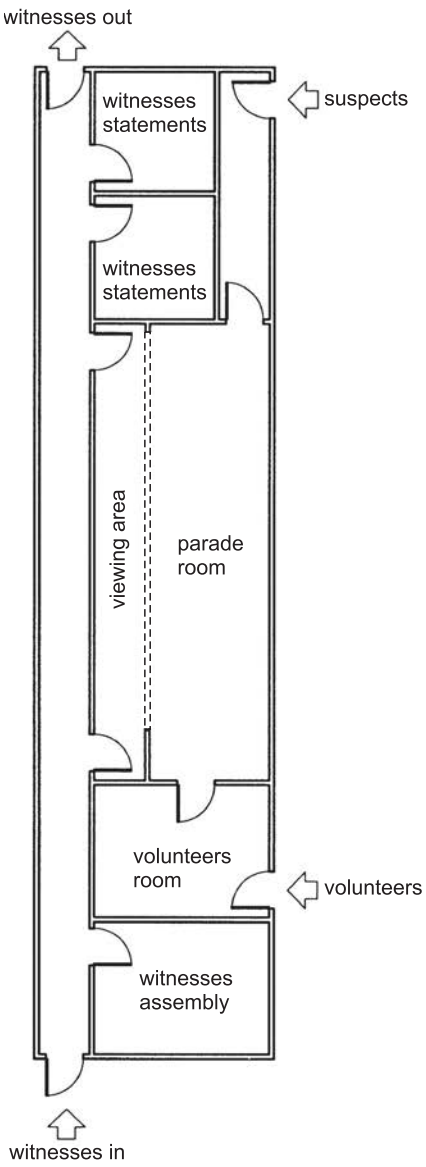
Prisoners' vehicle dock

This must be provided away from the main police vehicle yard, totally secure and adjacent to the prisoners' entrance to the building (Figure 18.15). Figure 18.16 gives data for the prisoner transport vehicle.

Identification parade facility

This has to be carefully sited outside the custody area but linked to it by a secure access route. Witnesses should be rigidly segregated from each other, and from all members of the parade before, during and after the parade; there must be no possibility of physical contact at any time, or visual contact except during the parade itself (Figure 18.17). Toilet facilities should be available for witnesses and volunteers.

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18.17 *Plan of an identity parade suite*

Messing and recreation
Catering is usually provided by self-help appliances such as frozen packaged food with grills or microwave ovens and hot/cold drink dispensers. In large stations there may be a canteen, but 24-hour operation is easier to control through packaged meals.

Toilets
Lavatory accommodation is related to size of station and disposition of rooms. Separate provision is made for:

- male sergeants, constables and civilian staff;
- female sergeants, constables and civilian staff;
- senior officers;
- chief constables and assistant chief constables have en-suite facilities;
- visitors, usually located at the public entrance;
- disabled people, also close to the public entrance;
- cell accommodation.

Blast proofing is now mandatory for all police stations; no car parking should be positioned within 15 m of the buildings, 10 m for operational vehicles.

Mechanical ventilation and cooling is provided for information and communications accommodation without natural ventilation.

Emergency electrical supply is essential throughout, not only for power failure but also in the event of fire. In large stations it will be necessary to ensure continuity of supply to the custody suite, radios, computers, teleprinters and communication service equipment, and must have 'direct on-line automatic start'.

An uninterrupted power supply (UPS) will be required for computer areas.

3.5 Custody suite

This includes detention rooms, charge desk(s) and ancillary accommodation (Figures 18.18 and 18.19). The police have to be alert to the possibility of someone in custody attempting suicide. Care needs to be taken to avoid this eventuality particularly in the design of the cells (see Section 3.6).

The custody area should be securely separated from other parts of the building. It should be located on a single level to avoid moving prisoners up and down stairs which should be avoided at all costs. Where minor changes in level are unavoidable internally or externally, ramps should be used.

Corridors and cells for female prisoners should be segregated from those for male prisoners. Each should have separate access to the exercise yard. Detention rooms for juveniles should also be separate from adult areas.

Catering
Prisoners and police within the custody area need to be fed. However, a kitchenette within the custody area is undesirable as it would divert the custody officer from essential tasks and also be a fire risk. The self-catering facility in the amenity area is also unacceptable as it would take officers away from the custody area. There is little alternative, therefore, to a staffed kitchen immediately outside the custody area preparing food in compliance with food hygiene regulations and providing the meals close to the users. If there is a canteen which is fully staffed for 24 hours, this may be used.

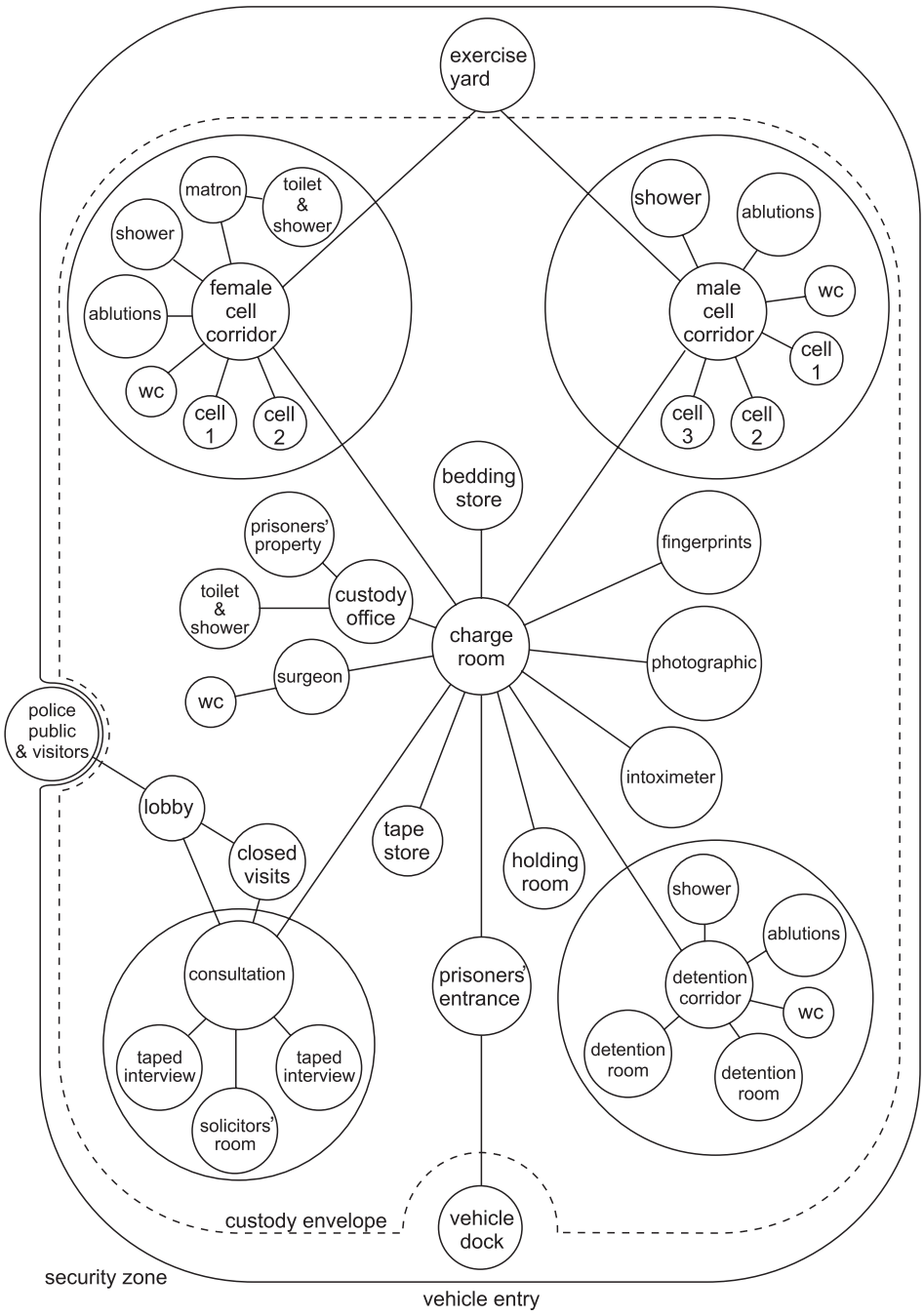
Detention suite
This is a facility where the WC is outside the cell (Figure 18.20), where additional washing facilities can be securely provided.

WCs
The compartment should have a stable-type hinged door, not a sliding one, with an observation aperture. The cistern should be outside the compartment with secured access and a protected flushing pipe. The flushing device should be outside the reach of a prisoner attempting suicide by drowning, and should not be a chain or project from the wall. There should be no projecting toilet roll holder, exposed overflow pipe, bracket, service pipe or stopcock. Fittings should not be able to be broken or extracted to make tools or weapons.

Washing facilities
Basins should not be inside cells. They should be supported on metal stands, not cantilever brackets, and provided with captive plugs without chains. Towel holders are not used as the towels could be used to facilitate suicide, and the holder would provide points to which a ligature could be attached. Facilities for female prisoners must be properly screened. For use inside cells, prisoners are provided with disinfectant/cologne-impregnated washpads as on aircraft.

Cell corridor
The entrance should be fitted with an iron gate. The corridor should have alarm pushes for the custody officer's use if attacked. There should be no exposed pipes, valves, electric cables or conduit, and any thermometer should be outside the reach of a passing prisoner.

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18.18 *Relationship and zoning diagram for a custody suite*

Exercise yard

The walls should be high enough to prevent a prisoner escaping, at least 3.6 m. There should be no ledges or other features which enable a prisoner to climb. However, where for any reason the height and detailing of the walls are deemed insufficient to prevent escape, a top cover may be used. There should be no doors or windows opening into the yard which might enable a prisoner to reach the top cover, nor any unlockable inspection chamber covers or gully gratings which could be lifted. Rainwater and soil pipes should be flaunched up in cement mortar to obviate handholds.

3.6 Cell design

The Police Design Guides are explicit in their requirements reflected in a typical design, as shown in Figure 18.21.

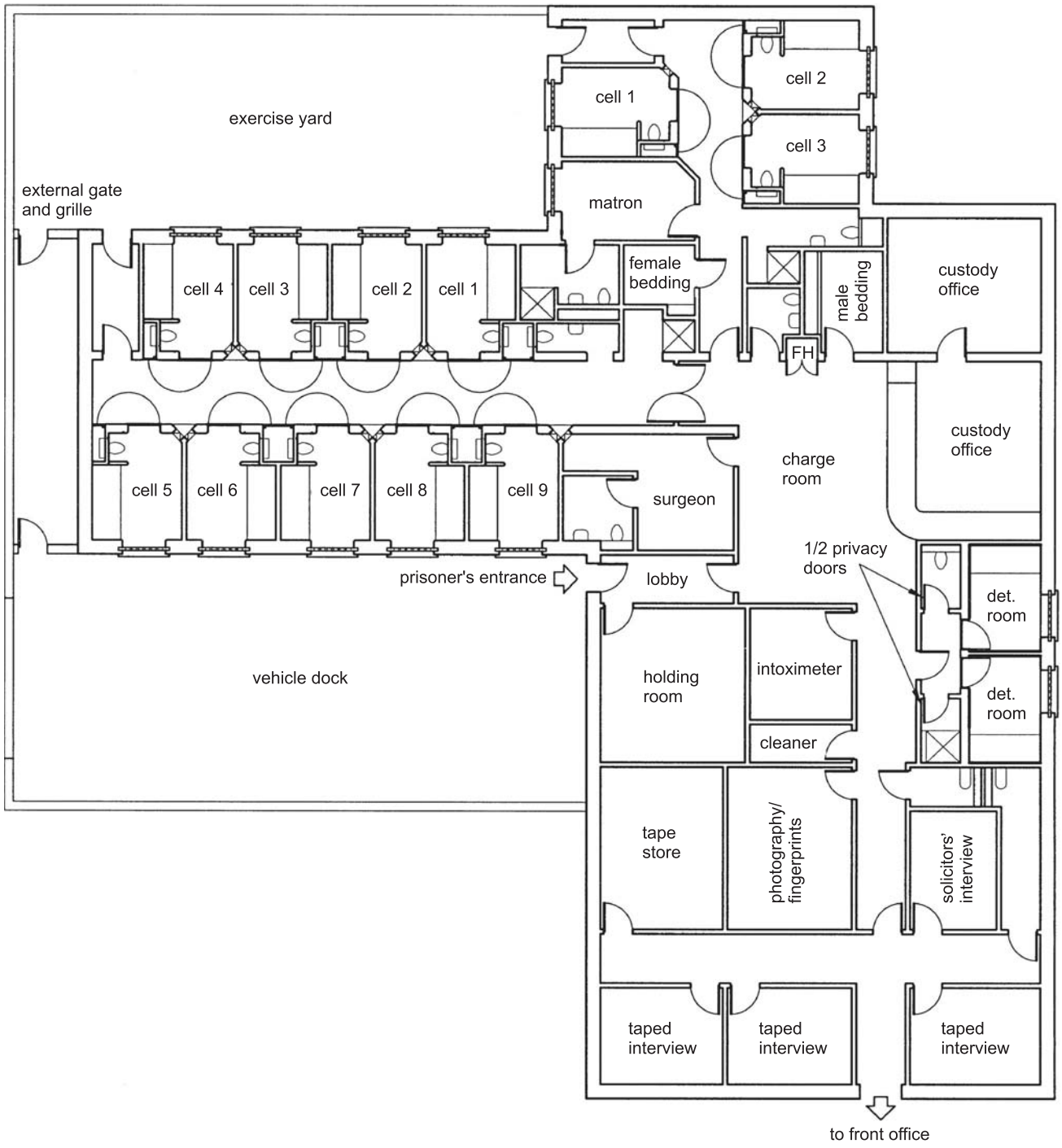
Windows

Cell windows which are unguarded and with openable panes should not overlook roads or other public areas. Windows overlooking exercise yards should be both guarded and screened to prevent observation. Windows to ancillary accommodation within the cell suite such as blanket store, property store, cell corridor, gaoler's room, toilets, etc. should all be guarded. The glazing should be of toughened opaque glass fitted flush to the wall with no protrusions to facilitate injury or suicide, or ledges facilitating escape and attacks on officers. The thickness of the glass increases with larger panes. Glass should not be replaced for ventilation purposes with, for example, perforated zinc.

Ceilings

Most suspended ceilings can be easily broken, giving access to other parts of the building and possibly providing improvised tools or weapons.

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18.19 *Plan of a custody suite (for security reasons this is based on the design principles, but is not an actual example)*

Doors
All doors should be prisoner-proof and flush.

Cell furniture
These should not be of timber or able to be prised loose to make a tool or a weapon.

Ventilation
Casings to trunking should be secure against breakage and use by prisoners to facilitate suicide. Grilles under cell benches should be securely fixed using non-withdrawable screws. High-level airvents with perforations should not be larger than 4.7 mm diameter, of a material that will break under load and fitted flush with the wall surface.

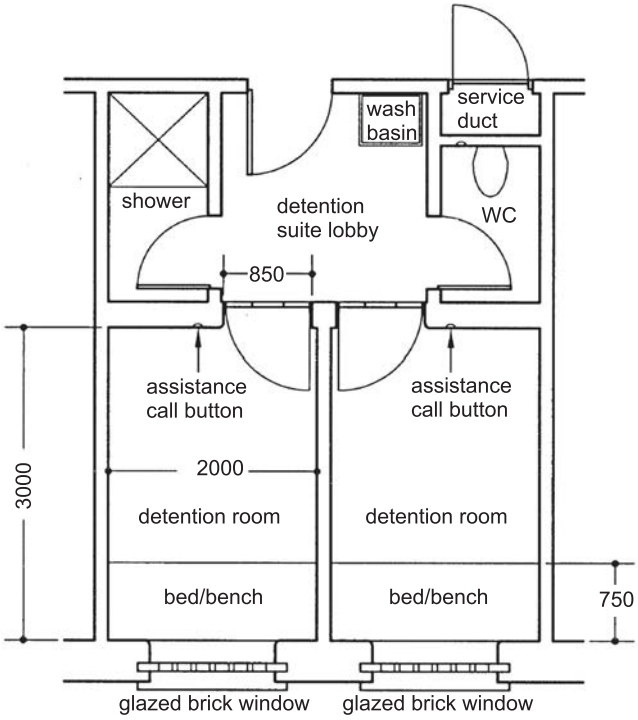
Lighting
Cell light fittings should be fitted flush with the ceiling with unwithdrawable screws. They should have twin lamp holders and plastic lenses. Electrical supplies should not be exposed and the switches should be outside the cell with cover plates that cannot be removed to gain access to live parts.

Heating
Electric radiant heaters with exposed wiring should not be used to heat cells, neither should exposed hot water radiators. There should be no protrusions of any kind to which a ligature could be attached.

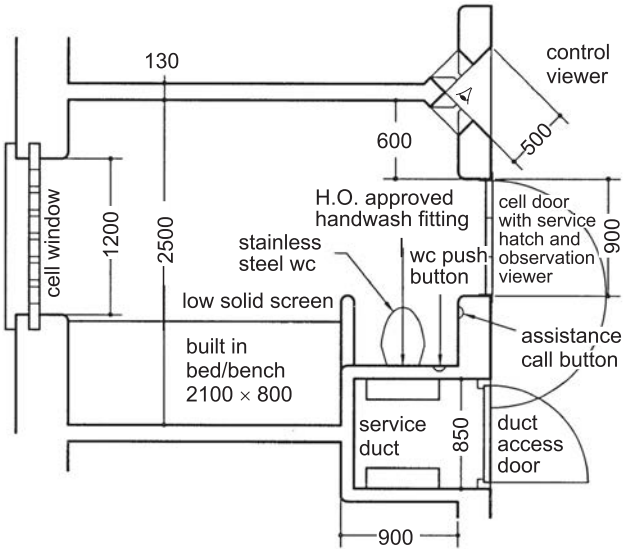
Cell call system
This should comprise a press button within the cell fitted flush with the wall operating a bell and indicator light externally. It should be

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18.20 *Plan of a detention suite*



18.21 *Plan of a custody cell*

on a separate circuit from the lighting, and the indicator light board should be under constant observation by the officer-in-charge.

Maintenance

Damaged cells should be withdrawn from use.

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NHS Estates, *Health Building Note 44.***a** *Dimensions*
b *Turning circles*

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19 Hospitals

David Clarke

CI/SfB: 41

David Clarke is an architect with a background in hospital design. Formerly of Nightingale Associates, he now runs his own consultancy, Clearwell Healthcare Planning Ltd

KEY POINTS:
- *Health services are trying to move closer to the patient*
- *More work is being undertaken in the primary sector*
- *Shorter stays in hospital are the norm*

Contents

1 Introduction
2 Services delivery
3 Facilities design
4 Healthcare provision – activities
5 Support services – outsourcing
6 Publications and guidance

1 INTRODUCTION

1.1 General

The provision of health services, and therefore the design of hospitals and other health facilities, has long been a politically charged issue which is subject to frequent policy change; the agendas and administrative structures which govern the provision of healthcare in the UK obviously impact on the design of the health estate, but this is a subject which is far too vast and changeable to set in detail here. The broad principles of hospital design, and notions of best practice, described below were accurate at the time of publication.

A healthcare building includes a large number of functions and activities across a range of healthcare provision services and non-healthcare support services such as laundries, kitchens, supplies and disposal services and estates maintenance facilities. These were previously collectively known as departments. We would like to avoid the use of this term as it has its history in an inflexible organisational structure. This is reflected in a building based on historic concepts of standard sized, standard types of healthcare buildings (Figure 19.1). District General Hospitals, Teaching Hospitals, Community Hospitals are examples of these stereotypes. The terminology will continue in use for some time but this chapter aims to separate out activities and the physical requirements for these activities. In some cases, these will be rooms, in others suites. Each could be applied in the context of a larger or smaller facility.

The almost universal use of market tested subcontracting of some services has also changed the key drivers in the design of elements such as catering facilities which are now largely briefed and designed in detail by the partner organisation responsible for the provision of the service. Some elements straddle clinical and non-clinical support services such as pathology services; this particular service is subject to a Department of Health mandate for the provision of central services supporting a number of different healthcare facilities in an area. Similarly sterilising services, known as centralised facilities, pathology and equipment sterilisation (CSSD) or HSDU are now considered under the heading of decontamination and are subject to a similar strategic approach by the Department of Health. This is also a separate area which will not be covered in detail by this chapter. Other facilities such as pharmacy services are heavily influenced by technology, in this case robotic dispensing, and a categoric template is determined in conjunction with providers of such equipment.

2 SERVICES DELIVERY

2.1 Drivers of change

In the search for ways of containing health service costs, health care delivery through the hierarchy of the organisation and the corresponding hierarchy of building types is also being reappraised. The aspirations of an extensive assessment of patient needs and wishes were the subject of a Department of Health review entitled *Your Health, Your Care, Your Say* (2006); this extended the momentum towards providing services which are devolved from the expensive acute sector out towards primary care organisations, community services and even into the home.

Similarly, the length of patient stay in hospital is being reduced; patients are being required earlier than before to recover at home, where they need additional community support; and many basic diagnostic and treatment procedures are being tested in the primary care setting. One consequence for the acute hospital is that patients who remain are, on average, more dependent and the procedures, on average, more sophisticated and complex.

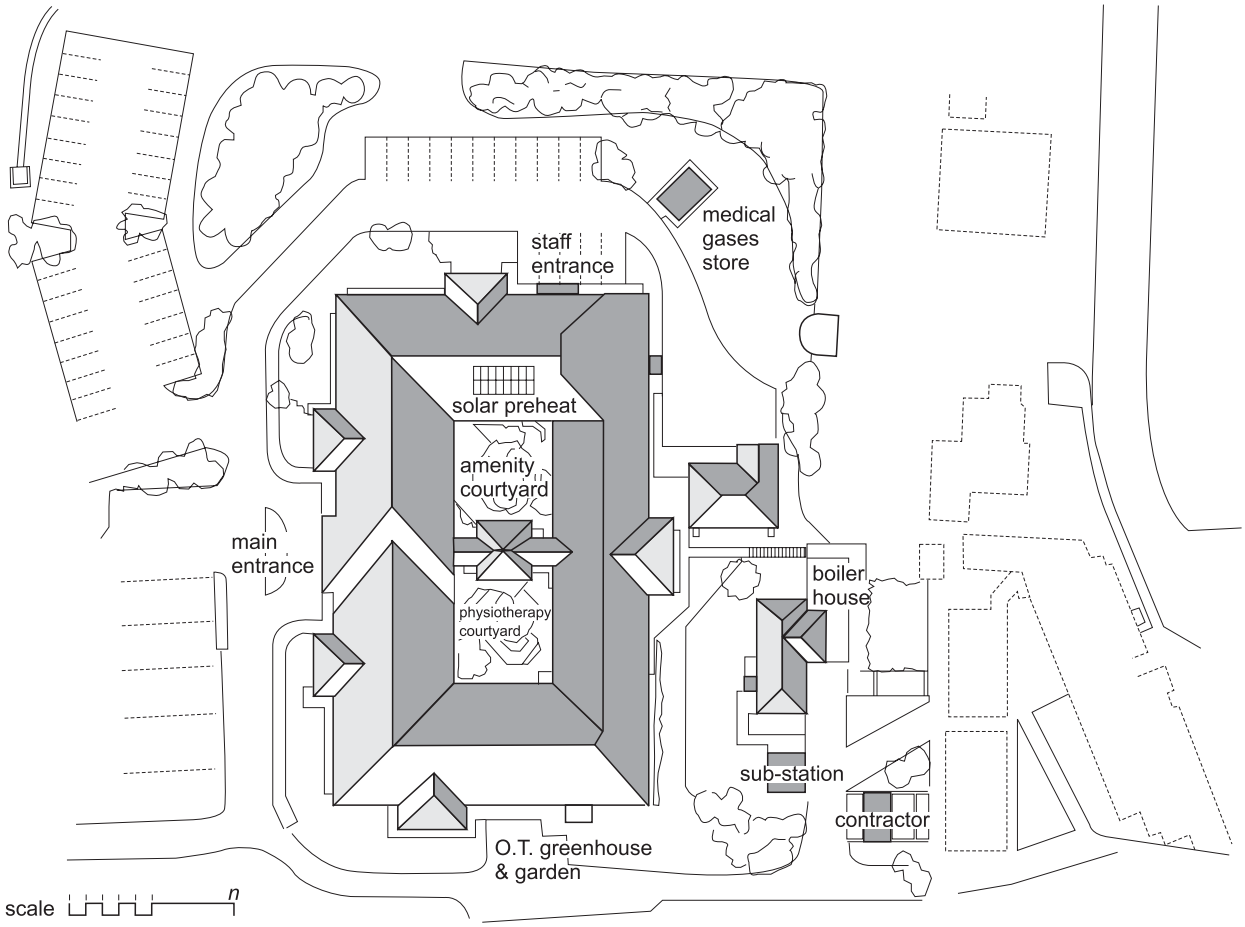
2.2 The hospital and the patient

Management concern for patients' response to the hospital service and environment encompasses such diverse issues as first impressions, signposting, waiting times in out-patient and accident departments and relationship with the ward nurse. It has recently been extended to reassessment of the basic relationships between treatment departments and the in-patient areas they serve. The idea of a hospital organised so as to ameliorate some of the more distressing aspects of patient stay – being shunted around the hospital, waiting in strange departments, disorientation and lack of a sense of place which is their own – found expression in the 1980s–1990s as a 'patient-focused hospital', often renamed in the UK as a 'patient centred hospital'.

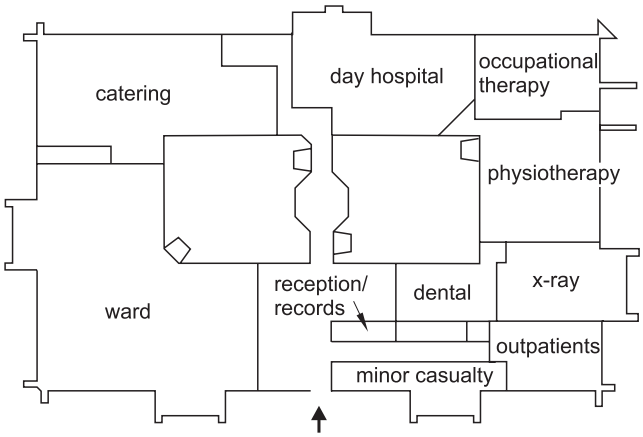
The principle which relied on the decentralisation of diagnostic services towards, principally, ward areas to reduce the amount patients needed to travel around the hospital also required a degree of multi-skilling which resulted in only limited implementation. Some physiotherapy, which had previously been centralized, moved to ward areas and bed areas but this was carried out by roving members of the physiotherapy team. The result has been a substantial increase in the required size of a bed bay to accommodate these activities, see Table I. Bed bay areas have also increased as the impact of lifting patients, use of hoists and more demand for the safety of nursing staff have come forward as priorities.

2.3 Information technology

The implementation of information technology has not had the substantial impact on the design of the building that had been anticipated. The dramatic reductions in the size of computer equipment, almost universal use of flat-screen displays and the relatively slow implementation of Patient Records systems and its evolution to the use of hand held pads rather than conventional computers has not generated significant effects. Medical records are still kept in paper form and the most appropriate future provision is for such areas to be located and able to adapt to future alternative uses.



a *Site plan*



b *General areas*

19.1 *Community Hospital in Mold. Clwyd Architect: William H. Simpson, Chief Architect, WHCSA*

3 FACILITIES DESIGN

3.1 Design drivers for the patients' experience

The Patients Charter, first published in 1991, set out objectives for the health service based on identified reasonable expectations of patients. These included timescales for delivery of services and importantly issues related to privacy and dignity that should be afforded to patients, particularly during a hospital stay.

It is now paramount, although often not achievable in older hospital premises, that toilet facilities are immediately available to patients, not only in single bedrooms but in multi-bed bays if provided. It is not acceptable for patients to walk through or be seen by patients of the opposite sex in order to visit bathroom areas.

An example of a four-bed bay with ensuite accommodation has been developed by Nightingale Associates to suite a number of issues related to multi-bed ward design (Figure 19.2).

Single bedrooms have advantages for privacy, dignity, confidentiality and safety. However, surveys have identified that by no means all patients wish to be in a single bedroom. A four-bed ward generates not only a small community with opportunities for companionship, but also a support structure in the event of a patient

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Table I Hospitals, typical room dimensions

Suggested areas for clinical and clinical support rooms with dimensions

	Room type	Width	Length	Area	Notes	Areas where used
1.01	Consult/Exam Two Side access	4.3	3.9	16.6		
1.02	Consult/Exam Single Side access	3.8	3.9	14.6		
1.03	Interview Room	3.3	3.3	10.6		
1.04	Treatment Room	4.2	4.0	16.8		
1.05	Venepuncture Room	2.7	3.0	8.1		
1.06	Patient Recovery (2 patients)	5.0	4.4	21.8		
1.07	Near Patient Testing Room	3.0	2.4	7.2		
1.08	Clean Supply Room	3.6	4.2	14.9		
1.09	Clean Utility Room	3.5	4.2	14.7		
1.10	Dirty Utility (Outpatients)	2.8	3.0	8.4		
1.11	Dirty Utility (Inpatient)	2.9	4.2	12.2		
1.12	Cleaners' Room	2.3	3.0	6.9	Dependent on FM provider	
1.13	Disposal Hold			10.0	Dependent on FM provider	
1.14	Relatives' Overnight Stay	3.7	3.7	13.7	Access to ensuite required	
1.15	Pantry/Refreshment Area	2.9	2.4	6.8		
1.16	Staff Rest Room	4.3	8.4	35.7		
1.17	Mini Kitchen (within Staff Rest)	2.2	0.6	1.3	Requires adjacent handwash	
				0.0		
2.01	Ambulant WC	1.1	1.7	1.8	Assumes concealed cistern not included in dimensions	Only areas for staff
2.02	Semi-Ambulant WC	1.2	1.8	2.1	Assumes concealed cistern not included in dimensions	All patient access ambulant WCs
2.03	Independent Wheelchair Accessible WC	2.0	1.9	3.8	Equivalent to Disabled WCs in public areas	
2.04	Assisted WC	2.8	2.7	7.6	Allows access for 2 assistants	
2.05	Standard Shower Room	2.3	1.1	2.5	Only suitable for ambulant	
2.06	Semi-ambulant shower room incl. WC	2.6	2.5	6.5		
2.07	Wheelchair Access Shower	2.6	2.0	5.2	Independent wheelchair user, no WC	
2.08	Assisted Shower & WC	2.3	3.1	7.1		
2.09	Ensuite full access WC/Shower	2.3	2.1	4.8	Assumes overhead hoist and door + folding door access	
2.10	Semi-ambulant accessible bathroom	2.3	2.7	6.1	Also possible with bidet at 2.4 × 3.1	
2.11	Independent Wheelchair Accessible Bathroom	2.7	3.3	8.9		
2.12	Assisted Bathroom Side Access	2.4	4.9	11.8	Assumes largest hi-lo bath Min. 1.7 × 4.65 m	
2.13	Assisted Bathroom End Access	2.9	5.1	14.6	Assumes largest hi-lo bath Min. 2.9 × 4.83 m	
2.14	Nappy Change	1.7	2.6	4.4		
2.15	Child Change	3.3	3.3	10.7		
2.16	Changing Room – Standard	1.1	1.8	2.0		
2.17	Changing Room – Wheelchair	2.2	2.0	4.4		

requiring assistance while being unable to use the nurse call system. A provision of single rooms is essential for those who either prefer that ward type or for whom it is a clinical necessity. Where multi-bedrooms are provided interview rooms are required for confidential discussions between the clinical staff and the patient. This will be disruptive to the doctors' ward round but of importance to the wellbeing of the patient.

The drive towards 100 per cent single rooms is laudable but not universally agreed upon as an objective. Current good practice is inclined to the provision of 75 per cent single rooms with four-bed bays providing the balance.

High-quality architecture and internal environment is demonstrated not only to enhance the experience of patients, staff and visitors but also to reduce the recuperation time required by patients. There is clear evidence, for example, in intensive care environments, that daylight and external views improve recovery times.

3.2 Design agendas

Hospital design is also the subject of a variety of centrally driven design guides and 'agendas' via organisations such as the Commission for Architecture and the Built Environment (CABE), the Building Research Establishment (BRE) and the Construction Industry Council (CIC).

Two significant initiatives that have emerged over recent years are the 'AEDET' design toolkit and the 'NEAT' environmental assessment procedure.

AEDET ('achieving excellence design evaluation toolkit', now known as 'AEDET Evolution') evaluates a design by posing a series of clear, non-technical statements which encompass the three areas of Impact, Build Quality and Functionality. Each area is assessed across a range of specific criteria:

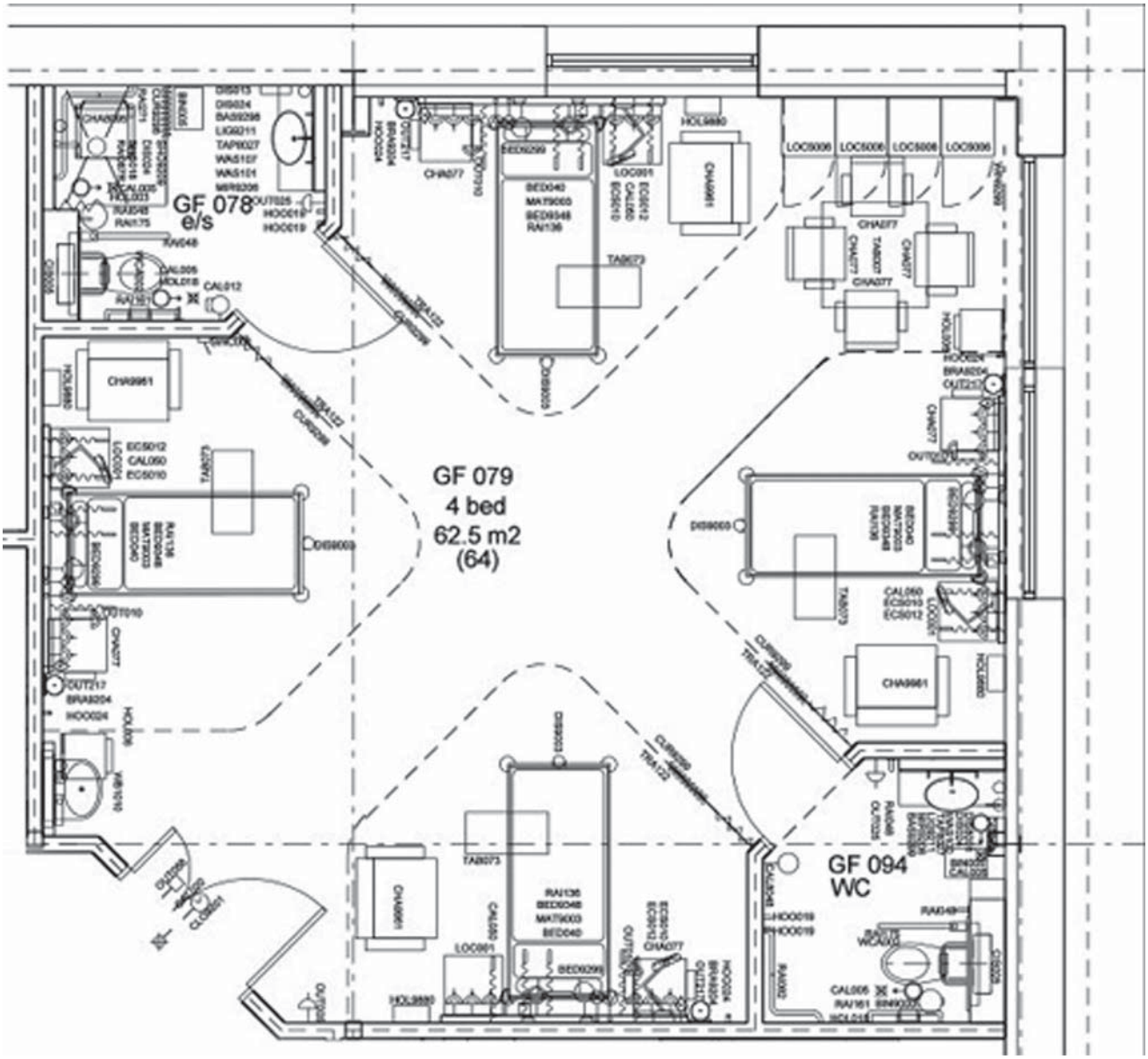
- 'Impact'
  - Character and innovation
  - Form and materials
  - Staff and patient environment
  - Urban and social regeneration
- 'Build quality'
  - Performance
  - Engineering
  - Construction
- 'Functionality'
  - Use
  - Access
  - Space

The idea is that if all three areas provide added value, the combined result will be excellence.

A further tool, ASPECT (standing for 'a staff and patient environment calibration tool'), provides extra assessment processes which can supplement AEDET. Details of both tools can be found on the Department of Health's online portal http://design.dh.gov.uk.

The NHS Environmental Assessment Tool (NEAT) is a self-assessment procedure, based on 'yes' or 'no' answers, that helps to assess the negative impact healthcare facilities may have on the environment. NEAT can be applied to any type of NHS healthcare

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19.2 *The four-bed 'New Nightingale Ward', designed by Nightingale Associates*

facility. The Excel-based system issues a numerical score along the following lines:

- below 25 per cent fail
- over 25 per cent pass
- over 40 per cent good
- over 55 per cent very good
- over 70 per cent excellent.

NEAT requires all new buildings achieve a rating of Excellent; refurbished buildings should achieve a rating of Very Good. NEAT covers 10 areas:

- Management
- Energy
- Transport
- Water
- Materials
- Landuse and ecology
- Pollution
- Internal environment
- Social factors
- Operational waste.

The toolkit can be downloaded from DH websites.

3.3 Functional relationships in healthcare buildings

The discussions of individual clinical areas below includes reference to adjacencies appropriate for efficient usage of space and minimising unnecessary travel by patients and staff (Figure 19.3).

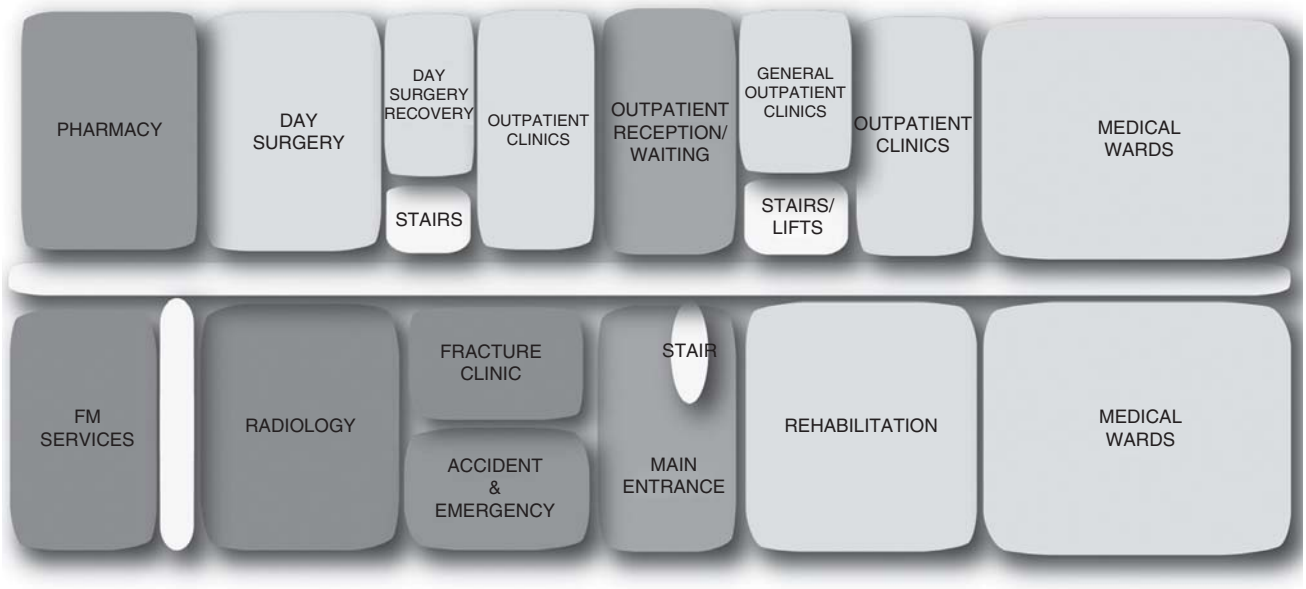
Logical adjacencies also ease the understanding of the building by patients, visitors and staff who are unfamiliar with the layout. Clear signposting, or way-finding, is obviously essential but the principle that 'people do not read signs' should not be dismissed. Table II illustrates some of the relationships between major activity spaces and their associated activities.

3.4 Future proofing – designing for change – growth and shrinkage

The delivery of healthcare services and the consequent healthcare estate configurations will continue to change. As more acute services are delivered closer to home, or at home, different building types will appear. Increased partnerships with the private sector will develop alongside partnerships with leisure, commerce and retail delivering healthcare closer to the places people spend their days.

While the concept of flexibility has for many years been a criterion of judgement about the quality of a healthcare building design, it is now recognised that flexibility, and its consequent cost penalties, should be considered more in the context of adaptability. The continued use of steel and concrete frames for the primary structure in major healthcare buildings provides the greatest

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19.3 *Relationship diagram of Darent Valley Hospital in Dartford Kent, an early PFI hospital designed by Paulley Nightingale Architects and completed in 2002*

Table II Hospital department relationship in an acute hospital

Department relationships in an acute hospital

Activities		Access requirements	Location	Relationship	Notes
In-patient services					
1	Adult acute wards		Level not important	Surgical beds to theatres	
2	Children's wards	To outdoor play area	Preferably ground floor	Theatre Includes parents overnight stay	
3	Geriatric wards		Preferably ground floor	Geriatric day hospital Rehabilitation	
4	Intensive therapy unit		Level not important	Accident dept; theatres	
5	Maternity dept			Antenatal clinic in OPD	
5.1	Wards			Delivery suite	
5.2	Delivery suite	Ambulance access may be required for dept as a whole	Level not important	Wards, theatres SCBU	Area includes dept. admin, etc.
5.3	Special care baby unit			Delivery suite	
6	Psychiatric dept	External access	Self-contained units may need private internal access		
6.1	Wards				
6.2	Day hospital				
7	Isolation ward	Private external access for infected cases	Level not important, but see 'access'	Children's dept	
Diagnosis and treatment					
8	Operating dept		Level not important	Surgical beds; accident dept	Special ventilation needs include refrigeration
9	X-ray dept		Usually ground floor	Accident dept; fracture clinic	Special ceiling heights and heavy equipment
10	Radiotherapy		Level not important	X-ray dept	
11	Pathology dept	External supply access may be required	Level not important but see 'access'	Radio isotopes, outpatient dept	Special attention to ventilation of noxious fumes
12	Mortuary and postmortem	Private external access for undertakers' vehicles	Level not important, but see 'access'	Morbid anatomy Section of pathology	Special attention to ventilation of postmortem area
13	Rehabilitation	Ambulance access	Ground floor	Medical and geriatric beds	Includes physiotherapy gymnasium (extra height), hydrotherapy pool (special engineering requirements) and occupational therapy
14	Accident and emergency	Ambulance access for emergency cases	Usually ground floor – see 'access'	Direct access to X-ray dept, fracture clinic, main theatres, intensive therapy unit	Relationships assume no separate X-ray or theatres in accident department
15	Out-patient department including fracture clinic, antenatal, dental, clinical measurement, ears, nose and throat, eyes, children's outpatients and comprehensive assessment	Pedestrian and ambulance access for large numbers, approx. 300–400 morning and afternoon	Main reception and waiting area usually ground floor but parts may be on other levels	Fracture clinic to accident dept, convenient access to pharmacy, good access to medical records dept-often adjacent	
16	Elderly day hospital	Ambulance access, access to outdoor area	Usually ground floor – see 'access'	Elderly wards, rehabilitation dept	
17	Adult day ward		Level not important	Theatres, X-ray, pathology	Includes additional space for 'sitting' cases

(continued)

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Table II (continued)

Department relationships in an acute hospital					
Activities		**Access requirements**	**Location**	**Relationship**	**Notes**
Support services					
18	Paramedical:				
18.1	Pharmacy	External supply, access may be required	Usually ground floor – see 'access'	OPD. hospital supply routes	
18.2	Sterile supply dept	External supply access	Usually ground floor – see 'access'	Hospital supply routes, operating dept	Special ventilation needs – wild heat problems
18.3	Medical illustration		Level not important		Often using digital images anywhere in the hospital
18.4	Anaesthetics dept		Level not important	Theatres, intensive therapy	
19	Non-clinical:				
19.1	Kitchens	External supply access	May be ground floor (for supply access) above ground (nearer to bed areas)	Hospital supply routes and bed areas served – dining room servery	
19.2	Dining room		Level not important but see 'kitchens'	Access from kitchen to servery, good staff access from whole hospital	
19.3	Stores	Supplies vehicle	Usually in services area, ground floor	Hospital supply routes	Special height may be needed for mechanical handling, increased use of 'Just in Time' provisions
19.4	Laundry	Supplies vehicle	Ground floor, service area	Hospital supply routes	
19.5	Boilerhouse – fuel storage	Fuel delivery vehicles	Usually ground floor in services area but may be elsewhere (e.g. rooftop) depending on choice of fuel	Work and transport dept	
19.6	Works – transport dept	Vehicle parking	Usually ground door in services area	Boiler house	
19.7	Administration		Level not important (tel. exchange ground floor)		Includes telephone exchange Purely administration functions could be off site
19.8	Main entrance accommodation	External access for inpatients, visitors, perhaps out-patients and staff	Usually ground floor – see 'access'	In-patient reception area or medical records main hospital horizontal and vertical communication routes	Also includes facilities such as bank, shops, etc.
19.9	Medical records		Level not important, Ground floor suits ground floor – see 'relationships'	Hospital communication routes	Only short term 'live' records on site, 24 h call up for others
20	Staff:				
20.1	Education centre		Level not important		
20.2	Non-resident staff changing		On route between staff entrance and departments served, level not important	Hospital supply route for clean and dirty linen	
20.3	Occupational health service	Level not important			May be in OPD complex
21	Miscellaneous: This will include car parking, garages, medical gas installation, recreational buildings				

level of adaptability although within these two principles there are significant variations which, in themselves, increase or decrease adaptability. Hospitals are very intensive in their requirements for penetrable floor slabs, walls tend to follow column lines and it must be recognised that the least penetrable locations in a floor are likely to be around columns and along the line of major structural beams. The introduction of penetrable zones in these areas will substantially improve the ease with which future adaptations can be made.

Expansion zones at the perimeter of buildings must be considered, with the capability of major circulation routes extending beyond the envelope without significant disruption. Expansion also occurs within the building for particular activities. Some specialties can be reasonably predicted as likely to expand, radiology and day surgery for example. Some can be predicted as likely to reduce, medical records for example. Some are likely to be relocated, CSSD being an example. Placing facilities likely to expand alongside those that will contract enables an inbuilt flexibility which can minimise the effect of disruption in the future.

Services may also contract. As more activity moves out of an acute hospital environment, they may not be replaced by an increase in the remaining acute services. The capability for both expansion and contraction is required to be demonstrated at business case stage and considered as part of the Strategic Outline Case.

3.5 Fire design

Healthcare buildings have to comply with requirements for fire safety and means of escape: those for hospitals are set out in Firecode published by the Department of Health. This guidance is covered by the Documents HTM 05-01, HTM 05-02 and HTM 05-03 in various sections. This guidance is deemed to satisfy Building Regulation Part B requirements. The major change is in the responsibility of the NHS client in England to prepare a Fire Safety Policy in response to HTM 05-01 Managing Healthcare Fire to inform the design process. The requirements for Scotland and Wales may differ, the 05-01 process is also not mandatory for Foundation Trusts. Some of the requirements influence overall form and will be dealt with here; others affect internal organisation and will be dealt with below.

Relationship of departments by fire characteristics

The risk to human life is greatest in those areas where patients are confined to bed and especially where they would be incapable, in the event of a fire, of moving to a place of safety without assistance. Those areas are termed normal dependency or very high dependency departments.

Departments posing the fire threat are those such as supply zones, fuel stores and other materials stores containing large quantities of flammable materials and those in which ignition is more likely such as kitchens, laundries, laboratories and boiler houses, referred to as

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Hazard Departments. The principle to be followed is that independent departments should not be placed adjacent to or above Hazard Departments unless protected by a 60 min barrier; auto suppression in the Hazard Department is required in some instances. Very High Dependency departments, such as ITU, Operating Theatres or Special Care Baby Units should not be located adjacent, vertically or horizontally to Hazard Departments. These requirements are noted in Table 1 in Section 3 of HTM 05-02.

Hospital Streets

The Hospital Street, a primary circulation route between areas of the hospital, can form a major fire-fighting platform. It also provides an alternative to an adjacent department for the purposes of progressive horizontal evacuation. Hospital Streets have particular requirements of maximum travel distances defined within Firecode. It is not necessary to provide a designated Hospital Street but a central circulation spine would naturally fall into this category.

Where a Hospital Street is designated, and in major units it has significant advantages for fire design and fire fighting, particular rules apply. The street must have a minimum width between handrails of 3 m. On the ground floor it must have at least two final exits no more than 180m apart. On upper levels a minimum of two staircases are required at a maximum distance of 60 m apart. The distance from a department entrance to a staircase should be no more than 30 m. This is not an exhaustive list of requirements, reference to HTM 05-02 paras 5.40–5.45 should be made.

Compartmentation

Compartmentation of a large building into areas of limited size, divided by fire-resisting partitions, allows escape away from the fire source into a nearby place of relative safety in the initial stages of the fire. In a hospital, it is essential that this movement is horizontal. Lifts cannot generally be used in a fire and staircase evacuation of physically dependent patients takes far too long to be a practical means of escape in this first stage.

The primary compartment is by floor, each floor being a 60 min fire compartment unless the building is above 30 m or nine stories in height in which case it is 90 min.

On each floor, the compartments are limited to 2000 m^2 in area and a minimum of three for each floor, one of which may be the Hospital Street, are required to satisfy the above conditions.

In practice, it is unusual to have a compartment as large as this. The requirements of section 5 for compartmentation by department boundaries will generally generate compartments of about 1000 m^2 as a maximum.

If a compartment is larger than 750 m^2, or which provides access to more than 30 patients, there is a requirement to sub-compartment the area. In general, more compartments should be provided on each floor, particular attention should be made to vulnerable patient groups such as the elderly and those with limited mobility such as orthopaedic patients. Further compartmentation is necessary in Very High Dependancy departments such as operating theatres and other critical care areas.

Sprinklers are not normally used in hospital buildings but in central urban areas may be required. Firecode includes requirements for both circumstances.

In a single storey construction, the maximum compartment area is 3000 m^2 although similar departmental rules apply as noted above.

Travel distances and escape routes

There is a limitation on maximum travel distance within a compartment and sub-compartments. Within a compartment the maximum distance is 60 m, within a sub-compartment 30 m. There is also a limit on travel distance to a major escape route. The escape route is a protected, smoke-free path leading to an unenclosed space at ground level and the main Hospital Street is commonly designed to satisfy these criteria. A general rule is that a compartment should have an exit to either two adjacent departments or one department and a Hospital Street.

It should be noted that most areas of a hospital are occupied by trained staff for substantial parts of the day and in some cases 24 hours. Unoccupied rooms such as stores and rooms which have a hazardous function, such as kitchens, or contain flammable materials represent the greatest fire risk and are designated as Fire Hazard Rooms. These rooms are required to maintain 30 min fire integrity and insulation.

3.6 Control of infection

The control of infection is a vital part of healthcare provision, and measures include behavioural and procedural ones (including the frequent washing of hands, use of alcohol gel and access restrictions) to design tactics (everything that is designed will have to be cleaned – all surfaces should be accessible to cleaning teams).

It should be recognised that infection by different pathogens can be minimised by different methods. Alcohol gel, for example, can work against MRSA but not C. Difficile which requires meticulous hand washing. The design of the environment cannot in itself eliminate the risk of infection but the strategic placement of hand wash basins and alcohol gel dispensers can enable good management by encouraging good practice.

Horizontal surfaces which are difficult to clean represent a hazard, radiused skirtings and the elimination of inaccessible areas, behind WCs for example, assist a cleaning regime in being effective.

The presence of highly infectious and dangerous pathogens such as MRSA and C. Difficile is a constant concern for medical staff and patients, and the situation regarding these bacteria is very changeable. Designers should be mindful of the dangers these bacteria pose and should take advice from medical and infection control experts at all stages of the design process.

4 HEALTHCARE PROVISION – ACTIVITIES

4.1 Emergency care

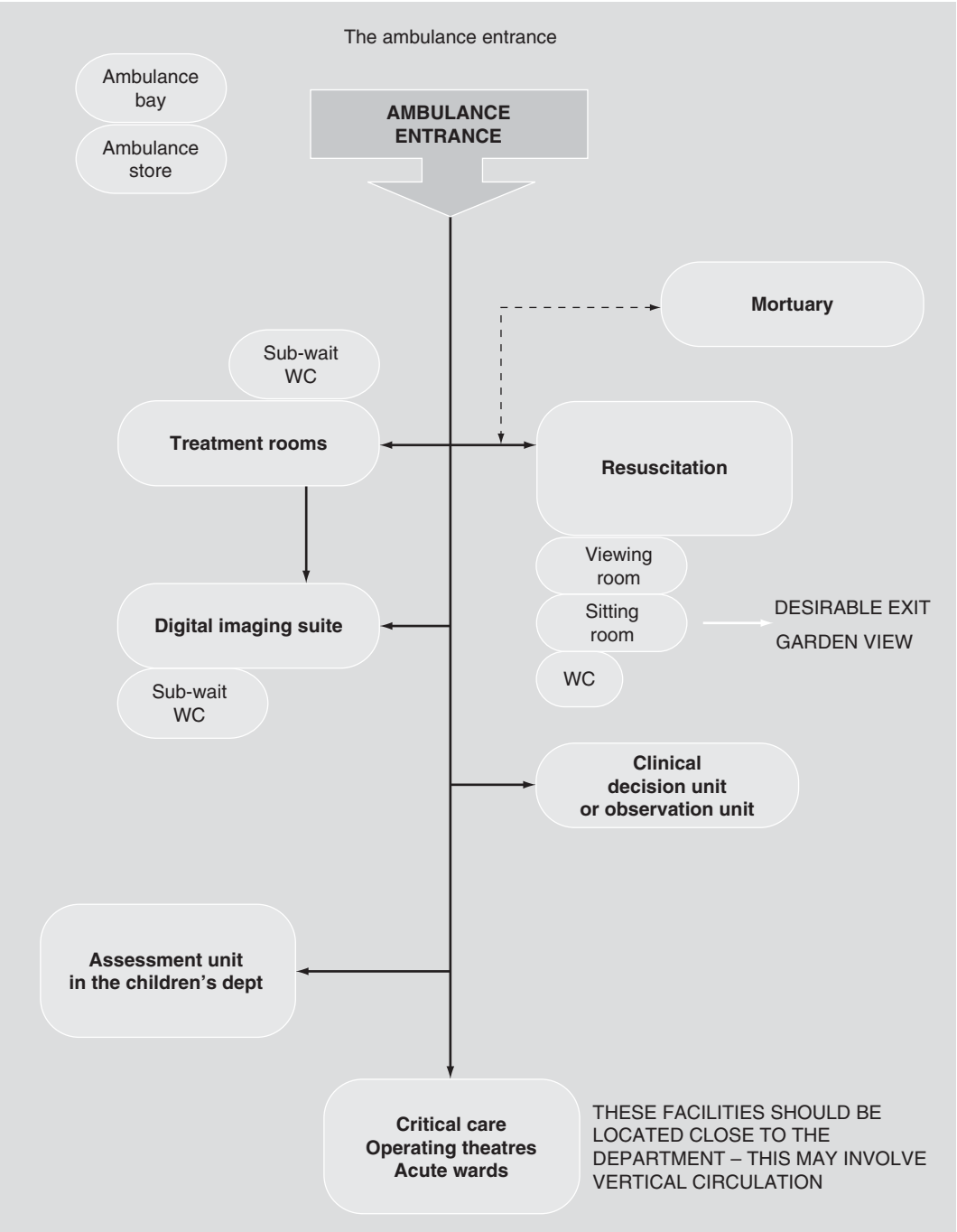
The provision of facilities for emergency care has evolved to enable cost-effective provision to be provided as quickly as possible. Greater emphasis is placed on paramedic services by response teams to emergency calls and on the provision of facilities for minor injuries. Minor Injury Units (MIU) are providing services from approximately 8.00am–11.00pm for patients not requiring the full scope of emergency care. This requires a degree of 'self-diagnosis' and has yet to achieve its full potential in efficiency savings.

Emergency care is increasingly being associated with other elements of critical care such as intensive therapy and operating theatres as a management unit and the overall facility is now under the umbrella of critical care. Emergency care has an obvious requirement for ground-floor access; operating theatres, being highly dependent on mechanical ventilation provisions tend to be on an upper floor. Dedicated vertical circulation is therefore important between the Accident & Emergency (A&E) and operating theatres. An alternative would be the provision of an interstitial plant floor. The Intensive Therapy Unit (ITU) would usually be co-located with the operating theatres and would share this vertical access from the A&E (Figures 19.4 and 19.5).

Specialist A&E facilities for cardiac care may be provided.

Because of the urgent nature of a high proportion of accident cases, the relationship with supporting departments is crucial. In particular, there should be direct access – by separate entrance if necessary – to the X-ray department for speedy diagnosis; alternatively separate X-ray facilities can be provided within A&E. Circulation of patients on beds or trolleys means that dimensions for these items are critical (Figures 19.6 and 19.7).

If X-ray facilities are not integral to the A&E facility a means of providing 24 hour access to a limited section of the X-ray department will be required.



19.4 *Diagram showing the relationships between spaces in a hospital emergency facility for patients arriving by ambulance. Source: Health Building Note 22*

Close proximity is also required to the fracture clinic because of the weight of traffic.

As direct access as possible should be provided from the A&E department to the operating department although its location has to respect the overriding needs of surgical wards and the ITU.

Out-patients should have access to the OPD directly through the main entrance. The OPD has the largest single daily requirement for provision of patients' records but whether this dictates a close relationship with the medical records department depends on the organisation and form of the records themselves.

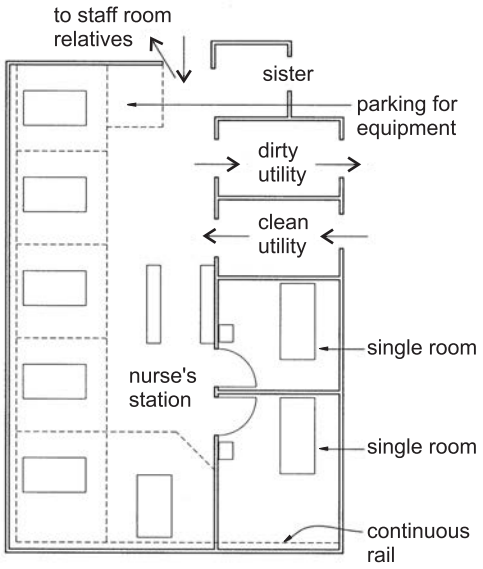
There will be considerable traffic from the OPD to the X-ray department and to the fracture clinic (which is usually shared with the A&E department). Until recently, a large proportion of out-patients called in at the pharmacy with their prescriptions but patients are now encouraged to use external community pharmacies and the location of the hospital department is not so critical, although it should be reasonably easy to find.

4.2 Invasive medicine

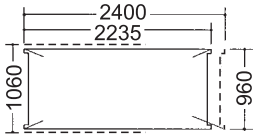
An operating department consists of one or more operating suites together with common ancillary accommodation such as changing and rest rooms, reception, transfer and recovery areas. An operating suite includes the operating theatre with its own anaesthetic room, preparation room (for instrument trollies), disposal room, scrub-up and gowning area and an exit area which may be part of the circulation space (Figure 19.9). An operating theatre is the room in which surgical operations and some diagnostic procedures are carried out.

Infection control is one of the key criteria in operating department design and this is one of the few departments requiring air conditioning that includes humidity control. To assist infection control, four access zones are defined: operative zone (theatre and preparation room); restricted zone for those related to activities in the operative zone who need to be gowned (scrub-up, anaesthesia and utility rooms); limited access zone for those who need to

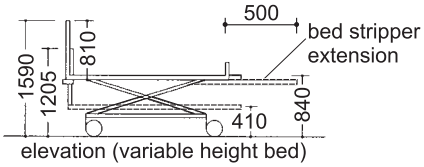
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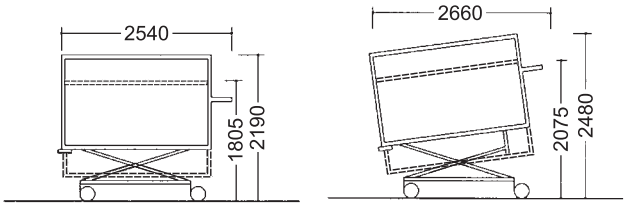
19.5 *Intensive therapy unit (ITU). Cubicle curtains are not used but movable screens may be. The location of the bed within the space varies with needs of patient, staff and equipment*



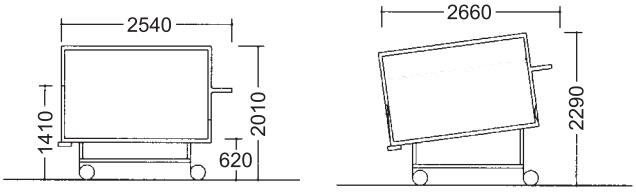
a *Plan*



b *Elevation of the variable height bed*

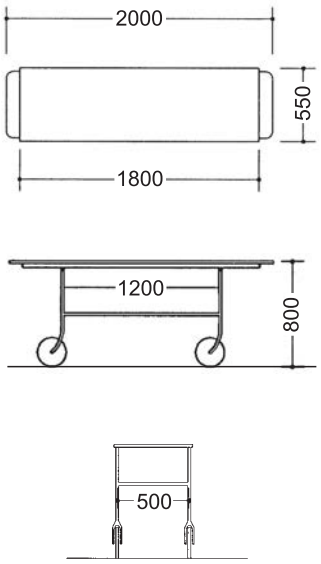


c *Elevations of the variable height bed with balkan beam*



d *Elevations of fixed height bed with balkan beam*

19.6 *King's Fund bed; critical dimensions given. These are likely to occur frequently and/or importantly. They may be increased by the various accessories which are available*



19.7 *Hospital trolley*

enter areas adjacent to the above (recovery, mobile X-ray store, darkroom, staff rest, cleaner); and general access zone to which anyone is admitted (staff changing, porters' base, transfer area, stores).

Separate 'clean' and 'dirty' corridors are no longer required for infection control reasons, although the four major components of traffic (patients, staff, supplies and disposal) may be segregated, in a number of possible combinations, into two corridors – on either side of the theatre – for reasons of good workflow.

There are strong economic arguments for centralising operating facilities in one department, located on the same floor as the surgical beds and in particular paediatric surgical beds should be on the same floor located as close as is feasible.

The ITU should be immediately adjacent with direct access which does not require usage of the main hospital circulation routes.

The journey from the A&E area should be as direct as possible although it may not be feasible for them to occur on the same floor.

4.3 Diagnostic imaging

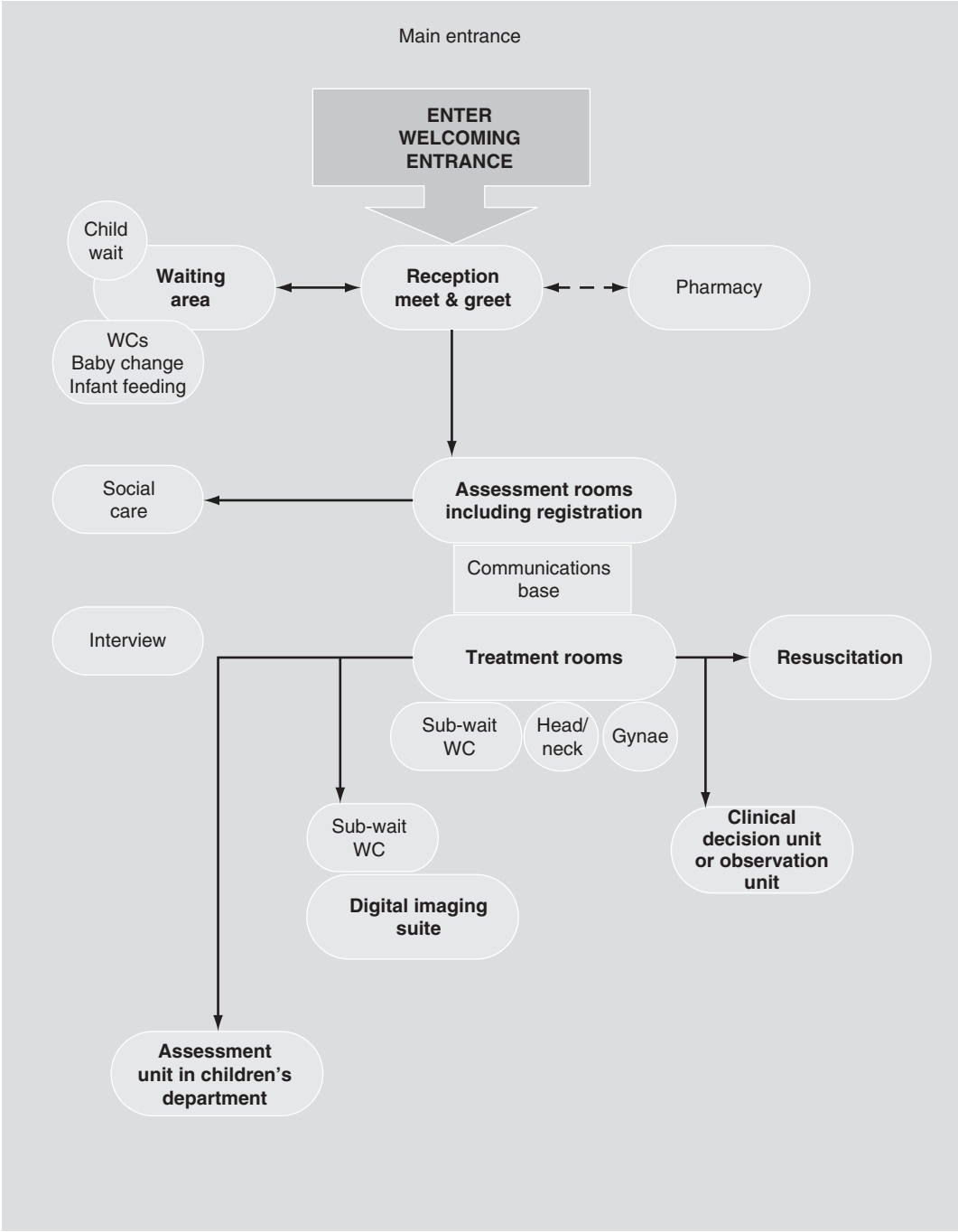
Also known as radiology, this is usually taken to refer to the use of X-rays for diagnostic imaging; when used for treatment, the term radiotherapy is used (Figure 19.10).

In addition to the conventional techniques for imaging bone structures, supplemented in the case of soft organs by the use of radio-opaque materials such as barium, an X-ray Department will now generally accommodate a computerised tomography (CT) scanner which builds up three-dimensional images and a unit for magnetic resonance imaging (MRI).

CT and MRI have a significantly increased purpose in the rapid diagnosis of tumours and are used in increasing numbers by emergency services, particularly associated with head injuries and for cardiac patients. Although MRI does not use X-ray radiation, very particular design requirements are needed for the MRI examination rooms because of the magnetic field generated by the magnet. The influence of the magnet extends beyond the examination room to an extent dependent on the power of the magnet and the amount of shielding built into the enclosure. All materials within the examination room need to be non-ferrous and MRI compatible. CT does use X-ray radiation and, since it uses 'slices' to build up a three-dimensional image a CT investigation will result in a far higher dose of radiation for the patient than a conventional X-ray; for this reason, it is used as sparingly as possible on one patient.

Of even greater impact in terms of throughput – and still growing – is imaging by ultrasound, which is simpler (not needing the

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19.8 *Relationship diagram, illustrating the emergency-related spaces for patients arriving by public or private transport. Source: Health Building Note 22*

protective measures demanded of X-rays), cheaper, faster and not requiring as much space.

Each of these services requires its own reception, waiting and changing areas. The X-ray services may in addition be grouped into, for example, specialised rooms, general-purpose rooms and barium rooms although the X-ray reception desk would probably be common to all. Where there are a large range of possible investigations departments are sometimes split into 'fast-flow' and 'slow-flow' areas depending on the throughput level of the area. The increased use of Picture Archiving and Communication Systems (PACS) has resulted in a reduced need for film processing and storage within the Imaging area, reporting can similarly be carried out in locations remote from the radiology facility, away from the hospital, or in a different country. This facility greatly enhances the possibility of using remote expertise to quickly arrive at a diagnosis which would not otherwise be achievable. The introduction of PACS has also had an impact on the take up of a more 'paperless' hospital environment although the full development of patient records available across the healthcare community remains fraught with technical, ethical and confidentiality issues.

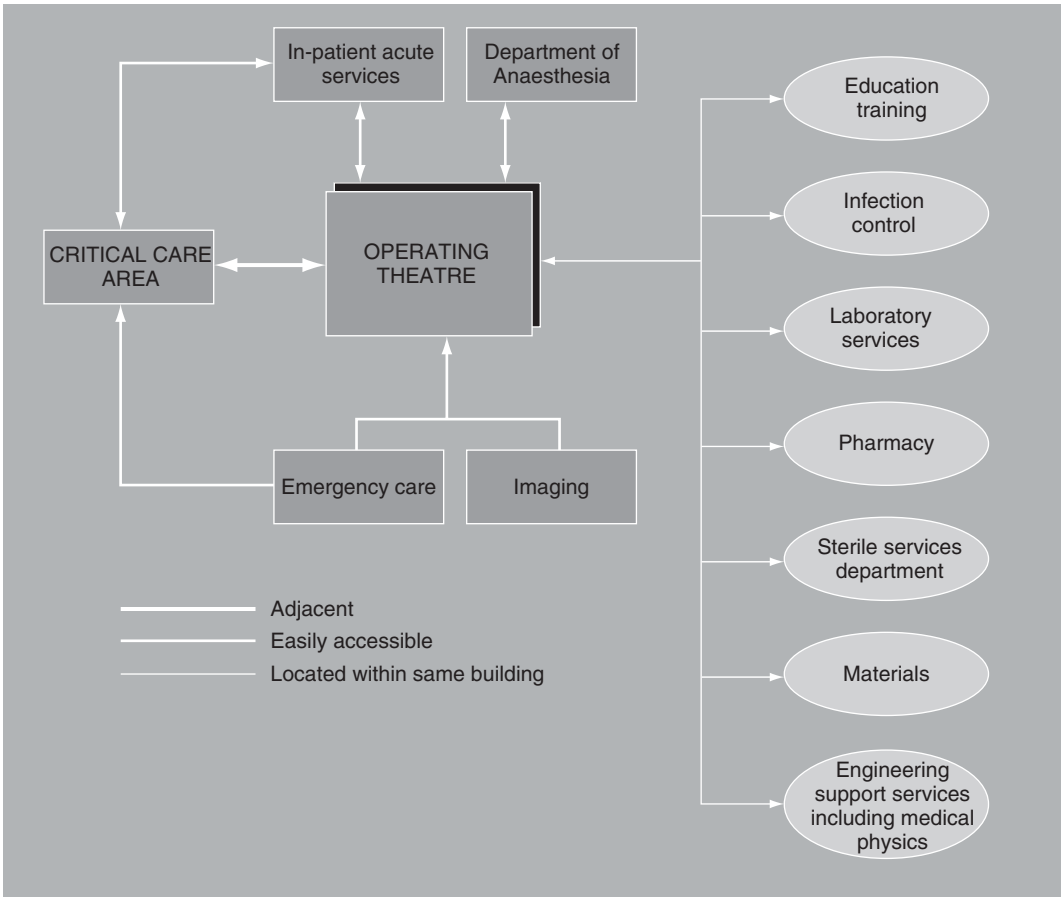
The department should be located next to the A&E and near the OPD with as direct an access as possible for in-patients. (Satellite departments in, for example, the AED are not generally cost-effective.) The layout should allow access to some diagnostic rooms outside working hours without opening the whole department (Figures 19.11 and 19.12).

4.4 Inpatient nursing care

The ward concept

Beds for in-patients in hospitals are grouped, for effective management, into wards of anything from 20 to 36 beds, under the charge of a sister or charge nurse who is supported by a team of qualified nurses, student nurses and aides. This team has to ensure that

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19.9 *Diagram illustrating the relationships between an operating theatre and other hospital services. Source: Health Building Note 26 volume 1*

patients are monitored, fed, allowed to sleep and use toilet facilities, kept clean, treated if required and encouraged to move around (Figure 19.13).

Patients will be taken from the ward to other departments for more complex diagnostic testing and treatment. Doctors will visit ward patients at least daily and other staff will come to administer treatment such as physiotherapy.

The ward will be supplied with food, linen, pharmaceuticals and sterile goods and will hold equipment such as wheelchairs, drip stands and walking frames. Used returns and refuse in various categories will be collected on a regular basis.

Two factors have come to radically influence the design of inpatient hospital wards in recent years.

Firstly, the recognition that, although beds may be grouped in clusters of 20–30 the nurses' responsibility is allocated to a smaller number of patients, normally around 12. Thus, the historically centralised staff base has been replaced by a number of smaller bases, each allocated to a nursing unit of around 12 beds. These contain the necessary facilities for managing the allocated group of patients but the clerical component of the ward administration is centralised to a facility for the Ward Clerk, usually at the entrance to the ward to allow monitoring of visitors to the ward area. A group of these clusters, containing up to 60 beds, provides a manageable unit for the provision of facilities management services such as catering and cleaning.

The second and more significant debate revolves around the provision of single bedrooms and multi-bed bays. Previous use of six-bed bays, heavily utilised by Best Buy and Nucleus together with other standard template designs, is no longer acceptable. More significantly strong arguments have been made about the use of 100 per cent single bedrooms. Clearly, the capital cost is higher but the counter arguments around control of cross infection, ability to isolate Hospital Aquired Infection (HAI) patients, reductions in medication errors, more dignified and quieter patient environments, more confidential discussions between patients and clinicians, all combine towards a strong case for 100 per cent single rooms. Ideally, each room should have a similar plan, i.e. not being a pair of handed rooms.

There are arguments against single room provision. Companionship in a strange and stressful environment is a benefit to many. Patients within a multi-bed ward also support each other when necessary, summoning staff, for example. The debate will continue but experience in Europe, particularly Denmark, indicates that such provision is a tangible, and provable in terms of Evidence-Based Design, factor in the elimination of HAI.

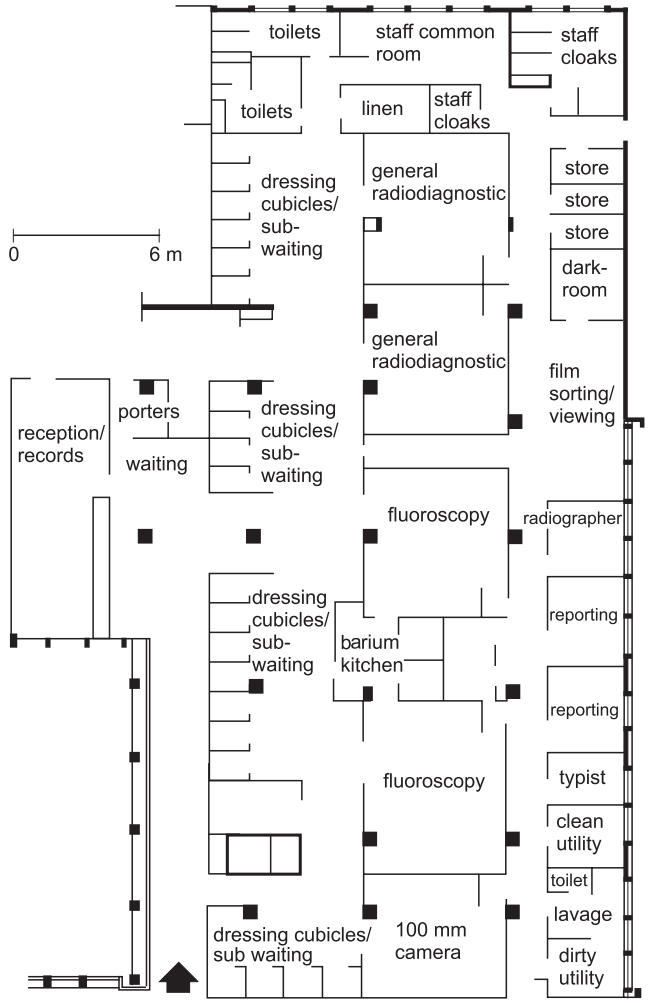
With so much claim on ground-floor locations, wards tend to be on upper floors unless, like geriatric and children's wards, they have a particular need for access to outside space.

Wards occupy about half the total area of a hospital so it is not possible for all wards to be adjacent to the most relevant departments. For surgical wards, location on the same floor is generally considered satisfactory on the grounds that horizontal travel is more predictable than vertical travel by lift. This is particularly pertinent to paediatric wards where lift travel following surgery is considered a high risk.

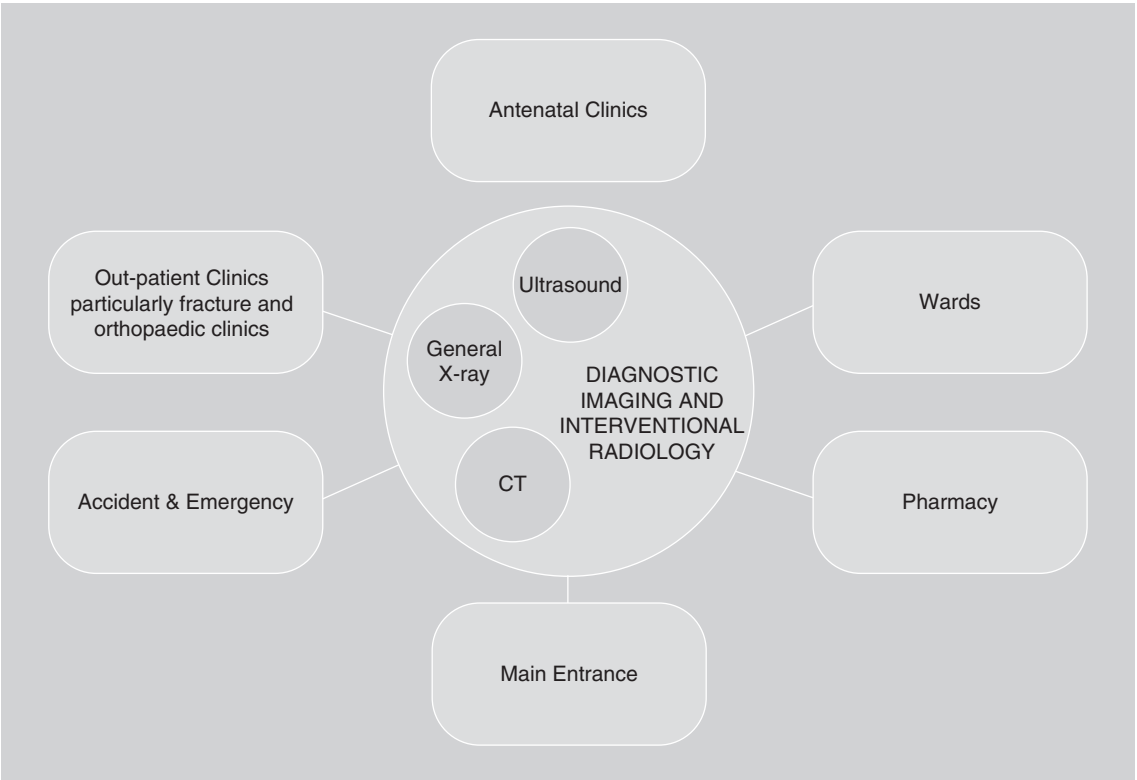
Wards cater for many types of patient such as surgical, medical, paediatric (children), elderly, intensive therapy but it is important that a common general pattern be adopted as far as possible so that changes of use can be made without disruption. High-dependency provisions including Intensive Care have such specific requirements that they cannot generally be provided within an acute ward design. Paediatric wards also have particular requirements such as overnight accommodation in the bed area for carers and are generally subject to specific design solutions.

Architects should refer to Health Building Note 4 for further details on ward design.

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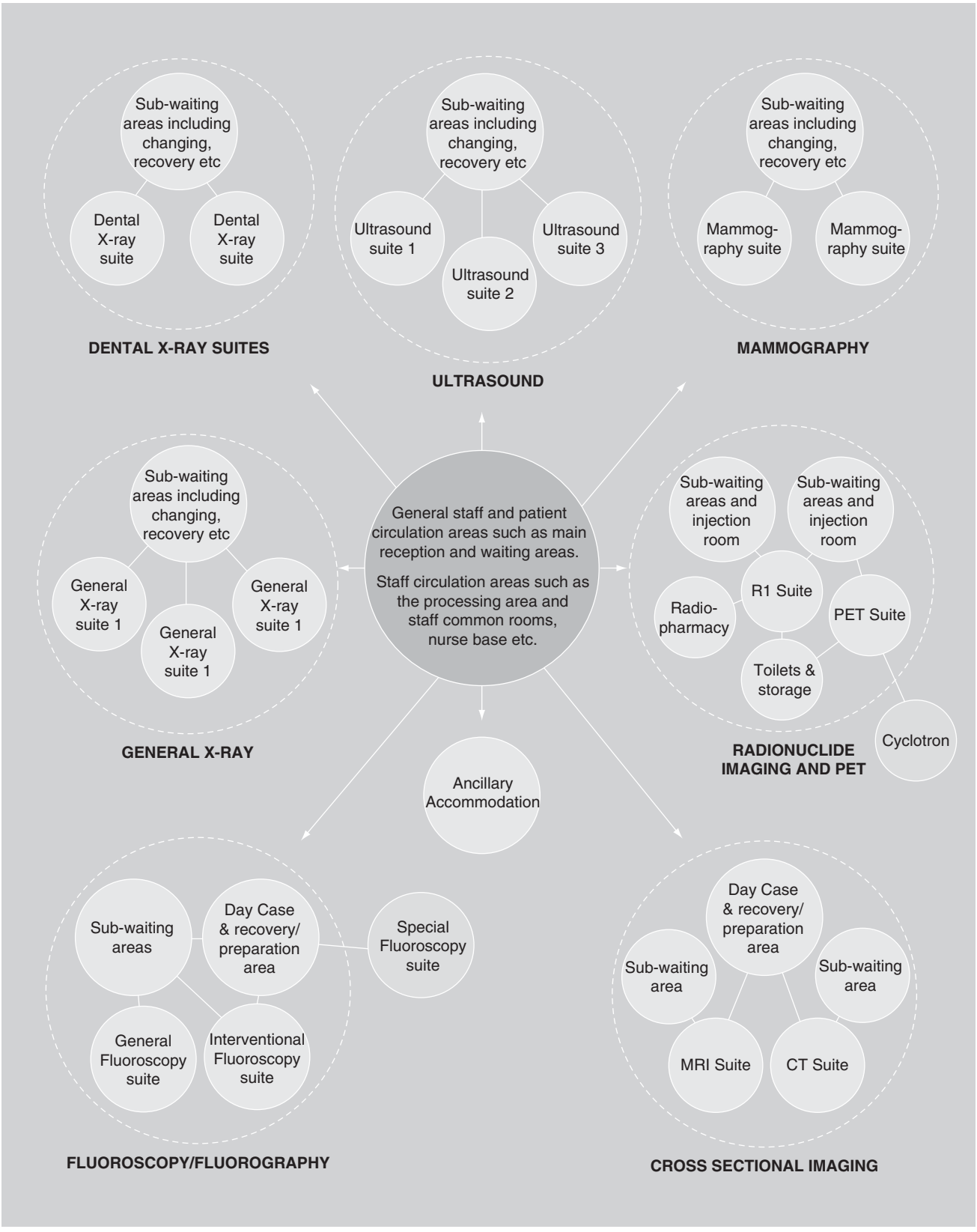


19.10 *X-ray Department at King Edward Memorial Hospital, Ealing. This illustration depicts a film approach to taking and developing X-rays. Digital techniques (known as Picture Archive and Communication, PAC, facilties) are more flexible*



19.11 *Diagram showing relationships between diagnostic imaging departments and other hospital units. Source: Health Building Note 6*

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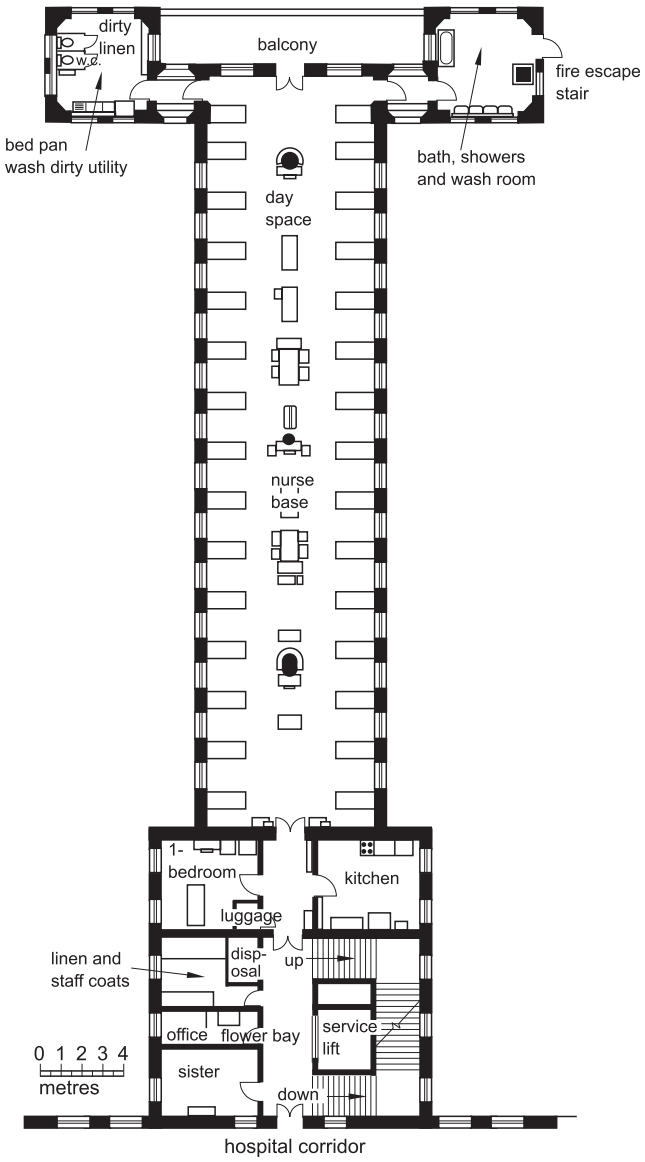


19.12 *Diagram showing relationships between different imaging areas within a hospital. Source: Health Building Note 6*

Ward types

- *Adult acute wards* accommodate general medical or general surgical patients. Although a ward generally will accommodate either one or the other (for doctors' convenience and efficiency of location) there is no significant difference in their facility needs and the ward is standard in its area provision and layout. Between half and three-quarters of a hospital's beds are to be found in these wards. Stroke rehabilitation wards would also generally follow the pattern of a general acute ward. Cardiac wards can generally be of a similar format to a general acute ward although the provision of telemetry to monitor vital signs to a central location provides for greater flexibility in the use of single bedrooms (Figure 19.14).
- *Children's wards* vary from adult acute wards in the greater areas devoted to day/play space and the need for access to an outside play area, the provision of education facilities and, of course, the specially designed fittings and furniture. Separate provision for adolescents is an important consideration as educational and recreational provisions are not compatible with

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19.13 *Nightingale ward in St Thomas' Hospital. Although the traditional Nightingale Wards provided excellent observation for nurses and some reassurance for patients, lack of privacy (and perhaps dignity) and increased disturbance was felt to be compromised*

lower age ranges. Provision for separate accommodation for males and females becomes significantly more important for this age range.

- *Wards for elderly people* again have more day space than adult acute wards because these patients spend longer in hospital and are ambulant for more of the time. Providing dignity and separation of sexes can be preserved, accommodation for elderly patients may benefit from a limited provision of multi-bed accommodation.
- *The intensive therapy and high dependency* units hold seriously ill patients, often transferred direct from the operating theatre. Significantly more space is required around the bed for monitoring and other equipment. Bed centres of 4.5 m are required for Intensive Care compared to 3.3 m in acute care. No day space is required, and the bed areas are designed primarily for efficient nursing. Because of the high staff/patient ratio, the size of the ward is usually limited to about 20 patients and a more usual provision at a district hospital (i.e. serving a population of 300 000) is between 10 and 12 bed spaces. The Planetree Foundation in the USA have devoted particular effort to providing critical care facilities which enable the patient to be nursed in a highly technical clinical environment but providing accommodation for relatives and carers to be in close contact without compromising care or hygiene requirements. Refer to Griffin Hospital, Derby, CT.

4.5 Outpatient services including pharmacy

The function of the OPD is to diagnose and treat home-based patients and if necessary admit them as in-patients. It is one of the largest departments in the hospital and is visited by the greatest number of patients daily. It is, therefore, best accessed directly from the main hospital entrance. Separate OPD facilities for children may be considered in the context of a hospital wide policy for children's services.

The patients' first point of contact is the main OP reception desk from which they are directed to the sub-waiting area serving the suite of consulting rooms in which their clinic is being held (Figure 19.15). The building block of the department is the consulting/examination suite which can be a number of combined Consult/Examination (C/E) rooms or some combination of consulting rooms and examination rooms. Combined C/E rooms are generally described as single or two sided, depending on the provision of permanent access to one or both sides of the couch. Typically single sided access requires 14.5 m^2 and two sided 16.5 m^2. The side to the right of the patient is prioritised for the staff.

In the combined C/E room, the doctor will both consult with the patient and examine the patient on a couch; while the patient is dressing, the doctor may move to an adjoining C/E room to deal with another patient and the rooms should, therefore, have interconnecting doors. Issues of confidentiality between rooms need to be carefully considered in these circumstances as without intrusive acoustic protection privacy will be compromised. In the consulting room + examination rooms arrangement, the patient moves to the separate room, undresses and waits for the doctor. The normal provision is an examination room either side of a consulting room. Because of the greater flexibility of space the C/E room provision is considered to have better utilisation. In a clinic where there is rapid throughput, a consultant, registrar and house officer may occupy a string of six or seven combined C/E rooms; where the throughput is slower (e.g. psychiatry), each doctor will occupy one room only.

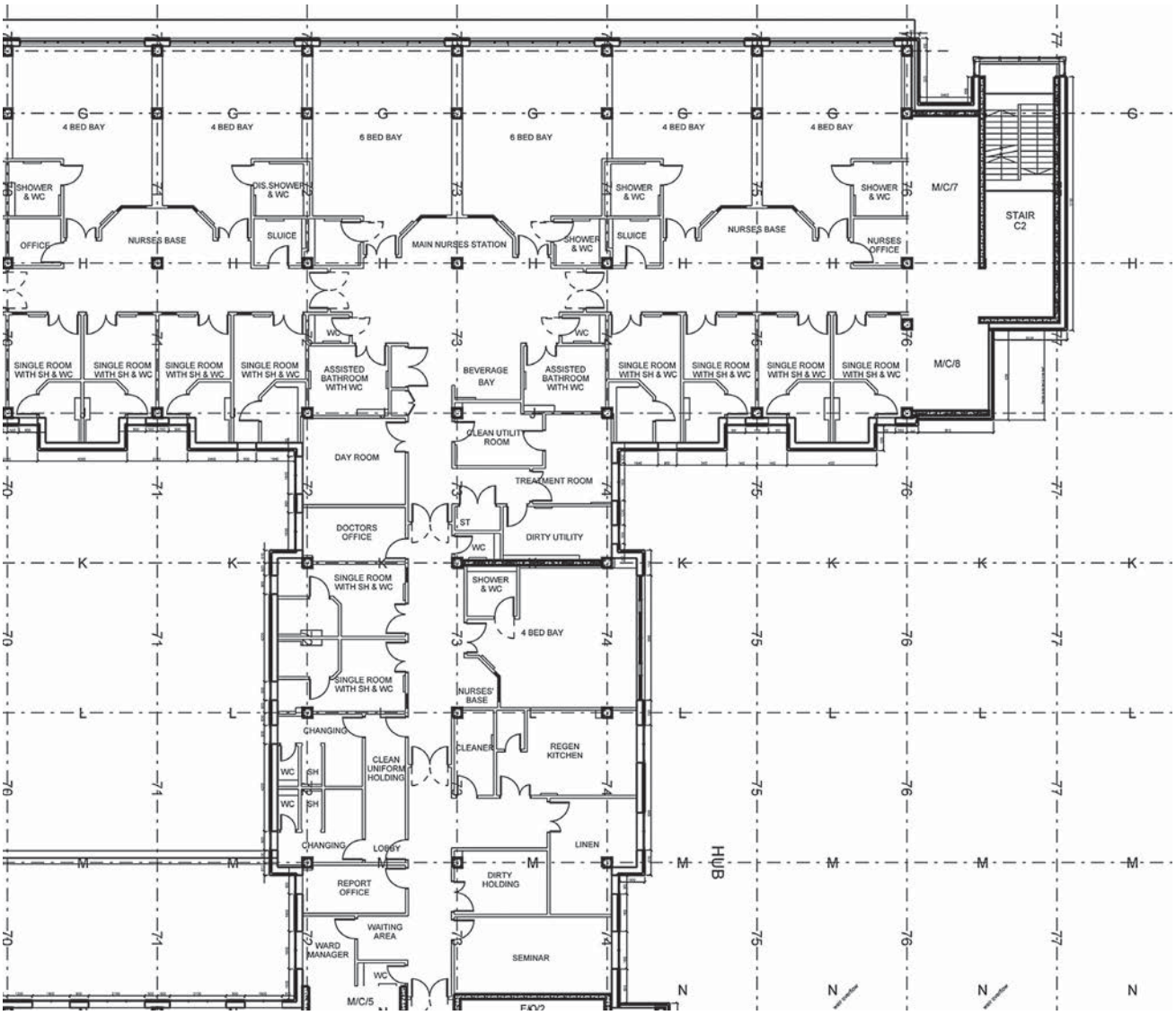
To provide such flexibility, strings of at least 6 rooms, and preferably 12, are required. This can, however, make it difficult to provide an external view for the sub-waiting area, a provision valued more highly in Scottish guidance. The potential further flexibility of these rooms being used, or converted for use as treatment facilities, suggests that this consideration be made at an early design stage, in particular, the room size and ventilation requirements. All consulting rooms should have an external wall location with natural ventilation and consideration of privacy needs to be made when overlooking may occur, in particular across a courtyard.

A move towards Rapid Diagnostic and Treatment Centres (RDTC) has resulted in the increased provision of facilities where the concept of a 'one stop shop' means that in some cases diagnosis and treatment can occur within the same visit. All diagnostic tools are provided within the facility and although the patient visit lasts longer, up to 5 h, consultation, diagnostic procedures and treatment in one visit substantially improves that patient experience.

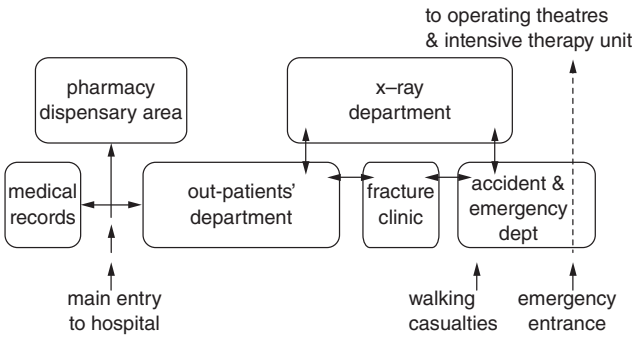
Orthopaedic and fracture clinics are often provided as part of the A&E department since many of their patients are receiving follow-up treatment resulting from injuries and some accommodation, like the plaster room, can be used in common.

Centralised pharmacy services, which may include manufacturing and preparation of intravenous fluids, are making increased use of robotic dispensing, particularly for outpatients and ward boxes. It is less necessary for the pharmacy to be located adjacent to the

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19.14 *General acute ward at The University Hospital of Coventry and Warwickshire. This could be split down the middle as the wards are a matching unit. Architects Nightingale Associates*



19.15 *Relationship diagram of out-patient and accident cluster*

outpatient service although the provision of a dispensing facility close to the main access point for outpatients is necessary. See Figures 19.16–19.20

4.6 Day patient services including ISTCs

Improvements in anaesthetic techniques and the vastly increased use of 'keyhole surgery' endoscopy and laparoscopy together with laser surgery have enabled routine invasive and ophthalmic procedures to be carried out in one day meaning that a patient does not require an overnight stay.

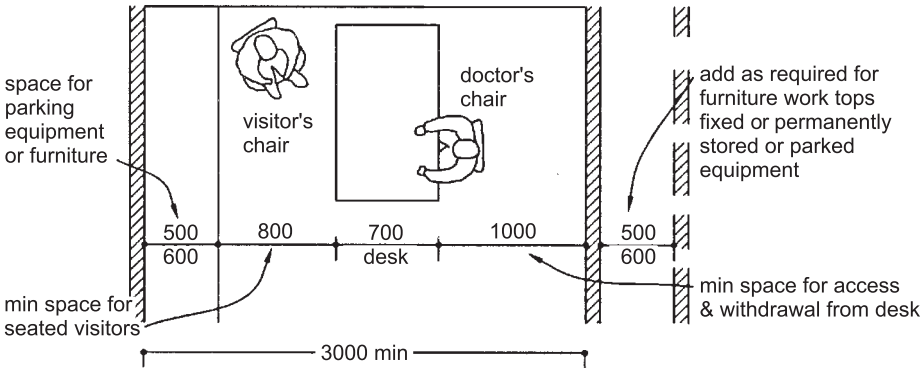
Day surgery operating theatres are generally designed and equipped to a similar level as inpatient theatres and often include an ultra clean hood, a ceiling mounted enclosure which provides a highly effective low-velocity hepa filtered environment, sometimes to the extent that surgical staff wear full body ventilated suits. Such provisions were previously exclusive to orthopaedic surgery and are still critical to this specialty but are in more general usage.

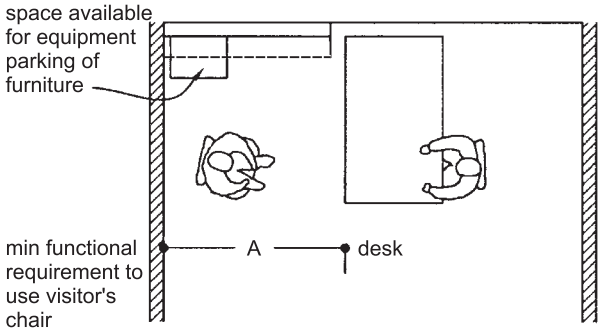
Day surgery theatres may be provided within the main operating department; however, the principle of day surgery facilities is to separate the elective (i.e. planned) service from the disruption caused by emergency admissions and procedures. Although potentially less efficient in theatre usage, day surgery theatres are often located adjacent to the outpatients department providing a centralised service for all non-inpatient clinical interventions. Such facilities are known as Ambulatory Care Centres.

Pressures on waiting lists have generated an increased scope for partnership between the NHS and the private sector. One such instance is the Independent Sector Treatment Centre (ISTC). These facilities, including staff, are provided by the private sector and the private sector partner is contracted to provide a prescribed service level over a prescribed period in a contract which transfers the estate related risks to the private sector. There are a number of ISTCs currently in operation.

Increasingly minimally invasive surgery (keyhole surgery) is likely to be used in the future, and as the trend towards moving

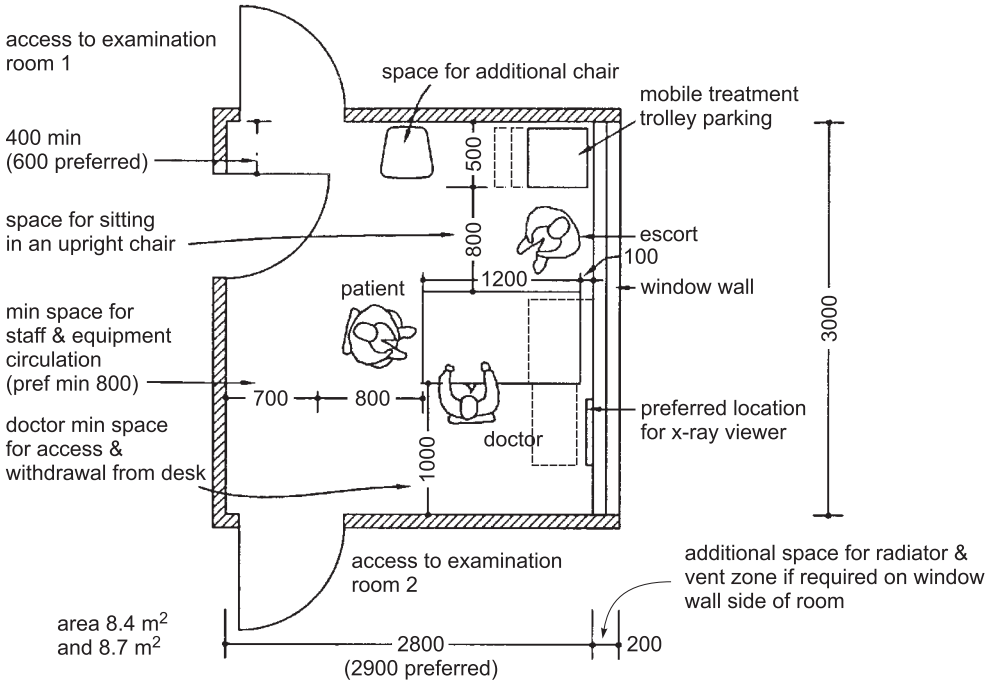
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19.16 *Space requirements for room width in consulting areas*
Dimension A:

- *minimum 1200 mm, psychologically unsatisfactory. The space in front of the desk should be larger than that behind*
- *preferred minimum 1300 mm giving more flexibility in arrangement and use of the space in front of the desk, and psychologically more acceptable*
- *1400 mm is the minimum permitting movement past a seated visitor*
- *1500 mm will permit passage behind a seated visitor*



19.17 *Separate consulting room*

care closer to the patients' home continues will move into locations further removed from acute hospital sites.

4.7 Rehabilitation services

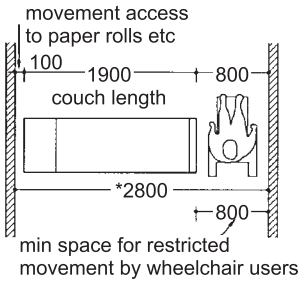
To encourage an integrated approach to patient treatment, the rehabilitation department encompasses a number of therapies:

- *Physiotherapy*: Dealing with problems of mobility and function using natural approaches such as movement and manual therapy, supported by electrotherapy, cryotherapy and hydrotherapy.
- *Occupational therapy*: Improving patients' function and minimising handicaps through the holistic use of selected activities, environment and equipment adaptation so that they can achieve independence in daily living and regain competence in work and leisure.
- *Speech therapy*: Dealing with communication problems, either individually or in groups, if necessary by introducing alternative methods of communication; family members may be involved and family counselling plays an important part.

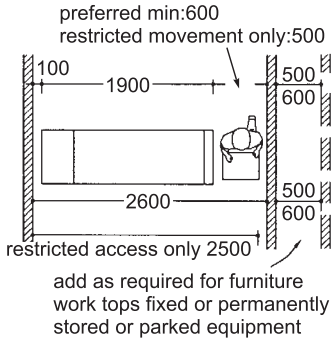
In addition, accommodation is needed for consultant medical staff.

Patients may be disabled: the department may need its own entrance if it is remote from the main entrance and must be near to car parking.

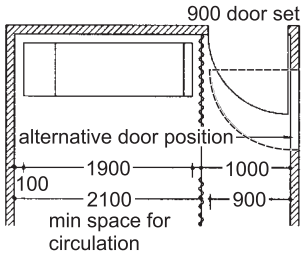
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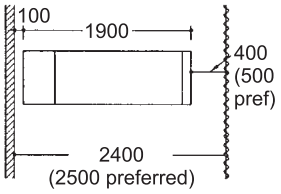
a *Access at foot end of couch for wheelchair movement. *2800 mm is also the preferred minimum dimension room length when standing workspace at foot or head ends of couch is required*



b *Where wheelchair movement at foot end not required*

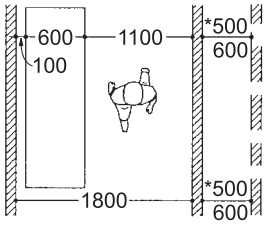


c *No access across foot end of couch*

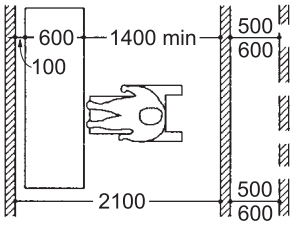


d *Minimum for restricted sideways access within curtained area*

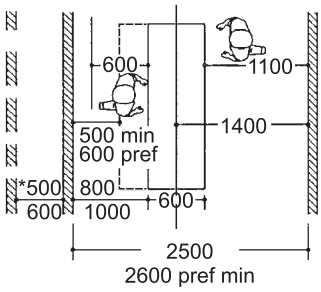
19.18 *Space requirements for room lengths in examination area*



a *Access to one side of couch only. 1100 mm is the minimum space for an ambulant patient changing*



b *Access to one side of couch only. 1400mm is the minimum space for a wheelchair patient changing*



c *Access to both sides of couch*

600 mm is the essential unobstructed space for access and examination
1100 mm is the space at the side of the couch for changing 1400 mm is the space at the side of the couch for wheelchair access
800 mm to 1000 mm is the clear workspace at the side of the bed or couch for examination and treatment, preferred minimum 900 mm
**add as required for furniture, workshop or equipment, which may be fixed, permanently stored or parked.*

19.19 *Space requirements for room width in examination areas*

In some instances, staff from the unit may require regular visits to outlying areas to provide services at home or in local health-care facilities. This may include the transport of equipment and the co-location of parking facilities for these peripatetic activities should be considered and discussed with planning authorities.

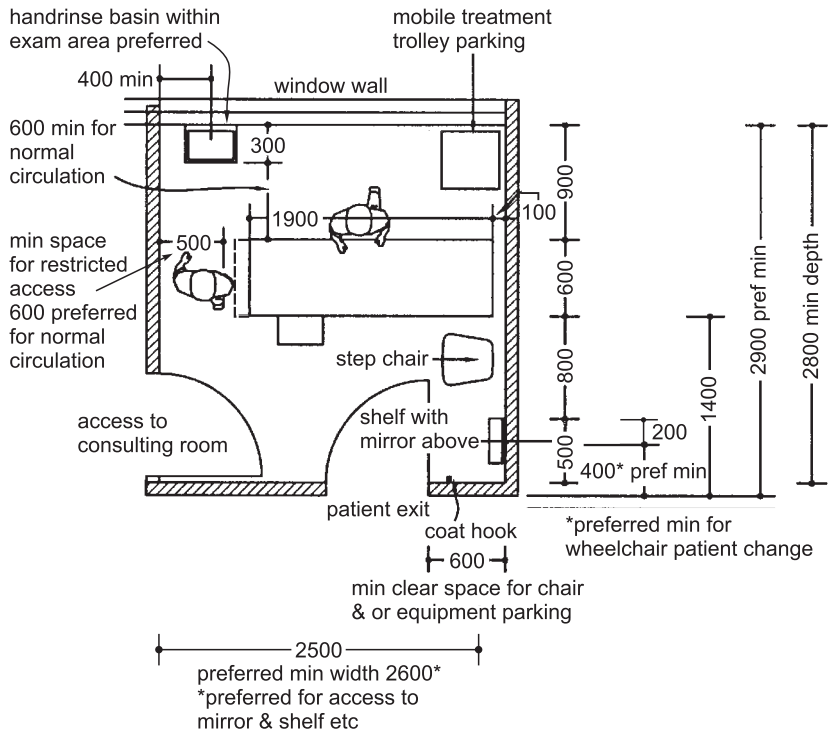
There are no strong internal relationships except between hydro-therapy and physiotherapy and between the central waiting space and all treatment areas. This generally means a close association with the Out-patients department or Ambulatory care unit described above.

4.8 Children's services

The needs of children are best met by having them together in children's units, nursed by staff with the relevant qualifications. Accommodation is required for out-patient facilities; compre-hensive assessment and care (for the investigation, treatment and diagnosis of children who fail to develop physically or mentally); in-patient facilities in 20-bed wards; and a day care unit.

The out-patient unit and assessment accommodation should be on one floor, either at ground level or served by a convenient lift, near to

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19.20 *Separate examination room: area 7 m² and 7.6 m²*

public transport and car parking. The out-patient unit should be near the plaster room and fracture clinic and could adjoin the main OPD.

In the children's ward, the need for observation is greater than in an adult's, but the need for privacy is less and more partitions can be glazed at both high and low level. All bedrooms should consider the need for a parent to stay with a child. Play space is required and space for teaching and physiotherapy; this should include outside areas, although these may double with other functions such as eating.

Avoiding an institutional atmosphere in the design is important in adult wards but even more so in children's: a light and sunny atmosphere should be the aim. Graphics and themes should be developed to stimulate, enable an understanding of the areas of the unit without the assumption of reading ability, and enable children to associate themselves with a particular area and become more comfortable with their environment. The Evelina Childrens Hospital at St Thomas' Hospital by Hopkins Architects and RKW is a good example of the development of the brief and the accommodation in consultation with children.

The accommodation generally will need to provide for infants, toddlers, school-age children and adolescents: the design should as far as possible take account of their varying needs.

4.9 Older people's services

More 'acute' elderly patients – those undergoing assessment or rehabilitation – are in most respects satisfied by the design for adult acute wards.

The development of Hospital Trusts and the separation of services into acute and mental health provided by separate Trusts has inevitably resulted in the dislocation of the services, often to different sites. It should be recognised, however, that elderly patients often have mental health difficulties alongside medical episodes. The reverse is also the case that mental health patients have medical demands in addition to mental health problems and facilities for the management of these issues should be considered as a component part of the accommodation.

Longer stay elderly wards, including those for the mentally infirm, should be more like home than hospital and include a higher variety of room types to accommodate different preferences, and more day space. More storage space is required for storing patients' belongings, including suitcases, mobility aids, continence aids, etc.

4.10 Maternity services

Policies concerning maternity care can vary widely and client policy towards the whole maternity process should be established at the outset. Co-location of Womens' services, and the co-location of Womens' and Childrens' services should be considered.

Nearly all births take place in hospital but current trends are towards increasing antenatal testing and, on that basis, prioritising cases so that low-risk ones can be delivered in the community (at home or in a community hospital) while higher-risk cases are dealt with in the hospital where operating theatres and other back-up facilities are closer to hand.

A strengthened community care service, with midwives accommodated in community clinics or local health care resource centres, could deal with most of the antenatal care process and minimise the need for visits to the hospital antenatal clinic. Such buildings would incorporate spaces for antenatal exercise classes and mother and baby clinics.

A number of philosophies concerning delivery may be encountered. Traditionally, the woman would be admitted direct to the delivery room or, if admitted early, to an antenatal ward. During labour, she would move to a separate delivery room – perhaps in a suite, central to all the maternity wards and near to the neonatal unit for the nursing of small or ill babies – for delivery of the baby, then returned to a postnatal ward which would be designed to allow rest following birth and to allow the mother to get to know her baby.

An alternative, used routinely in the USA, is the 'complete stay room' (or LDRP room – labour, delivery, recovery and postpartum) in which the whole process is enacted and which may include accommodation for the mother's partner. The provision of a birthing pool is another option with implications for the structure and infection control issues.

Within this range, there are many possible scenarios, each with its own implications for ward facilities (such as day rooms and sanitary provision) and for provision for abnormal delivery.

Occupancy of maternity wards is variable, throughout the year and with population changes. In principle, they should, therefore, be planned for easy conversion to adult acute use, although this might be difficult with some options such as the complete stay room. In the postnatal ward, the baby will be nursed in a cot alongside the

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mother, although nursery accommodation should also be provided to enable the mother to get some much needed rest on occasions.

The out-patient suite will incorporate a suite of consulting/examination rooms and supporting facilities; waiting areas which can double as space for classes and clinics; and a diagnostic ultrasound room with associated changing and waiting areas.

The design approach in all maternity accommodation should centre around the fact that the pregnant woman is not sick but undergoing a natural function: there is no strong reason for the environment to be particularly clinical in appearance. Concealing obvious clinical elements such as medical gas outlets behind removable folding panels greatly reduces the clinical appearance.

4.11 Mental health services

The scope of facilities for mentally ill people on the hospital site is subject to local initiative. It is, however, likely to include accommodation for the assessment and short-term treatment of adults, including the elderly, who are acutely mentally ill: this group of patients is most likely to need the support of diagnostic services and access to general acute facilities. They also gain from sharing catering, supply and disposal services.

The primary elements in the department will be the wards of 15 beds for adult patients and 20 beds for elderly patients and the day hospital which includes consulting, treatment and social areas together with occupational therapy. Very few adults will remain in the wards during the day but if ward and day hospital are intended to share day, dining, sitting and recreation facilities, experience has shown that full integration is required for this to work successfully.

The department should ideally be integrated into the hospital so as to facilitate communication but be independent enough to have its own (not too clinical) environment, although comments above under older people's services should be noted. Its configuration is unlikely to match that of other wards and evening activities may be disturbing to other in-patient departments. One solution is to plan it as a satellite with its own entrance, perhaps linked to the main hospital and possibly sharing some accommodation with an adjacent rehabilitation department. Although there are exceptions a ground-floor location with good access to safe, secure and observable external spaces is a high priority.

Within wards, the current recommendation of Building Note 35 is for 100 per cent single rooms. This caused some concern related to staffing levels and observation when introduced but has generally been accepted as the norm and has not shown substantial increases in staffing requirements. The wards should consider the needs of patients with varying levels of dementia. Functional and organic dementia provoke very different responses by patients to their environment, however it is still standard practice to nurse both groups of patients in the same ward area. For this reason, all wards should consider patients' needs for wandering, continuous walking, often on a circular, racetrack type route, and a variety of environments which provide either stimulation or a calming effect. Clinical discussions and handover between shifts, because confidential, tend to take place in the sister's office which, therefore, needs to be larger.

Psychiatric out-patient clinics are generally held in the main OPD. Many patients never enter the psychiatric department but others may attend the day hospital from one to three days a week, undertaking various types of occupational therapy and group therapy. They are also given a mid-day meal in two sittings. These activities can be accommodated in a number of rooms with comfortable sitting space for 10–20 people. Electro-convulsive therapy (ECT) may need to be accommodated: it requires treatment and recovery rooms but they would only be in use for perhaps 4 h a week and should be usable for other purposes.

Environmental design generally, particularly of the interior, is of even more importance in this department than elsewhere. Providing a non-institutional appearance, domestic scale and a 'sense of place' should be high priorities. Soft floor coverings may be appropriate for some non-wet areas but the need for cleaning after 'accidents' has resulted in a preference for a hard but non-institutional surface, hardwood floors are particularly successful; divan beds and careful choice of soft furnishings are crucial in creating a suitable atmosphere. Sound attenuation is needed for all rooms used for confidential interviewing; noisy areas (e.g. music room, workshop) should be located to reduce nuisance.

4.12 The Hi-tech specialties

A number of Hi-tech specialties are being introduced, some more quickly than others. These are dependent on specialist design and not within the scope of this chapter.

Robotically Assisted Surgery almost exclusively uses the 'Da Vinci Surgical System' – however, the costs associated with this technique are immense and it is not anticipated to be in general use for more than a very limited number of specialties.

Imaging, particularly interventional radiology, open MRI, which is less claustrophobic for the patient, and the co-location of MRI and Cardiac Catheterisation are developing activities which will see an increase in the shorter term.

Some subjects, such as 'Barn' theatres where a number of operating tables, with ultra clean hoods are located in the same room, have had a small impact on service delivery. Space savings are achievable though not considerable and the opportunity for surgeons to work across more than one table without leaving a sterile area has advantages.

5 SUPPORT SERVICES – OUTSOURCING

The following services are either now outsourced facilities (i.e. provided externally by third parties) or require little direct architectural input:

- sterile services/decontamination;
- pathology – hot, cold, automation;
- catering;
- linen service;
- supplies and disposal/clinical waste management;
- health records (policy debates regarding the retention of paper records or transfer to a digital database are ongoing).

6 PUBLICATIONS AND GUIDANCE

The Department of Health and previously NHS Estates have over years produced much valuable reference and guidance material. However, the very extensive scope of this material, the changing methods of service delivery and technological advances have meant that keeping the publications up to date is a task that has not been universally successful. Two key components of the guidance, Health Building Notes (HBNs) and Health Technical Memoranda (HTMs) are fundamental.

Both HTMs and HBNs have been contained within briefs for new hospitals either as mandatory or advisory documents. Such usage is unfortunate as although parts of the documents can reasonably be considered as mandatory, those related to infection control for example, it is rare for a whole document to be relevant. This has led to a demand for derogations and a loss of the spirit of most of the material which is intended to be for guidance and modification to suit particular circumstances.

It is, however, essential to have access to these documents in order to engage in informed dialogue during the design process. The documents are available online to the NHS only via the Department of Health Knowledge and Information Portal (KIP) but only available outside the NHS via third party construction industry information suppliers.

It is essential to discuss the relevance and status of the guidance with the Department of Health at the time of design.

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20 Hotels

Fred Lawson

CI/SfB: 85

Fred Lawson is a hotel expert and the author of many books on hotels and tourism.

KEY POINTS:
- *Competitive industry with high capital and operating costs*
- *Standards dictated by market demands and location*
- *Increasingly dominated by chain operators and branding*
- *Design must ensure efficient operation and value for money*
- *Ancillary facilities may be a major generator of business*

Contents

1 Introduction
2 General considerations
3 Guestrooms and suites
4 Public areas
5 Back of house facilities
6 Case studies
7 Bibliography

1 INTRODUCTION

1.1 The hotel industry

Hotels serve the needs of travellers, tourists, business visitors and others seeking temporary accommodation and other services. Essential requirements are clean, quiet and comfortable bedrooms together with good services that usually include meals. Ancillary facilities for business users and/or leisure attractions often influence choice although the costs involved and value for money are primary considerations.

Prior to the design stage many of the key requirements will have already been decided such as the location, number and types of rooms and the extent of facilities to be provided. Preliminary estimates of costs and revenues form part of the feasibility analysis for the investment. Design briefs are normally provided by developers, including hotel companies who may be involved in managing the property.

The trend is towards multiple chain operating groups specialising in hotel management. These offer a wide range of services including professionally trained staff, established confidence in the standards provided and the advantages of scale in their advertising and reservation systems. Chain hotels may be company owned but are frequently financed by separate investors and then operated by the hotel company under contract or through a franchise.

Hotels are seen as a business investment rather than property investment. The specific design requirements generally make future conversion to other uses difficult and expensive. High grade hotels typically offer a choice of suites as well as standard rooms and often extend their hotel services to apartments in associated developments such as in condominiums. Aparthotels are designed with apartments, instead of individual bedrooms.

1.2 Hotel classification

Standards of services and facilities in hotels vary widely from luxury to basic. Hotel groups distinguish the types of hotels they operate by branding with specific names and design features. Tourism authorities in most countries use symbols (stars, crowns, etc.) to classify hotels and other types of tourist accommodation. Some commercial agencies and travel publications also grade their members by prices and services offered.

Hotels are primarily categorised by their location (e.g. city, suburban, resort, country, airport, motel) and also by the main markets they serve (e.g. business travellers, convention groups, holiday seekers, motorists). Typical categories cover:

- 5* Luxury: exclusive named hotels in exotic destinations and prime city locations.
- 4* High class: with extensive facilities for business users and high spend tourists.
- 3* Mid-grade: full service traditional hotels, independent or company managed.
- 2* Budget: standard branded designs with some services for motorists and tourists.
- 1* Basic: economy brands designed with minimal space and limited facilities.

Grading also takes account of the extent of services offered. Staff requirements in a full service hotel are substantial with payroll absorbing up to one-third of the turnover. Designs must ensure maximum working efficiency and provide adequate employee facilities including controlled entry, separate changing rooms, lockers, toilets, restroom, canteen, security, personnel offices and – often – some living accommodation. Ratios of employees to guestrooms range from 0.2–0.3 budget, 0.5–0.6 mid-grade, 0.8–1.0 high grade, to 1.5 luxury standard.

Demands for value and convenience have led to increases in standardised chains' budget hotels (e.g. motels, inns) sited with highway service stations or around towns and near attractions. Some brands are designed to provide basic facilities operated with a minimum of staff.

1.3 Other tourist accommodation

Internet tourism services provide choice from a wide range of alternatives including domestic properties (e.g. B&B, guest houses), traditional inns and vacation use of university and college accommodation. Tourists, particularly families, increasingly choose self-catering facilities in new or converted properties and resort areas with alternative choice of eating places nearby.

Resort complexes are developed as self-contained tourist destinations complete with extensive leisure facilities and supporting services on site. Most are designed as seaside, marina, ski, spa, golf or forest-based holiday village resorts. Tourist resorts may be operated by a commercial company, or co-ownership management. In the latter, accommodation is based on apartments, lodges and other properties for sale on individual, time-share or condominium arrangements.

2 GENERAL CONSIDERATIONS

2.1 Sites and surroundings

The location and site largely dictate the design and relationship of the different parts of a hotel:

- Resorts – views of the attractions (e.g. sea, lake, park, spectacular scenery) provide marketing and higher value revenue benefits. This should be maximised for guestrooms and public areas such as restaurants. Interesting site activities (e.g. marina, golf course, swimming pool) and exotic landscaping also influence the layout.

- City centre developments – these are determined mainly by site constraints and planning considerations. High site costs may lead to high value frontages being used for shops and malls; penthouse floors as luxury serviced apartments or suites. Invariably, development costs are increased by the need for underground parking and basement services, including goods entry and docking. Multiple floors of guestrooms require extensive guest and service lifts as well as complex technical systems. The need for ancillary facilities such as convention/function halls can occupy a large part of the site area.
- Key city sites – these allow for high rise statement buildings which, themselves, attract attention. They may be designed entirely as a hotel or for multiple users with specific floors allocated for hotel accommodation and services. The latter requires more complex separate arrangements for guest reception and transportation as well as for goods services. Tower buildings require large structural core areas housing vertical services (lifts, stairs, ducts, service rooms, etc.) and the ratio of perimeter rooms per floor area is limited.
- Suburban sites – here site and construction costs are lower and allow greater flexibility in site layout and building design. There are savings in foundation and structural costs, technical services are often simplified and lift systems may be rationalised. These include hotels sited within or near airports on the outskirts of towns, or in locations which attract a mixed market of tourists, local functions and business travellers.
- Roadside and stopover places – these cater for motorists and other travellers and are invariably chain operated budget designs, with standardised rooms and minimal facilities for meals. Typical buildings are modular with prefabricated technical services, one or two storeys in height. Optimum sites are associated with other motorway services along highways, at main junctions and near attractions along tourist routes.

2.2 Access and site development

In the preliminary design stage, consideration must be given to:

- Restrictions, including planning, property rights and other legal limitations, which may limit plot ratio and height of building.
- Access routes to separate guests from goods delivery/services and employee entries.
- Site planning for parking requirements and potential future extensions.
- The main entrance must be prominent, appropriate for the style and grade of hotel. In urban hotels, secondary access from the car park must lead directly to the reception lobby. A separate entrance and reception may be required for large convention/function groups.

Car parking space depends on the location, patterns of use, transport modes and availability of public parking/taxi services. Motor and airport hotels typically provide 1.1 spaces/room, city centre hotels about 0.3 spaces/room plus 0.2 spaces/convention or function seat. Resort hotels may require only 0.2 spaces/room plus coach parking.

Provisions must also be made for separate staff parking.

2.3 Spatial and functional relationships

The functional requirements of a full-service hotel can be grouped into three distinct but linked areas: public, guest room and back of house/administrative (Figure 20.1).

2.4 Public areas

For guests and usually open to non-residents, public rooms include lounges, restaurants, bars, meeting rooms, ballrooms and other rooms catering for functions. Other facilities, such as fitness rooms, spas and leisure pools, may also allow for local club membership. Typical requirements include:

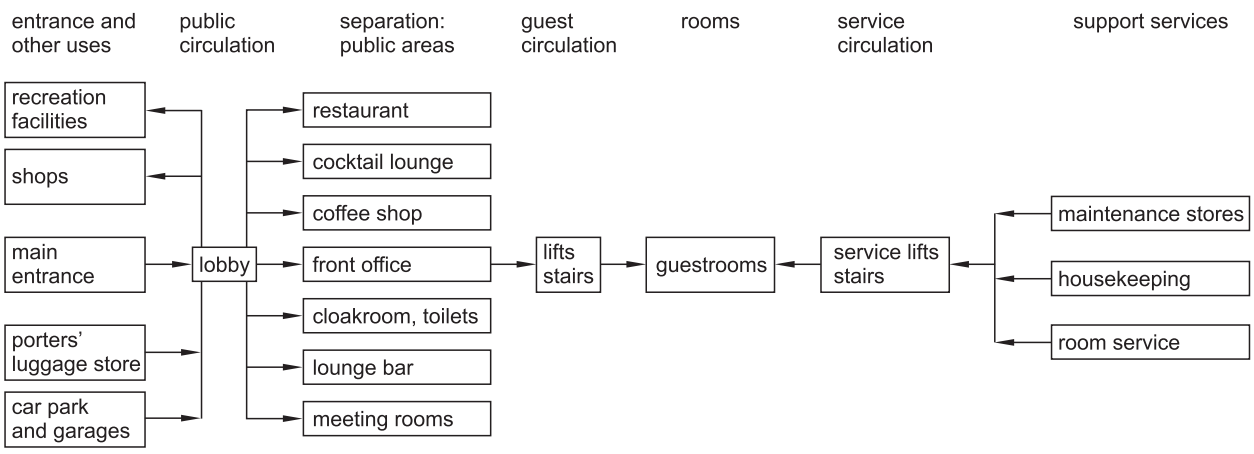
- large span spacious areas, to accommodate planned numbers of users and allow changes in layout and design to suit different requirements.
- situated at or near ground floor level to allow easy access, control and emergency exit.
- external views required for restaurants. Speciality restaurants and bars may be sited at roof-top level in tall buildings with dedicated lift access and services. In lobbies and convention/function halls an impressive, spacious interior design is important. Natural light is an advantage in lounges and break-out foyers.
- support areas (e.g. foyers, equipment stores, food service facilities, staff access) must be sited adjacent or easily accessible with effective screening to avoid disturbance in use.

2.5 Guestrooms

Bedrooms and suites for resident guests are located to benefit from views and designed to minimise noise and disturbance. Residential accommodation is the largest generator of net revenue and typically occupies some 70–75 per cent of the built area in full service hotels, see Table I.

Design features include:

- repetitive modular construction of rooms adjacent to vertical ducts enclosing pipes, cables and other technical services;
- careful planning of stairs, lifts and corridors to facilitate easy circulation and access for guests;
- guest circulations via the main reception area while staff have direct access from back-of-house areas (e.g. house keeping, laundry, kitchens, maintenance, stores);
- specific requirements apply for disabled access, fire escapes, security, safety and noise reduction.



20.1 *Circulation and relationship diagram*

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Table I Residential area ratios

Grade	Basic	Budget	Mid-grade	High-grade	Luxury
Room area (net)[(a)]	17.5	21.7	25.2	30.0 (+5%)	36.0 (+5%)
Gross factor[(b)]	0.25	0.25	0.3	0.4	0.4
Gross residential area[(c)]	22	27	33	44	53
Public & support areas[(d)]	5.5	8	12	18	22
Residential % of total	80%	77%	73%	71%	71%

(a) Median areas (m^2) for European hotels. 5% suites included for higher grade hotels. American hotels tend to use larger rooms

(b) Depends on building format. Higher grade includes part use of single loaded corridors.

(c) Figures rounded

(d) Increased to 22 for high grade hotels in developing countries and for hotels with extensive convention or casino facilities

2.6 Back of house and administration areas

These accommodate the technical and operational installations including staff facilities and workrooms. They are located in the least valuable areas with vehicle access for goods delivery and waste/recycling removal, maintenance and emergency services. Facilities include:

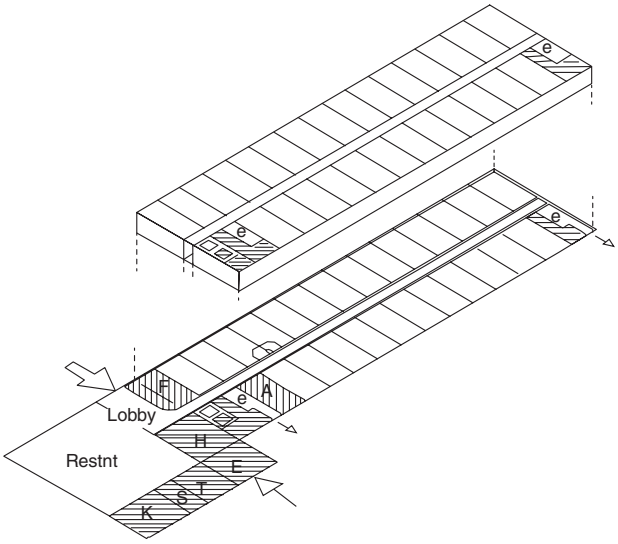
- Basements in large hotels and high value sites. Lift motor housing and ventilation/air-conditioning plant sited in screened roof top locations.
- Separate areas for loading docks, waste containment, control, storage rooms, engineering, housekeeping, laundries, employees, and main food storage and production.
- Internal service access (separate from guest areas) to guestrooms, and from service areas to public rooms (restaurants, bars, function rooms, furniture/equipment stores).
- Separate facilities for hotel administration are required. Offices for duty management are located near the reception lobby with access to the reception desk.

2.7 Circulation and signage

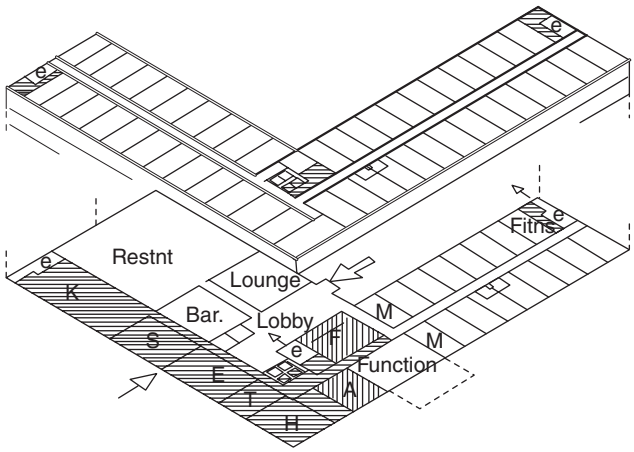
Routes to be taken by guests, non-residents and staff must be carefully planned to facilitate easy movement and control (Figure 20.2a–c). This also indicates the optimum locations for support facilities and the services required. All routes must be kept clear of obstruction and be wide enough to avoid congestion, particularly in areas where people congregate (e.g. reception desk, foyers, lift lobbies, luggage handling, service areas). Signs are required for directions and information, including evacuation routes. Graphic design must be an integral part of interior design and be co-ordinated throughout. Approved symbols must be used and all signs must be sited within normal viewing patterns.

2.8 Corridors and staircases

Corridors, stairs, ducts and room service lobbies add to net room areas, increasing the built areas and costs. Circulation in public

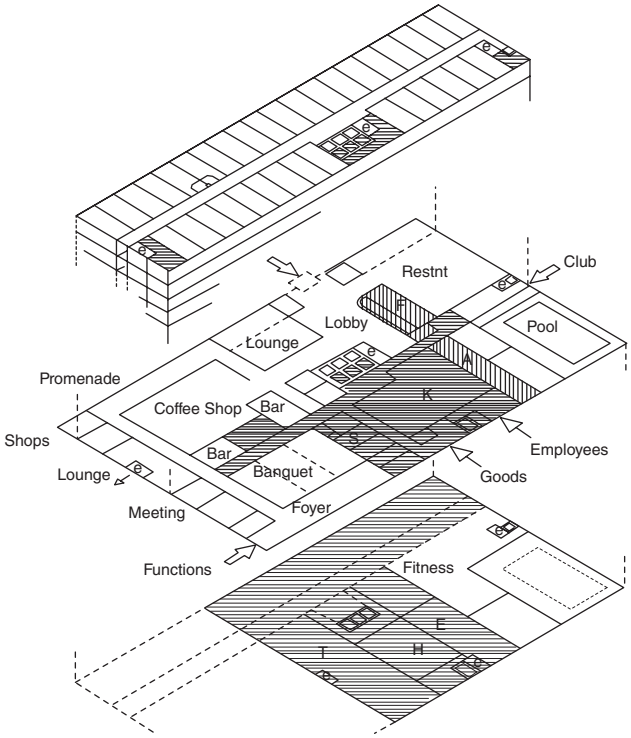


20.2a *Basic or budget hotel with restaurant illustrating the service arrangements (shaded). Guest rooms are generally in two storeys*



20.2b *Typical midgrade suburban and motor hotels, providing a wider range of public and function/meeting rooms with extended service areas. Residential areas are two or more storeys high and may be arranged as a square around a central lawn or enclosed atrium accommodating the restaurant bar areas.*

20.2 *Examples of three typical hotel types*



20.2c *Simplified diagram of public, residential and services areas (shaded) of a high grade multi-storey hotel.*

Key: A, administration and security offices; e, fire escape stairs and exits; E, employee entrance control, changing areas, toilets, canteen/restroom, Personnel offices; F, front desk and office; H, Housekeeping and general storage areas; K, primary kitchen and storage areas with access to finishing kitchens serving individual food and beverage outlets; S, storage for function room furniture and equipment; T, Technical plant and equipment

spaces should, wherever possible, be through areas of other use such as the lobby, lounges or shopping malls.

In residential floors, economic considerations (gross factors, corridor lengths) generally require bedrooms to be sited on both sides of the corridor. Typical gross factors are central 'double loaded' corridors 20–30 per cent, and 'single loaded' corridors and tower buildings up to 35–45 per cent.

Corridor and staircase design is dictated by fire regulations and codes. The main stairs should be prominently located beside the lift bank to allow easy alternative use and evacuation.

Secondary stairs must be provided at or near the end of each corridor and within the maximum travel distances allowed.

For corridors with sprinkler systems allowing two alternative means of escape this distance is usually 60 m although 90 m may be permitted. For one route of escape (suites and rooms beyond the end staircase) this is reduced to 9 m. Automatic self-closure smoke doors must be provided midway along the corridor. All exits must be clearly indicated, protected by smoke doors or ventilation control, meet fire resistance standards and lead to safe evacuation areas. (See Section 2.16 Fire safety.)

2.9 Lifts

Lift installations are generally required for guestroom floors above the second storey. The lift entry for guests must be visible from the reception desk and monitored by cameras on each floor. Guest lifts must be set back from corridors, have wide opening doors for easy access, good lighting and ventilation and have durable surfaces to resist damage by baggage. Floor leveling at landings is important.

Lift shafts must meet requirements for structural stability, fire resistance of shafts and doors, smoke venting and control. Machine rooms housing motors, pulleys, controls and hoisting beam are normally located above the shaft. All lifts must have safety mechanisms and efficient control systems, including emergency power, lighting and lifting gear together with fire over-ride controls with return to lobby or exit floor.

Performance requirements for large high-grade hotels:

- Carrying capacities – maximum number of passengers to be carried at peak times based on business pattern, and guestroom population.
- Waiting times – depend on round trip time and numbers of lifts installed but a good service for high standard hotels is around 25–30 seconds in peak use.
- Inter-connected collective controls – advanced signaling on landings are necessary in tall hotel buildings. In large hotels, banks of lifts are grouped in facing rows of no more than four with adequate space for assembly (3.5 m wide for guestroom lifts).
- Specialist installations – include basement car park lifts with fire safety provisions, direct lifts to leisure facilities and transparent lifts in atriums. High rise buildings may require fire protected enclosures with separate power supply and controls for fire fighting access.

2.10 Service lifts

- Separate provision of service lifts is needed for housekeeping and room services.
- Typically in the ratio of 1:2, 2:3 or 3:4 guest lifts depending on standards.
- Lifts open on to service lobbies and pantries on each floor and are commonly grouped back to back with the guest lift shaft.
- Service lifts extend down to the back-of-house areas and are designed for practical use transporting staff, trolleys, supplies and equipment.
- At least one must be large enough to take furniture such as a bed or, in emergency, a stretcher requiring direct transfer to ambulance.
- Large hotels may require a heavy duty lift for goods/equipment transfer from loading docks, including convention exhibits.

2.11 Environment

The internal environment must be attractive, engender confidence in the operation and leave a favourable impression. Each area will need to meet specified needs of space and facilities to achieve the design objectives within its allocated budget. In general, interiors and fittings must be safe, resist damage and be easy to repair or replace. Domestic furniture and furnishings are usually not suitable or sufficiently robust for hotel use.

2.12 Lighting

Lighting should assist in providing an appropriate environment, differentiate spaces, and illuminate signs and hazards.

- Light sources and controls are selected to serve particular requirements ranging from external flood lighting, to highlighting interior features and work areas such as reception desks, service counters and bars.
- Energy conservation in lighting, air-conditioning and power consumption is important in controlling utility costs. Provisions include zoned area regulation, guestroom electricity control with entry card, central energy recovery and recycling.
- Hotels must ensure that there is adequate provision of emergency lighting for safety and basic essential services. In high grade hotels, installed generators have capacity to meet all requirements. Automatic switchover is required.

2.13 Noise control

Hotels may necessarily be located in areas of high ambient noise such as highway and street traffic, airports and urban surroundings. Many hotel activities and equipment also generate noise externally (e.g. car parks, loading docks, generators and rooftop plant).

Internal work areas, plant rooms and other noise generating environments are largely grouped together in the back-of-house areas which can be separated or insulated from those used by residents and visitors.

Adequate standards of insulation are essential for rooms sensitive to noise intrusion particularly for the residential guestrooms at night. Sound insulation performance criteria for maximum ambient noise levels in rooms are usually based on Noise Rating (NR) curves covering a range of frequencies, for example:

- guest bedrooms: NR25 broadly an ambient level of 30–35 decibels;
- conference halls: NR25 with acoustic design to limit reverberation for clarity;
- smaller meeting rooms: NR30 including partitioned areas;
- restaurants: NR50 with noise/light screening from kitchens.

Construction of bedroom blocks is usually based on floor slabs with structural cross-walls which also provide a large mass and high density for good sound insulation and fire resistance. Acoustic treatment of flanking paths (e.g. bathroom ducts, ceiling voids, interconnecting doors) is necessary. Double glazing is usually required in busy urban areas with increased width/insulated spacing facing noisy highways. Insulation performance of various construction elements are expressed as Sound Transmission Class (STC) Ratings.

Provision must also be made for reduction of noise transmission through air-conditioning, plumbing and other installed systems as well as impact noise from lift movements. Measures include confinement of machine generated noise, reduction of vibration, design of distribution networks and sealing of ducts and voids.

Disturbance in bedrooms may also arise from internal sources. The design must minimise impact noise with resilient/absorbent floor-covering (carpets) as well as quiet door closures, locking systems, and moveable fittings. In adjacent rooms, noise generating areas such as bathrooms are grouped back to back and similar considerations determine the layout for quiet zones.

Public areas involve other considerations. Ballrooms and convention halls cater for large assemblies of visitors and

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alternative uses ranging from noise sensitive conferences and functions (speeches) to noisy entertainment. Noise control measures involve the location of public rooms away from residential areas and provision of foyers and service pantries as intermediary areas together with insulation requirements for the sensitive areas.

2.14 Safety

Providing accommodation for transient travellers and tourists who are unfamiliar with the layout and equipment, hotels need to have particular regard to their safety and security. Safety for employees and their work areas must also be considered.

Requirements are governed by statutory legislation, insurance conditions, hotel grading and operating standards. Safety features in all aspects of planning, design, operation and maintenance and the provisions for fire egress have a major influence on the arrangement of rooms and circulations.

2.15 Design checklists

For details of general requirements see Chapter 3 People and Movement and Chapter 11 Fire. Hotel design requires particular attention to the following.

Guest and visitor areas:

- Circulation: changes in floor level, positioning of signs, space for assembly.
- Stairs: maximum 16 steps between landings and minimum 3, non-slip with distinct edges, appropriate handrails.
- Door swings: landing areas, viewing panels, visibility of glass doors.
- Windows: glass specifications, method of cleaning, risk of accidental opening (locking/sealing), vertigo (sill height below 1120 mm).
- Balconies: safety/entry risks, structural stability, wind turbulence, drainage.

Service and work areas:

- Space: for work, equipment use, circulation.
- Ergonomics: (dimensions, shelf heights).
- Equipment protection: machinery, hot surfaces, flames (fire control), electrical safety.
- Environment: lighting (levels, shadowing), ventilation (temperatures, humidity, fumes).
- Fire: high risk areas, fire control, evacuation.
- First aid: locations, treatment facilities.
- Maintenance: requirements, accessibility, drainage

2.16 Fire safety

Protection and means of escape in event of fire imposes specific requirements in hotels. This is due to the large numbers of people who are sleeping in separate rooms, and are unfamiliar with the building and warning systems and need to be alerted and evacuated. Also, many guests may be elderly or very young, disabled, tired or inebriated. There may be large numbers of visitors attending functions or conventions, creating crowd control problems. In addition, staff are on duty intermittently, in different departments with few at night.

Requirements are:

- Fire loadings are high due to furnishings. Many areas present high fire risks (e.g. kitchens, stores, workshops, basement car parks).
- Minimum fire resistance periods for escape stairs are normally 1 hour, increasing to 2 hours for heights over 30 m. Basements require special provisions. Combustible material and surface flame spread ratings are controlled in escape routes.
- Sprinkler systems with fire mode ventilation switching, and alarm, smoke door and lift activation are commonly used in large hotels. Fire alarm, indication panel and hydrant systems must be installed together with portable and CO_2 extinguishers (for electrical equipment) in specific areas.
- Access for fire fighting vehicles, appliances, ambulances and other emergency services
- Tall buildings may require the provision of a fire fighting lift with independent power, external access and protected enclosure.

(See Chapter 11 Fire for details).

2.17 Security

Security is an important consideration for guests in unfamiliar surroundings, for confidential meetings and large group events as well as for control of loss and damage of hotel property. In operational terms security in hotels must be effective without becoming obtrusive or unduly restrictive.

By the nature of their business, hotels involve high investment costs in property and furnishings. They must be open to a wide spectrum of transient residents and visitors, many bringing valuable items. A high ratio of hotel employees are temporary with a high turnover rate and many services are contracted out. Theft, deliberate damage and vandalism are not uncommon.

Security measures include:

- Prevention of theft: construction (doors, walls, windows, access points), CCTV monitoring and sensor indicator systems, control of entry/exit through fire-escape and service doors, surveillance of car-parks, grounds, all hotel entrances.
- Control of entry: electronic card locking systems for residents and for staff (with restricted area access and master control). Staff and goods entrances through personnel and security controlled areas.
- Separation: residential lifts and stairs in view of reception desk. Planned and monitored circulations for restaurants, meeting/function rooms and support areas, service circulations separated from those for guests.
- Baggage: handling and checking controlled, baggage/lost property rooms isolated and have explosion relief.
- Administration: location and design of security offices. Banks of monitor screens and recording equipment, lockable secure interview room, direct lines to police, fire, ambulance and other emergency services.
- Hotel management: integrated computer systems of guest information, billing, accountancy, purchasing and stock records, employee and personnel details, maintenance, equipment and property records and contracts.

2.18 Hygiene

Hotels must maintain high hygiene standards to meet public health legislation and their reputation. This covers most areas, particularly design of food services, rubbish storage, water supplies, sanitation and air-conditioning including cooling towers.

2.19 Communication systems and services

The multiple functions involved in hotel operations call for highly sophisticated systems of telecommunications. Hotel management, finance, personnel, property operations, marketing, ordering and stock control, guest services and other requirements are increasingly computerised with automatic controls and customised software.

The rapid changes in equipment, installed networks and services have many implications in planning hotel buildings as well as for interior design, for example:

- High speed, large capacity external telecommunication network connections, receivers and booster equipment where required.
- Automatic back up installations, including power generators and information storage.
- Changes in requirements and mode of operation affecting design of reception desks and other departmental services.
- Extensive installation of sensing, monitoring and automatic response integrated computer systems for control of building engineering services, security, fire safety and other networks.

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- Provision of secure computer rooms with independent air-conditioning, work areas and associated equipment.
- Ensuring adequate access and space for maintenance and future changes in terminal equipment, cable conduits and ducts.
- Specialist design of cable networks including safe separation of different voltages, colour coding, access and detailed records.

Design of computer installations depends on the size, sophistication and complexity of hotel services ranging from fully integrated computerised systems in large high standard hotels to interfaced standalone systems and wi-fi supporting the required number of terminals.

2.19 Building engineering services

Requirements for technical and engineering installations vary with location, size construction and sophistication of the hotel. Guestrooms call for service ducts, conduits and tunnels to enclose pipe work and cables connected to each room. Zoned distribution networks are required for lighting, power, central ventilation and air-conditioning systems.

Site planning includes arrangements for foul and surface water drainage, utility connections, and requirements such as transformers. Most engineering services plant is located in back of house areas including basements. Ventilation and air cooling plant and other machinery is often located at rooftop level. High rise and complex buildings often require intermediary transfer/technical services floors. In all cases, space, access and facilities must be provided for maintenance as well as for future changes including additional requirements and replacement.

3 GUESTROOMS AND SUITES

3.1 Commercial criteria

Guestrooms take up between 65 per cent (luxury) and 85 per cent (budget) of the total built area of a modern hotel. The income from rooms is invariably the largest source of hotel revenue and makes the greatest contribution to gross profits.

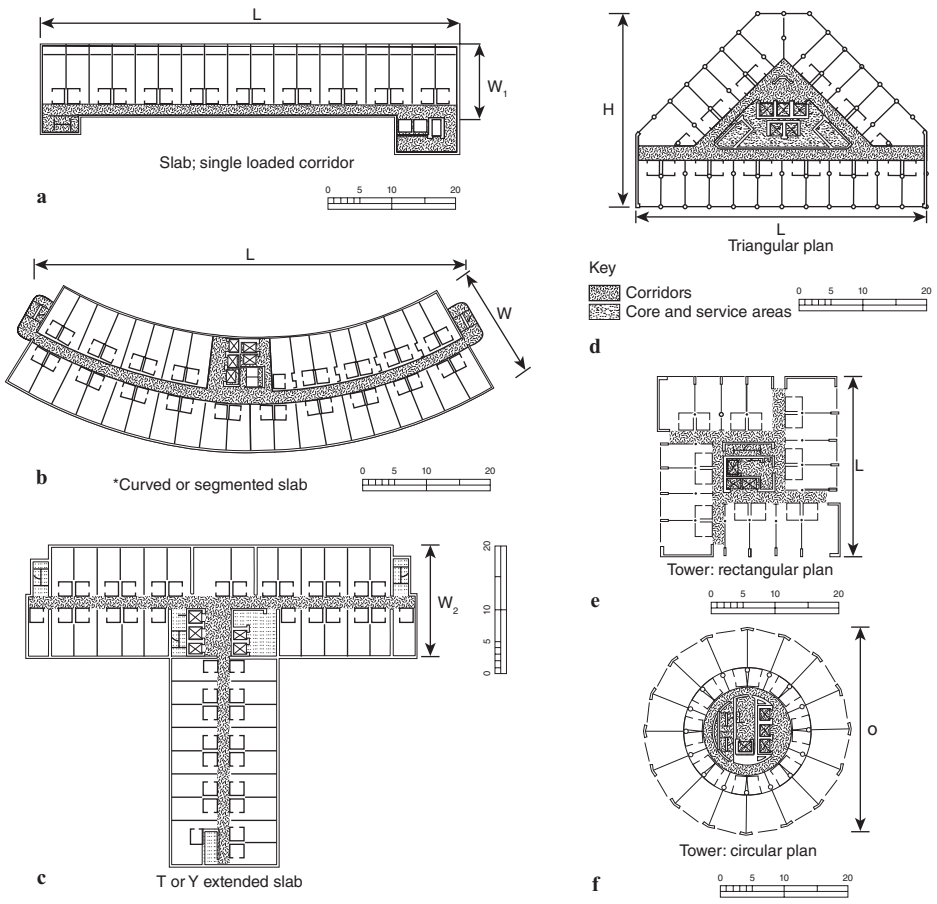
Requirements for guestrooms are largely dictated by market analysis of the potential users including:

- Main markets: demand for single, double, twin and family rooms. Work areas for business guests.
- Fluctuation: weekend, seasonal, etc. changes. Furniture and equipment. Adaptability.
- Quality and grade: standards of sophistication, size and room services. Suites.
- Lengths of stay: size and layout of rooms, amount of furniture and storage space.

Room dimensions are critical. A reduction or increase in room area is multiplied by the number of rooms involved. However, rooms which are too small are often visually restrictive or crowded, inflexible, difficult to service and liable to increase in damage.

3.2 Standardisation

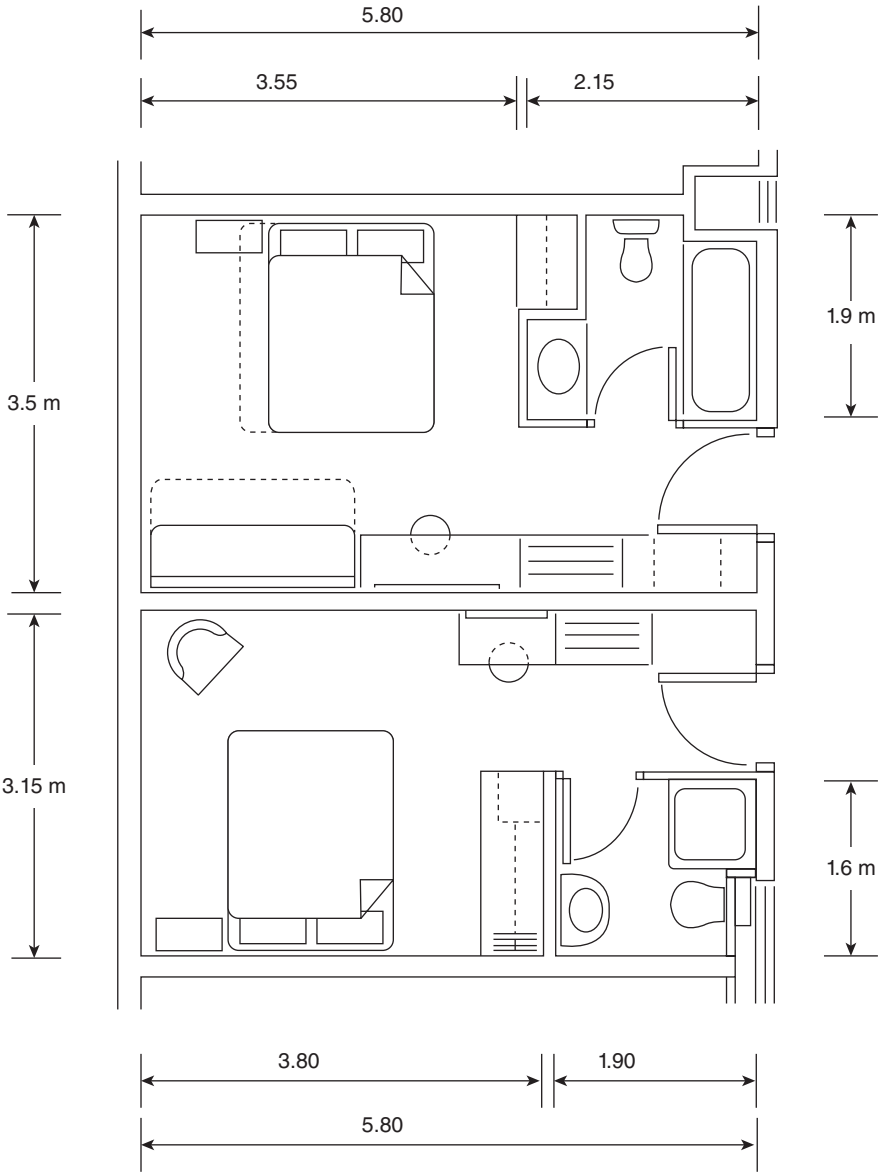
There are a number of generic block form hotel types ranging from linear to circular, Figure 20.3a-f.



20.3a-f *Guest room floor plans*

The configuration of guest room floors is largely determined by the site, orientation, support requirements of lower floors and lift arrangements. Slab construction is based on extended linear blocks which may be (a) single or double loaded, rectangular or (b) curved, or (c) T configurations or extended as an atrium round public spaces. Tower configurations include (d) triangular, (e) rectangular or (f) circular arrangements of rooms around a central structural core of lifts, stairs ducts and service rooms.

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20.4 *Reduced dimensions for economy hotels*

In multi-storey hotel buildings, repetitive modules from floor to floor are essential for structural design and location of service ducts. Hotel guest rooms are predominantly the same size and designed using similar furniture with options for internal arrangement. Standardisation of requirements is important for:

- cost and time savings in construction, prefabrication;
- uniform quality and pricing, particularly in brand design;
- efficiency in organising routines in housekeeping services;
- economy in bulk purchasing of equipment, furniture and furnishings;
- rationalisation of maintenance work and replacements.

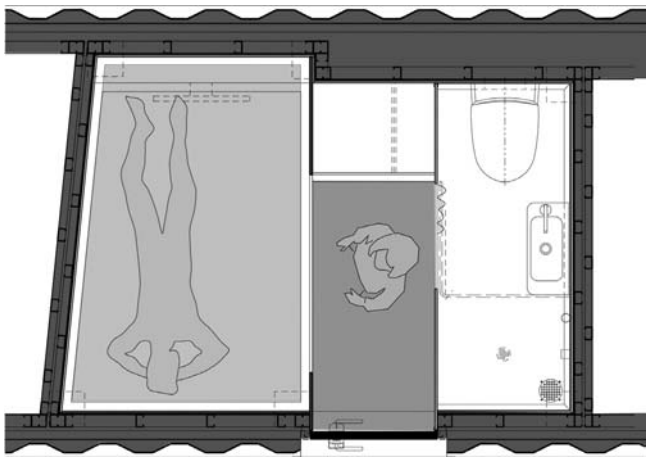
3.3 Room dimensions

Standard room widths are based on bed length of 2000 mm with wall furniture widths of 600 mm and circulation/activity space of 1000 mm adding to 3.65 m. For economy, this can be reduced to 3.5 m or increased to give a more spacious impression. Construction modules (to wall centres) add 200–230 mm.

It is important to ensure the most efficient use of room dimensions. Increase in width reduces the number of rooms or increases the length of corridors adding to gross areas and costs. Structural modules are invariably based on pairs of rooms sharing a common services duct.

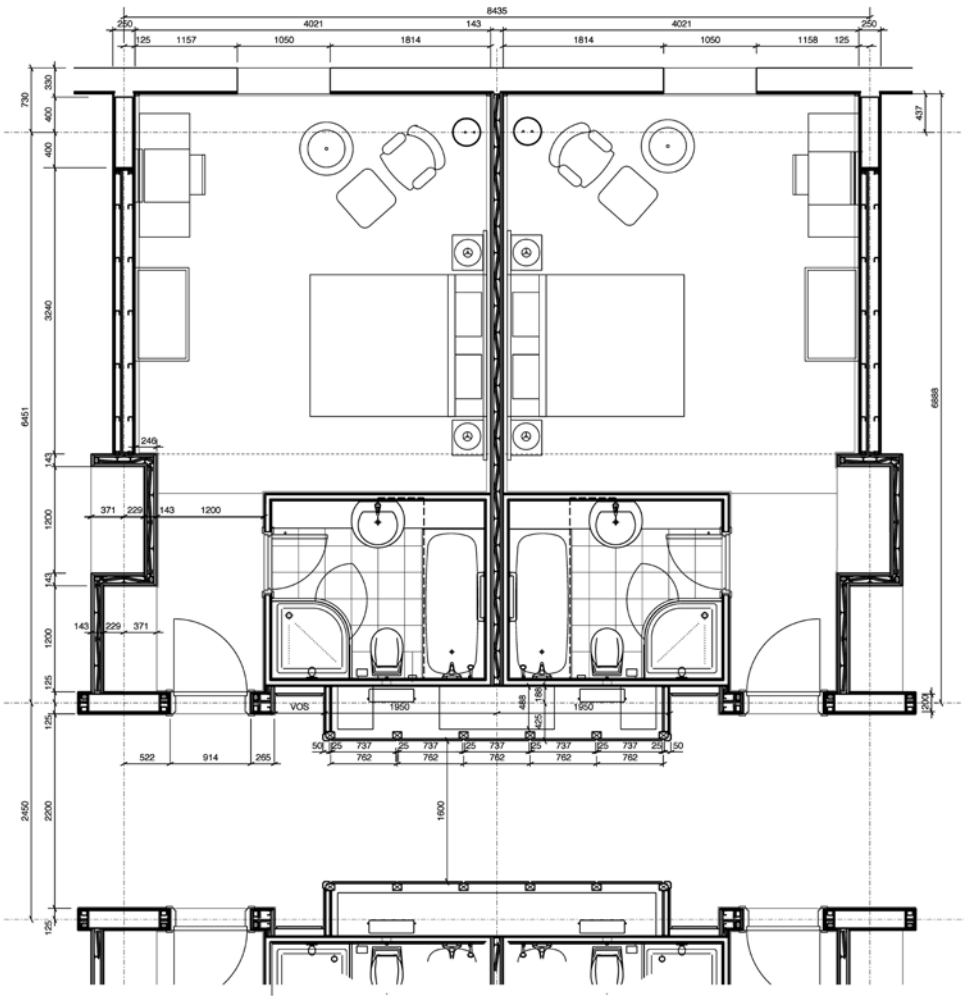
Room lengths are generally more variable although these may be dictated by site or structural restrictions. Bathroom dimensions are dictated by the number and spacing of fitments.

Net room areas vary with locations, land costs, standards and brand designs, Figures 20.4, 20.5, 20.6, 20.7, 20.8.

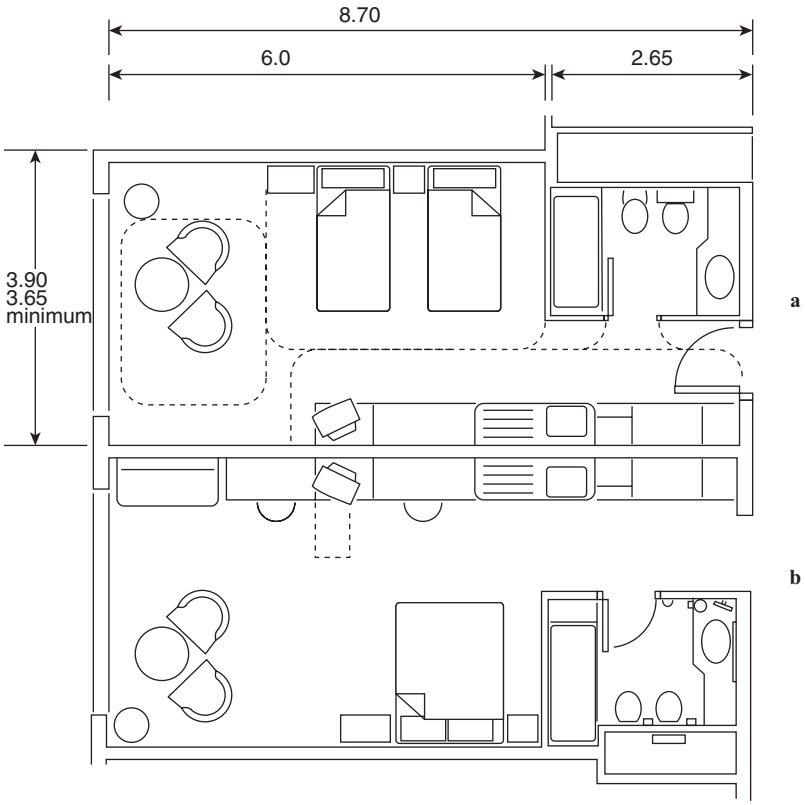


20.5 *Concept for a 2000mm x 2760mm bedroom in a converted shipping container (The Manser Practice)*

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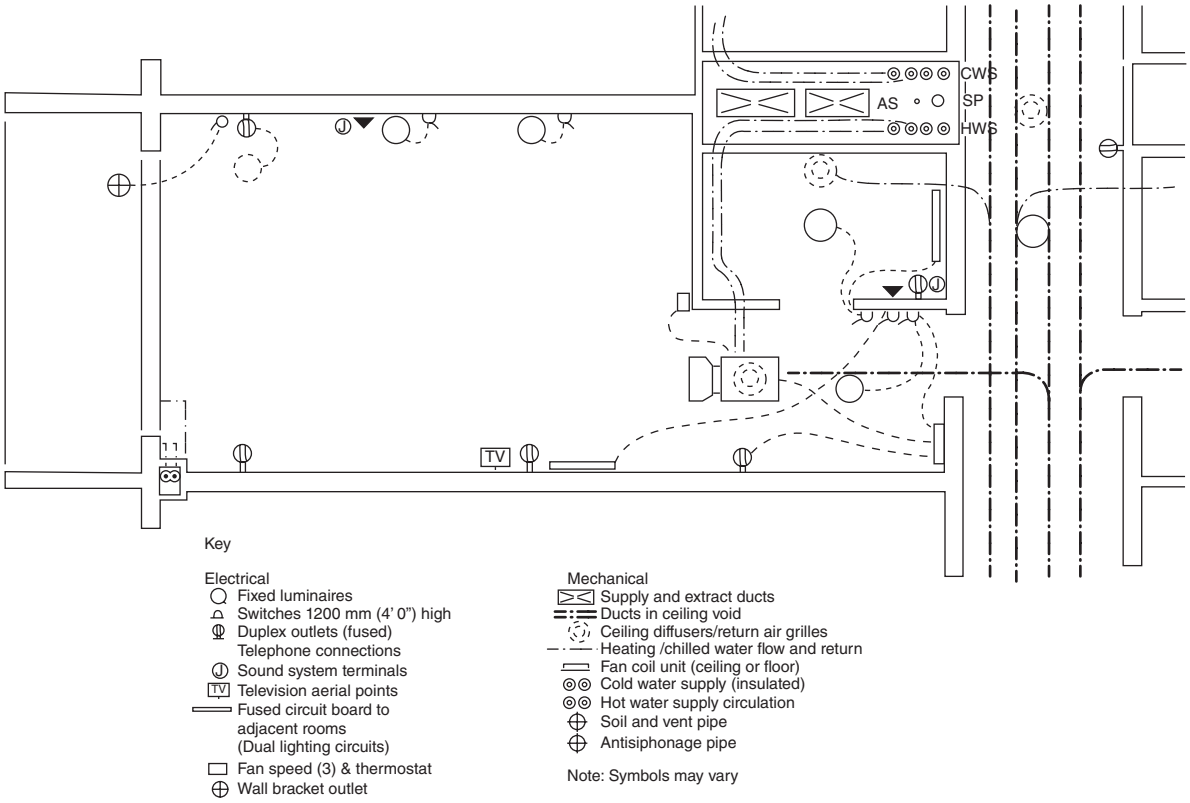


20.6 *Standard 28 sq m room designed for Gatwick Hilton (The Manser Practice)*



20.7 *Room layouts for a high grade hotel showing functional zones in a twin bedded room and an alternative double bed room with working area for business guests*

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20.8 *Technical installations in a high grade hotel guestroom*

Table II Typical room sizes

Typical standard	Area m²	Bedroom + bathroom and lobby
Basic (1*)	18	Shower or shared facilities
Budget (2*)	20–22	Variable use including families
Midgrade (3*)	25–27	Standard provisions. Twin rooms
High grade (4*)	27–30	Business and high spend users
Luxury (5*)	34–36	Individual designs. Variable layouts

(Note: Basic rooms adaptable for family use)

Table II gives typical sizes. In general, rooms are designed for double occupancy allowing flexibility in use.

3.4 Functional zones

Room interiors are planned to provide zoned areas for various functions with adequate space for furniture, convenient use and cleaning. Zoning indicates optimum positions for controls, switches, lighting/power connections, fittings and other installations required for planning engineering and technical services:

- lounge/work: near windows, views, daylight, moveable furniture;
- sleeping: quiet areas away from windows, beds screened from entrance;
- bedside: controls, lighting, telephone, easy access;
- dressing: good lighting, mirror, table, drawers, chair/stool, multiple use;
- luggage: convenient position/design, durable, damage protection, secure safes;
- storage: near entrance, wardrobe/shelves, visible interiors, supplementary lighting;
- circulation: width (luggage), dual use of space.

3.5 Variations in rooms

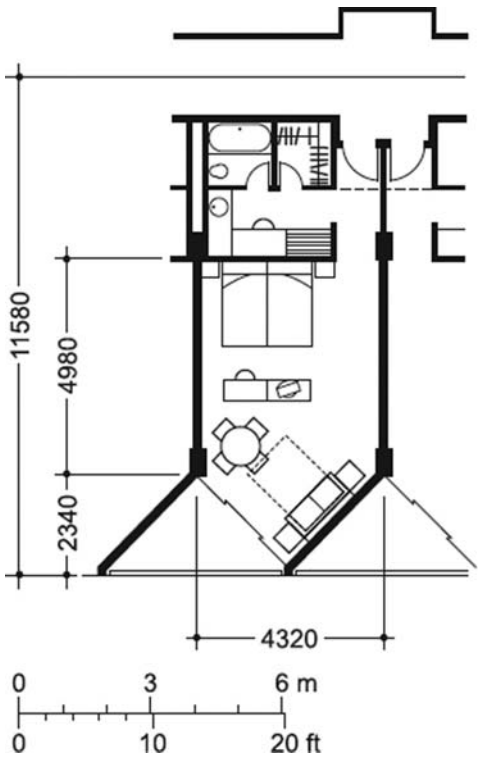
To rationalise circulation, guest rooms in multi-storey hotels are invariably grouped in linear blocks arranged to meet site, structure and statutory – particularly fire escape – requirements.

Housekeeping efficiency is also a consideration in grouping numbers of rooms.

Variations in room sizes and suites are best located on the top floors, at junctions of blocks and in specifically designed areas. Most standard suites occupy two modules. Connecting double doors (sound proofed, dual locks) between adjacent guestrooms provide for occasional family and special needs.

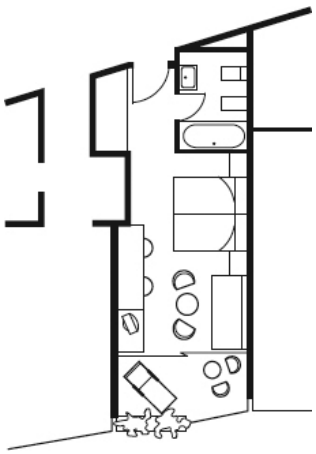
Balconies and terraces give rise to problems of safety, wind damage, drainage and security. They are normally limited to resort locations, Figures 20.9, 20.10.

By their nature, aparthotel rooms require additional space, Figure 20.11.

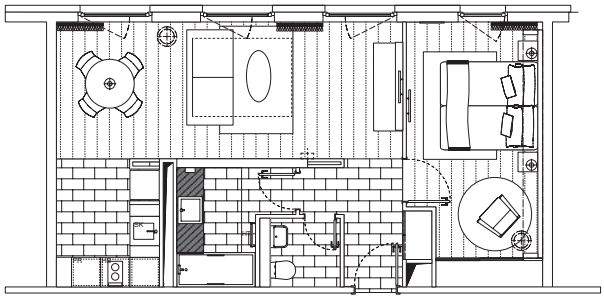


20.9 *Bedroom in a saw-tooth façade hotel*

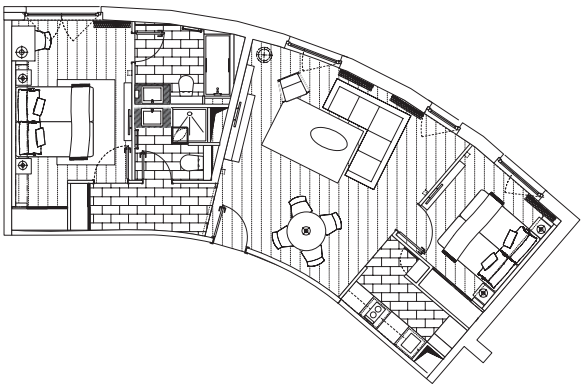
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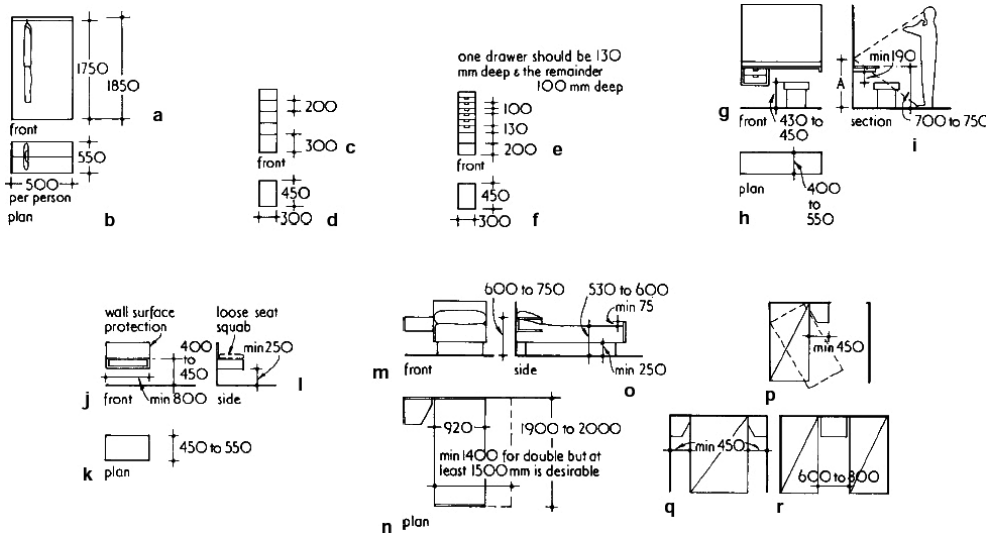
20.10 *Bedroom with small terrace*



20.11a *One-bed apart hotel suite (Source: Citadines Frankfurt by Buckley Gray Yeoman for PBMG Projekt-und-Baumangement gesellschaft mbH and The Ascott Limited)*



20.11b *Two-bed apart hotel suite (Source: Citadines Frankfurt by Buckley Gray Yeoman for PBMG Projekt-und-Baumangement gesellschaft mbH and The Ascott Limited)*



20.12 *Space requirements for hotel bedroom furniture. Note: the dimensions for wardrobe, shelf and drawer units are minimum clear internal dimensions. a Wardrobe front – per person; b Wardrobe plan; c Shelf unit front; d Shelf unit plan; e Drawer unit front; f Drawer unit plan; g Dressing/writing table front; h Dressing/writing table plan; i Dressing/writing table section. Dimension A must not exceed half eye height to achieve full-length view. For combined dressing and writing use the minimum table top area is 0.6m²; j Luggage rack front; k Luggage rack plan; l Luggage rack side; m Bedside table and single bed front; n Bedside table and single bed plan; o Bedside table and single bed side; p Bedside table for single bed; q Bedside tables for a double bed; r Bedside table for twin beds*

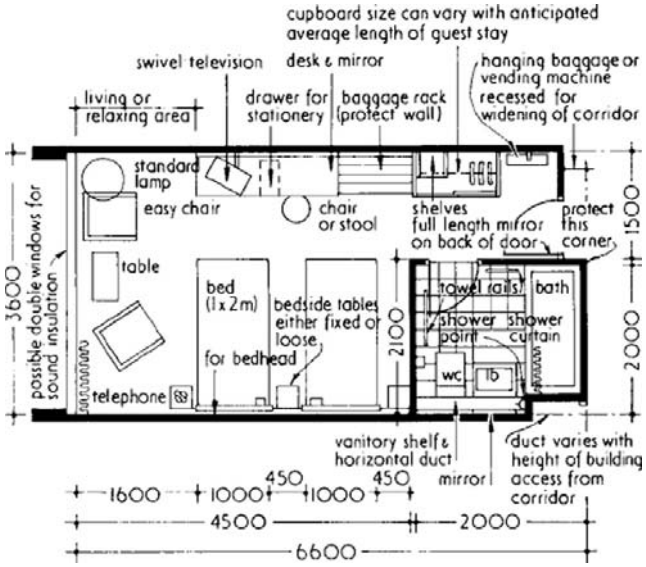
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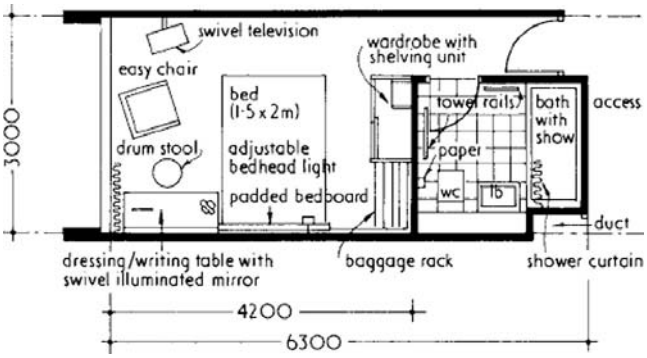
3.6 Furniture and furnishings

Room and bed occupancies (bednights) in hotels are perishable. They require high turnovers, intense use and efficient housekeeping to maximise revenues. Furniture, furnishings and interiors must be practical, robust and resistant to damage whilst meeting standards expected by the guests, Figures 20.12, 20.13, 20.14.

This calls for detailed specifications to meet quality and performance requirements.



20.13 *Twin-bedded room with clothes storage and dressing table along party wall. Size varies according to site constraints and standard of accommodation*



20.14 *Layout for single bedroom. Note double bed for use as double room is required*

Particular considerations include:

- Surfaces: resistant to breakage/damage by scraping, burns, stains and cosmetics etc. Vulnerable areas protected (dressing tables, luggage racks, walls, entrances).
- Support: firm anchorage in walls for cantilevered furniture and fittings.
- Framework: strong, rigid joints and construction. Ergonomic design standard units.
- Fittings: durable design, simple, easy use, quiet movement.
- Floor covering: carpets should be easy clean, durable, retain appearance, camouflage markings.
- Chairs, fabrics: complementary to design scheme, fire retarded, curtain closure.
- Beds: comfort, durability, retention of shape, edge reinforcement, quietness, standard dimensions, wall-fixed bedhead, cantilevered side cabinets, lamps.
- Bed linen, towels hard wearing, quality standards, duvet/blanket/pillow options/storage.

3.7 Bathroom location and design

Bathrooms are invariably located internally, back-to-back, enabling adjacent rooms to be serviced through a shared duct. This requires mechanical ventilation (in lowered ceiling void over the lobby) but allows savings in pipework and drainage, maintenance access, and efficient use of space and outside walls. Air extraction is automatically activated by the bathroom light switch (outside the door).

Exceptionally, luxury bathrooms (spa resorts) or economy shower rooms may be on an external wall. Bathrooms sited between guestrooms increase corridor lengths, built areas and drainage but may be suitable in low rise motels and building conversions.

Bathroom dimensions are dictated by number and arrangement of fitments, particularly baths:

- Typical fitments: 1500 mm bath, with grab bars, shower spray, retractable clothes line and curtain/screen; wc and washbasin. High grade hotels use 1700 mm bath, twin basins set in vanitory surrounds, wc and bidet. Luxury units include separate dressing rooms and shower.
- Requirements: acoustic ceiling; non-slip, drained flooring; tiled walls; mirror over washbasin; screened moisture-proof lighting; electrical safety provisions; mixer valve; thermostatic control of hot water; warmed air inflow/extraction; electric shaver point, shelf space; towel racks; toilet paper holder; coat hanger; toiletry tray; tissue dispenser; lidded waste bin. High grade hotels provide a telephone in the bathroom and music relay.

3.8 Rooms for guests with disabilities

As a rule, 1–2 per cent of guestrooms should be equipped for disabled use. Rooms for the ambulant disabled are generally on the ground floor for fire escape with easy access from the car park. Design requirements for access and room layouts must be consulted:

- Corridor width: Minimum of 915 mm with door openings 815 mm minimum with wider lobbies.
- Bathrooms: larger than standard with central turning space (1.52 m). Basin tops (860 mm high) with knee space. Toilet seat height (430 mm) Mirrors extended down. Grab bars fitted on head wall and sides of toilet and bath with easy access.
- Bedrooms: standard 3.65 m wide rooms can be adapted (with furniture changes), e.g. lower switches (1.2 m), increased space between beds, knee space below dressing tables, low window cill height (610 mm) where practicable.

4 PUBLIC AREAS

4.1 Hotel entrance and reception lobby

The main entrance and lobby must be prominent, spacious, appropriate to the style and grade of hotel. Design considerations:

- Mode of transport: parking, taxis, vehicle turn round, drop off facility, shelter.
- Identification: illumination, corporate styling, signage, assistance.
- Doorway: type, mechanism, width, safety, fire exit, security, transitional temperature/draught control, disabled use.
- Services: porter/luggage store.

4.2 Lobbies

The lobby is the hub of hotel operations and is important in creating the desired impression. It provides access to all the hotel facilities and about half the space is taken up by circulation.

The trend is for lobbies to be social spaces with cafes, workstations, wi-fi etc. and less dominated by the front desk.

Lobby facilities include the front desk, lounge seating, retail space, toilets, cloakrooms, information/assistance and other services. Typical areas, based on the number of guestrooms, are 0.3 m^2/room –budget hotels, 0.5 m^2/room – motor and airport hotels, 1.0 m^2/room –resort and city centre hotels.

The front desk is traditionally the main focus of activity and must be set back at least 1.25 m from circulation increasing to

6 m or more for large convention hotels. Counters are typically designed with a convenient counter height for the guest and lower working height behind.

Counter lengths are planned around 1.5–1.8 m wide designed workstations fitted with angled video display screens and keyboards. Functions such as registration, checkout and guest information are generally adaptable for open desk arrangement. Increasingly reservation services provide for automatic check-in and in room facilities can be used for check out payment reducing the peak demands on the desk. Desk lengths vary with size and grade of hotel e.g. 3 m – 50 rooms, 4.5 m – 100/150 rooms, 6.0 m – 200/300 rooms. Some hotels use individual podium stations instead of a continuous counter.

The desk has direct access to the front office including cashier and front office manager.

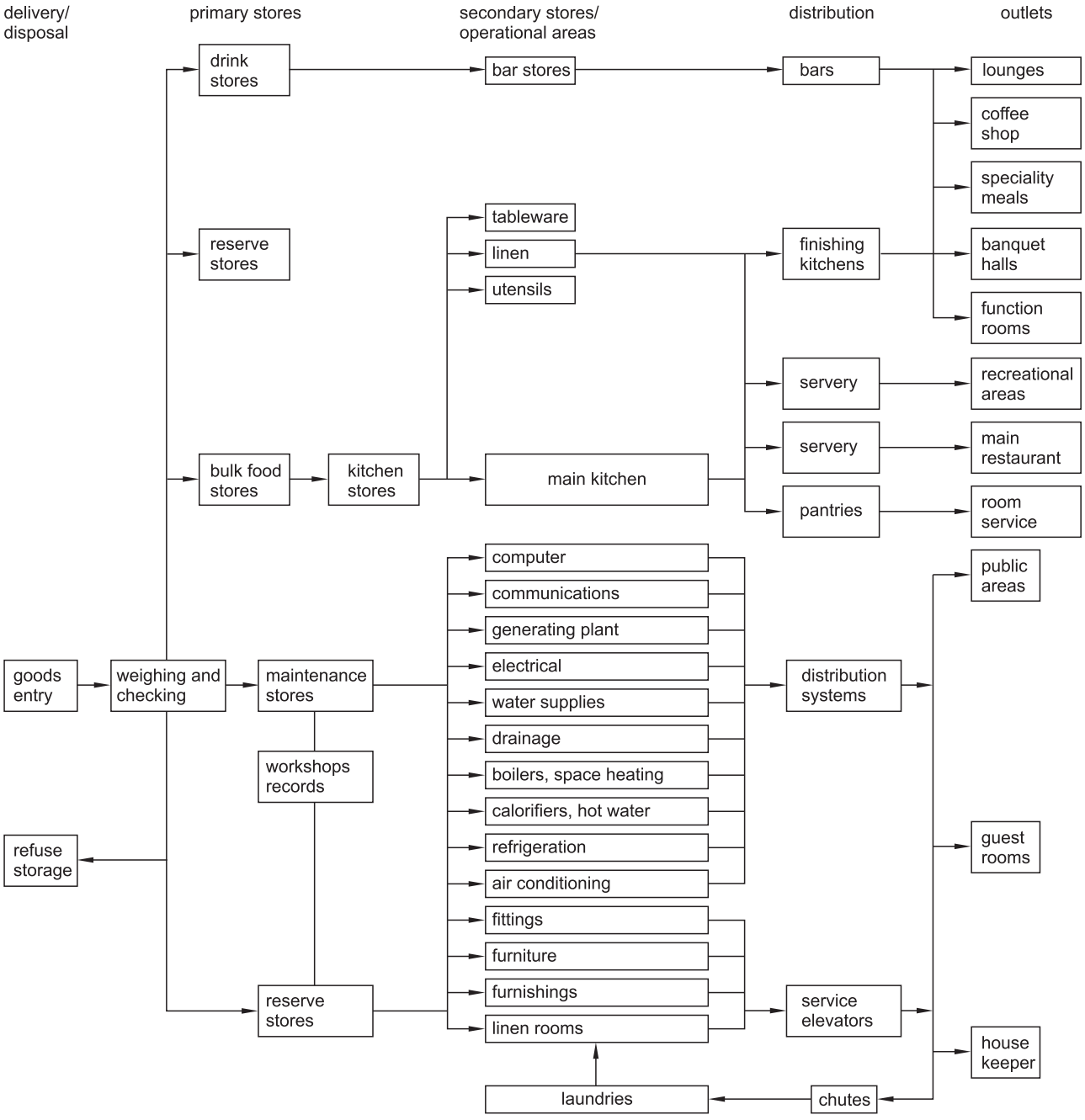
Locations for other administration services (security, telephone exchange and management offices) are more flexible.

In larger hotels, separate counters are usually provided for information, (concierge), assistance and group reception. A separate area for convention registration and assistance may be required.

4.3 Food and beverage services

Food services involve high investment and operating costs, short design life cycles (5-7 years) and rationalisation of restaurant seating and food preparation to ensure efficient use.

- Basic/budget: limited breakfast service or use of commercial restaurant operated independently.
- Midgrade/full service: single restaurant with adjacent bar and lounge. Seating capacity depends on location, types of guests, lengths of stay and local demand. Kitchen design for set or cyclical menus. Meeting/function room(s) may be provided for groups/parties/weddings.
- High grade: room service of meals provided with service pantries on guest floors. Most large high grade hotels offer a multiple choice of restaurants, including main, coffee shop/brasserie, ethnic cuisines and speciality themed designs. The largest is adapted for breakfast (mainly self service). Food production is centralised with zoned areas for storage, preparation and cooking. Direct access is required to individual finishing areas designed to serve each restaurant, Figure 20.15.



20.15 *Relationship diagram for technical and catering services*

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Typically, a sophisticated cocktail lounge and bar is located near the main restaurants and a general bar/lounge to provide a focus for relaxation. Refreshments are also served in the lobby lounge and some luxury hotels provide a café style tea room for daytime visitors.

Typical areas required per seats are given in Table III.

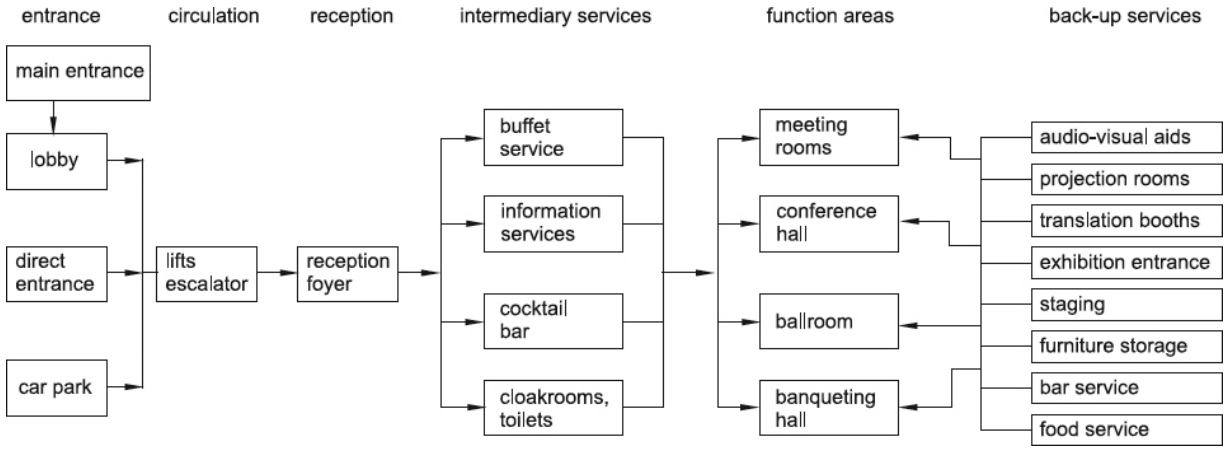
4.4 Conference/convention/function facilities

High grade hotels invariably offer extensive meeting/conference/function rooms and banquet halls, Figure 20.16. Rapid food service for large numbers requires specially fitted pantries with purpose designed systems and equipment. These are located adjacent to the function rooms with direct service access from the main kitchen. Noise and light screening is important.

High capacity halls for convention/banquet/exhibition use are limited to major catchment areas (large towns/cities and resorts). Good access to large car parks and truck facilities is necessary.

Table III Food service areas in m² according to numbers of seats

	Area per seat (m²)	Notes
Food services		
A-la-carte restaurant	2.0 to 2.4	Fine dining and ethnic speciality restaurants
Brasserie/coffee shop	1.6 to 1.8	Limited menu. Including counter
Lounge and bar	1.2 to 1.4	Including counter. 50% seated
Functions, banquet style	1.2	
Functions, conference style	1.6	
Foyer to banquet hall	0.3	Cloakrooms, toilets, add 20%
Staff canteens	1.1 to 1.2	Based on numbers per shift
Service facilities		
Main kitchen	0.7 to 0.9	Includes main preparation areas
Coffee shop kitchen	0.3 to 0.5	Including dishwashing
Food, liquor and china storage	0.2	Cold stores, etc.
Banquet kitchen	0.24	Or 20% of banquet room
Banquet storage	0.05	Or 8% of banquet room



20.16 *Relationship diagram for public functions*

Convention demand is mainly seasonal requiring adaptation for multiple use. Essential requirements include:

- Specific entrances for visitors, furniture and display equipment. Services must be provided together with planned and controlled circulations.
- Design requires large spans, high ceilings, division partitions and foyer/anteroom facilities for each area.
- Engineering: installations include individual controlled/zoned air-conditioning systems, sophisticated communication and audio-video installations, lighting and power controls and numerous technical services connections for alternative layouts.
- Screened access to food service lobbies and furniture storage. Purpose-designed furniture and carrier systems.

Table IV Areas for various spaces

Function	Area
Circulation and reception	
General allowance	Gross factors: 25–35% added to room areas
Lobby areas	2-star 0.6 m² per room to 4-star 1.0 m² per room
Cloakrooms	
Fixed rows of hooks	0.1 m² per user including staff circulation and space around counter
Hooks plus seats or lockers	0.2 to 0.3 m² per user
Health and fitness clubs	
Swimming pool	15.0 × 7.0 × 1.4 m plus 2 m surround plus changing rooms
Gymnasium	15 m² for a small fitness room to 65 m² for a large complex
Public assemblies	
Conferences (theatre style)	0.6 to 1.0 m² per person plus stage, plus translation booth or 1.0 to 1.2 m² overall
Dances	0.6 to 0.9 m² per person plus band space up to 12 m² for a 6-piece band

4.5 Leisure and other facilities

Most business and resort hotels provide leisure facilities for guests. Depending on grade and location, this may range from a basic exercise room to a fully equipped leisure centre with pool(s), sauna, and fitness rooms. Typical areas for these various spaces are given in Table IV.

In town centre locations leisure facilities are commonly located in basements. Costs of provision and operation are high and local club membership is common to increase usage.

Casino hotels specialising in gaming typically require large purpose-designed halls allowing zoned areas for various users with strict supervision and security measures. Public rooms are elaborate and large numbers of guestrooms usually required.

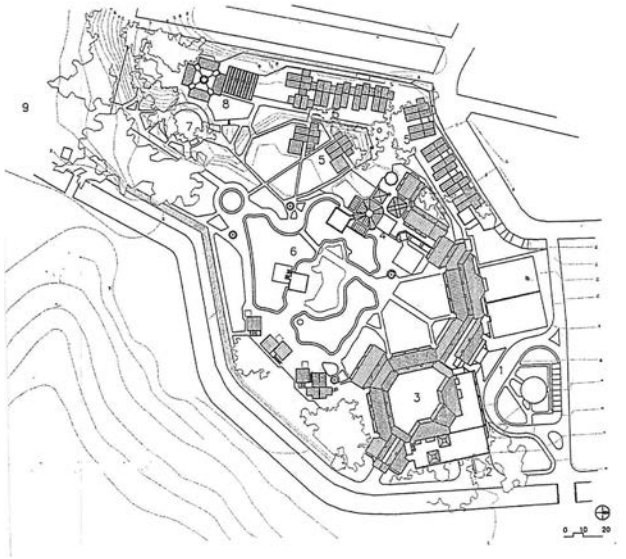
Resort hotels are planned to maximise the benefit of the area attractions with direct access to the golf course, beach, ski-lift system or marina. In each case the hotel facilities are designed to complement the tourist experience, Figure 20.17.

5 BACK OF HOUSE FACILITIES

5.1 General

Central support areas in hotels typically take up 12–14 per cent (high standard) to 7–8 per cent (budget) of the total built space. Requirements depend on the availability of offsite services. Most of the laundry, maintenance, and refurbishing requirements are contracted out saving space and labour. Hotel facility management requires planned maintenance and life cycle replacements which can be specified and organised in advance:

- Services – general checklist.
- Loading docks – vehicle (dimensions), rubbish storage, protection/screening, recycling facilities (separation/compression/chilling), delivery/security office.



20.17 *Arum Hotel, Side, Turkey. The 22,750m² hotel provides 196 guestrooms in tiers of interlinked blocks, most facing landscaped pools and the beach. Includes restaurants and cafes as well as outdoor and indoor leisure facilities. Architect: Professor Cengis Eren*

Key: 1 Main entrance, 2 Service entrance, 3 Guestrooms, 4 Indoor pool, fitness centre, Turkish baths, 5 Apartments, 6 Swimming pool, 7 Childrens' pool and play area, 8 Café, 9 Beach

- Storage – furniture/equipment/general. Food stores (frozen/chilled/dry goods/vegetables), access to service areas, transportation.
- Plant/technical – water supplies (circulations), heating/chilling (combined power) electric (switchgear/generators) workshops/offices.
- Housekeeping – laundry/sorting/storage/supervision, other stores, service lifts/control.
- Employees – entry control, personnel rooms, changing facilities/lockers, canteens/restrooms.

6 CASE STUDIES

6.1 Travelodge, Southwark, London

Architect: Dexter Moren Associates

Introduction

This 202 bedroom hotel is for budget hotel brand Travelodge and is situated close to Tate Modern at Bankside just south of the Thames in central London. See Figures 20.18–20.22.

Site and restrictions

The 0.14ha Union Street site is on the main pedestrian route from Southwark Station to the Tate Modern and backs onto rail viaducts. It is close to the landmark Palestra building.

Solution

At street level the 6105 sq m building features a tall glazed ground floor designed as sub-divisible commercial outlets. Internally, the spaces are conceived as a 'donut' form around a central courtyard and accommodate 202 bedrooms, a bar and 60-seater restaurant facilities. Bedrooms range from 15 sq m to 21 sq m.

The building incorporates two very different elevational languages relating directly to the surrounding context, the Palestra building in particular. This has been achieved by using silver metal-clad modules with blue vertical trims in a staggered rhythm. The rear elevations fronting rail viaducts have been designed as robust brick facades with regimented windows framed with blue metal hoods.

'Our sector is based on efficiency and maximising returns, a philosophy that DMA embraces, reflected in the fact that in some instances DMA have "found" up to 15 per cent extra bedrooms within the same envelope produced by their competitors,' says Travelodge development manager Rob Ryan.

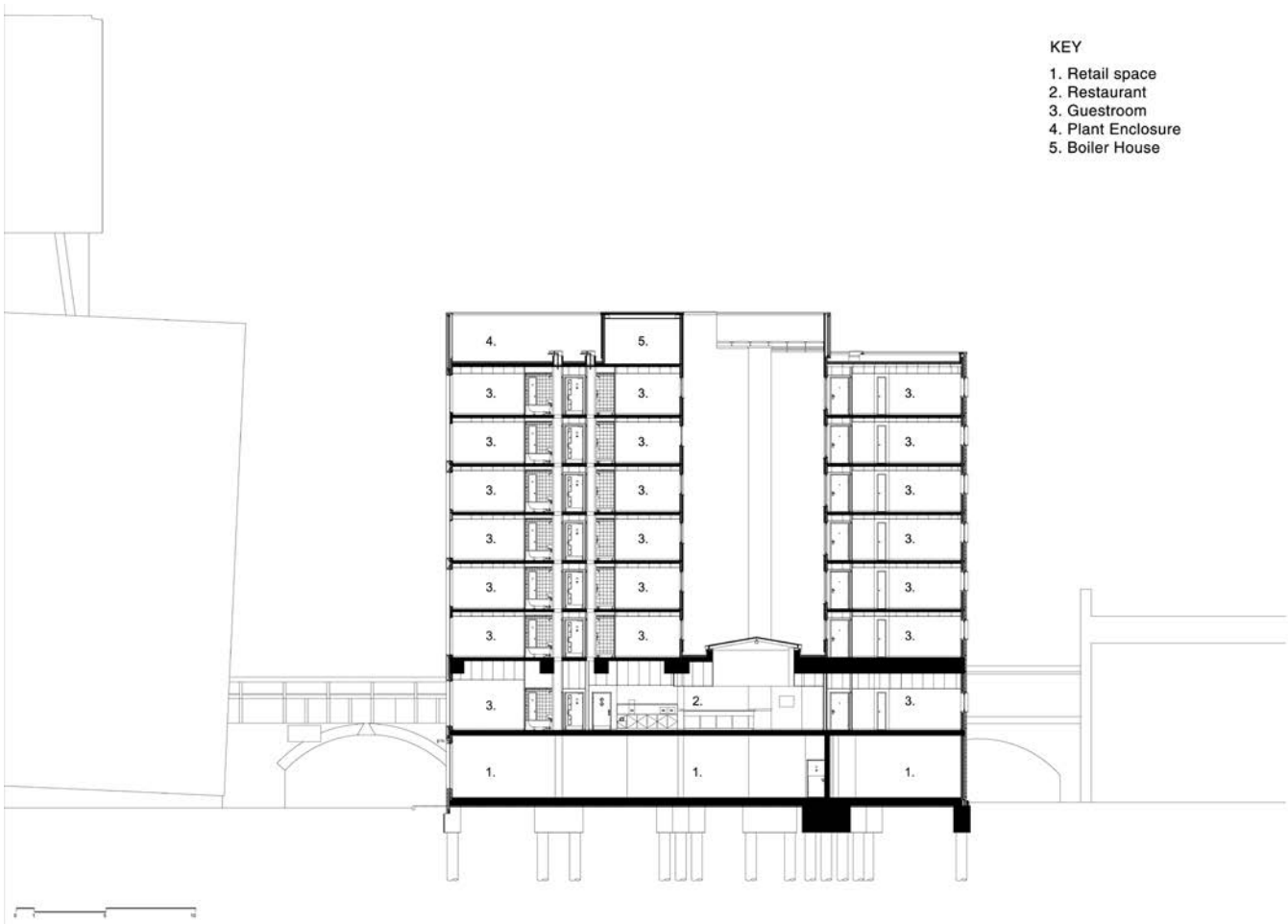


20.18 *Travelodge Southwark first floor plan showing reception area, restaurant and bar surrounded by perimeter guestrooms*

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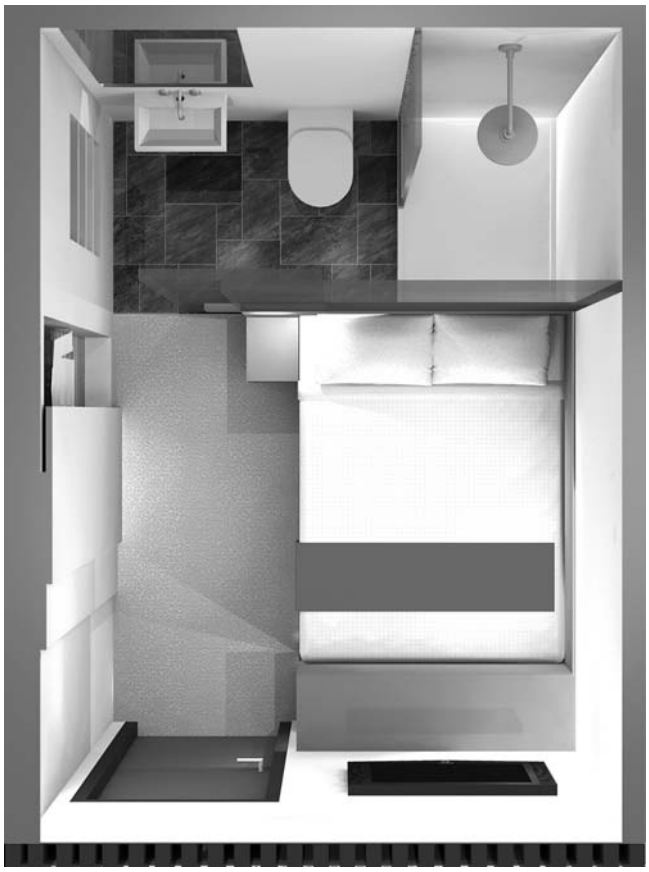


20.19 *Travelodge Southwark third floor plan with rooms arranged around a central light well*



20.20 *Section through Travelodge Southwark*

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20.21 *Overhead image of individual room at Travelodge Southwark*



20.22 *External view of Travelodge Southwark*

6.2 InterContinental, Westminster, London

Architect: Dexter Moren Associates

Introduction

This 18,416 m² redevelopment provided a new 256-bedroom hotel for the luxury hotel chain InterContinental in London's Westminster. See Figures 20.23–20.25.

The site

The project is a reworking of Queen Anne's Chambers, a nineteenth-century former hospital turned government office building.

Solution

The challenge was achieving a modern and coherent design within the constraints of the property's disjointed historic structure. This required major architectural interventions including the creation of a new porte cochère leading guests into an atrium reception featuring a triangular glass skylight.

Across the lower ground floor structural modifications and 2 m of excavation were required to accommodate conference facilities and a 24 hour gym for hotel guests. In addition, DMA installed eight new lifts within 2 new lift cores and incorporated a grand elliptical feature staircase to the lower ground floor. Much of the original facade was restored and retained.

On the ground floor, public spaces have been designed as a series of rooms that transition seamlessly into one another (Figure 20.23). The ground floor comprises reception, concierge, lobby lounge and Emmeline's lounge. At the heart of the hotel is a smokehouse and pub with its own entrance.

The hotel incorporates 256 new rooms including 30 studios, 14 one-bedroom suites, and a rooftop penthouse. These are arranged around four distinct wings and spread over six floors (Figures 20.24–20.25). Rooms are an average of 30 m², excluding suites and executive rooms.

The hotel interior space planning design was completed by Dexter Moren Associates and IDS with interior finishes by RPW.

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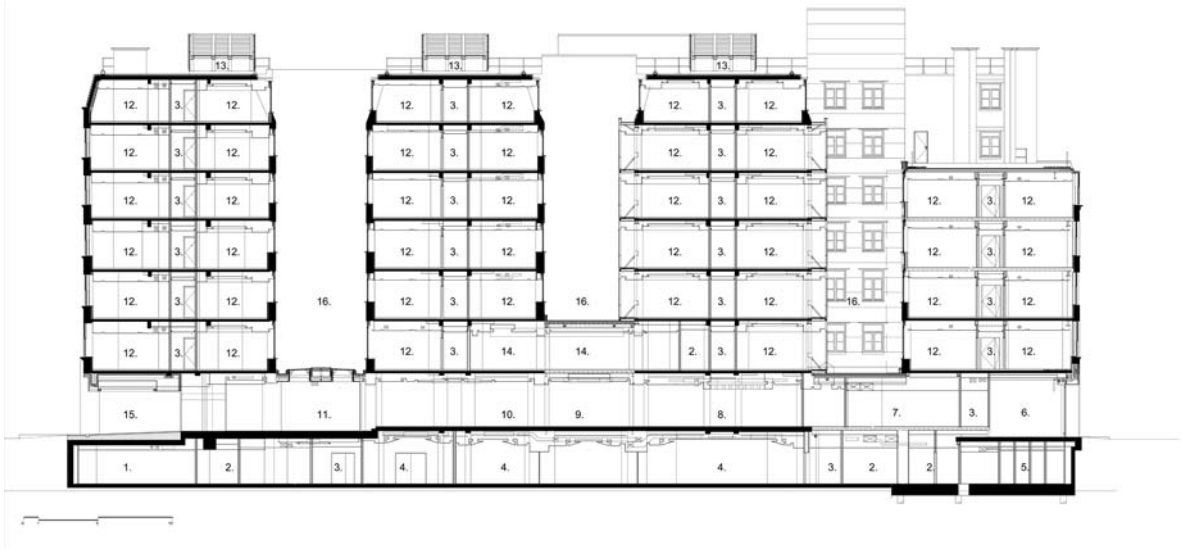


20.23 *InterContinental, Westminster, ground floor. Key: 1, Driveway; 2, Reception; 3, Store; 4, Hotel offices; 5, Tea lounge; 6, Wintergarden/ lounge; 7, Restaurant; 8, Private dining room; 9, Bar; 10, Kitchen; 11, BOH corridor; 12, WC; 13, Delivery/service bay*



20.24 *InterContinental Westminster, bedroom floor. Key: 1, Guestroom: Suite; 2, Guestroom: King; 3, Guestroom: Accessible; 4, Guestroom: Twin; 5, Guestroom: Premium standard; 6, Guestroom: Duplex; 7, Lightwell; 8, BOH; 9, Linen room*

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20.25 *InterContinental Westminster, Section. Key: 1, Hotel offices; 2, Store; 3, Corridor; 4, Meeting room; 5, WC; 6 Service Bay; 7, Kitchen; 8, Restaurant; 9, Lounge; 10, Tea Lounge; 11 Reception/lobby; 12 Guestroom; 13 Plant; 14, Executive Lounge; 15, Driveway/Entrance; 16, Lightwell*

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21 Houses and flats

John Chapman

CI/SfB: 81

John Chapman is a director at PRP Architects LLP, with contributions by Kathy Watkins, architect and standards auditor at PRP Architects LLP. PRP specialises in residential design and was on the advisory panel for the government's recent Housing Standards Review.

KEY POINTS:

- *Housing standards in England are currently (2014) under review by the Department for Communities and Local Government (DCLG). It is likely that a number of significant changes will be introduced in the coming years, both to planning policy and Building Regulations*
- *Housing space standards in the UK are considered to be amongst the lowest in Europe*
- *Low space standards lead to dissatisfaction particularly for public sector (social) housing which tends to be more fully occupied*
- *Accommodation has to be tailored to numbers and characteristics of expected residents*

Contents

1 Introduction
2 Published standards
3 Design data
4 Single-family houses
5 Purpose-built flats
6 House conversions
7 Accommodation for single people
8 Estate regeneration
9 Case study
10 References

1 INTRODUCTION

1.1 Housing standards

Successive governments have made attempts to influence or impose standards in housing over the last century. The Tudor Walters Report of 1918 and the Dudley Report in 1944 reflected the 'homes fit for heroes' feeling of post-war social optimism.

In 1961 the report 'Homes for Today and Tomorrow' was published by the Parker Morris Committee of the Ministry of Housing and Local Government (MHLG). The standards in this report, which subsequently became widely known as Parker Morris Standards, were imposed as mandatory on local authority housing in 1967 and were converted to metric in 1968. They were not adhered to by the private sector and ceased to be mandatory in 1981.

In 2013, the government began the Housing Standards Review, a fundamental review of housing regulations and standards in collaboration with various industry bodies and experts. As this edition went to press, the review was expected to result in a new national housing space standard to apply cross-tenure, with optional requirements for age-friendly and wheelchair housing to be incorporated into Building Regulations, and the withdrawal of several current standards including the Code for Sustainable Homes and Building for Life.

1.2 Public and private sector housing

In Britain, as in many other countries, housing is divided into privately and publicly funded sectors. Early in the twentieth century, the new local authorities (LAs) increasingly took over the provision of social housing from charitable foundations (such as the Peabody, William Sutton and Guinness Trusts).

The growth of municipal housing became such that in some urban boroughs most of the housing was in their ownership. This has been reversed in recent years by a number of government measures: right-to-buy, restriction of LA expenditure and by the growth (or birth) of charitable Housing Associations (HAs) and other Registered Providers (RPs), funded and subsidised through the Housing Corporation – now known as the Homes and Communities Agency. There is now an accelerating trend for local authorities to transfer some, or even all, of their housing stock to HAs, or other Registered Providers.

While historically the privately funded sector used to be geared to the provision of housing for rent, it now almost exclusively provides for purchase through mortgages, mainly from banks and building societies. With the volatility of interest rates, the level of affordable payments is crucial for most of its customers. There is therefore a tendency for standards in the 'spec housing' market to be cut to the minimum and private developers have a long tradition of resisting space standards imposed other than by the market.

There has, until recently, been a steady demand for small 'starter homes' – both flats and houses – at affordable prices. This reflects the demographic changes over the last century. Household sizes have fallen dramatically, but the numbers of independent households have grown rapidly, partly due to the steady growth of failed marriages and partnerships. Later, some of these initially small households, as occupants have more money, and perhaps a family, are able to sell and buy somewhere bigger. This may be a large, older house, or it may be one of the superior-quality, speculative houses that some developers are building at, or even above, social housing standards. It is uncertain whether the demand for starter homes will continue. In some cases they have been found difficult to sell when the original owners have required more space. Even people living on their own are beginning to demand more generous accommodation.

The public sector is very different. Tenants of social housing have less choice in their dwellings. Also, once the household is accommodated, their ability to move home is limited. Often the only opportunity is likely to be a mutual swap with another household. Clearly this does not happen very often, so the tenant is likely to be in his or her flat or house for a long time. Recent government changes to benefits – widely referred to as 'the bedroom tax' – are intended to encourage residents to move out of under-occupied properties. However the LA housing department, HA or RP is unlikely to have a larger, or smaller, dwelling becoming available for a requested transfer at the right time and in the right place. This is the argument for ensuring, especially in the publicly funded sector, that reasonable standards are maintained.

People must have the room to settle satisfactorily into what is likely to be their long-term home. Post-Parker Morris standards, the Housing Corporation (HC) did not lay down space standards, preferring to leave these to the experience and judgment of HAs or RPs, and to their architects. Instead, during the 1980s and 1990s the HC funded HA schemes according to its Total Cost Indicators (TCI), which laid down cost allowances based upon gross internal area in 5 m^2 increment bands. These bands were related to probable occupancies, but they were also very broad and approximate, so that the bands varied from well below to well above PM dwelling sizes.

Table I Comparison of dwelling sizes

Comparison of internal areas, including storage								
Standard		**Parker Morris[1] min area (m²)**	**HQI's[2] target area (m²)**	**London Plan min area (m²)**	**Lifetime Homes[4] min area (m²)***	**Wheelchair[4] min area (m²)***	**Wheelchair[5] min area (m²)***	**Wheelchair[6] min area (m²)**
Single	1b2p	47.5–48.5	45–50	50	50	60	65	55–60
storey	2b3p	60.0–61.0	57–67	61	55	66	75	70–75
dwelling	2b4p	71.5–73.5	67–75	70	75	86	85	75–80
	3b4p			74			100	80–85
	3b5p	80.0–82.5	75–85	86	85	95	110	90–95
	3b6p	88.5–90.0		95			115	95–100
	4b5p			90			116	
	4b6p		85–95	99	105	110	125	100–105
Two	2b4p	76.5–79.0	67–75	83	75	86	100	80–85
storey	3b4p			87			110	85–90
dwelling	3b5p	86.5–89.5	82–85	96	85	95	120	100–105
	3b6p	97.0					125	100–105
	4b5p			100			125	
	4b6p		95–100	107	105	110	130	105–110
	7p	114.5	108–115		111			
Three	3b5p	98.5	85–95	102				
storey	3b6p	102.5						
dwelling	4b5p			106				
	4b6p		100–105	113				
	7p +	118.5	add 10m² per person					

[1]Parker Morris (1961) (mandatory for publicly funded housing from 1967 to 1981)
[2]p27, Housing Quality Indicators v4 (May 2007 updated April 2008) published by the Housing Corporation (now the Homes and Communities Agency)
[3]p87, The London Plan (2011) published by the GLA
[4]p18, Habinteg Housing Association Design Guide (2003)
[5]p3, Wheelchair homes design guidelines published by the South East London housing partnership. It should be noted that the requirements in this document are more onerous than those of the WHDG
[6]Northern Ireland Department for Social Development
*Areas are the probable minimum. There are no mandatory minimum areas for these types of housing in England.

TCIs were replaced as a means of funding social housing by the Scheme Development Standards (SDS). These were in turn replaced by the Design and Quality Standards (D&QS), first introduced by the Housing Corporation in 2007 (see Section 2.3).

Following the formation of the Homes and Communities Agency (HCA) in 2008 by a merger of the Housing Corporation and English Partnerships, the National Affordable Housing Programme continues to operate according to the HCA Design and Quality Standards (see 2.3), accompanied by the Housing Quality Indicators (HQI) version 4 (updated April 2008), as inherited from the Housing Corporation.

1.3 Housing for different users

A significant proportion of the population is disabled in some way. While many people with disabilities are able to cope in normal dwellings, others, such as those in wheelchairs, require substantial modifications to enable them to live satisfactorily. Housing to special-needs standards is now being built, both for mobility and more onerous wheelchair use. Housing not specifically designed for people with disabilities is known as general needs housing. Part M of the Building Regulations, first introduced in 1999, extended the requirements for disabled access to all new dwellings, although the requirements do not go as far as those for wheelchair-using residents.

1.4 Parker Morris standards

For the reasons given above, it is important that public-sector housing, at least, is not allowed to slip below the standards that came to be accepted as reasonable during the period when Parker Morris ruled by statute. Research into housing built to PM standards has shown that, while there may be much wrong with other aspects of estate design, such as the confused and insecure arrangement of external spaces, there is usually a good level of satisfaction with the internal layout and space standards. Conversely, where public sector housing has been designed to lower than PM standards, or where PM housing has been over-occupied, the tenants have responded by consistently expressing dissatisfaction.

This edition of *Metric Handbook* therefore continues to include the minimum unit areas of the Parker Morris standards against which to benchmark and compare various other later standards as set out in Table I and in Table II. It should be emphasised that Parker Morris did not lay down minimum areas for rooms. The report simply stated that the dwelling had to be furnishable with a specified amount of furniture which had to be shown on the plans. It also required reasonable storage space, which has proved to be a popular and successful feature of Parker Morris housing.

1.5 Room area standards

In the publicly funded housing sector an additional set of space standards came to be widely accepted for the minimum sizes of individual rooms. These are quite commonly but erroneously referred to as 'Parker Morris'. As stated above, the PM committee went out of their way to avoid being prescriptive about individual rooms. The origin of these figures is understood to have been the Greater London Council (GLC), which funded many HA projects in the capital in the 1970s and early 1980s. They were particularly applied to refurbishment or rehabilitation projects, to which Parker Morris standards were never mandatorily applied.

After the demise of Parker Morris standards as statutory minimum, these room sizes were still widely adopted as reasonable, minimum, design standards for social housing. Many HAs still include them in their briefing documents to architects, and these are set out in Table II. Some London boroughs included these minimum room areas in the standards sections of their Unitary Development Plans, published in the early 1990s, as minimum which had to be achieved in any housing schemes, public or private, for which planning approval was sought.

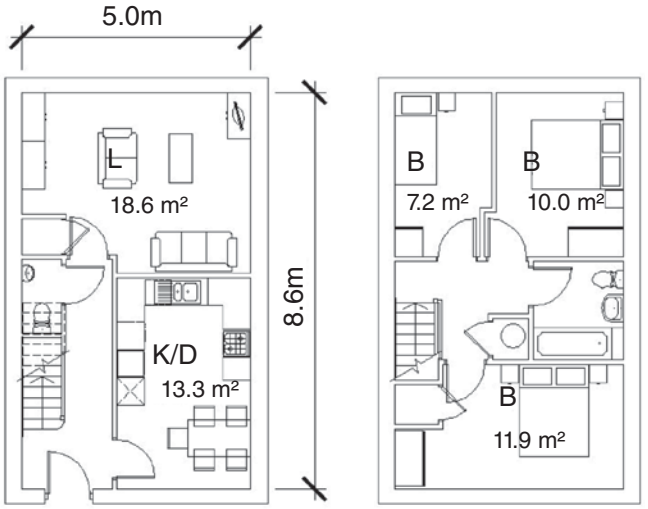
2 PUBLISHED STANDARDS

2.1 Building Regulations (England & Wales)

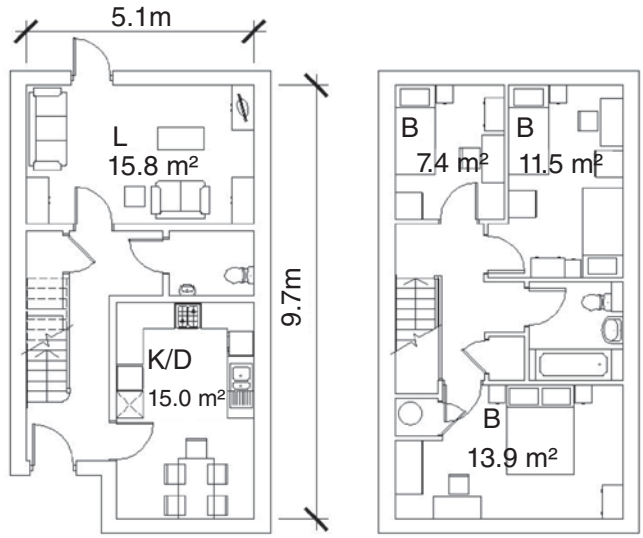
The Building Regulations, which apply to all tenures of housing across England and Wales (including London), are generally clear and easy to understand. All parts of the Building Regulations, now including Approved Document M (Access to and use of buildings), apply to housing. (See Table III.)

The extension of Approved Document M to cover dwellings from October 1999 was an important development. It came about following a gradual change in thinking in recent years that all housing should be accessible to people in wheelchairs, not least to permit them to visit friends and relations. This should also permit people to remain in their homes well into old age or infirmity, instead of having to move to more accessible special accommodation. As such, significant requirements now apply to, for example, provision of downstairs toilets and level front door access, and minimum corridor and door widths. (See Table IV.)

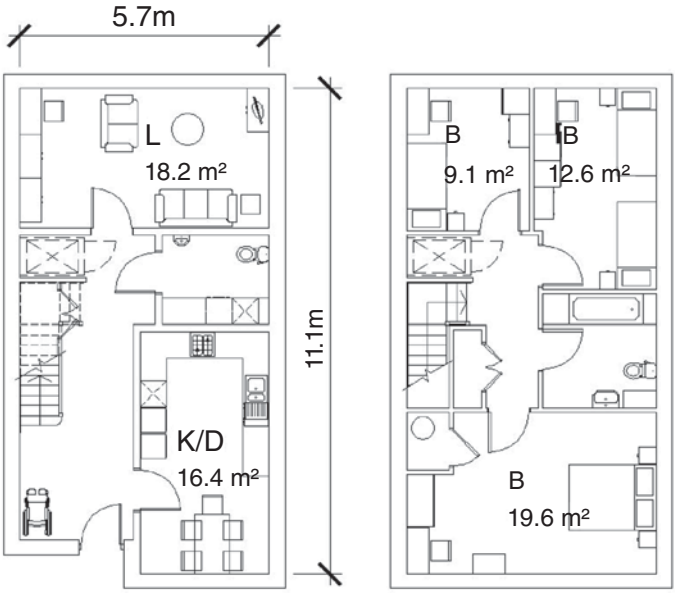
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a *Private for sale 85.0m²*



b *Design Quality Standards and Lifetime Homes Standard compliant 96.5m²*



c *Wheelchair Housing Design Guide compliant 124.5m²*

21.1 *Examples of three-bedroom, five person, two storey terrace houses to meet different standards. Architects: PRP Architects.*

Approved Document L was revised in 2013 and came into effect in 2014. This requires all new housing to achieve that equivalent of Code for Sustainable Homes Level 4.

All Approved Documents are available online via the Planning Portal.

The main parts affecting the planning of housing are set out in Table III.2.2

2.2 National Planning Policy Framework (NPPF)

The legal framework for planning decisions requires planning applications to be determined in accordance with the development plan unless material considerations indicate otherwise. The development plan will consist of the local plan for the relevant local authority (together with the London Plan in the case of London Boroughs) with more detailed guidance often produced as Supplementary Planning Documents (SPD).

Policies in local plans or guidance in SPDs often include detailed design standards for housing and can relate to external amenity, privacy, overlooking, sustainability, car parking etc. They can also cover such areas as defining appropriate housing density, external design and, in some cases, minimum room sizes. Although there is no minimum density prescribed in the NPPF, local authorities often use density as a tool in assessing the acceptability of a

Table II Comparison of 'Parker Morris' derived standards with current London housing standards

Parker Morris room sizes, minimum and recommended (area in m²)

Number of residents	1	2	3	4	5	6	7
Living room in a dwelling with dining kitchen	11 (11)	12 (12)	13 (13)	14 (14)	15 (15)	16 (16)	17 (17)
Living room in a dwelling with galley kitchen	13 (13)	14 (14)	16 (15)	17 (16)	19 (17.5)	20 (18.5)	21 (19.5)
Dining kitchen	8 (8)	9 (9)	10 (10)	11 (11)	12 (12)	13 (13)	14 (14)
Galley kitchen	5.5 (5.5)	6.5 (5.5)	6.5 (5.5)	7 (7)	8 (7)	8 (7)	9 (9)
Main bedroom (double)	9 (8)	12 (11)	12 (11)	12 (11)	12 (11)	12 (11)	12 (11)
Other double bedrooms				12 (11)	12 (11)	12 (11)	12 (11)
Single bedroom		9 (8)*	8 (6.5)	8 (6.5)	8 (6.5)	8 (6.5)	8 (6.5)

*a flat for two single people should have two single bedrooms of recommended 9m², minimum 8m² each
Minimum sizes (given in brackets)

Current London room sizes and widths (applicable to all housing in London)

Number of residents	1	2	3	4	5	6	7
Living/kitchen/dining *recommended width*		23 *2.8*	25 *2.8*	27 *3.2*	29 *3.2*	31 *3.2*	
Main bedroom (double) recommended width 2.75m		12 (11.5)*	12 (11.5)*	12 (11.5)*	12 (11.5)*	12 (11.5)*	
Other double bedrooms recommended width 2.75m				12 (11.5)*	12 (11.5)*	12 (11.5)*	
Single bedroom			8 (7.5)*	8 (7.5)*	8 (7.5)*	8 (7.5)*	
Bathroom**		4.4	4.4	4.4	4.4	4.4	
WC**		2.4	2.4	2.4	2.4	2.4	

*Recommended figures for all tenures, minimum sizes are acceptable for publically funded housing
**Figures are applicable to funded housing only

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Table III Building Regulations 2000 (England and Wales) applying to dwellings

Approved Document		Last revision	Applies to housing	Relevant to planning of housing
A	Structure	**2004** edition *(incorporating 2004, 2010 and 2013 amendments)*	*	
B Vols 1 & 2	Fire Safety (means of escape, etc.)	**2006** edition *(incorporating 2010 and 2013 amendments)*	*	*
C	Site preparation (resistance to moisture)	**2004** edition *(incorporating 2010 and 2013 amendments)*	*	
D	Toxic substances (cavity insulation)	**1992** edition *(incorporating 2002 and 2010 amendments)*	*	
E	Resistance to passage of sound	**2010** edition*	*	*
F	Ventilation	**2010** edition*	*	*
G	Sanitation, hot water safety and water efficiency	**2010** edition*	*	*
H	Drainage and waste disposal	**2002** edition*	*	*
J	Combustion appliances and fuel storage systems	**2010** edition*	*	*
K	Protection from falling, collision and impact	**2013** edition	*	*
L1A	Conservation of fuel and power (new dwellings)	**2013** edition	*	*
L1B	Conservation of fuel and power* (existing dwellings)	**2010** edition* *(incorporating 2010 and 2011 amendments)*	*	*
L2A	Conservation of fuel and power (new non-dwellings)	**2013** edition		
L2B	Conservation of fuel and power (existing buildings other than dwellings)	**2010** edition* *(incorporating 2010 and 2011 amendments)*		
M	Access to and use of buildings	**2004** edition *(incorporating 2010 and 2013 editions)*	*	*
P	Electrical safety – dwellings	**2013** edition	*	
	Regulation 7 – Material and workmanship	**2013** edition	*	

* to be read in conjunction with 2013 amendments

Table IV Summary of key requirements for accessible general needs housing from Building Regulations Approved Document M, 2004 edition.

Sections 6 to 10 apply to new dwellings

Section 6 – Means of access to and into the dwelling
This section covers level, ramped or stepped approach.

- Level approach should be no steeper than 1:20
- Ramped approach is allowed if the plot gradient exceeds 1:20, but not 1:15
- Ramps must be a minimum of 900 mm wide
- Ramp flights no longer than 10 m at 1:15, or 5 m at 1:12
- Top and bottom landings a minimum of 1.2 m length
- Stepped approach is allowed if the plot gradient exceeds 1:15
- Steps must be a minimum of 900 mm wide
- Rise of flight between landings must not exceed 1.8 m
- Top and bottom landings a minimum of 900 mm
- Suitable tread nosing profiles, and uniform rise of between 75 mm and 150 mm
- Going (tread) of steps no less than 280 mm
- Handrail to one side of steps with three or more risers, extending 300 mm at top and bottom
- Thresholds should be accessible
- In exceptional circumstances (a stepped approach) a stepped threshold of a maximum 150 mm rise
- External entrance door minimum clear opening 775 mm

Section 7 – Circulation within the entrance storey of the dwelling
This section covers internal corridor and door widths.

- Corridors should be minimum width 900 mm to 1200 mm, depending on door widths
- Corridors can be a minimum of 750 mm opposite obstruction such as radiator, for no longer than 2 m
- Door clear opening widths should be minimum as follows:

  750 mm at end of 900 mm wide corridor
  750 mm off 1200 mm wide corridor when approach not head-on
  775 mm off 1050 mm wide corridor when approach not head-on
  800 mm off 900 mm wide corridor when approach not head-on

- In exceptional circumstances (severely sloping plots) steps are allowed within the entrance storey. Such steps should be a minimum of 900 mm wide, with handrails to both sides

Section 8 – Accessible switches and socket outlets in the dwelling
This section gives heights for fittings to assist people whose reach is restricted.

- Switches and sockets in habitable rooms should be between 450 mm and 1200 mm height above floor level

Section 9 (and AD Part K) – Passenger lifts and common stairs in blocks of flats
This section gives requirements on lift dimensions, and on stair dimensions in blocks which do not have lifts.
Requirements for passenger lifts:

- 400 kg minimum load capacity
- 1.5 m × 1.5 m landings in front of entrances
- Lift door clear opening 800 mm
- Car minimum width 900 mm and minimum length 1250 mm
- Controls between 900 mm and 1200 mm above floor level

Requirements for common stairs in blocks of flats without a lift:-

- Contrasting brightness step nosings
- Suitable step nosing profiles (illustrated in the Approved Document)
- Step maximum rise 170 mm; maximum going (tread) 250 mm
- Non open risers
- Continuous handrail on both sides of flights of more than 2 steps, extending 300 mm onto landings

Section 10 – WC provision in the entrance storey of the dwelling
This section requires a WC on the entrance floor of any dwelling, and gives dimensional guidance.

- If there is a habitable room on the entrance floor, there should be a WC on that floor
- WC door should open outward, and opening should overlap WC pan by 250 mm
- Door widths should observe the measurements described in Section 7 (with clear opening widths in accordance with Table 4 of the Approved Document)
- In a front access WC, compartment should be 1000 mm wide (or minimum 900 mm wide)
- In an oblique access WC, compartment should be 900 mm wide (or minimum 850 mm wide)
- Transfer space 750 mm deep should be provided in front of WC

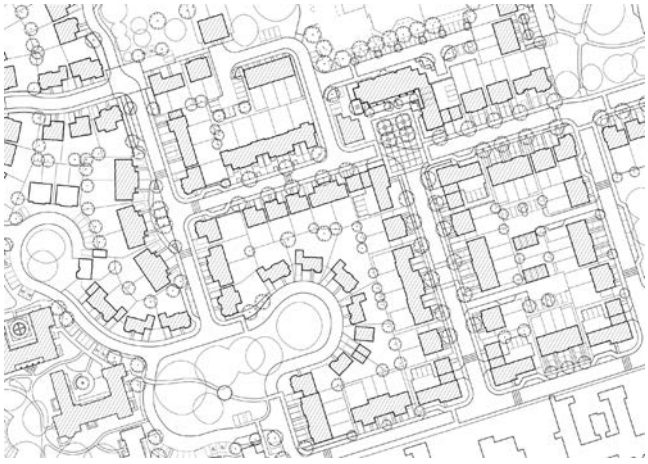
proposal. Planning densities are normally expressed in dwellings per hectare (or acre) or habitable rooms per hectare (or acre). The definition of habitable rooms is normally taken to be all living rooms, bedrooms and dining kitchens (the latter commonly only if more than 13 m^2). Densities for new housing commonly vary from around 150 habitable rooms per hectare (60 habitable rooms per acre) to 250 habitable rooms per hectare (100 habitable rooms per acre), see Figures 21.2 and 21.3 for illustrations of layouts at these densities. Different planning authorities have widely differing minimum dimension requirements, Figure 21.4. Some authorities allow higher densities for non-family housing, or for areas close to urban centres or good transport links.

Material considerations can cover broad and far reaching issues. Particular regard should be given to the effect of the proposal on the site's surrounding context, its bulk, scale and massing in the streetscene as well as the proposal's effect on privacy, outlook and loss of daylight/sunlight. Other important material considerations include the contents of the NPPF as well as a proposal's effect on the existing situation, e.g. flood risk, ecology and energy footprint.

Car-parking requirements vary considerably between planning authorities. Inner city authorities may require only one space per house and less for a flat, but suburban areas may demand two or more spaces per house. Visitors' spaces need to be added at 10 to



21.2 *Medium density housing layout of two and three storey houses and flats in a typical urban location with open car-parking area. Density 53 Dw/Ha (240 HR/Ha). Parking ratio 1.4 spaces per unit*

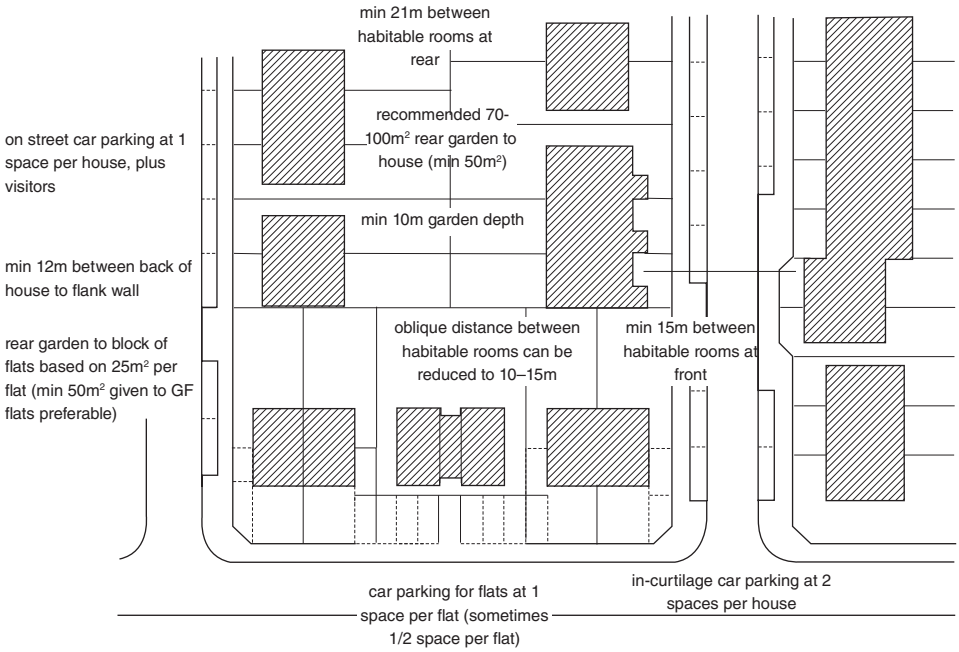


21.3 *Housing layout in a suburban location including conversion of existing buildings at an overall density of 30 Dw/Ha (150 HR/Ha). Parking ratio 1.7 spaces per unit*

20 per cent. Some authorities at present allow considerable relaxation of their requirements for social housing, on the basis of lower than average recorded car ownership. There is also a movement towards 'car free' developments, for some sites that are particularly well served by public transport.

2.3 The Homes and Communities Agency: Design and Quality Standards

The Design and Quality Standards apply to all new-build, general-needs, non-specialised, affordable and intermediate housing where the HCA is providing an element of grant funding, either facilitating or providing free or discounted land value or facilitating or funding major infrastructure investment as part of a regeneration project. Within the London area however, the HCA operates as regulator only. Responsibility for housing and regeneration activity in London lies with the Greater London Authority.



21.4 *Typical planning dimensions standards*

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Table V Housing Corporation requirements for furniture

Living space	1p	2p	3p	4p	5p	6p	7p	+
arm chair 850x850 – combination to equal one seat/person	2	2	3	1	2	3	4	+1
settee – 2 seat 850x1300 (optional; as above)								
settee – 3 seat 850x1850 (optional; as above)				1	1	1	1	
TV 450x600	1	1	1	1	1	1	1	1
coffee table 500x1050 or 750 diameter	1	1	1	1	1	1	1	1
occasional table (450x450)					1	1	1	1
storage units 500x1000 – and incrementally larger	1000	1000	1000	1500	2000	2000	2000	+
space for visitor chair 450x450	2	2	2	2	2	2	2	2
Dining space	**1p**	**2p**	**3p**	**4p**	**5p**	**6p**	**7p**	**+**
dining chair 450x450	2	2	3	4	5	6	7	8
dining table 800x800 – and incrementally larger	800	800	1000	1200	1350	1500	1650	+
sideboard 450x1000 (+ larger) (but not in dining/ kitchen)	1000	1000	1000	1200	1500	1500	1500	+
Bedrooms	**1p**	**2p**	**3p**	**4p**	**5p**	**6p**	**7p**	**+**
Double bedroom	**n/a**							
double bed 2000x1500 or 2 singles 2000x900		1	1	1	1	1	1	1
bedside table 400x400		2	2	2	2	2	2	2
chest of drawers 450x750		1	1	1	1	1	1	1
table 500x1050, and chair/stool		1	1	1	1	1	1	1
double wardrobe 600x1200 – could be built in		1	1	1	1	1	1	1
occasional cot space 600x1200 for family dwelling				1	1	1	1	1
Twin bedroom	**n/a**							
single bed 2000x900		2	2	2	2	2	2	2
bedside table 400x400		2	2	2	2	2	2	2
chest of drawers 450 x750		1	1	1	1	1	1	1
table 500x1050, and chair/stool		1	1	1	1	1	1	1
double wardrobe 600x1200 (or two singles) could be built in		1	1	1	1	1	1	1
Single bedroom								
single bed 2000x900	1	1	1	1	1	1	1	1
bedside table 400x400	1	1	1	1	1	1	1	2+
chest of drawers 450x750	1	1	1	1	1	1	1	2+
table 500x1050 and chair/stool	1	1	1	1	1	1	1	2+
single wardrobe 600x600 – could be built in	1	1	1	1	1	1	1	2+
Kitchen	**1p**	**2p**	**3p**	**4p**	**5p**	**6p**	**7p**	**+**
1 sink top and drainer 600x1000	1000	1000	1000	1000	1000	1000	1000	1000
2 cooker space 600x600	600	600	600	600	600	600	600	600
3 washing machine position / worktop 600x630	630	630	630	630	630	630	630	630
4 other base units 600x length	1200	1200	1600	1600	1600	2700	2700	+
5 ancillary equipment space 600x length -					600	600	1200	1200
6 fridge/freezer space 600x600 (space above not in VOL)	600	600	600	600	600	600	600	600
7 broom cupboard 600x600x1950. (Note this may be counted towards the 'tall storage' requirement)	600	600	600	600	600	600	600	600
8 tray space 600x150	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.
9 recycle bins space	300	300	600	600	600	600	600	600
10 length of fitments 1-9	4930	4930	5630	5630	6230	7330	7930	+
11 VOL- min capacity (cu m.) (MUST include drawers)	1.3	1.5	2	2.1	2.2	2.4	2.6	+
Any wall units provided should be 300 deep and 450 above base units.								
Note: Item 3,5,6,7,9 may be in adjacent rooms to the kitchen.								
Bathroom	**1p**	**2p**	**3p**	**4p**	**5p**	**6p**	**7p**	**+**
WC + cistern 500x700	1	1	1	1	2	2	2	2
Bath 700x1700	1	1	1	1	1	1	1	1
Wash hand basin 600x400 – 2nd one can be 250x350	1	1	1	1	2	2	2	2
shower tray 750x750 optional								
***All Sizes in mm**								

NB: The HQIs make use of material created for the Standards and Quality project by the NHF with the Joseph Rowntree Foundation (1998). This document includes illustrations of spaces required to access the furniture and to perform activities typical to each room.

For private-sale or open-market homes, the core standards would apply in any situation where a scheme receives HCA support through free or discounted land and/or through facilitating or funding major infrastructure investment.

The standards are accompanied by the Housing Quality Indicators (version 4 April 2008), inherited from the Housing Corporation which, whilst they do not lay down space standards for individual rooms, do include a schedule of furniture requirements which impinge on room sizes. See Table V.

2.4 National House Building Council (NHBC)

The National House Building Council publishes a comprehensive set of technical and performance standards for private house

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Table VI NHBC Key design requirements

Item	Requirement
Roof access	520 mm min dimension in any direction
	Plus large enough for removal of any services or fittings
	Not to be sited directly over stairs or other hazard
Kitchen / utility layout	1 m² circulation space in front of fittings and appliances
Storage	General storage and clothes storage required and where no central heating, an airing cupboard
Airing cupboard	Where provided must have:
	Min 0.5 m² shelf space
	Min 300 mm between shelves
	No shelf over 1.5 m above floor

builders, the current edition being NHBC Standards 2014. These must be followed if seeking a warranty. Other warranty providers also impose similar standards. The standards concern construction and performance.

The NHBC does not set space standards, but requires that purchasers are provided with floor plans showing that bedrooms can accommodate bed or beds without obstructing the door swing. Other free-standing furniture such as wardrobes, chests of drawers etc. may be shown at the builder's discretion. The key design requirements are noted in Table VI.

2.5 Scotland

Space standards, based on the New Scottish Housing Handbook, Bulletin 1: Metric Space Standards document, were removed from Scottish Building Regulations in 1987. The Building Standards Technical Handbook gives guidance on the design of dwellings, including some spatial requirements, but does not give minimum dwelling or room areas.

The Scottish Housing Quality Standard (SHQS) was introduced in 2004 and is the Scottish Government's principal measure of housing quality in Scotland. The SHQS is a set of five broad housing criteria which must all be met if the property is to pass SHQS. These criteria in turn consist of 55 elements and nine sub-elements against which properties need to be measured. The purpose is to provide a 'floor' below which a property should ideally not fall. In the case of the social housing sector (local authority landlords and Registered Social Landlords), Scottish Government has set a policy target for those landlords to bring their stock up to every element of the standard (where applicable) by April 2015. Private sector landlords and owner-occupied households in Scotland are not subject to the April 2015 policy target either but each property can still be assessed against SHQS if required.

2.6 Wales

The Welsh Assembly published the Development Quality Requirements in 2005 which sets out the standards that HAs and RPs in Wales must meet. They apply to all funded or part-funded housing, both new build and existing. In 2008 the Assembly issued revised guidance for social landlords on the implementation of the standards.

2.7 Northern Ireland

In Northern Ireland the Department for Social Development is responsible for the Housing Association Development Guide Design Standards which apply to all funded or part-funded new build housing.

2.8 Greater London Authority; London Plan

The interim edition of the Mayor's London Housing Design Guide (LHDG) was published in 2010 and sets out the Mayor of London's aspirations for the design of all new housing in the capital. It is expected that a final version of the guide will follow in due course.

The guide promotes better neighbourhoods, high environmental standards, better accessibility and better design and includes new minimum standards for the amount of floor space and private outdoor space, as well as guidance on natural light and ceiling heights. The Supplementary Planning Guidance (SPG) for Housing develops and refines the standards set out in LHDG, setting out how the policies of the 2011 London Plan can be implemented, and applies these to all tenures of housing development. The standards are the most comprehensive that apply to housing at the present time and as such are summarised in Table VII.

2.9 Other statutory controls

Underground rooms regulations, published by some Local Planning Authorities under the Housing Acts, cover lighting and ventilation of basement habitable rooms.

3 DESIGN DATA

There are several other important standards which include dimensional and spatial requirements for dwellings. These are not covered by statutory control but are often required.

3.1 Lifetime Homes

The concept of 'Lifetime Homes' was initially published and promoted by the Joseph Rowntree Foundation (JRF) in the early 1990s, and is now administered by Habinteg Housing Association. The idea is to construct dwellings that can be more easily adapted to cope with residents' future disabilities, should these arise. Such disabilities could be either temporary, such as resulting from an accidental injury, or permanent, from accident or illness. The recommendations are based on 5 principles: inclusivity, accessibility, adaptability, sustainability and good value. They take the form of 16 points covering the planning and construction of new dwellings. These 16 points are listed in Table VIII. The standards for Lifetime Homes are not mandatory, but they relate to the requirements now in Approved Document M of the Building Regulations, and in effect extend their scope, towards the same ends of improving accessibility. HAs and RPs have widely adopted Lifetime Homes as part of their design briefs, and many local authority planning departments now also require them, at least for a proportion of new dwellings.

3.2 Space standards for housing in relation to people with disabilities and wheelchair housing

People who use wheelchairs are as varied in their housing needs as the rest of the population. However, very little existing housing, or new conversions, are suitable for people permanently confined to wheelchairs (estimated to be about 2–3 per cent of all people with disabilities). In order to redress this imbalance and give people with disabilities a choice of housing of different types and tenures and to enable more people to remain in their homes if they become disabled, a proportion of new build, general purpose housing needs to be built to be suitable for adaption for wheelchair occupants. It generally needs to be on one level and have above-average space standards in order to allow for full wheelchair manoeuvre throughout.

When planning dwellings for regular occupation by users of wheelchairs or walking frames, it might be supposed that recommended room areas would need to be augmented. This is not necessarily always the case. Much more important are linear dimensions across circulation areas and between fixed appliances or obstructions. For this reason the planning of kitchens and bathrooms is especially important.

The Wheelchair Housing Design Guide (second edition), produced by Habinteg and Stephen Thorpe is generally viewed as the definitive guide to Wheelchair Housing. However, although this document is currently the essential reference document for the design of wheelchair housing for HCA-funded schemes, it is not universally applied.

Table VII London Plan Housing SPG; Summary of the Quality and Design Standards

Design Standards	
1.0	Shaping Good Places
1.1	**Defining Places**
1.1.1	Development proposals should demonstrate:- • how the design responds to its physical context, including the character and legibility of the area and the local pattern of building, public space, landscape and topography • how the scheme relates to the identified character of the place and to the local vision and strategy or how bolder change is justified in relation to a coherent set of ideas for the place expressed in the local vision and strategy or agreed locally
1.1.2	Development proposals should demonstrate:- • how the scheme complements the local network of public spaces, including how it integrates with existing streets and paths • how public spaces and pedestrian routes are designed to be overlooked and safe, and extensive blank elevations onto the public realm at ground floor have been avoided • for larger developments, how any new public spaces including streets and paths are designed on the basis of an understanding of the planned role and character of these spaces within the local movement network, and how new spaces relate to the local vision and strategy for the area
1.2	**Outdoor Spaces**
1.2.1	Development proposals should demonstrate that they comply with the borough's open space strategies, ensuring that an audit of surrounding open space is undertaken and that, where appropriate, opportunities to help address a deficiency in provision by providing new public open spaces are taken forward in the design process
1.2.2	For developments with a potential occupancy of ten children or more, development proposals should make appropriate play provision in accordance with the LP SPG, Providing for Children and Young People's Play and Informal Recreation
1.2.3	Where communal open space is provided, development proposals should demonstrate that the space:- • is overlooked by surrounding development • is accessible to wheelchair users and other disabled people • is designed to take advantage of direct sunlight • has suitable management arrangements in place
2.0	**Housing for a Diverse City**
2.1	**Appropriate density**
2.1.1	Development proposals should demonstrate how the density of residential accommodation satisfies LP policy relating to public transport accessibility levels (PTALs)* and the accessibility of local amenities and services, and is appropriate to the location in London
2.2	**Residential mix**
2.2.1	Development proposals should demonstrate how the mix of dwelling types and sizes and the mix of tenures meet strategic and local borough targets and are appropriate to the location in London
3.0	**From Street to Front Door**
3.1	**Entrance and approach**
3.1.1	All main entrances to houses, ground floor flats and communal entrance lobbies should be visible from the public realm and clearly identified
3.1.2	The distance from the accessible car parking space of requirement 3.3.4 to the home or to the relevant block entrance or lift core should be kept to a minimum and should be level or gently sloping
3.1.3	The approach to all entrances should preferably be level or gently sloping
3.1.4	All entrances should be illuminated and have level access over the threshold. Entrance doors should have 300mm of clear space to the pull side, and clear minimum opening widths of 800mm or 825mm depending on the direction and width of approach. Main entrances should have weather protection and a level external landing
3.2	**Shared circulation within buildings**
3.2.1	The number of dwellings accessed from a single core should not exceed eight per floor, subject to dwelling size mix
3.2.2	An access core serving 4 or more dwellings should provide an access control system with entry phones in all dwellings linked to a main front door with electronic lock release. Unless a 24 hour concierge is provided, additional security measures including audio-visual verification to the access control system should be provided where any of the following apply:- • more than 25 dwellings are served by one core • the potential occupancy of the dwellings served by one core exceeds 100 bed spaces • more than 8 dwellings are provided per floor
3.2.3	Where dwellings are accessed via an internal corridor, the corridor should receive natural light and adequate ventilation
3.2.4	The minimum width for all paths, corridors and decks for communal circulation should be 1200mm. The preferred minimum width is 1500mm, and is considered particularly important where corridors are 'double-loaded' and serve dwellings on each side, and where wheelchair accessible dwellings are provided
3.2.6	All dwellings entered at the fourth floor (fifth storey) and above should be served by at least one wheelchair accessible lift, and it is desirable that dwellings entered at the third floor (fourth storey) are served by at least one such lift. All dwellings entered at the seventh floor (eighth storey) and above should be served by at least two lifts
3.2.7	Every designated wheelchair accessible dwelling above the ground floor should be served by at least one wheelchair accessible lift. It is desirable that every wheelchair accessible dwelling is served by more than one lift
3.2.8	Principal access stairs should provide easy access regardless of whether a lift is provided. Where homes are reached by a lift, it should be fully wheelchair accessible
3.3	**Car parking**
3.3.1	Standard 3.3.1 (and Policy 6.13) – All developments should conform to LP policy on car parking provision (see Annex 2.3 of this SPG for guidance on implementation of relevant policy including LP Policy 6.13 and associated standards below). In areas of good public transport accessibility and/or town centres the aim should be to provide no more than one space per dwelling. Elsewhere parking provision should be broadly as follows, depending on location as indicated in Annex 2.4 • 4+ bedroom dwellings: 1.5 – 2 spaces per dwelling • 3 bedroom dwellings: 1 – 1.5 spaces per dwelling • 1 – 2 bedroom dwellings: Less than 1 per dwelling
3.3.2	Each designated wheelchair accessible dwelling should have a car parking space 2400mm wide with a clear access way to one side of 1200mm
3.3.3	Careful consideration should be given to the siting and organisation of car parking within an overall design for open space so that car parking does not negatively affect the use and appearance of open spaces
3.3.4	Where car parking is within the dwelling plot, at least one car parking space should be capable of enlargement to a width of 3300mm. Where parking is provided in communal bays, at least one space with a width of 3300mm should be provided per block entrance or access core in addition to spaces designated for wheelchair user dwellings
3.4	Cycle storage
3.4.1	All developments should provide dedicated storage space for cycles at the following levels: • 1 per 1 or 2 bedroom dwelling • 2 per 3 or more bedroom dwelling
3.4.2	Individual or communal cycle storage outside the home should be secure, sheltered and adequately lit, with convenient access to the street. Where cycle storage is provided within the home, it should be in addition to the minimum GIA and minimum storage and circulation space requirements. Cycle storage in habitable rooms or on balconies is considered unacceptable
3.5	**Refuse, post and deliveries**
3.5.1	Communal refuse and recycling containers, communal bin enclosures and refuse stores should be accessible to all residents including children and wheelchair users, and located on a hard, level surface. The location should satisfy local requirements for waste collection and should achieve full credits under the Code for Sustainable Homes Technical Guide. Refuse stores within buildings should be located to limit the nuisance caused by noise and smells and provided with means for cleaning
3.5.2	Storage facilities for waste and recycling containers should be provided in accordance with the Code for Sustainable Homes Technical Guide and local authority requirements
4.0	**Dwelling Space Standards**
4.1	Internal floor area
4.1.1	All developments should meet the following minimum space standards:-

	Dwelling type (bedroom/persons)	Essential GIA (sq.m)
Single storey dwelling	1p	37
	1b2p	50
	2b3p	61
	2b4p	70
	3b4p	74
	3b5p	86
	3b6p	95
	4b5p	90
	4b6p	99
Two storey dwellings	2b4p	83
	3b5p	96
	4b5p	100
	4b6p	107
Three storey dwellings	3b5p	102
	4b5p	106
	4b6p	113

For dwellings designed for more than 6 people, at least 10sq.m gross internal area should be added for each additional person.

(continued)

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Table VII (continued)

Design Standards	
4.1.2	Dwelling plans should demonstrate that dwellings will accommodate the furniture, access and activity space requirements relating to the declared level of occupancy **(Refer to Table 3 – HCA HQI standards)**
4.2	**Flexibility and adaptability**
4.2.1	Dwelling plans should demonstrate that dwelling types provide flexibility by showing that at least one bedroom is capable of being used and furnished as either a double or a twin room according to occupiers' preferences
4.3	**Circulation in the home**
4.3.1	The minimum width of hallways and other circulation spaces inside the home should be 900mm. This may reduce to 750mm at 'pinch points' e.g. next to radiators, where doorway widths meet the following specification:

Minimum clear opening width of doorway (mm)	Minimum width of hallway where door is in side wall (mm)
750	1200
775	1050
900	900

Where a hallway is at least 900mm wide and the approach to the door is head-on, a minimum clear opening door width of 750mm should be provided

4.3.2	The design of dwellings of more than one storey should incorporate potential for a stair lift to be installed and a suitable identified space for a through-the-floor lift from the entrance level to a storey containing a main bedroom and an accessible bathroom
4.4	**Living/dining/kitchen**
4.4.4	There should be space for turning a wheelchair in dining areas and living rooms and basic circulation space for wheelchairs elsewhere
4.4.5	A living room, living space or kitchen dining room should be at entrance level
4.4.6	Windows in the principal living space should be no higher than 800mm above finished floor level (+/- 50mm) to allow people to see out while seated. At least one opening window should be easy to approach and operate by people with restricted movement and reach
4.5	**Bedrooms**
4.5.3	In homes of two or more storeys with no permanent bedroom at entrance level, there should be space on the entrance level that could be used as a convenient temporary bed space
4.5.4	Building structure above a main bedroom and an accessible bathroom should be capable of supporting a ceiling hoist and the design should allow for a reasonable route between this bedroom and bathroom
4.6	**Bathrooms and WCs**
4.6.2	Where there is no accessible bathroom at entrance level, a wheelchair accessible WC with potential for a shower to be installed should be provided at entrance level
4.6.3	An accessible bathroom should be provided in every dwelling on the same storey as a main bedroom
4.6.4	Walls in bathrooms and WCs should be capable of taking adaptations such as handrails
4.7	**Storage and utility**
4.7.1	• In dwellings supported by the LDA or receiving public subsidy, built-in general internal storage space free of hot water cylinders and other obstructions, with a minimum internal height of 2m and a minimum area of 1.5 sq m should be provided for 1 and 2 person dwellings, in addition to storage provided by furniture in habitable rooms. For each additional occupant an additional 0.5 sq m of storage space is required • Private sector dwellings should ensure this minimum area (1.5 sq m) either within the dwelling itself or elsewhere within its curtilage provided minimum internal provision includes storage space free of hot water cylinders and other obstructions with a minimum internal height of 2m and a minimum area of 0.8 sq m for 1 and 2 person dwellings, in addition to storage provided by furniture in habitable rooms. For each additional occupant an additional 0.5 sq m of storage space is required
4.8	**Study and work**
4.8.1	Dwelling plans should demonstrate that all homes are provided with adequate space and services to be able to work from home. The Code for Sustainable Homes guidance on working from home is recommended as a reference

Table VII (continued)

Design Standards	
4.8.2	Service controls should be within a height band of 450mm to 1200mm from the floor and at least 300mm away from any internal room corner
4.9	**Wheelchair user dwellings**
4.9.1	Ten percent of new housing should be designed to be wheelchair accessible or easily adaptable for residents who are wheelchair users
4.10	**Private open space**
4.10.1	A minimum of 5 sq m of private outdoor space should be provided for 1-2 person dwellings and an extra 1 sq m should be provided for each additional occupant
4.10.2	Private outdoor spaces should have level access from the home
4.10.3	The minimum depth and width of all balconies and other private external spaces should be 1500mm
5.0	**Home as a place of retreat**
5.1	**Privacy**
5.1.1	Design proposals should demonstrate how habitable rooms within each dwelling are provided with an adequate level of privacy in relation to neighbouring property, the street and other public spaces
5.2	**Dual aspect**
5.2.1	Developments should avoid single aspect dwellings that are north facing, exposed to noise levels above which significant adverse impacts on health and quality of life occur, or contain three or more bedrooms
5.3	**Noise**
5.3.1	The layout of adjacent dwellings and the location of lifts and circulation spaces should seek to limit the transmission of noise to sound sensitive rooms within dwellings
5.4	**Floor to ceiling heights**
5.4.1	The minimum floor to ceiling height in habitable rooms should be 2.5m between finished floor level and finished ceiling level
5.6	**Air quality**
5.6.1	Minimise increased exposure to existing poor air quality and make provision to address local problems of air quality. Be at least 'air quality neutral' and not lead to further deterioration of existing poor air quality
6.0	**Climate change mitigation and adaptation**
6.1	**Environmental performance**
6.1.2	All homes should satisfy LP policy on sustainable design and construction and make the fullest contribution to the mitigation of and adaptation to climate change
6.2	**Energy and CO_2**
6.2.1	Development proposals should be designed in accordance with the LP energy hierarchy, and should meet the following minimum targets for carbon dioxide emissions reduction. Year — Improvement on 2010 Building Regulations 2010 – 2013 — 25 per cent 2013 – 2016 — 40 per cent 2016 – 2031 — Zero carbon
6.3	**Overheating**
6.3.1	Development proposals should demonstrate how the design of dwellings will avoid overheating during summer months without reliance on energy intensive mechanical cooling systems
6.4	**Water**
6.4.1	New dwellings should be designed to ensure that a maximum of 105 litres of water is used per person per day
6.4.2	Where development is permitted in an area at risk of flooding, it should incorporate flood resilient design in accordance with PPS25
6.4.3	New development should incorporate Sustainable Urban Drainage Systems and green roofs where practical with the aim of achieving a greenfield run-off rate, increasing bio-diversity and improving water quality. Surface water run-off is to be managed as close to source as possible
6.5	**Materials**
6.5.2	All new residential development should meet the requirements of the Code Level 4 with regard to using materials with lower environmental impacts over their lifecycle
6.6	**Ecology**
6.6.1	The design and layout of new residential development should avoid areas of ecological value and seek to enhance the ecological capital of the area in accordance with GLA best practice guidance on biodiversity and nature conservation

*Public transport accessibility levels (PTALs) are set out in The London Plan; Map 2A.3 for all London Boroughs and give a range of suitable densities in habitable rooms per hectare.

A much-distilled summary of some of the main requirements is given in Table IX. These recommendations will tend to lead to increases in the floor areas of kitchens and bathrooms, and widths of circulation spaces.

3.3 British Standard 9266:2013 Design of accessible and adaptable general needs housing

Whilst many British Standards have elements that can be applied to housing design, BS9266:2013 is a code of practice which specifically

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Table VIII Lifetime Home standards (Latest edition published by Habinteg Housing Association in 2010).

1 Parking (width or widening capability)	**1a 'On plot' (non-communal) parking** Where a dwelling has car parking within its individual plot (or title) boundary, at least one parking space length should be capable of enlargement to achieve a minimum width of 3300mm.	**1b Communal or shared parking** Where parking is provided by communal or shared bays, spaces with a width of 3300mm, in accordance with the specification below, should be provided	**2 Approach to dwelling from parking** The distance from the car parking space of Criterion 1 to the dwelling entrance (or relevant block entrance or lift core), should be kept to a minimum and be level or gently sloping. The distance from visitors' parking to relevant entrances should be as short as practicable and be level or gently sloping.	**3 Approach to all entrances** The approach to all entrances should preferably be level or gently sloping, and in accordance with the specification noted.	**4 Entrances** All entrances should:- • Be illuminated • Have level access over the threshold • Have effective clear opening widths and nibs as specified In addition, main entrances should also:- • Have adequate weather protection • a level external landing.	**5 Communal stairs and lifts**	**5a Communal stairs** Principal access stairs should provide easy access in accordance with the specification below, regardless of whether or not a lift is provided.	**5b Communal lifts** Where a dwelling is reached by a lift, it should be fully accessible in accordance with the specification noted.
6 Internal doorways and hallways Movement in hallways and through doorways should be as convenient to the widest range of people, including those using mobility aids or wheelchairs, and those moving furniture or other objects. As a general principle, narrower hallways and landings will need wider doorways in their side walls. The width of doorways and hallways should conform to the specification noted.	**7 Circulation space** There should be space for turning a wheelchair in dining areas and living rooms and basic circulation space for wheelchair users elsewhere.	**8 Entrance level living space** A living room/ living space should be provided on the entrance level of every dwelling.	**9 Potential for entrance level bed-space** In dwellings with two or more storeys, with no permanent bedroom on the entrance level, there should be space on the entrance level that could be used as a convenient temporary bed-space.	**10 Entrance level WC and shower drainage** Where an accessible bathroom, in accordance with Criterion 14, is not provided on the entrance level of a dwelling, the entrance level should have an accessible WC compartment, with potential for a shower to be installed.	**11 WC and bathroom walls** Walls in all bathrooms and WC compartments should be capable of firm fixing and support for adaptations such as grab rails.	**12 Stairs and potential through-floor lift in dwellings** The design within a dwelling of two or more storeys should incorporate:- • Potential for stair lift installation • A suitable identified space for a through-the-floor lift from the entrance level to a storey containing a main bedroom and a bathroom satisfying Criterion 14.	**13 Potential for future fitting of hoists and bedroom/bathroom relationship** Structure above a main bedroom and bathroom ceilings should be capable of supporting ceiling hoists and the design should provide a reasonable route between this bedroom and the bathroom.	**14 Bathrooms** An accessible bathroom, providing ease of access in accordance with the specification noted, should be provided in every dwelling on the same storey as a main bedroom.
15 Glazing and window handle heights Windows in the principal living space (typically the living room), should allow people to see out when seated. In addition, at least one opening light in each habitable room should be approachable and usable by a wide range of people – including those with restricted movement and reach.	**16 Location of service controls** Service controls should be within a height band of 450 mm to1200mm from the floor and at least 300mm away from any internal room corner.							

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Table IX Key requirements for wheelchair housing (from the Wheelchair Housing Design Guide)

Using outdoor spaces

Footpaths require a minimum width of 1200 mm.

Gates to private gardens should have a clear opening width of 850 mm.

Gardens should provide: accessible paving outside external door, accessible clothes-drying facilities, and accessible route from external door, external storage and external gate, scope for accessible planting.

Approaching the home

Provide a covered parking space (min. 3600 x 5400 mm) for every ground-floor level wheelchair user dwelling.

Where a garage is provided it should be a minimum of 4200 x 5400 mm.

Provide a level entrance landing 1500 x 1500 mm min. with a canopy 1200 mm x 1500 mm.

Where wheelchair dwellings are above the ground floor, a lift should be provided.

Negotiating the entrance door

Provide effective clear width of at least 800 mm.

Provide space beside leading edge of door, 200 mm min. for a door opening away from the wheelchair user, 300 mm min. for a door opening towards them, extending 1800 mm from face of door.

Entering and leaving; dealing with callers

Provide a transfer space (1100 x 1700 mm) within the house to manoeuvre wheelchair to transfer to a second chair and to store the first, clear of circulation routes and the required approach to furniture and doors.

Provide a 1500 x 1800 mm turning space to manoeuvre and turn.

Where there is an entrance lobby incorporated or provision made for added inner door, ensure adequate space to manoeuvre between doors.

Negotiating the secondary door

Provide nominally level landing 1500 x 1500 mm with 1200 mm clear of door swing.

Provide effective clear width of 800 mm to single or main door leaf.

Ensure space to approach, manoeuvre and pass through door on line.

Moving around inside; storing things

Ensure that passage widths or approaches where no turning or door approach is required are no less than 900 mm clear of all obstructions.

Ensure space beside latch edge of door, min 200 mm on push side and min. 300 mm on pull side.

Ensure that passage widths or approaches to turn through 90° are no less than 1200 mm.

Ensure that passage widths or approaches to turn through 180° are no less than 1500 mm.

Ensure at right angles that passage width clear of all obstructions for the extent of the turn is no less than 1200 mm width in one direction and 900 mm in the other, or 900 mm in each direction in combination with angle splayed by 300 mm.

Ensure 775 mm min. effective clear door width.

Increase where approach is at an angle.

Provide space to turn between doors at an angle to each other, 400 mm clear to each door from angle.

Ensure that depth and width of storage space, in combination with any shelving layout, provides optimum access to space and to stored items.

Moving between levels within the dwelling

Provide lift for independent use by a wheelchair user which connects floors and is accessed off circulation spaces at each floor level with adequate circulation space at each level to operate it.

Using living spaces

Provide space for furniture and for wheelchair user to approach it, circulate, transfer to seating, and approach and operate doors, windows, equipment and controls.

Using the kitchen

Lay out the kitchen to provide a practical working kitchen for a wheelchair user. Ensure clear manoeuvring space not less than 1800 x 1500 mm. Ensure wherever practicable, that windows are positioned for ease of control and cleaning.

Provide an appropriate length of 600 mm deep worktop, suitable for a wheelchair user.

Provide integral shallow sink and drainer to maximise height adjustability, suitable for wheelchair user.

Provide storage appropriate to the size of dwelling, the major proportion of which is in a position and format usable from a wheelchair.

Provide hob and built-in oven. The hob should have a knee space below and the oven should be at an accessible height, adjustable to suit the user. Provide 3 spaces (4 in larger dwellings) in addition to hob and oven for appliances/white goods.

Provide suitable internal refuse arrangements, manageable from a wheelchair.

Using the bathroom

In all dwellings provide fully accessible bathroom with WC, basin, and installed level access shower (1000x1000 mm min.) with provision for bath in place of shower.

Ensure provision for direct access from main bedroom into bathroom.

In dwellings of 4 or more persons, provide fully accessible second WC with basin.

Ensure independent approach/ transfer to and use of all fittings, including manoeuvring space clear of fittings and door swing if inward opening.

450 mm transfer space required at end of bath, where provided.

Using bedrooms

Provide bedroom layouts to ensure access to both sides of beds in double bedrooms and outer sides of beds in single bedrooms, access to other furniture and to window.

Operating windows

Ensure that wheelchair user can approach window.

Ensure that glazing line to windows in living, dining and bedrooms is no higher than 800 mm.

Table X BS9266: summary of key requirements

Externally
For blocks of flats or individual houses without on-plot parking one designated accessible parking bay should be provided in each parking location and/or lift core
Designated accessible parking bays should be 3600 mm x 6600 mm for parallel parking and 3600 mm x 6000 mm for perpendicular and echelon parking facilities
Setting-down points should be provided on firm and level ground and no more than 50m from an individual house or the communal entrance of a block of flats
Step-free access is required to the entrances of individual dwellings or blocks of flats from the street, parking spaces and setting-down points (an allowance is made on steeply sloping sites)
Steps should be provided in addition to any ramp where there is a level change of 300 mm or greater. The width of the flight should be a minimum of 1.2m when measured between walls, balustrades, etc. and a minimum of 1.0m between handrails. Handrails should be provided on both sides, be continuous around landings and provide a 300 mm run past
Internally
In blocks of flats with two floors in addition to the entrance level (i.e. three storeys), at least one passenger lift or one enclosed vertical lifting platform should be installed at each service core. Blocks of flats with three or more floors in addition to the entrance level (i.e. four or more storeys) should be served by at least one passenger lift at each service core. This includes floors with car parking and/or other communal facilities
Common steps and stairs should be designed to the same standard as external steps (see above)
On private stairs, the rise of each step should be between 150 mm and 200 mm, and the going of each step should be between 250 mm and 320 mm
In blocks of flats the effective clear width of entrance doors, and associated lobby and communal hallway doors, should be at least 1000 mm
A clear level space of at least 1500 mm x 1500 mm should be available in front of each individual flat entrance door, to enable a wheelchair user to turn
Internal circulation spaces should be not less than 900 mm wide × 900 mm deep, clear of door swings and other obstructions. There should be a space of not less than 900 mm deep clear of the front door swing
Provide a 300 mm clear space to the side of the leading edge of a swing door (on the opening side) for all rooms within an individual house or flat
Provide an accessible WC and washbasin (not a hand rinse basin)
Provide a manoeuvring space of 1500 mm diameter internally, adjacent to a balcony and in at least one bedroom

gives advice on the design of accessible and adaptable general needs housing. It is concerned largely with access to, within and use of, residential buildings covering both new build and refurbishment of general needs housing both in the form of flats and houses. Although not mandatory in its application, many housing providers require compliance with relevant British Standards as part of their brief. Table X details those clauses which may have the greatest impact on housing design and layouts as they are over and above other housing standards.

3.4 Code for Sustainable Homes

The Code for Sustainable Homes (the Code) is the national standard for the sustainable design and construction of all new homes, private or funded. The Code aims to reduce our carbon emissions and create homes that are more sustainable. It applies in England, Wales and Northern Ireland. It is entirely voluntary, and is intended to help promote higher standards of sustainable design above current Building Regulations.

The Code measures the sustainability of new homes against nine categories of sustainable design, rating the 'whole home' as a complete package. It covers energy/CO_2, water, materials, surface water runoff (flooding and flood prevention), waste, pollution, health and well-being, management and ecology. The Code uses a one to six star rating system to communicate the overall sustainability performance of a new home against these nine categories. The Code sets minimum standards for energy and water use at each level and, within England, replaces the EcoHomes scheme, developed by the Building Research Establishment (BRE).

The Code is not mandatory, nor is it a set of regulations, and designers should not confuse it with Zero Carbon policy. The only circumstances where the Code can be required are:

- where local authorities stipulate a requirement in their local plans;
- where affordable housing is funded by the HCA, which currently requires homes to be built to Code Level 4;
- where housing is funded by the GLA in London, which also requires homes to be built to Code Level 4.

The Level 3 energy standard was incorporated in the Building Regulations but removed in the revision to Approved Document L.

Clients may have a level set in their employer's requirements and a Code for Sustainable Homes pre-assessment carried out by a registered assessor will be required for most planning applications.

3.5 Secured by Design

Secured by Design (SBD) is owned by the Association of Chief Police Officers (ACPO) and is supported by the Home Office and Department of Communities and Local Government (DCLG). The publication is the source document for achieving a Secured by Design certification/award. It addresses the community safety and security requirements for most types of housing development including individual houses, housing estates and low- and high-rise apartment blocks.

The design and layout and physical security sections can be applied to both new and refurbished homes, regardless of their existing or future tenure. Additional information for sheltered housing projects is available from the SBD website (www.secured-bydesign.com).

Secured by Design is not a mandatory standard but should be applied as good practice and may be a specific client requirement. Compliance with the SBD scheme criteria can be a major indication that a scheme proposal has adequately addressed the crime prevention component required to be included in a Design and Access Statement (DAS).

The Code for Sustainable Homes awards points to developments that have met the requirements of Secured by Design – New Homes, Section 02; this section covers Physical Security (Building Control & Code for Sustainable Homes issues).

3.6 Building for Life

The latest version of Building for Life was published in 2012. It is an industry standard, endorsed by the government, for well-designed homes and neighbourhoods, based on the National Planning Policy Framework and is intended to reflect the vision that new housing developments should be attractive, functional and sustainable.

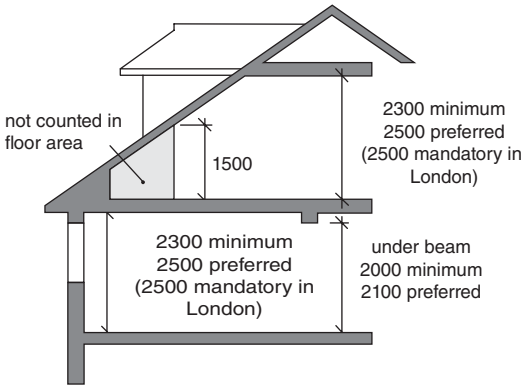
BfL12 consists of 12 questions which are designed to help structure discussions between local communities, the local planning authority and the development team. The 12 questions should be used at all stages of the development process. The performance of any scheme measured against the new criteria will be determined using a traffic light system of green, amber and red. As many 'green' lights as possible should be achieved, 'amber' lights should be minimised and 'red' lights avoided. Any 'ambers' and 'reds' should be identified early on in the process so that a suitable design solution can be found where possible. The overall assessment of a scheme will be reached by mutual agreement between the planning authority and the developer.

BfL12 is not mandatory but the partners expect that local planning authorities will adopt the guidance to help them assess the quality of proposed and completed developments and use it as a point of reference in the preparation of local design policies.

BfL12 is applicable for England only, however it may be requested by some local authorities in Wales. The HCA maintains a requirement for evidence of a BfL score in its 2011–2015 funding programme and the GLA and HCA London still encourage its use.

Regardless of whether it is a scheme requirement or not, Building for Life is a useful tool, which can be used to help

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21.5 *Ceiling heights and rooms in the roof, (for guidance only – no longer covered by Building Regulations)*

demonstrate how a residential development provides a high quality external living environment.

3.7 Ceiling heights

These have not been covered by Building Regulations since 1985. Despite this, the old standard of 2.3 m should still be considered the minimum reasonable ceiling height for domestic buildings and 2.4 m is preferable. For funded housing the HQIs suggested that 2.5 m or more is provided but this is not mandatory. The London Housing SPG requires a minimum of 2.5 m to all dwellings.

For rooms in the roof, floor areas are calculated to include only those parts where the ceiling height exceeds 1.5 m (Figure 21.5).

3.8 Staircase widths

These have not been included in Approved Document K of the Building Regulations since 1992. For means of escape purposes, widths of staircases to blocks of flats are covered in Approved Document B; but this does not cover the majority of single-family houses. The movement of furniture should be considered, and 800 mm should be the minimum reasonable clear stair width in domestic buildings.

Some HAs and RPs may, in their design brief, require the facility for the future installation of a stair lift. To comply practically and economically, a straight flight staircase width of 900 mm is preferable although it is possible (at additional cost) to install a stair lift to stairs with winders. See also Section 6.4 regarding alternating tread staircases which are permitted for access to one bedroom in a loft conversion.

3.9 Kitchen units

Fitted kitchen units are very standardised. Despite evidence that for the majority of able-bodied people worktops at 950 mm and sink tops at 975 mm are the most comfortable, most manufacturers provide base units that are 870–880 mm to the underside of the worktop.

For older people and the less mobile, use of a lower worktop, at 800–850 mm, can sometimes be appropriate. However, providing lower worktops generally at this height is not recommended as 'white goods' will rarely fit underneath. It is possible to provide adjustable height worktops in certain areas, around the hob for example, which, in conjunction with standard height worktops elsewhere, might provide the best solution.

4 SINGLE-FAMILY HOUSES

4.1 General

There is now a broad consensus that families with children should be housed at ground level in single-family houses, or in ground-floor flats or ground and first-floor maisonettes with direct entrances. It is not just that children need private gardens. Equally, if not more importantly, the shared entrances, staircases and corridors in blocks of flats, and the external spaces around them, have proved to be largely incompatible with family life. This is especially true in the public sector, where the resources to overcome the management and maintenance problems of communal areas are very limited.

4.2 Orientation and gardens

The relationship between the single-family dwelling and the adjacent public domain (i.e. the highway, the street, court, or much less satisfactorily the footpath) should be as clear and simple as possible. A private, front garden, with front gate and front path leading to the front door, and with minimum length of 2 to 3 m has proven benefits as defensible space. This is not to say that successful houses cannot be built without a front garden or with the front door opening directly, or via an inset porch, from the public pavement. There are many thousands of quite satisfactory houses planned like this in the Victorian inner cities; but in these cases the pavement is clearly part of the publicly maintained highway. When there is an intervening 'confused' space that is neither public nor private but needs to be communally managed, this is rarely satisfactory, and often leads to tangible neglect. Similarly, rear gardens benefit from simplicity and clarity of relationship to the house and of enclosure. Communal space is best kept either to a minimum or omitted altogether. Such is the concern about security that opinion is generally against any provision of rear access, especially from unsupervised rear pathways, even when these are of practical convenience, such as in uninterrupted terraces.

Orientation of the dwelling for best sunlight should not normally take precedence over achieving simple, clear relationships of private and public domains. However, within the dwelling it should normally be possible to arrange for one of the two day rooms (living room or dining kitchen) to get direct sunlight for a large part of the day. It is preferable for one of these rooms to face the front permitting supervision of the street, and for the other to face the rear giving direct garden access. Another factor is the potential for passive solar gain in the winter through the simple expedient of larger double-glazed windows on the southern elevation.

4.3 Height

Although the majority of family houses are of two storeys, three storeys can be appropriate in urban areas. The expense of building taller is usually more than compensated for by savings in foundations and roofs, making this an economical type. Four-storey houses, however, although possible, are difficult to plan, because of the need for an alternative escape route from the upper floors (Building Regulations Approved Document B1). Mutual escape is normally provided between adjacent houses via adjoining balconies; but this leads to potential security risks. However the provision of sprinkler coverage can eliminate the need for an alternative escape route.

4.4 Frontage widths

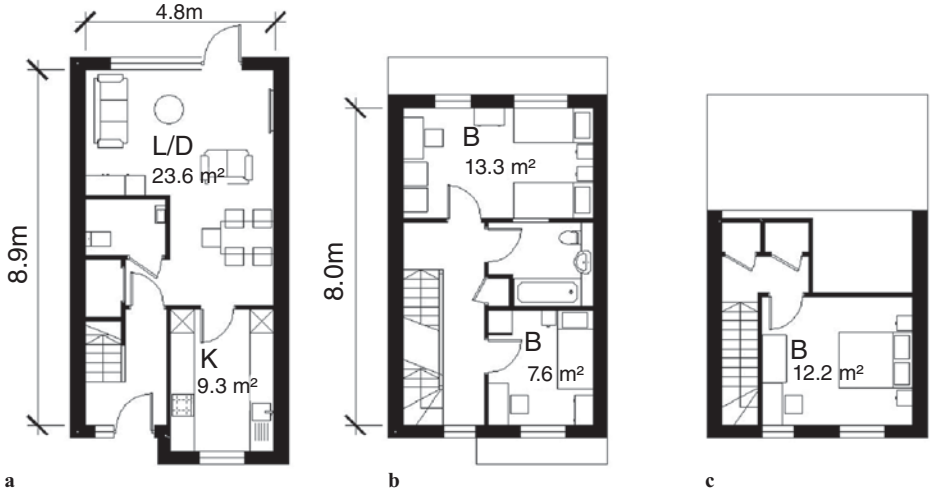
Because of the costs of providing roads and services infrastructure, there is often pressure to build narrow-frontage houses – especially in urban areas. Anything less than 4.8 m internal width can be considered narrow frontage. Although reasonably satisfactory houses have been built with frontages of 4.0 m, the stresses on internal planning start to build up below approximately 4.5 m. A reasonable minimum could be taken to be 4.3 m frontage. Below this width, rear gardens also become apologetic.

Taking 4.8 m as the normal terrace house frontage, Figure 21.6 shows a two-bedroom, four-person, two-storey house; Figure 21.7 a three-bedroom, five-person, two-and-a-half storey house; Figure 21.8 shows a four-bedroom, seven-person, two-and-a-half storey house.

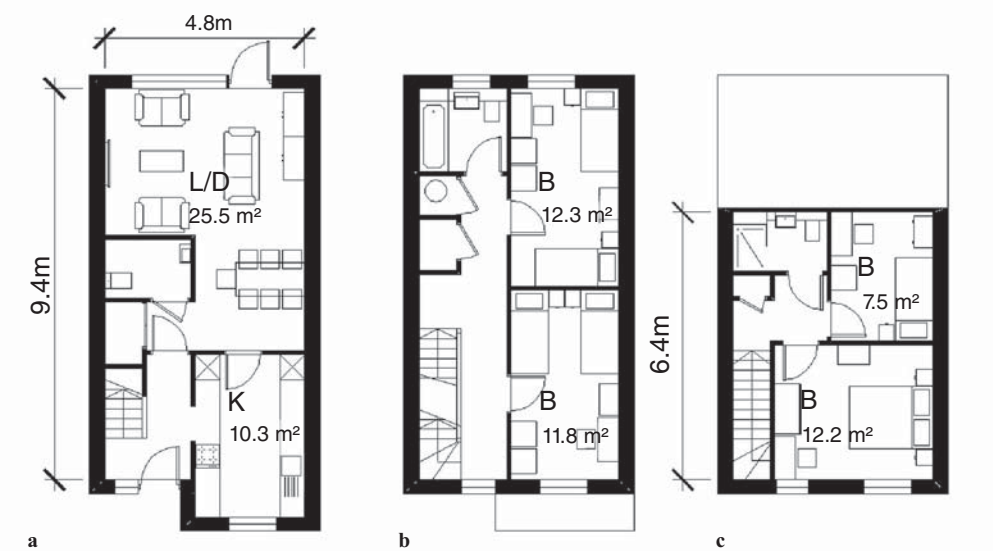
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21.6 *A two-bedroom, four person, two storey terrace house of 79.5m². Architects: PRP Architects. a Ground floor plan with living/dining room; b Alternative ground floor with kitchen/dining room; c First floor*

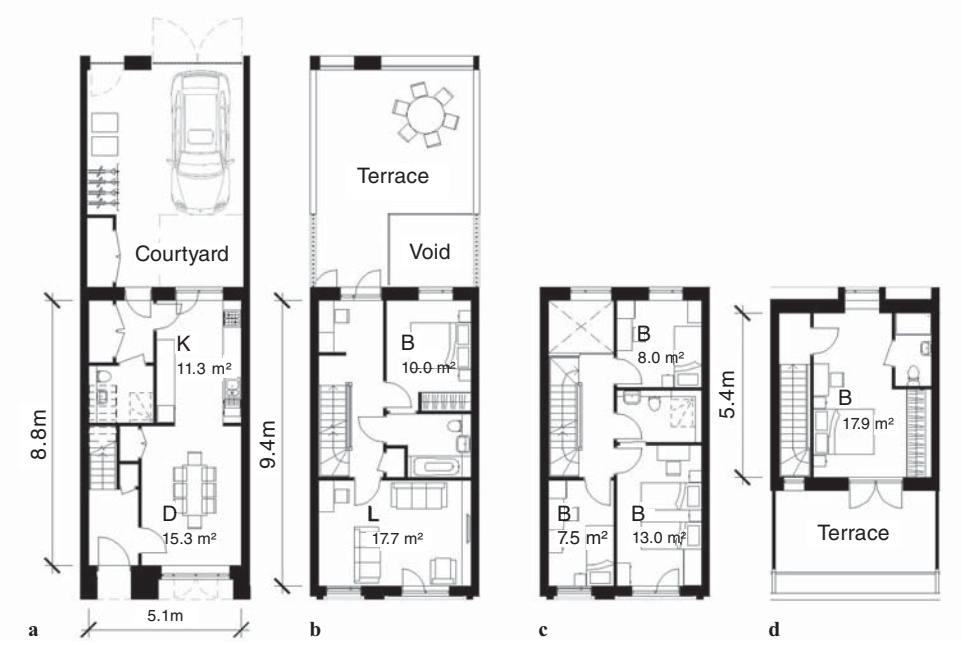


21.7 *A three-bedroom, five person, two and a half storey terrace house of 102.0m². Architects: PRP Architects. a Ground floor; b First floor; c Second floor*

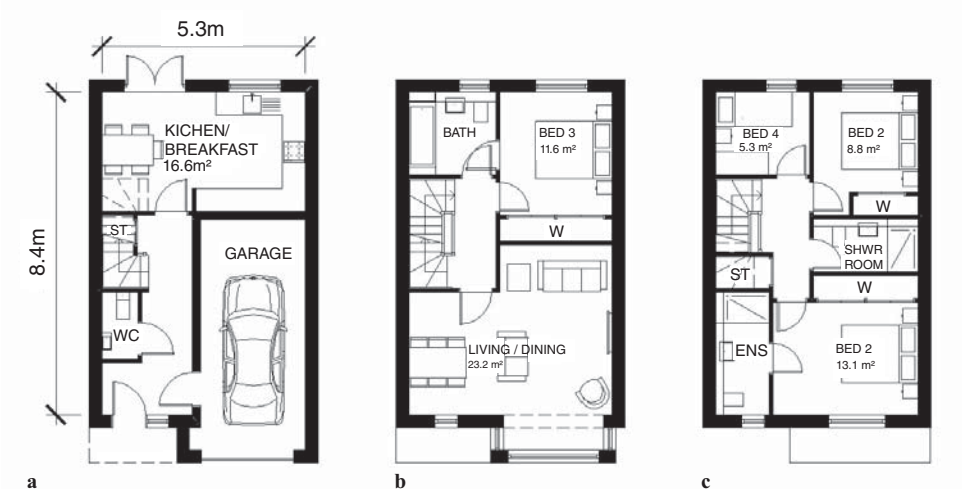


21.8 *A four-bedroom, seven person, two and a half storey terrace house of 123.5m². Architects: PRP Architects. a Ground floor; b First floor; c Second floor*

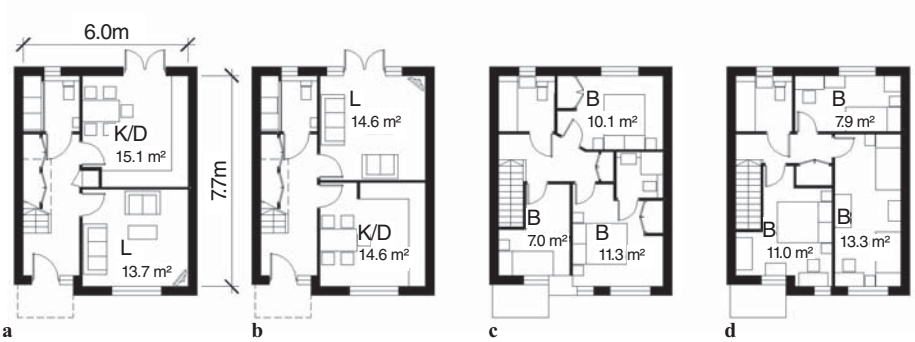
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21.9 *A five-bedroom, seven person, four storey terrace house of 167.0m². Architects: PRP Architects. a Ground floor; b First floor; c Second floor; d Third floor. Provided courtesy of CM LLP*



21.10 *A four-bedroom, three storey terrace house of 121.5m² (for Private sale). Architects: PRP Architects. a Ground floor; b First floor; c Second floor*



21.11 *A three-bedroom, five person, two storey terrace house of 90.5m². Architects: PRP Architects. a Ground floor with living room at the front of the dwelling, overlooking the street; b Ground floor with living room at the rear of the dwelling, overlooking the garden; c First floor to meet private for sale requirements; d First floor to meet affordable housing requirements*

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Table XI General storage (from the HCA's Design and Quality Standards)

minimum shelf areas per person (m^2)	1p 1.5	2p 1.5	3p 2.25	4p 3.0	5p 3.75	6p 4.25	7p 5.25	8p+ +0.75

4.5 Internal planning

Opinions continue to differ over the relative positions of living room and kitchen. It is, however, rarely satisfactory for the only access to the rear garden to be via the living room (in fact Parker Morris ruled this out). In narrow-frontage houses where the living room needs to occupy most of the full width of the front of the house, the dining kitchen will therefore tend to be at the rear, where it can provide a route to the garden. In three or four storey houses this sometimes works well in combination with a front living room at first-floor level as in Figures 21.9 and 21.10. Rooms can then be full width, and offer good outlook and supervision both to the front and rear, as well as benefiting from sunlight with almost any orientation.

Figure 21.9 shows a medium frontage plan with a through dining/kitchen and first floor living room. This house is designed to London Housing Design Guide standards with good storage provisions. Figures 21.6 and 21.11 show a wider plan which gives greater flexibility. It allows the living room to be at the front or rear of the dwelling depending on its orientation. In this instance it is also possible to provide a first floor layout to suit the private for sale market (with an extra en-suite) or the affordable market.

4.6 Living/dining versus kitchen/diner

Certain types, such as Figure 21.6, have the great advantage of offering alternative ground-floor plans with the dining space in either the living room or the kitchen; also the possibility of opening the two spaces into one. Use of the kitchen/diner is generally preferable and suits current lifestyles better as it offers two reception rooms allowing greater flexibility for active family life. This arrangement also ensures that one reception room will receive sunlight for much of the day.

4.7 The main bathroom

This should preferably be located on the floor with the most bedrooms. In three-storey houses this might be the first or the second floor. A ground-floor WC is now a requirement in all family houses, however small (Building Regulations Approved Document Part M). Although there is no longer a legal prohibition of WCs opening directly from kitchens, this arrangement is not normally either popular or advised. An exception might sometimes be a utility room containing a WC and forming the route to the garden. WCs must always have a handbasin (Building Regulation Approved Document Part G).

In larger family houses with four or more bedrooms, a second bathroom, or shower room, is recommended. This can be useful in three-storey houses, as it can mean having a WC on each floor. One bathroom or shower room can be en-suite with the main bedroom; however, this has not normally been considered to be appropriate in social housing.

In private sector housing it is normal to provide one family bathroom plus en-suite shower rooms to the master bedroom and any further double bedroom. Thus in a four bed, seven person house, there would normally be a family bathroom and two en-suite shower rooms.

4.8 Storage

Where Parker Morris scored highly was in specifying good standards for storage. This proved popular, with people becoming more acquisitive all the time and this is still the case. PM specified that a large part of the general storage space should be at ground level, accessible from circulation areas rather than from rooms. It was not intended that the loft space should count, as this is not normally conveniently accessible (though a good-quality loft ladder will make it more so) and trussed rafter construction makes the space much less usable. However boarding to at least part of the loft will create valuable extra storage space.

In addition to general storage space, Parker Morris also stipulated space for hanging outdoor clothes in the entrance hall, a space for a pram (1400 × 700) in houses for three persons or more, and a linen cupboard, all of which remain good practice today.

Bedroom cupboards such as built-in wardrobes were not stipulated. These can be valuable especially for low-income families. However, they need to be carefully planned in order to prevent them making the bedrooms less furnishable.

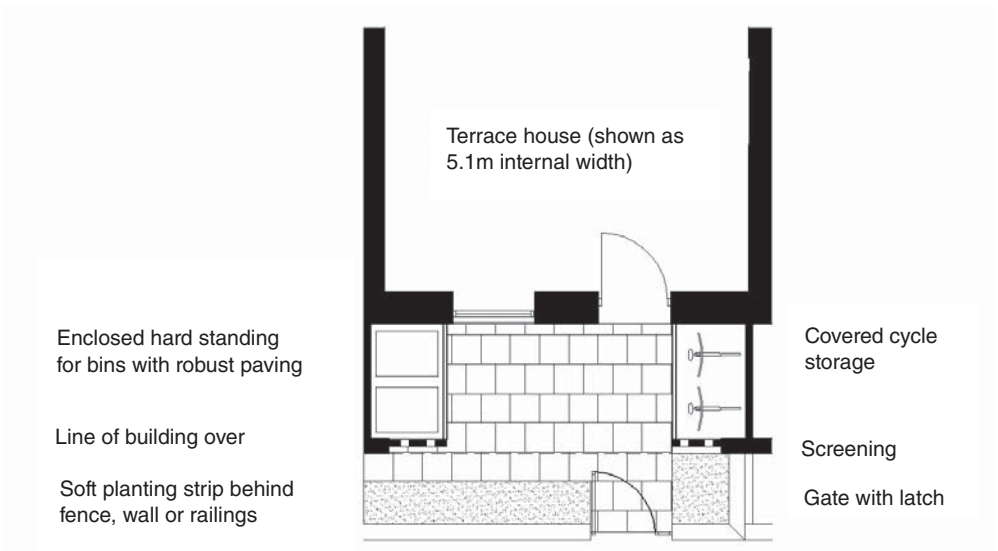
The Design and Quality Standards reiterated the need for good storage, although the requirements are not as generous, as shown in Table XI.

A minimum of 0.4 m^2 of the general storage should be located within an airing cupboard.

In addition to the general storage noted in Table XI, 0.5 m^2 tall storage is required per dwelling. Externally, for units with 1–4 bed spaces, storage should be equal to or greater than 2.2 m^2. For units with greater than 4 bed spaces, storage should be equal to or greater than 3.0 m^2. Where a garage is provided the external storage requirement may be deemed satisfied.

4.9 Stair configuration

Although the Building Regulations do not rule out winders provided that certain minimum dimensions are met, winders are



21.12 *Front garden of a terraced house showing refuse and cycle storage*

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intrinsically less easily negotiated and more hazardous, especially for young children and older people. It is important that large wardrobes and other furniture can be taken up and down the stairs. This needs to be carefully planned for, especially in three-storey houses, where the soffit of the upper flight can restrict the head height over the lower flight, and winders make the problems worse.

Some HAs and RPs do not accept staircases with winders. This can be for reasons of safety, economy and to allow for the easy future installation of stair lifts (as noted in Table VIII).

4.10 External design

Refuse storage space is almost always needed at the front of the house, Figure 21.12. The location for the dustbins or 'wheelie-bin' needs to be clearly identified, for example, by partial enclosure or change of paving surface. It needs to be close to the highway, the front gate and path, and not too far from the front or kitchen door. It should not be where smells would cause a problem, such as immediately under the window of a habitable room. It should always be copiously ventilated, and from this point of view the best form of enclosure is none at all.

Refuse storage requirements can vary from borough to borough. Many now require two 'wheelie-bins', one for general waste and one for recycling. Many also offer an option to have one specifically for garden waste. Designers must check local requirements to ensure refuse storage is properly integrated into the design at an early stage in the process.

Changes are imminent. In 2013 the government announced it will publish guidance on suitable provision for proper waste storage in new homes to tackle 'bin blight' of bins dominating residential streets and contributing to increased odour and roadside litter. This could include covert storage units for residents' bins, or simply ensuring that there is space for bins to be stored in backyards so that they are taken out only when necessary, on bin-collection day.

In addition to this, a ruling, from the European Union, which will take effect from 2015, states that all paper, metal, glass and plastic rubbish will have to be collected separately, which could lead to an increase in the number of containers of these different types of waste.

Meter positions can sometimes be integrated with that of bins, so that one can partially mask the other. This is more the case now that the service companies require external or externally readable meters.

The function of a front garden enclosure is different from that of the rear garden, and this should be reflected in the design, Figure 21.12.

Front fences, railings or walls should allow easy visual surveillance, both ways. A height of between 800 mm and 1300 mm is usually appropriate, and it is useful if the enclosure can be seen through below this level, but does not let dogs through. Thus railings and paling fences score over walls. Front gates should be of roughly the same height. A closed gate effectively excludes dogs and makes a defensible space feel rather more so; but gates, gate posts and catches need to be sturdy and carefully designed.

Enclosure of rear gardens is simpler. An impermeable wall or fence of approximately 1.8 m height is normally recommended at the far end. The side (party fence) enclosures can be reduced to approximately 1.2 m. Most people seem to welcome some garden-to-garden contact with their neighbours, though not immediately next to the house, where a greater height is preferred. If gates are provided in rear garden walls or fences, these should be full height (at least 1.8 m) and lockable with security-grade dead locks. The security of rear fences and garden walls can be improved where these are located against public or communal spaces, by the addition of timber trellis on top; between 450 mm and 600 mm in extra height.

5 PURPOSE-BUILT FLATS

5.1 General

A block of flats nearly always involves shared entrances, stairs, landings, balconies or lobbies, and often one or more lifts. These features tend to make flats undesirable for families with children. In many developments, one would expect the majority of flats to be two-bedroom, with a lesser number of one-bedroom and three bedroom flats.

Common areas and facilities become exponentially more difficult to manage with increasing numbers of flats in the block. Small blocks of four or six flats are easier to manage than those where the numbers get into double figures. Shared systems such as entry phones rely upon responsible behaviour. This is more achievable with a small number of households who know each other. The LHDG has a requirement for a maximum of eight dwellings served off a single stair core and this can be considered good practice. There is also the need to consider the provision of ventilation and natural daylighting to common areas.

5.2 Height of blocks

Parker Morris stipulated the maximum walk-up to a flat front door to be two storeys. Although the Homes & Communities Agency no longer rules out four-storey blocks without lifts, these are on the limit of acceptability. For five storeys and above, a lift is essential although surprisingly, Approved Document M of the Building Regulations does not make the provision of lifts a legal requirement.

5.3 Common stairs, corridors and balconies

Common corridors and lobbies are generally required to be smoke vented in order to prevent smoke and the products of fire in a flat from reaching the fire protected common escape stair. This can be achieved by natural smoke venting to external air via an AOV (automatic opening ventilator) or an internal smoke shaft. Alternatively, a mechanical smoke exhaust or pressure differential system can be utilised. Dry risers and possibly fire-fighting lifts, staircases and lobbies may be required in certain arrangements depending on building heights and floor areas.

Common corridor lengths are normally determined by the limitations of travel distance allowed for means of escape. These are 7.5 m where a single direction of escape exists or 30 m if alternatives routes are available. The provision of designed smoke control systems can allow for extended travel distances. Also the provision of sprinkler coverage within the flats enables the travel distance to be doubled.

In small single stair buildings (with no more than four storeys and no floor level over 11 m above ground) some allowances are made. If there are only two flats per storey these can open directly into the stair core as long as the flats have internal fire protected hallways. Also, if the travel distance in a common lobby or corridor does not exceed 4.5 m then the lobby/corridor is not required to be smoke vented.

Designers should also be aware of the potential problem of common areas over-heating if not adequately ventilated. BS 5925:1991 recommends that a free area of 1/50th of the floor area is provided for adequate ventilation.

5.4 Internal flat layouts (from a fire perspective)

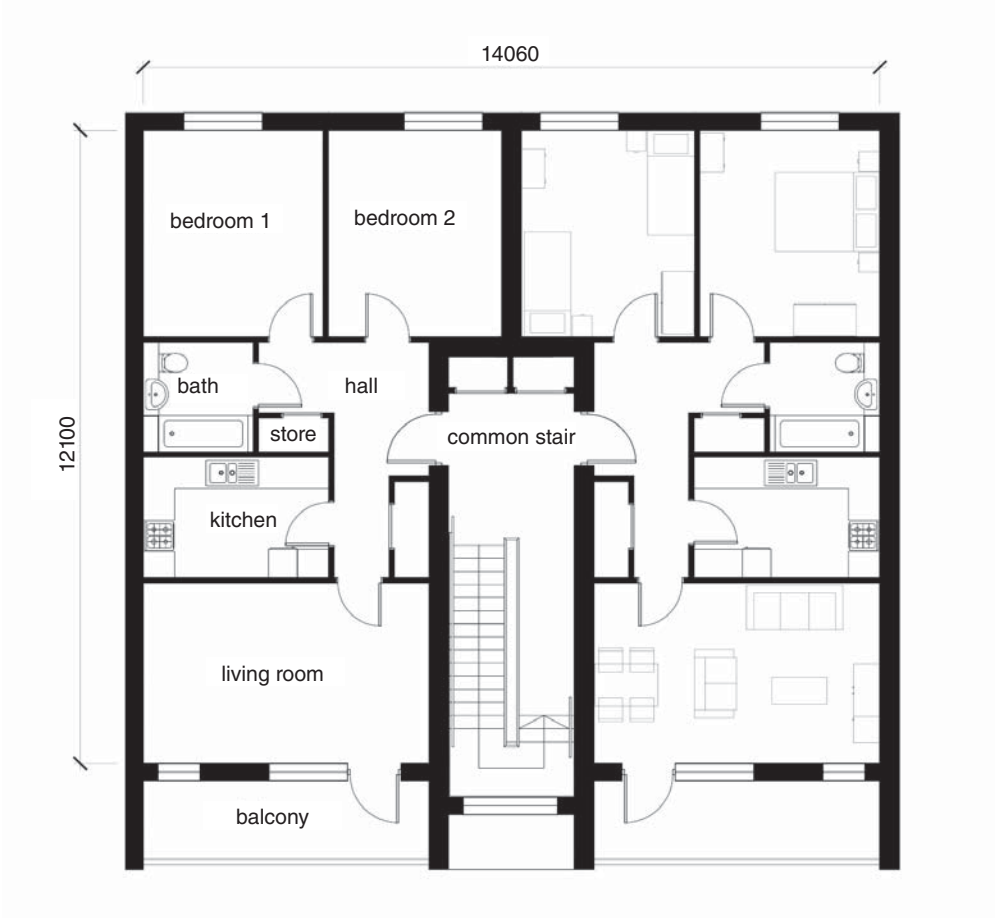
For fire safety purposes any flat that has an internal travel distance of over 9 m from the entrance door to any point of accommodation must be provided with a cellular layout around an internal fire protected hallway that in itself must not exceed 9 m length. Open plan layouts are therefore limited to small flats; however in larger flats the provision of sprinklers does enable open plan layouts. Duplexes require alternative escape routes from the non-entrance levels unless either a sprinkler system is installed or an internal fire protected hall, landing and stairway is formed and a LD2 automatic fire detection system is installed.

5.5 Stacking of similar rooms

All party floors have to provide sound insulation; but the levels of insulation that are mandatory cannot prevent all noise nuisance, and it is best if similar rooms are stacked one above the other. The worst combination is for a living room directly above another flat's bedroom.

5.6 Configuration of rooms around the common stairs

The minimum levels of sound insulation specified in the Building Regulations between all habitable rooms in flats and the common parts of the block are less than fully satisfactory and the adoption



21.13 *Block of two-bedroom, four-person flats, bedrooms located away from stairs. Each flat is 72 m². Lobbies between stairs and flats are required in larger blocks*

of higher performance standards is always preferable. It is desirable therefore to situate bedrooms away from the common stairs, Figure 21.13; and particularly, well away from any lift shaft.

It is usually preferable to plan day rooms at the front and bedrooms at the quieter rear, perhaps alongside the kitchen. There are however, many examples of small blocks of flats with bedrooms at the front alongside the stairs, and living rooms at the rear. This plan form combines the worst exposure of the bedrooms to noise nuisance from the common stairs with the least satisfactory orientation of day and night rooms.

5.7 Balcony access

Balcony or deck access was largely discredited by the social failures of much of the deck-access, medium rise, LA housing built in the 1960s and 1970s. However, some of the smaller, self-contained balcony access flat blocks built between the wars have proved quite satisfactory in long-term use. Balcony or deck access can avoid the squalor associated with wholly internal common circulation areas and provide cross-ventilation (an advantage in avoiding over-heating) but they can also enable the planning of large extended blocks, with too many flats using a single entrance and stair. This should be resisted.

A problem with balcony access flats is the dual aspect; some windows are directly onto the balcony. These are not popular, owing to lack of privacy and the security risks. Kitchens and bathrooms tend to be placed on the balcony side, but residents dislike strangers passing close to their kitchen sinks. There is also the potential for means of escape to be restricted (compromised) in the event of smoke from fire escaping out of flat windows.

However, with careful design and a reasonable limit on the number of flats served by them, balcony or deck access has become acceptable more recently.

5.8 Lifts

In blocks of flats these should always be capable of taking a wheelchair, preferably an eight-person lift as defined by BS 5655. Approved Document M of the Building Regulation does however allow rather smaller lift car dimensions, equating to a five-person lift. A thirteen-person lift should also be capable of taking a horizontal stretcher. Lifts in medium-rise flat blocks have become rather easier to plan, using hydraulic lifts with pump rooms at or near the base, as opposed to electric lifts with motor rooms at the top. Hydraulic pump rooms can be very compact and flexibly positioned. In blocks of flats with a floor level higher than 18 m above entrance level a firefighter's lift must be provided.

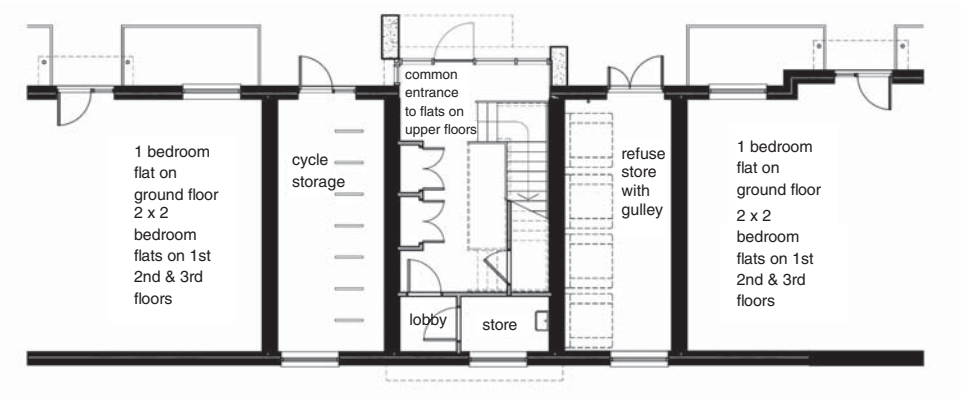
5.9 Refuse

This is always a challenge with flats. Traditionally, public-sector housing has used chutes. These cause a noise nuisance and tend to get blocked, and the inlet points can become particularly unsavoury. Additionally, the chambers at the base of the chutes, with paladins or skips, collect overflowing rubbish, vermin, and general mess and squalor. If blocks of flats can be kept small (up to six or eight flats) then it is quite possible to provide a discreet but easily accessible area containing a separate rubbish bin for each flat, clearly and individually marked, Figure 21.14.

For large or tall blocks, Building Regulations have an implied recommendation for refuse chutes. In actuality they are hardly ever provided nowadays and even very tall blocks rely on ground level refuse storage chambers and residents using vertical transportation for disposal from flats. If they are provided, the base area needs to be carefully designed, with robust and easily cleaned surfaces, good access for cleaning and copious ventilation.

Building Regulations also contain guidance on the maximum distance that residents should be required to carry waste to the

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21.14 *External planning for typical three-storey block of flats showing refuse storage*

storage point (no more than 30 m). Waste collection vehicles should be able to get within 25 m of that point. Maximum reversing distances for vehicles will also have to be considered and this will have an impact on the building and road layouts.

5.10 Incoming utilities: meters and services ducts

The provision of sufficient space for meters and services to the apartment block is paramount when planning the floor layouts, particularly around the common access stairs, lobbies and corridors. It is usual to provide vertical risers to house all incoming services, such as electricity, gas, telecommunications, phone/video entry, cable TV, data cabling, etc. These should be accessible for both installation of these services and their ongoing maintenance. Access into these service risers is often via fire doors opening onto the ventilated lobbies as discussed above.

It is advisable to obtain advice and guidance from the relevant national and local service providers, particularly regarding location of meters and routing of their services. Gas routing needs special consideration as all spaces containing a gas pipe, meter, valve etc. need to be vented to prevent the building up of undetectable gas, which could lead to explosion.

Also, there may be a requirement for meters rooms to be designed into the ground floor or at basement level, to facilitate easy meter reading by the providing authority. Routing from these meters rooms and the vertical risers will need careful consideration to avoid the risk of clashes with structure or compromising fire integrity.

Horizontal routing of these services from the vertical service shafts into the apartments should also be considered at an early stage. Access for ongoing maintenance will be a consideration when choosing finishes to ceilings and floors.

5.11 External areas

Unless there is a very competent management regime, shared external areas should be either minimised or avoided. Clearly the latter is not entirely possible, as access is needed to the common front door. The route to this entrance should be as simple as possible: broad and short. Areas to the sides of this access can be given to the ground floor flats as front gardens; and these will be much more successful if these flats have separate front doors independent of the common entrance. Similarly, the best use for the ground behind the block is normally as rear gardens for the ground floor flats.

Communal gardens sound good but rarely work, unless there is an exemplary system of management by residents' association or landlord. External space for upper floor flats is often provided by private balconies. The enclosure of front and rear gardens to ground floor flats should be similar to that for single family houses (see Section 4.10). The shared approach to the main entrance door should be treated rather differently. If there is no unallocated garden space there will be no fencing except on either side of this approach.

If there is any soft landscaping along the shared approach route, it needs to be carefully planned to withstand limited care. If flanked by well cared for private gardens, then the common approach path is best left as good quality hard landscaping and paving.

6 HOUSE CONVERSIONS

6.1 General

The conversion of large houses into self-contained flats in the 1970s and 1980s used to be the stock-in-trade of inner city housing associations, as well as private developers. There has been a falling off of this type of rehabilitation project, partly because of a gradual shift in demand, but also because HAs have turned more towards new build schemes since the Housing Act 1988.

6.2 Planning

Splitting up a single-family house involves creating at least one new dwelling, and thereby constitutes 'development' under the Planning Acts. Unlike extending a single-family house by an allowed percentage of its volume, this is not 'permitted development'. Therefore house conversions require planning permission which allows planning authorities to control this type of development if they feel that it is eroding the balance of single-family houses in the district.

Houses that are statutorily listed have more onerous constraints and require Listed Building Consent for any demolition (however small). Certain restraints also apply to all properties within Conservation Areas, possibly depending on what Article 4 directions have been approved. Conservation Area approval is no longer required for a small amount of demolition, such as of an outhouse; but a proposal of this nature might well lead to a spot-listing, when a Listed Building Consent would then be required. In many of these cases, the planning authority and/or English Heritage may then get very involved in detailed design and aesthetics.

This introduces the first discipline when dealing with an existing house, which is to respect its existing qualities and character. A natural conversion should aim to keep well-proportioned rooms intact wherever possible. This commonly means at least the main front rooms at ground and first floor levels. Avoid boxed-in lobbies in the corners of previously good rooms. These disrupt original decorative elements such as cornices and picture rails, and also make the rooms more difficult to furnish. Another implicit aspect of natural conversions is the aim to keep similar rooms stacked over each other. Day rooms of one flat should not be planned over bedrooms of another flat and bathrooms and kitchens are best stacked, thereby simplifying drainage and plumbing.

The same considerations about accommodation for families with children apply as for new-build. Family dwellings should be at ground and/or basement level, or at least have direct street entry and garden access. This will usually mean only one large unit in the conversion of a house, with one or more smaller units over it. In a wish to reduce the

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common areas, many conversions have been built the 'wrong way up' with a large unit over a one-bedroom flat at ground-floor level. This is unsatisfactory, especially in social housing. Family life is noisy, and does not fit well over single people or couples.

However it should be the aim to abolish or minimise common areas and stairs wherever possible, as these often cause continuing management problems. New external stairs may be added in some cases to achieve the objective of a separate direct entrance for each dwelling.

6.3 Building Regulations

Creating new dwellings constitutes building work and is controlled by the Building Regulations. Most of the same parts (see Table III) apply to conversions as to new build. The main exception is Approved Document L. In recognition of the fact that it may not be reasonably possible to add thermal insulation to all elements of the existing fabric to the standards required for new buildings, conversions must meet the requirements of AD L1B which applies only to existing buildings.

Some elements such as top floor ceilings, though, are quite simple to insulate, and could be upgraded to a higher level than required for new build to compensate for not insulating the walls. Thermal insulation can also often be added to the walls of rear extensions, where there is a greater proportion of exposed wall surface to floor area, and decorative features, which would be lost, are absent. The replanning of rear parts of the house to provide new service rooms may also give opportunities to add insulating linings. Also worth considering (subject to planning restrictions) is external insulation, as this can theoretically give a better thermal performance and reduces cold bridging. Approved Document B1 (Means of Escape) and E (Resistance to the Passage of Sound) apply to conversions as for new-build, and can impose significant requirements.

6.4 Loft conversions

If habitable rooms are converted out of loft space, the resulting floor area is measured over those parts that are more than 1.5 m high. A two-storey house is covered by Approved Document B1 of the Building Regulations only for escape from upper floor windows. However, when its loft is converted, extra requirements of Approved Document B1 come into force.

Under Approved Document K, alternating tread stairs are specifically allowed up to single rooms and bathrooms in a loft. Despite this, there are considerable reservations about the safety of alternating tread stairs, and they are not recommended, especially in social housing. A reasonable width for a staircase leading to a single habitable room in a loft is 800 mm, with a minimum of 700 mm.

6.5 External areas

Similar considerations apply as to purpose-built flats. The best answer is often the simplest – to give both front and rear gardens to the lowest dwelling, which is likely to be the largest. Balconies to upper-floor units are less likely to be feasible than with new build, unless a low rear extension provides an opportunity for a roof terrace. Some planning authorities discourage these as prejudicing the privacy of neighbouring gardens. In cases of detached, semidetached and end-of-terrace properties with easy access to the rear, plots for the upper flats can be provided by dividing the rear garden. There are also examples where first floor flats have been given access by means of external stairs. There is however evidence that small, subdivided rear gardens can lead to neglect, because residents feel less well 'connected' to them.

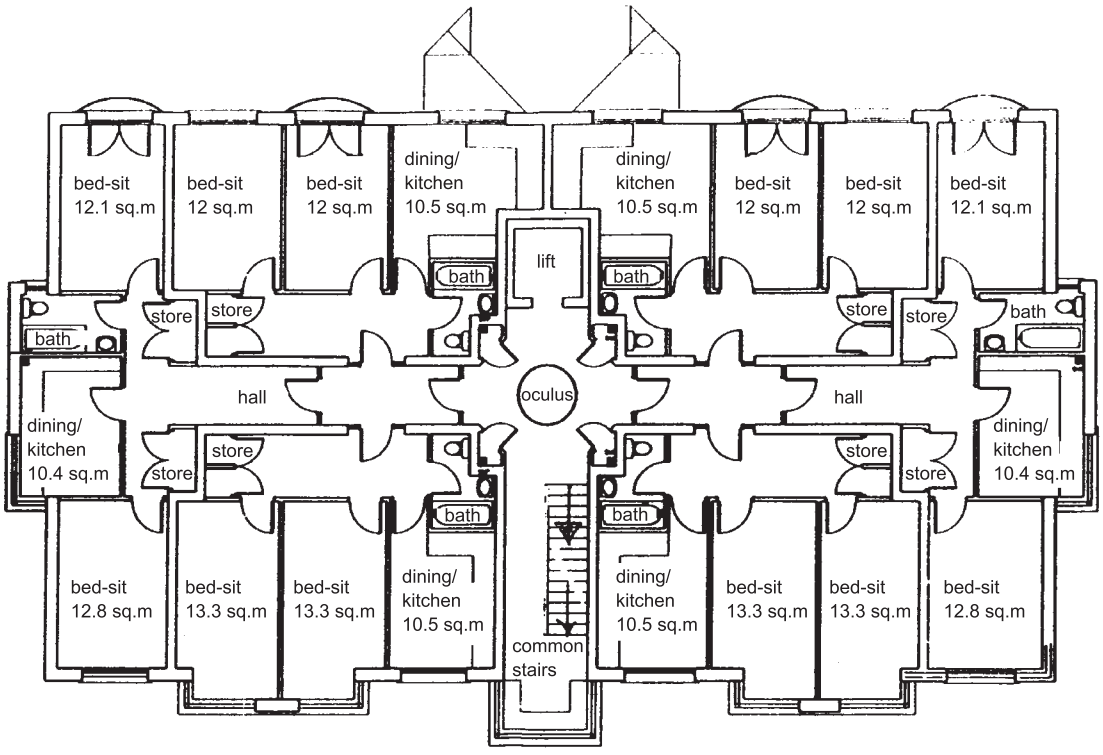
6.6 Change of use: offices to residential

In a drive to increase the delivery of new homes the government has relaxed the planning policy for conversion of office buildings into residential dwellings. However the relevant standards set out above need to be met which can be difficult within an existing structure.

7 ACCOMMODATION FOR SINGLE PEOPLE

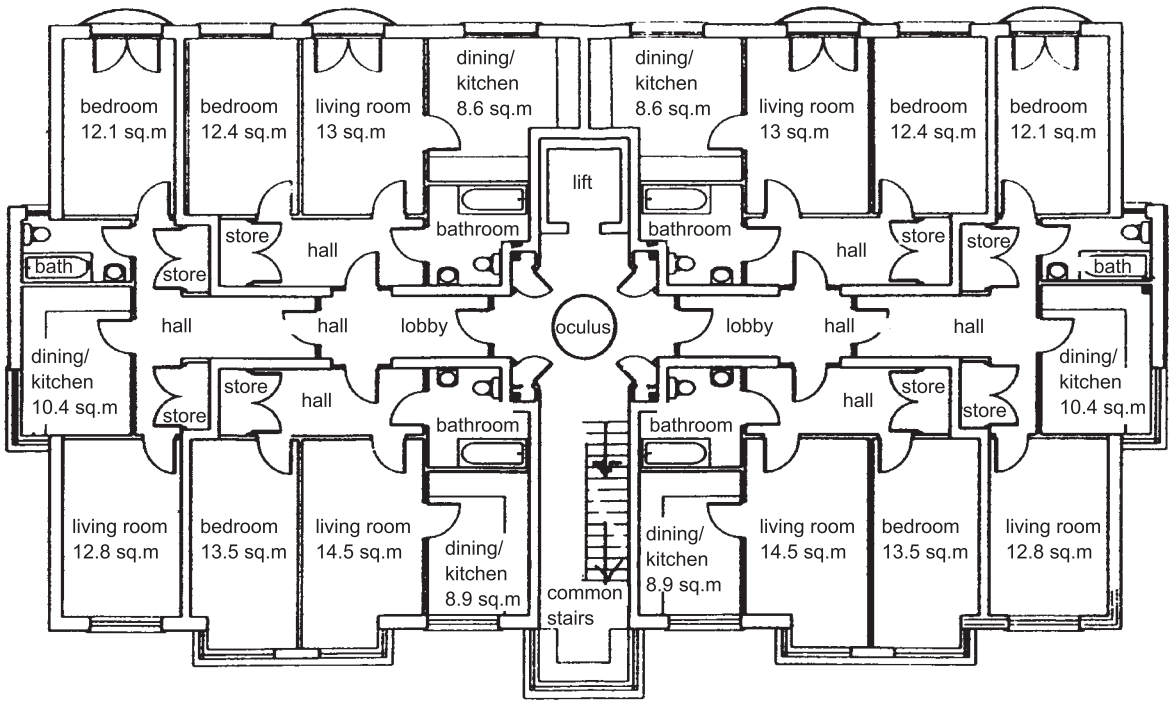
7.1 General

In the past, a distinction was drawn between the space requirement for *middle-aged permanent residents and for young mobile workers*. This led to a recommendation for small (25 m^2) bedsitting room flats for the latter category – sometimes referred to as 'studio apartments' or 'micro-flats'. The trouble is that young, mobile tenants turn into middle-aged, permanent ones quicker than housing

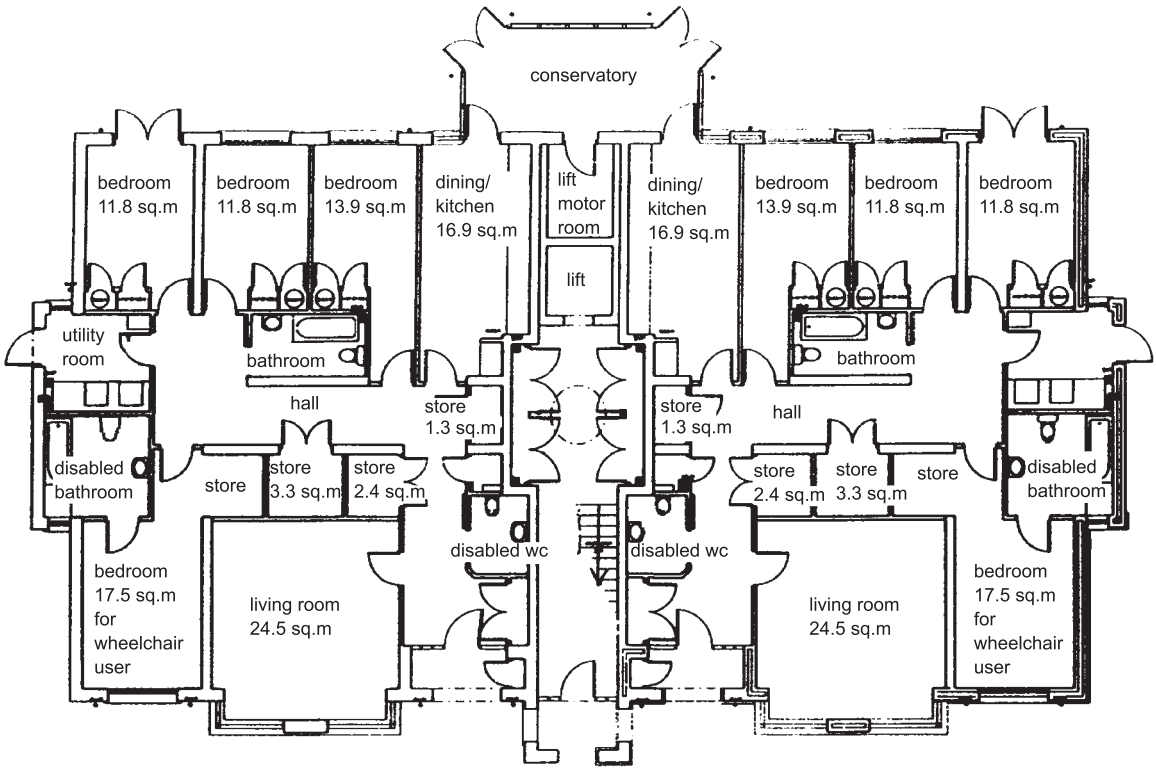


21.15 *First floor of a block containing six flats of 51m^2, each with two bedsitting rooms for single people sharing (see Figures 21.16 and 21.17 for other floors of this block)*

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21.16 *Second floor of same block as Figure 21.15 with six one-bedroom category I sheltered flats of 51 m². The third floor is similar*



21.17 *Ground floor of same block as Figures 21.15 and 21.16 containing two flats each of 165 m² with four bedrooms, one of which is for a wheelchair user*

managers can respond. This has resulted in a great degree of dissatisfaction with bedsit flats for single people.

The four principal types of accommodation provided for single people are:

- Self-contained one-bedroom flats, for which the HQIs recommend an area of 30–35 m². For furniture requirements see Table V.
- *Cluster flats* providing a number of bedsitting rooms, with shared dining kitchens, living rooms and sanitary facilities, Figures 21.15–21.17, and including Foyers (see 7.4).
- That which is suitable for students, nurses, etc. (see Chapter 23; Student housing and housing for young people).
- Sheltered housing for older single people (see Chapter 22; Homes for older people).

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Table XII Housing for single people from DB29

Numbers of single people sharing	1	2	3	4	Each additional person
Minimum areas (including storage) in:					
single-storey houses	33 m^2	48.5 m^2	65 m^2	85 m^2	20m^2
houses more than 1 storey				90 m^2	
flats	32.5 m^2	47.5 m^2	65 m^2	85 m^2	20m^2
maisonettes				90 m^2	
Personal storage					
including shelves or drawers	3 m^3	6 m^2	9 m^2	12 m^3	3m^3
with area not less than:	2 m^2	4 m^2	6 m^2	8 m^2	2 m^2
Dwelling storage					
including shelves or drawers	0.5 m^3	0.5 m^3	0.5 m^3	0.5 m^3	
with area not less than:	0.8m^2	0.8 m^2	0.8 m^2	0.8 m^2	
Kitchen storage					
Including shelves or drawers	1.4 m^3	2.1 m^3	2.8 m^3	3.5 m^3	0.7 m^3
with area not less than:	5 m^3	7 m^2	9 m^2	11 m^2	2 m^2
Electric socket outlets	9	12	15	18	3
Bath or shower	1	1	1	1	
Washbasin	1	1	1	2	
WC separate	1*	1*	1	2*	

*one may be in the bathroom.

7.2 Cluster flats

Because of the space needed for the individual bedsitting rooms, the floor areas for cluster flats should be rather greater than for the equivalent size of a general needs household, for three-person units and larger.

Storage space is particularly important for single persons sharing a dwelling. Still relevant as the definitive standard is DB29, published by the DOE (1974) which laid down minimum storage spaces, distinguishing between that for individuals and that for the dwelling as a whole (see Table XII). A minimum bedsitting room is 12 m^2, the recommended size for a medium to long-stay resident is 15 m^2, and a washbasin should be provided in each.

7.3 Common rooms

Where these are provided, the areas should be at least 20 m^2 for the first 25 persons plus 0.4 m^2 for each additional person. However, it is now less usual to provide common rooms, as schemes tend to consist of self-contained flats, either for one-person households, or of clusters, who share integral day rooms. Foyers are one exception that should be noted.

7.4 Foyers

A concept introduced from France in the early 1990s is the *foyer*, consisting of a complex containing accommodation for young single people either in one-person flats or more usually a number of cluster flats, or a mixture of the two types. It can also include substantial training facilities and other provision such as cafeterias, laundries and common rooms. To make it economically feasible, a foyer needs to house about 100 young people. Although successful in France, it has proved difficult to deliver as a viable model in the UK.

8 ESTATE REGENERATION

8.1 General

Local authorities have recently built little new housing, but they still own an enormous stock of existing estates built over the last hundred years. Many of these are now decrepit and out of date. Significant funds and initiatives are therefore being directed towards the special problems of these estates (see case study, 9).These initiatives have included government-financed Estate Action Programmes, City Challenge projects, Housing Action Trusts, Estate Renewal Challenge Funding, Single Regeneration Budgets and New Deal for Communities Initiatives. Funding via the HCA for stock transfers to housing associations has also been available, although the process is complex and costly and subject to a majority vote by residents so the outcome is uncertain.

8.2 Challenges

Many flat blocks built before the First World War are characterised by too small floor areas, outdated internal planning with inadequate kitchens and bathrooms, and unsatisfactory means of escape. The building services are probably obsolete, and central heating and thermal insulation absent. Some of these blocks, however, possess considerable architectural character, and have stable and supportive communities of residents.

Blocks built between the wars may also be lacking in modern services, heating and insulation but can be better planned internally and well-built structurally. Kitchens are still usually too small for modern requirements although otherwise floor areas increased. External planning was simple, but with more communal space than is now desirable. Blocks from this period represent a vast investment in housing stock, with enormous potential for improvement into good-quality modern housing.

Since the Second World War, social housing has suffered from too many well-intentioned attempts to rethink design and planning from scratch. Consequently the last 50 years have seen widely differing forms of housing, many of which have proved dramatically unsuccessful. High-rise blocks of flats are only the most prominent and publicised of mistakes. Some of the medium-rise (five or six storey) deck access estates have proved even less satisfactory.

Dwellings in these large usually inner-city estates generally complied with the good internal standards of Parker Morris. The problem is the external estate design that is often hated and feared by the residents, which fails to provide private and public open spaces appropriate for families with children.

8.3 Consultation

Estate modernisation presents many varied, peculiar and acute problems. First, an investigation to establish what the problems really are has to be carried out. These are rarely simple, and may vary widely from estate to estate. The people who understand the problems best are the residents, but they may need help to articulate them. Careful approaches and techniques under the general description of community architecture should be adopted to identify and address the tenants' concerns.

Architectural teams usually move onto the estate to conduct surveys, set up design surgeries, hold open meetings and distribute newsletters to reach their social clients.

8.4 Proposals

After this consultation, designs and proposals can be worked up in close collaboration with the residents. The works needed to improve estates will be different in each case; but may include some or all of the following:

- Moving family units down to ground level, perhaps by combining flats on ground and/or first floors into larger flats or maisonettes, and subdividing large flats on upper floors into small ones.
- Using unwanted external space to provide private gardens for the ground-floor units, with separate direct access from the public highway or estate road.
- Remodelling the flat interiors, giving larger dining/kitchens and better bathrooms.
- High-rise blocks that cannot be split up or effectively use entry phones can be provided with *concierge* systems; using

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a combination of electronic and human portering to provide 24-hour security.
- Improving refuse arrangements, aiming to disperse rather than concentrate collection points.
- Improving the fabric; adding thermal and sound insulation; adding pitched roofs on top of flat roofs; replacing windows with double glazing and controllable trickle ventilation.
- Renewing the mechanical and electrical services; adding central heating; improving ventilation by putting extract fans into kitchens and bathrooms. Where there is district heating with a central boiler house and a history of problems, replacing with unit systems in each dwelling. Consider heat-retrieval systems.
- Consider converting some blocks to integrated sheltered housing. In these cases, entrances and gardens must be clearly distinguished and separated.
- Communal external spaces to be reduced to either a minimum or abolished.
- If all family flats and maisonettes have their own private gardens, there is an argument that communal children's play space within the estate may be unnecessary. If not, it must be carefully sited as it may cause nuisance to neighbouring dwellings. Play space in local parks is preferable if they are nearby; or situated in clearly public spaces such as the squares that might feature in some large estates. A lack of security is often perceived; ideally, family accommodation without sufficient, private, open space should be avoided.
- Estate roads, car parking and emergency vehicle access often need to be replanned. Parking within the curtilage may be possible if the front gardens are deep enough; otherwise provide small parking bays in clear view of the dwellings they serve. Basement parking and car courts at the rear of blocks are best avoided because of the security risks they pose.
- Replan pedestrian routes in order to eliminate unnecessary footpaths and to maximise natural supervision from the dwellings of all routes.
- Adding lifts if over three storeys high.
- Consider enclosing open balconies and staircases, and splitting up long balcony access buildings into smaller more manageable blocks, preferably with no more than 10 or 12 flats in each.
- Adding entry phones to privatise staircases.

9 CASE STUDY – PORTOBELLO SQUARE, KENSINGTON, PRP ARCHITECTS LLP

9.1 Introduction

The regeneration of a failing housing estate provided the catalyst for the Portobello Square development in North Kensington, London. The site is at the northern end of Portobello Road, which is famous for its diverse and eclectic street market. But the historic connection between Portobello Road and Ladbroke Grove was severed when the Wornington Green Estate was built during the 1960s and 1970s, disconnecting the estate from its immediate context and destroying the Victorian street pattern, Figure 21.18.

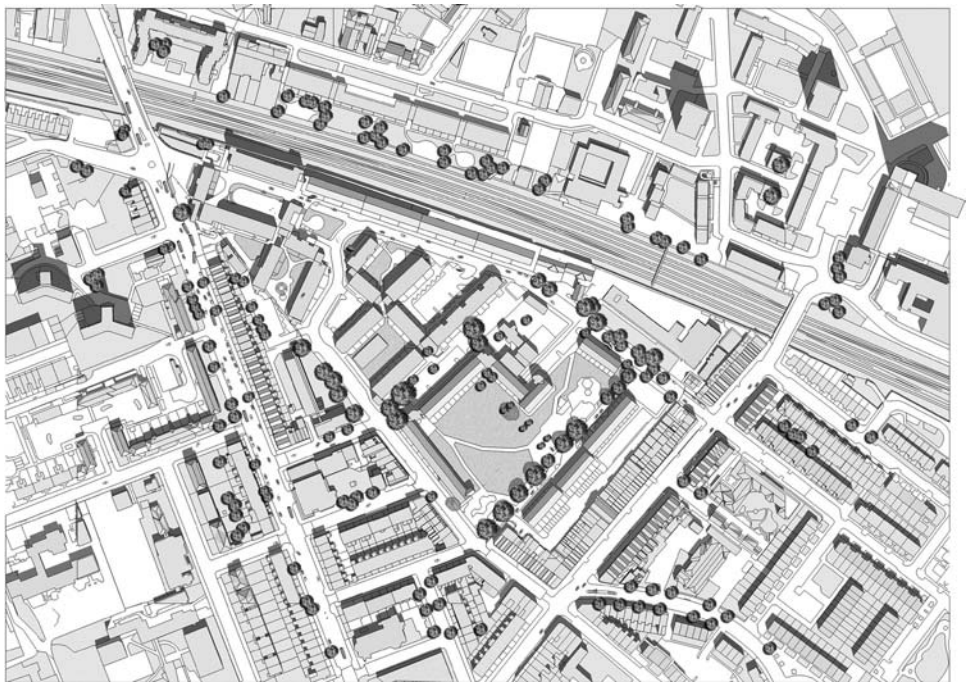
9.2 Site

The triangular 5.5 ha site is bounded by the main Paddington/West Country railway line to the north, Portobello Road and Golborne Road and represents one of the largest regeneration programmes in the Royal Borough of Kensington & Chelsea in recent years. Wornington Green Estate comprised 538 flats and houses predominantly in the form of deck-access, interconnected H-blocks set out around courtyards. The block form is alien to the historic grain of the area and poor construction methods have accelerated the decline of the estate, which suffered from damp and condensation associated with cold-bridging and poor insulation.

The application boundary included a number of assets owned by the Royal Borough of Kensington & Chelsea: Athlone Gardens – a public park extending to almost 1 acre, a sunken ball court, a community centre and 20 lock-ups used by market traders. These assets were to be re-provided in the redevelopment.

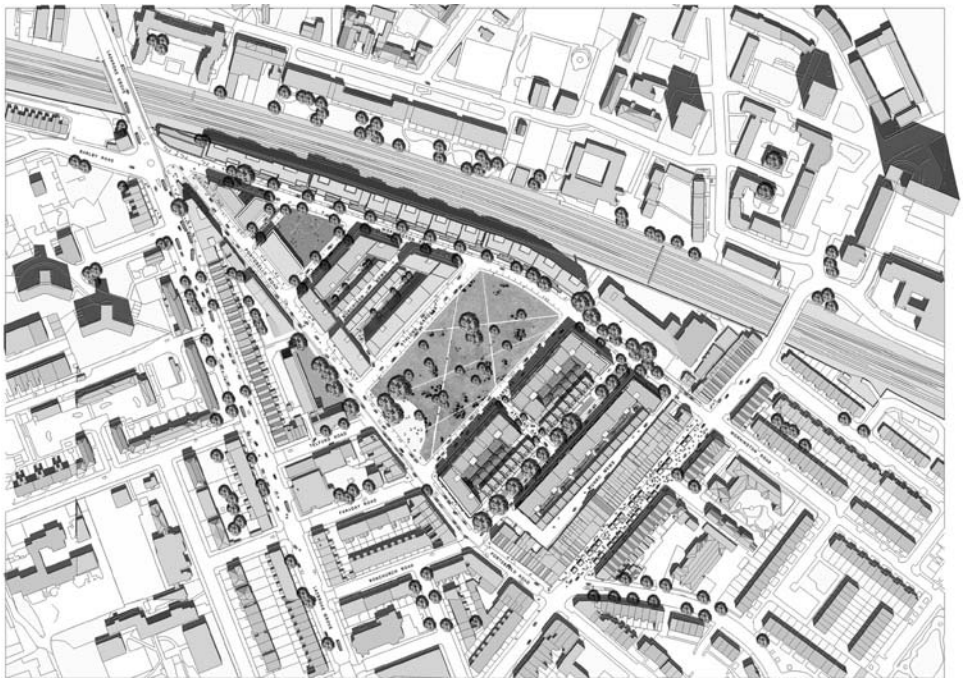
9.3 Aims

The key design objectives for the development were to reintegrate the site with its immediate neighbourhood context in the form of street-accessed properties, to re-provide the poorly-located open space as a 'Green Flag' park at the heart of the development and to provide new high quality housing employing a range of different typologies drawn from traditional Kensington residential precedents.



21.18 *Existing site*

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21.19 *Regeneration plan*



21.20 *Cross section*



21.21 *Mews houses*

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21.22 *Mansion blocks*



21.23 *Terrace*

9.4 Options

The design brief was set out through a Supplementary Planning Document (SPD) written by the local authority, following an initial capacity study by PRP. This capacity study identified options for refurbishment, partial redevelopment and full redevelopment which were presented to residents, officers and other stakeholders at public consultation. A majority support for redevelopment led to the development of the consented masterplan through continued consultation with all relevant parties. The affordable housing mix was largely determined by the re-provision of existing homes against a housing-need survey carried out for the residents. Permission was granted for up to 1000 new homes with the outline masterplan showing circa 920, of which 58 per cent were social rent. This provided a density of 134 dwellings (or 404 habitable rooms) per hectare.

9.5 Design

The masterplan, Figure 21.19, reinstates a number of the historic road positions in order to mend the urban fabric, reconnecting Portobello Road and Wornington Road to Ladbroke Grove. A new park, in the tradition of a London garden square, is located at the heart of the development. The community centre is re-provided on its own site on Portobello Road ensuring an active hub for community activity and flexibility of this land parcel for the future.

Mixed-uses at street level include new shopping and community facilities along the new extension to Portobello Road. These reinforce the existing retail facilities in the area and the junction with Ladbroke Grove and provide a new focal point for the community with pubs and restaurants at the northern end of Portobello Road.

A range of building heights from 3 to 9 storeys accommodates a variety of dwelling types, Figure 21.20. Dwellings are tenure 'blind' from the outside to provide quality throughout the development. Building typologies draw on contemporary interpretations of the mews houses, Figure 21.21, mansion blocks, Figure 21.22, town houses and terraces, Figure 21.23 of the adjacent conservation area London vernacular. Terraces are simple and well ordered in terms of form, fenestration and detailing. Particular features are generous fenestration and recessed balconies that provide accessible amenity areas for the residents. Traditional materials in the public realm and traditional relationships between streets and buildings ensure a feel that will be consistent with the rest of the Borough.

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A wide variety of affordable dwelling types are provided to meet existing tenant needs including 1, 2, 3 and 4 bedroom apartments, 4 bedroom mews houses and 3 and 4 bedroom duplexes. The latter have their own front doors to the street, with bedrooms at basement level, reflecting the traditional arrangement of many Victorian streets. The private dwelling types include 1, 2 and 3 bedroom apartments, 3 bedroom mews houses, 3 and 4 bedroom duplexes and four storey townhouses. The latter typology is specifically intended to maximise profit from private sale to cross-fund the redevelopment. The first phase is supported by significant HCA grant-funding but the remainder of the development will be self-funding through the private sale receipts.

The first phase complies with Parker Morris standards, as required by the design brief. Subsequent phases were designed to comply with the London Housing Design Guide or relevant standard. A high quality of design, finish and materials was achieved to maximise the benefit of private sale which helped to subsidise the redevelopment.

A range of energy efficiency and sustainability measures were incorporated into the development to achieve a Code for Sustainable Homes Level 4 rating. This includes Combined Heat & Power, brown roofs, photo-voltaic panels on all buildings apart from the houses and run-off water storage and attenuation below ground.

Construction commenced in 2011 with Phase 1 completion in 2016, and overall completion in 2020. The design represents part of an emerging new London vernacular through a number of important large-scale housing developments in the capital, and also a new benchmark in the approach to the regeneration of poor quality high density housing estates.

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22 Homes for older people

Ian Smith (updated by David Littlefield)

Before his retirement Ian Smith was a partner in Hubbard Ford and Partners

CI/SfB 44

KEY POINTS:

- *Because of other available accommodation, the people needing care are increasingly infirm*
- *There is a need for activities for residents other than watching TV*

Contents

1 Main elements of the plan
2 Relationship between elements of the plan
3 Planning allowances
4 Planning examples
5 Room data and space requirements
6 Building equipment and fittings
7 Furniture
8 Bibliography

1 MAIN ELEMENTS OF THE PLAN

1.1 Introduction

The design of homes for old people should create a homely, comfortable and friendly atmosphere. The importance of avoiding an institutional character is stressed in most design guides and instructions to architects.

1.2 Scope

This chapter deals with the design of homes in which the residents are in need of special care and attention. The special facilities provided may vary, depending on the degree of infirmity and mobility of the residents, but the basic relationship between the main elements of the plan are common to all homes for old people. Latterly, the concept of very sheltered housing (VSH) has been developed which can provide tenants with a home for life, offering them a choice of different levels of care and support which changes according to need. This removes the need for residents to move to other forms of supported housing. Independence is encouraged; residents can develop a sense of ownership over where they live and can be as self-sufficient as they choose.

1.3 Elements of VSH

A VSH development will likely include the following elements:

- independent self-contained flats designed to wheelchair-user standards. Flats would contain fully fitted kitchens, a shower room, bedroom and lounge;
- main catering kitchen and dining room providing at least one hot meal each day;
- communal lounge, often linked to the dining room;
- lift access to all floors;
- assisted bathrooms, usually one per floor;
- communal laundry;
- wheelchair/scooter recharging store;
- guest accommodation;
- non-resident building manager;
- separate care team based on site offering 24-h care. Facilities for staff and carers to include office, rest, meeting, changing and sleepover accommodation;
- extra community services, such as hairdressing, chiropody, shop, etc.

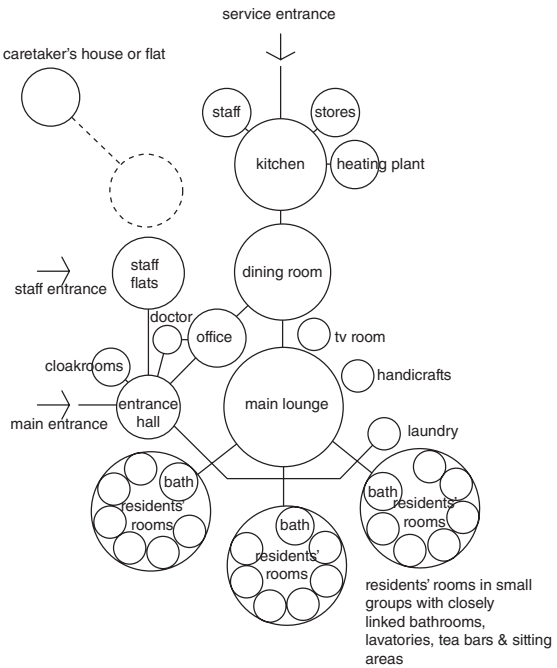
Design elements of a VSH development would include:

- full wheelchair standards;
- adequate passing points in circulation areas for wheelchairs and scooters;
- removal of obstructions such as fire compartment doors, which can be held open on magnetic pads;
- free swing door closers to residents' front doors and other doors regularly used by residents;
- centrally located lift and communal facilities to enable unobtrusive care delivery and minimise walking distances and possible feelings of isolation;
- centrally located staff facilities away from residential areas;
- clear separation between areas for residents, staff and visitors;
- good natural and artificial lighting particularly on circulation routes;
- good visual access throughout;
- carefully considered use of tone, colour and tactile materials to assist residents who are partially sighted or disorientated;
- interesting corridors, ideally naturally lit from windows or rooflights. Avoidance of long, dull vistas;
- handrails along both sides of circulation routes that are appropriately scored, and snag-free, to assist way-finding for those with visual impairments;
- appropriate ironmongery, taps, etc. for older people with limited dexterity;
- protected, sunny, sheltered outdoor spaces with design features appropriate for residents.

2 RELATIONSHIP BETWEEN ELEMENTS OF THE PLAN

2.1 Relationship structures

Figure 22.1 shows how the main areas of the building are interrelated. The aim should be to encourage social contact, but at the



22.1 *Relationships between elements of the plan*

same time to preserve individual privacy. The residents' rooms are often grouped round a small sitting room and services area containing a bathroom and lavatories. Circulation routes to the communal lounges and dining room should be as short as possible, although routes through the residents' groups should be avoided. Communal areas may either be centralised or divided between the residential groups, but most homes have a main dining room, which should be close to a sitting area. The administrative offices should be close to the entrance hall, and, if possible, within easy reach of the kitchen. Staff accommodation should be provided in self-contained flats with separate outside entrances.

2.2 Lighting and materials

Internally, developments should seek to create an uplifting experience that is welcoming, non-institutional and friendly for both residents and visitors. Particular attention must be paid to the building's entrance. Careful lighting, colour schemes and use of materials can help create a special environment, although they should remain domestic in character and specified with consideration for the sensory impairments suffered by older people.

2.3 Circulation planning

The general arrangement of circulation spaces in a VSH scheme should be clear and 'rational' to assist people who are suffering from dementia or memory loss. Complicated planning of circulation routes must be avoided: they will confuse and disorientate. Breaking down the building into identifiable clusters and the provision of visual clues (through pictures and graphics) and signage will greatly assist easy way-finding. Careful planning can reduce the length of corridors, thus reducing the travel distances and minimising an institutional feel. Corridors should have contact with the outside at some points along their length to help people orientate themselves within the overall building and to provide some natural daylight. Windows in the end wall of corridors are not ideal as they create glare, making the corridor appear dark in contrast. A window in the sidewall, near the end of the corridor, will still provide daylight and ventilation while avoiding the glare problem.

3 PLANNING ALLOWANCES

Typical accommodation allowances are given in Table I.

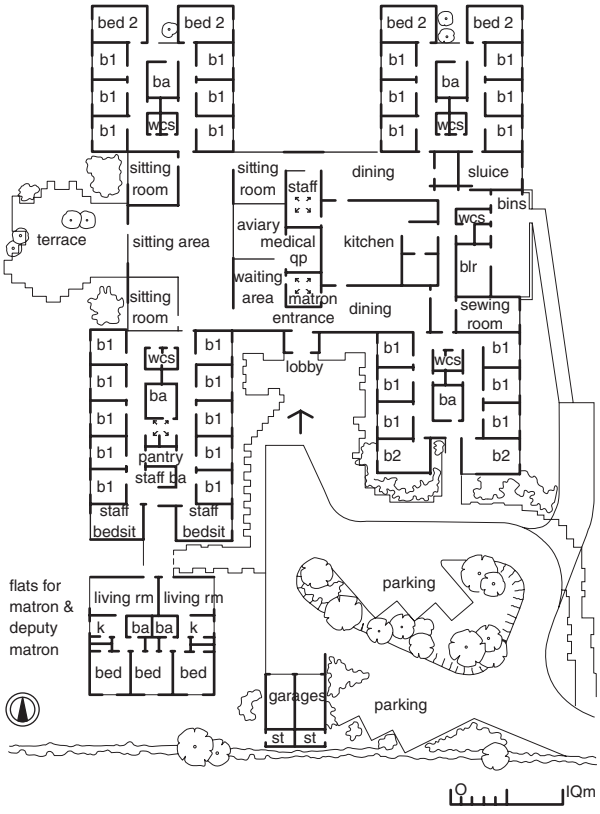
Table I Planning allowances

Accommodation and facilities		
Residents	Single bedsitting rooms	9.6–12m²
	including private WC	15.3 m²
	Double bedsitting rooms	14.8m²–16m³
	Bathrooms and lavatories	8.8 m²
	Sitting areas and tea bars Stores	
Communal rooms	Entrance hall and visitors' cloakroom	
	Lounges	2.3 m² per person
	Dining room	1.5 m² per person
	Handicrafts or sewing room	15 m²
Kitchen	Larder and dry store	12.15 m²
	Food preparation and cooking	42.50 m²
	Washing up	15 m²
	Cloakroom and non-resident staff room	12 m²
Administration	Matron's office	11 m²
	Doctor's room	10 m²
	Visitors' room	10 m²
Ancillary rooms	Sluice rooms	6m²
	Laundries	20 m²
	Linen storage	8 m²
	Cleaners' stores	4 m²
	Box rooms	8 m²
	Boiler and plant room	25.30 m²
	Garden store and WC	10 m²
Staff accommodation		
Self-contained flat for matron		70 m²
Self-contained flat for assistant matron		60 m²
Two-staff bedsitting rooms		12 m²
Staff bathroom		
Staff kitchen		6m²
Two-staff garages		
Staff lounge		12 m²

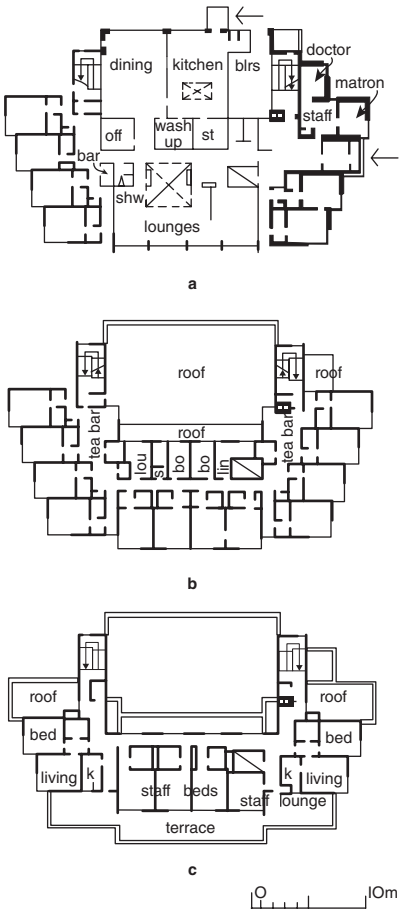
Note: Room areas in typical 40-person home

4 PLANNING EXAMPLES

The plans of two typical homes are shown in Figures 22.2 and 22.3.



22.2 *Plan of Glebe House, Southbourne*



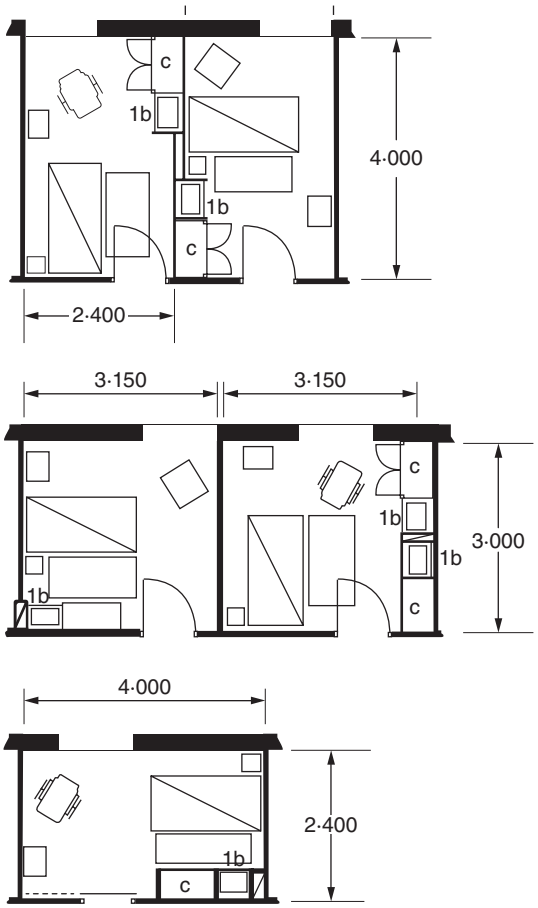
22.3 *Maidment Court, Dorset. a ground-floor plan. b plan of first and second floors. c third-floor plan*

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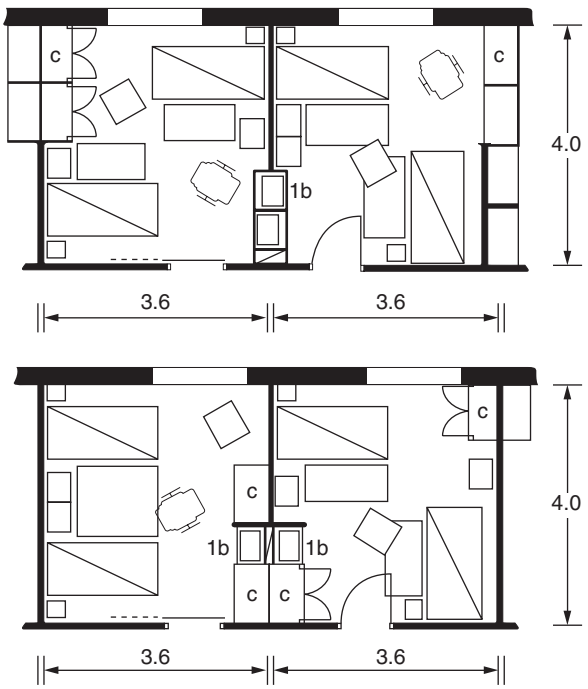
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5 ROOM DATA AND SPACE REQUIREMENTS

Typical layouts are given for single rooms (Figure 22.4) and double rooms (Figure 22.5). These layouts, from DHSS Building Note 2, with rooms of varying proportion, show ways of providing a flexible arrangement within clearly defined sleeping/sitting areas. With narrow rooms, corridor circulation is reduced to a minimum, but other types may well be suitable where a different overall plan form is chosen.



22.4 *Room data and space requirements for single rooms*



22.5 *Double room requirements*

6 BUILDING EQUIPMENT AND FITTINGS

6.1 Introduction

Some of the information below repeats material in previous chapters. It is also included here because of its importance for this building type.

6.2 Limitations

Elderly people should be encouraged to do as much as possible for themselves. To facilitate this, the design of the accommodation and appliances should take into account the limitations imposed by age.

6.3 Taps

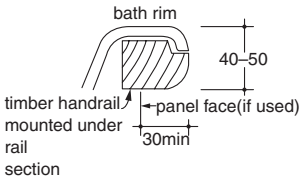
Choose taps that can be manipulated by arthritic fingers. Surgeon's taps are not recommended, however, as in extreme cases ordinary taps can be modified to provide a similar facility. Within one building, it is sensible to maintain consistency as to the location of hot and cold, e.g. hot always on the right as is now provided in current standards. In addition, the taps should always be boldly colour-coded. It is hoped that in the near future a standard for additional tactile identification will be introduced.

6.4 Washhand basins and baths

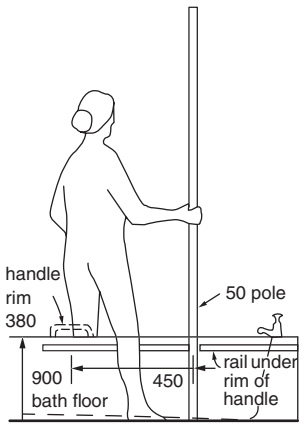
Washhand basins should be fitted with their rims between 800 and 850 mm high. Bathrooms should be large enough for undressing and dressing, and for someone else to lend a hand. Low-sided baths are available, as the rim, which should be easy to grip (Figure 22.6), should not be higher than 380 mm from the floor. Alternatively, the bath may be set with the trap below floor level. It should have a bottom as flat as possible and should not be longer than 1.5 m; lying down is not encouraged. Grab handles and poles should be provided as in Figure 22.7 to help getting in and out. A seat at rim height is useful for sitting on to wash legs and feet. Bathroom and lavatory doors should open out, with locks operable from the outside in emergencies (Figure 22.8).

6.5 Showers

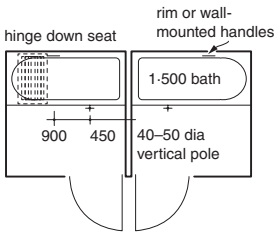
Some old people find showers more convenient to use than baths (Figure 22.9). If the floor of the compartment is of smooth non-slip material with a fall to a drain of 1:40, there is no need for a tray



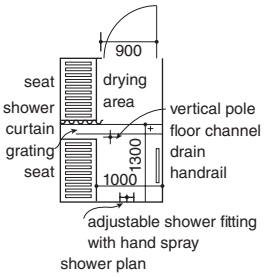
22.6 *Bath rim adapted for easy gripping*



22.7 *Aids for getting in and out of the bath: pole, handle and rim. Maximum height of rim from floor 380 mm*



22.8 *Plan of bathrooms showing handing to suit people with disability of either right or left leg, and position of pole aid*



22.9 *Plan of shower room showing seats and aids*

with an upstand to be stepped over. The compartment should be well heated, with pegs for clothes on the dry side, divided from the wet with a shower curtain. The water supply should be automatically controlled to supply only between 35°C and 49°C. The shower head should be on the end of a flexible hose, with a variety of positions available for clipping it on. WCs should have a seat height of 380 mm, and handles provided as in Figure 22.10.

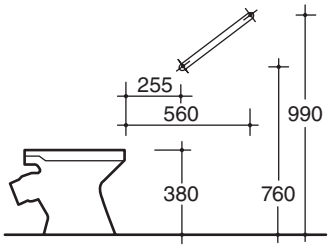
6.6 Cupboards

Shelves and cupboards should acknowledge the limitations of elderly people. The clothes cupboard rail should be mounted 1.5 m from the floor, and the cupboards should be at least 550 mm deep (Figures 22.11 and 22.12).

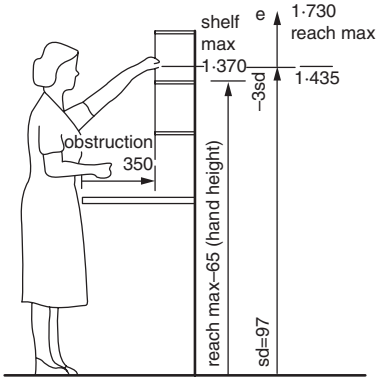
7 FURNITURE

7.1 Easy chairs

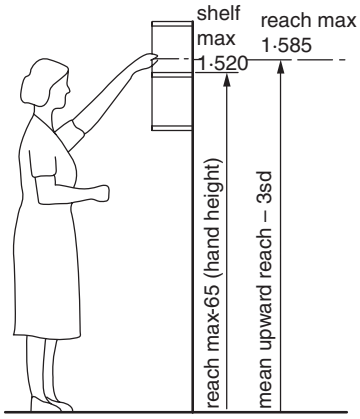
A variety of chair types should be provided in sitting and common rooms, to ensure maximum comfort for all the old people. Seats



22.10 *Inclined rails mounted on walls of WC*



22.11 *Maximum reach over worktop*



22.12 *Maximum reach to unobstructed wall-mounted cupboard*

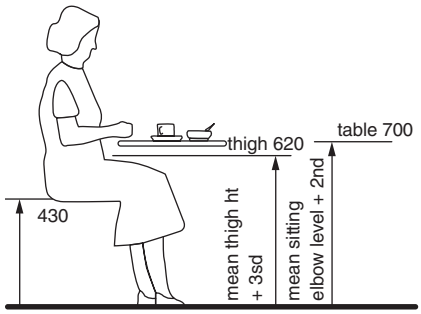
should not be too low, as this makes the chair difficult to get out of; but if too high, the feet may end up off the floor. A height between 400 and 430 mm is about right, with footstools available for those with extra-short legs. A seat depth between 410 and 470 mm is ideal: any more and cushions become necessary. The back should be angled at 28° to the vertical, and high enough to support the head, for which an adjustable pad is useful. Armrests 230 mm above the seat at the front facilitate getting up, but if lower at the back, make sewing and knitting easier. There should be a gap under the seat to allow the heels to be drawn right back when rising. Generally, the padding should not be too soft and generous, as this can put strain on the tissues rather than allowing the bone structure to support the body.

7.2 Tables and dining chairs

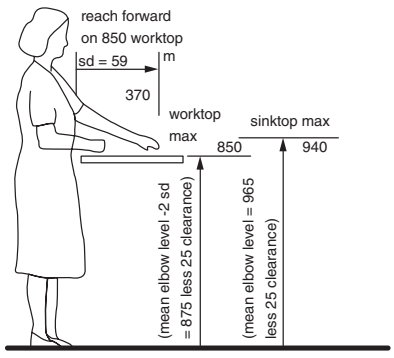
Occasional tables in common rooms should not be lower than chair seat height. Dining tables should be 700 mm high and used with chairs having a seat height of 430 mm and a depth of 380 mm. There should be a gap for the thigh between the chair seat and the underside of the table top of at least 190 mm (Figure 22.13).

7.3 Worktops

Comfortable reach to worktops is shown in Figure 22.14.



22.13 *Table and sitting worktop design, giving height and thigh clearance*



22.14 *Standing worktop design, giving height of working surface and reach forward to fittings (scale consistent with 3613)*

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23 Student housing and housing for young people

Liz Pride

Liz Pride is an Architect and Director of MJP Architects LTD

Please note that plans used to illustrate this chapter are of built projects and that there may have been changes to standards and legislation since they were completed. They are therefore illustrative only.

KEY POINTS:

- *Student housing is normally designed to a budget that relates to the rent charged. There is an increasingly wide range of options to suit different preferences and budgets*
- *The availability, choice and quality of accommodation are factors students consider when choosing a university, and students are becoming more discerning as fees and charges increase*
- *Private companies, as well as universities, now develop and manage a significant proportion of student accommodation*
- *There is a trend towards larger schemes, including tower blocks, where designers should aim to avoid an impersonal, institutional feel*
- *Student housing that is also used for conference accommodation has additional requirements*

Contents

1 Introduction
2 Students
3 Types of accommodation
4 Building form
5 Standards and regulations
6 The study bedroom
7 Kitchen/dining rooms
8 Bathrooms
9 Other facilities
10 Conference use

1 INTRODUCTION

1.1 Scope

This chapter deals with the design of accommodation for students, but is also relevant to accommodation which is occupied for a limited period by other groups of independent, single people, such as 'spring-board' accommodation for young professionals. The term 'university' is used to refer to Higher Education Establishments (HEEs), Further Education Establishments (FEEs), colleges and other similar institutions.

1.2 Importance

In recent years legislative and economic change has had a significant effect on students and the provision of student accommodation. Recent government policy has led to a considerable expansion in student numbers while, at the time of writing, the impact of the sharp rise in student fees has yet to be discovered. However one effect is clear: students are becoming increasingly discerning and the availability, variety and quality of accommodation is an important factor when choosing a university. There is more competition between universities to attract good students and so the universities – and also some private commercial providers of accommodation – are increasingly concerned with the 'student experience' that they offer. As costs increase, the views of parents on standards of accommodation are also becoming more important.

1.3 Ownership

Student accommodation is owned and managed in a variety of ways, which can have significant implications for design. Universities provide communal rented accommodation on or off campus, which they own and/or manage. In recent years there has been a significant growth in the number of private sector commercial operators building and managing accommodation, developments which are required to return a profit and to be a long-term financial asset. They usually accommodate large numbers of students – from 200 to 1,000 students or more. Private developments are often pre-let to a university and may be designed and managed in liaison with the university. A large proportion of students still live in individual shared houses or flats within the community, while others live at home.

1.4 Rents

The government does not fund student accommodation and schemes are normally self-funding through the rental income that is charged for the rooms. Project budgets are therefore determined by the level of rents that students can afford or are willing to pay, and this is directly reflected in the size of the study bedrooms and extent of other facilities provided in the scheme.

Where accommodation is provided by a university, there is a concern to keep rents to affordable levels, although their offer usually includes some choice of accommodation at different rents. The private market also offers a range of room types and rents, and there has been a marked increase in 'luxury' accommodation targeted at those who can afford high rents, including a high proportion of international students. To illustrate the wide range of accommodation available from universities and private commercial operators, rent levels in 2010 for a room in purpose-built accommodation with self catering varied between £50 and £285 per week.

1.5 Student experience

Issues relating to social sustainability and the 'student experience' are becoming increasingly critical, and are particularly challenging in the design of larger, potentially impersonal, schemes. Where accommodation is designed for a university, there will generally be a concern to make the students feel part of the university community. (This might be achieved by, for example, arranging buildings around a courtyard to provide a shared focus and identity for the residents, or by placing social spaces such as common rooms and kitchen/dining rooms where they are very visible.) Universities generally also have systems of pastoral care with wardens or senior students living among the students. With a private commercial provider, there is likely to be a different emphasis to the student experience, using the building design to promote a particular 'lifestyle' and branding.

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1.6 Context

Consideration should be given to the relationship of the accommodation to the local community, particularly where it is located in a town rather than on campus. The design of the building and landscape can help to integrate the university and its students with the community, and it can also help to avoid potential conflict. Students can cause nuisance to neighbours, particularly where there are large areas of student accommodation within one neighbourhood (known as 'studentification'). Conversely there can be risks to the students for personal safety and theft of property.

1.7 Sustainability

Sustainability is an important issue for universities (as well as for many individual students) and the government, through the funding body HEFCE, has set demanding carbon reduction targets for university estates. Consideration should be given in the design of residences to reducing energy consumption and carbon emissions and the inclusion of renewable energy sources. Other issues include reducing water consumption, waste and recycling, sustainable urban drainage and sustainable transportation. Universities will usually set targets for BREEAM and possibly EPC ratings. Provision for future flexibility should be incorporated into the design where possible, as requirements and aspirations change – examples in recent years include the impact of computers and IT, the preference for en-suite bathrooms and improved standards for disabled access. Ultimately there may even be a need to adapt accommodation to new uses if the demand for student residences reduces.

1.8 Timing

Projects will generally be programmed to complete construction in late summer in time for occupation in a new academic year.

2 STUDENTS

2.1 Tenant range

Conventionally, students are perceived as young, single, mobile, adaptable and with little money to spend. While this is still largely true, there is also an increasing need to cater for a broader range of people from different cultural and economic backgrounds, and for students with different needs: students with disabilities, mature and married students and those with families. Postgraduate students are older and require a quieter and more 'adult' living environment. Many universities have a significant number of students from overseas, including 'international students' from outside the EU who pay higher fees and make a significant contribution to university income. Some students study part time, while many have to manage part time jobs to support themselves through university. There is an increasing demand for convenience and flexibility in the way that services, including accommodation, are provided to them.

2.2 Availability

Universities rarely have accommodation for all of their students, and priority is usually give to first year students and students from overseas who need more support to settle into the university community. Some accommodation is rented only during term time, and is used for conference and holiday lets out of term, while other accommodation is rented for the whole academic year.

2.3 Characteristics

The characteristics which differentiate student accommodation from other housing and from hotel accommodation, and which should be addressed in design, are:

- an appropriate environment in which to study as well as to live, socialise and sleep and a building in use 24 hours a day;
- creating a university community, with opportunities for informal academic and social interaction;
- privacy where people are living in close proximity and are sharing facilities – most students will not have the opportunity to choose their neighbours;
- design, including the selection of materials and fittings, must be appropriately robust for student use and easy to maintain – whole life costing is an important consideration;
- avoiding an unpleasant institutional character, which can easily arise where large numbers of identical study bedrooms are arranged to maximise efficiency;
- for many people student accommodation will be their first experience of living away from home. Well-designed student accommodation has the potential to broaden awareness of architectural design and environmental issues.

2.4 Priorities

The Times Higher Education's Student Experience polls reveal that students have the following concerns.

High importance:

- Availability of internet access in the study bedroom
- Availability of cooking facilities
- Security
- Journey time and closeness to the university
- Cost
- Local amenities and communal facilities.

Less important:

- Number of students in each flat
- Provision of en-suite bathroom
- ANUK accreditation (see Section 5.2)
- On site amenities
- Catering provided
- Car parking.

Other issues:

- Room size
- Noise
- Clean facilities.

3 TYPES OF ACCOMMODATION

3.1 The brief

When establishing the brief for accommodation, key items for discussion are:

- the 'style' of the accommodation: staircase, house, hall or flat?
- the number and mix of room types: single, shared and studio;
- the number of students sharing each kitchen;
- provision of en-suite bathrooms or shared bathrooms;
- provision of other facilities – common room, reception, gym, laundry etc.;
- the requirement for lift and wheelchair access – to all rooms?
- whether the facilities will be used for conferences out of term time.

3.2 Style of accommodation

The vast majority of student accommodation is based on provision of an individual study bedroom for each student, although universities and private providers are offering an increasing range of choice to suit different requirements and budgets, including study bedrooms shared by two students (for lower rents), 'studio' rooms with an en-suite bathroom and a kitchen area, or larger studio flats for one person or a couple. These larger units are particularly suited to postgraduates and mature students who are more independent. The studio model is also used for other young, single people outside the world of education – for example young professionals or key workers. A proportion of rooms should be designed for wheelchair users, with numbers agreed with the local authority.

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In schemes with individual study bedrooms the 'style' of the accommodation is largely determined by the way that study bedrooms are grouped together to form a social unit, and the way that shared facilities (kitchens, common rooms etc.) are provided. A university may instill a sense of responsibility and independence by placing small groups of students in separate shared flats, or it may exercise a greater degree of supervision and pastoral care through a communal hall arrangement, where typically several hundred students are accommodated in rooms off shared corridors.

3.3 The number of students in each unit

Good social relationships are crucial to support students who are new to university and to reduce drop out rates. Students use computers a great deal, which can result in them spending too much time alone in their rooms. It is generally agreed that students form friendships more easily and are more likely to behave responsibly – reducing management and maintenance problems – if they are in small groups: typically 5 to 10 students sharing a self-contained flat or house. However, in small groups students who have not chosen to live together may not get on. Larger groups can provide a greater choice of friends, particularly when combined with a greater level of pastoral support from university staff: in a traditional 'hall', the social unit is the whole hall, creating a stronger sense of allegiance to the university itself.

3.4 The shared facilities in each unit

Kitchens: traditionally, central catering facilities were provided in larger halls of residence, with minimal facilities for cooking close to the study bedrooms. The intention was to encourage students to be a part of the wider university community, and many universities still offer accommodation with central catering included as part of the rent. However for reasons of economy, culture and convenience, most students prefer the freedom of catering for themselves or of eating out. As a consequence, in most new accommodation – whether in the form of halls, flats or houses – kitchen-dining rooms are provided for self-catering, each serving a group of study bedrooms and effectively defining the social groups. As noted above, some schemes include studio rooms, where each student has their own kitchen facilities.

Bathrooms: the majority of new study bedrooms are now provided with en-suite bathrooms, and where it is intended that the rooms will be used for conference accommodation out of term time, en-suite bathrooms are practically indispensable. In some schemes a single en-suite bathroom is shared by two study bedrooms. Schemes with en-suite bathrooms are not necessarily more expensive than those with shared bathrooms, particularly when washbasins are also provided in all of the study bedrooms as well. Costs will depend on the detailed arrangement of the plan and floor areas.

Other shared facilities: common rooms, laundries, reception, seminar rooms, staff/wardens' flats etc. will be provided where the student numbers are large enough to support them, where there is a demand associated with teaching or conference uses or, especially in the case of commercial providers, where the facilities are intended to attract a particular market. Facilities in commercial schemes can be extensive: for example a games room, gym, cinema or café.

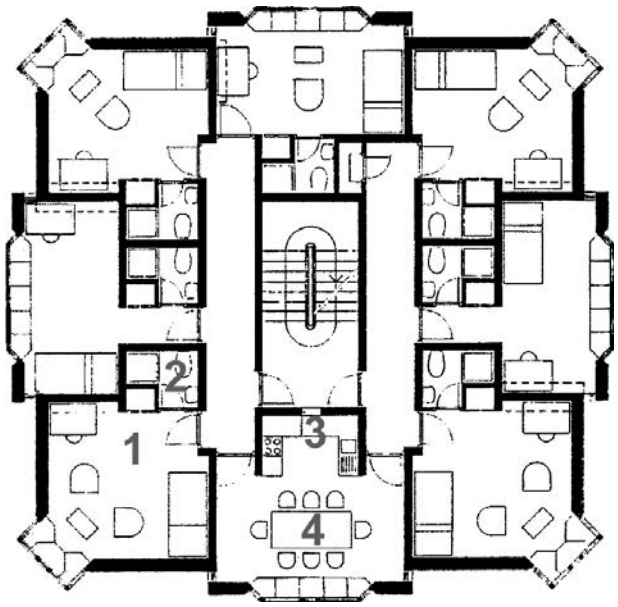
4 BUILDING FORM

4.1 Study bedrooms

Study bedrooms form the basic building block of student accommodation and can be arranged in a number of ways. In each case the study bedrooms may have en-suite bathrooms or there may be shared bathrooms.

4.2 Staircase

In the traditional 'Oxbridge' model, buildings arranged around a quadrangle are divided into 'staircases' with a small number of study bedrooms at each level served by a single stair (Figure 23.1).



23.1 *Generic type: Student residence with a traditional college staircase arrangement, Jowett Walk, Balliol College, Oxford. Architects: MJP Architects. 1, study bedroom; 2, en-suite bathroom; 3, kitchen; 4, dining*

A kitchen may be provided on each floor or on one level, and is shared by the rooms on the staircase. A loose social group is defined by the staircase, but there is also a strong association with the wider college or university.

However, it is difficult to incorporate lift access economically, as separate lifts are required for each staircase. An arrangement where lifts are not provided and wheelchair access is restricted to the ground floor level may not be acceptable to the university and is unlikely to be appropriate where conference use is proposed.

4.3 House style

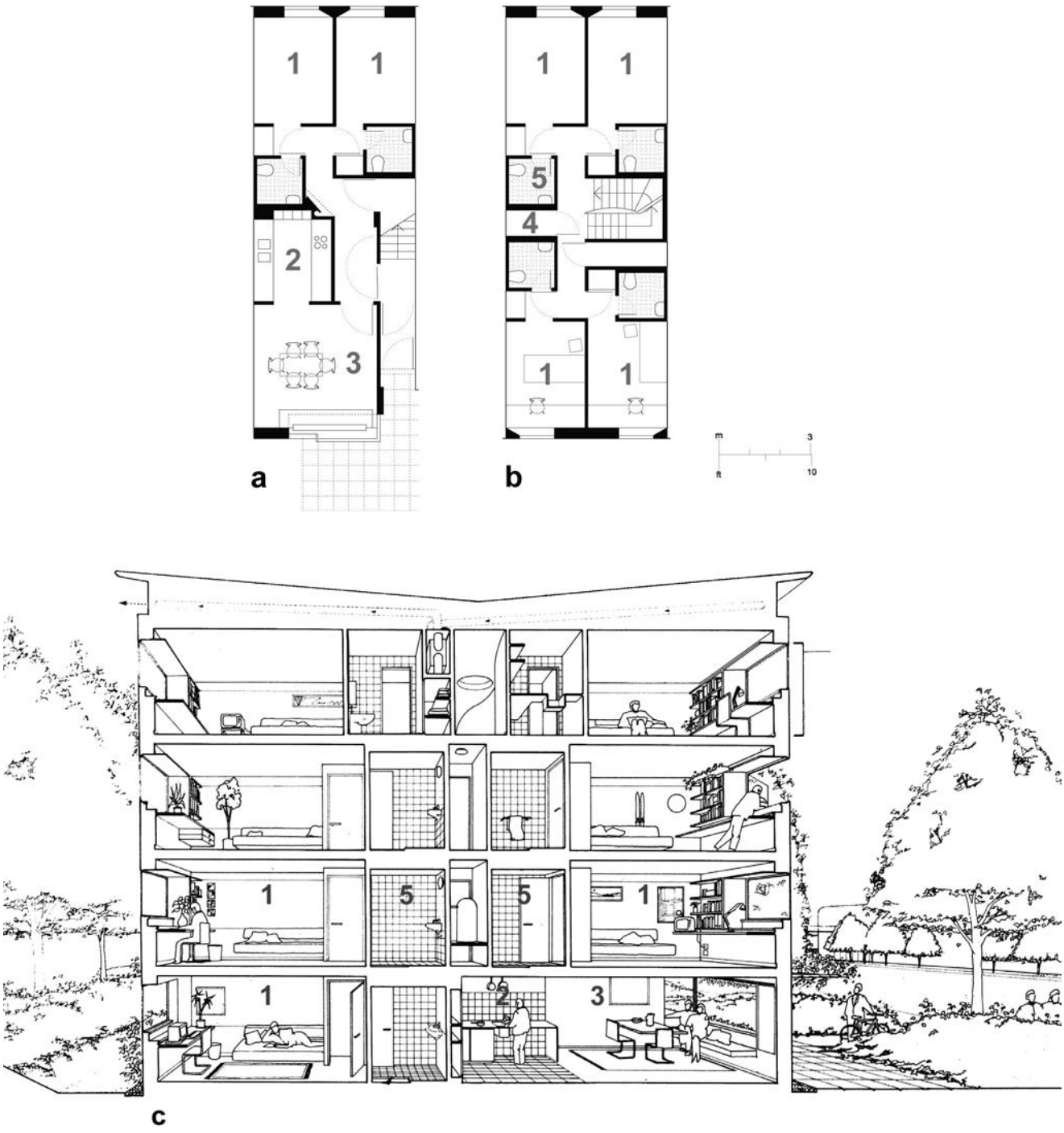
This replicates the popular model of a traditional private house shared by students (Figure 23.2). It is similar to the staircase model with a limited number of study bedrooms on several levels served by a single stair, and a shared kitchen/dining room at ground level. The house has its own front door so that the social group is well defined and there is a greater sense of independence. However the problems of incorporating lifts and disabled access are the same as for the staircase model.

4.4 Hall or corridor

Rooms are arranged off a corridor (Figures 23.3–23.5). Corridor schemes allow for large numbers of rooms to be served economically by lift, providing disabled access as well as easy access for conference guests, cleaning staff and students with luggage. The hall itself forms a single large social group, but smaller units are less easy to form. The corridors may be divided along their length to form groups of rooms with a shared kitchen, but this cannot provide the domestic character and scale of a shared flat or college staircase. In some schemes corridors are doubled up in order to form separate flats. Schemes which consist of studio rooms or studio flats are usually also arranged on corridors. Corridor access schemes tend to have a higher proportion of circulation area than staircase schemes. It is difficult to bring natural light and ventilation into double-loaded corridors, and their design requires careful handling to avoid monotony and a dull institutional character.

4.5 Flats

Rooms are grouped into self-contained flats with a number of study bedrooms (typically 5–8) and shared kitchen/dining room (Figures 23.6 and 23.7). This arrangement is very common and defines a self-contained social group with its own front door. Lift access can be arranged economically to serve groups of flats.



23.2 *Generic type: Terraced house plus self-contained flats. Constable Terrace, University of East Anglia. Architects: Rick Mather Architects. 1, study bedroom; 2, kitchen; 3, living/dining; 4, services/storage/cleaners; 5, shower/wc. a Ground floor plan, b First floor plan, c isometric sectional view*

4.6 General design factors

Depth of plan: student study bedrooms are usually small – typically 13m^2 for a room with en-suite bathroom – and the space is more useable if the room is rectangular. Placing the en-suite bathroom at the back of the room in the centre of the building produces a deeper building plan, particularly with a double loaded corridor, and reduces the length of corridor. It is therefore generally the most cost-effective layout. Providing bathrooms as shared facilities (as opposed to en-suite) will impact on corridor length and escape distances.

Escape distances: the escape distance from the farthest study bedroom to the escape stair is a key factor in the arrangement of the plan. Arranging narrow study bedrooms in a row allows the number of rooms served by each escape stair to be maximised. However the width of the rooms must also be considered in relation to use of the space and the need to maintain sufficient width for wheelchair access and manoeuvering.

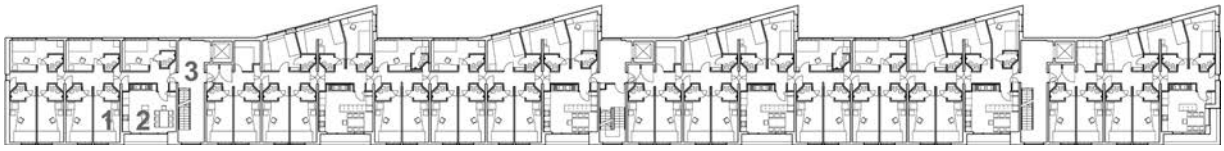
Lifts: the requirement for inclusion and for access for wheelchair users to different parts of the building is discussed in Section 5.7. Provision of lift access to all floors and all study bedrooms will have implications for the arrangement of the plan, as it is normal to aim to limit the number of lifts in a scheme to reduce cost.

Modern Methods of Construction (MMC) and pre-fabrication: study bedrooms are repetitive units and, where large numbers are involved, they lend themselves to modern methods of construction such as tunnel form or off-site modular and volumetric construction, although care is required to ensure that this does not produce a dull, institutional character in the internal layout or elevations of the building. Pre-fabrication can be used for whole rooms or for separate elements such as en-suite bathroom pods. The system speeds

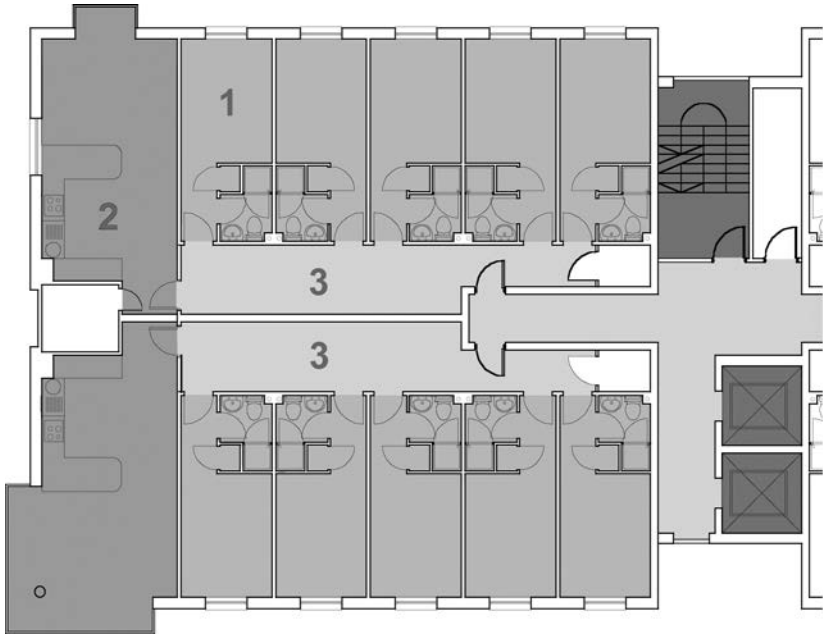
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23.3 *Generic type: Student and key-worker housing with a corridor arrangement: Friendship House, London. Architects: MJP Architects. The corridor arrangement is wrapped around a courtyard to provide a focus for residents. 1, study bedroom; 2, study bedroom for disabled residents; 3, shared kitchen; 4, common room; 5, courtyard; 6, garden; 7, railway viaduct*

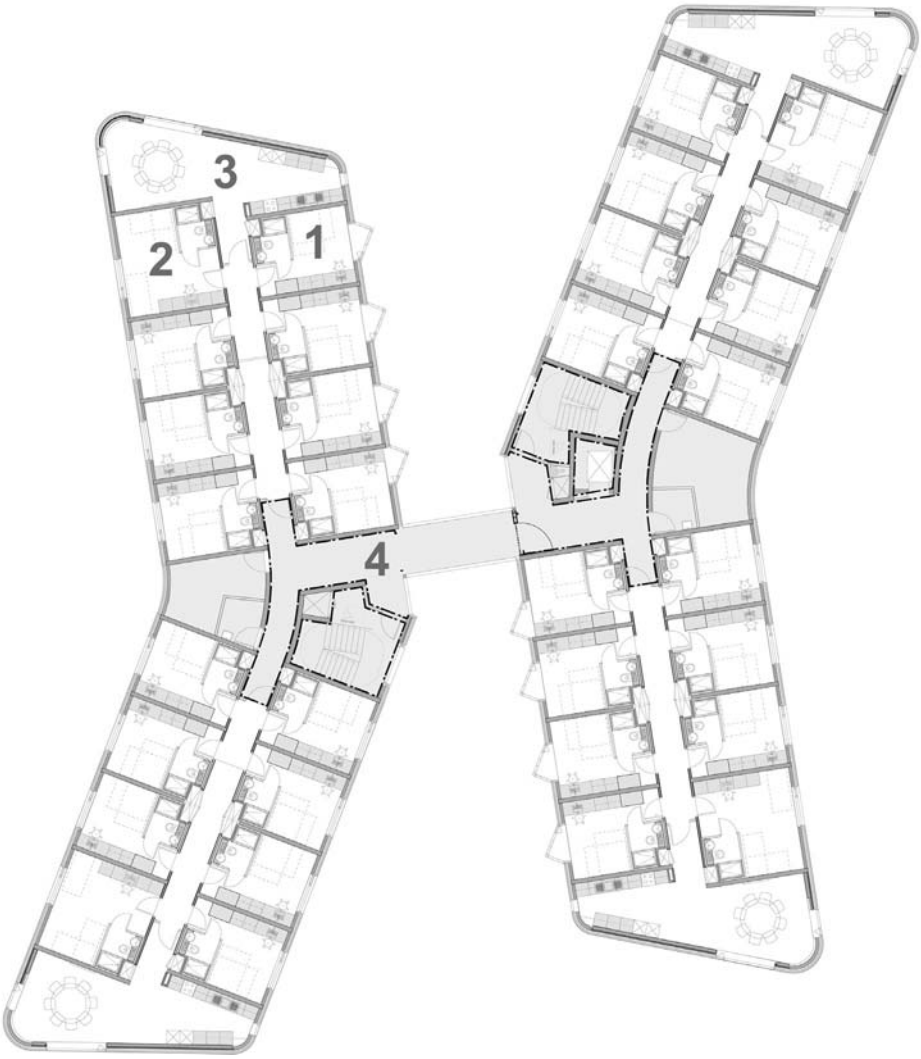


23.4 *Generic type: Student residence with a corridor arrangement: Pooley House, Queen Mary University of London. Architects: FCB studios. The long corridor is sub-divided to form flats. 1, study bedroom; 2, shared kitchen; 3, communal circulation area*

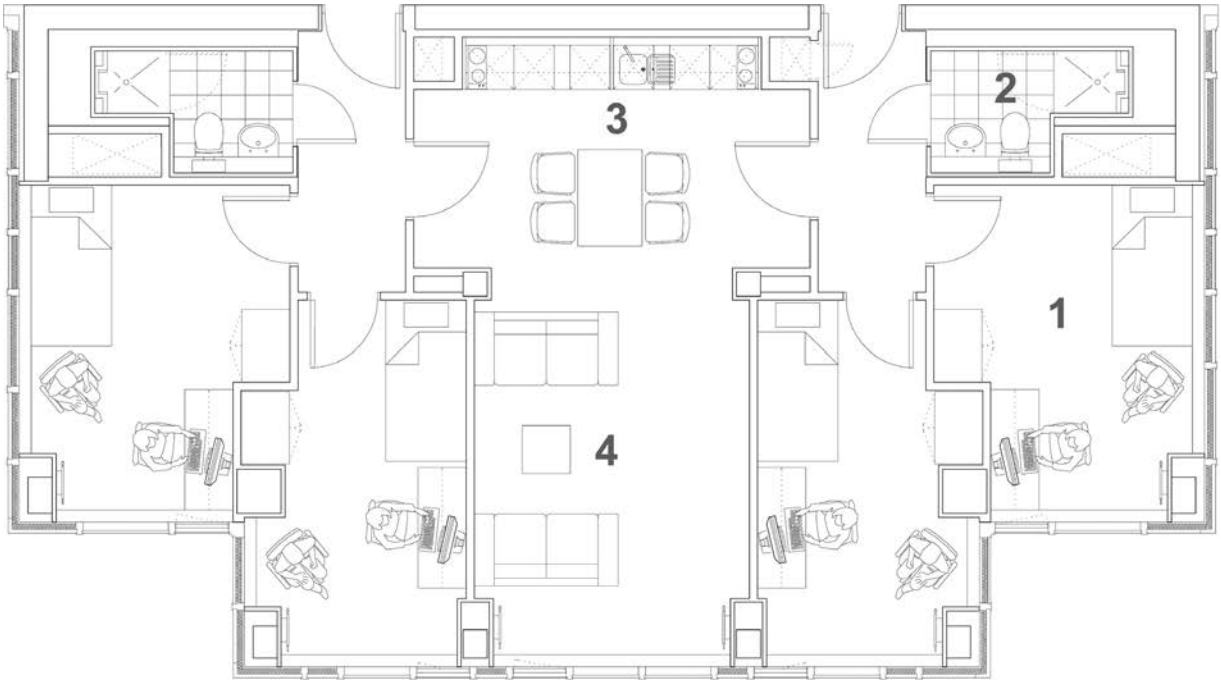


23.5 *Generic type: Student residence with twinned corridor arrangement to form separate flats: Purbeck House, University of Bournemouth. Architects: Architecture PLB. 1, study bedroom; 2, kitchen; 3, flat circulation*

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23.6 *Generic type: Student residence with flat arrangement: Bluebell Views Residences, University of Warwick. Architects: Page\Park Architects. The angled blocks help to define separate flats, while projecting windows reduce overlooking. 1, study bedroom; 2, twin study bedroom; 3, kitchen/dining room; 4, communal circulation area*



23.7 *Generic type: 4 bed cluster apartment: Nido Spitalfields. Architects: t p bennett. Private commercial developers have developed different flat types. 1, study bedroom; 2, shared bathroom; 3, shared kitchen; 4, living room*

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up construction, reduces waste and allows complicated elements to be constructed to a high standard in factory conditions; however there is usually a capital cost premium to be balanced against any savings from the reduced construction programme. The decision to use modular construction needs to be taken at an early stage in the design process as there are implications for dimensions and interfaces with surrounding elements and for the procurement route.

5 STANDARDS AND REGULATIONS

This section gives guidance on key areas of legislation, but is not intended to be comprehensive. The standards and legislation referred to are current at March 2011. Designers should check that these have not been superseded. Illustrations are of completed projects and the standards that were current at the time they were built may have been superseded.

Designs should comply with all statutory requirements contained within Housing, Building, Planning, Disability Discrimination, Equal Opportunities, and other relevant legislation and standards.

5.1 Town and Country Planning Act 1990 and amendments – planning permission

Student accommodation falls into different use classes under the Town and Country Planning Act depending on size and whether it is provided by a university/college or by a private provider.

Developments by private providers

HOUSES IN MULTIPLE OCCUPATION – SMALL PROPERTIES (3–6 OCCUPANTS)

In 2010 government legislation introduced a new use class – Class C4 houses in multiple occupation – which covers small shared houses or flats occupied by 3 to 6 tenants, who are not related to each other, and who share one or more basic amenities (such as a kitchen). Student accommodation which is managed by an educational establishment is excluded from Use Class C4.

Legislation allows local authorities to require a planning application for a change of use from a dwelling house to a house in multiple occupation, so that they can prevent a high concentration of rented houses in one area, a situation known as 'studentification' which can cause problems for the local community.

HOUSES IN MULTIPLE OCCUPATION – LARGER PROPERTIES (OVER 6 OCCUPANTS)

Larger houses in multiple occupation with more than 6 tenants, are unclassified by the Use Classes Order and are described as 'sui generis' (of their own kind). Discussion with the planning authority will be required to clarify their requirements.

Developments by Higher Education Establishments

Student accommodation for residential colleges will generally fall into Use Class C2, 'Residential Institutions'.

5.2 The Housing Act 2004

Part 1: Housing conditions

Part 1 of the Housing Act relates to housing conditions and applies to every type of accommodation. It provides a system for assessing conditions – the Housing Health and Safety Rating System, HHSRS – and gives local authorities powers to tackle poor housing based on the severity of the health and safety hazards.

Part 2: Licensing of houses in multiple occupation (HMOs)

ACCOMMODATION MANAGED OR CONTROLLED BY PRIVATE SECTOR PROVIDERS

Statutory controls on HMOs under the Housing Act can be confusing. The term HMO applies to a wide range of housing types, mainly in the private rented sector where standards have historically been low. In essence the Housing Act defines HMOs as accommodation occupied by more than one household and where households share one or more basic amenity (such as a kitchen).

Part 2 of the Housing Act regulates HMOs by providing for them to be licensed by the local authorities. Licensing is mandatory for larger HMOs (this includes those that are 3 stories or more, 5 or more people of 2 or more households) but can also be extended to smaller HMOs by the Local Authority.

ANUK/Unipol's *Code of Standards for Larger Residential Developments: for Student Accommodation Not Managed and Controlled by Educational Establishments, 2010* gives guidance for private sector providers of student accommodation and their tenants on similar lines to the codes that apply to HEEs described below.

ACCOMMODATION MANAGED OR CONTROLLED BY HIGHER EDUCATION ESTABLISHMENTS

Student accommodation for people attending full time courses which is managed or controlled by an educational establishment can be 'excepted' from the definition of an HMO and from the licensing requirements of the Housing Act (except for Part 1, which still applies), provided the accommodation is designed and managed in accordance with an approved code of practice. The following codes were current in March 2011:

- *The Universities UK/Guild HE Code of Practice for the Management of Student Housing*, dated 17 August 2010;
- *ANUK/Unipol's Code of Standards for Larger Residential Developments for Student Accommodation Managed and Controlled by Educational Establishments*, dated 28 August 2008.

The codes deal with a range of physical standards and management practices and also address student welfare and the fair and reasonable treatment of student tenants, reflecting the special characteristics of student accommodation which encompasses more than the basic provision of facilities. The codes provide general guidance for the design of accommodation rather than detailed specifications, as the provision will vary between different projects and different locations. They include requirements for:

- furniture and storage;
- kitchen facilities – level of provision refers back to local authority requirements;
- toilet and personal washing facilities – level of provision refers back to local authority requirements;
- laundry facilities;
- mail deliveries;
- health and safety – gas and electric installations and appliances, fire safety, security;
- the environment – waste, recycling, energy, water supply, drainage, landscaping;
- windows and ventilation;
- lighting of communal areas;
- cleaning and maintenance;
- inclusion of accommodation for residential staff in larger schemes.

The ANUK/Unipol Code goes on to identify four key areas – student care, sustainability, security and community interface – where enhanced provision can achieve 'star' rating for a scheme. The codes are also appropriate for accommodation for other non-HEE students and young people, but additional legislation may apply, for example if accommodation is provided for students under 18 years of age in FE establishments.

5.3 Local authority requirements for HMOs

Different local authorities develop their own codes of practice for HMOs, which are generally more specific than the codes described above. The requirements may vary for different types of student accommodation – bedsits, studios, shared flats etc. – and there may

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be variation in the way they are applied, for example where there are requirements from other legislation, such as for listed buildings. The local authority's environmental department should be consulted at an early stage in the design. Typical requirements are as follows.

Space standards
- Minimum room areas for study bedrooms, for single and shared occupancy.
- Minimum room areas for kitchens, kitchen/dining rooms and living rooms.

HHSRS rating system (see above)
- Design requirements to avoid hazards – damp, cold, security, lighting, sanitation, water, falls, electricity, heating and cooking.

Personal washing facilities
- Ratio of baths/showers to number of occupants – typically a minimum of 1 bath or shower for 5 people.
- Washbasins to be provided with all toilets.
- Washbasins may be required within bedrooms in larger HMOs.
- Maximum distance of shared bathrooms from bedrooms – typically no more than 1 floor away.
- Design and layout of bathrooms, minimum dimensions of appliances, finishes, heating, lighting and ventilation

Toilet facilities
- Ratio of toilets to number of occupants – typically a minimum of 1 toilet for 5 people. Provided in a separate room to the bathroom if it serves more than 4 people.
- Maximum distance of shared toilets from bedrooms – typically no more than 1 floor away.
- Design and layout, finishes, heating, lighting and ventilation.

Facilities for storage, preparation and cooking of food
- Maximum distance of kitchen from bedrooms – typically no more than 1 floor away, but can be further in smaller buildings such as 'house' style accommodation.
- Provision of dining rooms and furniture.
- Design and layout of kitchens to allow safe use by several people at the same time. Finishes and minimum dimensions of appliances, heating, lighting and ventilation.
- Ratio of kitchen facilities to number of occupants – typically 1 set of facilities for 5 people comprising a sink and drainer, a food cupboard (500 mm wide base unit or 1000 mm wide wall unit), a fridge (130 litres), freezer space (60 litres), worktop (1000 mm min), 3 double power sockets in addition to those required for the appliances, a cooker with 4 burners, oven and grill. Additional facilities should be included where the kitchen is shared by larger numbers of people.

Fire safety and means of escape
- Requirement for fire doors, fire separation, lobbies, emergency lighting, fire fighting equipment and automatic fire detection systems.
- Internal layout of shared flats – escape from bedrooms must not be through a higher risk area such as a kitchen.

Management: The Management of Houses in Multiple Occupation (England) Regulations 2006
These regulations set out the responsibilities of both managers and occupiers. They include requirements for cleaning, maintenance and repairs, and provision of water supply, drainage, gas and electric supplies, means of escape, ventilation, recycling and waste management as well as safety protection to roofs, balconies and windows.

5.4 Fire safety

Each local authority has requirements prior to issuing a license for use of a building as a HMO. All must comply with The Management of Houses in Multiple Occupations (England) Regulations 2006. As for other building types, the responsibility for safety lies with the 'responsible person', who is required to prepare a Fire Risk Assessment under the Fire Safety Order.

New build HMOs should be designed in accordance with the UK Building Regulations. Compliance can be achieved by following the guidance set out in the Approved Document B – Volume 2, Buildings Other than Dwellinghouses, which provides guidance on means of escape, external fire spread, internal fire spread and fire brigade access. It also provides guidance on fire safety systems required in buildings.

The Approved Document B helps define the number of occupants within the building and to design escape routes appropriately, with recommendations for the planning and protection of escape routes and separation between areas of higher fire load. It also sets out provisions for splitting larger buildings into smaller fire rated compartments. External fire spread from the building of fire origin to adjacent premises is addressed in Document B and provisions are made for the fire service to access the building externally and internally. Note that access for fire engines to different parts of the building can have significant implications for the site plan and form of the building, particularly on constricted sites.

An alternative approach to following the Approved Document B is to adopt a Fire Engineered solution where the fire safety for the building is tailored to the risk involved and the layout to achieve an equal level of life safety protection. The use of fire engineering is especially valuable when a change of use to an HMO is adopted, when it is often difficult to meet the recommendations of the Approved Document B. Means of escape in case of fire is also covered by the Housing Act and by the approved codes of practice that apply to educational establishments (see above).

False fire alarms can be a problem in student residences both for the fire services and for residents, particularly where full evacuation is required. In some areas the fire services will only answer an alarm call if the existence of the fire is confirmed. Fire systems should be designed to minimise accidental false alarms insofar as this is possible. The location of extinguishers, detectors and call points, the design of fire doors and glazing should be considered carefully to reduce the risk of misuse – e.g. extinguishers let off, fire doors wedged open – and to avoid an institutional feel.

5.5 Noise

The Building Regulations, Approved Document Part E (Resistance to Sound) applies to 'Rooms for Residential Purposes', and includes requirements for different parts of the construction. Noise is a major source of annoyance in student residences, because the uses of neighbouring study bedrooms rooms for leisure, study and sleep contain inherent conflict and students do not keep regular hours. Consider noise from both inside and outside the building: from kitchens and circulation areas, badly adjusted door closers, lifts, service ducts, telephones, etc. In planning the accommodation, it is important to separate potentially noisy areas from student bedrooms and to insulate each individual study bedroom to a high standard.

5.6 Ventilation

The Building Regulations, Approved Document Part F (Ventilation) apply to student accommodation.

Shared bathrooms and kitchens are used intensively. In student accommodation bathrooms are usually internal, so problems of condensation are common where ventilation is inadequate. Student rooms may be left unoccupied for long periods during the holidays, and adequate background ventilation is important.

5.7 Access and inclusion: BS8300, Disability Discrimination Act and Equality Act

Under the Equality Act 2010, universities must not discriminate against students in the provision of education, or access to any benefit, facility or service, by excluding them or by subjecting them to

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any other detriment. From October 2010, the Equality Act largely replaces the Disability Discrimination Acts (DDA). The obligation to make adjustments for disabled students under the Equality Act 2010 remains and participation of the institutions and groups of disabled students at planning stages through construction is also important. BS 8300:2009+A1:2010 BS 8300 gives recommendations for the design of buildings and their approaches to meet the needs of disabled people including requirements for accessible rooms. It applies to university and college halls of residence.

The Building Regulations, Approved Document M (Access to and Use of Buildings) aims to ensure that buildings are accessible and useable by everyone, regardless of disability, age or gender, and without unnecessary separation or segregation. Universities place great importance on inclusion. It is likely that many more disabled students will be ambulant disabled or have visual or hearing impairments or learning disabilities, rather than be wheelchair users. Sleeping accommodation should aim to be convenient for all – a proportion should therefore be designed for independent use by wheelchair users, while standard rooms should have a degree of flexibility or adaptability to be suitable for people who do not use a wheelchair, but may have other difficulties, e.g. a visual impairment or limited dexterity. The Approved Document M puts provision for wheelchair accessible bedrooms at 1 for every 20 bedrooms (5 per cent). However BS 8300 suggests that for new buildings the percentage should be 15 per cent. The local authority are likely to have their own requirements based on local need, and early consultation is essential.

Accommodation for disabled people should be integrated with other student rooms, which suggests that they should be distributed throughout the residences at different floors. Wheelchair users should be able to reach and use all facilities – common rooms, kitchen, laundry etc. Socialising with other students is an important part of student life – and therefore protected through disability/equality legislation as a 'civil' right – so access to social areas, such as kitchen/dining rooms, is doubly important. These issues have implications for provision of lifts and consequently for the form of the accommodation (see section 4 above). Some universities will require disabled students and wheelchair users to be able to access all study bedrooms so that they can visit friends. Others provide study bedrooms for wheelchair users and the kitchen/dining room at ground floor level, but no lift access to other rooms (for example in 'house' style accommodation). This approach can be argued as acceptable, but it is still likely to be interpreted on a case-by-case basis by each different local authority. Where residential accommodation is used for conferences and holiday letting, it becomes more like 'hotel' accommodation, and should therefore incorporate appropriate provisions, e.g. sizing of stairs, doors and the provision of lifts.

Access for wheelchair users increases the area required for circulation space, including the entrance to standard study bedrooms when there is provision for wheelchair users to visit other students: the effective clear width of doors to standard study bedrooms will need to be adequate to admit wheelchair users. Some students require a high level of assistance. Consideration should be given to the provision of an adjacent bedroom next to the accessible room, with a connecting door, for a 'companion'/personal assistant. Appropriate fittings and equipment will be required in shared facilities such as kitchen/dining rooms and laundries as well as in accessible rooms. A unisex wheelchair accessible WC should be provided for visitors.

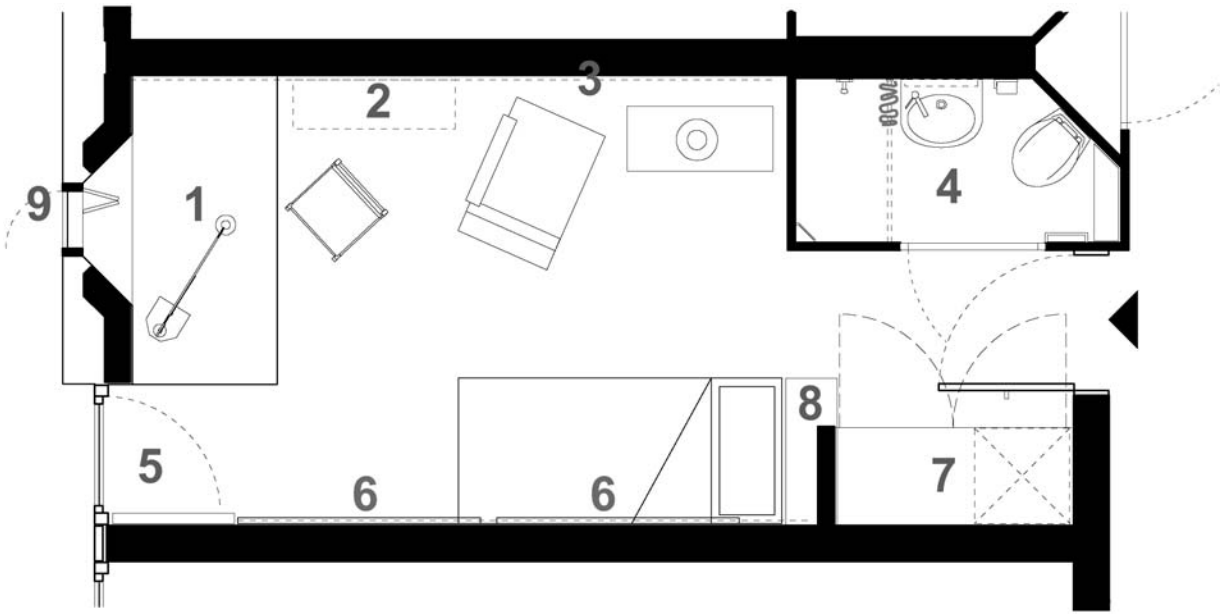
6 THE STUDY BEDROOM

6.1 Functions

The study bedroom is the most important element in the design. It has to facilitate a range of functions in a small space – sleeping, studying, relaxing and socialising. It is the students' home while they are at university, and they should be able to impose their personality on it. The room should be designed to allow the furniture to be arranged in different layouts, to help avoid the institutional character that can easily arise with large numbers of repetitive rooms. It must feel private and secure and, ideally, have a reasonable view. It must have good light and ventilation which the student should be able to control. Good acoustic insulation from adjoining rooms, corridors and from the outside is very important. The room and furniture must be robust and easy to clean and maintain. Study bedroom types include rooms with or without en-suite bathrooms, and 'studio' rooms with en-suite bathroom and kitchen area. Rooms may be single or shared. The most common type is the single, en-suite study bedroom (Figure 23.8).

6.2 Room size and shape

A study bedroom for one person (without en-suite bathroom) can be as small as 8 m^2, but this is extremely tight and a more appropriate minimum area is 10 m^2. A small sized room with en-suite bathroom is typically 13m^2. To optimise the plan, study bedrooms



23.8 *Room with en-suite bathroom. St Hugh's College, Oxford. Architects: David Morley Architects. 1, desk; 2, movable shelf; 3, hanging rail; 4, bathroom pod; 5, full-height window; 6, movable pinboard; 7, wardrobe; 8, built-in bedhead shelf/storage; 9, window with shutter in splayed opening*

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are usually rectangular with the en-suite bathroom at the rear of the room. Where there is wheelchair access to the room, the room width will need to be approximately 2.8 m to allow the wheelchair to pass the bathroom and turn within the room. Typical modest room sizes for other types of student room are:

- Study bedroom shared by two students with en-suite bathroom: 20 m^2
- Studio room for one student with en-suite bathroom and kitchen area: 18 m^2
- Studio flat for one student or a couple with en-suite bathroom and kitchenette: 30 m^2

Carefully consider the proportions of the room – the furniture layout and the position of the door, window, built-in cupboards, sockets and fixed lighting to ensure that the room will accommodate different activities and moods. The larger the area, the easier this becomes, but even a small room should be designed to allow some variation in the arrangement of furniture. Features such as window seats, built-in shelves, alcoves, etc. can be also used to enhance character. Consider the height of the window and views when the student is sitting at the desk or on the bed. Where it is feasible to provide larger rooms – for example where students have a choice of rents – it is possible to design for greater flexibility and to 'zone' the different functions of the room (Figure 23.9).

6.3 Furniture and finishes

The careful design of built-in furniture and careful selection of loose furniture is essential to the function and appearance of small study bedrooms. Furniture and fittings should be robust, but not institutional in character. Built-in furniture can be used to enhance the character of the room. Typical provision is as follows:

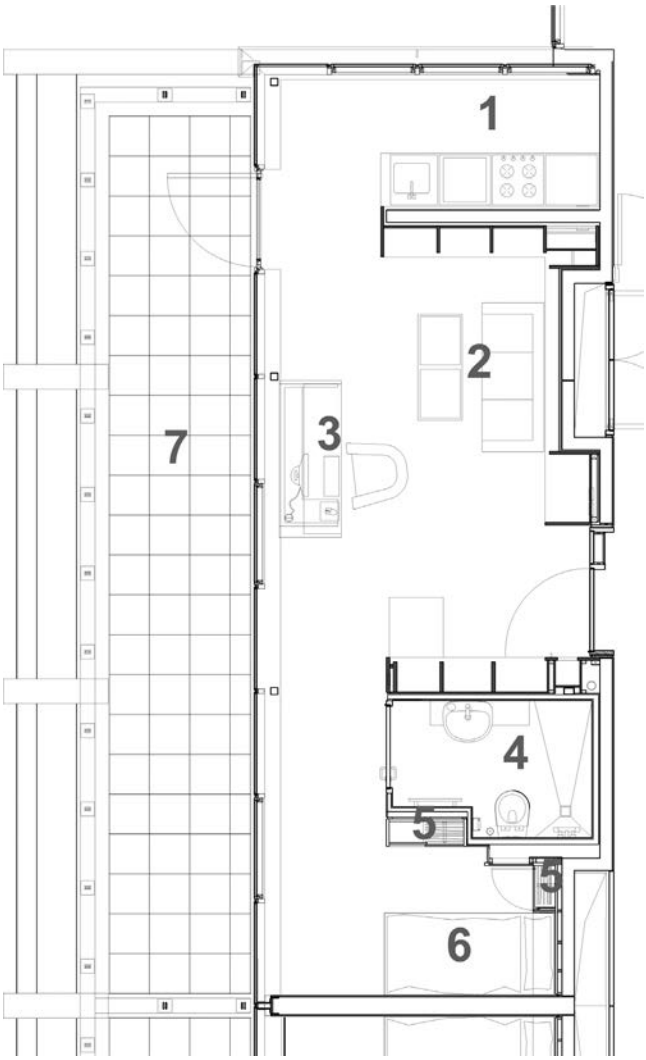
- Bed: may have a storage drawer under. Usually doubles as a sofa, so consider providing a back rest along the wall. Wider beds (approx. 1350 mm) are provided in some schemes.
- Desk: should be as generous as possible to take a computer, books, files etc., with drawers large enough to take files. Incorporate hole for cable management. If the window cill is at, or slightly above, desk height it can be used as an extra shelf.
- Desk chair.
- Easy chair: if sufficient space.
- Shelving: often built-in. May be arranged to serve the function of a bed side table.
- Wardrobe: often built-in.
- Chest of drawers: can be used to extend the desk if it is same height and depth.
- Pinboard: generous provision to discourage use of walls. A small pin board on the outside of the room door is useful.
- Washbasin: a washbasin is often provided in study bedrooms when en-suite bathrooms are not provided, and should be separated from the main area of the room, by containing it within the wardrobe unit or behind a room divider.
- Mini-fridge: occasionally required.

6.4 En-suite bathrooms

En-suite bathrooms add approximately 2.8 m^2 to the study bedroom area and should be carefully planned to ensure that the small space functions well. They can be designed as a wet room with a floor drain, or incorporate a shower tray with a door. A wet room helps to optimise use of the space, but make it more difficult to keep the contents of the small space dry. The floor also takes time to dry. Bathrooms are often supplied as prefabricated pods, which allows the intricate work involved in the finishes and in waterproofing showers and floors to be carried out under factory conditions and avoids delays to other trades on-site.

6.5 Studio rooms

Studio rooms include an en-suite bathroom and a kitchen area (Figure 23.10). The kitchen area usually includes a small fridge,



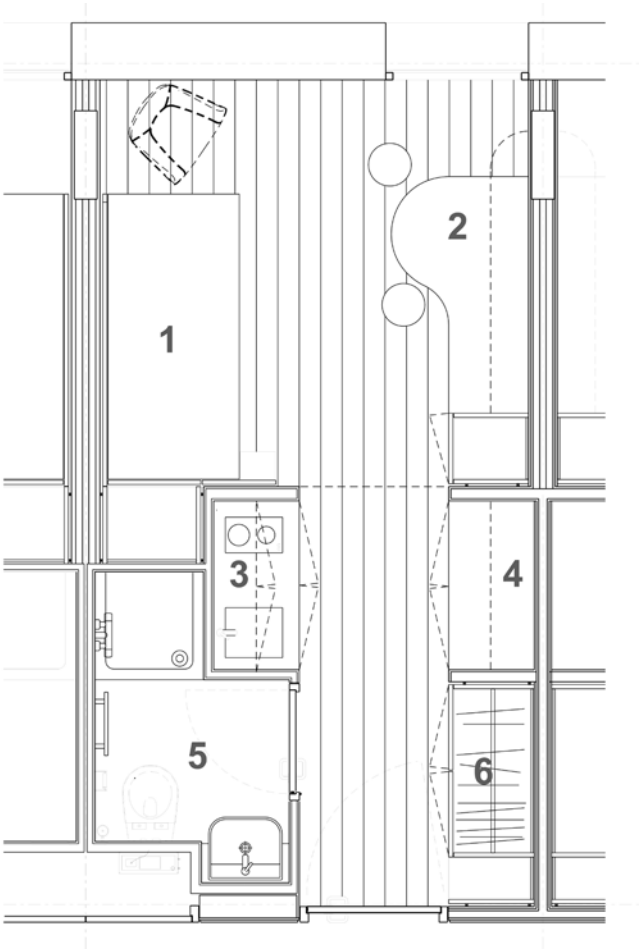
23.9 *Junior Research Fellows Suite. Kendrew Quadrangle, St John's College, Oxford. Architects: MJP Architects. The larger studio room is zoned. 1, kitchen; 2, living area; 3, desk; 4, shower room; 5, wardrobe; 6, bed; 7, terrace*

sink, cupboard, hob or microwave and cooker extract. Extraction to external space (rather than less efficient re-cycling of air) will require ducts to be incorporated into the plans. The kitchen should be designed so that it doesn't dominate the study bedroom. If the kitchen area is located on the escape route between the sleeping area and the room door, details should be agreed with the local authority. Additional fire provisions will be required.

6.6 Services

Students should be able to control their environment. Consideration should also be given to erratic patterns of occupation of study bed rooms and measures should be incorporated to reduce energy consumption, e.g. to ensure that lights are not left on when rooms are vacant (see also section 5). Access for maintenance and meter reading should be arranged from corridors to avoid the need for access to the student rooms.

- *Lighting:* good natural light is important. General artificial lighting should be supplemented by task lighting to serve desk and bed positions and should be switched so that it can be controlled from the bed and room door.
- *Internet and communications:* students require excellent internet access for study and social activities. TV provision is increasingly provided via the internet. Technology for internet access is constantly advancing, so that the most appropriate system should be agreed as each project is designed. Data cabling systems



23.10a *Studio room with en-suite shower/WC/basin and kitchenette. 1, bed; 2, desk; 3, kitchenette; 4, kitchen storage; 5, shower room; 6, wardrobe.*



23.10b *Studio room with en-suite shower/WC/basin and kitchenette. Torquay Street, London. Architects: MJP Architects.*

perform better and are more secure than Wi-Fi, but Wi-Fi is significantly cheaper and gives students the flexibility to work where they choose. If trunking and sockets are provided, positions should be coordinated with furniture arrangements.

- Shared phones in common areas may be required for occasional or emergency use.
- *Heating and electricity:* systems and controls will be determined by the university or commercial provider's strategy for energy conservation and for charging, and also by the length of let (term time only, or all year). Background heating may be provided within the rent, with the facility to boost heat in each room.
- A minimum of four double sockets is appropriate for equipment, which may include computer/printer, phone charger, kettle, hair drier, light fittings, etc. The location of sockets should be considered in relation to alternative furniture arrangements. Sometimes mini-circuit breakers are used to prevent use of larger electrical appliances.
- *Ventilation:* Natural ventilation should be provided with opening windows where possible, fitted with restrictors to prevent students from falling.
- *Recycling:* Bins for re-cycling may be required within the study bedroom.

6.7 Students with disabilities

Requirements for accessible rooms are addressed in BS 8300:2009+A1:2010. Wheelchair users require larger study bedrooms, with room for a wheelchair turning space between furniture and provision of an appropriate en-suite bathroom. The design of fittings and finishes should be suitable for access from a wheelchair. Study bedrooms may also require adaptations to meet the specific needs of individual disabled students, as these will vary depending on the particular nature of their disability. Consider:

- Design of room door and access into the room.
- Height of the desk (which may be adjustable) and space below for wheelchair to slide under.
- Access and use of cupboards and shelving.
- Design of ironmongery and controls for window opening, curtains and blinds.
- Position of electrical sockets and switches.
- Provision of telephone, emergency call point and fire alarm beacon.
- Provision of space to store the unused wheelchair without obstruction.
- Design of en-suite bathroom.
- Levels of lighting and choice of colours for people with visual impairments.
- Visual alarms or vibrating alarms for people with hearing impairments.

7 KITCHEN/DINING ROOMS

7.1 Role

In student accommodation, kitchen/dining rooms provide a key social focus for each group of students that they serve, with opportunities for casual encounters, friendship and support. This fosters a sense of ownership of the accommodation which in turn encourages responsible behaviour. One kitchen/dining room will typically serve 5–8 students, although in some universities they may serve 10 or more, particularly in 'house' type accommodation or in halls where the university also provides central catering facilities as an alternative.

Kitchen/dining rooms can be arranged to overlook common areas such as entrances, stairs and halls, providing further opportunities for interaction and a degree of security through informal supervision. They should be located to avoid noise and nuisance to study bedrooms. The dining areas should be designed to allow all the students in the unit to eat at the same time. Furniture should not be fixed to avoid creating an institutional character. Kitchen/dining rooms may be extended to incorporate a living area with sofas and a television. Provision of Wi-Fi will make dining and living areas more useful.

Kitchens will be heavily used and should allow several people to prepare food simultaneously. They must be designed to be functional, robust and easy to clean. As a guide, a length of work surface of approximately 3600 mm, including cooker and sink, will be sufficient for five people. Circulation space between units should be 1200 mm minimum. Where kitchens serve larger numbers of students, the provision of cookers, sinks, fridges and storage will need to be increased to meet statutory requirements (see item 5 above). Ideally a microwave oven should be provided as well as a

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conventional cooker. Cupboards should be provided for each student for storage of tins and dry goods. In some accommodation locks are provided on cupboards and even fridges to avoid food being stolen, while in others – particularly self-contained flats and houses – there are no locks, to promote a sense of mutual responsibility. At the other extreme, in some accommodation students are expected to keep cooking equipment and food in their rooms, but this is inconvenient, causes mess and undermines social interaction.

7.2 Services

Measures should be incorporated to reduce energy consumption (see Section 9.5):

- *Electric power:* provide sockets at worktop and at low level. Some universities monitor and charge for cookers separately to discourage wasteful use of energy. Cookers can be fitted with a time switch in case they are left on by mistake.
- *Lighting and mechanical extract:* Provide generous opening windows where possible (with restrictors) positioned to avoid nuisance from noise and smell to neighbouring study bedrooms.
- *Refuse and recycling:* position bins for easy cleaning and emptying. Separate recycling bins should be provided in line with university waste management strategies.

7.3 Inclusive access

Where the kitchen serves study bedrooms for wheelchair users, it should be designed with appropriate equipment and fittings and sufficient area to allow for wheelchairs to manoeuvre, including worktops with adjustable height and room for the wheelchair to slide below. Some duplication of equipment may be necessary.

8 BATHROOMS

8.1 Facilities

Bathrooms, showers and WCs are usually designed to the minimum practical area. Numbers of facilities should be in accordance with statutory requirements (see section 5). Shared WCs should be separate from bathrooms unless serving very few people. Where facilities are shared, additional washbasins are often provided in study bedrooms.

Facilities need to withstand rough use and simpler arrangements are potentially easier to construct, clean and maintain. Factory-assembled bathrooms 'pods' are often used to achieve a high standard of construction. Service ducts should be carefully detailed and located, with service access to en-suite bathrooms from corridors. Where bathrooms are not en-suite, consider proximity to study bedrooms and acoustic and visual privacy.

Provide good mechanical ventilation, especially in showers, with moisture-resistant light fittings. Towel rails, shelves and hooks in the shower area should be out of the way of the shower itself. Blocked or leaking showers are a common problem and even where a shower tray is used, the floor in a shower room should ideally drain to a floor gulley. Thermostatic balanced pressure mixers should be provided to showers to avoid risk of scalding. Flooring should be slip resistant.

9 OTHER FACILITIES

Provision will depend on the number of students living in the accommodation and on the availability of facilities nearby. They may include the following.

9.1 Reception and circulation areas

Entrances should be light and welcoming and avoid a mean or utilitarian character – the design should create an identity for the residences. In larger residences there may be a staffed reception or porter's lodge or office. In other schemes, provision may be required for a temporary reception to receive students at the start of term or conference guests in the holidays. In up-market commercial schemes, the design and 'branding' of the reception is important and a more generous area with seating will be required. A place for mailboxes may be required. Long narrow corridors without daylight or views should be avoided. Staircases are a place where chance meetings occur, and are an opportunity to design an attractive feature on circulation routes.

9.2 Laundry

A laundry serving groups of residents should be provided with washing and drying machines of a robust commercial type with emergency cut-off switch, plus a sink for hand-washing clothes, facilities for ironing and folding clothes and seats for waiting. Provide good lighting and ventilation and floor gullies to avoid flooding. Fittings and equipment should allow easy maintenance. Services such as electricity supply, hot water, etc. must be adequate for the level of use. Choose the location carefully – a laundry close to a common room can form part of a social hub, but laundries can be noisy, smelly and humid and should be arranged to avoid nuisance to study bedrooms or at the building's entrance.

9.3 Cleaners' storage

Where accommodation is in independent flats or houses, cleaning is generally the students' responsibility and a tall cupboard will be sufficient. Where the university arranges cleaning, provide central stores for the cleaners within a reasonable distance of the rooms. In larger schemes there should be a store on each floor. Provision may also be required for facilities for the cleaning and reception staff: WCs, lockers, staff room etc.

9.4 Other possible facilities

- Central common room/television room/party room: often poorly used if insufficient thought has been given to demand. Common rooms should be located so that activity is visible from main circulation routes to encourage use. Party rooms need to be located to reduce nuisance to study bedrooms. A kitchen area will be required for students to prepare food and drink.
- Seminar room/study area: central rooms with WiFi or data cabling can provide a place for group working and a sociable alternative to working in study bedrooms.
- Games room.
- Music practice room.
- In more luxurious schemes a gym, cinema, café or convenience store may be provided.
- Luggage store.
- Wardens/staff flats may be provided adjacent to or within the scheme, and may be studios or flats of various sizes, including family accommodation.
- Guest bedrooms.

9.5 External areas and parking

Well-designed landscaped areas around residences can provide places for socialising and informal working, particularly if Wi-Fi is available. Spaces for informal games – football, frisbee etc. – and for barbecues are popular.

The planning authority and the university will have policies for the provision of parking, and the allowance for student parking is usually very minimal, although spaces will be required for disabled parking, which should be close to entrances. To guard against theft and for personal safety, parking areas should be overlooked, well lit and relatively close to entrances. Each student arrives at the start of term with quantities of luggage and sufficient space should be provided near to entrances for unloading several vehicles simultaneously. Taxis are often used for nights out and there should be provision for taxi drop-off close to entrances. To encourage use of sustainable modes of transport, there should be well-designed foot paths and cycle routes and good provision of secure, covered cycle parking.

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9.6 Energy consumption

There are many opportunities to reduce energy consumption in the detailed design of the accommodation and choice of controls, fittings and appliances, including:

- BMS systems, and a good understanding of how to use the building (heating, ventilation etc.) by staff and residents.
- Low energy light fittings.
- Presence detectors for kitchen and en-suite bathroom lights.
- Thermostatic radiator valves.
- Mini circuit breakers in study bedrooms.
- Heat recovery systems.
- Low flow rate taps and dual flush WCs.
- Sustainable urban drainage.
- Renewable energy sources.

9.7 Refuse and recycling collection

Develop a waste management strategy at an early stage and consult the waste collection services about their requirements for access. The size of any bin store will depend on the number of students, the requirements for re-cycling and the frequency of collection. Bins filled by staff may be cleaner and tidier than those used by students, but all are potentially untidy, smelly and attract vermin. Stores should be easy to access, clean and maintain. Locate to reduce nuisance to residents, and provide good ventilation.

9.8 Safety and security

The design should address potential risks of attack, vandalism and theft. Personal safety is a major issue in student housing and students often return home late at night. Theft is also a common problem, as students own computers and other valuable equipment, and it is difficult to prevent strangers entering residences by 'tailgating'. Windows to ground floor rooms are particularly vulnerable. The building should be designed so that external areas – such as entrances, paths and car parks – and common areas within the building – such as staircases – are overlooked to provide informal supervision. Good external lighting is essential, with provision of safe walking routes. CCTV and alarm points may also be required in external areas.

Swipe card systems are often used for doors instead of keys, which are expensive to replace when lost. Where there are sufficient number of residents there may be a staffed reception. Where this is not possible entry phones may be provided, with handsets in each study bedroom. Provide spy holes in study bedroom doors.

The design should also avoid features that encourage anti-social or dangerous behaviour: skate-boarding and climbing are common problems.

10 CONFERENCE USE

10.1 Additional needs

Many universities use student residences for conferences or holiday lets during the vacations and this has implications for design:

- The Fire Risk Assessment should address the proposed conference use.
- Rooms with en-suite bathrooms will be preferred.
- A higher standard of fittings and finishes may be required.
- Central linen stores may be required with easy access to study bedrooms.
- A term-time store for equipment that is provided to conference guests, such as kettles.
- Lockable storage may be provided for students' possessions and a safe for conference guests.
- Reception area, seminar rooms or other facilities to support conference activities.

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24 Industrial facilities

Jolyon Drury and Ian Brebner

The Jolyon Drury Consultancy advises on the design of production, distribution and storage systems and facilities. Ian Brebner is a partner of architecture practice Austin-Smith:Lord

KEY POINTS:
- *Constant change is endemic*
- *Increasing demand for small units and starter accommodation*

Contents
1 Introduction
2 Classification of production building types
3 Adaptability
4 Working methods
5 Machine sizes
6 Outline specification of a typical multi-strategy factory
7 Non-production accommodation
8 Bibliography

1 INTRODUCTION

1.1 Industrial facilities

An industrial facilty is a building enclosure and site within which goods are manufactured, assembled, stored or shipped/transshipped. Manufacturing processes continually develop, improve and evolve, but have generally been classified as either:

1 A transformation of elemental raw materials into a finished product or material that requires further manufacturing to become a finished product (commonly referred to as Heavy Industry). These are typified by traditional industries, such as steel manufacture, chemical manufacture, refining plants, etc.
2 An assembly process which integrates finished components into a finished product (commonly referred to as Light or Medium Industry). These are typified by automotive manufacturing, white goods manufacturing, electronics manufacturing, etc.

A third category of Technology manufacturing is rapidly evolving from the development of artificial/assisted intelligence, communications and biotechnology. The intellectual capital required to sustain this third category is a step change from the more traditional light and heavy industries that have previously predominated in the developed economies. Developed economies are changing their manufacturing base to this third category as a means of generating added value to sustain the increasing income aspiration of their workforce and maintaining their global trading position. This category demands greater integration of further education and research with the actual manufacturing activity. It is generally recognised that clustering together research and manufacturing facilities produces a catalytic effect where the total output (physical or intellectual) can exceed the sum of the parts – even though they may be separate enterprises. This has significant implications on the nature of the enclosure which accommodates these new industrial facilities.

1.2 History of industrial facilities

The history of industrial development has been one of the continual changes following improvements in production equipment, management and techniques. The key stages of the development of manufacturing which have influenced the design and nature of industrial building have been:

1 Craft-based manufacture, where individuals or small groups of individuals created the finished product from elemental raw materials. The buildings which facilitated this were in the main, relatively small-scale workshops, or indeed, individuals' dwellings. An industrial building typology was not generally identifiable.
2 Power-assisted manufacture, where production machines were powered rather than manually operated. Significantly, the use of power increased the capacity of the machine and allowed the subdivision of the production process, decreasing reliance on the skill of the individual. This, in turn, facilitated a greater concentration of manufacturing capacity in a single location. Early power systems relied on extended shaft drives with belt-driven power transfer to individual machines. Belt drives had a finite limit on their length and operated at right angles to the drive shaft. The buildings which accommodated these power systems were characterised by their distinctive long thin shape on multiple floors. The first distinctive industrial (factory) building typology had evolved, amongst the earliest examples being Cromford Mill at Belper in Derbyshire by Richard Arkwright, 1771.
3 The assembly line. The development of compact individual electrical, fluid- or air-driven 'engines' released the production machine from the constraint of being tied to a central power engine. These new machines had relatively unlimited capacity and power. Together, these factors allowed machines to be located to match the assembly sequence needed to produce the final product. The assembly evolved. The buildings which accommodated this new form of mass production were typified by being single storey, comparatively large with clear internal spans to provide the flexibility to reconfiguration of the assembly line to suit changes to the product in a more rapidly evolving marketplace. The industrial building typology evolved into large enclosures, single storey with large internal spans.

2 CLASSIFICATION OF PRODUCTION BUILDING TYPES

Factories can be broadly categorised as bespoke or generic.

2.1 Bespoke

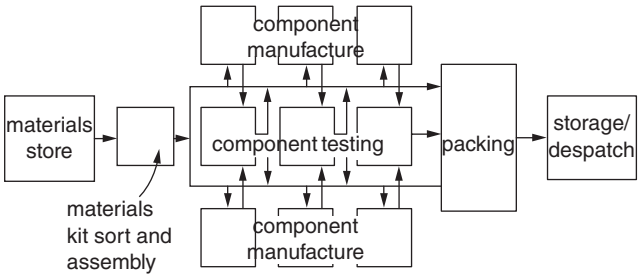
These include:

- high-precision work in controlled conditions (Figures 24.1–24.3);
- highly tailored to a unique or very specialised process;
- primary manufacturing sites which double as headquarters or 'flagship' manufacturing sites.

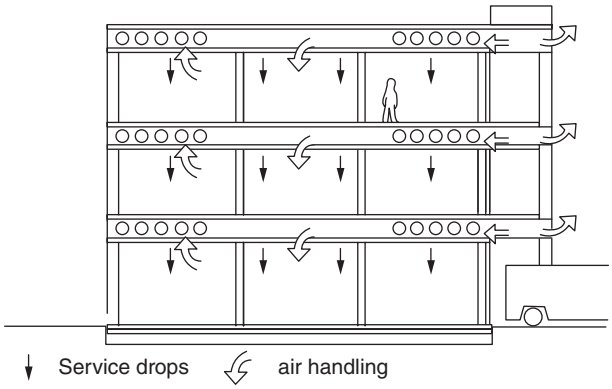
Design will depend on circumstances, but will tend to approximate to laboratory or office type design conforming to Planning B1 classification.

2.2 Medium industries

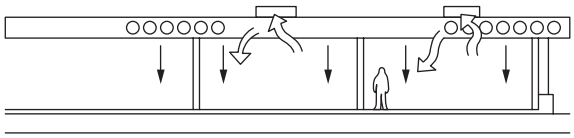
The greatest need for careful and thoughtful design is in this field. These industries can be subdivided into:



24.1 *Typical process flow diagram for light production and assembly such as small electronic components' manufacture, and similar high-technology processes. 'Kit sort' refers to the making up of kits of components for assemblers*



24.2 *Section through typical factories for light, high-technology production; multi-storey construction, as new or conversion of existing building: could be flatted units*



24.3 *Light production and assembly: single storey for small-scale and high-technology assembly. High degree of service freedom in roof zone*

- Light – medium small-scale engineering and assembly, clothing factories, paint shops, similar to Figure 24.4.
- General – medium batch production of components for other factories, medium-sized printing, Figures 24.5 and 24.6.
- Heavy – medium industries requiring intensive use of buildings and services as in mass production, Figures 24.7 and 24.8.

2.3 Heavy industries

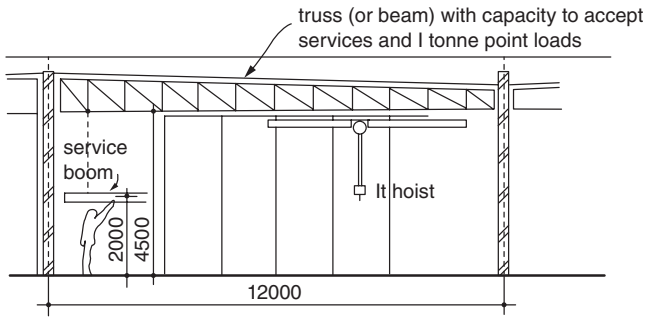
Industries such as steel-making and shipbuilding require spaces (not necessarily enclosed) designed around the work or the mechanical plant (Figure 24.9). Traditionally, it is difficult to build adaptable structures (Figure 24.10), but modern handling techniques enable 'loose fit' buildings to be designed (Figure 24.11).

3 ADAPTABILITY

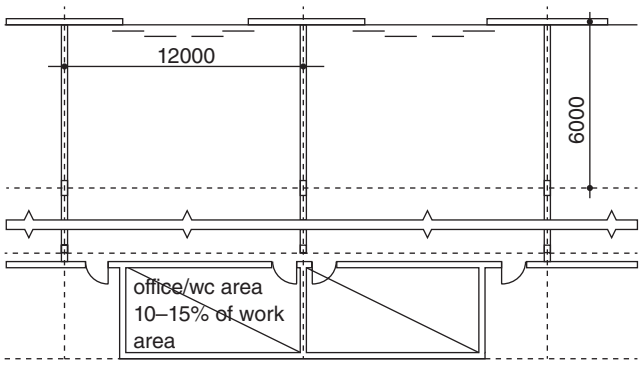
3.1 Design for change

An industrial facility is designed to either:

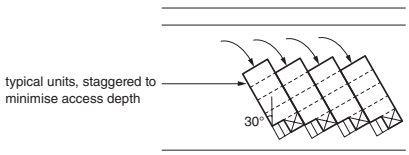
- 'institutional' standards, where the configuration of the building is geared to the requirements of the financial institutions who fund



a *Section through unit*

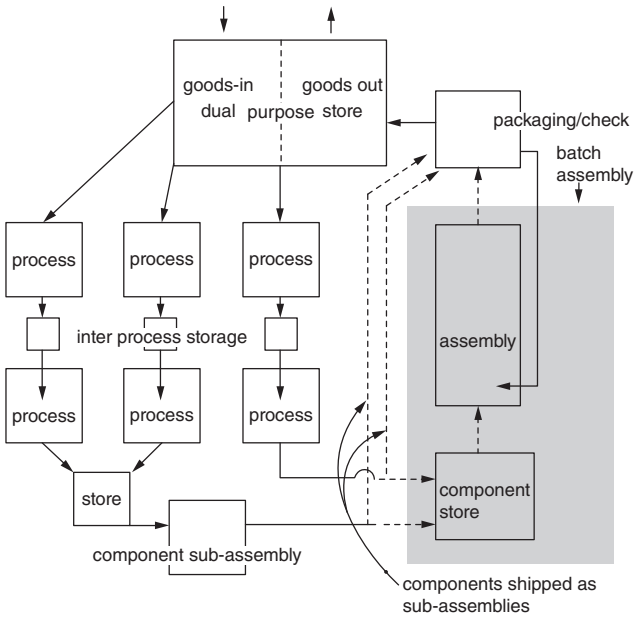


b *Part plan*



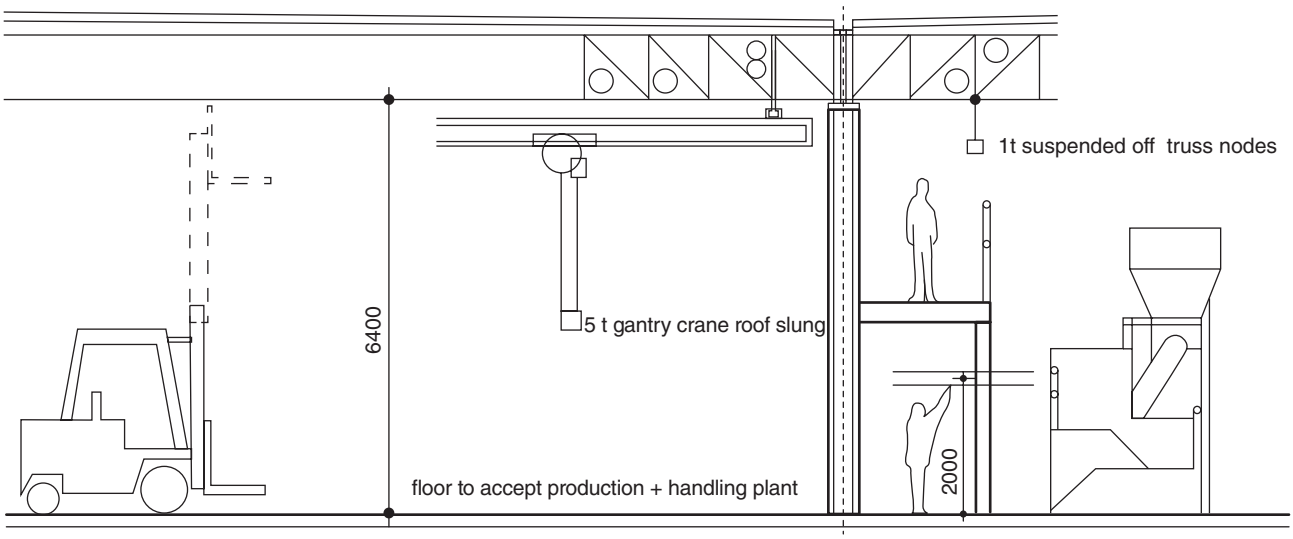
c *Units staggered in plan to reduce site depth required*

24.4 *Typical 'nursery' for light production and assembly, low technology, may be built speculatively*

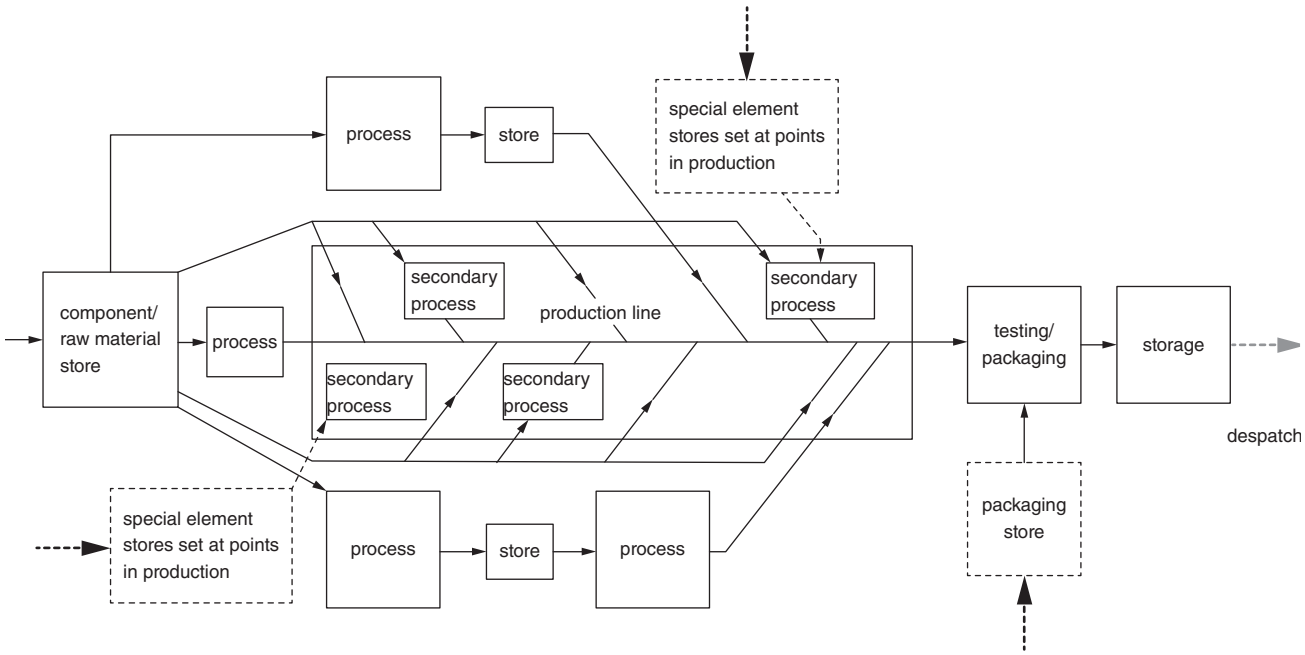


24.5 *Process flow diagram for batch production and assembly. Sometimes involves the assembly and shipping out of complete sub-assemblies, more commonly the production and dispatch of batches of discrete components*

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24.6 *Section through typical purpose-built batch production building. The spans, typically 18 × 12 m and trussed roof construction are selected for cheap and rapid adaptation to a variety of uses. Floor loading 25 kN/m²*

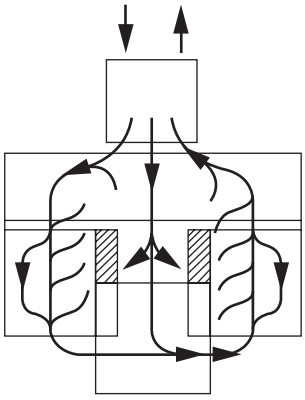


24.7 *Process flow diagram for mass production and assembly. This applies to high-volume line assembly as in the motor industry, with some components being built into sub-assemblies before final assembly on the main line*

the development. These requirements manifest themselves in a very flexible building which can be adapted to other industrial process or distribution uses if the initial occupier vacates the building. Typically, the buildings are regular in shape (optimally around 2:1 to 3:1 ratio of length to width) with internal height related to the floor area (typically, 6 m clear to underside of structural obstructions for floor areas up to 2500 m² and up to 12 m clear to underside of structural obstructions for floor areas of 10,000 m² and above). Distribution facilities would normally start at a height of 12 m and rise to 18 m where automated 'picking' equipment is intended.

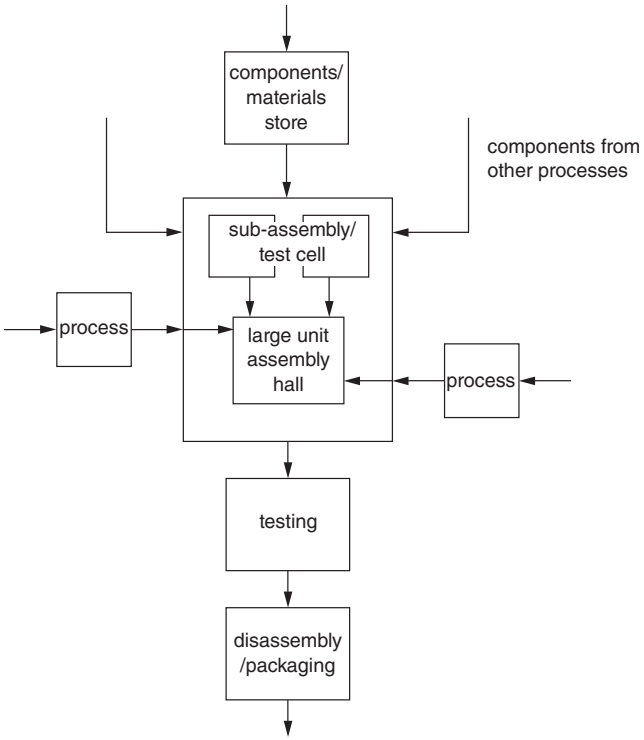
It is desirable to have the maximum clear internal spans. The most economic form of frame is the portal which can economically span up to 36 m and can be duplicated to increase the width of the building as required. The most economic primary grid spacing is between 6 and 7.2 m.

As proportion of the total floor area, the total of office and welfare accommodation will typically range from 10 per cent in total

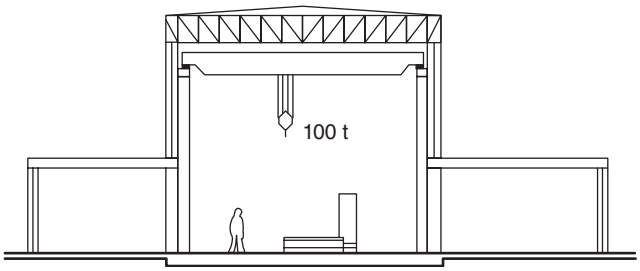


24.8 *Materials flow for mass production does not have to impose a predominantly linear building form. Group assembly 'cells' may feed onto a circulatory route, allowing personnel and services to be grouped into specifically equipped zones*

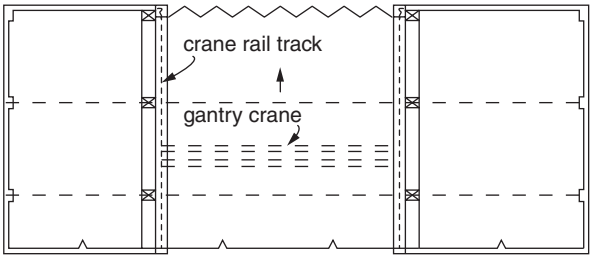
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24.9 *Process flow diagram for typical heavy engineering. The workpiece is the centre to which sub-assemblies are routed. It is likely to be disassembled for shipment*



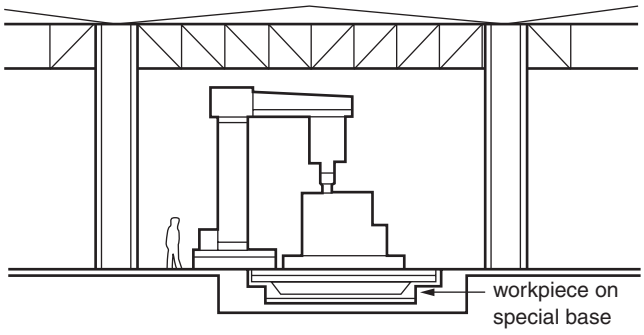
24.10a *Section and*



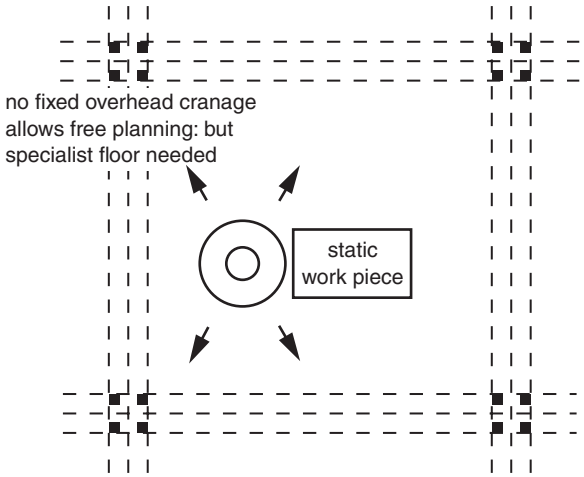
24.10b *Part plan of traditional type. Heavy-duty gantry cranes move the workpiece to the appropriate machine tools and assembly areas*

floor areas of 1000 m^2 to 5 per cent in total floor areas of 10 000 m^2 and more.

Recognising the needs of the occupier who is likely to require smaller floor areas, around 1000 m^2, the provision of dock levellers is much reduced in comparison with larger buildings of, say, 10 000 m^2, where as many as 6–8 may be desirable.



24.11c *Section and*



24.11d *Part plan of recently developed workshop where large workpieces remain static, being built up on special bases that are likely to be employed for transport and installation. Machine tools and components are brought to the workpiece, air-cushion techniques are widely used*

- Bespoke industrial facilities are usually required where the process is so unique that it is unable to fit within the simple flexible layout of the 'institutional' building, cannot be contained in a single building or does not require full enclosure. In these circumstances, the building enclosure effectively becomes part of the process. This will limit the future flexibility of the building, in the extreme, rendering it unusable for anything but its intended use. Bespoke buildings are usually associated with capital intensive processes where the process equipment is relatively immovable – in contrast to the type of process equipment that can be readily accommodated in the 'institutional' building. For the designer, a thorough understanding of the process requiring a bespoke solution can offer rich opportunity for expressive functional design.

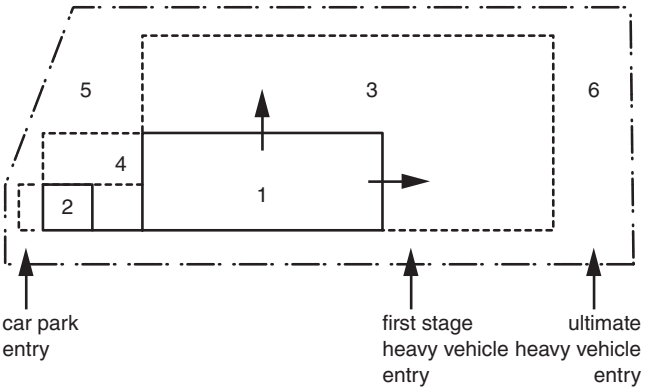
The evolving technology industries tend to conform well to the 'institutional' building model which offers greater flexibility for change in the format and type of process. The extreme example is Biotech or Biopharma production processes which are organised as multiple production cells within a large uniform enclosure, each cell is capable of being stripped out and replaced with a completely different process without disruption to the remaining operating cells.

There is a reducing requirement for the bespoke industrial facility, at a practical level and resulting from the means of funding of modern industrial facilities.

Adaptability must allow:

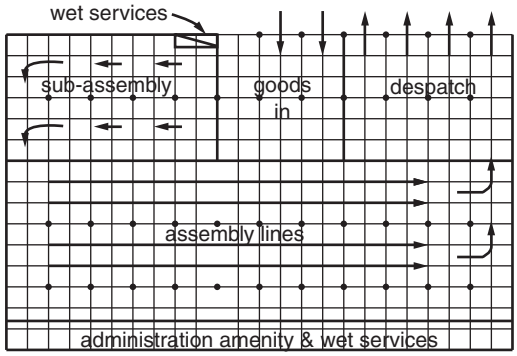
- change of process to avoid obsolescence;
- change of process and product following change of ownership.

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1 first stage factory
2 first stage office
3 factory expansion
4 various options for office expansion
5 car park
6 heavy vehicle area

24.12 *Small or medium-size factory development, with a free-standing office building. The uneven boundary increases the possibility of conflict when the factory and offices expand simultaneously, and restricts commensurate expansion of car parking*



24.14 *Mass production buildings have to accept changes in production technology. This plan shows a conventional line assembly that may be adapted to the form in 24.15*

Changes will normally only be within the broad groupings of building types given in Section 2.2.

3.2 Design for extension

Apart from alterations within the envelope, there may also be requirements for extension; and the design should anticipate this (Figures 24.12 and 24.13).

4 WORKING METHODS

4.1 Alternative methods

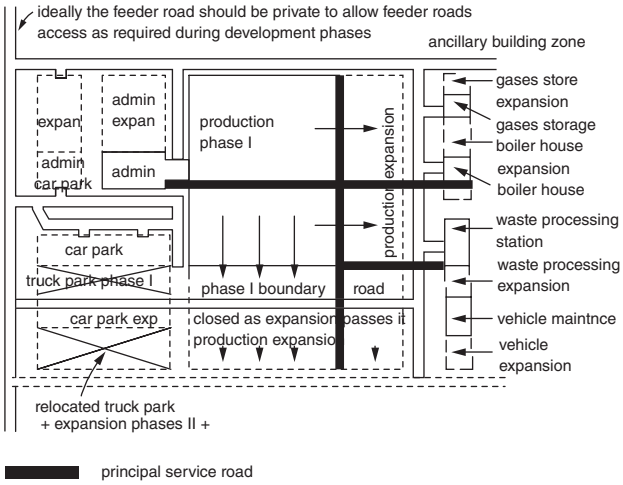
The alternative methods of work organisation are:

- linear assembly
- team technology.

While the latter is a more recent introduction, there is no indication that it will completely supplant the former. Consequently, production buildings must be able to accommodate either or even both in different areas (Figures 24.14 and 24.15).

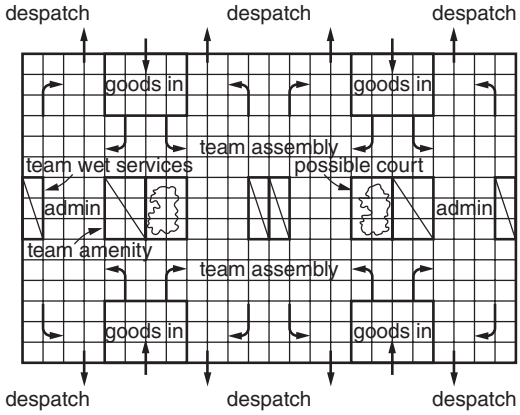
4.2 Linear assembly

In this method, machines are arranged along work-travel routes. At each station, components are added until the work has been completely assembled and finished. Supplies of components and materials are needed at each station; and waste must be removed.



24.13 *A large plant with segregated development zones:*

- *The factory and associated car and truck parking. When the factory expands the truck park becomes the expanded car park and a new truck park is constructed adjacent to dispatch*
- *The administration block and associated car parking, separated from manufacturing by landscaping*
- *The ancillary area, incorporating individual growth provision for each element within the zone boundary.*



24.15 *The factory can change to team assembly due to new product. Note localisation of amenity and wet service areas to identify with teams. Chance of opening courts adjacent to amenity areas, though these may change position as production demands*

4.3 Team technology

This appears to restore to the labour force a feeling of responsibility and achievement. The machines are arranged in groups, and all or a substantial part of the work is assembled within the group. There is a need for storage of materials and components. The main planning requirements are for unrestrictive space and strong floors to enable the machines to be relocated at will, with adaptable overhead services systems. Storage and assembly spaces should be interchangeable.

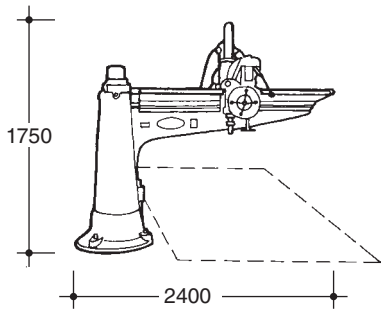
5 MACHINE SIZES

The sizes of typical machines for light and medium duty industries are shown in Figures 24.16–24.21. The majority of machine tools do not exceed 7.5 kN/m^2 in loading on the floor.

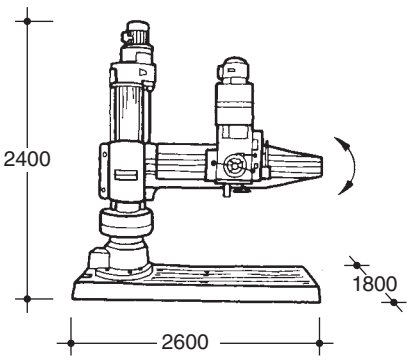
6 OUTLINE SPECIFICATION OF A TYPICAL MULTI-STRATEGY FACTORY

Table I provides an outline specification of a typical multi-strategy factory.

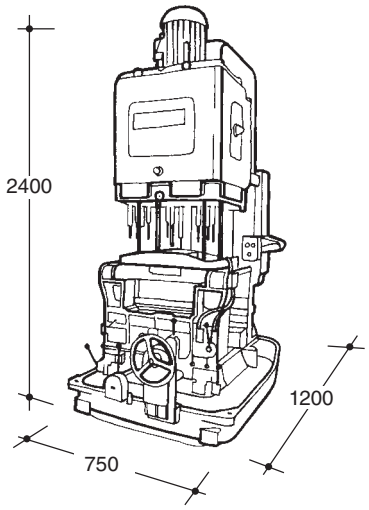
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a *Plate drill*

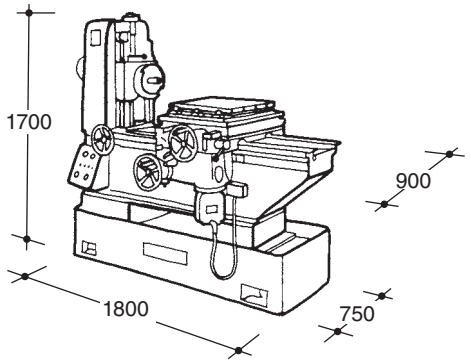


b *Radial drill*

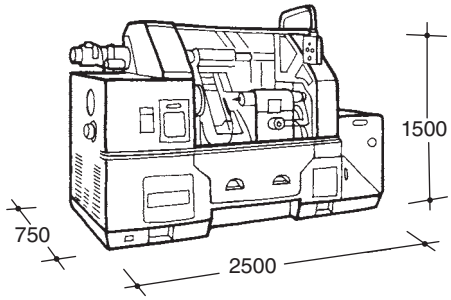


c *Adjustable multi-drill*

24.16 *Drilling machines*

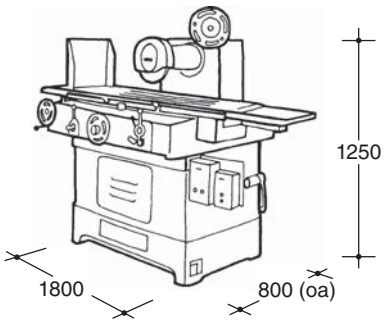


a *General purpose chuck lathe*

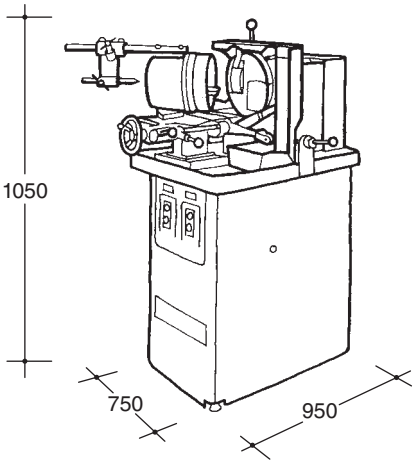


b *Hydraulic copying lathe*

24.17 *Lathes*



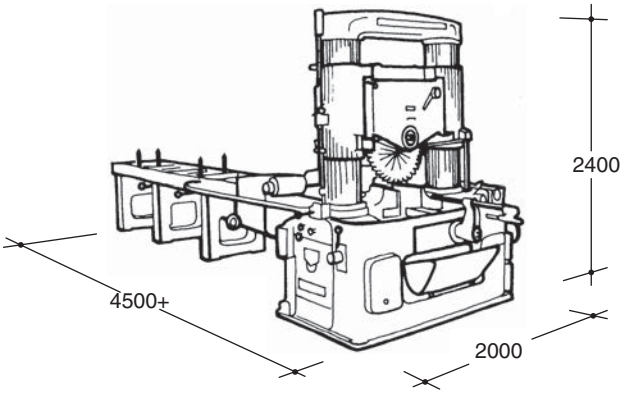
a *Surface grinder*



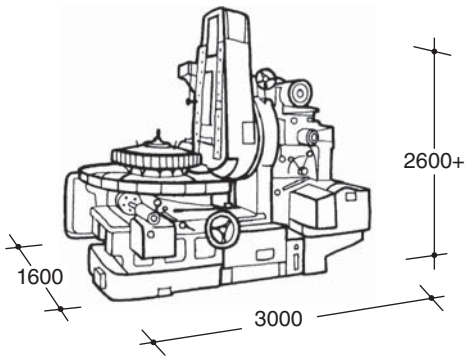
b *Twist drill grinding machine*

24.18 *Grinding machines*

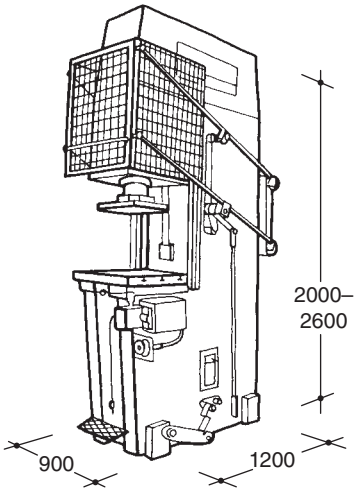
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24.19 *Cold sawing machine*



24.20 *Gear cutting machine*



24.21 *Hydraulic pedal press*

7 NON-PRODUCTION ACCOMMODATION

7.1 Offices

There is a tendency for administrative and production space to be interchangeable. Two types of offices will be required in close conjunction with the production space:

- Foreman's desk space in sight and proximity of work supervised. This is formed from easily demountable components to allow for rapid relocation. Sometimes to avoid floor obstructions this accommodation is raised to mezzanine levels where visibility is improved.
- Executive offices for the local administrative staff, or the company headquarters where these are not elsewhere. This type of accommodation is designed in accordance with Section 16, Offices, Shops and Railway Premises Act 1963, and will depend on the numbers to be accommodated. As a rough guide, allow 10–15 per cent of the production floor area, or 5 m^2 per person.

Table I Outline specification of a typical multi-strategy factory

Scope		
Type of industries for which appropriate	Buildings of this type are suitable for most manufacturing functions, excluding 'light', 'heavy' and 'process' industries.	
Size of project	Total area of production space can vary widely. Average size of all projects is 2500 m^2, so most are smaller. This specification is suitable for projects from about 1000 m^2 upwards.	
Type of project	40% of industrial projects are adaptations and extensions of existing premises. This specification sets out the general requirements of those projects, or parts of projects, free from special restraints.	
Criterion	**Performance specification**	**Design notes**
Requirements of the process		
Adaptability	Should be designed for general-purpose use and not around a particular process. General-purpose characteristics should be maintained wherever possible, e.g. in stores and production warehousing as well as in production space itself.	Building positioned on site leaving maximum possible room for extension, preferably in two directions. Single-storey building designed as a large open space. Standardised, mainly dry construction, easily extended or modified. Framework able to carry a variety of alternative roof and wall claddings, services and handling equipment. Those external walls not on or near site boundaries designed for easy demolition.
Plan shape	Probably not critical except where linear flow processes employed. Rectangular form maximises usable area, facilitates extension.	Rectangular plan form with ratio of long to short sides between 1:1 (minimises internal travel distances where no particular traffic routes are dictated by process) and say, 3:1 (average 2:1).
Physical environment	Process requirements will not usually be critical: workplace environment and energy efficiency are very important.	See under 'Environmental requirements of labour force'. In general, the production process will not require special dust-free conditions, nor will it create a dusty or especially dirty atmosphere. If there are toxic or corrosive hazards within the general production space, these should be isolated by local compartmentation and extraction equipment. High standards of cleanliness (e.g. very exact avoidance of foreign matter) or hygiene (e.g. avoidance of bacterial contamination) for some high-technology factories.
Structural dimensions	Exact plan dimensions rarely critical, except where flow processes employed. Aim should be to optimise convenience for production layouts provided by open space, e.g. the convenience of stanchions for locating small equipment, switches, etc. balanced against the potential adaptability: freedom for service drops and the location of equipment against the cost of greater spans and the loss of overhead craneage.	Span 18 m; bay spacing 12 m or even 18 m (which would permit production line to be turned at right angles if needed). These are proven dimensions in the USA but are greater than those found in many British factory buildings and (excluding 18 m square bays) are unlikely to increase costs significantly over smaller spans.

(continued)

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Table I (continued)

Criterion	Performance specification	Design notes
	Internal clear height probably most critical dimension, for once built can only be modified with difficulty. Height needed for high stacking, overhead equipment, possibly facility to install mezzanines (for works offices, lavatories, control gear, extension of production space, etc.), overhead conveyors, etc. Space for services needed above clear height level.	Internal clear height minimum 6 m. Main vehicle entrance doors (ground level loading) 5 m. For intensive manufacture, high stacking, overhead hoists or mezzanine floors a minimum height of 7.5 m is recommended.
Structural loadings	Within economic restraints, design for heaviest likely loads.	Ideally point loads of 36 kN, but 25 kN sufficient for general-purpose use for buildings less than 6 m high to eaves. For very dense storage, typically mini-load automated component stores, 30 kN/m^2 distributed loading.
Provision for services	Facility to take any production service (water, steam, gas, electrical power, etc.) to any point within production area with minimum disturbance to building, and therefore production.	Production and building services carried in roof space above level indicated by 'clear height', with vertical droppers as required to machine positions. This eliminates overhead craneage, but allows monorail hoists and conveyors. Roof structure designed appropriately. Drainage used to be below floor level, although alternative more costly but flexible arrangements are preferable. A permanent grid of drainage runs beneath the floor (a minimum of, say, one run in the middle of each 18 m span) will minimise disturbance.
Provision for movement of materials and equipment	It should be possible for the production engineer to use the type of material-handling equipment best suited to the product and production methods. Use of fork-lift trucks or similar wheeled materials-handling equipment will be general; overhead conveyors may be used. Cranes more usual in engineering than other industries. Heaviest floor loading is likely to result from wheels of fork-lift trucks (36 kN) and point loads from stacked storage cages and from pallet racking.	Separate foundations will be provided for any special or heavy equipment, especially that which vibrates. Wherever possible, the upper surface of such foundations will be at or below finished floor level. Much equipment is now 'stuck-down' to the floor. Conventionally, an RC floor slab with integral granolithic finish is used, although deterioration of the floor finish is a common problem in industrial buildings. Durable floors can be obtained, but they require a suitable base, good workmanship and close supervision. Particular finishes may be needed to resist attack from acids or oils used in certain processes.
Support for production loads	There are two opposed points of view about supports for such production loads as conveyors, local hoists and other overhead equipment. One is that since production loads cannot be predetermined, they should not be allowed to bear on the building structure, and should be loads carried either on the plant or on a separate structure, as and when this becomes necessary. This can lead to substructures inhibiting floor area and future flexibility. Although initially more expensive the preferred alternative is to design the roof structure to carry a general minimum of local loads, and to provide the facility to suspend conveyors, etc. at will.	Design assumptions might be that bottom boom of trusses (assumed spaced at 3–3.6 m centres) carry uniformly distributed load of 8 kN/m run, and a point load of 10 kN on any panel point at, say, 3 m centres. Structural supports for heavier loads are then provided on an ad hoc basis by the production engineer.
Environmental requirements of the labour force		
Visual environment	Practically all visual tasks will be met by illumination levels within the range of 200–750 lux; illumination in the middle of the range will be most common. Limiting values of glare index (as IES Code) are likely to be within 22–28. Colour schemes should be designed both to assist the distribution of light and to minimise fatigue. Natural light design levels: warehouse, packing, large assembly, heavy forging, casting, saw mills, Daylight Factor 2% (say 10–15% floor area) 300–500 lux: Bench and machine work, fine casting, motor repair, general office work, average general purpose lighting, Daylight Factor 4–5% (say 12–15% floor area) 500 lux: Drawing work, medium assembly, weaving, small typesetting, Daylight Factor 6% (say, 15–20% floor area) 500–750 lux: Small inspection and assembly, small bench and machine work, 1000 lux+Daylight Factor 10%.	Either daylight or 'windowless' design. If daylight design, 'north light' is a useful compromise between even light level and energy conservation. View windows in external walls. Fluorescent lighting installation arranged in regular pattern over whole production floor to give 300–500 lux consistent illumination level E_{min}/E_{max} must be at least 0.7 wired in three phases to reduce flicker, and in trunking for simple replacement. Point luminaires may be used in areas of higher headroom, or to provide a high and even intensity. Reflecting surfaces decorated with colours of high reflectivity (e.g. underside of roofs: Munsell value 9), but care that glare from surfaces does not disturb machine operators, e.g. fork-lift truck drivers. For 10% and over use PSALI (permanent supplementary artificial lighting installation). For a general purpose building and for resale the design level should not be below a Daylight Factor of 5%. The method of achieving this must be checked against insulation regulations.
Thermal environment	Optimum values of temperature, air movement, etc. will depend largely upon nature of work – whether, for example, it is sedentary or active. Main environmental problem will be to avoid uncomfortable heat in summer. Minimum temperatures: heavy work 10º, light work 13ºC, sedentary 16ºC.	For most light industry plant should be able to provide air temperature of 18–21ºC. Mechanical ventilation, at least in factories of average or greater size. Air-change rate (fresh air supply) minimum 5 l/s/person
Acoustic environment	Production processes highly variable in noise output. Control by encapsulating machinery and by using interspersed storage stacks.	Thermal insulation material can give a measure of acoustic control, particularly in providing absorption.
Fire protection	Some industries are regarded as having 'abnormal' fire risk because of the process or materials used; building design will be affected by requirements for additional compartmentation. Generally, fire hazard is classed as 'moderate' to 'low'. The general requirement of fire safety, of a maximum division of the production area into self-contained fire-resisting compartments, is at variance with the general production need for open space, and should be carefully considered. The requirements of the occupiers' insurers may be more onerous than the requirements of Building Control. The most common standards to refer to are FM Global and LPCB – Loss Prevention Certification Board.	Fire division walls may be required to obtain acceptable insurance rate. Areas will depend on process, etc. 'Fire curtains' in roof space. Fire vents in roof surface of total area not less than 1% of floor area. Avoidance of combustible materials in sheeted claddings. Sprinklers are also being increasingly required by insurance companies, both over the process and in the roof depth to protect services.

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Table I (continued)

Criterion	Performance specification	Design notes
Explosion hazard	Not normally considered critical, but can be accommodated with blow-out panels, or placing part of process outside the main building.	
Building economics	The cost of using a factory building is an important element in the long-term cost of manufacturing. Nevertheless, without adequate justification, few managements are prepared to pay more than the minimum to obtain their essential specification, one reason being that investment in plant, equipment, perhaps labour is likely to show a higher return than investment in buildings (see Sections 3.1 and 3.2).	A 'basic' specification: concrete floor slab; exposed structural framework and services; simple finishes, such as painted steelwork, untreated concrete, fairfaced brickwork; self-finished insulating materials forming roof lining.

7.2 Lavatories

For sanitary accommodation see Chapter 3. A first aid facility is normally provided in conjunction with this.

7.3 Canteens

Staff are not allowed to eat in dirty or dusty surroundings. If the process demands a clean environment the reverse may apply, and the importation of food into the working area may need to be discouraged. Canteens are therefore nearly always now provided. See Chapter 34 for details of design.

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25 Industrial storage buildings

Jolyon Drury, updated with advice from Stephen George & partners

CI/SFB 284

The Jolyon Drury Consultancy advises on the design of production, distribution and storage systems and facilities.

KEY POINTS:

- *Modern warehouses need the height to use mechanical aids at maximum efficiency*
- *Scales have increased massively; a 'big shed' now is ten times the size of the largest building only 20 years ago*

Contents

1 Introduction
2 Identification of warehouse and storage types
3 Preliminary decisions
4 Height, area and type of handling system
5 Storage method
6 Disposition of the racking
7 Relationship of storage method, mechanical handling equipment and building height
8 Outline specification
9 Security
10 Handling equipment
11 Fire precautions
12 Bibliography

1 INTRODUCTION

Few industrial storage buildings are designed to make a profit (steel stockholders and cash and carry stores are exceptions); the majority perform the function of a valve or pipeline, limiting the supply of a product to suit demand, to stabilise prices and allow steady and economic manufacture within fluctuating market conditions. Industrial storage is therefore a service at a cost that must be minimised.

The payback period most frequently chosen for such a building is 25 years. During that time, it is likely that the storage method will need to change at least three times, and that the type of goods handled will change even more frequently. Flexibility for expansion and manner of use are therefore important design considerations.

Large distribution buildings are now even larger than they have ever been. Twenty-five years ago, a large industrial 'shed' contained approximately 100 000 ft^2 of space. Industrial storage buildings are now being constructed 10 times that size.

At the time of writing, industrial storage buildings cost approximately £32 per square foot to build (£336 per square metre). This price regime and changes to building regulations (Part L in particular) may well make the purchase and reinvention (through recladding, etc.) of an existing building unviable, i.e. it would be cost effective to construct a new building.

2 IDENTIFICATION OF WAREHOUSE AND STORAGE TYPES

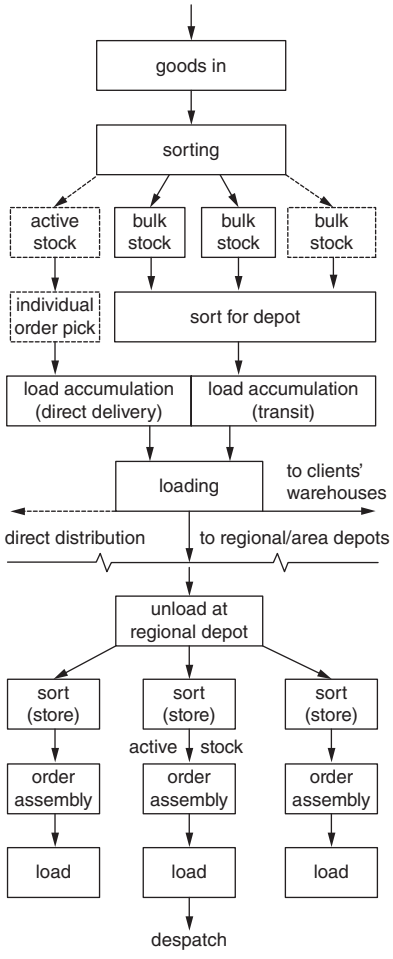
The three main types are:

- Transit between manufacture and the market, Figure 25.1.
- Distribution: similar to a transit unit, but accepts a wide variety of goods from a number of manufacturers, sorts them into orders and distributes them to a number of outlets, Figure 25.2. A components warehouse for a factory performs a similar function.
- Repository: a warehouse used for stockholding, either as a service (e.g. a furniture repository) or within a company (e.g. a cold store), Figure 25.3.

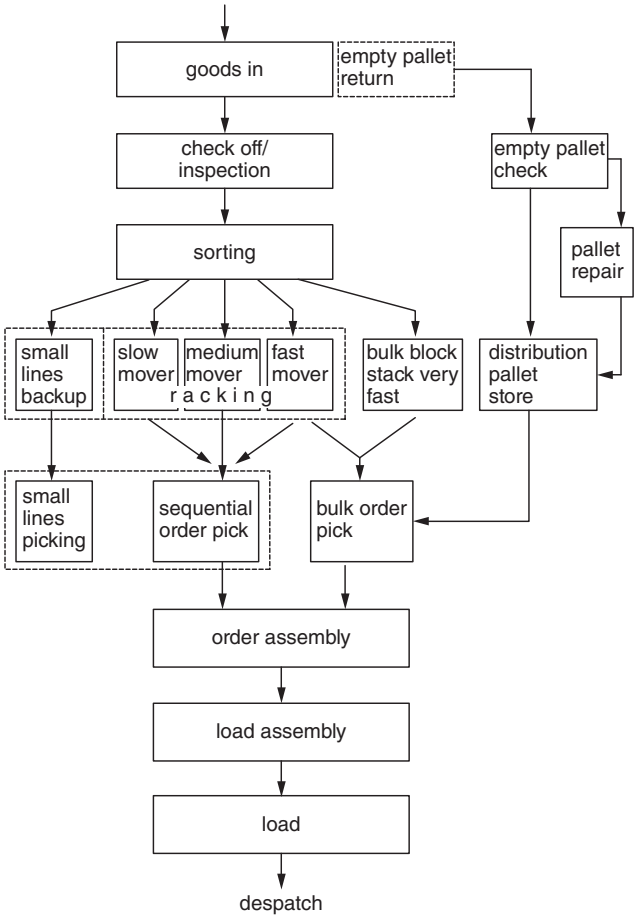
3 PRELIMINARY DECISIONS

The initial decision about what type of building is required will involve a choice between these three types, dependent on the client organisation's needs. Such a study is generally undertaken in cooperation with a specialist consultant. Other factors to be considered at the pre-design stage are:

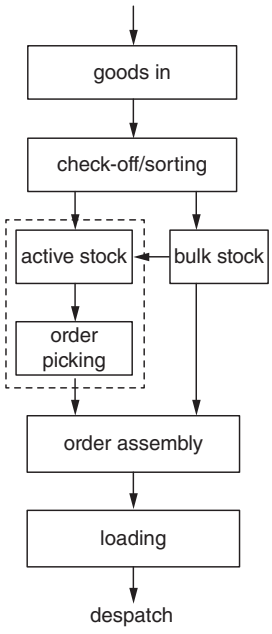
1 The orientation of the loading bays and the heavy vehicle marshalling areas. Future expansion must be taken into account.
2 The orientation of the goods sorting and load accumulation areas which must be related to the disposition of the storage area, i.e. block stacks or racking and loading bays.



25.1 *Relationships in warehouse for transit between manufacturer and market*



25.2 *Relationships in distribution warehouse*



25.3 *Relationships in a stockholding warehouse. The bulk stock area is dominant*

3 Will the required bulk of the building be acceptable in terms of planning consent?
4 Are the existing roads suitable to meet increased demand?
5 Is there public transport for operatives?
6 Are there night operating restrictions which will entail special features to muffle night noise? Can this be catered for by any design measures/configurations?

4 HEIGHT, AREA AND TYPE OF HANDLING SYSTEM

The most economical way of gaining volume for storage is to use height – Table I; this affects the choice of the handling system to be employed. Typical structures are shown in Figure 25.4. Consider also:

- The type of unit load to be handled and the physical characteristic of the goods – crushability, durability, the type of unit loads that will be assembled after sorting (Table II).
- The speed of turnover. This will determine what storage method is the most efficient.
- The position of the construction and movement joints within a concrete floor. Generally, columns should be hidden within the racking, as should the floor joints. Access widths should suit the selected loading mechanisms and racking should not obscure exits. In a portal frame construction, columns are typically set at 32.2 m centres. A grid of 8.2 m can accommodate two dock levellers.

Table I Typical internal clear heights for storage areas

Minimum clear internal height* (m)	Type of storage
5–5.5	Minimum-cost low-rise block stacking warehouse. Suitable for light industrial factory use
7.5	Minimum for any industrial storage building combining racking and block stacking
9+	When narrow-aisle trucks are used
15–30	Fully automatic, computer-controlled warehouses and stacker cranes are to be used

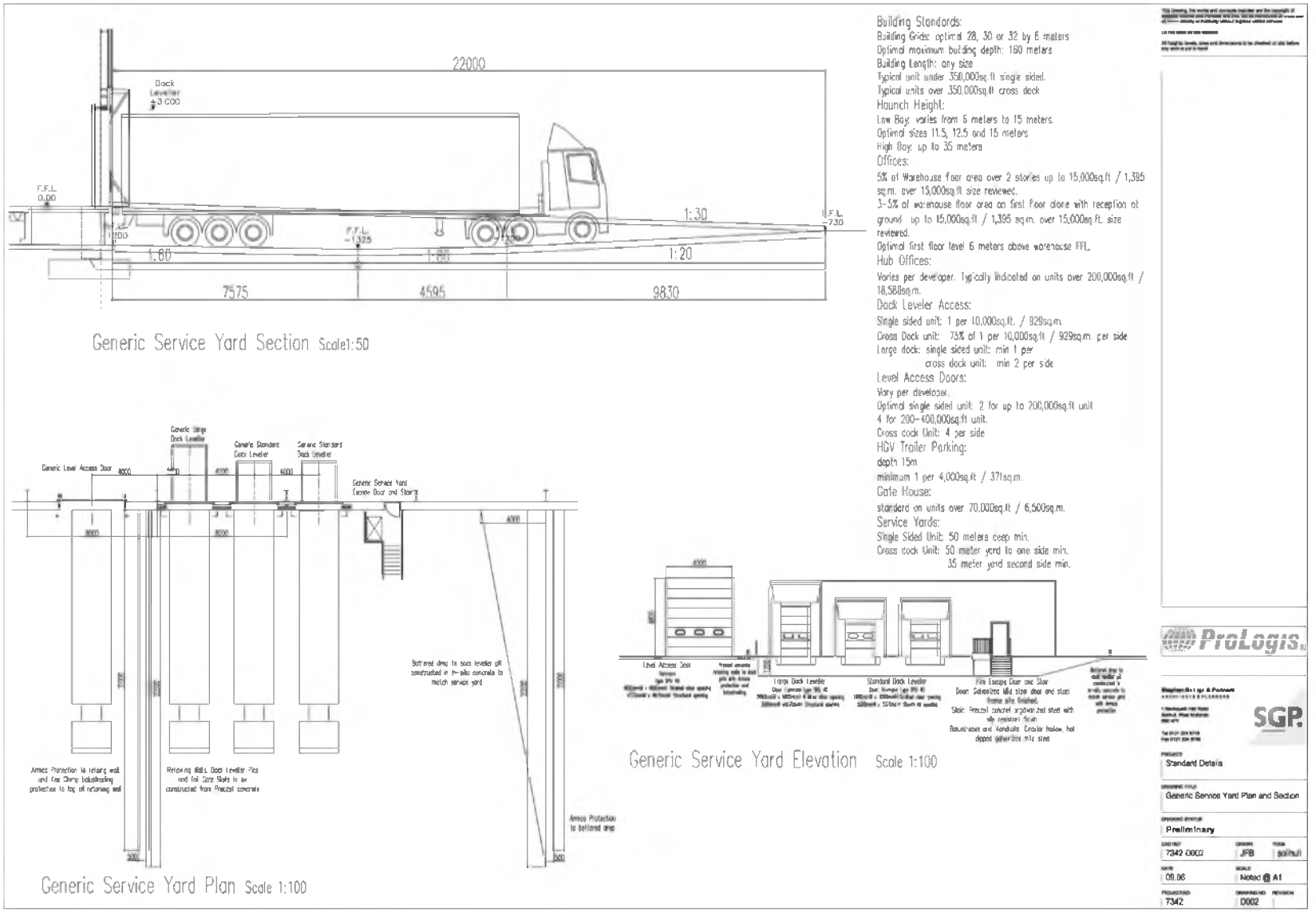
*Clearance for structural members, sprinklers, lighting must be added to obtain overall height of buildings

Table II Classification of materials for handling and storage as unit loads

Description	Examples	Storage method
Materials not strong enough to withstand crushing – not suitable as integral unit load	Automobile components, made-up textiles, electrical appliance components, manufacturing chemists' sundries, light engineering products, glassware	On pallet in rack
Materials strong enough to withstand crushing – suitable for unit loads	Casks and drums, sawn and machined timber, sheet materials	On pallet, or self-palletised and block stowed
Irregular-shaped materials, strong in themselves suitably packed into unit loads	Goods in cases, creates or cartons	On post pallets and stacked, on pallets in rack or self palletised
Bagged materials which form a flat surface under load	Grain, powder and similar	On pallet and block stowed
Bagged materials which do not form a flat surface under load or will not take pressure	Forgings, moulded or machined parts, nuts and bolts	On pallet in rack
Large irregular loose materials	Moulded plastics; sheet metal pressings	On post pallets and stacked
Small irregular loose materials	Machined and moulded parts, pressings, forgings	In cage pallets and stacked
Materials hot from production process	Castings and forgings	On post pallets and stacked
Materials too long to be handled other than by side loader or boom	Steel sections, tubes, timber	Horizontally in tube or bar racks
Materials strong enough to withstand crushing but subject to damage	Partly machined automotive parts, painted finished materials, books	Steel box pallets with special partitions
Perishable goods	Frozen meat, vegetables, drink	Cartons, soft packs pallets, box pallets, etc.

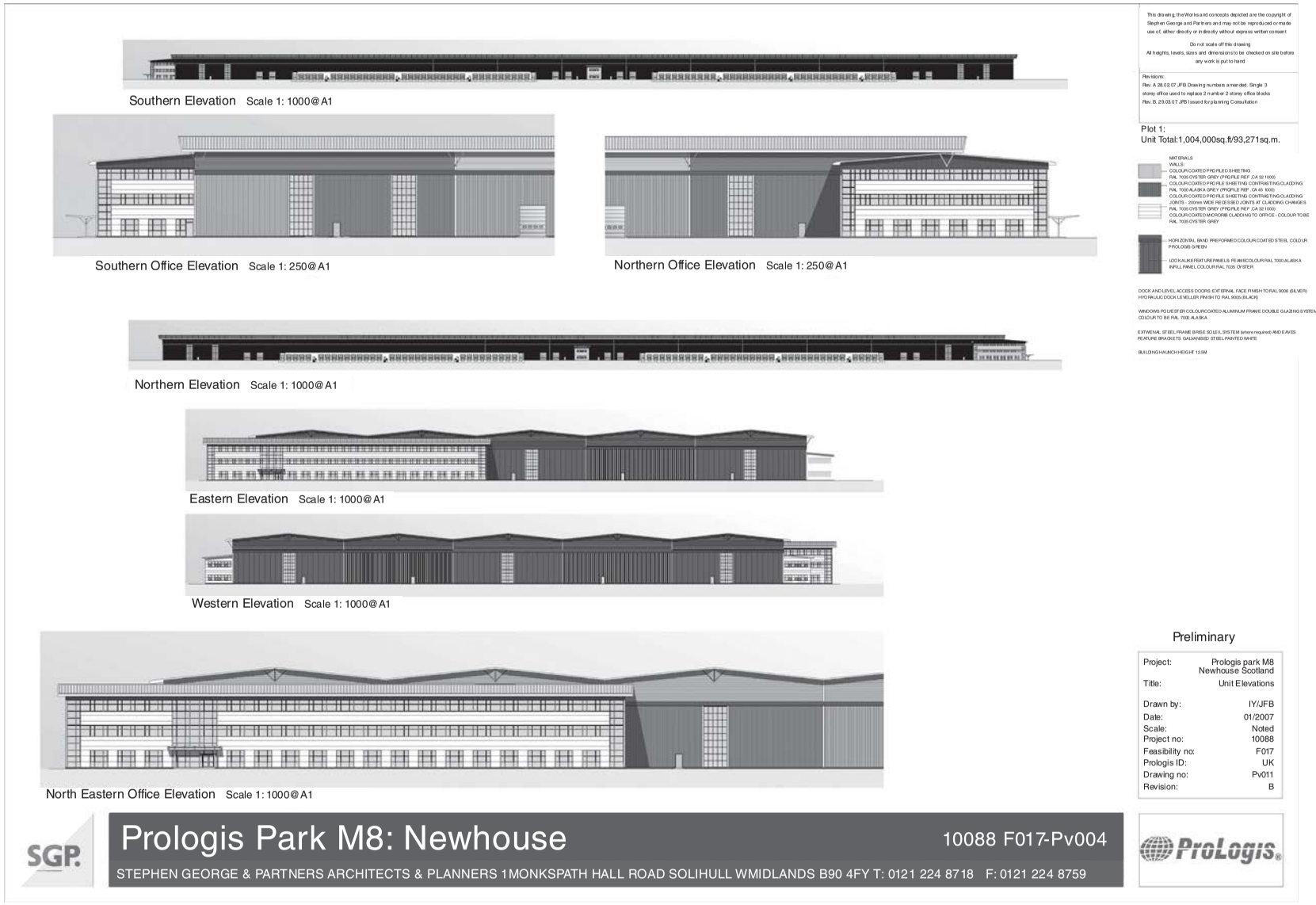
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a *Generic service yard section and elevation*

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b *Modern 'big box' warehousing – 520 × 170 m industrial storage unit for ProLogis by Stephen George & Partners. The unit contains 78 loading bays on its northern and southern sides, with 5000 m² of office space*

25.4 *Examples of typical structures*

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Table III Mechanical handling

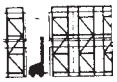
	Block stacking	Post pallets	Drive-in racking	Beam pallet racking	Gravity live storage	Powered mobile racking
						
Cubic space utilisation (%)	100	90	65	35–50	80	80
Effective use of installation capacity (%)	75	75	75	100	70	100
Accessibility of unit loads (%)	10	10	30	100	30	100
Order picking (%)	Poor	30	30	100	30	100
Speed of throughput	Fastest	Good	Poor	Good	Good	Quite good
Load crushing	Bad	Nil	Nil	Nil	Some	Nil
Stability of load	Poor	Fair	Good	Good	Fair	Good
Ease of relocation	Not applicable	Not applicable	Fair	Good	Difficult	Difficult
Speed of installation	Not applicable	Not applicable	Good	Fastest	Fair	Slowest
Rotation of stock	Poor	Poor	Poor	Good	Excellent	Good

Table IV Manual handling

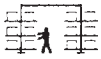
	Long-span Shelving	Tiered shelving	Raised storage area	Cantilever shelving	Lightweight live storage	Fir tree racking
						
Cubic space utilisation (%)	45	45	80	50	65	25
Effective use in installation capacity (%)	95	95	50	100	70	70
Accessibility of goods	Good	Good	Poor	Good	Excellent	Good
Ease of relocation	Good	Fair	Difficult	Fair	Very difficult	Best
Load range (kN/m^2)	2–9.5	2–9.5	2.8–11	2–4.7	Up to 0.2 kN/m run of track	2.6–4.4 kN/arm
Speed of picking	Good	Fair	Poor	Good	Very good	Good
Speed of installation	Very good	Good	Fair	Fair	Slowest	Fastest
Rotation of stock	Very good	Good	Poor	Very good	Excellent	Very good

Table V Load mounting

Load mounting	Type of load								
	Heavy unstable load	Flat cards/ sheets	Sacked/ bagged loads	Small unit loads	Drums Reels Barrels	Coils	Casks	Bales	Textile Raw materials
									
Special cradle with/without pallet	*								
Standard pallet		*	*	*	*	*	*	*	
Flat board pallet + decking supports		*	*		*	*			
Direct mounting on timber panels		*	*	*		*	*	*	*
Drum supports					*				
Post pallets cage/bin			*	*		*	*		
Coil supports					*	*			*
Skips/skeds With skids							*		

5 STORAGE METHOD

Storage methods (see Tables III–V) include:

1 Very fast throughput involving a limited number of products: block stacking, Figure 25.5, rather than racking. First in, first out, or first in, last out configuration, depending on the shelf life of the goods.
2 A wider variety of goods, but still with fast turnover: drive-in racking, Figure 25.6, or 'live' (roll-through) storage, Figure 25.7. Pallets are placed into racking up to four positions deep, with the pallets' edges resting on runners attached to the rack's uprights. First in, last out. Live racking involves inclined storage lanes. For heavy pallets and shock-sensitive goods, braking and separating equipment can be incorporated.
3 Pallet racking, Figures 25.8 and 25.9. For a wide variety of goods, the speed of throughput decreases. Pallet racking is the solution with a large variety of products, brands or pack sizes. Each pallet is normally allotted a unique position in the racking.

6 DISPOSITION OF THE RACKING

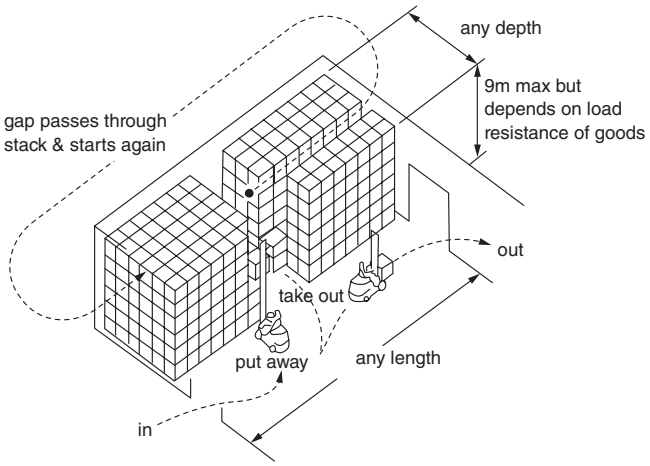
There are two common alternatives:

- The rack is oriented at 90° to the order assembly areas, with the fast turnover stock in the bays nearest to it or
- One complete racking face is oriented along one side of the order assembly area and reserved for very fast-moving stock.

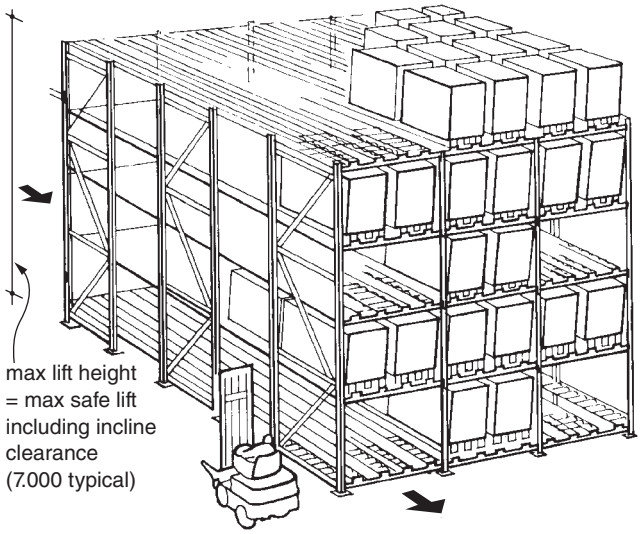
7 RELATIONSHIP OF STORAGE METHOD, MECHANICAL HANDLING EQUIPMENT AND BUILDING HEIGHT

The effect of handling equipment on warehouse section is shown in Figures 25.10–25.13. These factors depend on site conditions:

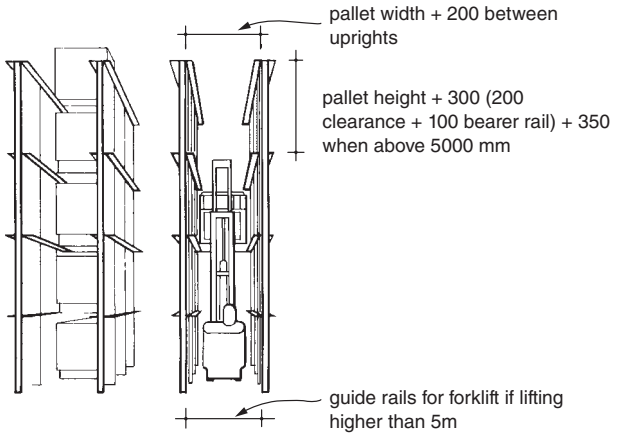
1 For very constricted sites where a large volume of goods needs to be held high-bay, automated warehouses can prove the most economical solution. Such warehouses have been built up to 30 m high, the racking being used as the roof and wall cladding



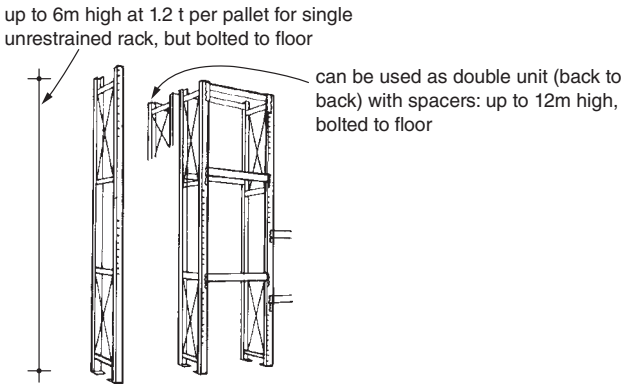
25.5 *Method of block stacking for stock rotation. Where cartons are being stacked on pallets, a height of three pallets is the normal maximum*



25.7 *Roll-through racking*



25.6 *Drive-in racking for fork-lift. A maximum depth of six pallets, with fluorescent lighting in the racking structure. Four-pallet depth is preferable*



25.8 *Pallet racking*

supporting structure. Handling machines run on fixed tracks, Figures 25.13 and 25.14.

2 For medium- and large-scale installations where full automation is not justified, storage areas up to 12m high allow free-standing racking (bolted to the floor) with aisle widths marginally wider than the largest pallet, Figure 25.15. 'Narrow-aisle trucks' used in this type of plant are free path machines based on fork-lift technology, Figure 25.16.

3 Where the cost of high-bay stacking and high-lift machinery is not justified, fork-lifts and reach trucks are used, Figure 25.17. Reach trucks are suitable for conventional pallet weights (1–1.5 tonnes) over flat floors. They can lift to 9 m and operate in aisles of about 2.8 m. A fork-lift truck can carry heavier loads but requires aisles of 3.2–4 m width, Figure 25.18. Heavier trucks are required to lift greater heights and tend to require a greater aisle width.

4 Mobile racking where pallet racking is mounted on mobile bases and rests face to face may be suitable where storage is to be installed in an existing structure or where the site is limited in area and the turnover of products comparatively low. It is costly to install and the floor slab has to accept double the normal distributed load.

8 OUTLINE SPECIFICATION

8.1 Storage area

Pitched roofs, though strong on first cost, waste storage volume and run the risk of being damaged by handling equipment: Three factors favour the flat or low pitch roof type:

- The column pitch can be wide, Figures 25.17 and 25.18.
- They are more adaptable to a change of use or changes dictated by new processes.
- They are more suitable for the installation of services such as cooled air.

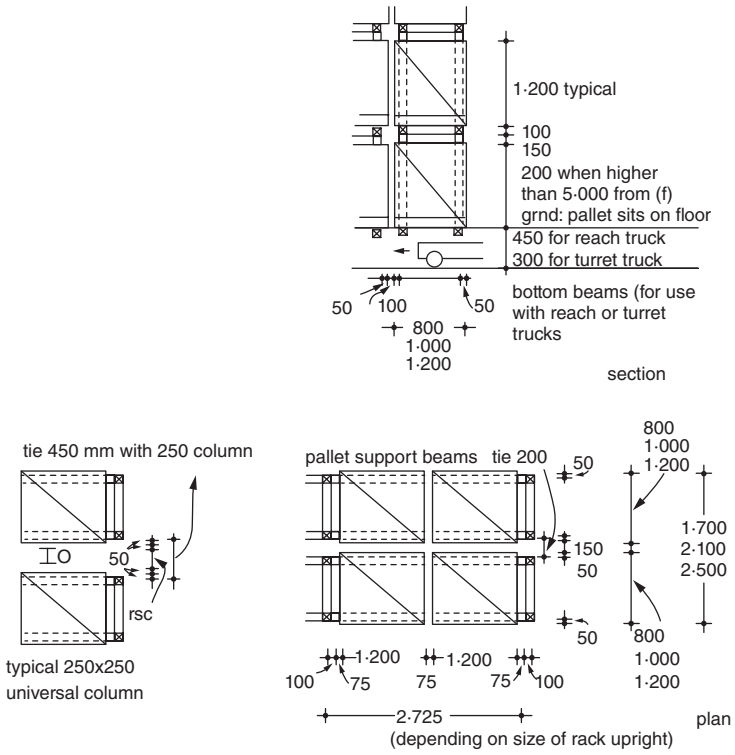
8.2 Order picking and assembly

Space demanded will vary with the type of business involved and the method of order assembly, in turn generated by the method of despatch and transport. For instance, a brewery warehouse may despatch whole pallet loads, Figure 25.7, but a pharmaceutical warehouse may handle and assemble a very large number of small items. Therefore, it may require a large area for order assembly, Figures 25.19–25.21.

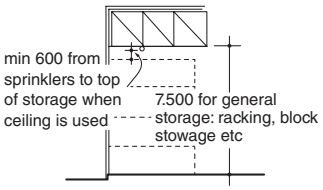
8.3 Loading bay and load accumulation area

The loading bay is the critical link between the storage and distribution system, Figure 25.22. It usually combines inward and despatch movements. It must provide sufficient space for:

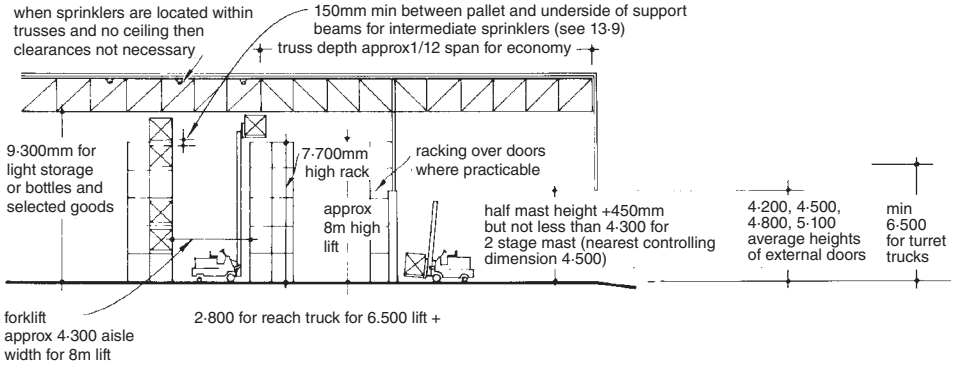
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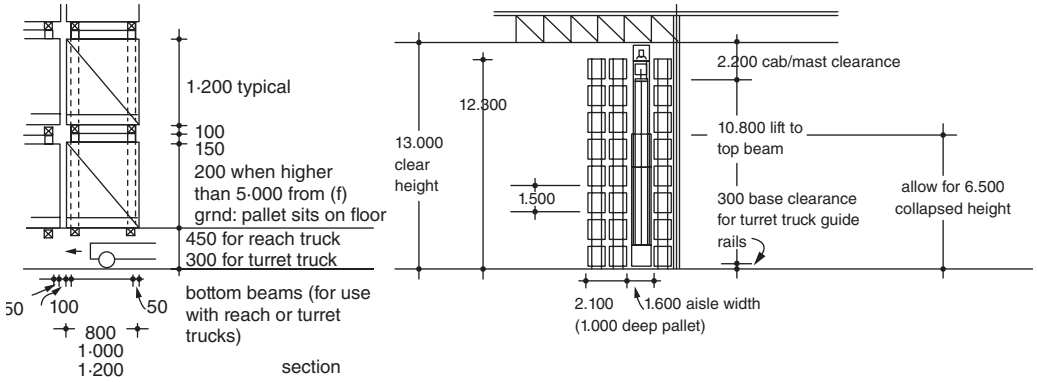
25.9 *Construction of pallet racking*



25.10 *Section through small warehouse for fork-lift operation*

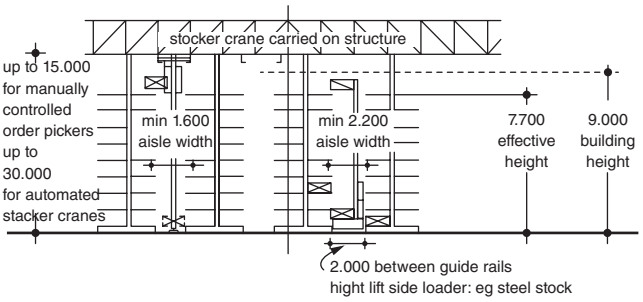


25.11 *Section through large warehouse for fork-lift or reach truck operation*

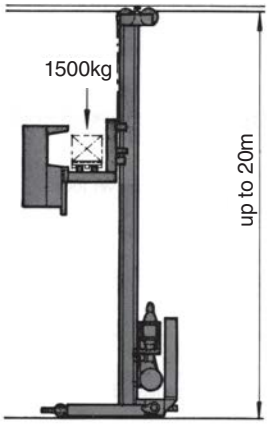


25.12 *Section through warehouse for narrow aisle truck operation. Floor tolerance ±3 mm in 3 m run*

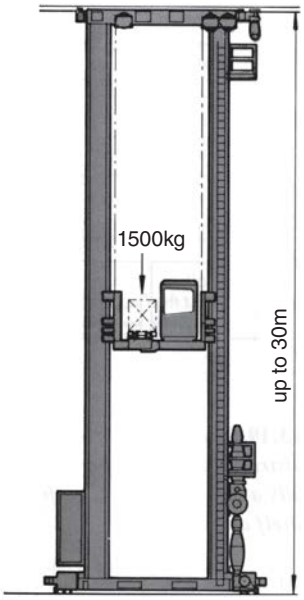
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25.13 *Section through warehouse for stacker crane handling (left) and steel stockholding with side loader (right)*

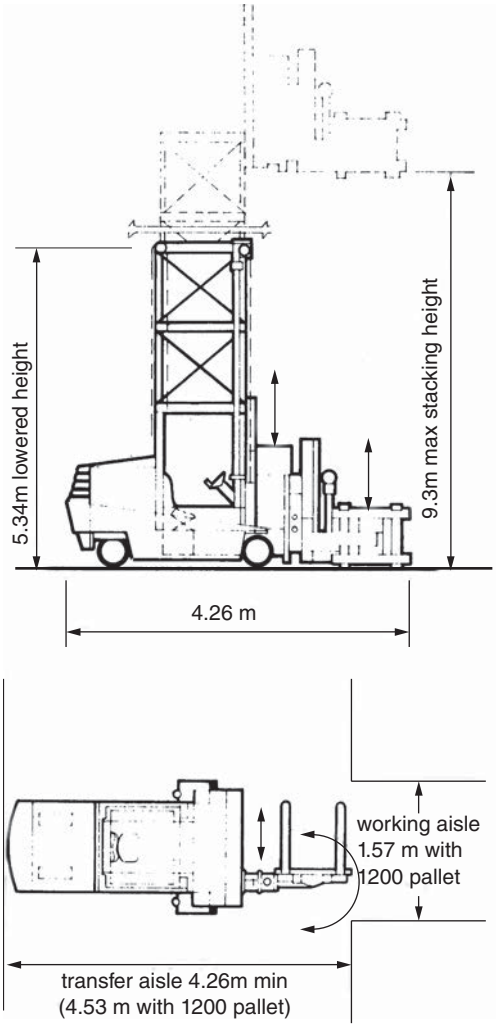


a *Order picker*

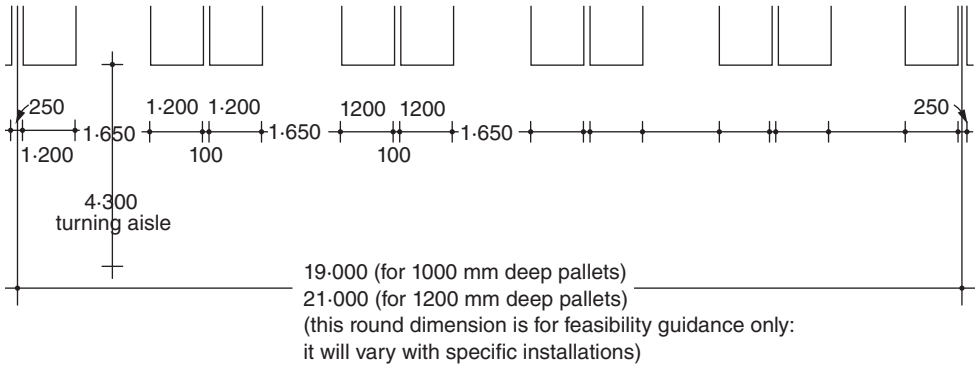


b *Stacker crane*

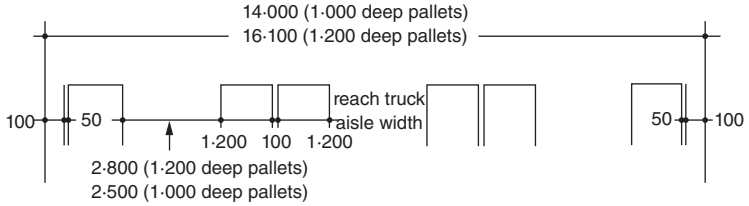
25.14 *Dimensions of: a order picker and b stacker crane*



25.15 *Free path stacker/order picker with elevating cab, fixed mast and rotating fork. The four-post mast gives extra stability. Out of the aisle can also be used as a fork-lift truck. The free lift on the fork carriage also allows differential movement between the pallet and the picking platform. Minimum building height 2.2 m above top lifting level*

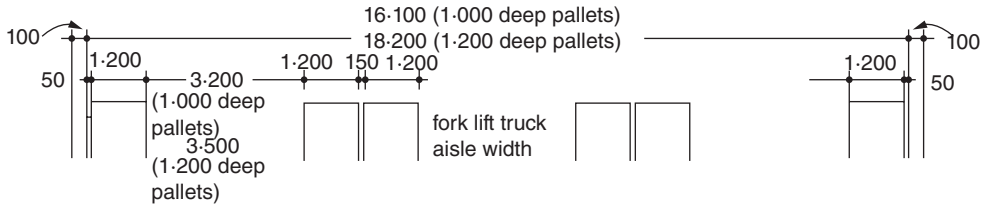


25.16 *Relationship to structure of narrow-aisle truck aisles*

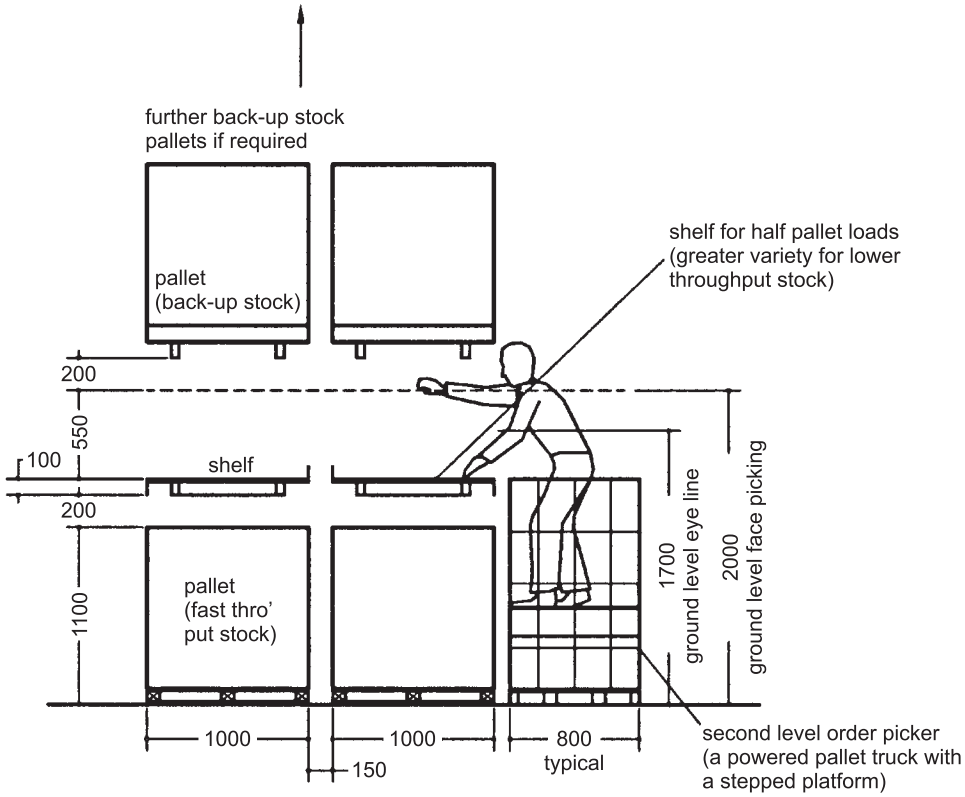


25.17 *Relationship to structure of reach truck aisles*

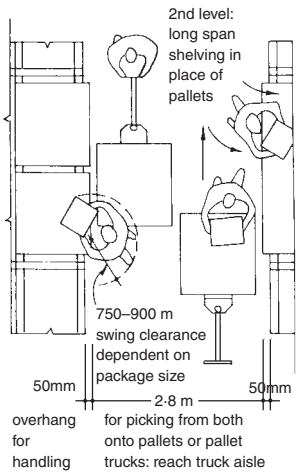
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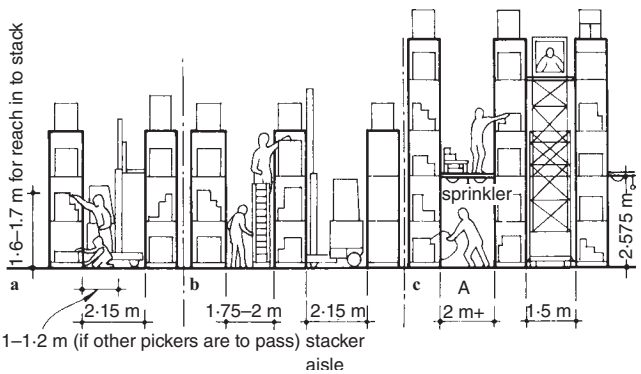
25.18 *Relationship to structure of fork-lift truck aisles. Note: 16100 mm span is common to fork-lift and reach truck requirements*



25.19 *Second level order picking, typically used for food distribution and supermarket replenishment. The operative fills a roll pallet or cage from the pallet on the floor and the shelf above it*



25.20 *Reach truck aisle for second-level order picking*



25.21 *Stacker aisles for order picking: a Pulling from lower levels – replenished by stacker truck (Figure 25.25) b Alternating pick-up and replenishment aisles c Multi-level alternative aisles, replenished by narrow aisle truck*

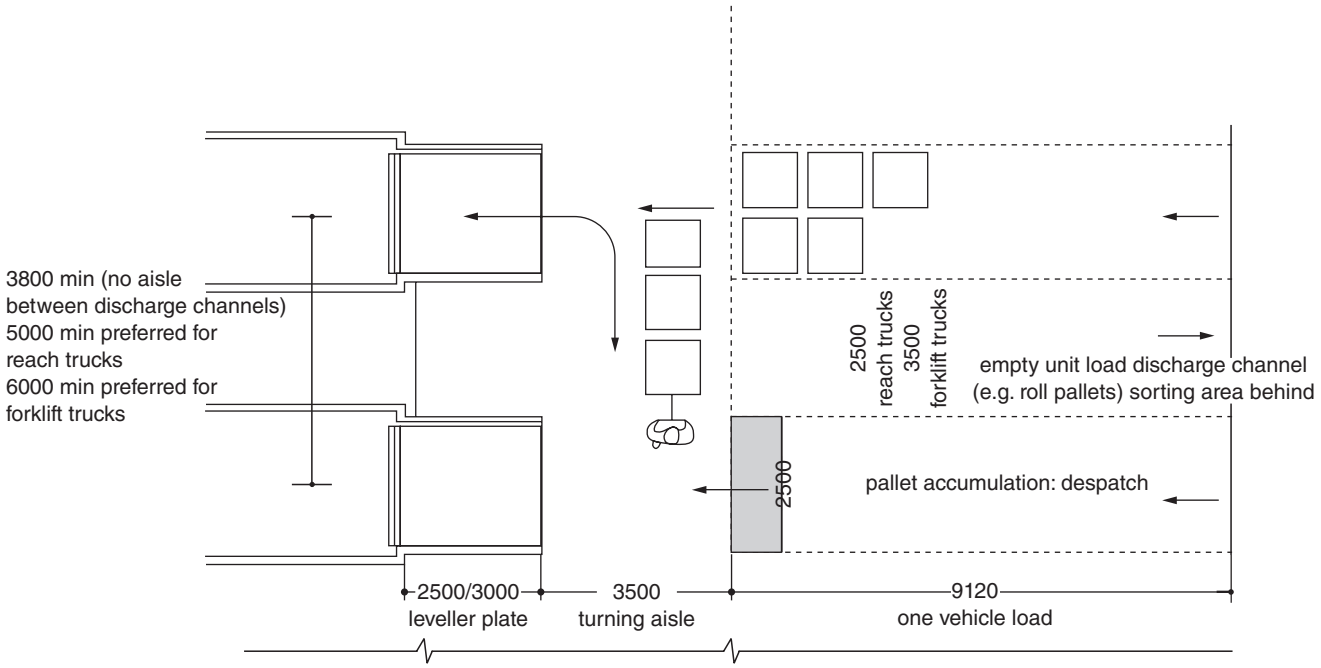
- incoming goods to be checked off;
- empty unit load devices to be removed;
- despatch loads to be accumulated

A full vehicle length (12m) should be allowed as the zone behind the loading dock.

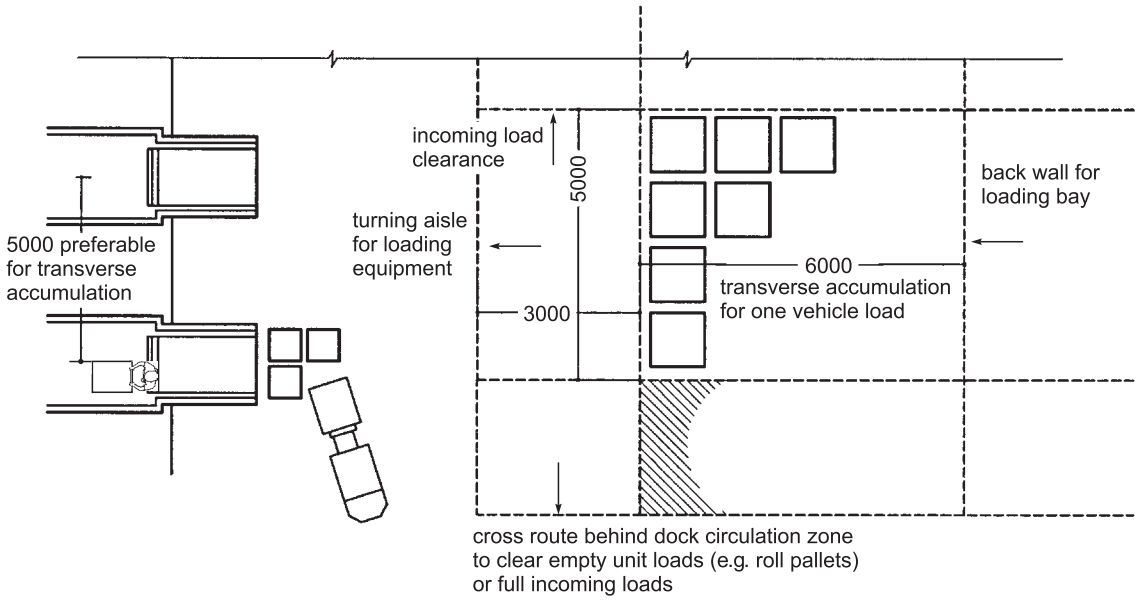
8.4 Office and amenity areas

Large warehouses can employ more than 100 order-picking staff (mainly female) each shift. Extensive washing and changing facilities will be required, also space for operatives to rest and smoke outside the storage area. See BS 6465-1:2006 (which supercedes BS 6465-1:1994) for full details of sanitary installations.

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a *Where available*



b *Where depth is limited*

25.22 *Combined arrival/despatch loading bays*

Clients and developers generally prefer the office element of a distribution building to face the main entrance to the site, leaving loading/unloading at the rear. If this means offices facing south (taking advantage of sunshine) it may mean fixing brise soleil to the facade.

8.5 Equipment maintenance areas

Most mechanical handling equipment for internal use is battery-powered electric. The batteries need charging at night or after shifts of about 12 h. Requirements for maintenance areas are:

- a distilled water supply;
- tonne hoisting tackle for removing batteries;
- fume extraction;
- acid-resistant floor.

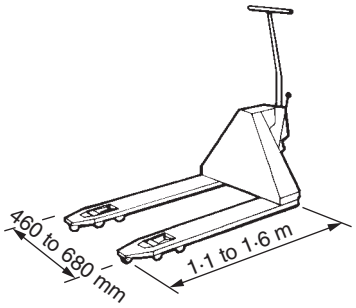
Major services and repairs tend to be done off site.

9 SECURITY

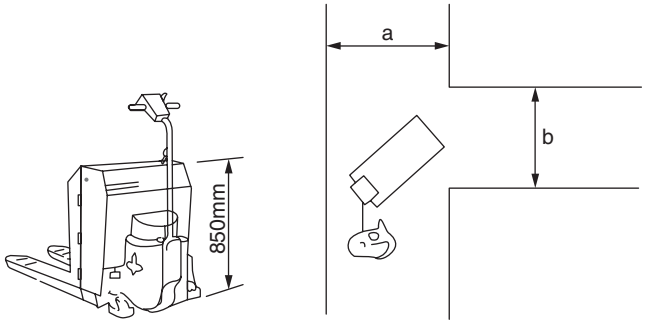
Warehouses are, by definition, prone to theft. Most thefts are carried out during working hours. This can be minimised by ensuring that:

- There is no direct access from loading bays to the warehouse, especially through the order-picking zone, without supervision.
- Access from office accommodation to the warehouse should be visible from the office area.
- The changing rooms, showers (necessary in cold stores) and WCs should not have direct access from the warehouse, and equally, should not be accessible from outside. Visiting drivers should have segregated WC facilities.
- If small, valuable goods are involved, a search room may be required.
- Operatives' parking should be well separated from heavy vehicles' parking and away from the loading area.

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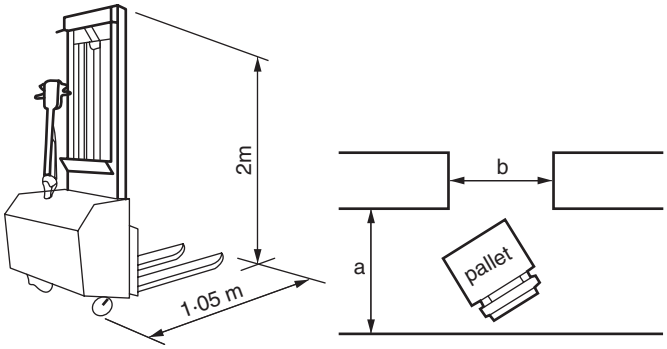
25.23 *Manual pallet truck. For use inside the warehouse building up orders, loading vehicles on raised docks or with tail-lifts, general pallet handling. Increasingly used in retail premises for handling bulk goods. Capacity up to 1500 kg generally and for short-distance travel (operatives soon tire when pushing heavy loads any distance). Forklengths available 0.8–1.6 m, widths from 460 to 680 mm. Heights: lowered 83 mm, raised 203 mm. Pallet width should be 150 mm overfork (typical length is 1.06 m for a 1.2 m pallet). Where gangways are narrow and stability is important, a heavy truck should be used with maximum width between forks. This device will turn in its own length but needs additional clearance for overhangs. Normally, it requires level floors to operate satisfactorily, but large wheels in nylon or with solid rubber tyres plus articulating axles are available for use in older buildings; although instability may occur. Steel wheels are available but are less popular. Where loading ramps are used, pallet trucks with brakes should be used. Adaptors are available for use as a stillage truck*



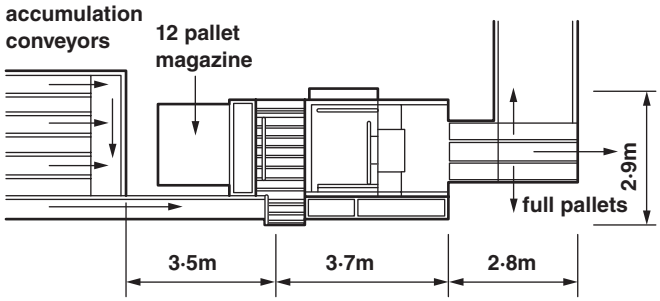
25.24 *Powered pallet truck. For internal transfer, loading vehicles on docks, order build-up, transporting roll pallets to load assembly position. For use with all types of pallet and cages. Capacity 1800–3000 kg, forklengths 0.75–1.8 m, speeds up to 3.6 km/h running light, widths up to 850 mm, usually 760 mm. Long forks available to carry three roll pallets at once. Special forks for drums and paper rolls. Will turn in its own length but needs additional clearance for overhangs. Some have 200° turn on the single power steering wheel. Aisle width depends on forklength:*

a *(90° stacking aisle) = 1840 mm (truck + 1 m pallet)*
b *(intersecting aisle) = 1570 mm*

Turning circle 1.78 m radius with 960 mm long forks. This device requires level floors and a three-phase charging point. It can manage ramps up to 10%. Some larger-capacity units can also be ridden on, and can tow non-powered pallet trucks if long distances are involved



25.25 *Power travel and lift pedestrian-controlled stacker truck. When travelling the pallet rests on the stacker frame which has travel wheels. Power lifting is independent of the travel frame, and is directly into the rack. Only suitable for short travel distances. Lifting range up to 3.6 m. Can be supplied with attachments. Capacity up to 1500 kg at 600 mm centres, straddle width 0.86–1.3 m, travel speed up to 4.8 km/h laden. Will turn with full load on 2.1 m aisle*

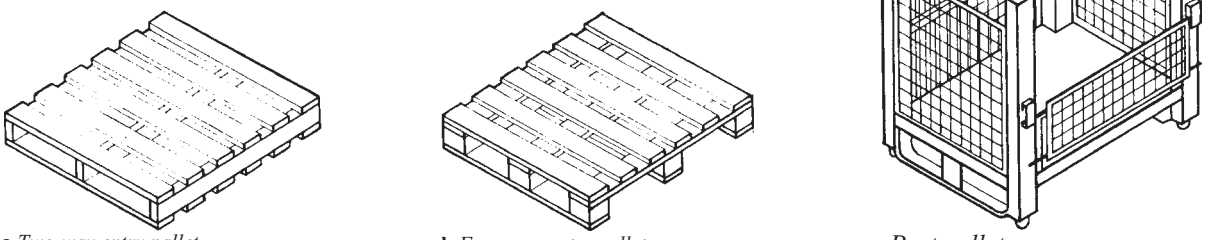


25.27 *Plan of typical palletising machine. Top right is buffer track required for slower shrink wrapper*

10 HANDLING EQUIPMENT

Goods handling systems are now highly specialised and only their general layout falls into the architectural remit. Computerised and robotic handling systems, controlled from a central database, can represent half the build cost.

Some typical handling equipment is shown in Figures 25.23–25.27.



a *Two-way entry pallet* **b** *Four-way entry pallet* **c** *Post pallet*

25.26 *Types of pallet*

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11 FIRE PRECAUTIONS

It is worth remembering that the goods stored within a building may be worth more than the building itself. Therefore, it may be worth considering the protection of the goods rather than the building – indeed, this may be a crucial part of the operator's business plan. Compartmentalisation and the judicious arrangement of sprinklers may need to be considered.

Table 12 of Approved Document B (Fire Safety), which came into effect April 2007, provides details about compartment sizes. If a building is fitted with sprinklers throughout, there is no need to compartmentalise; if a decision has been taken to dispense with sprinklers, then buildings must be compartmentalised. Each compartment must be no larger than 20 000 cubic metres and no higher than 18 m. In high bay buildings (up to 35 m), automatic sprinkler systems must be installed. Note: the more sophisticated and more sequential the sprinkler system, the less potential water damage.

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26 Laboratories

Catherine Nikolaou and Neville Surti

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KEY POINTS:

- *A modern laboratory should provide a stable environment for the production and replication of scientific data as well as adding value by considering flexibility and interaction via good space utilisation and planning*
- *Working collaboratively with key stakeholders in the production of a robust set of requirements for each space ensures a proper understanding of the activities undertaken and therefore the reduction of risks and hazards through design*

Contents

1 Introduction
2 Laboratory layout guidance
3 Space organisation
4 Environment
5 Case studies
6 Bibliography

1 INTRODUCTION

1.1 Definition

A laboratory is a facility which provides controlled conditions in which scientific methods including research, development and analysis may be performed and/or taught.

1.2 Scope

There is great diversity amongst laboratories; however, many commonalities are found in their architecture and engineering. This section of the handbook provides an indication of the basic requirements specific to a broadly representative range of laboratory facilities (the scope is far too extensive to cover in any detail in this document). The information provided relates primarily to bench-scale laboratories, focusing mainly on the commonalities and provides guidance for their planning and design. The figures presented are based on average requirements. Specific needs, ascertained through detailed briefing with the client, may vary these figures.

Whilst this section provides information on the design of new facilities, the broad principles can also be applied to renovation/refurbishment projects. In these instances, compromises may need to be made due to space restraints and operational procedures may have to be put in place to compensate.

1.3 Laboratory types and sectors

In this handbook, laboratories are grouped into two main types, wet and dry, all of which incorporate various scientific disciplines and work processes.

Wet laboratories: utilise, test and analyse chemicals, drugs or other material/biological matter. They typically require piped services (including water, specialised utilities) and ventilation, e.g. chemical science, biomedical laboratories.

Dry laboratories: contain dry stored materials, electronics and/or large instruments. They typically require some piped services, accurate temperature and humidity control, dust control and clean power, e.g. analytical, engineering laboratories.

Teaching laboratories may be wet or dry laboratories or a combination of both but they differ in that they *teach* scientific method. They can be found in primary, secondary schools and higher education.

1.4 Sectors

Laboratories can be found in private, public or academic sectors.

Private laboratories: focus on research, development and analysis but are usually driven by the need to enhance the operation's profit potential

Public laboratories: focus on research, development and analysis specifically in the public's interest. They are in many respects similar to those of the private sector.

Academic laboratories (excluding schools): focus on teaching laboratory methods and include laboratories that engage in generating research within an academic institution. They may be privately or publicly funded. School laboratories focus on teaching science as set out in their curriculum and include laboratories that engage with other subjects such as design, technology and food studies.

Laboratories (excluding schools) are typically part of a facility which may include various space types such as:

- Reception/lobby
- Office/write-up
- Auditorium/conference/seminar/meeting
- Social/interaction
- General storage
- Library
- Food service
- Child care
- Clinic/health unit
- Physical fitness (exercise room)
- Joint use retail
- Loading dock
- Parking.

In the past, private sector facilities were more expensive and larger than government or academic facilities as commercial concerns need to produce a constant flow of discoveries that can be taken to market. Consequently, more 'incentives' were provided in the form of state of the art facilities to retain and attract talent. This model has been recently adopted by many academic institutions and smaller research organisations as a result of increasing competition within the industry leading to an improvement in the quality of their facilities as well.

1.5 Environmental conditions

A detailed assessment should be made with the stakeholders and the relevant regulatory authorities to define the environmental conditions and operational practices required for the facility as part of the briefing process and before the design starts, as this will impact on the specification of the laboratory's physical and servicing requirements and its operational costs.

The final form of the facility will also be dictated by the individual site constraints and opportunities for each project and the varied preferences and detailed needs of the stakeholders which are also defined as part of the briefing process.

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1.6 Containment

In some laboratories, conditions are no more dangerous than in any other room. In many, however, hazards may be present that need to be contained and/or controlled including (but not limited to):

- Biological/infectious agents (to humans and/or animals)
- Genetically modified organisms
- Poisons/chemicals
- Flammable substances
- Explosives
- Radioactive material
- Magnetic interference
- Moving machinery
- Extreme temperatures
- High voltage

In accordance with legislative requirements, these hazards must be identified and countermeasures or mitigation strategies specific for each facility determined/implemented. Reference should be made to the legislative guidance, approved codes of practice and regulations produced by the law and relevant advisory bodies. Refer to Bibliography.

1.7 Cleanrooms

A laboratory may be designed as a cleanroom facility. A cleanroom is defined as a room in which the concentration of airborne particles is controlled; which is constructed and used in a manner to minimise the introduction, generation and retention of particles inside the room; and in which other relevant parameters such as temperature, humidity and pressure are controlled as necessary. Cleanroom conditions are typically required, for example, in micro and nanoelectronic research.

The grades of cleanroom are defined by the global ISO classification system, EN ISO 14644-1 which classifies ranges from ISO 9 (least clean) to ISO 1 (cleanest). Table I shows how it compares to other international standards in the ranges ISO 3 to ISO 8. Refer to EN ISO 14644-4 for guidance on the design, construction and start-up of cleanrooms.

Table I Comparison of the global ISO cleanroom classification system, EN ISO 14644-1, with other international standards

Standard and Date Published	Classifications					
EN ISO 14644-1 (1999)	ISO 3	ISO 4	ISO 5	ISO 6	ISO 7	ISO 8
US Federal Standard 209D (1988)	1	10	100	1,000	10,000	100,000
US Federal Standard 209E (1992)	M1.5	M2.5	M3.5	M4.5	M5.5	M6.5
*EU GMP (1998)	–	–	A/B	–	C	D

*Good Manufacturing Practice (GMP) is a set of regulations, codes, and guidelines for the manufacture of drugs, medical devices, diagnostic products, foods products and Active Pharmaceutical Ingredients (APIs).'The Orange Book' (refer to Bibliography) covers most aspects of GMP.

Laboratories may be designed as both cleanroom and containment facilities. For example, some products require a containment level Category 2 to protect the operator and a cleanroom environment of ISO Class 5 to 8 to protect the product. Refer to bibliography for further reference on the design, construction and start-up of combined cleanroom and containment facilities.

2 LABORATORY LAYOUT GUIDANCE

2.1 Key points

The planning and design of modern laboratory facilities should be based on a combination of current best practice and predictions together with recognition of the future needs for flexibility.

Safe and secure: Safety must always be the first concern in laboratory design and what the law requires is to look at what the risks are and to take measures, so far as is reasonably practicable, to tackle them. Securing a facility from unauthorised access is also of critical importance to prevent theft, misuse or, for facilities handling infectious agents, the release of pathogens.

Statistically reproducible data: One of the most fundamental requirements of successful scientific research is to provide statistically reproducible data. The ability to achieve this relies not only on the availability of high quality reproducible material but also on the quality and appropriateness of the controlled physical environment.

Responsive to change: The need for change will result from the continuing and rapid developments in technology/equipment, evolving working methods and procedures and increasingly stringent regulations. It should therefore be a fundamental principle that the basic design of a laboratory allows sufficient flexibility for future changes to be accommodated without the need for major and often costly alterations and with minimum disruption to operations.

Interaction and collaboration: Scientific interaction and collaboration often leads to new inventions, new cures and faster progress. As a result, equipping laboratory facilities with spaces that encourage interaction and collaboration generally enhances the occupant's ability to succeed.

Recruit and retain staff: Because of increasing competition in the scientific field, more effort and money is often invested to recruit and retain the best talent by creating high quality facilities that include attractive environments, state-of-the-art laboratories, extensive amenities and the latest in computer technology. These facilities serve to support employees and enhance user satisfaction, efficiencies and productivity.

Sustainability: Laboratories are typically energy-demanding because of their requirements as highly serviced spaces. In addition, they may have intensive ventilation requirements and must meet health and safety codes which add to energy use. There are however significant opportunities for improving efficiencies while still meeting or exceeding operational and health and safety requirements. The basic objectives are to reduce consumption of non-renewable resources, minimise waste, and create healthy, productive environments. If deemed important, a suitable strategy should be agreed between stakeholders and the design team. Labs 21 (in USA and UK) and Lab 2020 (in Europe) are examples of organisations that provide useful information on sustainability in laboratories.

2.2 Laboratory planning modules

A starting point for the planning and design of many laboratory facilities is the planning module which accommodates basic planning requirements. It should provide adequate space for partitions, benches, floor standing equipment and extract devices and aisles which minimise circulation conflicts/safety hazards. The laboratory module should also be fully coordinated with the architectural and building engineering systems.

The width of a typical laboratory planning module is defined in Table II.

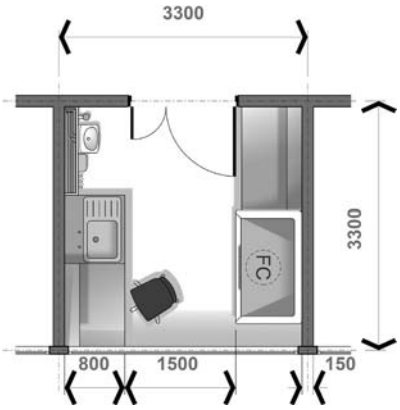
Table II Factors defining the width of a typical laboratory module

Planning requirement	Width (mm)
2 × half wall thickness between module (50mm)	100
2 × clear bench depths (600mm or 900mm)	1200–1800
2 × service spines above bench (200mm)	400
minimum space between benches	1500*
Total module width	**3200–3800** **

*This is the recommended minimum distance which will accommodate the required distance between a bench and a fume cupboard and also requirements for DDA compliance.

**The minimum and maximum figures are largely dependent on equipment requirements. A 3300 mm minimum module width is recommended for most generic laboratory facilities to ensure that a bench and a fume cupboard (nominal 900mm) can be accommodated on either wall.

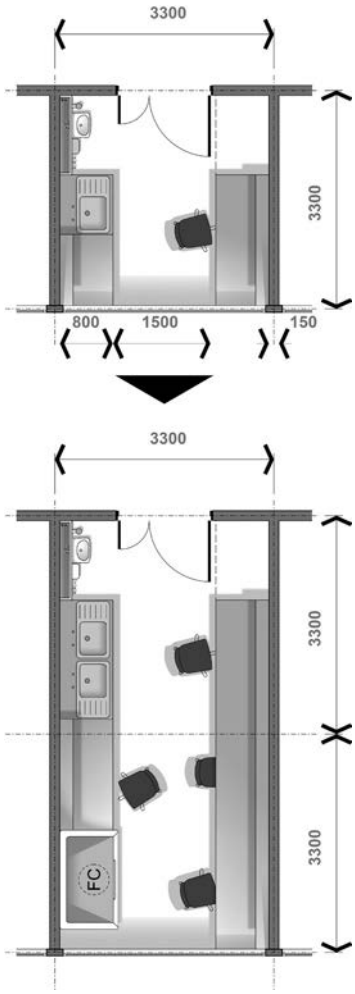
The length of the module will depend on the unit size of the chosen laboratory furniture, requirements for freestanding equipment and the number of persons that will occupy the space (Figure 26.1); however further flexibility can be achieved by designing a laboratory module that works in both directions. This allows laboratory benches and equipment to be organised in either direction, Figure 26.2a. This concept is more flexible than the basic laboratory module concept but may require a larger building.



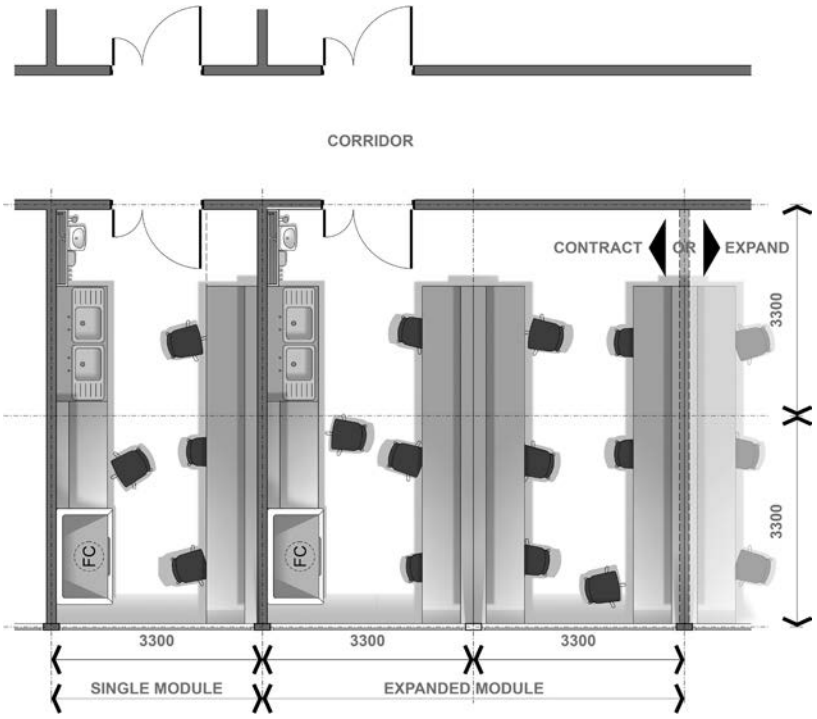
26.1 *The basic planning module. A two-directional laboratory planning module offers maximum flexibility*

2.3 Combining modules

In addition to accommodating the basic and functional spatial requirements, modularity maximises efficiency and the potential for flexibility/adaptability. As modifications are required because of changes in laboratory use, instrumentation or departmental organisation, partitions can be relocated and laboratory units expanded or contracted into larger or smaller units without requiring significant reconstruction of structural or mechanical building elements (Figures 26.2a, 26.2b, 26.2c).

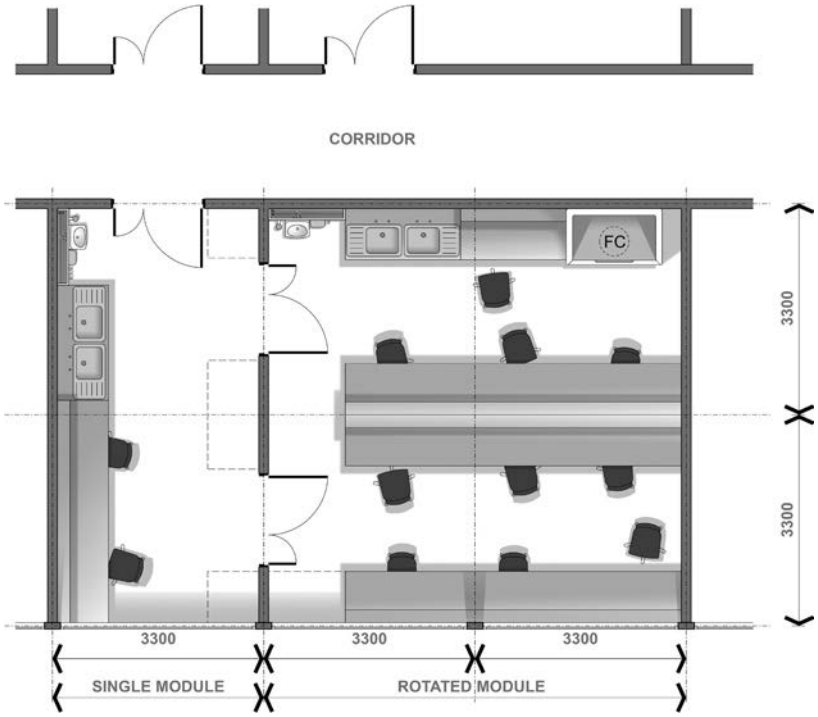


26.2a *The planning module needs to accommodate basic planning requirements for partitions, laboratory benches, equipment, extract devices and circulation in addition to laboratory personnel*

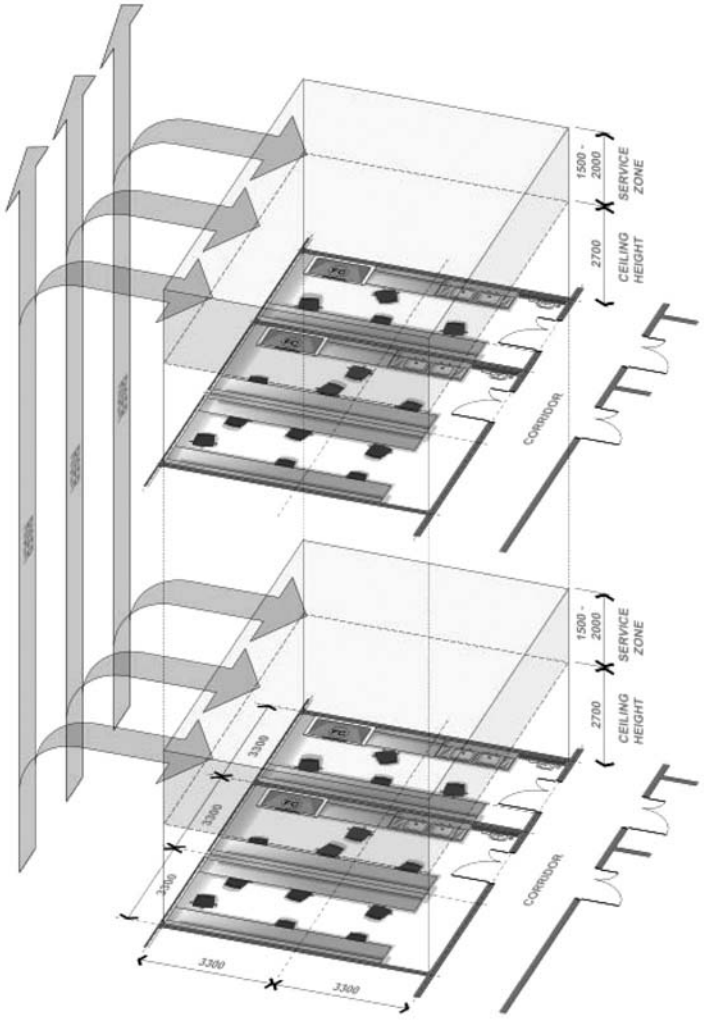


26.2b *Utilising the concept of modularity in laboratory planning to create efficient, flexible and adaptable spaces that can be expanded and contracted to meet changing requirements*

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26.2c *A laboratory module that works in both directions allows laboratory benches and equipment to be organised in either direction*



26.3 *Three-dimensional laboratory planning module*

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Three-dimensional laboratory module: To create a three-dimensional laboratory module a basic or two-directional module must be defined, all vertical risers including fire stairs, lifts, restrooms and utilities shafts must be fully coordinated (for example, vertically stacked) and the mechanical, electrical and plumbing systems must be coordinated in the ceiling to work with the corridor/circulation arrangements, Figure 26.3. This concept provides the greatest flexibility.

2.4 Structure

Key design issues to consider in evaluating a structural system include:

- ability to coordinate the structure with the laboratory planning modules;
- slab thickness and effective floor to floor height;
- ability to create penetrations for laboratory services in the initial design as well as over the life of the building;
- potential for vertical or horizontal expansion;
- superimposed loads;
- vibration criteria;
- cost.

2.5 Structural grid

The basic laboratory planning module forms a 'template' for the building's structural grid. In most cases the structural grid width equals 2 basic laboratory modules. The structural grid length is determined by not only the basic planning requirements but also the cost effectiveness and functional requirements of the structural system (Figure 26.4).

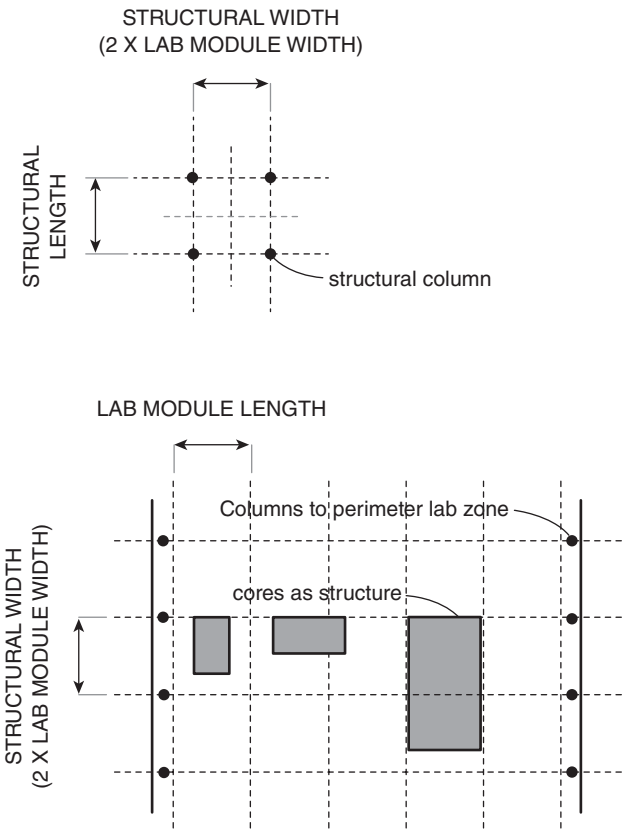
Ideally, any columns placed on grid should either be incorporated into the design (for example within cores and built out walls or to the perimeter of the laboratory zone) to provide an obstruction free work zone. In addition to columns, all fixed elements of structure, for example floor slabs, braced bays, shear walls, service shafts, lift shafts and staircases, should be planned to minimise constraints on the extension and reconfiguration of the layout (Figures 26.4 and 26.5).

2.6 Floor to floor height

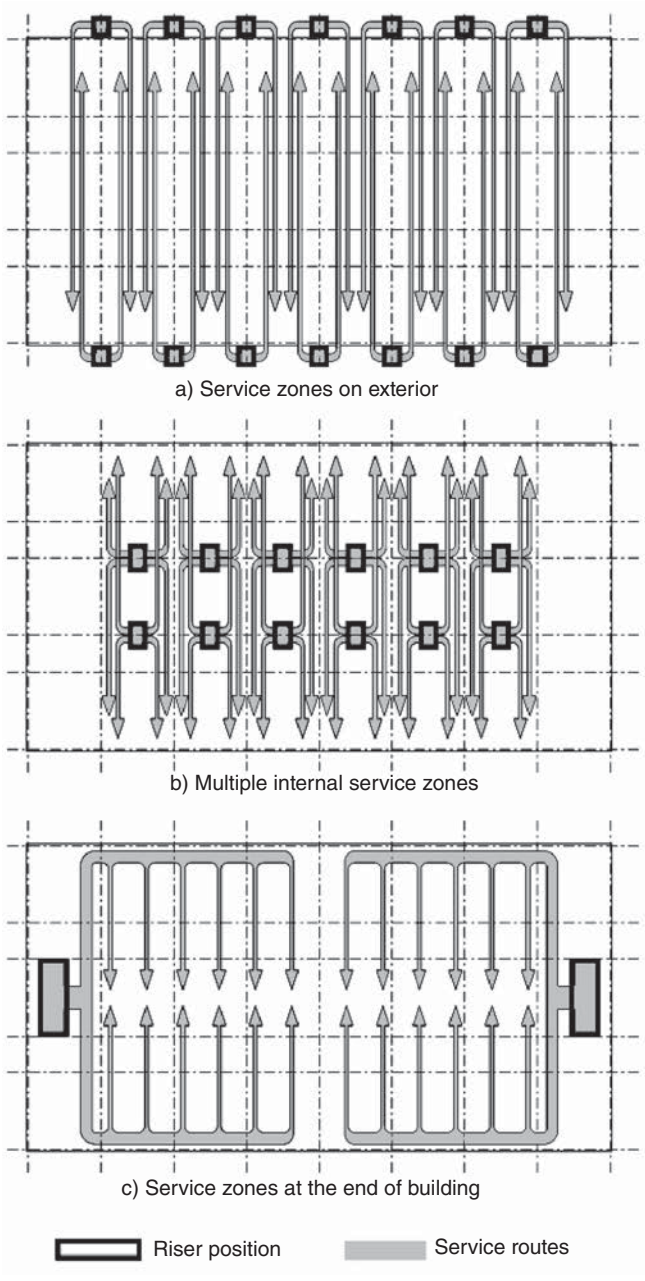
Actual floor to floor heights will need to be determined through thorough discussion with the stakeholders and the needs of the equipment and building services to be incorporated within the space. The issue of flexibility will also need to be reviewed and heights proposed to maximise the future use of the space (Table III, Figure 26.3).

In cases where floor to floors are more restrictive such as refurbishment works in existing buildings and where safety requirements do not require a cleanable suspended ceiling, exposed soffit fixed services could be considered.

Note, however, that the dimensions tabled may be inadequate for specialist equipment (for example cyclotron, MRI, PET/CT Scanners etc.). This requires individual consideration.



26.4 *The building's structural grid derived from the laboratory planning module, the cost effectiveness and the functional requirements of the structural system. For maximum flexibility, columns should be integrated or placed outside the grid*



26.5 *Maximising flexibility through the rational placement of fixed elements such as risers*

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Table III Effective floor to floor height, minimum and maximum recommended figures

	Height (m)
Minimum ceiling height in laboratories	2.7*
Minimum ceiling void	1.0**
Preferred ceiling void	1.5–2.0**
Slab thickness (nominal allowance)	0.3
Floor to floor height	**4.0–5.0**

*To allow clearance height for extract cabinets.
**To allow adequate depth for the installation of building services. Consider exposed mechanical, electrical and piped systems for easy maintenance access from the laboratory.

Superimposed loads: Structures must be designed in accordance with the appropriate British Standards which will depend on the structural material adopted for the structure. For generic/bench-scale laboratories including equipment and corridors subject to loads greater than from crowds, such as wheeled vehicles, trolleys and similar, design for:

5.0 kN/m^2 + 1 kN/m^2 for lightweight partitions

Heavy engineering equipment and rigs such as cyclotron, NMR, electron microscopes etc., are most economically located on ground floors and require individual and separate consideration.

2.7 Vibration

The structural frame system should take into account vibration throughout the laboratory areas where sensitive equipment, balances and microscopes are being utilised. The principal sources of vibration that need to be considered are shown in Table IV.

Note that noise induced vibration is an issue of acoustics requiring specialist input (refer to bibliography). This section deals primarily with human and equipment/plant induced vibrations in more detail.

Vibrations can either be controlled directly through the design of the structure, independently by the use of isolation bearings or damping materials, or a combination of the two. The aim should be to design an economic structure with an appropriate level of vibration response.

Basic techniques that should be utilised where possible to control vibration are listed in Table V.

The accurate selection of vibration criteria and prediction of vibration levels is important in laboratory design because construction costs increase as designed floor vibration levels decrease. Confirmation is also critical as it will significantly impact on slab thickness and weight with consequences to all other aspects of the structure (column sizes, transfer beams, foundations etc.).

Vibration criteria can be determined based on published vibration limits, manufacturer-provided criteria, and subjective tests of vibration-sensitive equipment.

ASHRAE and BBN: The ASHRAE studied the effects of vibration generated by HVAC equipment in buildings and defined criteria widely adopted through the industry. Similarly the BBN developed the VC curves.

Response factors: Vibration levels are referred to in terms of Response Factors (R) where human perception is the primary concern. The R is simply a multiplier on the level of vibration at the average threshold of human perception. Therefore R1 represents the magnitude of vibration just perceptible by a human, R2 is twice that and so on.

Root Mean Square Velocity (RMS): In addition to human perception of vibration, in research spaces the vibration response needs to be limited for sensitive equipment such as microscopes, which often drives the design. Equipment manufacturers typically specify vibration limits in terms of RMS velocity (root mean square velocity) as measured in one-third octave bands of frequency over the frequency range of 8 to 100 Hz. This is a measure of average amplitude over a certain period.

Table VI compares both ASHRAE and BBN as well as Response Factors (R). The ISO criteria for human exposure are also shown. Criterion VC-A to VC-E are applicable to laboratory facilities.

Whilst it is a requirement to provide a high level of flexibility, it is normally accepted that to design all parts of the building such that extremely sensitive research equipment can be placed anywhere without further local isolation is not practical. Therefore, a vibration design criterion and design strategy must be adopted that will satisfy the majority of needs, whilst accepting that local isolation devices will be used where a particular item of equipment has more stringent requirements. An economic solution with a defined level of flexibility (agreed with the laboratory user) may be to categorise the vibration response of different areas of the floor using response curves. For example, a maximum rms velocity of 50 micrometers per second may be set as the target at the centre of floor panels. At points close to the columns the criterion would increase to 25 micrometres per second thus allowing more sensitive equipment to be located at the perimeter or column locations.

Table IV Sources of vibration

Source	Description
Human induced	occupant activity
Ambient	external sources, surrounding infrastructure e.g. roads, railways
Plant	building services plant
Machinery	laboratory equipment e.g. centrifuges
Airborne	Noise

Table V Basic vibration control techniques

Vibration control	Technique
Building location	Away from traffic, vibration sources
Room location and floor features	Slab-on-grade/stiff floor/isolated floor
Equipment location	Away from centre of bay, motorised equipment
High rigidity and low weight tables/ benches	Top honeycomb structures
Direct isolation of equipment	Rubber mounts/air springs/isolators
Active vibration isolation	Piezoelectric/electrodynamic actuators

2.8 Building services

Typically, more than 35–50 per cent of the construction cost of a laboratory building can be attributed to the building services systems (mechanical, electrical and process). Close coordination of these systems is necessary to ensure a flexible, economic and successfully operating facility.

Three common strategies for servicing laboratories are as follows though needs may dictate a combination of any of them:

- Embedded Service Risers
- Sidestitial Service Zone
- Interstitial Floor Service Zone

Embedded service risers: Vertical service risers are located within the building floor plate as required (Figure 26.6). Whilst this option offers the most economical solution, it is also the least flexible with respect to floor planning (Table VII).

Sidestitial service zone: A vertical continuous service zone is located within the length of the laboratory area (Figure 26.7). This option offers good flexibility and maintenance access and is potentially best suited to sites with unsuitable/undesirable views to one side (Table VIII).

Interstitial floor service zone: A complete service floor zone is located either above or between laboratory floors (Figure 26.8). This is potentially the most expensive of the options however it

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Table VI Design criteria for sensitive instrumentation and equipment not otherwise vibration-isolated

Criterion Curve	Max. Velocity Level V_{RMS} (μm/s)	Velocity Level (dB) Ref: 0.025μm/s	*Detail Size (μm)	Description of Use
Workshop (ISO2631& BS6472) R=8 ASHRAE J	800	90	N/A	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office (ISO2631& BS6472) R=4 ASHRAE I	400	84	N/A	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day (ISO2631& BS6472) R=2 ASHRAE H	200	78	75	Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power to 20× microscopes.
OP. Theatre (ISO2631& BS6472) R=1 ASHRAE F	100	72	25	Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity.
VC-A (BBN-A or ASHRAE E) R=0.5	50	66	8	Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners etc.
VC-B (BBN-B or ASHRAE D) R=0.25	25	60	3	An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 micron line widths.
VC-C (BBN-C or ASHRAE C) R=0.125	12.5	54	1	A good standard for most lithography and inspection equipment to 1 micron detail size.
VC-D (BBN-D or ASHRAE B) R=0.0625	6	48	0.3	Suitable in most instances for the most demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of capability.
VC-E (BBN-E or ASHRAE A) R=0.03125	3	42	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

*The detail size refers to the line widths for microelectronics fabrication, the particle (cell) size for medical and pharmaceutical research, etc. The values given take into account the observation that the vibration requirements of many items depend upon the detail size of the process.

offers the greatest flexibility and excellent access for maintenance with minimum disruption to the laboratory functions (Table IX).

3 SPACE ORGANISATION

3.1 Definitions

The following definitions apply for the purpose of measurement within research laboratories.

Laboratory worker: A user who is allocated a bench space within the primary laboratory space.

Researcher: A user who is directly involved in scientific work, including staff that may not have an allocated bench space within the primary laboratory space (e.g. staff working predominantly on computer applications or senior staff who may work principally from an office space).

Net Useable Area (NUA): The Net Useable Area (NUA) is the sum of Primary, Secondary and Tertiary space. In laboratories and large open plan spaces (e.g. multi-occupancy offices or grouped write-up spaces) the measurement of secondary circulation spaces as contributing to Net Usable Area or to Balance Area may depend upon the configuration of the spaces and the extent to which circulation space may be considered to contribute to the use of the space, other than exclusively for access and circulation. Schedules and drawings will clearly need to identify which areas have been measured as part of the Balance Area.

NUA = Primary space + Secondary space + Tertiary space

Gross Internal Area (GIA): The Gross Internal Area (GIA) is the sum of Net Usable Area (NUA) and Balance space. The GIA does not include plant areas. The area required for plant rooms is particularly difficult to define at the early stages of design as, depending on requirements, this could be anything between 25–100 per cent of the laboratory floor area. Therefore comparative data is more useful if plant rooms are excluded from Balance & GIA.

GIA = NUA + Balance space

Table VII Pros and cons of embedded service risers within the building floor plate

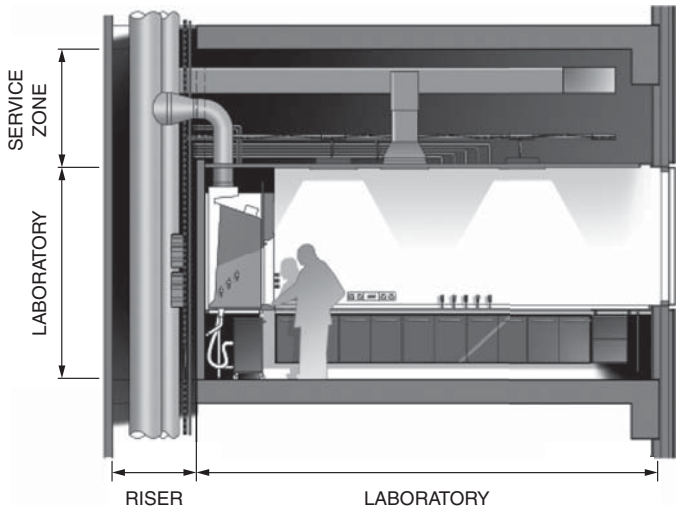
Pros	Cons
Potentially unrestricted views out	Restricted flexibility
Short horizontal service runs within ceiling void	Changes could disrupt adjacent spaces
Least space required out of floor plate	Maintenance access within “clean” environment
Low cost impact	

Table VIII Pros and cons of a sidestitial service zone

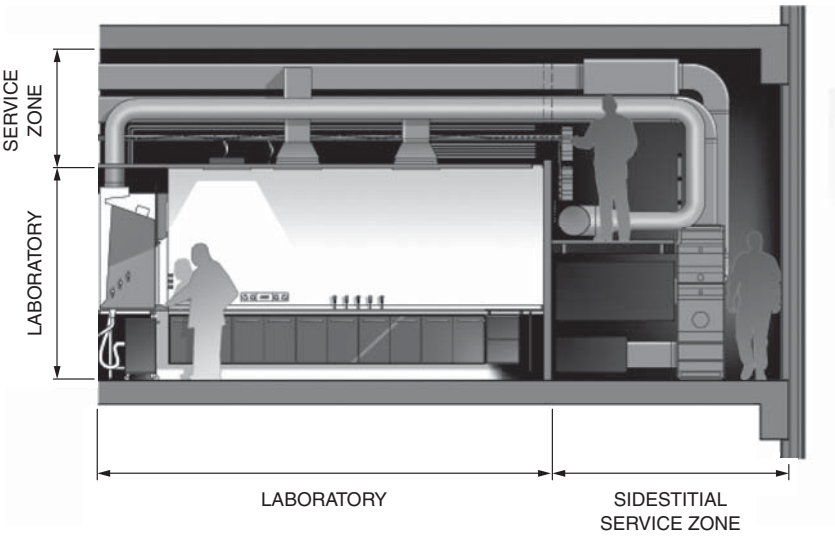
Pros	Cons
Good flexibility especially if services are modular	Restricted views on one side
Short horizontal service runs within ceiling void	Medium cost impact
Maintenance access outside “clean” environment	Dedicated zone required out of floor plate

Table IX Pros and cons of an interstitial floor service zone

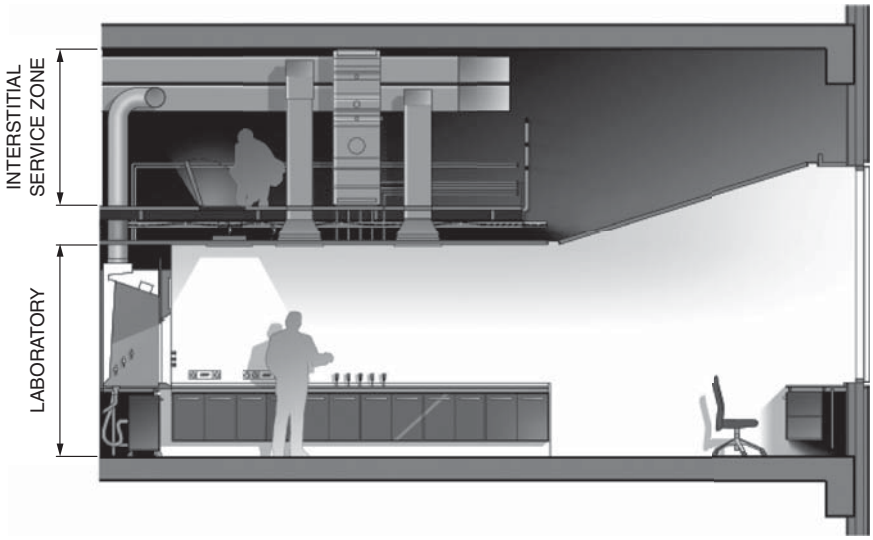
Pros	Cons
No restrictions to views out	High cost impact
Total flexibility for laboratories above or below	Increased building height
Maintenance access outside “clean” environment	
Limited horizontal service runs within ceiling void	



26.6 *Embedded service risers within the building floor plate*



26.7 *Sidestitial service zone*



26.8 *Interstitial floor service zone*

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3.2 Space designation (academic teaching)

In primary schools, science is regarded as one of the specialist practical activities in the curriculum and generally utilises a space that could also be used to teach design and technology (including food) and art. This space can either be a stand-alone discrete room or an open bay within a standard classroom. The base requirements for these spaces are a sink, washable floor and furniture for 'wet' practical activities.

In secondary schools, laboratories are generally located as suites. In addition to the laboratories, non-teaching support spaces are required such as preparation and storage areas. These areas would also provide a departmental staff base with space for the secure storage of pupil's records and other paperwork. Other associated teaching spaces for post-16-year-old students could include spaces such as a small science project room, green house or microbiology room. The Department for Children, School and Families (DCSF) has commenced various measures to improve the teaching of Science, Technology, Engineering and Mathematics (STEM) at all levels in line with comprehensive vision for UK science and innovation as set out in the government's Science and Innovation Investment Framework 2004–2014. One of the consequences of this could be that science teaching rooms become more flexible to allow the merging of computer design activities alongside the science curriculum.

In higher education, the traditional distinction between teaching and research laboratories has become less important and an increasing number of institutions are integrating these areas. There are several reasons for creating 'homogenous' laboratory facilities:

- Students at all levels are introduced to current techniques.
- Interaction is encouraged between faculty, graduate students and undergraduates.
- A standard serviced laboratory module accommodates change readily.
- Common and specialised equipment may be shared reducing project costs.
- Common facilities can share support spaces and specialty rooms.
- Greater utilisation of space and equipment enhances project cost justification.
- Teaching laboratories can be used for faculty research during semester breaks.

For these reasons, the standards applicable to academic research laboratories are also applicable to higher education.

3.3 Space designation (wet and dry research laboratories)

For the purpose of organisation, the different spaces in a laboratory facility are designated as primary, secondary, tertiary and balance spaces.

Primary space: Primary space is the area in which researchers perform their tasks. It is divided into primary laboratory space and primary office/write-up space, each with different accommodation and service requirements.

Primary laboratory space will normally include:

- Designated bench space for laboratory workers, including those who also have the use of an office/write-up space equipped with appropriate services and local storage.
- Additional workstations associated with a piece of equipment or an experimental procedure, which are not the principal work location of a particular person, but may be used by one or more persons from time to time including PC and other IT terminals, fume cupboards, extract cabinets and laminar flow cabinets.
- Shared storage for laboratory equipment and materials.
- Shared general facilities including display and notice boards, telecoms, dispensers.
- Facilities for waste disposal.
- Services as applicable to the laboratory type.

Primary office/write-up space will normally include:

- write-up areas for researchers/laboratory workers;
- offices for senior researchers/laboratory workers;
- services as applicable to the space type (similar to a standard office environment).

Secondary space: Secondary spaces (sometimes referred to as 'ancillary areas' or 'slave spaces') include all areas which accommodate functions directly related to the operations carried out in the primary space.

Secondary space will normally include:

- Facilities such as equipment rooms, instrument rooms and preparation rooms, which may not have special accommodation or service requirements, but which are better separated from the primary laboratories to increase utilisation through shared use.
- Highly specialised laboratory facilities such as containment suites, fermentation suites and decontamination suites whose accommodation needs are very different from primary laboratory spaces.
- Services as applicable to the laboratory type.

Tertiary space: Tertiary spaces are those whose functions, in addition to the primary and secondary spaces, support the goals and aspirations of the facility such as conference/meeting rooms, interaction spaces, general storage etc.

Balance space: Balance space will normally include cleaner's rooms, circulation spaces, lavatories, service risers and other circulation/support areas which are not defined as primary, secondary or tertiary space.

3.4 Assembly

Primary, secondary and tertiary space functional adjacencies: Zoning the building between laboratory and non-laboratory spaces will reduce costs because of the differing environmental requirements. For example, the ventilation of laboratories may require 100 per cent outside air while non-laboratory spaces can be designed with re-circulated air or naturally ventilated, similar to an office building.

Primary laboratory space is typically designed as modules to suit the briefed team sizes and their requirements with secondary laboratory spaces in close proximity to the primary space for ease of access. As the secondary spaces will be shared by the laboratory teams a separation zone or corridor should be included between the two to ensure no interference to the on-going research in the primary areas.

Primary office functions should be physically separated from the laboratory functions in accordance with Workplace Health and Safety guidelines. This ensures that laboratory activities are contained to areas where appropriate finishes, containment and air handling can be provided.

Primary write-up functions may be incorporated into the primary laboratory space subject to risk assessment in accordance with Workplace Health and Safety guidelines. Considerations for adjacencies between the office/write-up and laboratory space include:

- Visibility/safety: if processes are occurring in the laboratory that require viewing from a write-up space then laboratories and write-up should be directly adjacent to each other with good visibility between.
- Convenience: if the user is writing up an experiment and conducting an experiment simultaneously then direct adjacency is desirable.
- User preference: if neither of the above applies, then this is a matter of user preference.

Tertiary spaces do not always need to be close to the primary and secondary areas. Their location is a matter of preference and is determined through discussion with the stakeholders.

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Refer to Section 4 with respect to two case studies which illustrate different ways of assembling primary, secondary and tertiary spaces for a biomedical facility. Data provided for each indicates the ratio of the areas relative to the gross floor plate as well as primary/secondary/tertiary split.

3.5 Layout considerations

- Views/wall space: do the stakeholders want a view from their laboratories to the exterior or will the laboratories be located on the interior with wall space used for laboratory benches and equipment?
- Light sensitivity: some scientific methods do not require or cannot be exposed to natural light. Special instruments and equipment such as nuclear magnetic resonance (NMR) apparatus, electron microscopes, and lasers cannot function properly in natural light. These are typically located in the interior of the building.
- Shape of space: regular and rectangular shapes are generally the most efficient for laboratories although in some instances the shape of a space can be dictated by the size of a specialist piece of equipment, such as a robotics rig. Irregularities on the perimeter of a space will reduce the overall effective area.
- Open/cellular laboratories: in open plan laboratories, partitions should be used only where required for environmental, privacy or security reasons. This allows researchers to share not only the space itself but also the equipment, bench space and support staff. This format facilitates communication between scientists and makes the laboratory more easily adaptable for future needs.
- Interaction/collaboration: are the different spaces within the laboratory facility arranged so that the potential for formal and unplanned interaction is maximised? This is seen as key to promoting innovation amongst scientists.

Table X shows the relative areas for primary, secondary and tertiary spaces in a laboratory facility.

3.6 Areas/workspace in schools

Primary school (combined food/science/design and technology room): In primary schools shared practical spaces are provided where activities such as science, food and design and technology are taught. These specialist spaces would normally be provided with a sink, washable floor area and resources for simple 'wet' practical activities. For an example of a room layout see Figure 26.9a. Space standards shown in Table XI are based on Building Bulletin 99 (2nd Edition): Briefing Framework for Primary School Projects, DFES (BB 99, refer to Bibliography).

Secondary school (science laboratory): In secondary schools the preferred layout is for laboratories to be planned as suites or clusters that are flexible enough to allow for group and individual teaching. These spaces should integrate latest IT technologies to incorporate the teaching of design and engineering as well as durable finishes to allow for the teaching of 'wet' science. For an example of a room

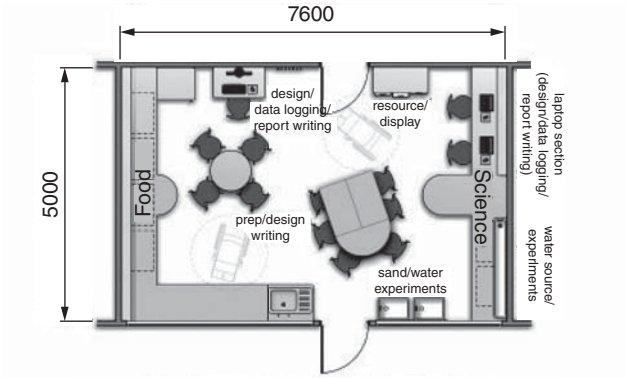
Table X Table of relative areas for primary, secondary and tertiary spaces in a laboratory facility

Laboratory space type	% of Gross
Primary laboratory space	18–23
Primary office/write-up spaces	14–18
Total primary space	32–36
Secondary space	16–23
Total primary plus secondary space	50–59*
Tertiary space	9–18
Total net useable space	**65–70**
Gross internal area (excluding plant rooms)	**100**

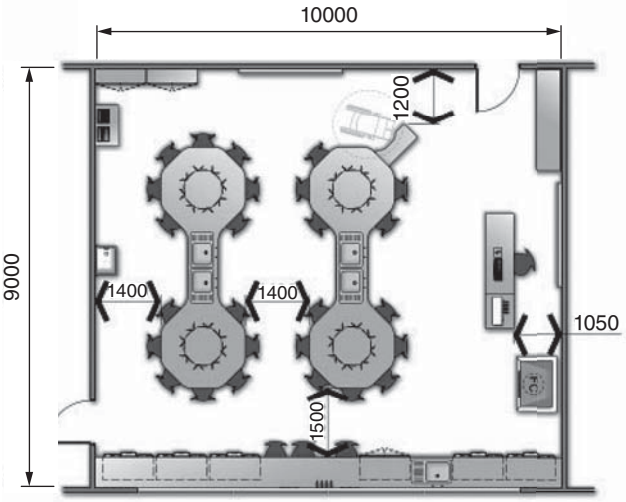
*The ratio of secondary to primary space is in the range 40–70%. It will depend, among other things, on the disposition of equipment between laboratory space and special instrument rooms.

Table XI Space standards for primary education laboratories

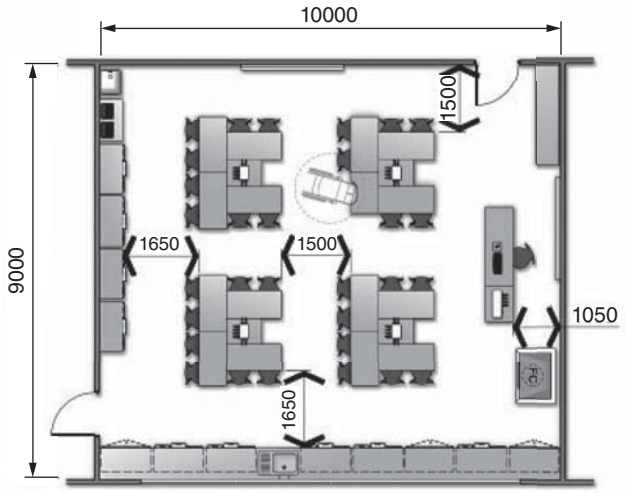
School size: Number of places	Group size (maximum number)	Average room size (m^2)	Number of rooms (minimum)
Less than 180 infants	8	24	1
Up to 120 juniors	8	24	1
121–360 juniors	8	38	2



a *Primary school laboratory suite for science and food activities (38m²)*



b *Secondary school laboratory suite (90m²) -lsland octagon option*



c *Secondary school laboratory suite (90m²) -8 person bollard/service column option*

26.9 *Typical layouts for academic (teaching) facilities (a) primary school; (b&c) secondary school laboratory suites*

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Table XII Space standards for secondary school laboratories

Secondary School 11–16 years old with no curricula emphasis
Space standards based on BB 98

School size: Number of places range in brackets	Group size (maximum number)	Average room size (m^2)	Number of rooms (minimum)
600 (577–642)	30	90	5
900 (850–945)	30	90	7
1200 (1125–1251)	30	90	9
1500 (1399–1555)	30	90	11

In addition to the above each room will require a 13 m^2 combined science preparation room/chemical store space.

Secondary post-16 years old, i.e. sixth form with no curricula emphasis
Space standards based on BB 98

Form size: Number of places	Group size (maximum number)	Average room size (m^2)	Number of rooms (minimum)
100	30	90	1
250	30	90	2

In addition to the above a single room will require 23 m^2 and two rooms will require 36 m^2 of combined science preparation room/ chemical store space.

Example of secondary school 11–16 years old with science, design and technology curricula emphasis

School size: Number of places	Group size (maximum number)	Average room size (m^2)	Number of rooms (minimum)
834–927	30	90	8

In addition to the above each room will require a 13 m^2 combined science preparation room/chemical store space.

Example of secondary post-16 years old, i.e. sixth form (with science, design and technology, music performing arts curricula emphasis)
Space standards based on BB 98

Space standards for secondary education laboratories

Form size: Number of places	Group size (maximum number)	Average room size (m^2)	Number of rooms (minimum)
137–361	30	90	3

layout see 26.9b and 26.9c. Space standards in Table XII are based on Building Bulletin 98: Briefing Framework for Secondary School Projects, DFES (BB 98, refer to Bibliography).

In addition to the standards shown in Table XII each laboratory will require a 13 m^2 combined science preparation room/chemical store space.

3.7 Academic (research), government, private/corporate

Laboratory allocation may be driven by space per researcher (e.g. biology and chemistry laboratories) or by equipment needs (e.g. analytical and engineering laboratories) leading to greater variances between facilities. In this handbook, the areas provided are based on space per researcher. Equipment driven laboratories require individual consideration with the stakeholders on a project basis. Table XIII provides recommended average areas for laboratory workers/researchers in the academic (research) and government sectors.

Note: Whilst, for example, a biologist needs far less fume cupboard space than say a chemist, there is a significantly greater need for ancillary equipment such as refrigerators, incubators, centrifuges and environmental rooms. The overall space requirements balance, for the purpose of flexibility, should be generic.

Private/corporate sectors often have their own standards for space organisation. They typically use benchmarking to estimate the amount of space and benching to be provided to each researcher. Benchmarking can be an unreliable process in part because it is difficult to acquire solid, relevant data. There is a very wide range between the minimum and maximum for commercial data which

Table XIII Table of average areas per person (academic, government sectors)

	Area/Person (m^2)
Net primary laboratory area/laboratory worker	6–10*
Net total primary space/researcher	10–16
Net primary plus secondary space/researcher	15–25
Gross internal area (excluding plant rooms)/person	20–30

*Add 2–3 m^2 when a writing place is included in the laboratory area.

Table XIV Table of average areas per person (example of guidelines adopted by a large UK private pharmaceutical company)

	Area/Person (m^2)
Net primary laboratory area/laboratory worker	10–11
Net total primary space/researcher	14–17
Net primary plus secondary space/researcher	18–24
Gross internal area (excluding plant rooms)/person	23–34

Table XV Recommended aisle distances in laboratories

Minimum distance	Width (mm)
Between front of bench or work station and a facing wall, other furniture or equipment or pedestrian route (with one person at bench)	1000*– 1400*
Between benches, furniture or equipment without work spaces either side allowing passage of one person at a time	1000*
Between two people back to back but no need for a third person to pass between front of facing benches, work stations or equipment where people work allowing one of the people to pass behind the other	1400*
Between two people back to back where space is required for a third person to pass between front of facing benches, work stations or equipment where people work allowing a third person to pass behind the others	1450*–1650 (1800 exceptionally)

*1200 mm is required for DDA compliance and 1500 mm (subject to risk assessment) when opposite a fume cupboard or microbiological safety cabinet.

reflects the complexity of uses in laboratory environments (e.g. US laboratories can range from 22.7–41.1m^2/person, net primary plus secondary space/researcher). The areas provided in Table XIV are the guidelines adopted by a large UK private pharmaceutical company.

3.8 Circulation

General

- Corridors, stairs, lifts, ramps, holding and other balance areas must allow ease of movement of people, materials, waste and equipment in respect of access routes dimensions, configuration and doors.
- Circulation should provide safe pedestrian egress from each individual laboratory and laboratory support space through an uncomplicated path of egress to the building exterior at grade.
- Separation of workspace and circulation reduces the likelihood of accidents and eases the problem of escape from hazards.
- The circulation system should accommodate the preferred adjacencies identified for the relationships between primary, secondary and tertiary laboratory spaces.

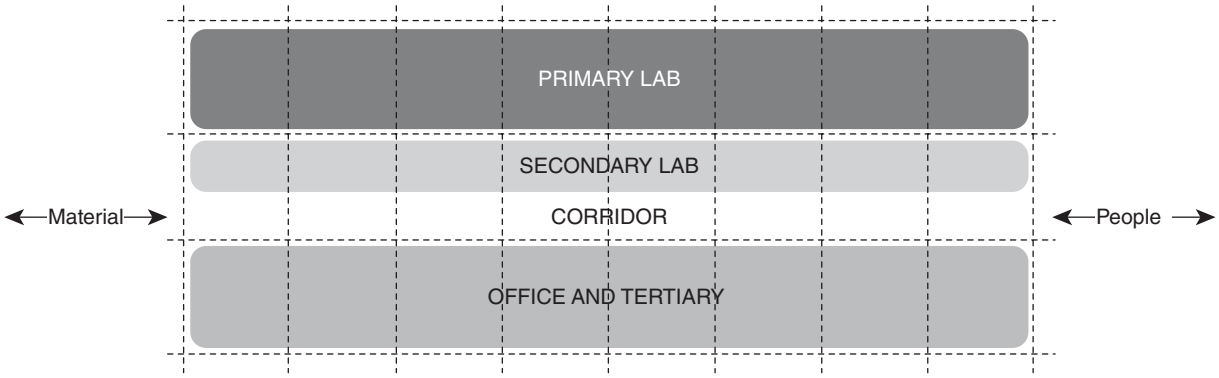
Adjacencies with corridors can be organised with a single, two (racetrack) or a three-corridor scheme. There are a number of variations to organise each type (Figures 26.10, 26.11 and 26.12).

Distance between aisles

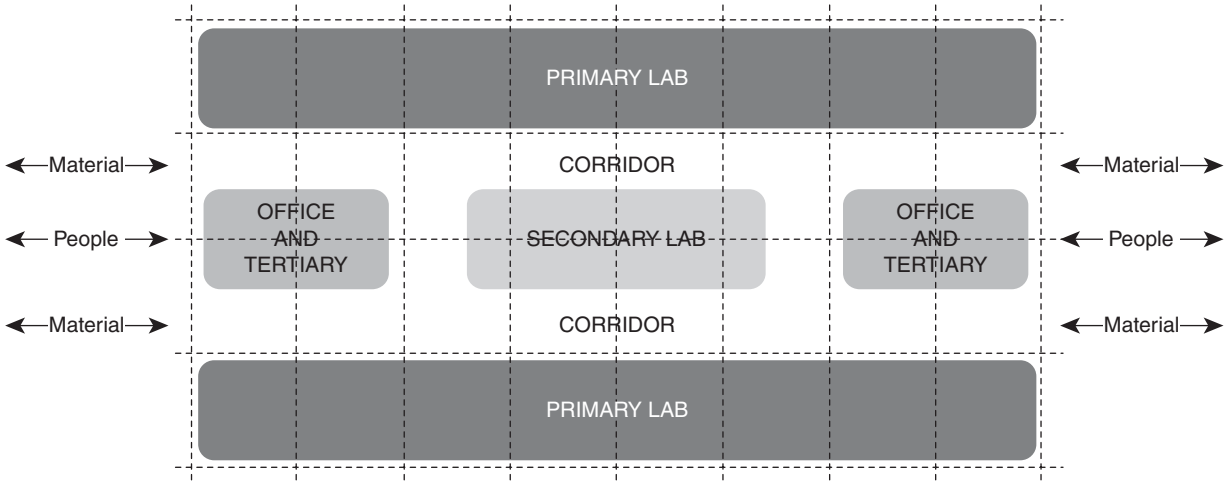
Recommended clear distances between aisles in laboratories is indicated in Table XV and illustrated in Figure 26.13.

Aisles and corridor widths

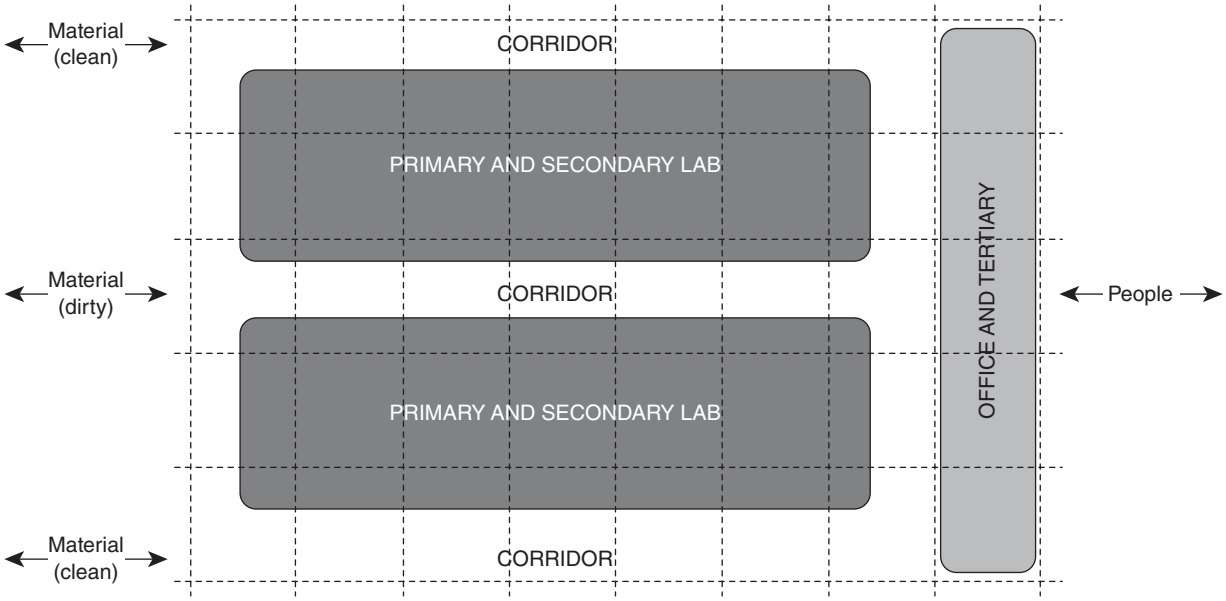
Recommended clear distances between aisles and corridors in laboratories is indicated in Table XVI and illustrated in Figure 26.14.



26.10 *Plan layout illustrating a single-corridor arrangement. This layout is efficient however the single circulation route may result in material/people flow cross-over and conflict*

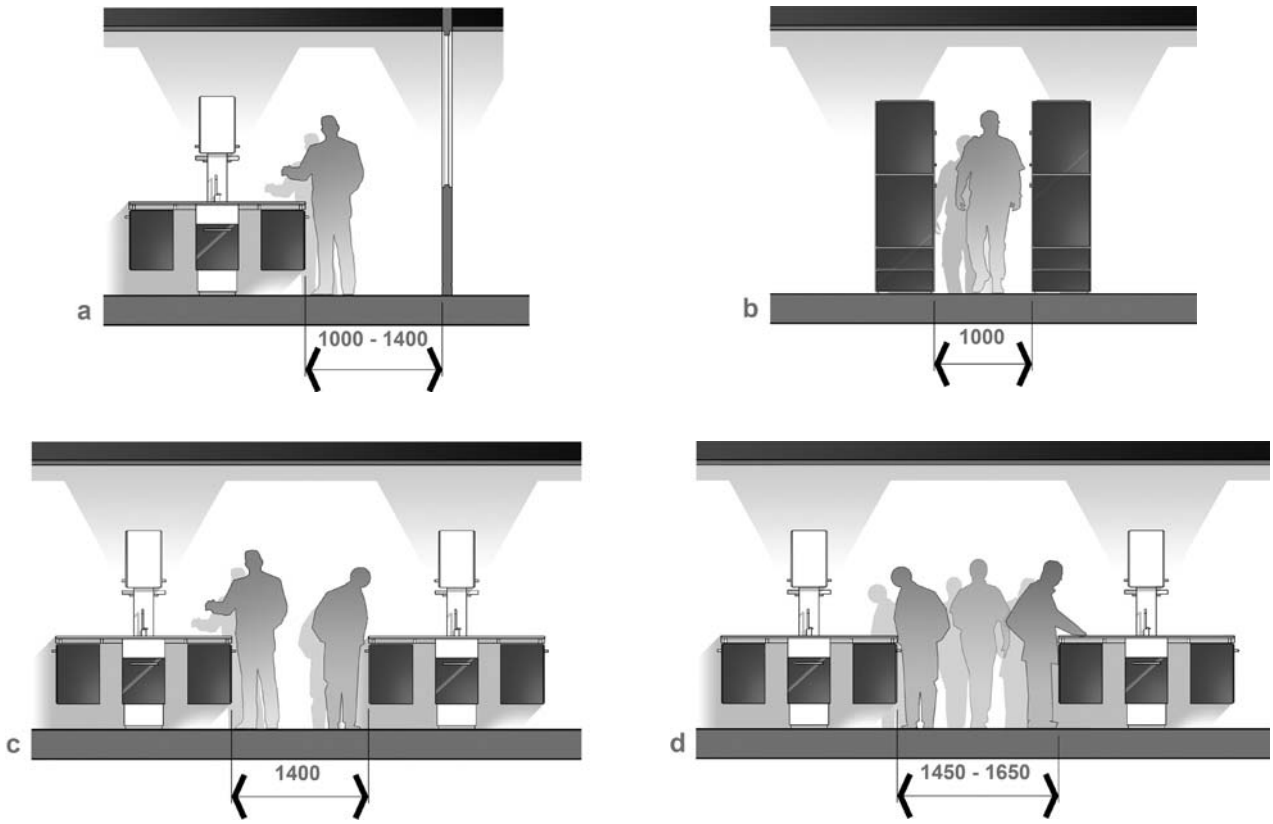


26.11 *Plan layout illustrating two-corridor (racetrack) arrangement. This layout effectively separates people and material circulation within the facility*



26.12 *Plan layout illustrating three-corridor arrangement. This layout provides the greatest opportunity for optimising circulation within the facility however it is also potentially the most inefficient with respect to area*

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26.13 *Aisle distances (a) bench and wall/equipment, single throughway; (b) bench and/or equipment, no workstations, single throughway; (c) two workers back to back, single throughway; (d) two workers back to back, multiple throughways*

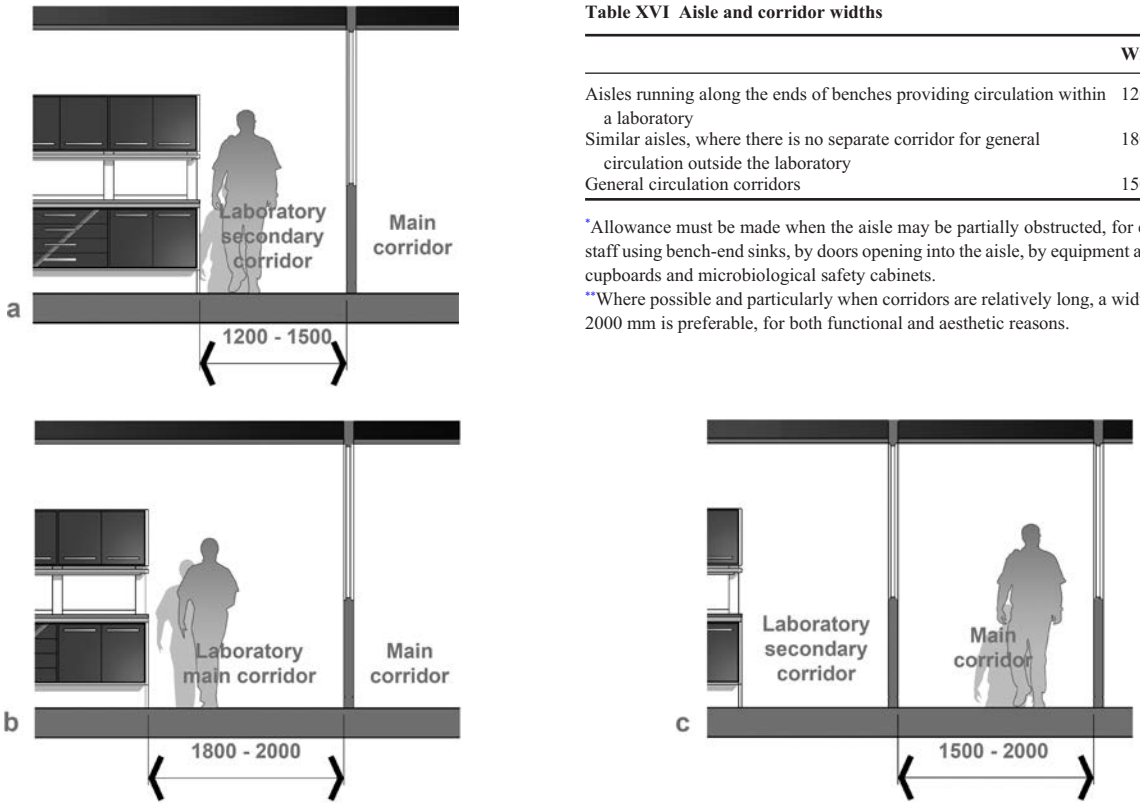


Table XVI Aisle and corridor widths

	Width (mm)
Aisles running along the ends of benches providing circulation within a laboratory	1200–1500*
Similar aisles, where there is no separate corridor for general circulation outside the laboratory	1800–2000*
General circulation corridors	1500–2000**

*Allowance must be made when the aisle may be partially obstructed, for example by staff using bench-end sinks, by doors opening into the aisle, by equipment and by fume cupboards and microbiological safety cabinets.

**Where possible and particularly when corridors are relatively long, a width of 1800–2000 mm is preferable, for both functional and aesthetic reasons.

26.14 *Aisle and corridor widths (a) at the ends of benches, additional means of circulation within the laboratory; (b) at the ends of corridors, single means of circulation within the laboratory; (c) general circulation*

Doors

Table XVII indicates the minimum width dimension (clear opening) recommended for at least one door into laboratories and equipment rooms to accommodate the periodic movement of equipment. This can be accomplished using an opening with a 900 mm active leaf and a 300 mm inactive leaf. Future equipment should be anticipated and equipment lists reviewed to verify that individual pieces of equipment can be transported and manoeuvred between spaces.

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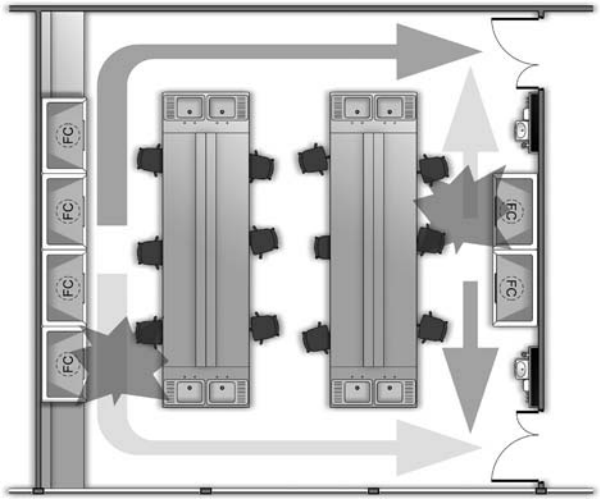
Table XVII Door width requirements (minimum)

	Leafs (no.)	Leaf width (mm)
At least one doors into laboratories and equipment rooms	1.5 leafs	1200

3.9 Escape

Under the Building Regulations 2000 Approved Document B (AD:B) Volume 2 (2006 Edition), laboratories are considered under the same purpose group as an office whereby the maximum travel distance where travel is possible in more than one direction is 45 m while if in one direction only it is 18m. In the past, the Building Regulations stipulated a variation to this of 18m travel distances where travel is possible in more than one direction while 9 m if in one direction only for laboratories with open heat sources (e.g. bunsen burners) defining them as 'Places of Special Fire Hazard'. This is no longer included in the latest amendment (2006) as all fire safety in work places is covered by Regulatory Reform (Fire Safety) Order 2005 where the onus now is for a 'responsible person' to arrange for a risk assessment for fire safety to be undertaken, Figure 26.15. Additionally, BS 9999:2008 – *Code of practice for fire safety in the design, management and use of buildings* offers alternative design solutions for fire escape provisions. Guidance is given on how the prescriptive requirements of AD:B can be relaxed using fire engineering principles.

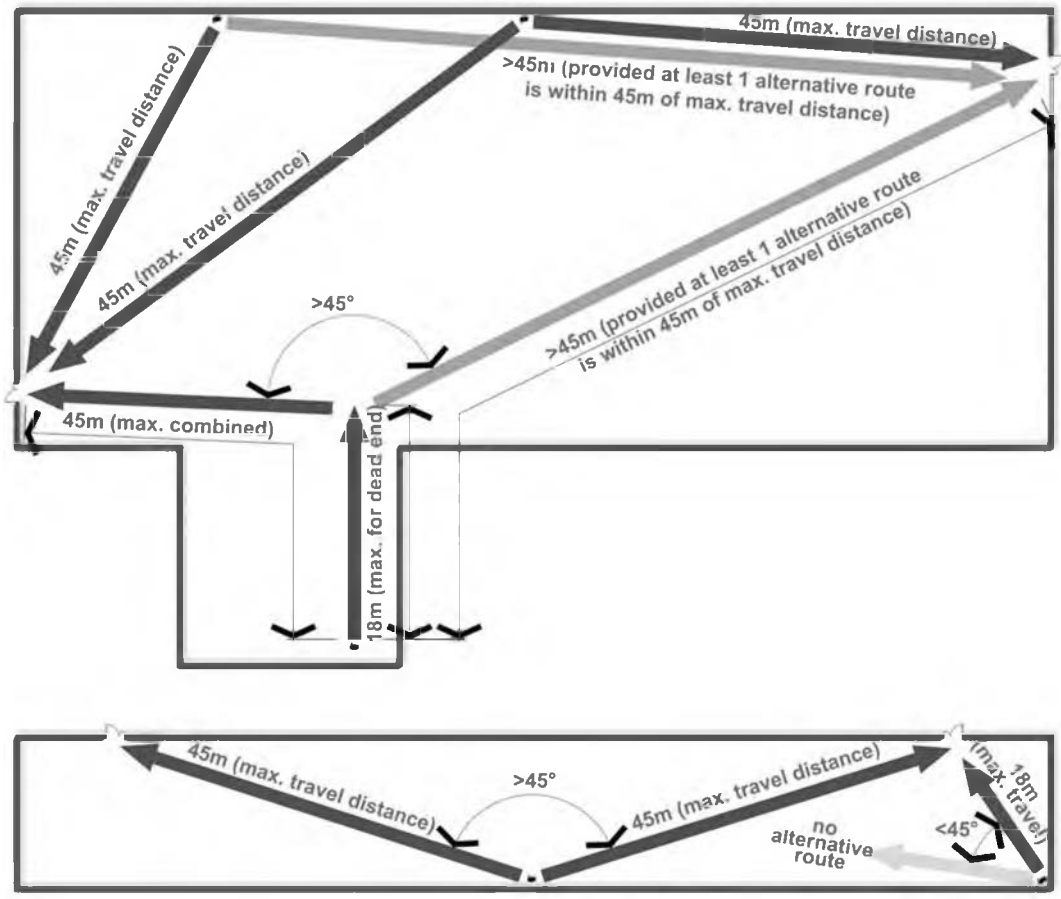
Where a piece of equipment in a laboratory, which could be the source of a health hazard (such as a fume cupboard exploding), is located within an escape route it is recommended that an alternative route be allowed for in the design. In addition to this, if gas cylinders are required within a laboratory they should be securely fixed in a position away from any escape route or final exit (Figure 26.16).



26.16 *Alternative means of escape where potential sources of hazard/s exist*

3.10 Lifts

The service lift also often doubles up as access to the plant room for items of plant. Engineers will typically ask for a lift with the capacity to take a 2 m cube (minimum) to allow items of air handling equipment to be dismantled and taken down in the lift and this would generally be a suitable size to accommodate most large equipment in a laboratory, for example, a –80˚ freezer or an item of furniture. Specific requirements should be confirmed with the stakeholder.

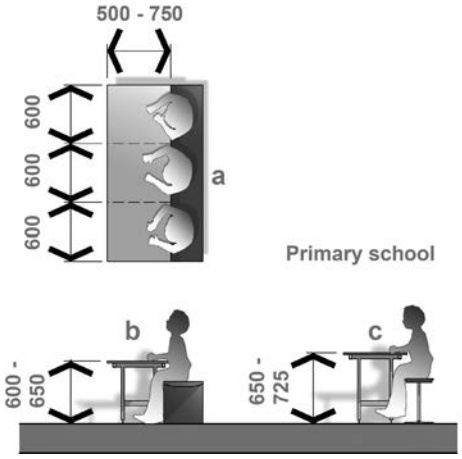


26.15 *Means of escape in a laboratory*

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Table XVIII Recommended student laboratory benching dimensions for primary schools

	Dimension (mm)
Length of bench per student	600
Clear bench depth for normal requirements	500–750
Bench height seated	600–650
Bench height standing/seated on laboratory stool	650–725



26.17 *Recommended student laboratory benching dimensions for primary schools (a) plan of bench; (b) seated; (c) standing/seated on laboratory stool*

3.11 Furniture: general concepts

Laboratories should be designed to allow relocation of furniture within the limits of the modular configuration. Particular reference is made to the selection of laboratory benching and storage systems and the distribution of services systems. Performance criteria to consider when selecting laboratory benching include:

Modularity

- Modular lengths (typically in increments of 1000 mm for UK furniture manufacturers and 600, 900 or 1200 mm for other European manufacturers), depths and heights.
- Pre-installation services.
- Prefabrication of furniture.
- Provision of interchangeable components and accessories.

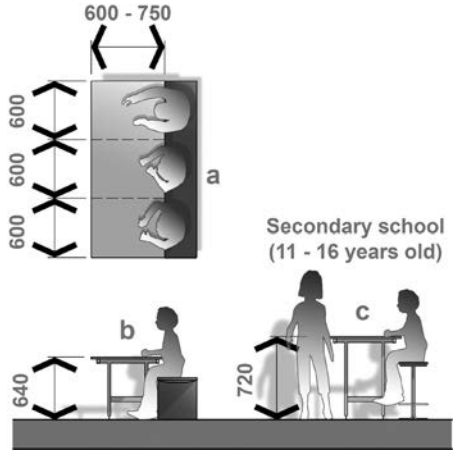
Flexibility

- Flexible and adaptable system that can be readily moved, repositioned with little or no impact on the building structure and finishes and with minimum disruption to the end user.

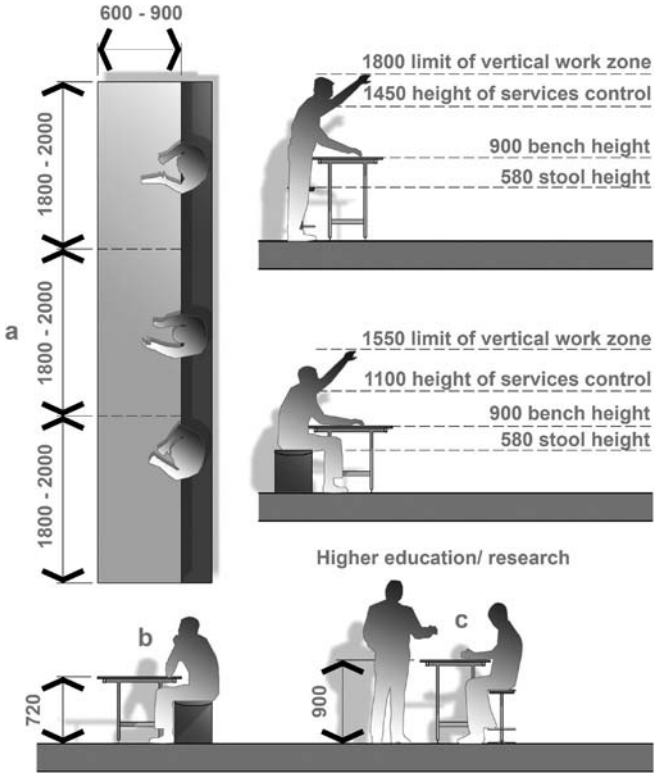
Table XIX Recommended student laboratory benching dimensions for secondary schools (a) plan of bench; (b) seated; (c) standing/seated on laboratory stool

	Dimension (mm)		
	Secondary (11–16 years)	Secondary (post-16 years)	DDA
Length of bench per student	600	600–1200	1200
Clear bench depth for normal requirements	600–750	600–750	600–750
Bench height seated	640	720	850
Bench height standing/ seated on lab stool	850	900	
Bench height adjustable	700–1050*	700–1050*	700–1050*

* Recommended height adjustability range where necessary.



26.18 *Recommended student laboratory benching dimensions for secondary schools (a) plan of bench; (b) seated; (c) standing/ seated on laboratory stool*



26.19 *Recommended laboratory benching dimensions (length, depth and height) for higher education/research. (a) plan of bench; (b) seated; (c) standing/seated on laboratory stool*

- Height adjustable bench and laboratory chair is recommended where possible (subject to budget and requirements for vibration control and cleanliness).
- Services distribution independent from the laboratory furniture with service pick-up points from ceiling, walls or pods.
- Under bench and overhead storage systems independent of laboratory furniture, movable and readily relocatable.
- Vibration (where sensitive microscopes are used, anti-vibration tables should be considered).

Maintenance

- Ease of cleaning and maintenance and ease of access for service and maintenance purposes.
- Robustness

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Table XX Recommended laboratory benching dimensions for higher education/ research

	Dimension (mm)
Length of bench per researcher	1800–2000 (2400 exceptionally)*
Clear bench depth for normal requirements	600–900**
Bench height seated	720***
Bench height standing/seated on laboratory stool	900****
Bench height adjustable	700–1050*****
Height of services control (sitting/standing)	1100/1450
Limit of vertical work zone (sitting/standing)	1550/1800

*Suitable length will depend upon the amount of bench-mounted equipment. 2000 mm is a good starting point. Exceptional cases include benchmark allowances made in private/corporate sectors.
**Certain operations and pieces of equipment may require a greater bench depth. These need to be identified early in the briefing process and are generally accommodated on double depth peninsular benches. 750 mm is a good median figure.
***Increases to 850 mm for DDA compliance.
****Care should be taken to co-ordinate the bench height with under bench equipment such as refrigerators and freezers as these vary in height.
*****Accommodates DDA requirements and is recommended where possible (subject to budget and requirements for vibration control and cleanliness).

Disabilities Discrimination Act (DDA) Requirements

- Provide height adjustable furniture where possible to accommodate various equipment and DDA requirements.
- Provide at least one DDA compliant workstation/write-up area for each laboratory unit and in accordance with stakeholder requirements.

Finishes

- Work surfaces should in general be impervious and readily cleanable and where required chemically resistant. Commonly used materials are laminate faced boards, stainless steel faced boards, solid timber sheets, laminated timber sheets, solid laminate sheets, solid epoxy resin sheets, solid phenolic resin sheets and acrylic polymer sheets. The most appropriate of these will depend on the materials and chemicals being used and cost parameters for the each laboratory bench.

Bench length, depth and height (primary schools)

As science is undertaken in a multi-functioning area around clusters of tables, perimeter benching or a combination of the two and limited to groups of 8 children the only critical dimension in planning such a space is to ensure wheelchair access to key facilities within it (Table XVIII and Figure 26.17).

3.12 Storage

General concepts

- Centrally located storage rather than local is preferred (for ease of maintenance, avoiding duplication, diversity and more intense use of equipment).
- Storage depth and height dimensions should be based on convenient reach.
- Modular (based on industry standard sizes where possible).
- Movable/adjustable.
- Robust.

Convenient reach

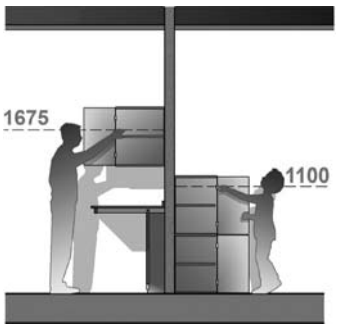
Comfortable reach into a 300–500 mm deep cupboard above floor level is as follows (Table XXI and Figure 26.20).

Cupboard depth and height

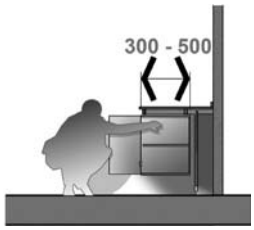
The depth of storage cupboards should be from 300–500 mm for ease of access and fit with bench top and rail, Figure 26.21. The maximum height and lowest level of storage which is frequently used should be based on convenient reach. Extreme high and low zones tend to be used for dead storage (Table XXII and Figure 26.22)

Table XXI Convenient reach dimensions for ages 7–18+ and DDA compliance

Age	Convenient Reach (mm)
7 years	1100
9 years	1170
10 years	1260
11 years	1300
12 years	1375
17 years	1640
18 years +	1675
DDA reach height	1160



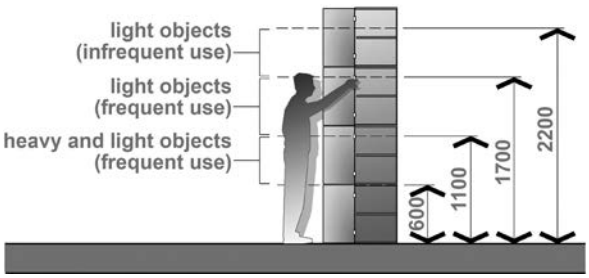
26.20 *Convenient reach dimensions for ages 7–18+ and DDA requirements*



26.21 *Storage depths based on convenient reach*

Table XXII Recommended storage heights based on convenient reach

	Dimension (mm)
Light objects infrequently used	1700–2200
Light objects frequently used	1100–1700
Heavy & light objects frequently used	800–1100
Heavy objects infrequently used	600–800
DDA control height	1200 max – 380 min

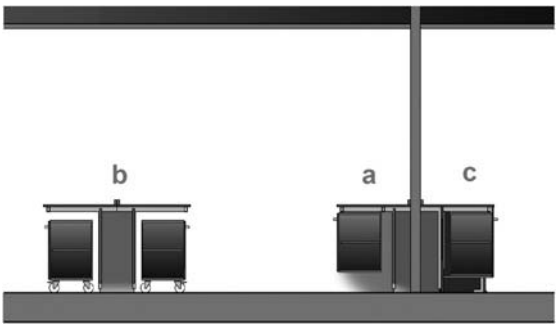


26.22 *Recommended storage heights based on convenient reach*

Underbench storage

Underbench storage is generally provided in three ways namely mobile (on castors or glides), suspended units (supported above the floor off furniture frame) and plinth mounted (floor standing), Figure 26.23. The location and number of these need to meet functional requirements allowing sufficient gaps where anyone will be working seated. Movable units (i.e. mobile or suspended) are recommended where cleaning around, ease of maintenance and

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26.23 *Underbench storage options (a) suspended; (b) on castors or glides; (c) plinth mounted*

relocating of storage units in areas are seen as important. In an ideal situation space occupied by underbench units should not exceed 50 per cent of the underbench space.

Gas cylinder storage
The mechanical engineering consultant will be primarily responsible for defining gas cylinder storage requirements, however, the following should be considered:

- Local standards and regulations (refer to Bibliography).
- The types of gas required and whether they are to be temporarily stored for later transportation or permanently stored for piping to their locations.
- Gas store proximities, cylinder separation for different gas types, explosion proofing/venting/fire rating, accessibility for delivery lorry to refill dewar/s.
- Pipework distribution routes, venting, proximity to electrical services.
- Leak detection and alert systems including links to fire alarm/building management system (BMS)/shut off at manifold and laboratory.
- Electrical equipment in store and laboratory.
- Ventilation equipment in laboratory.
- Gas supplier to the facility.
- Facility representative responsible for the above.

Liquid nitrogen storage
If the fill point is located internally, continuous ventilation and an oxygen level detection system linked to the BMS will be required. Ideally, store externally, located against a fire rated external wall. This requires no specialist venting. The only requirement for an external fill point would be a secured lightweight lean-to-roof arrangement, to protect it from the elements. In areas where liquid nitrogen is being transferred between containers, care should be taken in the selection of floor and wall finishes as contact with liquid nitrogen can lead to their rapid deterioration due to thermal shock.

3.13 Equipment

General concepts
Space allocation is dependent on individual requirements which are subject to change. Utilise removable or relocatable equipment in preference to purpose-built fixed facilities where possible. Ideally, laboratory benching should be removable to allow floor standing equipment to be incorporated as required during the life of the laboratory.

General equipment
General/standard floor standing equipment may include items noted below (indicative sizes are shown). Confirmation with manufacturers is necessary as individual sizes vary considerably depending on capacity and make.

- Underbench fridge/freezer 600w × 600d × 650–875h
- Tall/floor standing fridge/freezer 600–750w × 600–750d × 1800h
- –50° to –80° freezer 1130w × 875d × 1990h
- Centrifuge 900–1200w × 900d × 950h
- Oven 1000w × 1000d × 800h

(Note: large storage freezers, typically –80°C, should be located within designated freezer rooms which will provide sufficient noise attenuation and local cooling also reducing energy usage.)

Special equipment
Special equipment may include:

- NMR
- X-ray and other imaging equipment
- IT equipment
- Balances and other measuring equipment
- Mass spectrometers
- Autoclaves.

Room dimensions, structural loading, rigidity and resonance, environmental conditions, wave and particle shielding and services connections for special equipment require individual consideration and therefore should be dealt with on a case-by-case basis and must take full account of manufacturer's and health and safety requirements. Where equipment that is affected by magnetic fields is being considered, care should be taken to check their proximity to moving metal objects such as lifts.

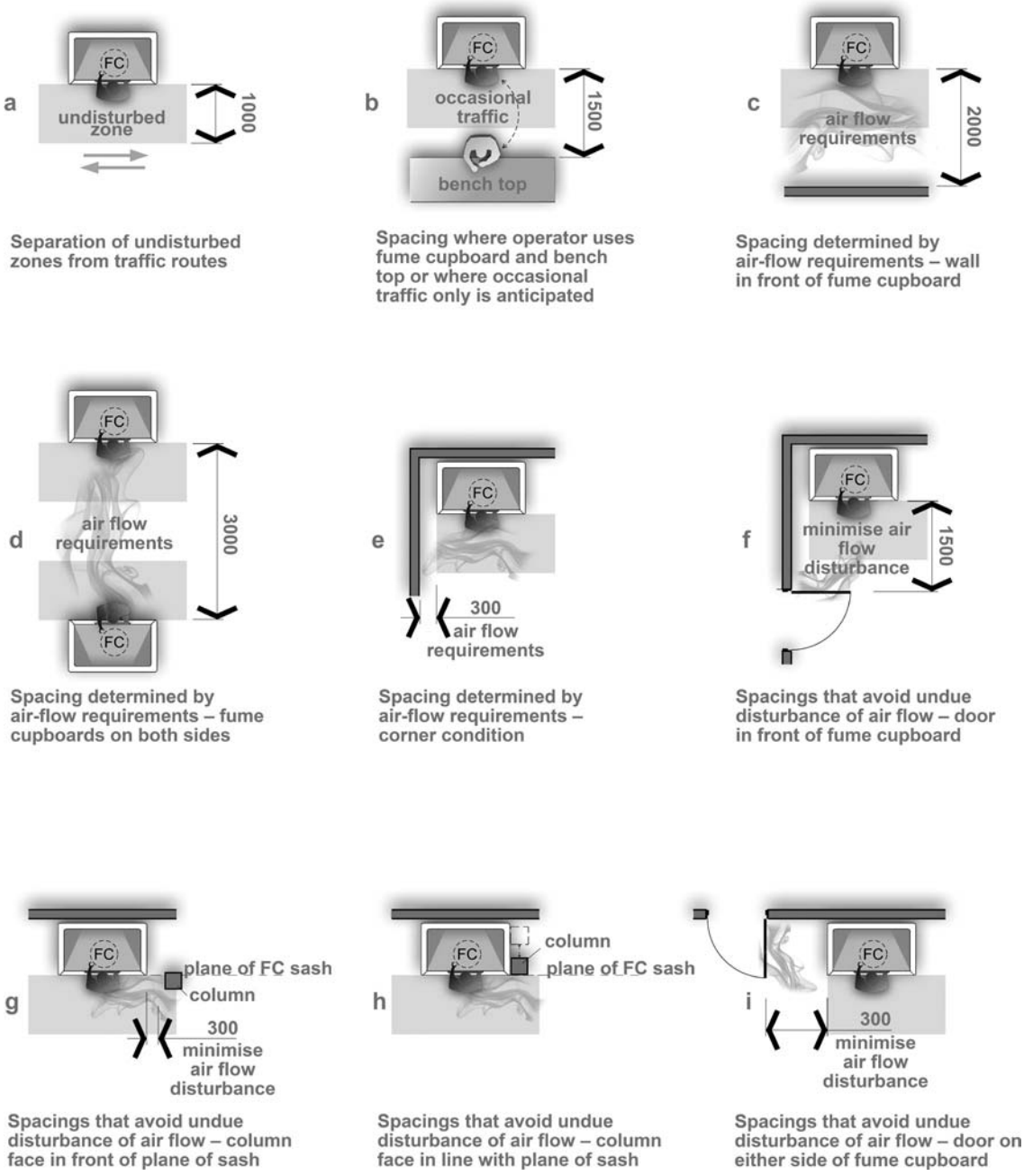
Local exhaust ventilation (LEVs)
A LEV is a ventilation system that takes dusts, mists, gases, vapour or fumes out of the air so that they can't be breathed in. The Control of Substances Hazardous to Health Regulations require prevention or adequate control of exposure to hazardous substances. Where the risk assessment determines that local exhaust ventilation is required as part of the control measures employed, the LEV must be suitably selected, used, tested and maintained and appropriate records kept. An LEV may be tiny and built into a hand-held tool or it may be large enough to walk into, such as a fume cupboard (described in more detail in this section).

Fume cupboards (FCs)
BS EN 14175 Parts 1 to 6 represents the most recent fume cupboard standard and partially supersedes some parts of the previous standard, BS 7258. BS EN 14175 applies to types of fume cupboard not previously covered by BS 7258, such as walk-ins, VAV, horizontal sashes and low cill cabinets. It is more of a product standard and is relatively weak with reference to installation requirements. BS EN 14175 puts greater onus on individual testing by manufacturers to justify the performance of their cupboard. It is hoped that as more tests are published greater guidance will become available on locating them. Until this is forthcoming, reference should continue to be made to elements of BS 7258.

All FC setting out should give optimum protection to the user working with chemicals/aerosols. Single person fume cupboards are generally 1500–1800 mm long. Larger standard units, generally for two persons, are up to 2400 mm long. They should be positioned to avoid disturbances to the cupboard and its operator (Figures 26.24 and 26.25). Disturbances include people walking parallel to it, open windows, air supply registers or laboratory equipment that creates air movement such as, for example, vacuum pumps and centrifuges. They should be located away from high traffic areas, doors and air supply/exhaust grilles that may interrupt airflow patterns. There should be an alternative means of escape in the event of an explosion/fire.

The use of re-circulating fume cupboards (non-ducted) can greatly reduce energy consumption although the cupboard usage may be limited. Before selecting a re-circulating fume cupboard a

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26.24 *Fume cupboard minimum distances for avoiding disturbances to the fume cupboard and its operator (as stipulated in BS7258)*

review of the chemicals being used within needs to be undertaken to ensure its filter is able to maintain a safe working environment. Refer to BS 7989 specification for re-circulatory filtration fume cupboards. Though the standard is distinct from BS 7258, it is similar in structure and cross-references BS 7258.

Re-circulating and re-locatable FCs with flexible ducting and variable extract are recommended for maximising flexibility and minimising energy consumption. The number of fume cupboards required should be confirmed with stakeholders.

Microbiological safety cabinets (MSCs)

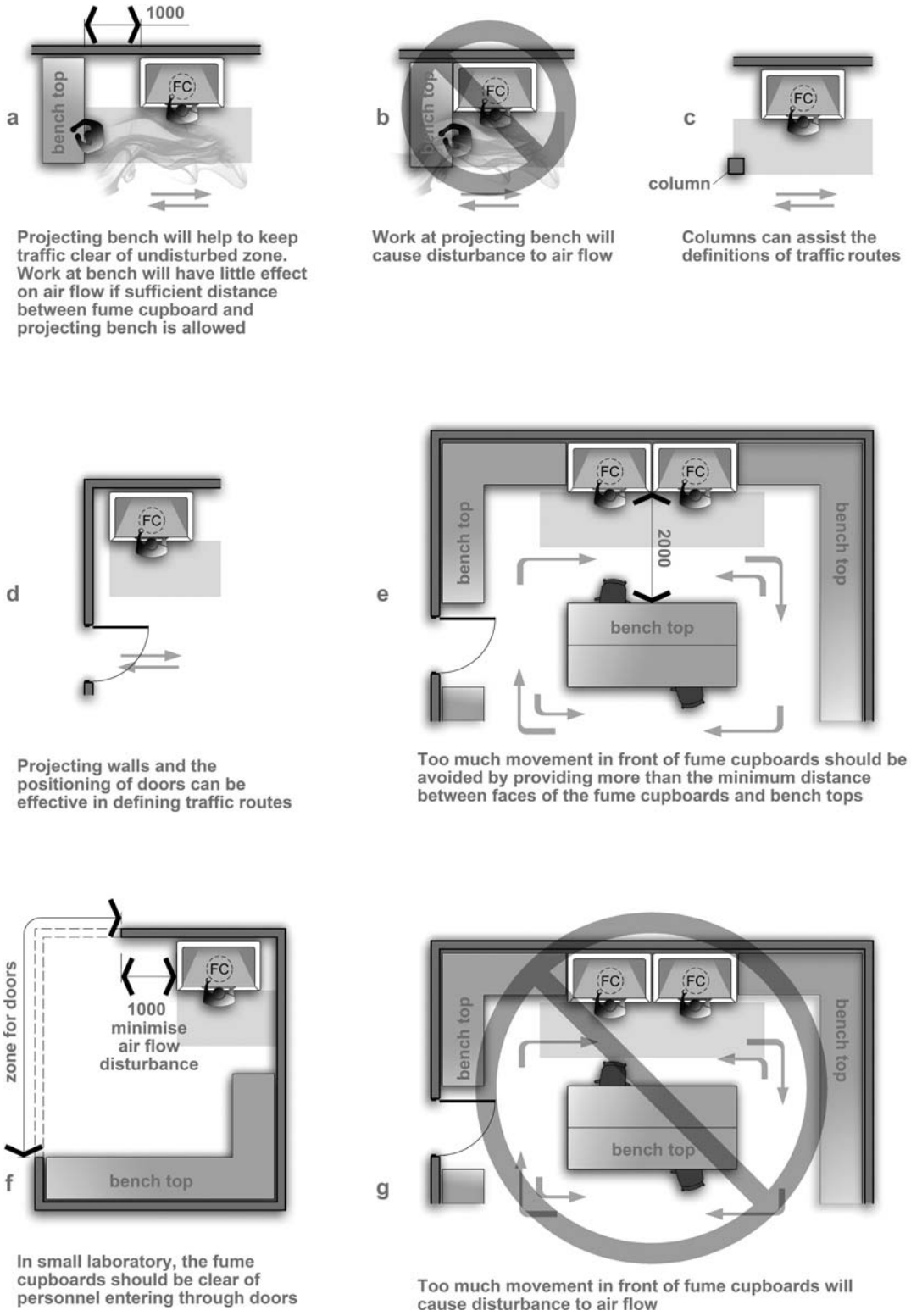
All MSC setting out should comply with BS 5726 and EN 12469 to give optimum protection to the user working with biological agents up to Hazard Group 4. Single person safety cabinets are generally 1300–1800 mm long. Larger standard units, generally for two persons, are up to 2400 mm long.

They should be positioned to avoid disturbances to the cupboard and its operator (Figures 26.26 and 26.27). Disturbances include people walking parallel to it, open windows, air supply registers or laboratory equipment that creates air movement such as, for example, vacuum pumps and centrifuges. They should be located away from high traffic areas, doors and air supply/exhaust grilles that may interrupt airflow patterns.

All MSCs are designed to comply with one of the three classifications defined in BS EN 12469:

- A Class I safety cabinet provides a wide performance envelope for the user from aerosol hazards and other particulate within the cabinets work area. All extract air is exhausted through HEPA (high efficient particulate air) filtration generally to atmosphere. Re-circulating MSCs are also available though the usage of these is dependent on the work being undertaken within them.
- A Class II safety cabinet, unlike the Class I safety cabinet, provides protection to both the user and the material within the cabinet's working area. Protection for the user is provided by means of an advanced inflow air curtain whilst the sample material in the cabinet is protected from the dirty laboratory environment by a constant stream of HEPA filtered air.

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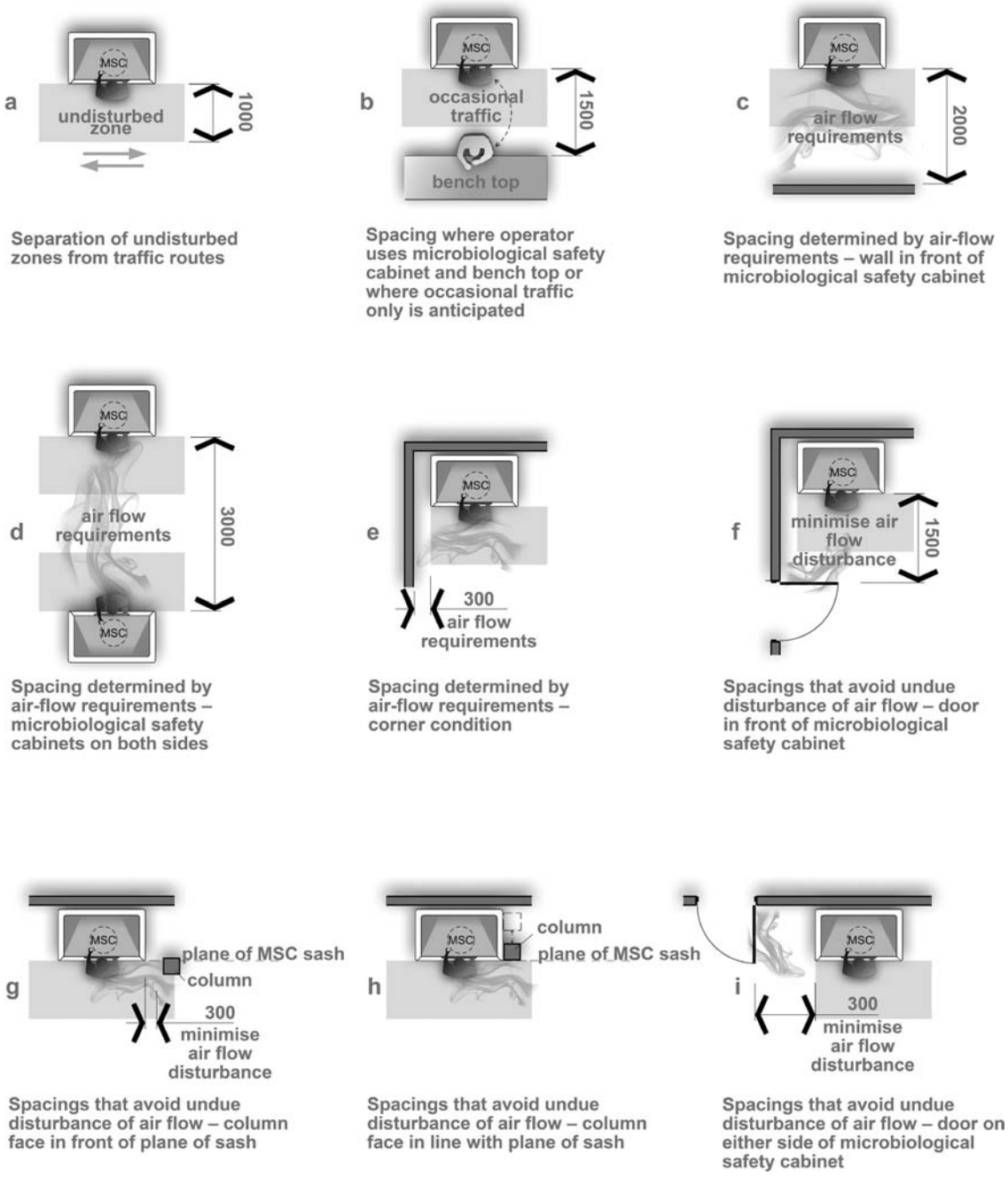
26.25 *Fume cupboard planning arrangements for avoiding disturbances to the fume cupboard and its operator and from other personnel (as stipulated in BS7258)*

- A Class III safety cabinet, like the Class II safety cabinet, provides protection for both the user and product but with a higher degree of protection than a Class II cabinet. For the user this is achieved by means of an additional barrier such as working through gloves or gauntlets and protection to the material within the cabinet by means of the filtered supply air operating at a negative pressure to the surrounding environment and with the exhaust air being vented through a HEPA filter to atmosphere. A Class III microbiological safety cabinet is a highly specialised product designed for the most hazardous work, typically carried out in a Containment Level 3 or 4 facility.

Some manufacturers also produce a hybrid Class I/III cabinet but this is not described within the British Standard. The hybrid, as the name suggests, can be used as either a Class I or a Class III cabinet by the use of a removable port that attaches to the front aperture. However the construction and testing of these cabinets is such that when used in Class III mode it is not equivalent to the specification of a standard Class III cabinet and should always be checked.

Both BS EN 12469 and the Advisory Committee for Dangerous Pathogens (ACDP) recommend that natural gas should not be used with the cabinet (as this will have an impact on the cabinet's airflow, the down flow filter integrity and could possibly prove to be a

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26.26 *Microbiological safety cabinet minimum distances for avoiding disturbances to the cabinet and its operator*

fire hazard – several cabinets have been set alight this way), as such this should not be offered as a standard fixture on the Class II MSC. If, after a risk assessment, it is deemed necessary to have natural gas then a special gas solenoid type tap together with a low profile, foot operated ignition type burner should be used. The number of cabinets required should be confirmed with stakeholders.

3.14 Finishes and fittings

Finishes

Finishes should be suitable to the relevant usage, containment level and cleanroom classification for the laboratory. For general wet chemical and biological laboratories and darkrooms, a solvent resistant, slip resistant and coved vinyl or rubber flooring using sheet goods rather than tile is recommended. Walls and ceilings should be robust and cleanable. Generally a fully accessible suspended ceiling installation (where containment/cleanroom classifications do not require it to be fully sealed) will allow full access to above ceiling services infrastructure and allow some acoustic treatment to the space though in some spaces no ceiling at all can be more appropriate. Refer to bibliography for further references on finishes specification.

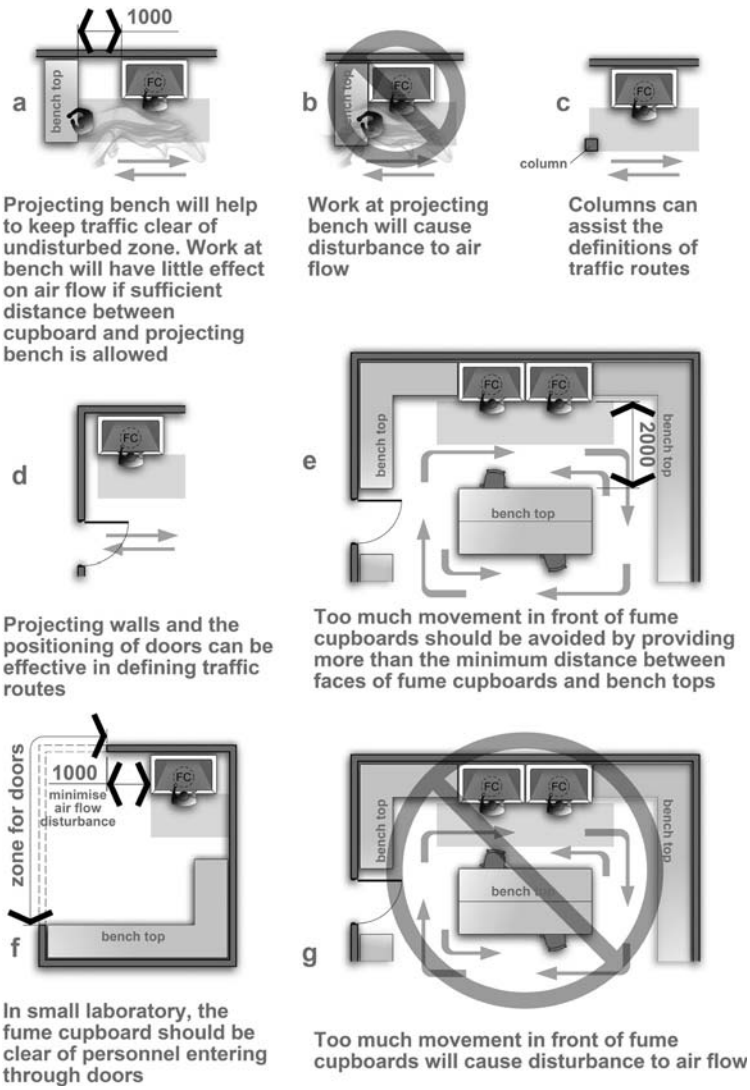
Handwashing sinks

Handwashing sinks are typically required for each laboratory and should be located near the point of exit from the laboratory or in the anteroom. Handwashing sinks for particularly hazardous chemicals or biological agents may need elbow (for Containment Level 2 areas) or electronic sensor controls (for Containment Level 3 areas).

Emergency eyewash and safety shower facilities (EE/SS)

Laboratories using hazardous materials must have an eyewash and safety shower ideally located in the corridor, close to and highly visible from the laboratory exits and within nominal 10 seconds travel time from the chemical use areas or current Workplace Health and Safety Requirements (whichever is most stringent). Eyewashes and safety showers should preferably have plumbed drains, they should

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26.27 *Microbiological safety cabinet planning arrangements for avoiding disturbances to the cabinet and its operator and from other personnel*

be conspicuously labelled and flooring under safety showers should be slip-resistant. Safety showers may have privacy curtains, particularly in large laboratories or teaching laboratories.

3.15 Services requirements

General

Systems must deliver laboratory services suitable for the accurate and reliable conduct of research procedures, conforming to relevant standards and codes of practice and satisfying specific criteria, in respect of parameters, including:

- composition;
- purity;
- stability and reliability (e.g. temperature, pressure, uninterruptible power supply (UPS), flow rate);
- control of delivery.

A well-controlled system will provide flexibility and minimise the operational cost of the building. Considerations should include:

- Expansion space allowed in the utility corridors, ceilings and vertical chases for future heating, ventilation and air conditioning (HVAC), plumbing and electric needs.
- Easy connects/disconnects at walls and ceilings to allow for fast and affordable hook up of equipment.
- Modular distribution.

3.16 Power

Three types of power are generally used for most laboratory projects. Requirements should be confirmed with stakeholders during the briefing phase.

Normal Power: Circuits are connected to the utility supply only, without any backup system. Loads that are typically on normal power include some HVAC equipment, general lighting and most laboratory equipment.

Standby Power: Depending on the size or height of the building, standby power, which is created with generators, may be required for life safety systems (e.g. smoke control systems, sprinkler pumps, fireman's lift, car park extract etc.). Standby power may also be necessary from a business continuity/loss of product point of view in the event of a normal power cut-off (e.g. power to plant servicing critical temperature rooms, maintaining pressure to containment or clean room applications, power to sump and sewage pumps, extract systems for radioactive areas, etc.).

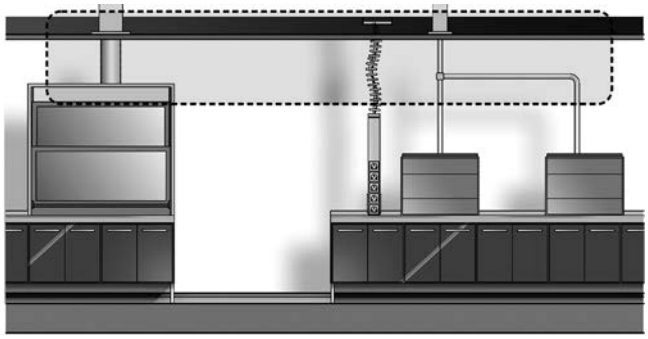
Uninterruptible Power Supply (UPS): UPS is required to condition and maintain uninterrupted power to critical loads for data recording, certain computers and micro-processor controlled equipment and selected bench outlets where long running experiments may be connected. The UPS can be either a central unit or a portable system pending extent of requirement, cost and space constraints. UPS systems are very expensive and therefore careful consideration is necessary when defining their rating.

Load: Connected electrical loads are anticipated loads estimated during the briefing phase. The loads provided in Table XXIII are

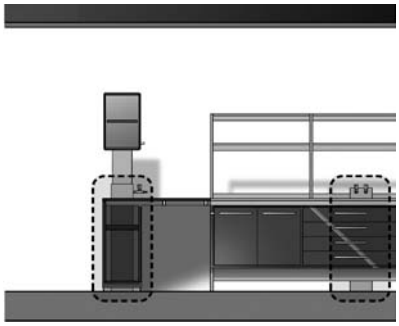
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Table XXIII Connected electrical loads (indicative)

	Load (W/m²)
Laboratories	325
Equipment and Instrument Rooms	650
Shared Support Rooms	430
Glassware Washing/Autoclave Rooms	540



26.29 *Overhead flexible services distribution*



26.31 *Distribution of services through floor mounted bollards*

indicative to assist with preliminary sizing of a generic bench scale laboratory building.

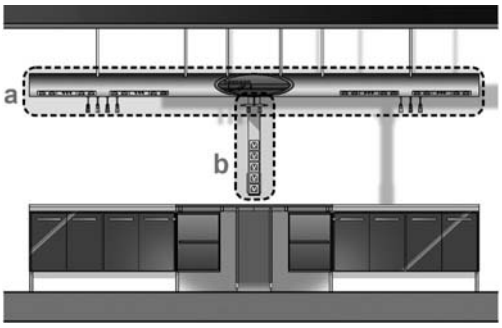
3.17 Services distribution

The method of distributing services to furniture and equipment has a major influence on the flexibility of layout possible during the laboratory's total life. There are three main methods of distributing services (power, data, gas, water) to laboratory benching and equipment. This allows furniture to be arranged in peninsular/perimeter and/or island configurations (Figures 26.28–26.31).

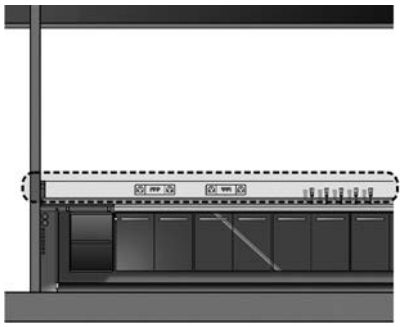
- overhead (fixed services);
- overhead (flexible services);
- perimeter (on walls);
- under floor.

Where services are integral to the furniture, equipment and partitions, any major change in layout will involve adaptation or extension of the service runs. If, however, the distribution of services within the laboratory can be separated and flexible connections made to loose services units, layouts can be adjusted directly by stakeholders to meet new requirements.

The greatest flexibility can be achieved by providing flexible services delivery to point of use from movable ceiling pods and bench mounted masts connected to a ceiling services infrastructure via flexible hose connections and flying electrical leads (Figure 26.29). This is achieved through the use of fully relocatable services integrated with the ceiling and laboratory furniture and equipment.



26.28 *Overhead fixed services distribution (a) service wing; (b) service column*



26.30 *Perimeter services distribution through walls and trunking*

This approach requires full design co-ordination and consultation with the mechanical, electrical and piping engineers.

Power and data services outlets: Utilise accessible trunking that can readily accommodate the future addition and subtraction of outlets as required. Extension leads should be avoided for health and safety reasons.

Socket outlets should not be placed immediately adjacent to sinks where splashing could present a risk (refer to BS7 671).

The number of outlets required should be confirmed with stakeholders and the services engineers. An indicative guide (typically maximum) for generically designed laboratories is as follows:

- Double power at 450 mm centres/bench and equipment run
- Double data at 900 mm centres/bench and equipment run

Cleaner's sockets should be provided and clearly identified to avoid cleaner's equipment interfering with active experiments/laboratory equipment.

Piped services: Laboratory piped services should be delivered to each laboratory on a modular basis (even though all services may not be initially required in all of the laboratories) for flexibility and to minimise remodel and retrofit costs as laboratory use changes. Each laboratory unit should have separate shut-off valves located in a consistent, accessible manner for repairs or emergency shut-off without affecting other laboratories. Except for waste and vent systems, distribution systems are recommended to be looped.

Initially the frequency and quality requirements should be assessed. Where demand is intermittent or a particular quality is required, localised sources may be provided.

Basic requirements include:

- Potable Water, Hot and Cold (HW, CW)
- Industrial Water, Hot and Cold (IHW, ICW)

Optional (as required):

- Deionised Water (DI)
- Purified Water (PW)

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Table XXIV Basic laboratory piped services requirements (indicative – subject to confirmation with stakeholders)

Service	Outlets/Module
CW (for emergency eyewash and safety shower facilities)	1
IHW	1
ICW	2

- Laboratory Air (Air)
- Natural Gas (NG)
- Vacuum (VAC)
- Compressed Air (CA)
- Steam

Specialty gases (as required):

- Should be provided by local cylinders

Table XXIV provides guidance for basic requirements (to be determined with the engineer and stakeholders).

4 ENVIRONMENT

4.1 General

The typical laboratory uses far more energy and water per square metre than the typical office building due to intensive ventilation requirements and other health and safety concerns. Therefore, designers should strive to create sustainable, high performance, and low-energy laboratories that will minimise overall environmental impacts and optimise whole building efficiency on a life-cycle basis.

Systems must however maintain background environments suitable for the accurate and reliable conduct of research procedures satisfying criteria for each accommodation type, in respect of:

- temperature;
- relative humidity;
- ventilation rates (air change rate, heat loads, equipment extract);
- room pressurisation;
- control and variation of environmental parameters.

4.2 Design criteria

Temperature

The recommended temperature values listed in Table XXV for laboratory and laboratory support spaces are generally acceptable; however individual requirements should be confirmed with stakeholders. Natural ventilation and higher or lower values may be specified depending on laboratory containment/cleanroom classification, type of activity, equipment and personnel clothing.

Relative humidity (RH)

Requirements should be confirmed with stakeholders. Humidity lower than 30 per cent can cause electrostatic effects and relative humidity above 50 per cent can augment oxidation and corrosion. Relative humidity is more difficult to regulate than temperature. Reducing the relative humidity as low as 40 per cent is possible with standard cooling methods. Dehumidification below this level requires expensive desiccating equipment. Fluctuation ranges below +/–2 per cent are difficult to achieve and maintain and are very expensive.

Ventilation rates

Air Change Rate: Typical air changes per hour (ac/hr) for laboratory and laboratory support spaces are 6–10 ac/hr depending on the use and individual requirements.

Heat Loads: Heat loads from laboratory equipment for each space are calculated during the design stage for each project. The specific laboratory heat loads shown in Table XXVI are based on anticipated loads for generic research scale laboratories and are provided to assist with the preliminary sizing of the building systems.

Table XXV Indoor design conditions (temperature) for laboratory and laboratory support spaces

Space	Typical Summer Room Temperature ˚C	Typical Winter Room Temperature ˚C
Laboratory	24 max (22 +/–2 ˚C)	20 min (22 +/–2 ˚C)
Laboratory Support	24 max (22 +/–2 ˚C)	20 min (22 +/–2 ˚C)
Specialist areas	(to user specification requirements)	

Table XXVI Preliminary heat gain from laboratory equipment (indicative loads)

Space	Load (W/m)
Research Laboratory (wet, microbiological/clinical)	75
Research Laboratory (dry)	65
Laboratory Support (Equipment Rooms)	175
Laboratory Support (Instrument Rooms)	100

Table XXVII Preliminary extract requirements from equipment (indicative)

Extract Type	Extract Air Flow (m^3/sec)
Fume Cupboard	0.30–0.50
MSC	0.15
Equipment Vent	0.02–0.04
Snorkel	0.07–0.1

Equipment Extract Rates: Schedules should be developed for each space during briefing for each project. The extract schedule (Table XXVII) is provided to assist with the preliminary sizing of the building systems.

Room pressurisation: For environments requiring containment, relative pressure to surroundings is typically negative, principally for the containment of hazards and smells. For cleanroom environments, relative pressure to surroundings is typically positive, principally for the control of dust/particles into the room.

Lighting design: Lighting levels should not be less than CIBSE recommendations. The illumination levels recommended for general laboratories (performance of visual tasks of medium contrast or small size) are 350 lux generally, 500 lux on the working plane. Consider local task lighting to reduce overall illumination levels. Good to high colour rendering should be considered in laboratory areas. Emergency lighting needs to comply with BS6651.

Acoustics: The recommendation for background noise levels in general laboratories is NR 45. Noise control methods include the use of acoustically lined enclosures and reduced sound level operating equipment. Silencers may be used in air distribution systems within the materials and constraints available. Duct liners should be avoided.

Control and variation of environmental parameters: Where economically viable and without compromising the functionality of the research environment, stakeholders should be allowed limited control over their immediate environment including temperature and lighting. Consider natural ventilation to the offices and any atria/light-wells.

5 CASE STUDIES

5.1 Scottish Centre for Regenerative Medicine, University of Edinburgh

Client:	University of Edinburgh
Location:	Little France campus, Edinburgh
Team:	Architect: Sheppard Robson
	Engineers: Buro Happold
	Cost Consultant: Summers Inman
	Contractor, Miller Construction Ltd
Start:	2006
Finish:	2011

Research: The Scottish Centre for Regenerative Medicine will provide a unique environment, developing new treatments for human diseases affecting the nervous system, liver and other organs. It is the first large-scale purpose built facility of its kind in the UK.



26.32 *The Scottish Centre for Regenerative Medicine*

Assembly: The internal form mimics the 'pebble in a pond' effect; smaller, darker spaces such as the cell culture rooms, are positioned in the centre of the building. Laboratory spaces are positioned in the middle and write up spaces are located next to the outer walls, allowing opportunity for natural ventilation and lighting. The lower floor of research space consists of spaces requiring specialist clean environments while the upper floor provides a more generic and flexible laboratory environment. Sandwiched between them is an interstitial plant space which services both the laboratory floors.

Facilities within the building include:

- ACDP CL2 Research Laboratories
- ACDP CL2 Specialist Laboratories
- Translational Unit cGMP Grade A-D (Class 100 – 100,000) Cleanroom Suite and cGMP Grade B (Class 100) Radioisotope Cleanroom Suite
- Offices and Support (Meeting, Breakout, Tea-points)
- Administration and Stores

Furniture and fittings: The furniture within the laboratories consists of wall assemblies of fixed or movable tables and peninsulas consisting of movable tables around a fixed sink unit. All worktops are made of solid laminate panels with sealed joints. All underbench storage is mobile, which in places is supplemented by wall mounted cupboards or open height adjustable shelving. Services to wall benching are provided via wall mounted dado trunking while the peninsular areas have a floor standing fixed spine with a service dropper from the suspended ceiling set out to the laboratory planning modules. In specialist areas where holes in walls are not accepted the floor mounted frames are extended above the worktop to accommodate overhead storage. Each space has a handwash station incorporating eye wash unit, soap dispensers and paper towel dispenser.

Table XXVIII shows the building data summary for this project.

Sustainability: This is one of the UK's first laboratory buildings to have received a BREEAM Excellent certificate. The building employs a number of sustainable features, including ground source heat pumps, rainwater harvesting and chilled beams in order to reduce energy usage and to help achieve the targeted excellent

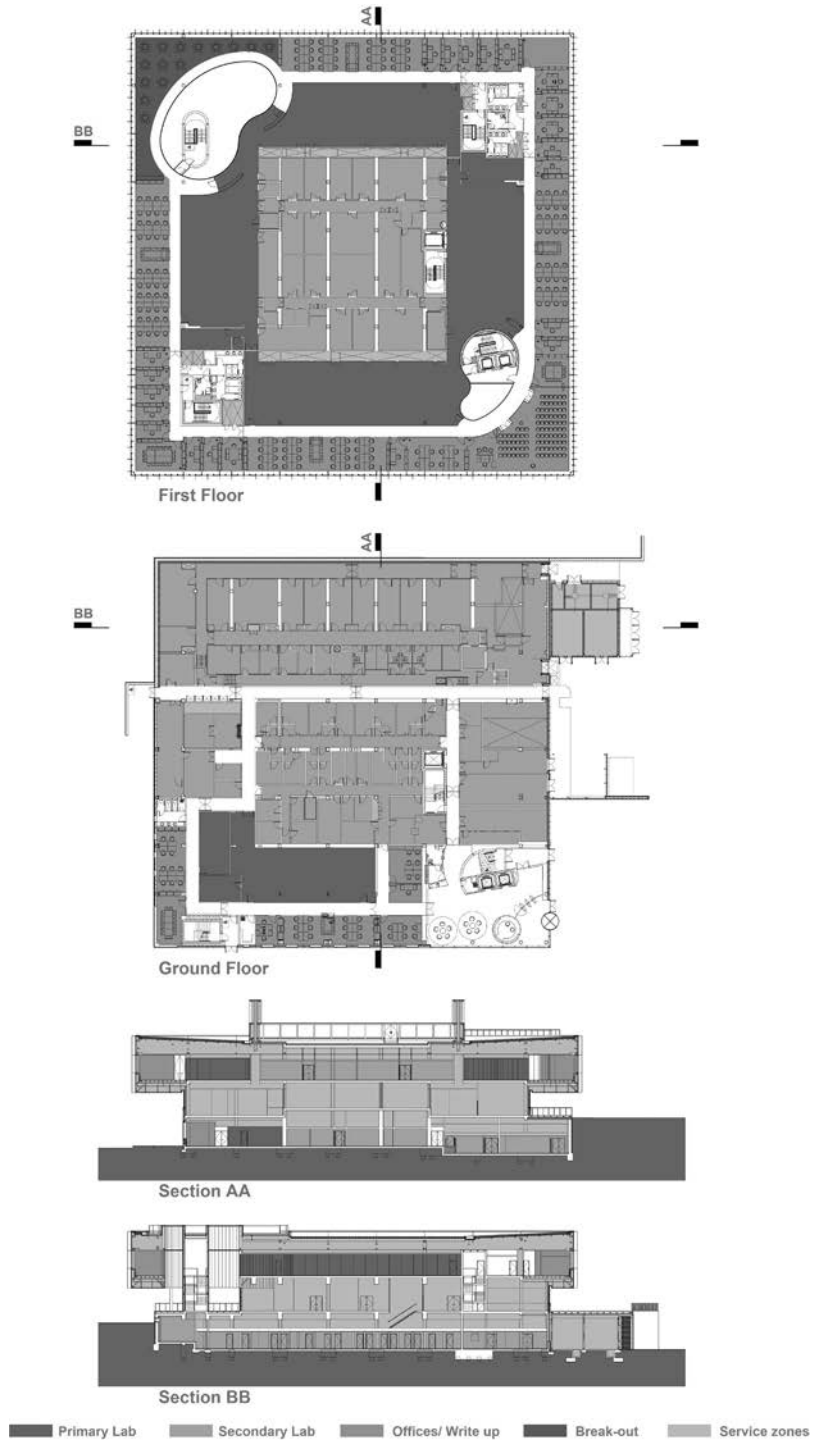
Table XXVIII Building data summary

Description	Type	Wet and Dry
	Sector	Public
	Environment	ACDP CL 2. Clean room Class A/B & D
Planning	Basic Module width	3.4m
Structure	Structural Grid	6.8m × 6.8m
	Floor to Floor	4.4m–5.0m
	Floor Load Design	5kN/m^2
	Vibration Design (Response Factor)	R=1
Services	Riser Zoning Strategy	Interstitial floor
Area m^2/ Researcher	Net/Gross Primary/ Secondary/Tertiary Net Primary Secondary	4843m^2/6500m^2 (74.5%) 2085m^2/2260m^2/ 498m^2 (43%/47%/10%) 13.9m^2 + 15.1m^2
Circulation	Type	Racetrack
	Bench/Equipment	Floor standing benching with mobile or fixed underbench storage units
	Distance Bench/Wall	n/a
	Distance Back to Back	1.8m
	Widths Bench Aisle	1.9m
	Width Main	2.4m
Laboratory Finishes	Floors	Epoxy Resin and non-slip vinyl and rubber sheeting
	Walls	Cleanable paint and pre-finished metal faced panels
	Ceiling	Cleanable paint and pre-finished perforated and solid metal tiles
Environment	Temperature (Summer) max	22˚C+/–2˚
	Temperature (Winter) min	19˚C+/–2˚
	Relative Humidity (RH)	50%+/–15%
	Ventilation Rates (Air Changes per Hour)	6–10 AC/Hr in general labs, 30 AC/Hr in specialist "clean" spaces.
	Room Pressurisation	Varies in steps between -10Pa to 50Pa
	Lighting (average levels)	500 lux at working surface
	Acoustics	40NR
	Control	BMS for all areas with BEMS to part
	CO_2 Emission Savings	18% reduction target

Table XXIX Building data summary

Description	Type	Wet
	Sector	Academic
	Environment	ACDP CL 2 & 3.
Planning	Basic Module width	3.3m
Structure	Structural Grid	9.9m × 10.5m
	Floor to Floor	4.7m
	Floor Load Design	5kN/m^2
	Vibration Design (Response Factor)	R=4
Services	Riser Zoning Strategy	Sidestitial floor
Area	Net/Gross	4383m^2/6760m^2 (64.8%)
	Primary/Secondary/Tertiary	3300m^2/816m^2/267m^2 (75%/19%/6%)
M^2/ Researcher	Net Primary Secondary	13.6m^2 + 3.1m^2
Circulation	Type	Racetrack
	Bench/Equipment	Floor standing benching with mobile or fixed underbench storage units
	Distance Bench/Wall	2.0m
	Distance Back to Back	1.8m
	Widths Bench Aisle	1.8m
	Width Main	2.1m
Laboratory Finishes	Floors	Epoxy Resin and non slip vinyl sheeting
	Walls	Cleanable or elastomeric paint and pre-finished metal faced panels
	Ceiling	Cleanable or elastomeric paint and pre-finished perforated and solid metal tiles
Environment	Temperature (Summer) max	24˚C+/–1˚
	Temperature (Winter) min	21˚C+/–1˚
	Relative Humidity (RH)	50%+/–20%
	Ventilation Rates (Air Changes per Hour)	6–10 AC/Hr in general labs, 14–20 AC/Hr in specialist "clean" spaces.
	Room Pressurisation	Varies in steps of 15 Pa between –45Pa to 0Pa
	Lighting (average level)	500 lux at working surface
	Acoustics	55NR
	Control	BMS for all areas
	CO_2 Emission Savings	13% reduction target

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26.33 *Floor plans and sections indicating adjacencies of key spaces*

BREEAM rating. To achieve the buildings target emissions rating (TER) target of 18 per cent, an approximate 60 per cent on site renewable contribution is required.

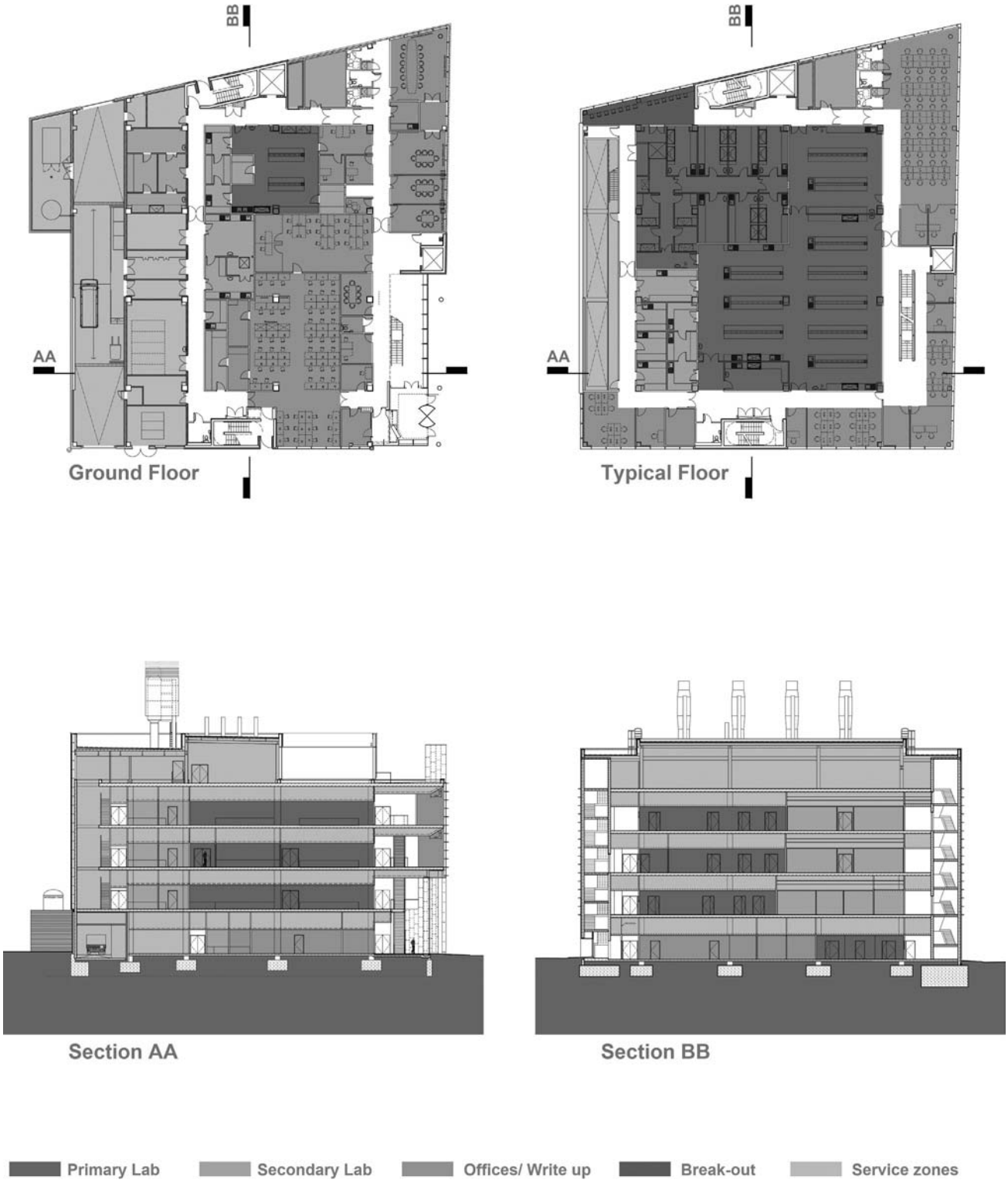
5.2 Centre for Tropical and Infectious Diseases

Client:	Liverpool School of Tropical Medicine
Location:	Pembroke Place, Liverpool
Team:	Architect: Sheppard Robson
	Services Engineers: Hayden Young
	Structural Engineer: Arup
	Cost Consultant: Gleeds
	Contractor: Shepherd Construction
Start:	2002
Finish:	2007

Research: The Centre for Tropical and Infectious Diseases (CTID), for the Liverpool School of Tropical Medicine (LSTM), is the UK's leading specialist research centre for microbial diseases undertaking ground breaking research on malaria vector control.

Assembly: The Centre has been given a contemporary design with the laboratories in the middle of the floor plate and write up spaces and offices around the perimeter. The new facility provides 7,000 m^2 of laboratory, write up and office space set over four floors. The laboratories have fully glazed perimeters that allow daylight to penetrate to the core of the building. The circulation around the building is in a 'race track' form, increasing links between staff and visitors, maximising the opportunities for interaction and collaboration. The building's footprint follows the

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26.33 *Floor plans and sections indicating adjacencies of key spaces (contd.)*

shape of the site in response to the brief to maximise the area of the building resulting in an 'oblong' shape. The laboratories are contained within a regular rectangular zone based on a standard laboratory module to maximise efficiency, with freer spaces such as meeting rooms, teapoints and support spaces, which can fit into the irregular corners of the building. A walk-in sidestitial service zone is located at the rear of the site adjacent to highly serviced laboratories.

Facilities within the building include:

- ACDP CL3/SAPO 2 Insectuary
- ACDP CL3 Specialist Research Suite
- ACDP CL2 Research Laboratories
- Offices and Support (Meeting, Breakout, Tea-points)
- Administration and Stores.

Furniture and fittings: The furniture within the smaller laboratories consists of wall assemblies of fixed workstops with fixed under-bench storage, while in the larger laboratories it consists of fixed workstops with mobile underbench storage along the perimeter walls and islands consisting of modular spines with 2-tiers of reagent shelves and ceiling mounted services columns with movable tables abutting each spine. Services to wall benching are provided via wall mounted dado trunking. All worktops are made of solid laminate panels with sealed joints.

Table XXIX shows the building data summary for this project.

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Table XXX Legislation and standards

TITLE	AUTHOR/PUBLISHER	BRIEF SUMMARY
Bench and Equipment		
BS EN 285:1997 Sterilization. Steam sterilizers. Large sterilizers	British Standards Institution (BSI)	Provides guidance on specification requirements and the relevant tests for large steam sterilizers
BS 2646-2:1990 Autoclaves for sterilization in laboratories	British Standards Institution (BSI)	Provides guidance on basic setting and associated services for autoclaves
BS 3202-2:1991 Laboratory furniture and fittings. Specification for performance	British Standards Institution (BSI)	Provides guidance on specification & testing procedures for different grades of laboratory furniture
BS 3202-3:1991 Laboratory furniture and fittings. Recommendation for design	British Standards Institution (BSI)	Provides guidance on space and dimensional information for different types of laboratory furniture
BS 3970-1:1990 Sterilizing and disinfecting equipment for medical products	British Standards Institution (BSI)	Provides guidance on specification requirements and the relevant tests for sterilizers and steam sterilizers
BS 5726:2005 Microbiological safety cabinets	British Standards Institution (BSI)	Provides guidance on siting and use of cabinets
BS 7258-2:1994 Laboratory fume cupboards	British Standards Institution (BSI)	Provides guidance on siting and use of cabinets
BS EN 12347:1998 Biotechnology. Performance criteria for steam sterilizers and autoclaves	British Standards Institution (BSI)	Provides guidance on specification requirements and the relevant tests for sterilizers and autoclaves
BS EN 12469: 2000 Biotechnology. Performance criteria for microbiological safety cabinets	British Standards Institution (BSI)	Provides the minimum performance criteria for safety cabinets, test procedures for microbiological safety cabinets
BS EN 13150:2001 Work benches for laboratories	British Standards Institution (BSI)	Specifies safety requirements, test methods and recommendations on sizes
BS EN 14056:2003 Laboratory furniture – Recommendations for design and installation	British Standards Institution (BSI)	Provides basic information on furniture types and services provision
BS EN 14175 Parts 1–6: Fume cupboards.	British Standards Institution (BSI)	This standard was introduced to cover fume cupboards of the filtration type that were not covered by BS
BS EN ISO 15883-3:2006 Washer disinfectors Washer-disinfectors. Requirements and tests for washer-disinfectors employing thermal disinfection for human waste containers	British Standards Institution (BSI)	Provides guidance on basic setting and associated services for washer disinfectors
Services: electrical		
BS EN 61010-1 2001 safety requirements for electrical equipment for measurement, control and laboratory use	British Standards Institution (BSI)	Provides guidance on electrical equipment in laboratories
Energy efficiency in buildings. 2nd edition. (Including corrigenda 2004)	The Chartered Institution of Building Services Engineers (CIBSE)	Provides information on both the energy requirements committed by the design and the energy costs in use
Electricity at work regulations 1989. Statutory Instrument SI 1989/635	Legislation UK	
BS 7671:2001, Requirements for electrical installations.	The Institution of Electrical Engineers	Provides legal requirements for electrical works and their isolation
IEE Wiring Regulations. Sixteenth edition		All electrical wiring works must follow the Wiring Regulations to ensure a safe and efficient electrical installation
Services: gas		
Safety in the installation and use of gas systems and appliances: Gas safety (Installation and Use) Regulations 1998. 2nd edition	Health & Safety Executive (HSE)	Provides guidance on the safe installation, maintenance & use of gas
IGEM Technical Publications	Institute of Gas Engineers & Managers (IGEM)	Provides a variety of technical advice information
Industrial gas cylinder manifolds and distribution pipework/ pipelines (excluding acetylene) Code of Practice CP4: Revision3: 2005	British Compressed Gases Association (BCGA)	Provides guidance on the minimum safety standards for the design, installation, operation, and maintenance of industrial gas supply manifolds and associated narrow pipework
Code of Practice for the Storage of Medical, Pathology and Industrial Gas Cylinders.	Department of Health (DH)	Provides advice on design, installation and testing of gas systems
Safety of pressure systems. Pressure systems safety regulations 2000. ACOP (SI 2000 No 128)	Health & Safety Executive (HSE)	Provides guidance on pressure systems including gas cylinders
Guidance Notes for Siting Gas Manifolds	BOC Gases	Provides general guidance on the siting of gas manifolds and storage of cylinders
Guidance Note GN2: Guidance for the Storage of Transportable Gas Cylinders for Industrial Use	British Compressed Gases Association BCGA)	Provides basic design information on storage compounds and proximity of different types of cylinders
Guidance Note GN2: The Safe Use of Individual Portable or Mobile Cylinder Gas Supply Equipment	British Compressed Gases Association BCGA)	Provides guidance on the safe use of individual cylinder gas supplies provided from a single cylinder regulator
Guidance Note GN11: The management of risks associated with reduced oxygen atmosphere	British Compressed Gases Association BCGA)	Provides information on the risks of utilising gases which when accumulated can become hazardous
HSG71 Chemical warehousing–The storage of packaged dangerous substances.	Health & Safety Executive (HSE)	Provides guidance on the hazards associated with the storage of packaged dangerous substances includes safety; fire, emergency aspects
The safe use of gas cylinders	Health & Safety Executive (HSE)	Provides simple advice on eliminating or reducing risks
Dangerous Substances and Explosive Atmospheres Regulations 2002	Health & Safety Executive (HSE)	Require employers and the self-employed to carry out a risk assessment of work activities involving dangerous substances
Services: water		
Water supply (water quality) regulations 2001 SI 3911	Legislation UK	Provides legal standards for water to be used within a building
Plumbing engineering services design guide. 2002 edition. Part 2 – Hot and cold water supplies	Institute of Plumbing	Provides information and guidance on current technologies and practices
The Water Supply (Water Fittings) Regulations 1999	Office of Government Commerce (OGC)	These Regulations replace the water bylaws in England and Wales only
L8 Legionnaires' disease: The control of Legionella bacteria in water systems. Approved Code of Practice and guidance.	Department of Health (DH) Health & Safety Executive (HSE)	Provides the approved code of practice for preventing or controlling the risk from exposure to Legionella bacteria
TM13 Minimising the risk of Legionnaire's disease	The Chartered Institution of Building Services Engineers (CIBSE)	Provides advice on the design necessary to minimise the risk of infection from Legionella bacteria
Services: Environment/ventilation/energy		
BS 5720:1979 Code of practice for mechanical ventilation and air conditioning in buildings	British Standards Institution (BSI)	This standard has been withdrawn as the code of practice as it is now out of date, but still referred in the Building Regulations
Guide A Environmental Design	The Chartered Institution of Building Services Engineers (CIBSE)	Provides information on the design of low energy sustainable buildings.

(continued)

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Table XXX (continued)

TITLE	AUTHOR/PUBLISHER	BRIEF SUMMARY
TM32 Guidance on the use of the carbon emissions calculation method	The Chartered Institution of Building Services Engineers (CIBSE)	Provides the basis of a procedure for applying the carbon emissions calculation method (CECM).
The Enhanced Capital Allowance Scheme	Carbon Trust	Provides guidance & forms for making an ECA claim; depends on the purchase energy-saving equipment
Conservation of fuel and power in new buildings other than dwellings (2006 edition) Building Regulations 2000: Approved Documents L2A or L2B	Office of the Deputy Prime Minister (OPDM)	Provides building control advice for England and Wales on environmental & energy issues
Best Practice Guide: Chilled Beams in Laboratories:	Laboratories for the 21st Century (Labs21)	Provides advice on effective design, construction and operation of chilled beams in laboratories
Best Practice Guide: Optimising Laboratory Ventilation Rates	Laboratories for the 21st Century (Labs21)	Provides advice on how to reduce energy requirements by optimising ventilation airflow
ASHRAE Handbook – HVAC Applications: Chapter 14 Laboratories, 2008	American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)	Provides information on HVAC applications in laboratories
Health and safety		
The Health and Safety at Work etc. Act 1974	Primary Legislation UK	Sets out guidance, approved codes of practice and legislation with respect to occupational health and safety at work
Animal Health Act 1981	Primary Legislation UK	Aim to control the spread of diseases and to eventually eradicate them. This is done by controlling the movements of animals and isolating areas where disease is confirmed. Animal welfare is also controlled by the Act
The Control of Substances Hazardous to Health (COSHH) Regulations 2002	Secondary Legislation UK	Requirements for employers to assess the risks from hazardous subtances and take appropriate precautions
The United Kingdom Good Laboratory Practice Monitoring Authority. Guide to UK GLP Regulations 1999	Legislation UK	Sets out the organisational processes and conditions under which certain laboratory studies are undertaken
Various Guidance and advice notes	Health & Safety Executive (HSE)	HSE provide numerous useful guidance sheets which are relevant to different types of laboratories such as in sections on Biotechnology, Dangerous Pathogens, Health & Safety Regulations, Nanotechnology
The Workplace (Health Safety and Welfare) Regulations 1992	Legislation UK	Sets out legislation with respect to most workplaces
Microbiological protection		
BS EN 12128:1998 Biotechnology. Laboratories for research, development and analysis. Containment levels of microbiology laboratories, areas of risk, localities and physical safety requirements	British Standards Institution (BSI)	Specifies minimum physical requirements for the four levels of containment for biological safety in laboratories
BS EN 12738: 1999 Biotechnology. Laboratories for research, development and analysis. Guidance for containment of animals inoculated with micro organisms in experiments	British Standards Institution (BSI)	Specifies minimum physical requirements for the four levels of containment for biological safety in laboratories
BS EN 12740:1999 Biotechnology. Laboratories for research, development and analysis. Guidance for handling, inactivating and testing of waste	British Standards Institution (BSI)	Provides information on different types of waste produced by different containment level laboratories and methods for their disposal
BS EN 12741:1999 Biotechnology. Laboratories for research, development and analysis	British Standards Institution (BSI)	Provides information on basic protocols within different hazard level laboratories
BS EN 13441:2002 Biotechnology. Laboratories for research, development and analysis. Guidance on containment of genetically modified plants	British Standards Institution (BSI)	Provides information on safety measures in laboratories where plant biotechnology and genetic work is being undertaken
Advisory Committee on Dangerous Pathogens (ADCP) The management, design and operation of microbiological containment laboratories 2001	Health & Safety Executive (HSE)	Provides guidance on the management and operation of Containment Level 2 and 3 microbiological labs
The Genetically Modified Organisms (Contained Use) (Amendment) Regulations 2005	Legislation UK	Specifies minimum physical requirements for the four levels of containment for GM work in laboratories
CR 12739:1998 – Biotechnology. Laboratories for research, development and analysis. Guidance on the selection of equipment needed for biotechnology laboratories according to the degree of hazard	British Standards Institution (BSI)	Provides guidance on selecting safety measures and laboratory equipment to provide protection in differing bio-hazard areas
NHS Estates Health Building Note 15, Accommodation for Pathology Services.	Department of Health (DH)	Provides guidance on facilities for pathology services provided within acute general hospitals
Radiological protection		
HBN 6 Vol. 3 2002 Accommodation for magnetic resonance imaging	Department of Health (DH)	Provides design and specification information for MRI areas
BS 4094–1: 1966 Recommendation for data on shielding from ionizing radiation. Shielding from gamma radiation	British Standards Institution (BSI)	Provides information on legislation, regulations, guidance and other standards
HBN 6 Vol. 1 2002 Facilities for Diagnostic Imaging and Interventional Radiology, HBN 6 2002	Department of Health (DH)	Provides design and specification information for imaging & associated areas
Working with ionising radiation Ionising Radiations regulations 1999 Approved Code of Practice and guidance	Health and safety Executive (HSE)	Provides is guidance on safe working practices when in exposed to radiation arising from work with man-made or natural radiation
Fire protection		
Conservation of fuel and power in new buildings other than dwellings (2007 edition) Building Regulations 2000: Approved Documents B Vol. 2	Communities & Local Government	Provides building control advice for England and Wales on fire issues
BS 9999:2008 Code of practice for fire safety in the design, management and use of buildings	British Standards Institution (BSI)	Provides information on types of premises and relevant codes of practice, access and facilities for fire-fighting and covers vehicle access, water supply, control systems, heat and smoke control and electrical services, on measures that enable disabled people to be assisted to safety in the event of a fire, fire protection of services and fire safety systems

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Table XXX (continued)

TITLE	AUTHOR/PUBLISHER	BRIEF SUMMARY
Building Bulletin 100: Design for Fire Safety in Schools 2007	Department for Education & Skills (DFES)	Provides information on fire safety in schools
Cleanrooms		
BS EN 14644-1: 1999 Cleanrooms and associated controlled environments. Classification of air cleanliness	British Standards Institution (BSI)	Provides guidance on definitions and classifications of clean rooms
BS EN 14644-4: 1999 Cleanrooms and associated controlled environments. Classification of air cleanliness	British Standards Institution (BSI)	Provides guidance on design and servicing of clean rooms
Rules and Guidance for Pharmaceutical Manufacturers and Distributors 2007 – the 'Orange Guide'	Medicines and Healthcare products Regulatory Agency (MHRA)	Covers most aspects of Good Manufacturing Practice (GMP)
Schools		
Building Bulletin 80: Science accommodation in Secondary School – Rev 2004	Department for Education & Skills (DFES)	Provides design information on laboratories in secondary schools
Building Bulletin 88: Fume cupboards in Schools	Department for Education & Employment	Provides design information on fume cupboards in secondary schools
Building Bulletin 98: Briefing Framework for Secondary School Projects	Department for Education & Skills (DFES)	Provides general spatial for secondary schools
Building Bulletin 99: Briefing Framework for Primary School Projects	Department for Education & Skills (DFES)	Provides general spatial for primary schools
Project Faraday Vol. 1 & 2 2008	Department for Education & Skills (DFES)	Examples of sciences facilities in schools
Science Labs for the twenty first Century	Department for Education & Skills (DFES)	Provides design and planning information on laboratories in schools
Designing & Planning Laboratories Guide G14-2009	Consortium of Local Education Authorities for the Provision of Science Services, (CLEAPPS)	Provides design and planning information on laboratories in secondary schools
The Good Lab – Concise Guide 2009	Andy Piggott National Science Learning Centre (NSLC)	Provides design, planning and fittings information on laboratories in secondary schools
School Science Laboratories Design for the 21st Century, 2006	North Eastern Education & Library Board (NEELB)	Provides design, planning & fittings information on laboratories in secondary schools
Laboratory Design for Health and Safely, Chapter 6, Topics in Safely, 3rd edition, 2001	The Association for Science Education (ASE)	Provides advice on school health and safety issues
Vibration		
Design of Floors for Vibration: A New Approach, SCI Publication 354, 2009	Steel Construction Institute (SCI)	Provides guidance on forms of construction and their response to vibration
Design Guide on the Vibration of Floors. SCI Publication 076, 1989	Steel Construction Institute (SCI)	Provides guidance for the design of floors in steel framed buildings against vibration
BS 6472-1:2008 Guide to Evaluation of Human Exposure to Vibration in Buildings (1Hz to 80Hz)	British Standards Institution (BSI)	Provides guidance on predicting human response to vibration in buildings
A Design Guide for Footfall Induced Vibration of Structures: CCIP-016, 2006	Willford, MR., and Young, P. The Concrete Centre	Provides advice on designing for footfall vibration with worked examples
Design of Stiff, Low-Vibration Floor Structures, 1991	Amick H., Hardash S., Gillet P. and Reaverley R. International Society for Optical Engineering (SPIE) Vol 1619	Conference paper on design of floors supporting vibration sensitive equipment.
ASHRAE Handbook – HVAC Applications: Chapter 47 Sound and Vibration Control, 2008	American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)	Provides guidance on controlling sound transmission and vibration from many procedures with examples.
Other		
The BRE Green Guide to Specification	British Research Establishment	Provides guidance on the relative environmental impacts of elemental specifications
BCO Guide 2005 – Best Practice in the Specification of Offices	British Council for Offices (BCO)	Provides advice on future design and construction of office buildings, including sustainability, business performance and cost and value
The Disability Discrimination Act 1995 (DDA)	Legislation UK	Legislation concerning disabled requirements

Sustainability: The client prescribed from the beginning that the achievement of a BREEAM 'Very Good' rating was required to satisfy their project funding criteria from the Bill and Melinda Gates Foundation. The building employs a number of sustainable features, including specification of pre-fabricated and modular construction components that result in less waste on site, low energy lighting with controls (with presences detection/daylight linking/BMS automation) and heat recovery from the exhaust ventilation system.

6 BIBLIOGRAPHY

6.1 Legislation and standards

Any design shall be formulated acknowledging as relevant all design and codes, regulations, standards and statutory requirements. The examples listed in Table XXX should not be regarded either as prescriptive or inclusive. These generally state minimum requirements though there is nothing to prevent a designer from exceeding the applicable requirement especially once a risk assessment has been undertaken by the stakeholder on the space's operational requirements.

6.2 Websites

Table XXXI lists some useful websites.

6.3 Acknowledgements

Particular thanks are due to the late Gordon Kirtley for his pioneering work on the Wellcome Trust's 'Guidance on space standards, layout and specification for biomedical buildings'.

Sincere thanks are also due to Andrew Bowles for his support, to Patrick Ng and Robin Base, for producing the graphics and Anna Stamp, Daniel Bennett, Luke Thurman and Pedro Santos for their assistance with the case studies.

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Table XXXI Websites

SITE ADDRESS	ORGANISATION	BRIEF SUMMARY
www.hse.gov.uk	Health & Safety Executive (HSE)	Provide numerous useful guidance sheets which are relevant to laboratory working environmental and safety requirements for UK.
www.cibse.org	The Chartered Institution of Building Services Engineers (CIBSE)	Provides numerous publications relevant to various service disciplines and environmental requirements for UK.
www.dh.gov.uk/	Department of Health (DH)	Provides statistical reports, surveys, press releases, circulars and legislation with respect to health care facilities in UK.
www.wbdg.org	Whole Building Design Guide (WBDG)	Provide information on various laboratory types based mainly on US projects.
www.dfes.gov.uk	Department for Education & Skills (DFES)	Provides information of school planning and spatial requirements in UK.
www.cleapss.org.uk	Education Authorities for the Provision of Science Services. (CLEAPPS)	Provides an advisory service for subscribers, supporting practical science and technology in schools in UK.
www.ase.org.uk	The Association for Science Education (ASE)	Provides information produced by teachers helping teachers that teach science.
www.phac-aspc.gc.ca	Health Canada	Provides considerable data on microbiological labs produced by Government of Canada.
www.bco.org.uk	British Council for Offices (BCO)	Provides research data on best practice in all aspects of the office sector in UK.
www.carbontrust.co.uk	Carbon Trust	Provides information on grants and technologies funded by UK Government to help promote low carbon technologies.
www.bcga.co.uk	British Compressed Gases Association BCGA)	Provides information on gases supplied to manufacturing industry, laboratories, and the medical sector for UK.
www.igem.org.uk	Institute of Gas Engineers & Managers (IGEM)	Provides a variety of technical advice information.
www.bsistandards.co.uk	British Standards Institution (BSI)	Provides opportunity to purchase UK and European standards.
www.labs21.org.uk	Labs21 UK	Established by the Higher Education Environmental Performance Improvement (HEEPI) project to support more sustainable design and operation of laboratories in Britain. It draws, with permission, on the experience and materials of the Labs21 initiative in the USA.
www.labs2lcentury.gov	Labs21	Labs 21 is a voluntary partnership program dedicated to improving the environmental performance of U.S. laboratories.
www.lab2020.com	Lab 2020	Lab2020 is a study based in Germany looking at sustainable environments for pharmaceutical and biotechnological laboratories exchanging the experience of manufacturers, designers and users.

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27 Libraries

Brian Edwards with Ayub Khan

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KEY POINTS:
- *The community role of public libraries is changing rapidly*
- *Information is delivered in all kinds of media, not just books*
- *Libraries are social anchors and knowledge gateways*
- *Libraries are getting bigger and embracing more functions*
- *The university library is leading design and management changes*

Contents

1 Introduction
2 Community role of libraries
3 Library design
4 Room layout, furniture and shelving
5 Space standards
6 Environmental considerations
7 Financing and resources
8 Case study
9 Bibliography

1 INTRODUCTION

1.1 Changing role of the library

The evolving role of the library has created a set of new and complex challenges for those delivering library buildings and services. The libraries of the twenty-first century are no longer simply familiar repositories for books with space for reading and lending. They have changed and expanded, been rethought and redesigned. Libraries now provide an increasingly wide range of services, using a multitude of media, and reach a more diverse audience than ever before; see Table I and Figure 27.1.

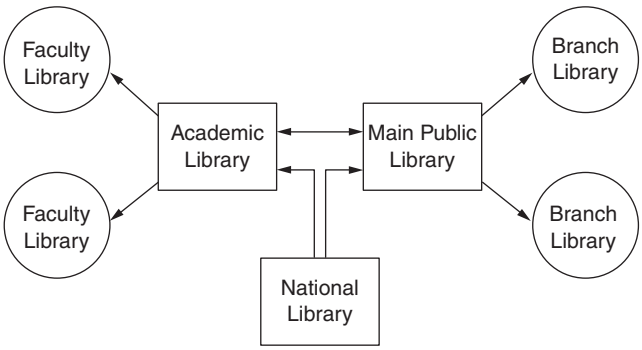
As libraries broaden their social and educational role to become 'ideas stores' and 'knowledge gateways', there is pressure to increase the extent of non-library accommodation within their walls. The problem for the architect is how to bring the library and non-library functions into a coherent whole (see Table II).

One trend is towards social or public functions rather than merely library ones on the ground floor. Such public functions may include cafes, bookshops, exhibition areas, meeting rooms, community and welfare offices. The library then rises from this welcoming community base. Many academic libraries follow a similar model with student, welfare and registry facilities linked to printing, binding, bookshops and cafes on the entrance level with the main library spaces above. With such plans, noise abatement may be required and careful zoning to ensure security of the collection.

Some argue that libraries of the future will be without books. Such buildings will be knowledge markets, open to all without security barriers, and freely engaged in social exchanges of various kinds from learning to networking, using ever advancing IT to expand human knowledge and creative potential. Recent examples include the bookless public library at San Antonio, Texas and the paperless academic library at the School of Engineering, Stanford University. However, books are likely to remain in most libraries but take an increasingly back seat in this fast evolving building type. Surviving books are likely to have sentimental or archival interest rather than be the first point of contact for readers.

1.2 Revival of the library

After years of relative neglect as a building type, the public library enjoyed a renaissance towards the end of the twentieth century. This was partly the result of new information technologies challenging the supremacy of the book and other forms of paper based media. The IT revolution highlighted the important social,



27.1 *Ideal pattern of public library*

Table II Main factors leading to change in design of library buildings

- New information technology and new forms of electronic data exchange
- Greater social, community and educational role for public libraries
- Expansion in types and diversity of education, including life-long learning, has undermined the exclusivity of public libraries
- Impact of mass culture and new social media
- Impact of environmental sustainability on the design of libraries

Table I Library types

Main types of library	Key features
National Library	• National collections of books, journals, maps etc. • Research focused • Conservation element • Specialist readership
Public Library	• Collections of books and CDs primarily for loan • Place to meet and exchange • Wide range of material of local interest • Community base for local people • Integration with other 'cultural' or civic buildings
Academic Library	• Support for teaching, learning and research • Place where new knowledge is generated and exchanged • Large specialist and research collections • Separate IT and multi-media areas • 24 hour access
Professional and Special Libraries	• Specialist collection of books and professional journals • Often contains rare or fragile non-paper material • Limited public access • Conservation element

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educational and cultural role of library buildings, particularly to the life and welfare of cities. CABE in particular was instrumental in pushing forward a vision for more inclusive and dynamic public libraries. Under pressure from CABE and in response to wider social changes in Britain's cities, interesting new solutions to the architecture of the public library appeared in London's Watney Market, Whitechapel and Peckham as well as at Worcester, Norwich, Brighton and more recently in Birmingham, where Mecanoo's new public library opened in 2013 (see Section 8 Case Study). Although the pace of change has slowed under economic pressures in much of Europe, the USA, China and Canada are building a clutch of interesting new libraries that integrate media and promote cultural solidarity.

The university library too has undergone considerable change as the emphasis shifts from libraries as storehouses of knowledge to places where new knowledge is generated and existing knowledge (whether digital or paper) is openly shared in teaching, learning and research. Examples of a fresh approach to the design of academic libraries are found at the Saltire Centre, Glasgow Caledonia University, designed by BDP, new libraries at the Open University by Swanke Hayden Connell Architects, Leicester University by Associated Architects and at Aberdeen University by Schmidt Hammer Lassen. Many extensions to existing university libraries as at Liverpool, East Anglia and Portsmouth Universities provide space for IT and new forms of media to augment older book-based provision. These areas, known sometimes as 'Learning Commons', reflect the change in pedagogy from lecture-based teaching to student-focused open learning based on course work rather than examination. Useful examples can be sourced on the SCONUL journal *Focus* and the *Designing Libraries* website.

Outside the UK there has also been new thinking on the design and civic purpose of library buildings with OMA's public library in Seattle, the Snøhetta designed library in Alexandria, Egypt and that by Patkau Architects in Montreal being notable examples. Across Europe there has also been much new building of university libraries to meet the expansion in higher education including the Free University Berlin by Foster & Partners and Brandenburg Technical University by Herzog and de Meuron. The libraries of universities in particular have had to adjust to new pedagogic practices as well as a revolution in the form and use of knowledge.

1.3 A place to meet

Today the library, whether public or academic, is a place to meet, discover, learn and exchange information within welcoming, light and airy surroundings, Figures 27.2, 27.3. Libraries come in many shapes and forms. Generally, there are four main types but within each there is much variability. One trend is towards bigger libraries whether faculty or community based. Large scale provides the basis for better integration of book and digital media, of providing a wider range of support services (computer training, language skills, networking skills) as well as more extensive non-reader facilities (café, exhibition areas, shop).

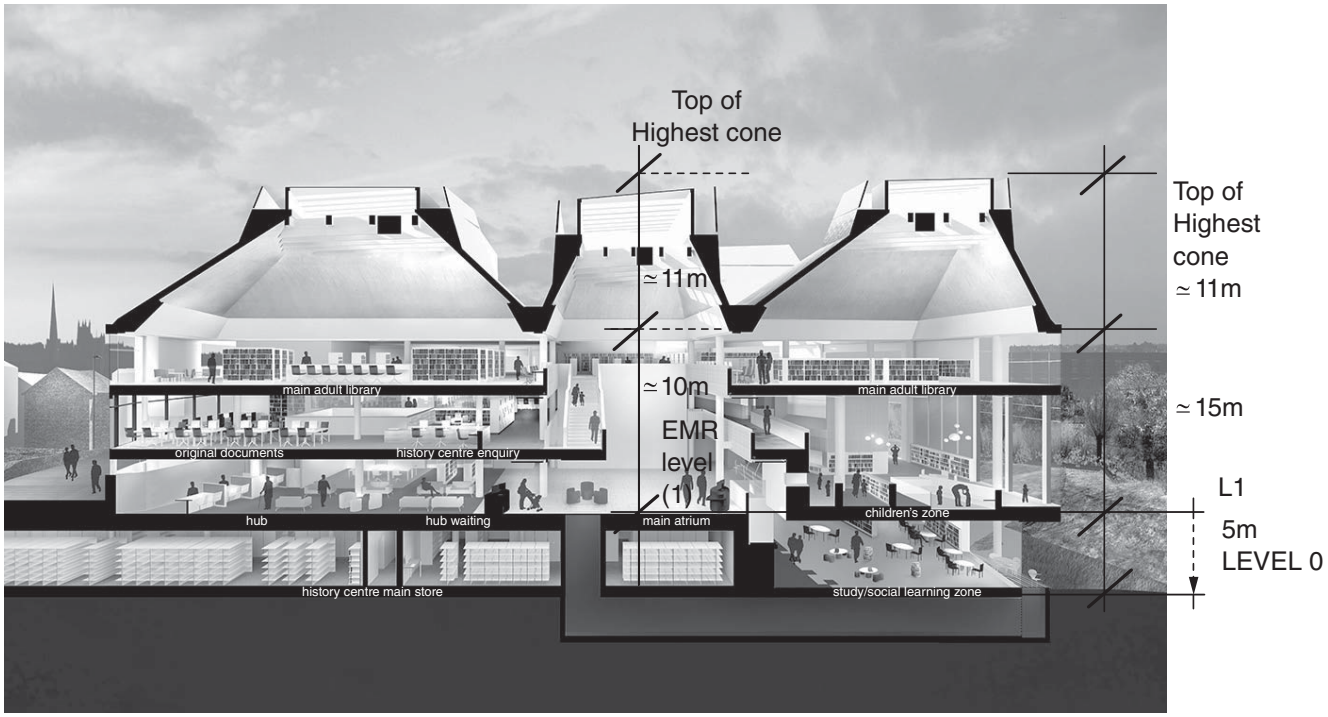
It is important that libraries are well designed from a civic point of view, providing an architectural response which is welcoming, inclusive and offers a range of services able to attract young people as well as old, locals and new residents, whether IT literate or not. Today's libraries therefore need to provide a variety of different types of space to serve these different users. Although small libraries are good at community engagement, large ones are increasingly favoured since they serve the needs of readers, business and education on a regional basis.

2 COMMUNITY ROLE OF LIBRARIES

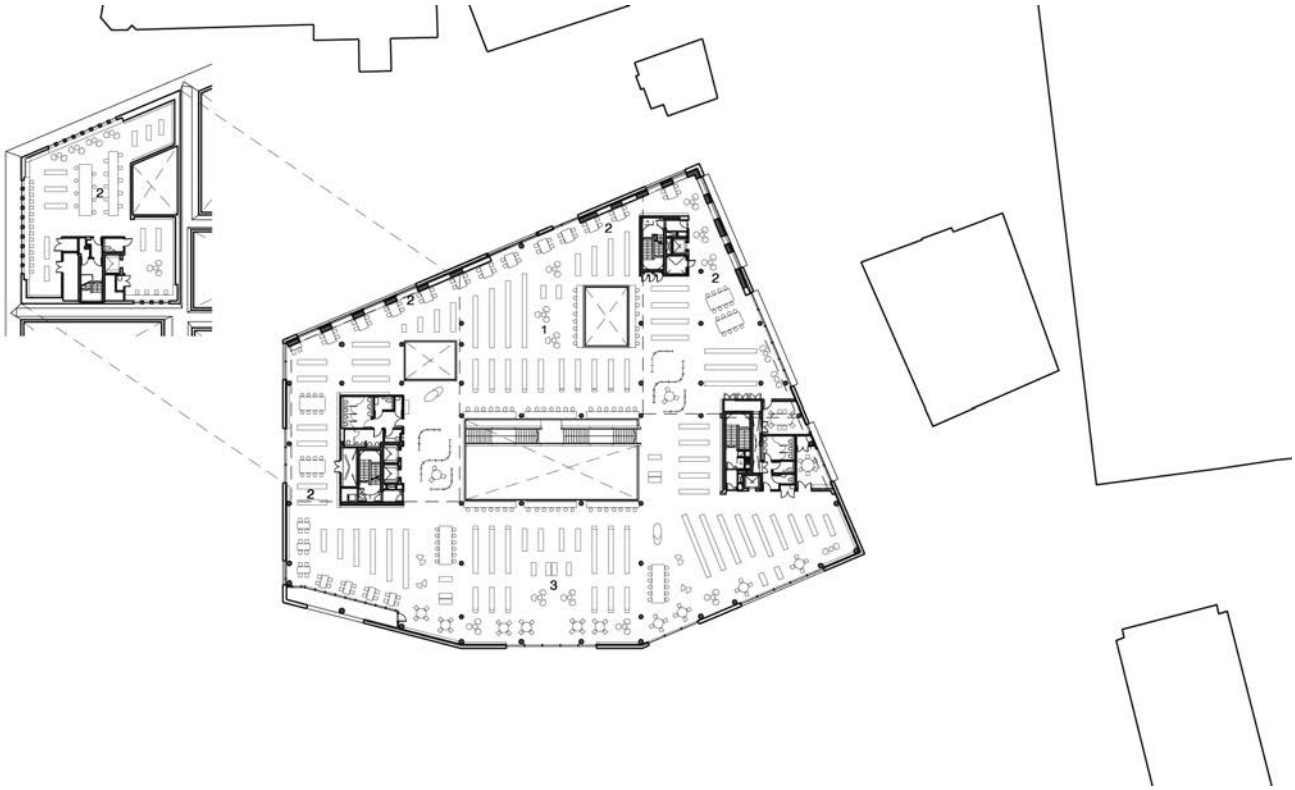
2.1 New functions for libraries

The revival of interest in the library as a building type has three main roots. First, new media technologies, particularly IT-based knowledge packages and new ways of communicating (Facebook and Twitter) have led government and university clients to reassess the role and design of libraries in a digital age. Second, the resurgence of interest in other cultural building types – notably the museum and art gallery – encouraged many public clients and their architects to see libraries as buildings to visit in their own right rather than merely providing access to books, journals and IT services. Third, the expansion of universities worldwide led to a re-assessment of the role of the academic library in teaching, learning and research, and this in turn influenced the design of public libraries.

As a result of these changes libraries have become inclusive and inviting buildings where their transparency acts as a lighthouse of knowledge in many towns and on many campuses. Once inside



27.2 *Section of The Hive public library in Worcester, designed by Feilden Clegg Bradley Studios*



27.3 *Level 3 plan of The Hive public library in Worcester, designed by Feilden Clegg Bradley Studios*
Key: 1 Library/study, 2 Quiet study, 3 Social learning

these new libraries, the spaces are animated by the sound of knowledge use, knowledge sharing and social discourse. However, not all is noisy: new libraries have had to zone their spaces to meet different types of knowledge use and to serve the needs of different users.

The twenty-first-century library is typically a building with exciting external public spaces, interesting architectural forms and a more 'market place' interior quality. Attention is paid to urban design as well as building design, to the creation of reading rooms which invite contemplation, reflection and exchange across media types and between readers, and to the provision of exhibition, café and bookshop areas. Libraries have changed from being mainly depositories of books, newspapers and journals to being multimedia knowledge centres playing an active role in the modern digital age. Today the typical library (see Tables III and IV) is an interactive network of spaces which encompass books for loan, journals (many of which are electronic), CDs, videos, internet sources and special study collections. Increasingly the network contains links to the home and educational centres, thereby supporting learning and reinforcing the role of schools, colleges and universities in the community. This expanded role has been accompanied by a change in design values, the job description of librarians and a broadening of the brief of a typical library.

Rather than lead to the obsolescence of the library, new technology has liberated the library from increasingly unpopular stereotypical forms, and altered the fundamental assumptions behind their design. One such is the requirement for silence in all but designated areas. The strategy today is to encourage the sharing of knowledge and to welcome the use of the spoken word either between individuals or in groups. Since the library is often used for teaching and learning within the community, silence is expected only in private study areas. Elsewhere the pleasure of discovery and exchange is welcomed (see Figure 27.4). Restricting silence to special areas allows the remainder to become a place for sharing ideas and jointly pursuing knowledge.

Table III Contemporary role of the public library

- Buildings which help cement together a community
- Buildings which are meeting places
- IT learning and support centre
- Complements art gallery and museum
- Access point to council services
- Life-long learning and literacy centre

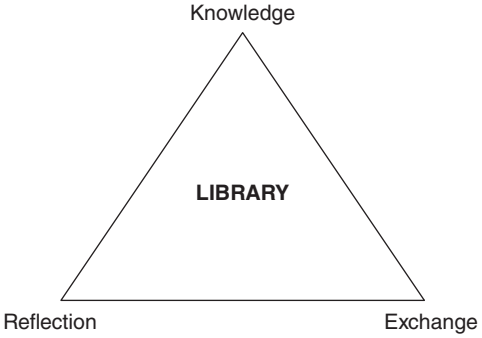
Table IV CABE's summary of public library trends

- Each library will develop its own bespoke range of services
- Libraries will develop in partnership with other services
- Adaptability is a key factor in layout and design
- Reader development, communication and literacy skill are central library services
- Libraries will become communication centres for mobile populations
- Long stay use of libraries for study requires friendly and efficient support facilities
- Electronic links between homes and libraries will increase
- Children's services will grow in importance
- Virtual library services will be provided 24 hours a day
- Librarians will change their role from custodians of culture to knowledge navigators

Adapted from *Better Public Libraries*, CABE 2003 pp. 7–8.

2.2 Integration of book and digital media

Although books remain vital to the library, the first point of contact is usually the catalogue screen or digitised media messaging. The



27.4 *Key relationships in the library (Brian Edwards)*

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interaction between digital knowledge and the printed word is a dynamic one requiring space characteristics different from that of the traditional library. Many modern libraries place the computer screen at the front door allowing the reader to pass through knowledge layers as they navigate the library. The role of library staff is to aid navigation through types and modes of knowledge rather than exercise security or sit behind glass screens. Today's librarians are data networkers and media and subject navigators with direct contact with readers at the front desk and at various points within the library. In directing readers to the diversity of new material, there is a great deal of interaction, both verbal and digital, which inevitably affects the interior layout and character of the library.

Another significant shift over the past two decades has been the increasing role of libraries in life-long learning, in providing community information, and in supporting the needs of the elderly particularly in the area of IT provision and training. By 2020, nearly half of Europeans will be over 65 years old and here the library has particularly important services to provide. This has ramifications for the design and layout of library buildings, the level of lighting and provision of facilities from workstations to toilets and disabled access.

For people who do not possess English as their first language, or for individuals who are newly arrived in an area, the library is often the first point of community contact. Hence, the qualities and values expressed through architectural design leave a lasting impression. For these reasons the library today is seen as a gateway to learning and a shop window to new knowledge and community services. The latter leads to some public libraries taking on the role of citizens advice bureaus with librarians quasi social workers.

3 LIBRARY DESIGN

The design of library buildings should be addressed at three levels:

- Urban design
- Building design
- Interior design.

Each has specific requirements which involve dialogue with user and interest groups, and each level has its own exacting demands which cannot be overlooked (see Table V). Library design is more than an exercise in architectural form making in spite of the growing interest in typological reinvention.

Table V Planning

Principal site planning considerations	Issues to consider
Civic presence	• Relationship to other public buildings • Visible presence
Public access	• Access to public transport • Disabled access
Service access	• Access to road system • Delivery and storage areas
Urban design	• External public gathering space • Safe, secure and legible routes

3.1 Urban design

It is vital that libraries are buildings that the community can be proud of and want to use. The design should be open, inviting and transparent. There should be a sense of 'library-ness' in the design of the building as a whole, its main spaces and more intimate study rooms. This may be translated differently between a major public library and an academic one but the building should still communicate its essentials as a library: a place where society's knowledge is stored and made available free of charge.

The trend away from branch libraries and separate faculty libraries means the library is assuming ever greater importance as a prime civic building as it becomes a centralised facility. The public library therefore needs to be well connected to civic life and the academic library located at the centre of the college or university. Good access to pedestrian flows and public transport is essential, as is the ability to service libraries with their ever evolving collections and needs.

Hence, there will normally be a public front and a service rear or undercroft. However, the public entrance is not normally the library door but a gathering space immediately outside it.

Libraries should turn outdoor spaces into assets that support meeting, exchanging ideas, reading outdoors or simply sitting in attractive surroundings. These should be designed with the characteristics of a public square with attention to landscape design, public comfort (i.e. seats) and community or personal safety. The library 'square' is where users will meet, escape from the confines of the library to reflect on the material, or take short breaks to eat sandwiches or visit local cafes and other cultural facilities. Aristotle defined the city as 'a collection of buildings where men live a common life for a noble end' and nowhere is this more evident than in the public library.

The external library space should be free of cars although public modes of transport can (and often should) pass nearby. There also needs to be provision for disabled access and facilities for the storage of bicycles. Hence, a level access is preferable and ramps essential where changes of level are inevitable. The public space alongside the library entrance provides an opportunity to make a statement of the building and this in turn can help signal the significance of the library. It also provides the chance to incorporate sculpture or other forms of public art into the city – some of which may contain text references to the library collection.

With university libraries the building needs to be centrally placed on the campus and located where 24 hour surveillance is possible. There is often a linear plaza at the centre of campus where other academic institutions are located such as senate house, refectory, gymnasium and registry. This provides an opportunity for the formation of a student-centred academic mall which ties together the key shared facilities with links to the separate faculty buildings further afield. Hence, one role of the academic library is to define the centre of the campus both spatially and in terms of building hierarchy.

The flows from the external public space to the main building entrance are more clearly defined if attention is paid to urban design at the briefing stage. The choice of site often dictates external relationships. Proximity to public transport and existing pedestrian or cycle flows is imperative. There are parallel flows too which need to be considered such as the delivery of books, newspapers, furniture and access for staff. The service entrance needs to have good road access and a limited amount of delivery and parking space. Increasingly, information is electronically delivered using wire or wireless technology and this eases the demand upon physical service areas. However, delivery and storage of the library material is a major consideration at the site planning level.

3.2 The design of the library

Libraries are used for long periods of time. Therefore if the public library is to serve society and the university library its students and teaching staff, then great attention is needed to interior design, furnishings and fittings of both study and more public spaces (see Table VI).

It is important that the brief for a new library mentions the values the building should entail (see Table VII). Briefs are more than flow diagrams and floor area charts. A good brief contains higher ambition, thereby ensuring the building meets society's aspirations for libraries. There needs to be a clear diagram for the library in

Table VI Design

Key design characteristics of libraries
Visible, recognisable and legible as a type
Adaptable to new information technology and physically extendable
Comfortable and disabled friendly
Inviting, safe and secure for users
Protection and security of the collection

plan and cross section. Clarity in plan allows the user to comprehend the logic of the layout with the main features (such as reading rooms and IT suits) in obvious locations. Creating a clear diagram is a challenge too in section and here the library needs to have a coherent strategy for daylight, ventilation and acoustics.

The external square or set back public space leads the library visitor immediately to the entrance doors. These need to be inviting, wide and transparent, and arranged so that the interior can be viewed immediately upon arrival. It should also be possible to see the major library spaces from the outside, thereby providing links to the life of the city (see Figure 27.5). Too frequently in the past the demands for security interrupted the physical and visible flows between the inside and outside worlds.

In large libraries it is often possible to form an outer foyer before the user reaches the library proper. Here there may be lockers, information boards relating to community activities, a café and sandwich bar and meeting rooms. This transition space between the inner and outer worlds requires particular attention in order to avoid disruption to the library. Once inside the library the user should be able to comprehend the key spaces and principal routes.

3.3 Library desk

The library desk and control barrier provides an essential element in the working of the library. It is the main point of contact between users and library staff and the spoken work is essential to aid navigation through the collection. The library control desk should not form an impervious wall but provide an inviting permeable barrier through which visitors pass. The trend towards self-service check in and out of books and other material frees up the librarians to become 'floor walkers' aiding readers in their search for information. The control or self-service point where books are checked in and out should remain part of the entrance experience rather than the dominant element for the visitor. Increasingly, the next point of contact is with the computerised catalogue or the IT support area which is usually nearby. To counter the dominance of digital information systems in some libraries (which can deter the elderly) there is often a magazine or newspaper area nearby.

3.4 Arrangement strategy

There are two main strategies for arranging the book collection. The first is to stack the books near the centre of the library arranging reading tables around the edge where there is good access to natural light and external views. The second is to place the books around the perimeter with a large central reading room often lit from above. The latter provides the opportunity to create an interior volume where readers can move between paper and electronic media. The integration of modes of knowledge and types of media is often difficult in practice because of the specific requirements of computers and the nature of some paper-based collections such as old newspapers or photographs. So in spite of the ideal of integration, there are often special study areas dedicated to types of media or study material.

3.5 Flexibility

Since the storage and use of knowledge is changing rapidly, libraries need to retain a high level of flexibility. The ability of the building to change over time without compromising the key attributes of what constitutes architecturally a 'library' is an important consideration at the design stage. Libraries are recognisable buildings where spaces like the reading room help to define the type. To provide flexibility at the price of character risks removing the important civic dimension. However, libraries need to be able to adapt to changing information technologies and their evolving cultural or social role if they are to achieve their full relevance in the twenty-first century.

3.6 Circulation

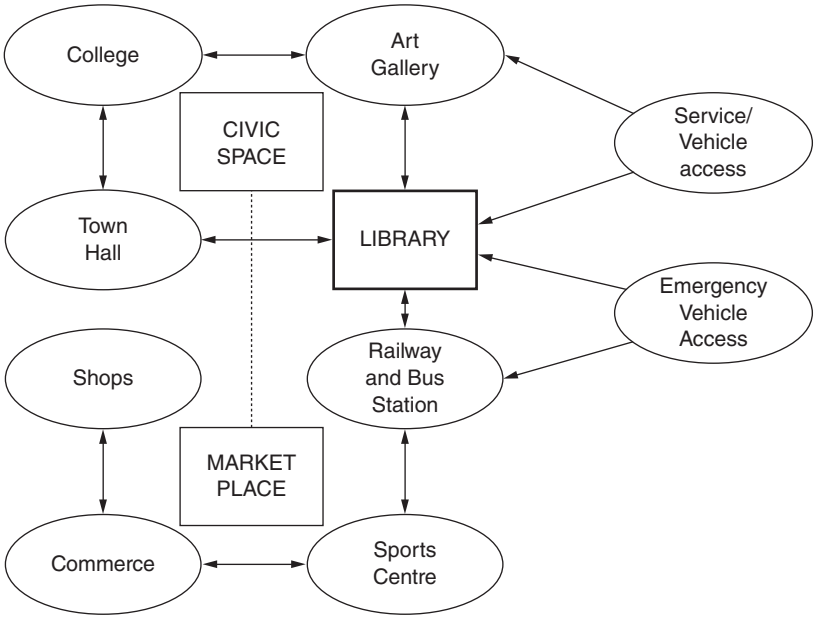
Circulation, which may account for 10–20% of floor areas, is used for access and for socialising. Such areas should contain seats and niches off the flow to encourage informal exchanges. Major staircases should also be designed as processional spaces where the scope and fluidity of knowledge is experienced architecturally.

3.7 Zoning

Zoning the interior of the library into distinctive areas (Figure 27.6) rather than separate rooms is the policy generally adopted in all but national libraries (Figure 27.7). Integration is the norm within the constraints imposed by noise, PC screen conditions and reader comfort.

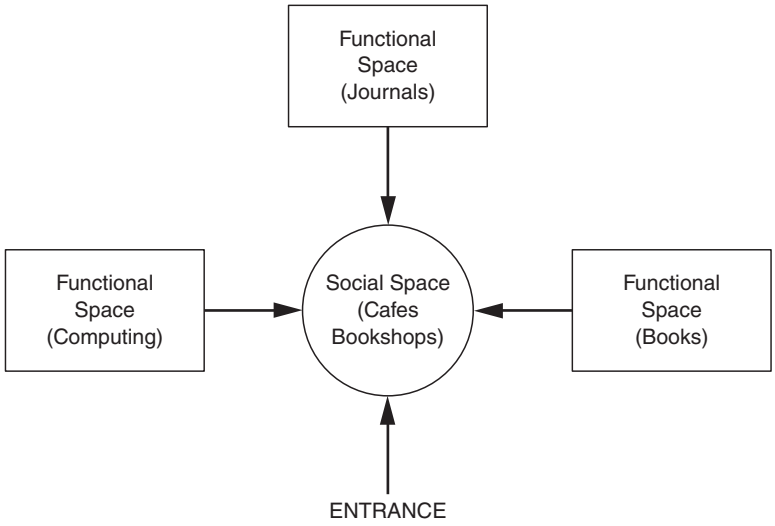
Table VII Key factors to consider in interior design

Technical
Are the floor loadings adequate for the collection?
Is the wiring and wireless layout suitable for future IT needs?
Are the environmental conditions acceptable for the planned use?
Is the building energy efficient?
Is the collection secure from fire or theft?
Aesthetic
Is the building welcoming as well as functional?
Are the routes and major spaces legible to the user?
Is there space for reflection?
Do readers have good access to daylight and views?

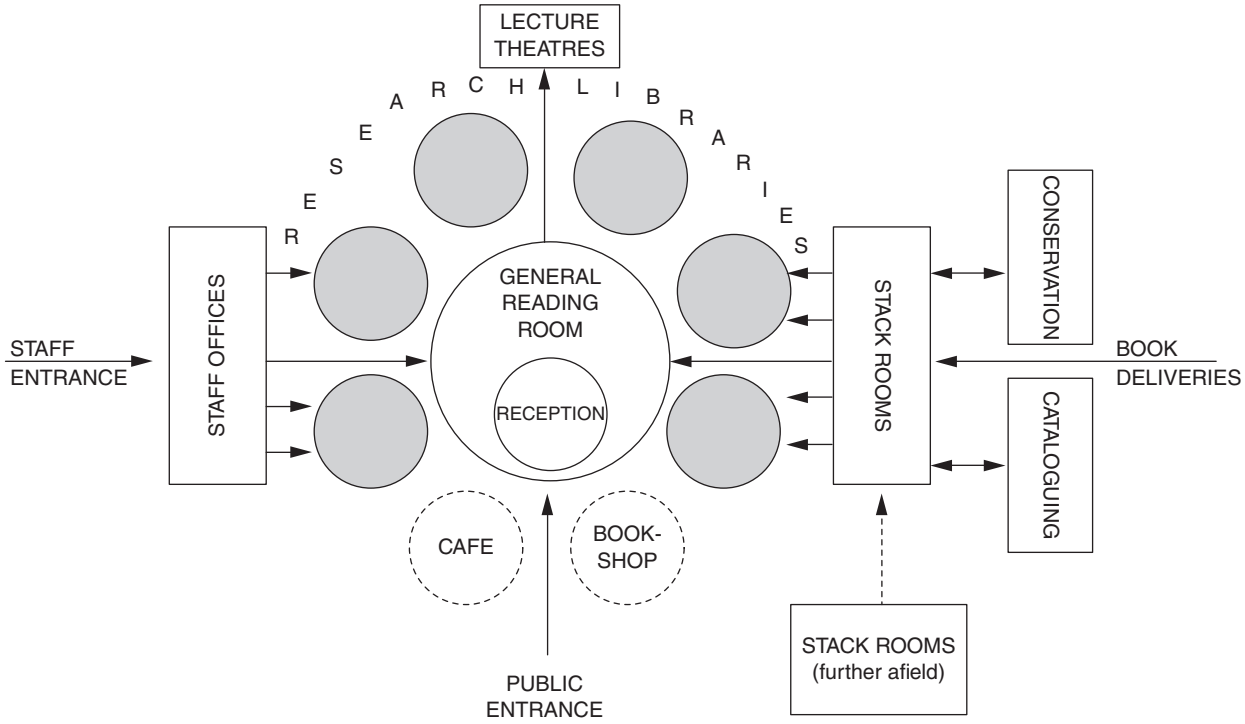


27.5 *Conceptual diagram of the relationship of library to other civic functions (Brian Edwards)*

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27.6 *Relationship between the functional and social zones in the library (Brian Edwards)*



27.7 *Diagrammatic layout of a national library (Brian Edwards)*

These separate zones may be distinctive functional areas but they are generally linked by wide connecting spaces. Zoning allows one area to adopt a different policy on noise or security than another, permits internal change without disruption to the whole and allows different users to employ the library resources in different ways. A varied interior culture is preferable to one where there is a corporate standardisation across the whole building. Such variety can be engineered or left to grow as the nature of users and the collection changes (see Table VIII). At Peckham Library for example, there are three pods within the main book areas designed specifically to house the special collections. Each is specific to the collection and tailored to the tastes of potential users.

Increasingly paper and electronic sources are physically integrated on the reader's desk but there is usually a zone or room for computer users; a separate area for those referring to journals or newspapers; a defined floor area for the library book stacks; a separate space for reading desks and perhaps special study carrels.

Table VIII Typical services provided within a public or academic library

- Access to and loan of books
- Access to journals and newspapers
- Use of workstations
- Access to the Internet
- Electronic access to research journals
- Guidance to sources of information
- Community learning and visitor support
- Café and refreshment area

3.8 Access

Libraries require a great deal of service access for the delivery of books and study material, and for the removal of waste. However, the prime access consideration relates to users, both able and disabled. Wheelchair provision is essential in all areas of the library except in compact storage zones. Wheelchair users need to be able to reverse at the end of bookstacks and to rise unimpeded between floors. Security barriers should also be wide enough for wheelchair access. Disabled access in libraries is relatively straightforward. However, problems can occur around cafes and bookshops where wheelchair access for library users may become obstructed.

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4 ROOM LAYOUT, FURNITURE AND SHELVING

4.1 Book stacks

Most libraries are sub-divided by book stacks which provide the basis for zoning areas into functional parts (see Table IX). The stacks provide also acoustic protection, have important environmental qualities (they provide thermal mass) and help define routes through the library. The position and type of shelving is essential to the smooth operation of a library and needs to be located carefully in relation to the fixed parts such as columns, lifts, stairs, walls and doors. The book stacks also dictate the layout of seating, tables and the position of workstations.

Table IX Book stacks

Layout of book stacks	Secondary issues
Position book stacks to define routes through library	Ensure safety exits are visible
Use book stacks as acoustic barriers	Consider acoustic and thermal properties of book stacks
Compress stacks to create reader areas at perimeter of building	Provide adequate space for safe and disabled use in dense stack areas
Provide light sensors in deep stack areas	In large libraries lighting is the major energy user hence use LED and other energy saving technologies
Ensure floor loadings are adequate for dense book stacks	Changing stack layout can be constrained by structural limitations

Normally, book stacks are centrally located with reading spaces around the edge of the building or around the perimeter of atria spaces (Figures 27.8, 27.9). However, main libraries have large and distinctive reading rooms. Such spaces may be on upper floors or overlooking external spaces and will in all probability be used by readers surfing book, journal and internet sources. Reading rooms are usually different to IT areas but there may be physical overlap.

4.2 IT provision and digital media

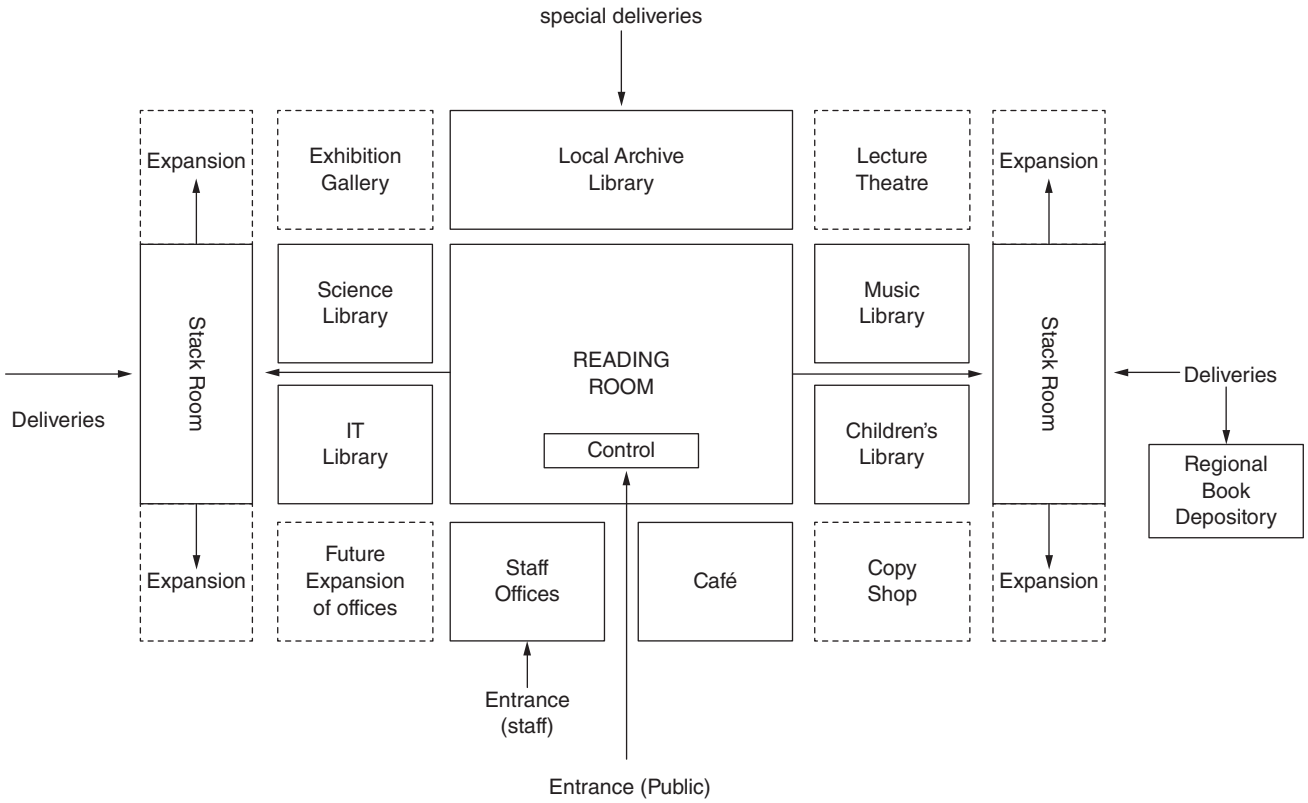
Growth in IT provision is sometimes at the cost of areas for book storage. As a result shelving is often closely spaced and increasingly aspects of the book collection are stored elsewhere. Growing use of libraries is sometimes at the expense of space standards, both in seating area and library shelving. Designers need to consider both the needs of readers and of staff who have the task of servicing the collection. Although books are generally decreasing in size, art books are getting larger, and whereas PCs are also shrinking with growing use of laptops and tablets, the number of readers who arrive armed with the latest digital technology is increasing rapidly. Hence, layouts and service points need to accommodate these changes.

Academic libraries provide much more computer space than public libraries (Figure 27.10). In some university libraries, the areas given over to IT-based learning resource centres can exceed that of book and journal storage. The use and loan of CDs, the development of a learning rather than a teaching culture has led also to the academic library being extensively employed in group teaching. Rooms are set aside for seminars within the library itself, and often the Internet provides the main resources on which students draw. As a result the nature of the interior spaces changes into a hybrid between the traditional library reading room and something more akin to a market trading floor (Figures 27.11, 27.12). The use of the library for seminar type teaching also puts pressure on the lifts, stairs and corridors at the end of timetabled teaching and this can disrupt private study areas.

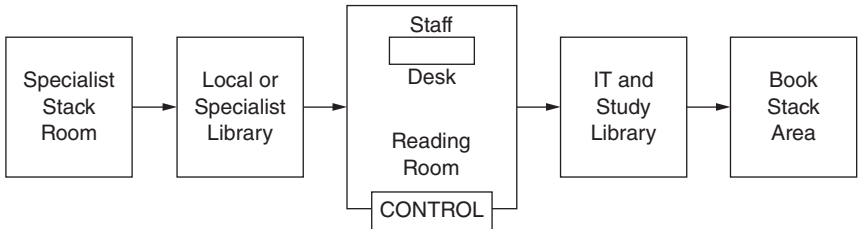
Table layout is an important consideration since the distribution of reader spaces can influence the configuration of columns and interior walls (see Table X). The layout of tables and shelves is

Table X Furniture

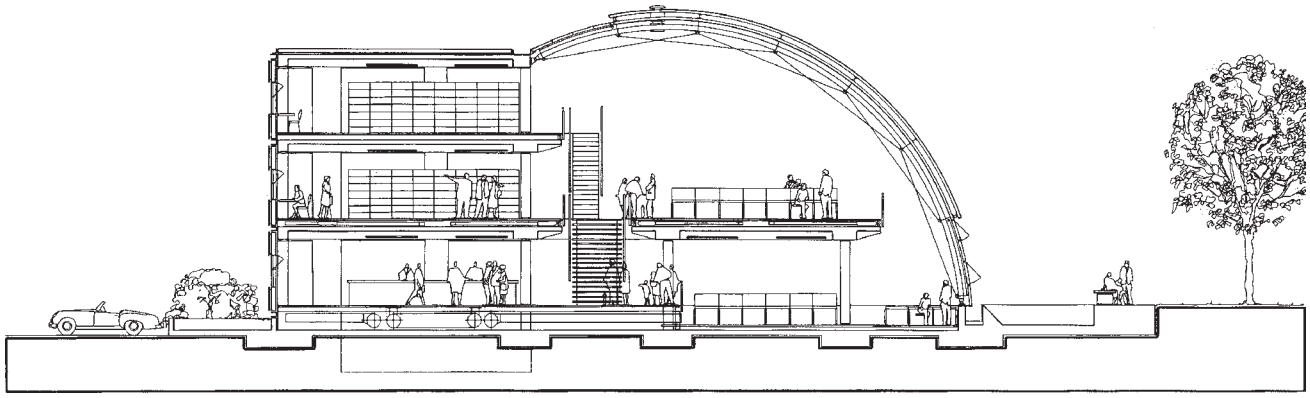
Layout and design of library furniture	Secondary issues
Provide visible staff desks on each floor to guide readers	Library staff should be visible to aid readers
Provide reader tables in areas well served by natural light	Place tables at edge of library or in internal atria spaces
Divide large reader tables into personal study areas	Provide separate power points along length of table
Ensure mix of table sizes and layouts to suit nature of collection	Atlases and newspapers require different table designs
Ensure tables are connected to IT systems	Encourage mixture of media usage at study tables



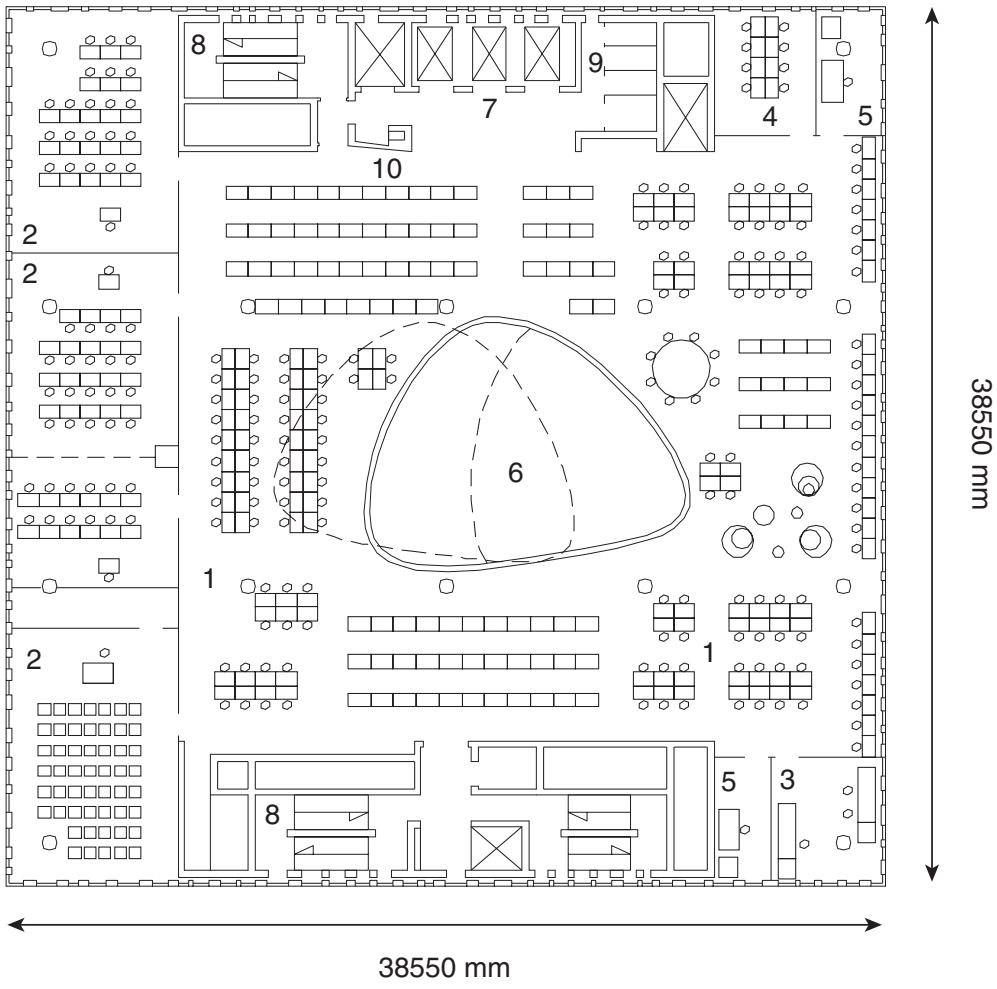
27.8 *Diagrammatic layout of a central public library (Brian Edwards)*



27.9 *Diagrammatic layout of a branch library (Brian Edwards)*



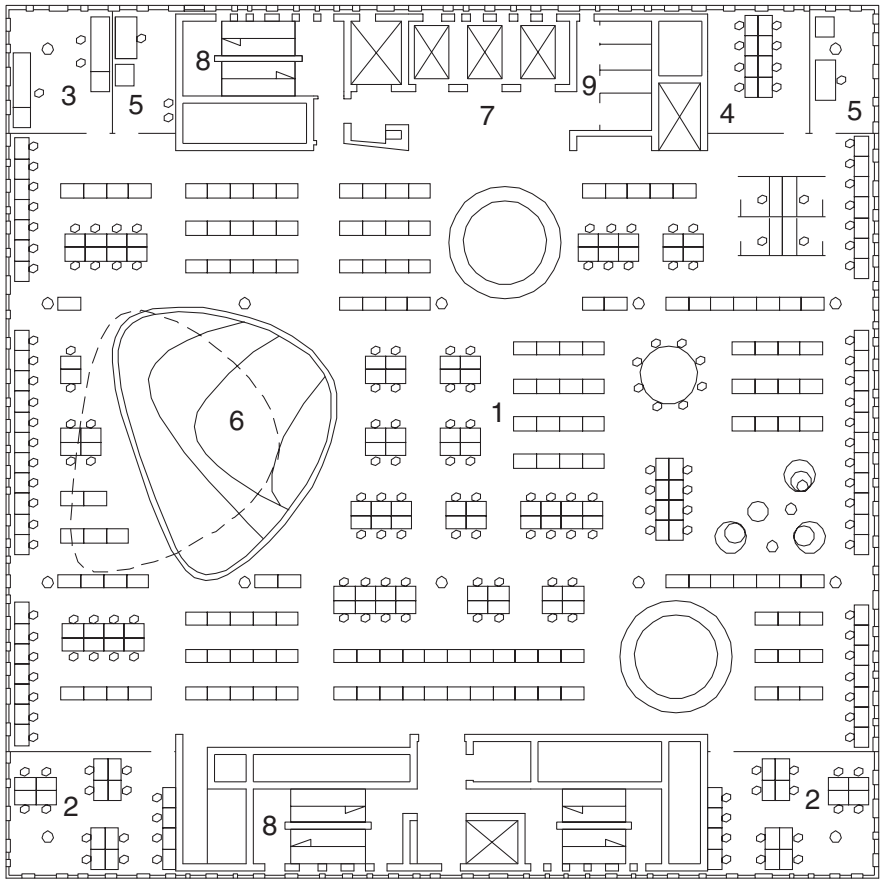
27.10 *Traditional library structure (left) and computer and discussion space (right) are combined effectively in the Learning Resource Centre at Thames Valley University (Richard Rogers Partnership)*



27.11a *Plans of Aberdeen University Library designed by Schmidt Hammer Lassen*

Level 2
1 Study space, 2 Seminar room, 3 Work room. 4 Group study space. 5 Office. 6 Atrium, 7 Lifts, 8 Stairs, 9 Toilets, 10 Information

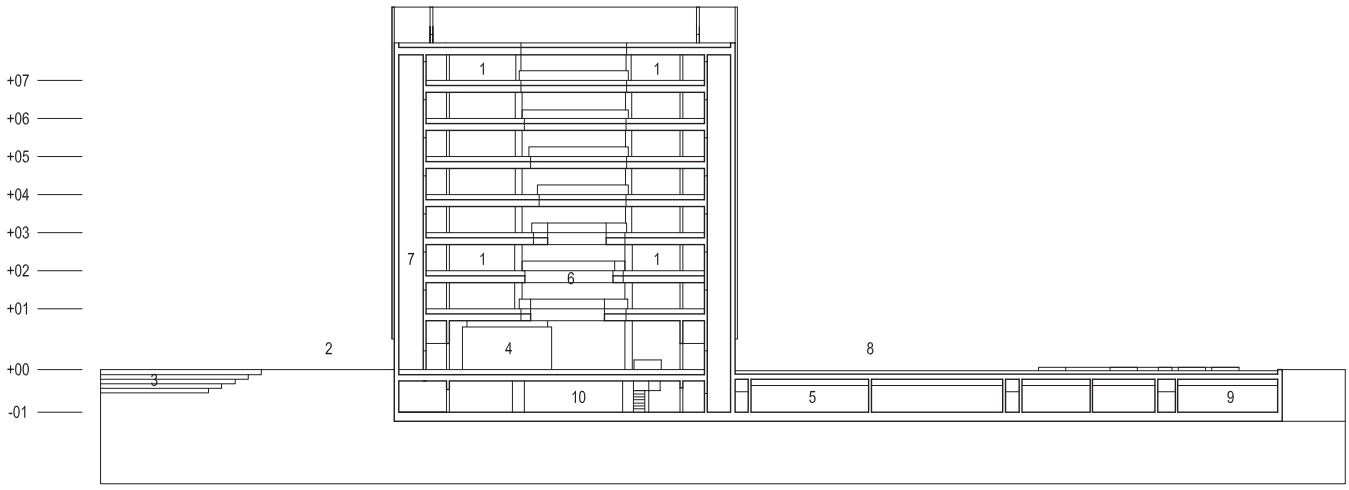
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27.11b *Level 6*

1 General Library, 2 Quiet area, 3 Work room, 4 Group study space, 5 Office, 6 Atrium, 7 Lifts, 8 Stairs, 9 Toilets

largely dependent upon the type of library in question. Libraries with large book collections increasingly store less frequently used material in basement areas or in other locations. Here compact rolling book stacks can be employed, thereby saving on space and cost. Basement storage is useful because the high loadings can be more readily accommodated than on upper floors and the reader is not kept waiting too long for the material to be accessed. Reader tables, rather than individual study desks, are the norm and these are usually placed near the perimeter of the library or in special reader rooms. Tables usually have the facility to use a laptop and often



27.12 *Section of Aberdeen University Library designed by Schmidt Hammer Lassen*

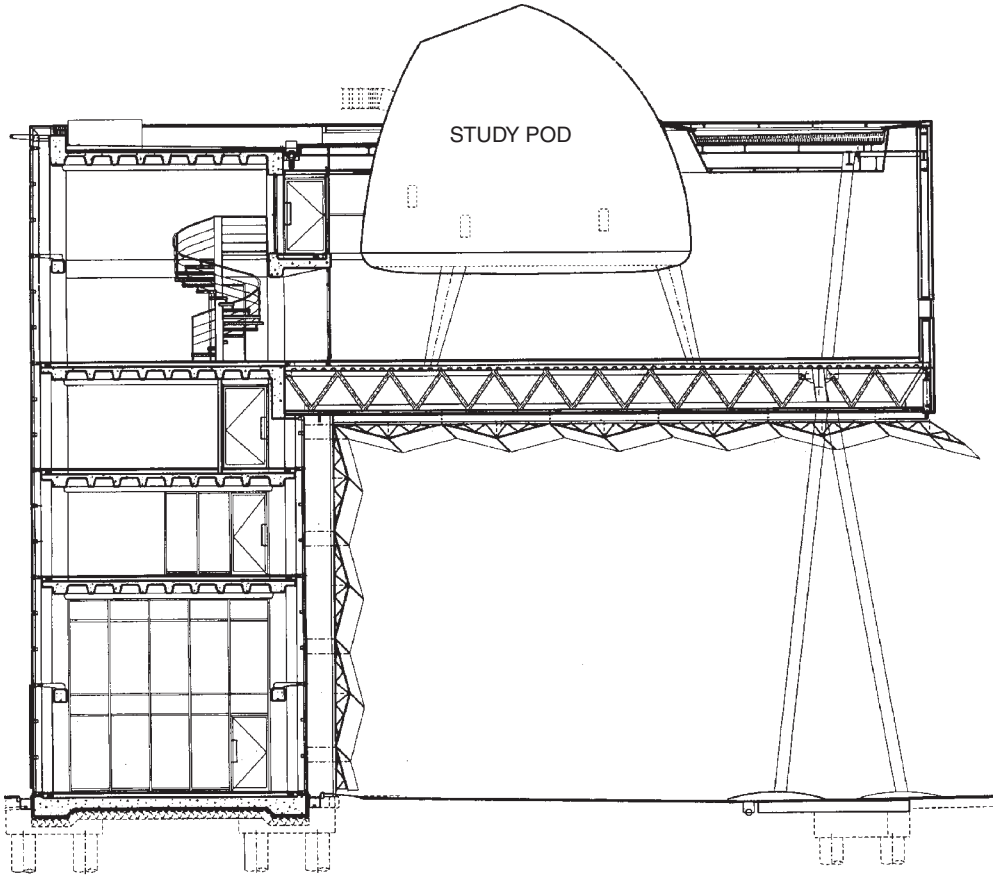
Key: 1 Library, 2 Library garden, 3 Amphitheatre, 4 Exhibition area, 5 Archive, 6 Atrium, 7 Lifts, 8 Secret garden, 9 Conservation suite, 10 Reading room

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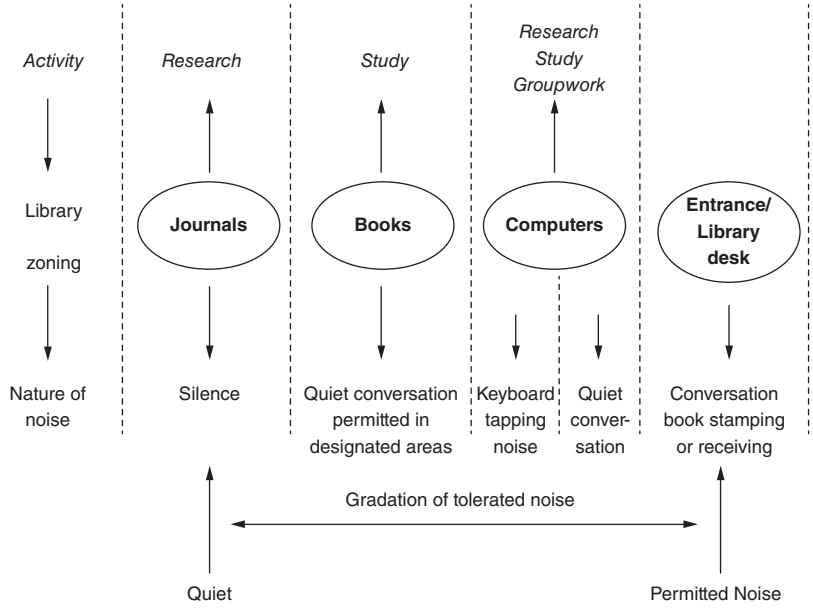
there is a desk lamp and small storage area provided per reader space on a shared table of perhaps 8 seating positions.

An area needs to be set aside also for special library use such as employing large atlases or maps, broadsheet newspapers and archival material. There may be security issues to consider as well as furniture needs such as large tables. Often there is the need to make copies and this can pose a noise and environmental problem. In public libraries there is often a sharing of tables for a variety of purposes but in academic and professional libraries, study areas are set aside for specific purposes, Figures 27.13, 27.14, 27.15.

Dedicated areas for the use of electronic media are increasingly provided in libraries of all types. Although the integration of digital and paper-based systems is the ideal, often the constraints of security, noise and readership needs lead to the zoning of an area for the prime use of CDs and other forms of electronic media. In many academic libraries a dedicated learning resources centre is provided catering specifically for computer use often with associated mixed-media, printing and teaching spaces. These areas require provision not unlike that in many business premises. Hence, the design breaks the mould

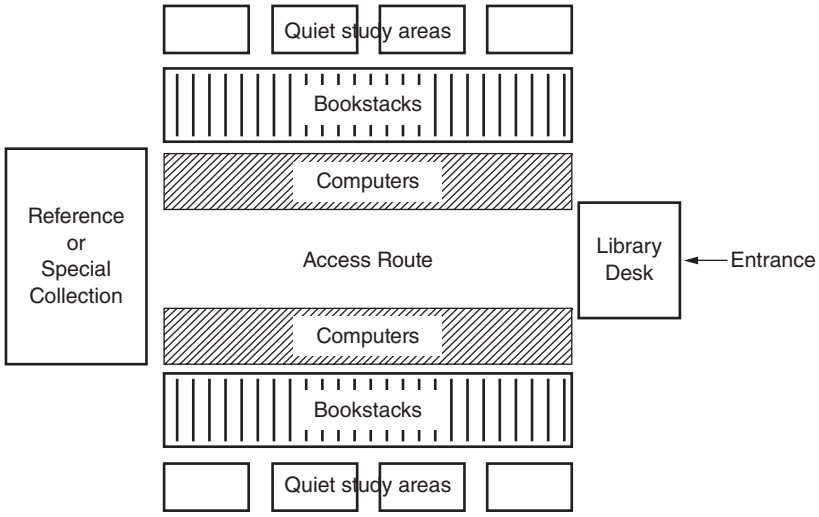


27.13 *Section through Peckham Public Library designed by Alsop and Störmer*



27.14 *Noise zoning in a typical academic library (Brian Edwards)*

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27.15 *Noise planning in a typical academic library (Brian Edwards)*

of the traditional library in the type of lighting, wiring layout and acoustic provision. As result there is often a library and IT learning centre side by side either as two joined buildings under the same envelope (Thames Valley University, Figure 27.10) or two separate but adjacent buildings (University of Sunderland). In public libraries where the level of IT provision is lower, the two activities are normally integrated.

5 SPACE STANDARDS

5.1 Space types

There are no international standards for space in relation to public libraries, as the range of groups served is deemed to be too variable (IFLA, 2001). However, schools and academic libraries have recommended space allowances related to the numbers of students.

Normally seven types of space need to be provided in a new library building:

- *Collection space* – to take account of books (open access and closed), periodicals (display and back issues) and non-print resources. Digital resources may need some space allocation.
- *Electronic workstation space* – for staff use, public use in the main areas as well as in meeting room areas. A public access catalogue used from a seated position requires 4 m^2.
- *User seating space* – at tables or alone. Plan for 5 seats per 1000 users. Table seating requires 2.5 m^2 per reader, a study carrel, and lounge chairs 3–4 m^2. A useful average is 3 m^2 per seated reader.
- *Staff work space* – including areas in the public part of the library and separate work room facilities. Fifteen square meters per staff work area (e.g. issue counter, help desk) is a good planning guide.
- *Meeting space* – including conference space, a lecture theatre or a room for children's activities. Space would also need to be allocated to other functions like cafes with storage space for equipment.
- *Special use space* – e.g. a local history room, job centre, tourist information centre or special collection with appropriate facilities for users to access the material.
- *Non-assignable space* – including toilets, stairs, lifts, corridors and space required for heating or other systems on which the library depends. In general, non-assignable space accounts for between 20 and 25% of the gross floor area of a typical library.

5.2 Usage data

Current library data should be taken into account in the specification for a new library relating to:

- opening hours (all or part of the library including out-of-hours);
- peak usage times;
- usage broken down by hours;
- days of the week library open;
- times of the year (particularly for university/college libraries);
- number of users (preferably separate figures for each part of the library);
- associated activities, e.g. meeting rooms, exhibition area(s);
- facilities, e.g. toilets, vending area, café;
- staff services to users – how many staff will be on duty/service points, security points;
- staff facilities, e.g. workroom, offices, post room, services, storage.

5.3 Public libraries

There are no absolute standards on the amount of public library space per capita. The 2001 International Federation of Library Associations guidelines state (p. 43) that:

> The amount of floor space required by a public library depends on such factors as the unique needs of the individual community, the functions of the library, the level of resources available, the size of the collection, the space available and the proximity of other libraries

and they go on to say that because these elements vary so much, 'it is not possible to propose a universal standard on the space required for a public library'.

Although dated, the publication 'The Public Library Service: IFLA/UNESCO Guidelines for Development' includes (in Appendix 4) a set of guidelines produced for Ontario Public libraries in 1997, which states that, for a community under 100 000, the appropriate amount of floor space for public libraries is 56 m^2 per 1000 capita. This set of guidelines goes on to prescribe:

- Collection space: 110 volumes/m^2
- User space: five user spaces per 1000 capita, user space = 2.8 m^2
- Staff space: 16.3 m^2 per member of staff (assuming 1 member of staff per 2000 population)
- Multi-purpose rooms: depends on community service and programme objectives
- Non-assignable space (staircases, toilets, etc.): 20% of net space (=space taken by first four categories).

In 2001, the DCMS consulted on a net figure of 23 m^2 of new library space per 1000 population as a potential public library

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standard. Analysis shows that figures currently in use for planning purposes are around 30 m² per 1000 population range. There has been a tendency for the figure to rise through time, not least because libraries are acquiring more functions, often at the behest of central government.

5.4 Academic and college libraries

CILIP's Guidelines for colleges recommend the following:

- 1 library study seat per 10 full-time students in further education
- 1 library study seat per 6 full-time students in higher education:
- 2.5 m² per student workspace in resource-based learning-rooms or learning resource centres
  - between 2.5 m² and 4 m² per student workspace in higher education
  - reader modules minimum 900 mm × 600 mm
  - ICT/ILT spaces minimum 1200 mm × 800 mm
  - circulation space (gangways) of 1200 mm minimum (1800 mm preferred); access to desk or workstation requires 1000 mm minimum; private space for user 600 mm outward from desk. However disabled space needs may exceed these figures.

6 ENVIRONMENTAL CONSIDERATIONS

6.1 Natural light and ventilation

Libraries are big consumers of environmental resources. The bulk of energy consumed is normally in artificial lighting. Hence, the design strategy should seek to maximise daylight and to use the incidental gains from electric lighting for supplementary heating. This assumes integration between lighting, heating and ventilation with mixed mode technologies, heat recovery and judicious use of renewable energy (see Table XI).

One trend is towards the use of atria to create internal lighting conditions which reduce the demand for artificial sources. Noise transmission and fire risk will, however, need to be considered in atria-based layouts.

Natural light and ventilation are preferable, especially in the reader areas, but security and plan depth can make this difficult to achieve. As a result most libraries employ a mixed-mode ventilation system which incorporates a hybrid of natural and mechanical systems, often employing atria spaces and sometimes double façades. Since libraries use a great deal of artificial lighting, solar heat gain can be a problem especially where large areas of glazing are provided on south facing elevations, leading to glare, discomfort and excess temperatures. It is better to avoid a southern orientation; ideally reading rooms should face north to avoid these problems. But where unavoidable, solar screening using internal and external blinds, or fixed solar shading or special glass may be required (Figure 27.16). However, the use of solid facades to exclude adverse external conditions is not advisable if the library is to assume a level of social engagement. It is façade transparency which often identifies the library as a key building in the city or on campus (Figures 27.17, 27.18).

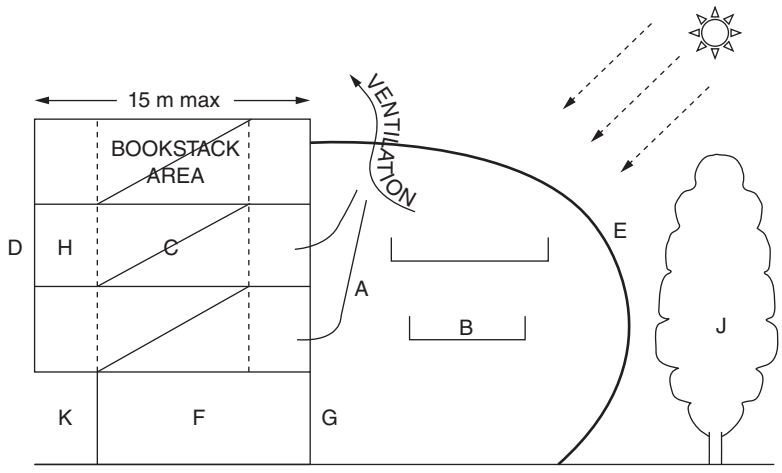
Table XI Environmental considerations

Restrict plan depth to 15 metres for maximum daylight penetration
Create internal atria in large depth libraries
Provide solar shading and internal blinds on large south and west facing glazing areas
Use external light shelves to increase daylight penetration
Place reader tables in well-lit areas
Avoid air-conditioning except in 'hot spots'
Employ mixed-mode ventilation systems
Maximise natural ventilation in public areas

In many ways the book collection itself stabilises internal temperatures using thermal mass. The position of bookstacks also helps too with acoustic zoning. Often exposed concrete construction is used to reduce temperature fluctuations using the thermal capacity of construction sometimes linked to chilled beams. Here it is worthwhile considering both the mass of the library collection and that of its structure together. However users, their equipment and lighting can stress temperature expectations leading to reader fatigue.

6.2 Artificial lighting

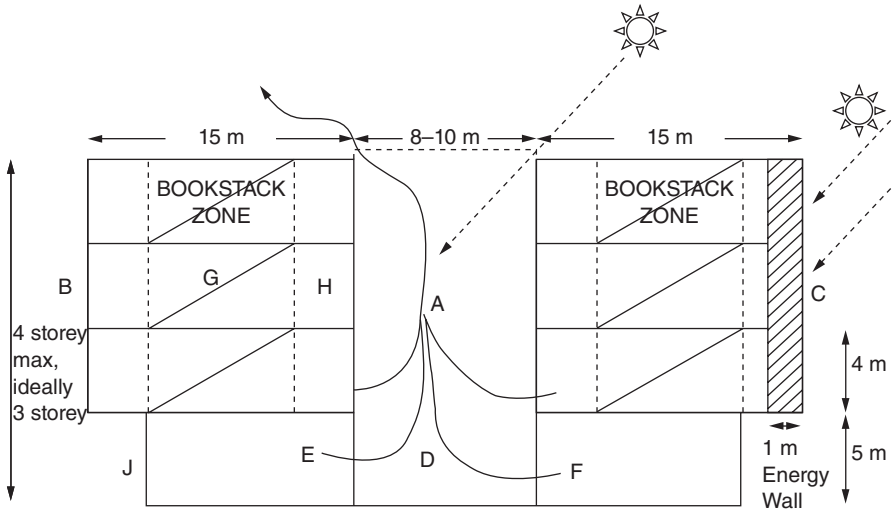
As a matter of course low energy light fittings and sensors should be fitted in all areas. The use of task lighting can result in lowering general light levels but with a growing elderly population, reducing overall light levels can result in accidents and poor user



A - Open Plan Learning Resource Centre
B - Banks of computers on decks
C - Library floors, bookstacks in centre
D - Fully glazed north façade
E - Solar protected south façade, freely ventilated at top
F - Café, exhibition area
G - Entrance into library at central point
H - Reader carrels at building periphery
J - Planted shade on south side
K - Sheltered routes to library

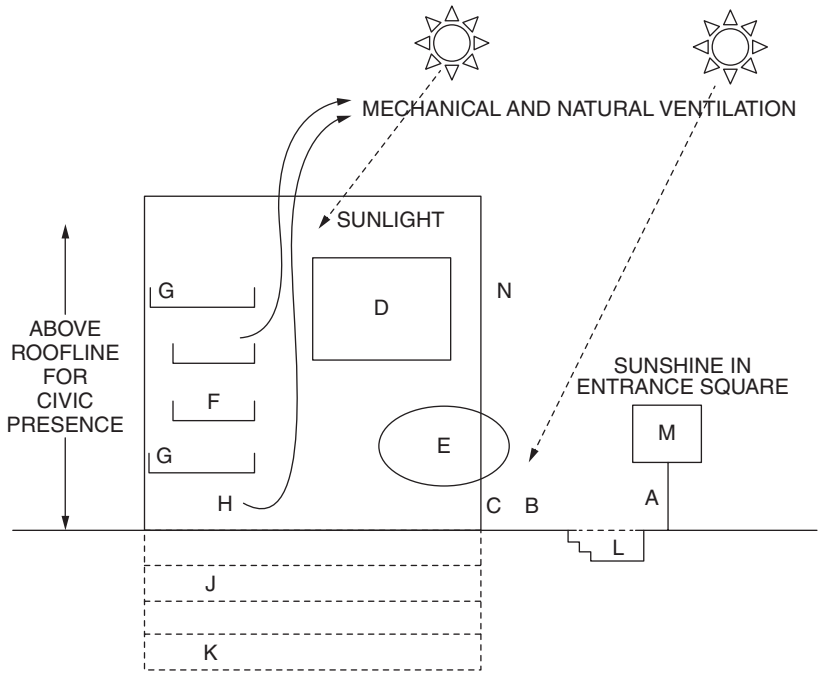
27.16 *Diagrammatic section of a modern university library (Brian Edwards)*

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A - Atrium in centre for stairs and lifts.
Direct sunlight and natural ventilation.
Acoustic ceiling and walls.
B - Fully glazed north façade.
Reader desks against periphery
C - Solar protected south façade.
Shaded reader desks against periphery.
D - Well identified, sheltered entrance.
Disabled friendly, pram and bicycle storage.
E - Café and exhibition space.
F - IT Resource Centre.
G - Library floors, bookstack in centre for thermal capacity.
H - Computer terminals in bays around atrium.
J - Sheltered routes to library

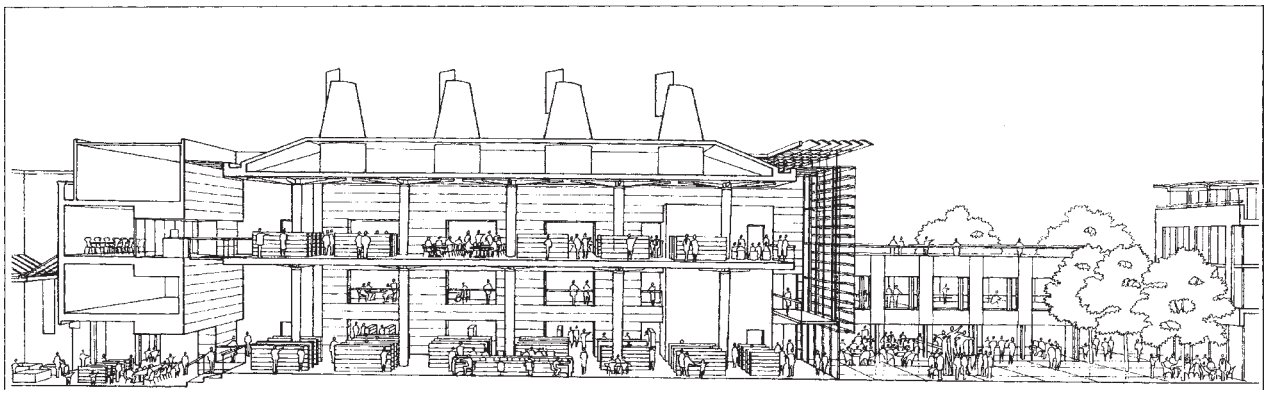
27.17 *Template for design of public library (Brian Edwards)*



A - civic presence on street.
B - gathering square.
C - spacious entrance with exhibition space.
D - special collections readily identified.
E - auditorium near entrance.
F - library floors by subject.
G - reader spaces against permeter.
H - computer catalogue access and toilets.
J - conservation.
K - storage of collection.
L - amphitheatre for external performance.
M - conference.
N - energy conscious facade.

27.18 *Template for design of national library (Brian Edwards)*

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27.19 *Brighton Public Library is designed with both study and environmental concerns in mind (Bennetts Associates)*

satisfaction. Light reflection on computer screens is also a consideration and generally results in PCs being in more central areas.

In order to maximise natural light and ventilation, the plan depth should not exceed 15 meters. However, this is difficult to achieve in all but the smallest of libraries, and hence artificial conditions are provided in most areas. Since most libraries are constructed in urban centres, the main environmental factors are normally glare, solar gain, external air quality and noise pollution (Figure 27.19). Hence a great deal of attention should be directed to site choice and layout, the design of external facades and the internal zoning of the building using light wells and mini atria (as at the new Birmingham City Library).

As a general rule readers like to work in natural light. This normally results in the perimeter placing of reader tables. Some seating areas can also be provided in inner sunlit spaces, particularly where magazines and newspapers are read. The creation of relaxation areas as distinct from study areas should take into account the different environmental conditions which may exist. Readers like views and hence study spaces or carrels generally occupy the library perimeter with major reading rooms placed on upper floors. Views of the city and of nature are usually preferred.

7 FINANCING AND RESOURCES

7.1 Hard times and the centralising of facilities

The enthusiasm that accompanies the planning of a new library can induce an artificial atmosphere of plenty even amid harsh financial constraints, and architects need to remember that libraries, especially branch ones, can experience difficult times. While many cities such as Birmingham and the larger London boroughs are building large new facilities to catch the public eye and often employing architects of note, branch libraries are being starved of funding and community groups are increasingly helping to staff and maintain them under the present UK government's localism initiative. There may be staffing cuts, cuts in book fund or the need to cancel journal subscriptions.

7.2 Operating budgets

The problem in many new library projects is that the construction budget is not always reflected in the library's operating budget. When the new library opens its doors, the public will flock in to enjoy its many attractions, but if there is an inadequate budget to support new or expanded services, this can lead to difficulties. In a recent example, a new central library was planned with staffing based on a projected 5000 visitors a day. However, the day after opening, the number jumped to 9000. Moving the existing collection also requires many additional staff hours, as does the setting up and configuring of the large amount of state-of-the-art equipment.

7.3 Efficient staffing

Library staff numbers are generally reducing, while new electronic resources take an ever larger proportion of the budget. It is important to design a library that can be staffed safely and efficiently by the smallest possible number of people. For example, book stacks and work areas need to be arranged so that staff can use their time efficiently and flexibly. Generally, equipment needs to be centralised so that the building can be adequately operated and staff desks located so that one librarian can provide surveillance over a large physical area. A well-designed library of today is usually able to achieve lower staffing levels than a poorly designed library from the 1970s or 1980s allowing staff to be the readers' subject navigators.

8 CASE STUDY – BIRMINGHAM LIBRARY

Introduction

Redevelopment of Birmingham's central library, the largest public library in Britain, stemmed from a desire to build a new urban landmark as part of wider transformations of the city centre. The new library, designed by Dutch practice Mecanoo, replaces a modernist library built in 1974 to designs by the John Madin Partnership and addresses both urban design and library design in a fresh way which is as much about people as it is about books. It is one of a generation of super libraries found increasingly in the world's major cities where the book remains a prominent part of the library experience.

Urban design

The new Birmingham library stands in Centenary Square sandwiched between two distinguished neighbours – the Birmingham Repertory Theatre and the Art Deco Baskerville House. Mecanoo restructured the square and sought to revitalise it as a largely pedestrian experience, providing a place to meet before entering the library and somewhere to read or think within the hectic city. It also provides internal links to the theatre and an underground gateway to the library.

Entrance

The 35,000 sq metre library is approached beneath a large canopy which projects into the square (Figures 27.20, 27.21). Above this stands the double height reading room with external balcony which provides users with views into the square and beyond to the city.

Layout

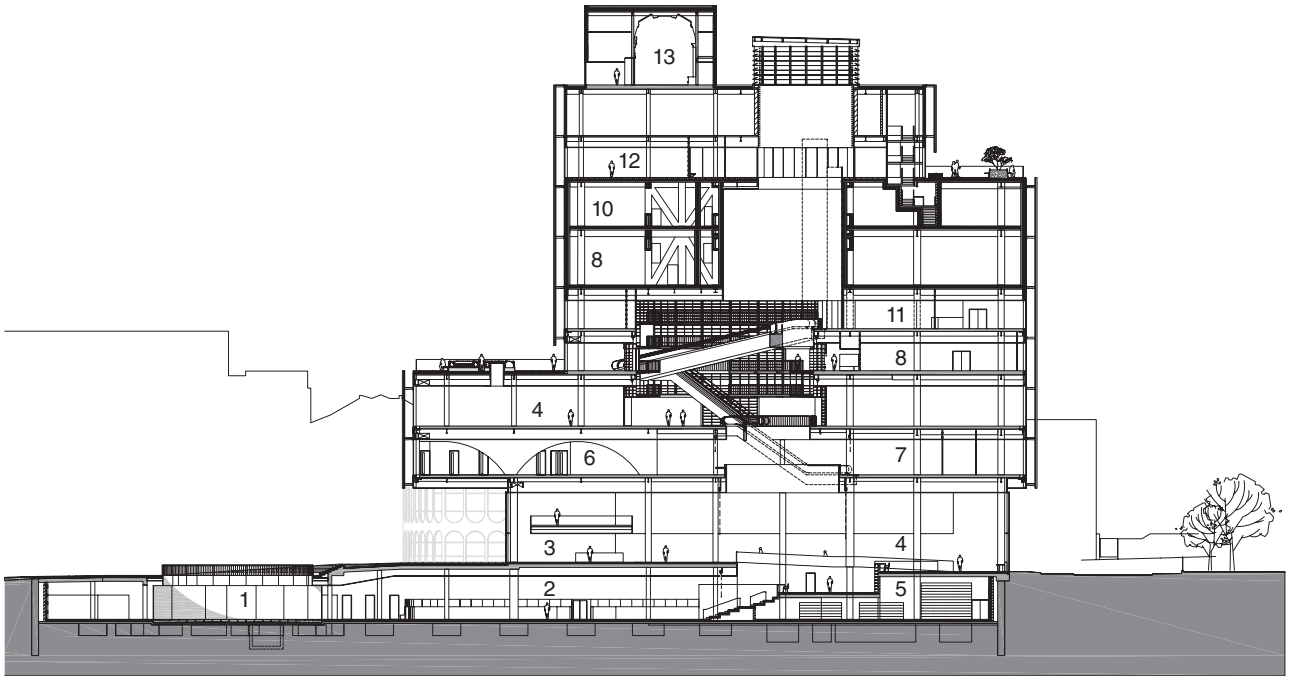
The ten storey library houses a children's library and book store in the basement. On the ground floor (Figure 27.22), a lofty entrance foyer with café and exhibition area leads via escalators to eight floors of reading rooms, multi-media areas, IT study and archive spaces. On the roof within a gold coloured rotunda stands the reconstructed Shakespeare Memorial Room rescued from the original Birmingham public library built in 1874. It contains one of the largest Shakespeare collections in the UK.

Although books are found on all levels, three floors of the library contain book stacks housed in dense mobile storage systems

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27.20 *Section of Birmingham Library with new public square to the left*



27.21 *Section of Birmingham showing library accommodation*

Key: 1 Music zone, 2 Children's library, 3 Foyer, 4 Readers' services, 5 Storage, 6 Meeting room, 7 Business & training, 8 Gallery, 9 Heritage, 10 Archive, 11 Archive & heritage open research, 12 Staff offices, 13 Shakespeare Memorial Room

or double height stack rooms. This compaction allows space to be provided for readers in well-lit areas around the library perimeter or close to atria. Here, IT and traditional reading tables are integrated although there are also separate multi-media and quiet study rooms. The main book collection is housed on open shelves which radiate out from the main atria giving readers views to the outside world.

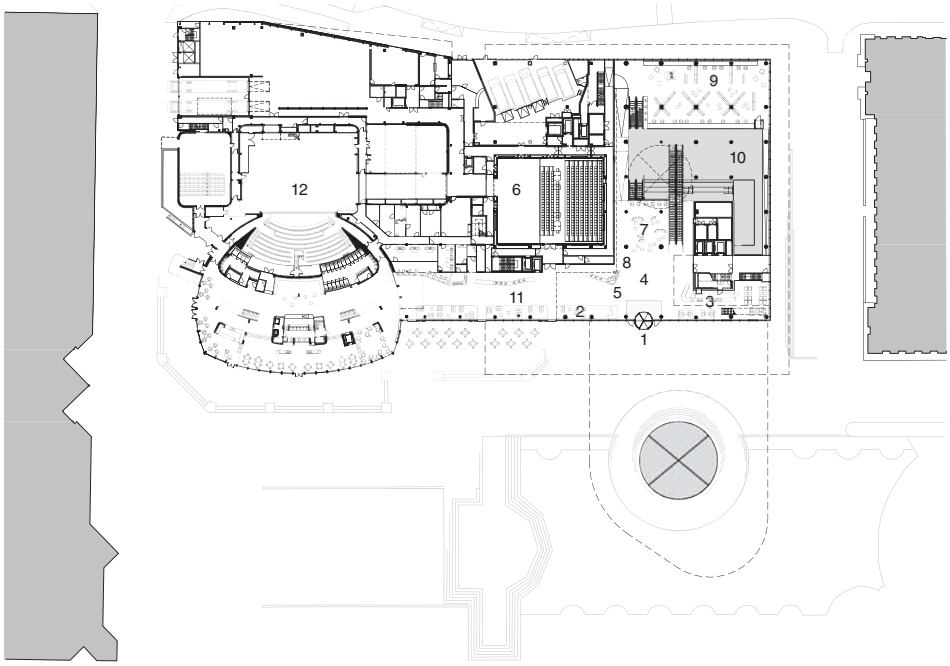
Different spaces are designed according to the nature of the collection or the demands of the media employed (Figure 27.23). Rooms and study areas are therefore distinctive rather than standardised with archive, music and heritage collections having their own special spaces fashioned by conservation demands or the character of the collection (Figure 27.24).

Circulation

Circulation is mainly via escalators and atria recalling the ambience of a department store. The circular atria are lined with books or murals and their distinctive character helps users navigate through this large library.

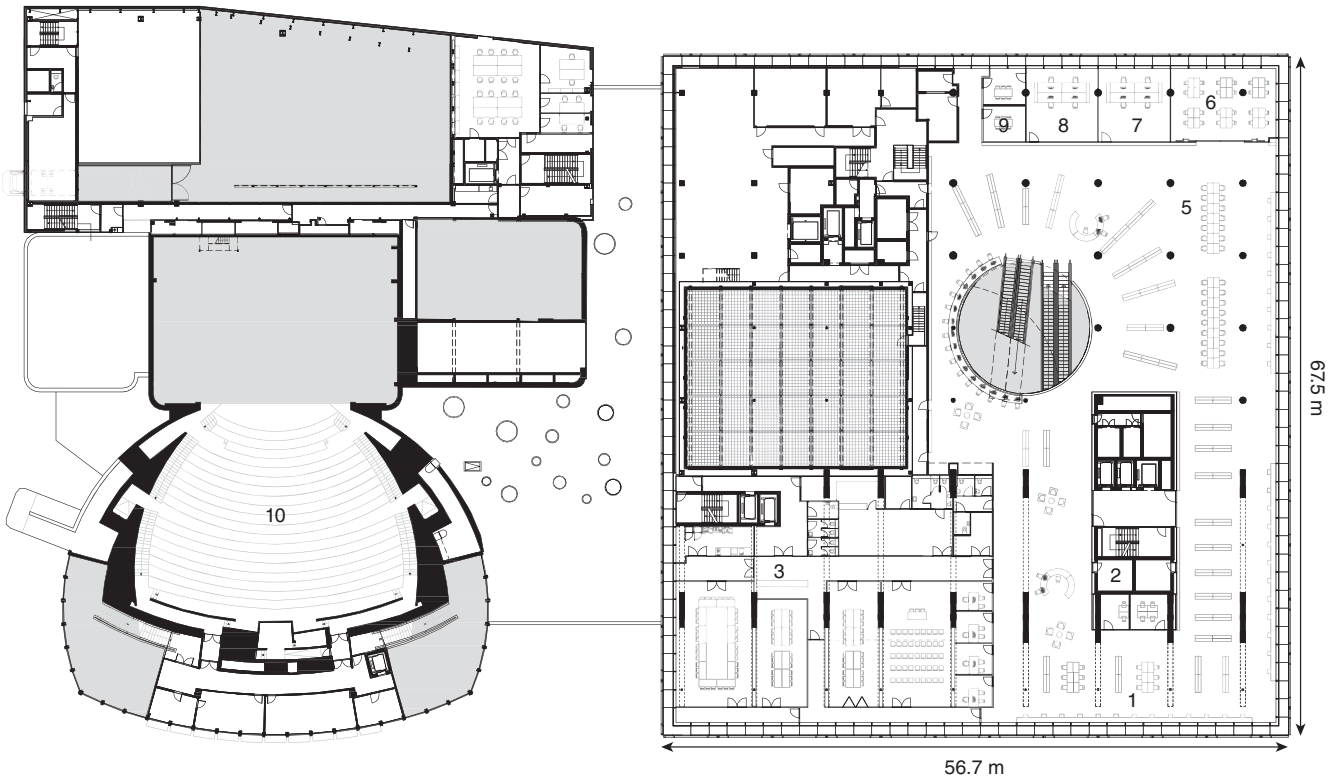
The atria also provide natural light and solar assisted ventilation within the deep planned areas. Light from above filtering into atria creates uplift physically (for air movement) and psychologically

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27.22 *Ground floor plan: Book Browse*

Key: 1 Entrance, 2 Retail, 3 Library café, 4 Foyer, 5 Information point/reception, 6 Studio theatre, 7 Spotlight, 8 Meeting point, 9 Upper lending terrace, 10 Lower lending terrace, 11 Seating area, 12 Repertory theatre

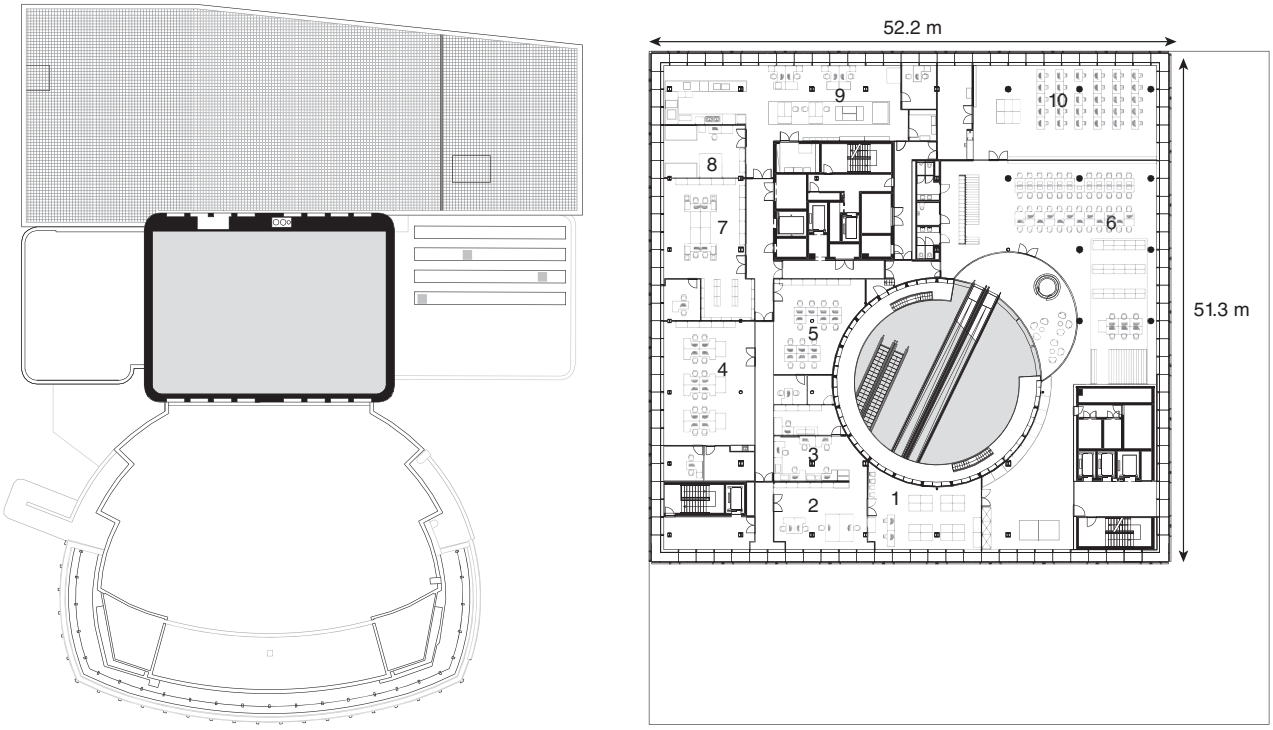


27.23 *Level 1 floor – Business, Learning & Health*

Key: 1 Supported learning, 2 Staff area, 3 Library meeting rooms, 4 Interview rooms, 5 Group study area, 6 Innovation hub, 7 Business incubation, 8 Training suite, 9 Recording studio, 10 Theatre

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27.24 *Level 4 – Archives & Heritage/Search Area*

Key: 1 Learning space, 2 Outreach room, 3 Digital room, 4 Cataloging room, 5 Staff area, 6 Open search area, 7 Photograph office & cataloging room, 8 Box making machine room, 9 Conservation lab, 10 Supervised search area

(for the spirit). Fatigue is further relieved by generous provision of escalators and lifts which are placed to entice you into the building.

Routes are designed to make connections between digital and paper based media, and between open and enclosed spaces.

Facade design

The facades are unified by the application of an external metal grille of matt and silver circular bands. Where the inner facade is fully glazed, these act as solar shades and daylight filters to reduce heat gain and glare inside. Where the walls are solid, they provide a filigree pattern of shadows giving interest and depth to the facades. As a unifying motif this controversial circular decoration alludes to the industrial heritage of the city of Birmingham.

Energy

As with all libraries, the main users of energy are lighting and cooling. Birmingham Library is rated BREEAM Excellent and incorporates ground-sourced water from deep aquifers which provides chilling of the building structure as well as grey water systems. On the basement floor where the children's library is located, the mass of the soil provides acoustic buffering and thermal stabilisation.

The building has a mixed mode and natural ventilation strategy with the facade allowing fresh air intake and outflow.

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28 Masterplanning and landscaping

David Simister with Guy Walters and contributions by Sarah Burgess, Hugh Barton and Marcus Grant

David Simister is creative director of Aedas. Guy Walters is a landscape architect at, Aedas. Sarah Burgess, Hugh Barton and Marcus Grant teach at the University of the West of England

KEY POINTS:

- *A masterplan will describe a vision for the development of a large site in words and drawings*
- *A masterplan can be defined as a type of planning brief outlining the preferred usage of land and the overall approach to layout, with detailed guidance for subsequent planning applications*
- *A well-conceived masterplan will include proposals drawn in three dimensions, taking into consideration massing and scale and the location and role of open space*
- *A masterplan will contain a strategic framework – a statement of aims for physical regeneration over a large area of land extending beyond the spatial masterplan*

Contents

1 Introduction
2 Philosophy
3 Site analysis
4 Methodology
5 The strategic framework
6 The spatial masterplan
7 Implementation plan
8 Digital masterplanning
9 Coherence, variety and uniformity
10 Urban design analysis
11 Infrastructure and connectivity
12 The anatomy of the site: highways, servicing and car parking
13 Site planning and landscape design
14 Open space
15 The geometry of site planning
16 Plot testing
17 The built heritage
18 The importance of detail: delivering design quality
19 Some alarm bells
20 Conclusions: evaluating a masterplan design
21 Masterplanning for healthy communities
22 References
23 Appendix: Key documents and case studies

1 INTRODUCTION

A masterplan will describe a vision for the development of a large site in words and drawings whether for mixed-use, commercial, educational, industrial, cultural, and residential or landscape, and will be a blueprint for place-making.

A masterplan should address the following parameters:

- Planning and Development policies
- Uses
- Functional efficiency
- Form, building density and massing
- Public open space, private and semi-private space
- Commercial viability
- Topography and soils
- Landscape, landmarks and vistas/focal points, visibility
- Climate, micro climates, and aspect
- Environmental harmony, wildlife and ecology
- Sustainability, energy and resource efficiency
- Transport and movement in all forms,
- Site and plot drainage including sustainable urban drainage systems
- Security
- Phasing
- Materials.

The site could cover a region, district, zone or plot but would always look beyond its own border to consider adjoining land to either suggest influence or inform its own outputs.

Masterplan has become an often misused term to illustrate the mechanism for design and delivery of large projects over extended time periods. Planning departments, developers and their consultant teams have come to rely on masterplans for consultation with landowners and local people and this concept is reinforced by government studies through the Urban Task Force, The Landscape Institute, CABE and Homes and Communities Agency and has become enshrined in the statutory planning system.

The Planning Portal (http://www.planningportal.gov.uk/) defines 'masterplan' to be a type of planning brief outlining the preferred usage of land and the overall approach to the layout of a developer and to provide detailed guidance for subsequent planning applications. Planning Policy Statements (PPS) govern planning policy. Planning Policy Guidance Notes (PPGs) and their replacements Planning Policy Statements (PPSs) are prepared by the government after public consultation to explain statutory



28.1 *Telford town plan extension, Aedas Architects*

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provisions and provide guidance to local authorities and others on planning policy and the operation of the planning system. They also explain the relationship between planning policies and other policies which have an important bearing on issues of development and land use. Local authorities must take their contents into account in preparing their development plan documents. The guidance may also be relevant to decisions on individual planning applications and appeals.

Some of the key themes emerging from the Review of PPGs and replacement with PPSs are:

- Enhancing the quality of the local environment – distinctive local character and sense of place (PPS1 – 'Delivering Sustainable Development' and its supplements: 'Planning and Climate Change' and 'Eco Towns')
- Reducing the need to travel by promoting local facilities clustered around public transport nodes; designing streets for pedestrians and cyclists (PPG13 – 'Transport')
- Making best use of existing resources of urban land and buildings and thus regenerating decaying localities. Reducing the stimulus to car use by rationing parking in housing and commercial/institutional developments (PPS3 – 'Housing')
- Reviving rural market towns, by encouraging more local service provision and diversification of local economies (PPS7 – 'Sustainable Development in Rural Areas')
- Reducing waste during construction and use (PPS10 – 'Planning for sustainable waste management')
- Key ingredients of local spatial plans and the key government policies on how they should be prepared (PPS 12 – 'Local Spatial Planning')
- Consideration of the effect of development on areas susceptible to flooding (PPS25 – 'Development and Flood Risk')

The Countryside Agency and English Nature have produced a Character of England Map (1996) which identifies the unique character of an area in terms of landscape character, sense of place, local distinctiveness, characteristic wildlife and natural features which can all influence both large and small scale design and masterplanning and should be a starting point for understanding the context of a site.

Masterplans vary in their portrayal of architectural and urban design vision. Place making and high quality environment requires the masterplan to promote high standards in landscape and architecture even if not proscriptive about other aspects. Images will be used to capture special aspects of development through wide angle aerial or ground level views. Specialist software can be used, from simple block modeling to elaborate photo-realistic renders but equally effective is free-hand drawing.

The Rio Earth Summit of 1992 sets out three particular principles relevant to developments within the landscape:

- The promotion of environmental protection as an integral part of the development process, in order to achieve sustainable development.
- The participation at the relevant level of all concerned citizens in handling environmental issues with appropriate access to information.
- The need for Environmental Impact Assessment on developments that are likely to have adverse effects on the environment.

CABE guidance suggests the masterplanner's task is to determine the appropriate level of prescription and standard-setting, while also providing for flexibility in the face of an unpredictable future, bearing in mind that:

- Development is likely to occur in a number of phases and may not take place continuously.
- Individual buildings or groups of buildings may be developed by different architects and/or developers.
- The masterplan may only be implemented in part.
- Requirements and economic conditions may change during the course of its implementation.

A well-conceived masterplan will include proposals drawn in three dimensions, not necessarily in detail, but taking into consideration massing and scale and the location and role of open space. These drawings will be read in conjunction with the written part of a masterplan, which will deal with the following:

- What is the masterplan trying to achieve and what are its aims and objectives?
- What is the masterplan trying to define or to pin down, and in what respects are matters being left open?
- What is the policy context for the masterplan, and what is the need for aspects of the masterplan to be adopted as policy, for example through supplementary planning guidance or design briefs?
- Who are the key partners in the development and what are their respective roles: regeneration agencies, the local planning authority, developers, funders, designers, the community, and tenants, transport providers, etc.?
- What is the delivery strategy for the masterplan, for example phasing and funding?
- What is the mechanism for assessing detailed proposals as they come forward, against the masterplan?
- What is the mechanism for changing the masterplan if circumstances change?

It is likely that a masterplan will address the issues of land use, but that is not its principal purpose. Mixed-use neighbourhoods are now a primary aim of government planning policy, and close control of different uses is no longer given the priority it once had. While it will always be important to identify 'bad neighbour' uses, and potential conflicts, it is more important to try to create places of lasting quality which can accommodate changes to their patterns of use over time. Places of enduring quality can usually accommodate significant changes of use.

2 PHILOSOPHY

Various pillars underpin the philosophy and approach to master planning projects:

- *Context.* The character and setting of the area within which a masterplan will sit, including natural and human history; forms of settlements, buildings and spaces.
- *Integration.* Connection and overlap with surrounding areas, infrastructure, transport, movement, and social infrastructure.
- *Functional efficiency.* Creating individual elements which work together as part of an efficient whole.
- *Environmental harmony.* Creating a masterplan which is energy efficient and ecologically sensitive in both its construction and use.
- *Urban design.* Buildings and public realm.
- *Commercial viability.* Ensuring that the development responds to the realities of development mix and delivery within its local context.
- *Health and activity.* Working, living and leisure providing a place which can encourage healthy living and an active lifestyle. Combating heart disease, respiratory problems and mental illness, for example relies on factors such as healthy exercise, air quality, fresh food and local social networks, all of which are influenced by the physical nature of localities.
- *Creating a sense of place.* Creating a responsive environment which is recognisably distinct but simultaneously strengthens local identity.
- *Understanding the context.* The Urban Design Compendium sets out a number of benefits of understanding the full context of the scheme in order to understand the position of the development and how to position the development taking into account the following priorities:

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- *Strengthening local communities.* To help ensure that proposed development reinforces, rather than undermines local communities and assists successful project delivery.
- *Creating places of distinction*. Drawing inspiration from a neighbourhood's indigenous character strengthens local identity. Context-less design leads to 'anywhere places'.
- *Harnessing intrinsic site assets and resources*. Harnessing intrinsic resources of the site – the existing development forms, soils and geology, drainage, landscape, solar and wind energy – to create a more sustainable development.
- *Integrating with surroundings*. Achieving careful integration with the landscape or surrounding built environment, using the right materials, forms and landscape elements for the locality; respecting footpaths, street and road linkages and relating to existing urban structures.
- *Ensuring feasibility*. To ensure economic viability and deliverability.
- *Providing vision*. A vision focuses community aspirations, sells a scheme to a developer and provides a long term aim for project participants. It embodies a strategy for the future that everyone can sign up to and work towards over a period of time.

3 SITE ANALYSIS

Before diving in to a design it is important to ensure that the design team have a deep understanding of the site and its characteristics. The following information should be compiled early on in the process and be made available to the whole design team.

- *Climate and microclimate.* Monthly and annual rainfall, wind direction and strength (wind rose), average temperatures, dates of first and last frosts; drainage of cold air across sites; frost pockets; shelter; shadow projections.
- *Geology and soils.* Solid and drift geology; trial holes positions and sections (ee BS ISO 25177-2008 *Soil quality – Field Soil Description* and BS 5930: *1999 Code of Practice for Site Investigations*. Check nature of the soil be it natural or made up.)
- *Hydrology and drainage.* Water courses; water bodies, direction of flow of surface water, land drain systems, flood plains and temporary flooding, access to existing drainage infrastructure, soil porosity for sustainable urban drainage systems.
- *Landscape value.* The Countryside Agency's and English Nature's joint Character of England Map (1996) illustrates the natural and cultural characteristics of the English Countryside based on biodiversity and landscape. (See the Landscape Institute's Guidelines for Landscape and Visual Assessment, 2013.)
- *Vegetation.* Trees and important shrubs, Tree Preservation Orders, existing tree and hedge lines, covenants and existing ground vegetation. (Survey guidelines in BS5837:2005 *Trees* in relation to construction.)
- *Biodiversity and habitats.* Aspirations of Local Biodiversity Action Plan. Types of habitat; associated flora and fauna. Ancient Woodlands, local and national nature reserves. Sites of Special Scientific Interest (See www.magic.gov.uk the UK government's web-base interactive environmental map service for England and Wales.)
- *Land use.* Current and proposed land uses in relation to neighbouring areas. Agricultural land classification.
- *User survey.* Social, demographic and economic factors of the proposed site in relation to neighbouring areas.
- *Structures, roads and services.* Existing buildings roads, car parks, hard standings, footpaths, paved areas, walls, fences, gates; foul and surface water drains; manholes (invert and cover levels); gas, water, electricity, telephone and TV services (overhead and underground); pipelines; notes on materials, including those suitable for re-use; underground workings.
- *Archaeological and local history data.* Information on site previous uses, scheduled buildings and ancient monuments, adjacent designed landscapes or listed buildings which may be affected by change in their setting.
- *Access and communication.* Existing pedestrian and vehicular routes to public roads, footpaths, rights of way, bridle paths, bus stops, railway stations, shops, schools and areas of employment.
- *Pollution factors.* Constraints on or off site that can affect future uses, e.g. noise or chemical pollution of air or soils.
- *Legal and planning aspects.* Land ownership; boundary ownership; rights of access, light etc.; easements and way-leaves; Structure Plan designation; road improvement lines; Areas of Outstanding Natural Beauty; requirement for an Environmental Impact Assessment.
- *Zones of influence.* Views in and out of the site and likely receptor areas to be affected by the development.

Blending the traditional techniques of analysis, drawing and measurement with a number of computer tools, some specifically developed by R&D professionals and as part of a suite of tools, it is possible to view drawn information compiled into a single framework enabling multiple layers of data, analysis and proposals to be read in conjunction with one another. Such tools assist clients, stakeholders, members of the public and consultants to engage with the project in an open and transparent manner.

Master planners enjoy a close working relationship with other consultants who bring depth and understanding to the work particularly around the subject of sustainability. Often R&D teams consist of a number of sustainability experts who always ensure that work carried out by others is fully integrated within the proposals. Beyond the core activities there are additional services that the masterplanner assists or becomes involved with, such as stakeholder consultations and design charettes.

Stakeholder consultations and design charettes support design development and the Urban Task Force in Towards an Urban Renaissance (1999) stated that a successful masterplan must be:

- *Visionary*. It should raise aspirations and provide a vehicle for consensus building and implementation.
- *Deliverable*. It should take into account likely implementation and delivery routes
- *Integrated*. Fully integrated into the land use planning system, while allowing new uses and market opportunities to exploit the full development potential of a site.
- *Flexible*. Providing the basis for negotiation and dispute resolution
- *Participatory*. The result of a participatory process, providing all the stakeholders with the means of expressing their needs and priorities.

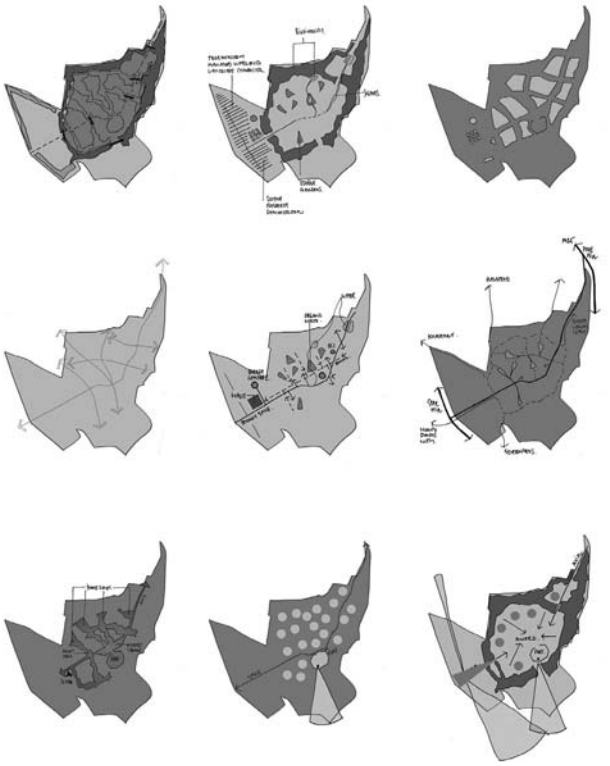
4 METHODOLOGY

Each project is unique but the key stages of work are outlined below. These may happen sequentially but there is often a degree of overlap between them.

Opportunity and constraints mapping will show the significant results of the site analysis and will often set the framework within which the development will eventually be placed. This should identify key site-based drivers to the scheme (physical, planning, climatic, socio-economic).

4.1 Visioning, principles and objectives

- Framework analysis based on matching the key performance indicators to the constraints/site analysis.
- Landscape structure plan identifying key structural landscape elements of the plan and how they relate to the wider landscape.
- Bring together the strategic framework to structure the proposal.
- Develop the spatial masterplan: parameter drawings and design codes (including character areas) for reserved matters.
- Implementation plan: deliverability, phasing and flexibility.
- There are three key outputs from the masterplanning process outlined above – the strategic framework, the spatial masterplan and the implementation plan.



28.2 *Fort Halstead Masterplan, Sevenoaks, Aedas Architects reforestation, working landscape, building cells, permeability, energy/water/waste, connectivity*

5 THE STRATEGIC FRAMEWORK

This contains a statement of aims and objectives for physical regeneration over a large area of land and may consider a much wider area than the spatial masterplan. It is based on analysis of the baseline data and is a key output functioning as the brief for the spatial masterplan. It also incorporates early ideas about how to deliver the proposed developments.

6 THE SPATIAL MASTERPLAN

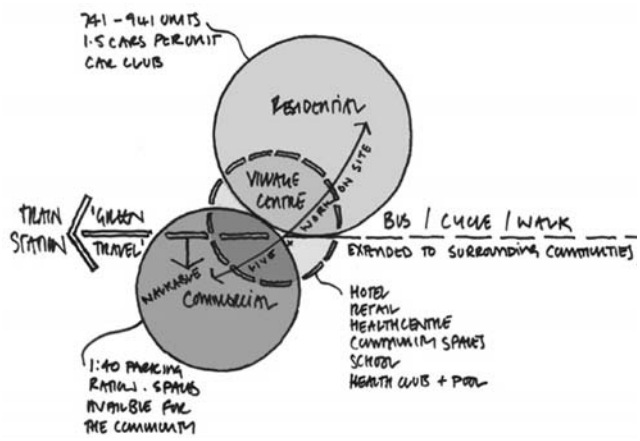
This develops the broad vision into three-dimensional proposals. It consists of plans, visuals and written documentation. A spatial masterplan is a sophisticated model which shows how streets, squares and open spaces of a neighbourhood are to be connected, defines the height, bulk and massing of buildings, sets out suggested relationships between buildings and public spaces, determines the activities and uses which will take place in the area, identifies the movement patterns for people on foot, or by bicycle, car or public transport, as well as looking at the needs of service and refuse vehicles, sets out the basis for the provision of utilities and other infrastructural elements, relates the physical form of the site to social, economic and cultural contexts and takes account of the needs of people living and working in the area, and shows ways in which new neighbourhoods can be integrated into existing ones.

7 IMPLEMENTATION PLAN

This is the strategy for how to turn the vision and plans into reality. The masterplan is not complete without considering and testing how the proposals will be implemented. Implementation will require a written statement addressing cost, programme and other issues. Even if actual work on site is not imminent, these issues must be considered early on.

8 DIGITAL MASTERPLANNING

This allows investors, public and private planners, architects and urban designers to generate and evaluate scenarios for accessibility, transport, visual integration, mixed-use developments, massing etc.



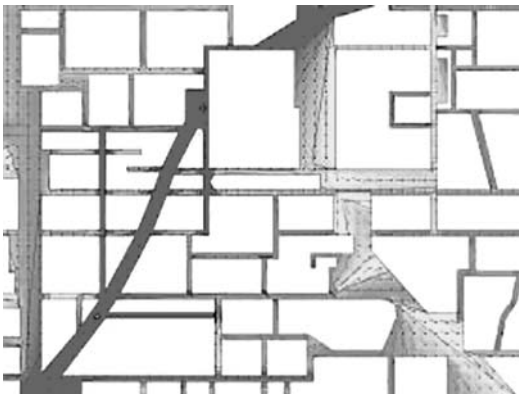
28.3 *Fort Halstead Masterplan, Sevenoaks, connectivity, Aedas Architects*



28.4 *Fort Halstead Masterplan, Sevenoaks, access levels, Aedas Architects*

8.1 Access levels

Access levels are calculated on the basis of walking times to/from access points. Pedestrian walking times are assumed to be shortest routes. Optimisation of the pedestrian network can be approximated by setting values for a distance within which the program searches for new path connections that would shorten the access time by a set value.



28.5 *Fort Halstead Masterplan, Sevenoaks, catchment areas, Aedas Architects*

8.2 Catchment areas

Catchment areas indicate the plots and spaces that use a given access point – i.e. public transport node. CDR calculates them not on manual straight radii but on 'actual' reachable distances.

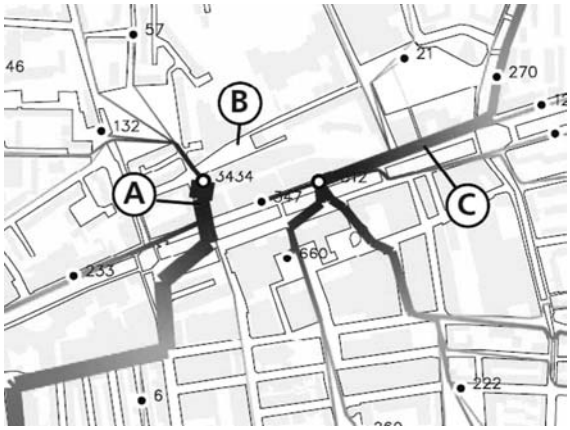
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28.6 *Fort Halstead Masterplan, Sevenoaks, desire lines, Aedas Architects*

8.3 Desire lines (movement and circulation)
CDR provides interactive tools to generate networks of desire lines through a site generally or to specific points. Desire lines can be based on shortest metric distances and/or simplest access routes (least turns). While local residents would use shortest metric routes, visitors and tourists are more likely to use simplest access routes.



28.7 *Fort Halstead Masterplan, Sevenoaks, footfall approximation, Aedas Architects*

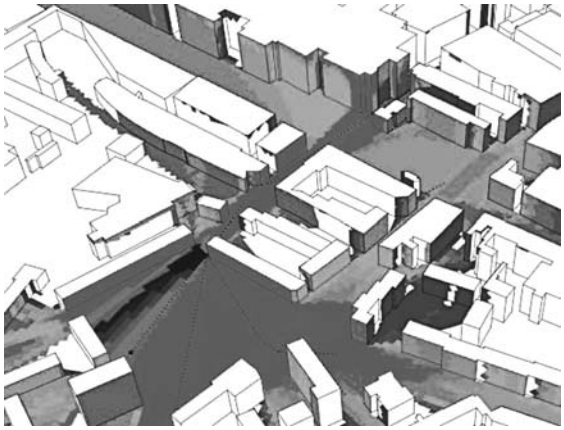
8.4 Footfall approximation
Desire lines and routes can be weighted by the number of people departing from surveyed locations. The resulting mapping indicates the loading of calculated routes showing the approximate footfall on routes. Footfall measurement can also help to identify types of routes into smaller and private to larger and public routes.

8.5 Movement/circulation
To find primary and secondary circulation and movement networks within a masterplan, a two step process generates the most 'sustainable' road network connecting activity locations on the basis of most direct and therefore shortest metric distance. Locations are set by the designer and can be site-internal and external. The resulting network of circulation defines the block outlines for massing development.

8.6 Way-finding and signage (visual integration)
From the desire line and footfall calculations, CDR combines the two measurements to load frequencies of visual instances along

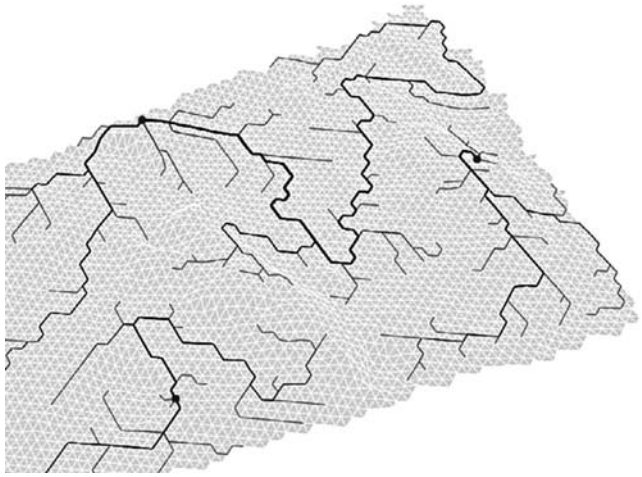


28.8 *Fort Halstead Masterplan, Sevenoaks, movement and circulation, Aedas Architects*



28.9 *Fort Halstead Masterplan, Sevenoaks, way-finding and signage, Aedas Architects*

the desire lines. The visual sampling in 3D provides evidence for elements in an urban and architectural context that are well visible during a journey and therefore become significant during way-finding. Elevations and locations that are well visible increase in rental/retail importance and serve as orientation support. Iconic buildings should have high values of visibility.



28.10 *Fort Halstead Masterplan, Sevenoaks, slope/height dependent access, Aedas Architects*

8.7 Slope/height dependent access
Design and access requires equal access opportunities for all demographic sections. CDR developed two tools that calculate access levels when topography or vertical circulation is taken into account. Especially for hot climates, a slope-dependent routing analysis helps to identify 'physically non-demanding' routes.



28.11 *Fort Halstead Masterplan, Sevenoaks, visual massing envelopes/landscaping, Aedas Architects*

8.8 Visual massing envelopes/landscaping

The visual disturbance of massing – single building or masterplan – can be calculated by an application that takes the terrain, building footprints and viewpoints on the terrain into account. The resulting massing indicates the extruded footprints that do not interfere with the selected viewpoints. Landscaping options can be analysed by visual performance.



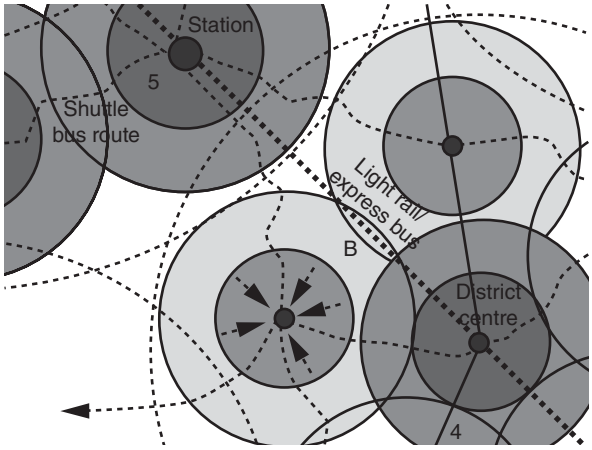
28.12 *Fort Halstead Masterplan, Sevenoaks, land-use/mix, Aedas Architects*

8.9 Land-use/mix

Tolerances in area schedules for mixed-use development can be evaluated by building automated scenarios for land-use allocations, density and mix. All three aspects are computed simultaneously on the basis of constraint specifications including:

- land-use relations
- site conditions
- accessibility levels.

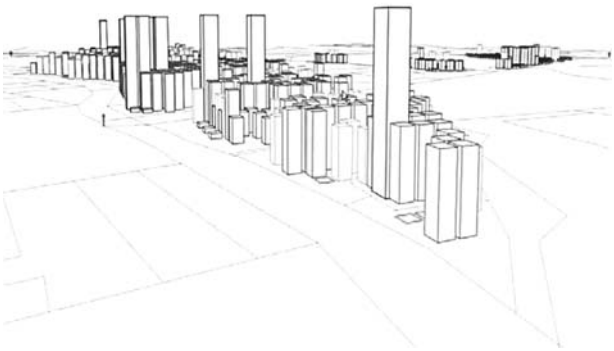
Densities per land-use are fixed at maxima and minima but the tool indicates the ideal quantities at all locations in relation to all other land-uses and accessibility values.



28.13 *Fort Halstead Masterplan, Sevenoaks, service provision modelling, Aedas Architects*

8.10 Service provision modelling

The land-use and mix simulation can absorb any number and type of land-use. Communal services such as schools or hospitals can be automatically suggested by the application on the basis of the density resulting from the development brief. The resulting quantities of required services will be fed-back into the development brief and urban codes.



28.14 *Fort Halstead Masterplan, Sevenoaks, density indication, Aedas Architects*

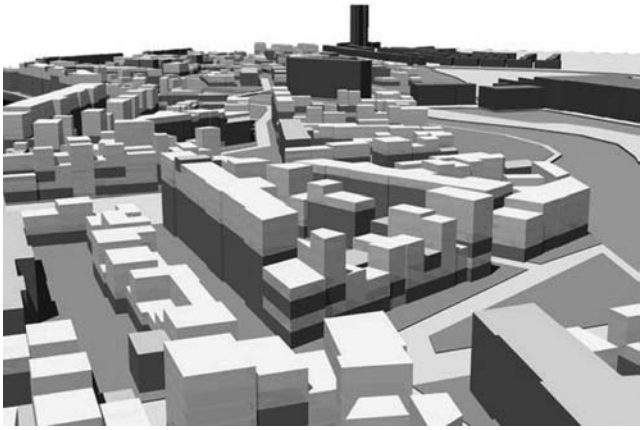
8.11 Density indication

The scale and density of building mass on all plots can be indicated by a special visualisation function in the mixed-use application. The density indication visualises a relative height for each land-use to other neighbouring plots within given minimum and maximum height constraints. The indicative heights therefore integrate all other calculations on accessibility and land-use relations and generate autonomous neighbourhood scales.

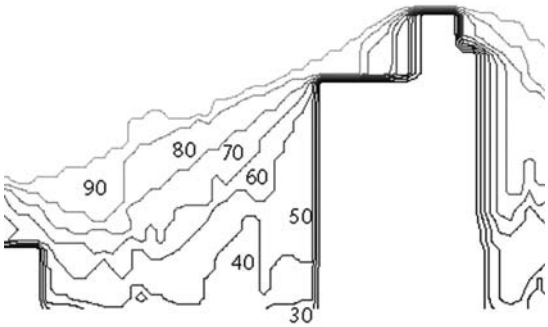
8.12 Plot subdivisions/massing arrangement

For complex configurations of plot subdivision and plot massing arrangement, two design applications have been developed by the CDR that build scenarios for plot arrangements and plot/apartment arrangements. The plot/apartment arrangement applications can integrate daylight access calculations to generate optimised massing configurations for passive design.

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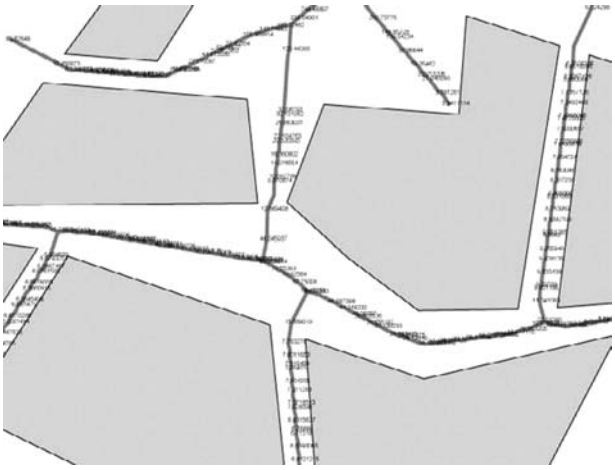
28.15 *Fort Halstead Masterplan, Sevenoaks, plot subdivision/ massing, Aedas Architects*



28.16 *Fort Halstead Masterplan, Sevenoaks, solar shading analysis, Aedas Architects*

8.13 Solar-shading analysis

To comply with daylight access regulations, a shading-envelope can be calculated that indicates the maximum massing achievable without overshadowing neighbouring plots and habitable rooms. All parameters are adjustable to duration of direct sunlight or amount of shading.



28.17 *Fort Halstead Masterplan, Sevenoaks, public realm appropriation, Aedas Architects*

8.14 Public realm appropriation

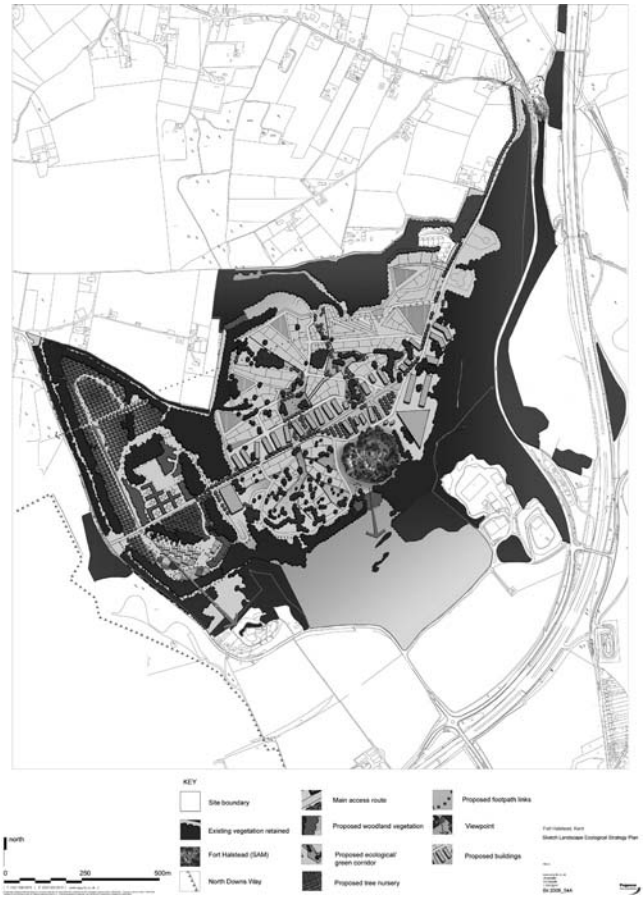
Maintenance of public and semi-public spaces depends on the sense of propriety and participation of individuals in society. This sense depends on clear definition of spaces through traffic regulation, urban furniture, landscaping and the shape of the built environment. Aedas R&D has developed an application that visualises the boundary between public and private spaces based on block outlines. The methods will help to establish what parts of public and open spaces 'belong' to which property.

8.15 Active frontages

Safety and crime levels within an urban context can be related to the level of activity and supervision within public realm. Activity measured by quantities of windows and doors bordering and overlooking public spaces can be evaluated and disclose the levels of 'activity' for distinct areas. Activity levels help to determine land-uses and surveillance installations, as well as potential pedestrian movement patterns.

8.16 Site loading scenarios

Development areas can be evaluated by visualising the diagram of density within an approximation of block outlines. Development areas for land-uses, maximum building heights and the block outlines need to be set by the designer. The block outlines can also be generated by a complementary application that produces a road network with maximum connectivity of roads and preset block size ratios.



28.18 *Fort Halstead Masterplan, Sevenoaks, scheme drawing, Aedas Architects*

Check lists are useful to assess the ingredients of a successful masterplan and CABE suggest these should include:

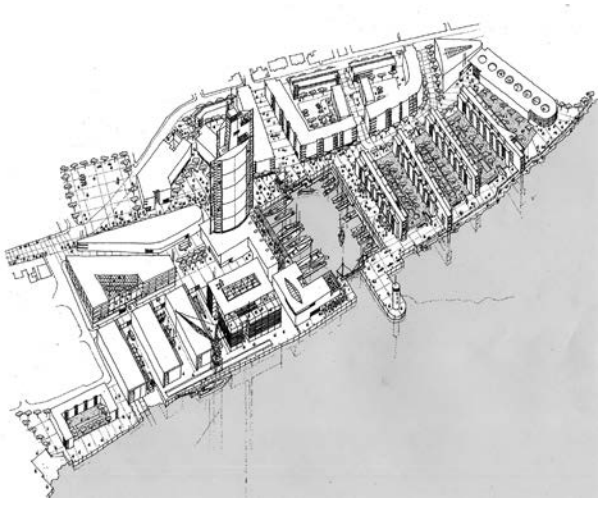
- A client committed to quality.
- A local authority committed to quality.

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- Identifying what skills are required in the consultant team, and appointing a team with those skills in a timely manner.
- Getting the process right from the beginning, including the setting of realistic programmes and budgets, and the securing of funding to meet that budget.
- The right balance of design skills in the design team – urban design, architecture, landscape design, transport planning and others.
- A project structure with strong client leadership that encourages collaboration rather than competition between members of the design team.
- A collaborative relationship between local authority and applicant, involving mutual trust and understanding – and give and take.
- Early consultation of stakeholders, including community interests.
- Flexibility by local authority in relation to operation of statutory planning system.
- Recognition by all involved that the right degree of 'control' contributes to quality of place and therefore, to commercial success and liveability, rather than hampering would-be investors and developers.
- Genuine mixed use, rather than lip service to the concept.
- A commitment on behalf of local authority and landowner to seeing the vision through to completion.

9 COHERENCE, VARIETY AND UNIFORMITY

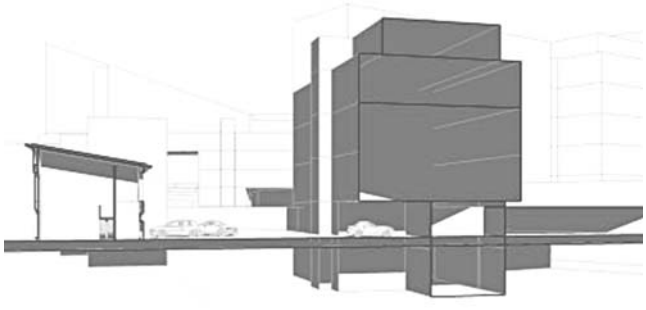
- Variety of uses.
- Planning geometries.
- Building typologies and building forms.
- Building height and massing.
- Architectural style, patterns of fenestration etc.
- Building and landscaping materials and colours.
- Consistency of public realm treatment, and hard and soft landscape design.
- Legibility of layout, are different routes and their nodes differentiated from one another by designing differing qualities of spatial enclosure.



28.19 *Vosper site, Woolston, Southampton for SEEDA, Roger Stephenson Architects*

10 URBAN DESIGN ANALYSIS

- The nature, including surroundings, of a site.
- Connections and desire lines between site and surroundings, and the pattern of movement of pedestrians and vehicles.
- The existing patterns of built form on the site and around it, including heritage issues.



28.20 *Holbeck Village, Leeds, parking strategy, Aedas Architects*

- The site's topography, soil availability, its hard and soft landscape and its wildlife habitats and ecology.

11 INFRASTRUCTURE AND CONNECTIVITY

- Permeability: will the site be well connected, for pedestrian and vehicle movement in all directions?
- Are the desire lines and connections that have been brought out in the analysis addressed in the proposals?
- Are difficult infrastructure issues tackled, or have they been ducked?
- Will the 'site boundary' melt away, or will it remain as an actual or implied barrier?

12 THE ANATOMY OF THE SITE: HIGHWAYS, SERVICING AND CAR PARKING

- Is thinking about vehicle movement and highways design integrated with landscape design?
- Is the proposal honest about the impact of likely volumes of traffic?
- Does the design for traffic prioritise the needs of pedestrians over those of drivers?
- Has car parking been designed into the project from an early stage?

13 SITE PLANNING AND LANDSCAPE DESIGN

- Has an attitude to landscape design informed the development of the design from the beginning?
- Is there a good balance between the form of buildings and the form of open space?
- Robustness: have the buildings and open spaces been designed suitable for the widest range of likely activities and future uses?
- Visual appropriateness: has a vocabulary of contextual and visual clues been found to communicate levels of choice already designed into the plan?
- Richness: does the design increase choice for users through design for the senses with variety in visual stimuli, motion, smell, hearing and touch?
- Personalisation: does the design allow for future users to personalise places, this being the only way that most people can put their own stamp on their environment?
- Has the masterplanning been a holistic process, which reinforces commercial and public objectives whilst delivering resilience in the face of a changing climate and assisting in the reduction of greenhouse gas emissions?
- Will a lack of green areas within the masterplan intensify the urban heat island effect leading to risks to human health?
- Will the masterplan exacerbate water shortages through a lack of sustainable urban drainage systems?
- Is the masterplan likely to increase the biodiversity of the area?
- Is the proposed landscape scheme multifunctional by providing the ability to provide food, energy, water storage and flood

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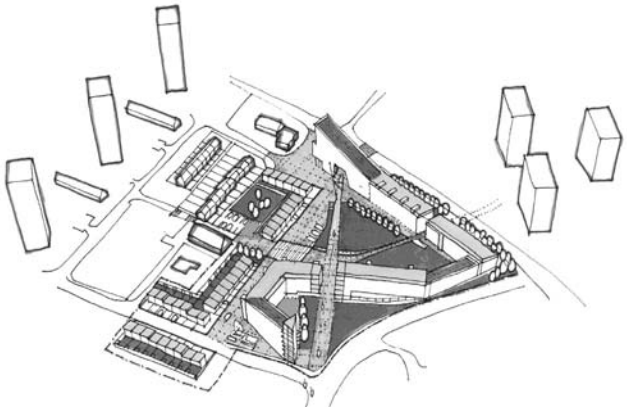
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mitigation as well as providing a valuable resource for biodiversity and promoting health and well-being?
- Does the landscape response incorporate a range of, inter-linked and mutually reinforcing, mitigation and adaptation principles which can provide wider socio-economic and environmental benefits?
- Has the process provided a holistic approach to the protection, conservation and enhancement of urban and rural landscapes which will take into account current and future environmental, social and economic conditions?
- Does the design fully integrate building and site planning into the landscape planning process, taking into account landscape characteristics such as topography, vegetation and microclimate and help to maximise the benefits of shelter from intense wind and sun while seeking to incorporate maximum solar energy and water heating benefits?
- Has the layout provided for attractive opportunities for local outdoor leisure which will contribute to improving public health, well being and community engagement?
- Can the plan integrate and maximise local food production in the landscape, thereby reducing 'food miles' and promote more localised self-sufficiency?
- Has the plan included the creation of urban carbon sinks via the provision of green spaces which remove carbon from the atmosphere?
- Can the plan include for the installation of green roofs and green walls, thereby improving the thermal efficiency of buildings and reducing the use of conventional heating and cooling systems, whilst also alleviating flood risk?
- Could the open space be used for ground source heating and cooling?
- Has the choice of materials been considered on a local and sustainable basis?
- Can effective adaptation to climate change be facilitated by green infrastructure approaches to planning and design? Green spaces and corridors help to cool our urban environments, improve air quality and ameliorate surface run-off. A green infrastructure planning approach will reduce flood risk, protect building integrity and improve human health and comfort in the face of more intense rainfall and higher temperatures. Well-connected green infrastructure also provides wildlife corridors for species migration in the face of climate change as well as wider benefits for recreation, community development, biodiversity, food provision and place shaping.
- Can sustainable urban drainage systems (SUDs) reduce the negative impacts of development on surface water drainage? SUDS can minimise the risk of flooding and pollution via attenuation and storage with additional benefits including improvements to local environmental quality, the creation of habitats for biodiversity and general improvement to the quality of life for local communities.
- Does the landscape plan incorporate a robust green infrastructure with a network of spaces and natural elements that are currently present in and interconnect our landscapes?
- Will the proposed scheme recognise the important and multifunctional role green infrastructure has to play in providing benefits for the economy, biodiversity, wider communities and individuals?

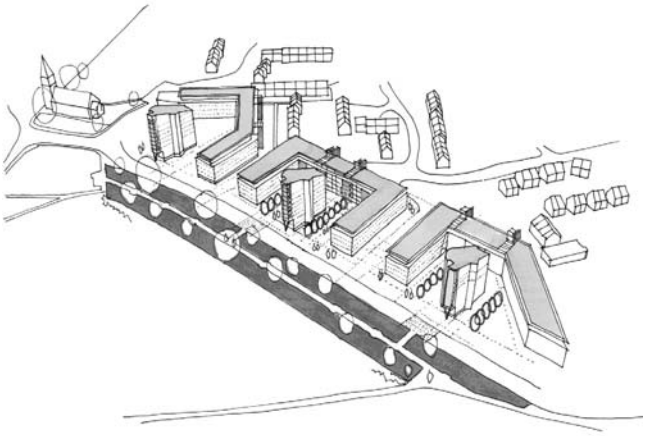
14 OPEN SPACE

What is the space for?

- Could it accommodate a variety of uses?
- Does it require to accommodate community sports facilities?
- Does its location make sense in relation to its use – is it meant to be a focal point or a quiet, out of the way place?
- How big should it be?



28.21 *Holbeck Village, Leeds, site planning and landscape, Aedas Architects*



28.22 *Holbeck Village, Leeds, open space, Aedas Architects*

- Who will use it and at what hours of the day?
- Is it as safe as possible for everyone who will use it?
- Who will own and maintain it, and how will maintenance be paid for?

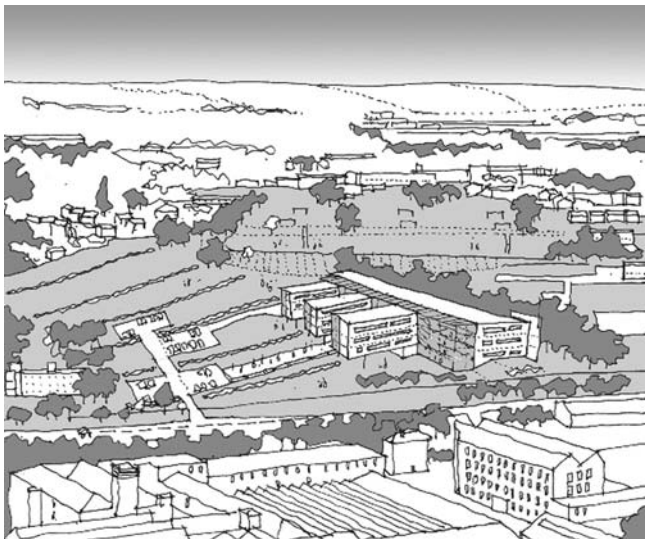
15 THE GEOMETRY OF SITE PLANNING
- Is the site planning informed by a clear attitude to geometry?
- Does the geometry contribute to the legibility of the site?
- Do the results make sense in terms of the blocks and building plots that result?

16 PLOT TESTING
- Does the plot make sense in relation to likely sizes, shapes and uses of buildings?
- In cases where there is not yet a developer or developers, will the blocks, plots and buildings implied by the master plan correspond to what developers will want to build?

17 THE BUILT HERITAGE

Does the site analysis demonstrate an understanding of the site's history?

- Has that understanding informed the design?
- Are the elements of built heritage given an appropriate status in order of the project?
- Is the built heritage treated as an asset rather than a liability?



28.23 *Holy Trinity school, Halifax, Aedas Architects*

18 THE IMPORTANCE OF DETAIL: DELIVERING DESIGN QUALITY

- Does the masterplan set out a vision for the architecture of the buildings and the design of the landscape between them? Does it set quality standards?
- Will the process by which the master plan will be implemented address the question of how quality standards will be delivered?

19 SOME ALARM BELLS

- Unresolved conflicts within the client organisation.
- Lack of common ground between local authority and developer.
- Lack of clarity about the purpose of the masterplan.
- Lack of clarity about what the masterplan is intended to define.
- Lack of clarity about the status of 'indicative' illustrations of what buildings or places will look like.
- Failure to tackle existing infrastructure difficulties.
- Failure to recognise the importance of landscape design.
- Failure to deal with highways and parking issues as part of landscape design.
- Failure to make connections and 'think outside the red line'.
- Failure to acknowledge importance of design quality.
- Failure to put in place mechanisms to secure the quality of architecture, landscape design, details and materials.

20 CONCLUSIONS: EVALUATING A MASTER-PLAN DESIGN

- Does it reconcile, in terms of its site planning, economic goals and other public aspirations such as place-making?
- Does it propose an urban structure that connects well with its surroundings (in all directions)? Is it easy to explain and use, and is it robust for future cycles of redevelopment?
- Does it integrate with its surroundings so that the area to be developed and surrounding areas each benefit by presence of the other?
- Does it allow phased implementation? Will it work if only executed in part?
- Can landscape structure planting be achieved for the whole site at the outset in order to provide more mature landscapes for future phases of development?
- Is it flexible and open-ended, and so able to respond to changes in demand?
- Is it likely to achieve a sense of place and a distinct local identity?
- Does the master plan contain an overarching vision? If there is one, is it appropriate and relevant to the aims and objectives? If there isn't, is the lack of vision a problem?
- Does the design address the quality of the public realm and landscaping?
- In its proposals for urban blocks, building plots and buildings, does it provide opportunities to achieve good architecture and public places?

21 MASTERPLANNING FOR HEALTHY COMMUNITIES

Sarah Burgess, Senior Lecturer, UWE; Prof Hugh Barton, Director WHO Collaborating Centre for Healthy Cities and Urban Policy, UWE; Marcus Grant, Deputy Director WHO Collaborating; Centre for Healthy Cities and Urban Policy, UWE

21.1 Health

The World Health Organisation defines health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (World Health Organisation, 1946). Health therefore is more than just the provision of health services and health care, it is about quality of life. The built environment has an important role in ensuring people have the opportunity to achieve this state of well-being, facilitating or prohibiting healthy lifestyle choices.

21.2 Health and the built environment

The issue of health and planning is not a new concept. The necessity to plan our towns and cities was borne out of the need to address health issues in the nineteenth century. In today's society however, many of our urban environments are having a detrimental effect on our health and well-being as shown in Figure 28.24.

There is a growing body of research on the relationship between the built environment and health with strong evidence that the urban environment has a significant influence over the wider determinants of health.

21.3 Considering health impacts

To ensure that new developments facilitate healthy choices and lifestyles, rather than restricting them, health impacts need to be considered throughout the masterplanning process, right from the concept development, including defining the brief, through to implementation and management. By considering health in the design of new neighbourhoods and development, the physical environment can help in tackling health inequalities and obesity issues, and supporting healthy ageing, active lifestyles and community cohesion. Other agendas such as climate change, facilitating adaptation and mitigation can also be met, leading to the design and implementation of cost effective interventions.

21.4 Creating healthier places – an integrated approach

There are a multiple of influences that affect a person's health and well-being. It is therefore fundamental that an integrated and collaborative approach to the planning, design, implementation and management of a development is undertaken to ensure that problems are understood and effective solutions can be promoted. This requires leadership, co-operation, creativity, a long-term view and commitment as well as an understanding of the local context and strategic direction for the wider area.

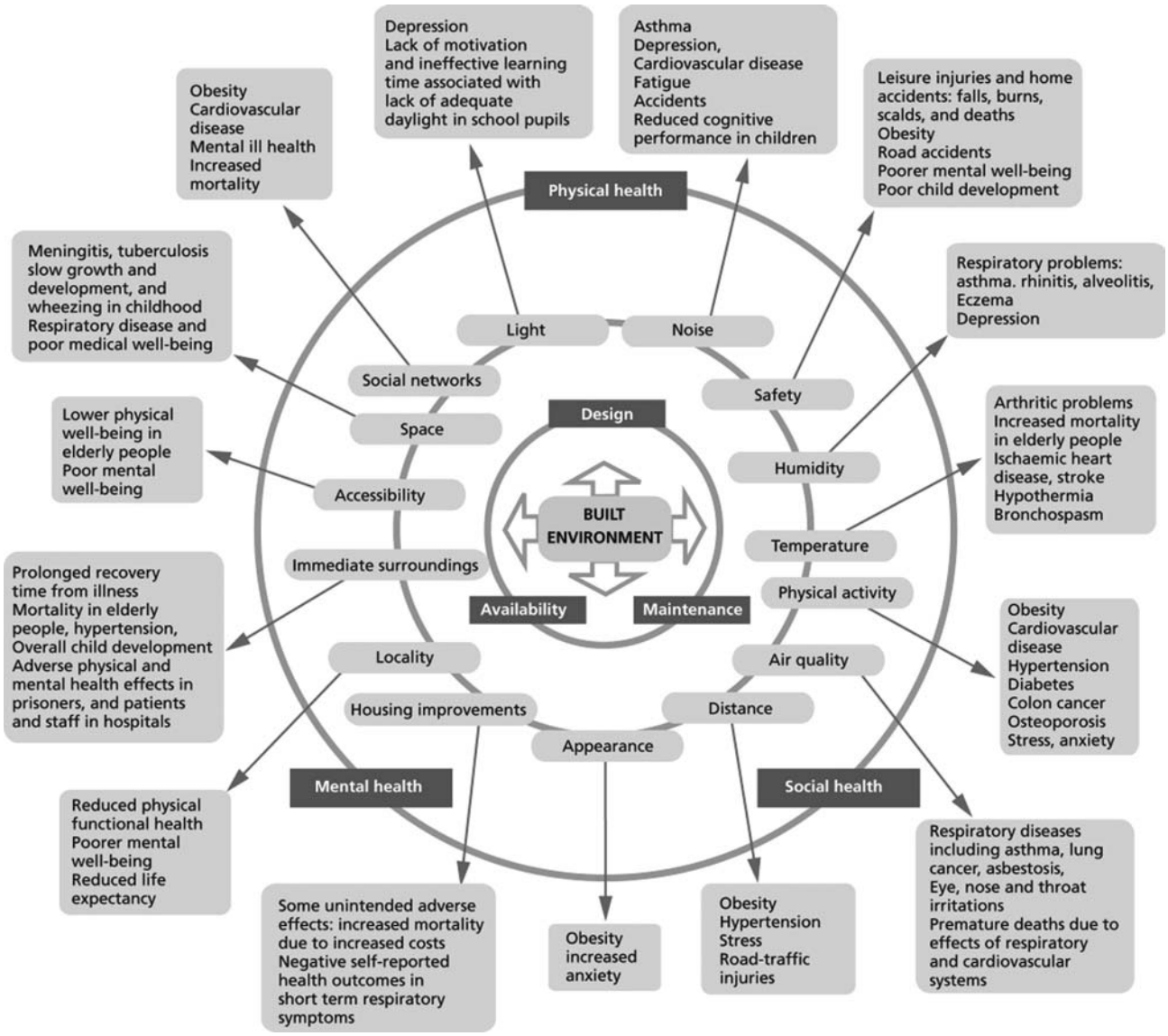
Figure 28.25 illustrates a seven stage process for undertaking a major development, to ensure that all stakeholders have a common vision and shared ownership of the project. Beginning with 'taking the initiative' and working around the circle to 'learning lessons', this needs to be undertaken collaboratively with the local community, the local authority and other stakeholders.

21.5 The health map

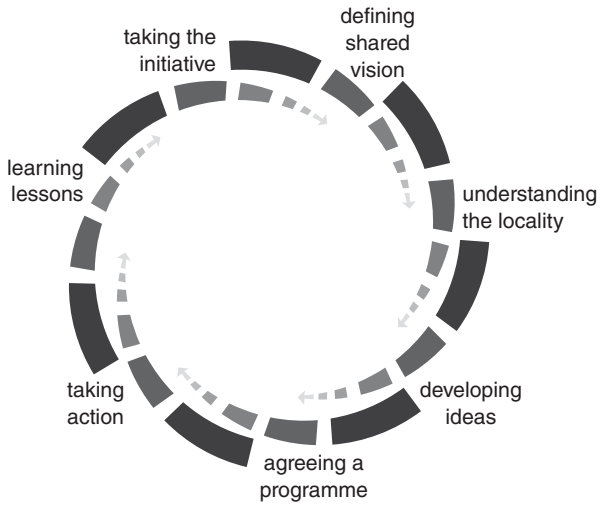
Adapted specifically for built environment professionals, the health map as shown in Figure 28.26 is a useful tool to better understand the relationship between health and well-being and the built environment. It strategically locates people at the centre of the diagram, who are surrounded by layers of social, physical, economic and

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28.24 *The detrimental effect of urban environments*

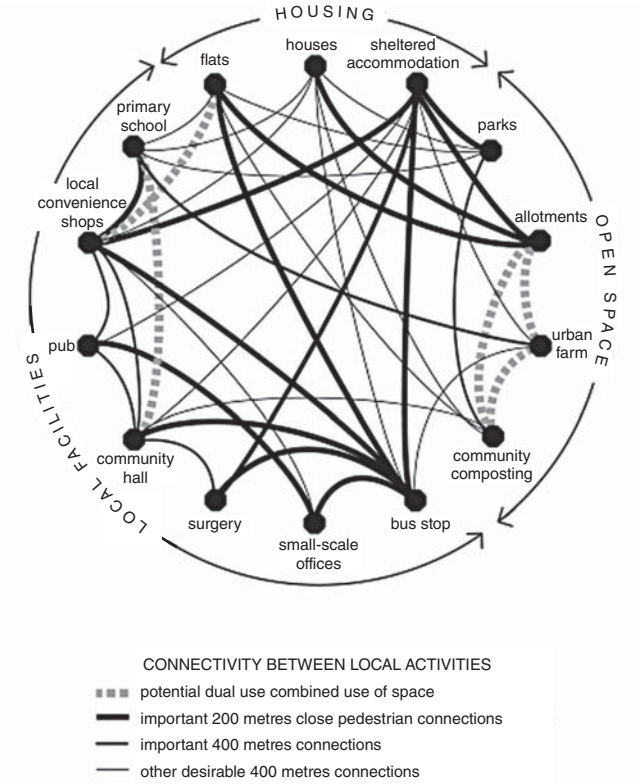


28.25 *Understanding a major development*

environmental factors that all influence a person's health and well-being. Based on an ecosystem approach, the health map places all of these layers within the global context, which sets environmental limits on growth. The influence of each of the layers works in both



28.26 *Health map*



28.27 *Connectivity between different land uses*

directions, with implications and impacts on other layers as well as people in the centre of the diagram.

21.6 Key principles of creating a healthier and more sustainable built environment

There are some key principles that should be considered when planning and designing for health and well-being. These are set out below.

21.7 Appropriate location

Providing access to employment, key services and facilities is fundamental to supporting healthy lifestyles and well-being. If the location of new development is inappropriate, where it is not integrated with existing areas, communities may not have access to local shops and services and also have limited transport options other than the private car. It is therefore critical that the site of new development should be in a location where it can integrate into existing public transport and cycle networks and provide residents with access to existing centres, jobs, services and facilities.

21.8 Mixed use environments

Mixed use environments encourage walking and cycling, offer opportunities for social interaction and can provide greater access to open space, recreation opportunities and fresh food. Shops, services and facilities should be located close to public transport stops and walking and cycling routes in locations that have sufficient foot-fall and catchment to ensure viability, clustered where possible to encourage shared use of facilities and pooling of resources, and at a level appropriate to their nature and scale. This will encourage active travel and social networks. Figure 28.27 illustrates connectivity between different land uses and recommended distances to encourage walking and cycling.

21.9 Graded density of people and land uses

The density of people and activity (not just housing density) should be higher around public transport nodes and core use areas (such as local centres and high streets) and lower near open countryside, major roads or open space wedges. This will increase land efficiency, giving greater opportunity for the provision of public realm and open spaces and will increase the viability of local shops, services and public transport. This will contribute to maintaining people's independence and well-being.

- ★ *A fair average net density is 50 dwellings per hectare (approximately 100–120 people per hectare)*
- ★ *For dwellings located above ground floor, generous balconies or roof terraces should be provided*
- ★ *Land needed for other uses to support the community should be factored into gross density calculations*

21.10 Streets for people

Street networks should be permeable and promote walking and cycling to reduce reliance on private vehicle use. Streets are the longest lasting components of the built environment and they define the size of development plots, the character of the public realm, the movement opportunities, accessibility and connectivity in an area. It is therefore fundamental that they are designed to maximise opportunities for walking and cycling, and provide spaces for people to meet and interact in a pleasant and safe environment. This will assist in encouraging active travel as well as developing social capital and community cohesion.

- ★ *For pedestrian permeability, as a general rule, the maximum block size should be 100 m × 200 m*
- ★ *The Manual for Streets (DfT, 2007) promotes priority for the pedestrian and cyclist, slow traffic speeds, restricted sight lines, connectivity, multi-use streets and safety at junctions for pedestrians*
- ★ *Every dwelling should be within 400 m of a bus stop and the cycling network should be planned from the outset with a close grid of safe routes*

21.11 Interlinked green networks

Green networks should be carefully planned as an integral part of a place. Consideration about the location of green space and green corridors, the function of green space, how it is integrated into the neighbourhood and the management implications needs to be given at the start of the planning and design process. Green space provides the opportunity for healthy recreational activity and delight in nature. It can reduce stress, improve mental wellbeing, filter pollutants, increase biodiversity as well as provide a place for recreation and social interaction. It can also provide important movement corridors for people and wildlife and can also be used for composting and local food growing. Green space also plays an important role in carbon capture, climate mitigation and climate adaptation.

- ★ *Need to form partnerships to positively locate, design and manage green networks*
- ★ *The green network includes multi-functional greenspace areas which have different functions and may include designed, natural and semi-natural spaces, as well as allotments, fields, gardens and parks*
- ★ *Natural features such as steep slopes, watercourses, hedgerows, hill crests should be integrated into the greenspace network*

This material has been derived from the publication Shaping Neighbourhoods *by Hugh Barton, Marcus Grant and Richard Guise (2010).*

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23 APPENDIX: KEY DOCUMENTS AND CASE STUDIES

Key documents

PPG and PPS
Planning Policy Guidance and Statements

PPS1 Delivering Sustainable Development
PPS1 sets out the Government's overarching planning policies on the delivery of sustainable development through the planning system.

PPG2 Green Belts
This PPG outlines the history and extent of Green Belts and explains their purposes. It describes how Green Belts are designated and their land safeguarded. Green Belt land-use objectives are outlined and the presumption against inappropriate development is set out.

PPS3 Housing
Planning Policy Statement 3: Housing (PPS3) underpins the delivery of the government's strategic housing policy objectives and its goal to ensure that everyone has the opportunity to live in a decent home, which they can afford in a community where they want to live.

PPS4 Planning for Sustainable Economic Growth
Planning Policy Statement 4 (PPS4) sets out the government's comprehensive policy framework for planning for sustainable economic development in urban and rural areas.

PPS5 Planning for the Historic Environment
This document sets out planning policies on the conservation of the historic environment. The development plan making policies in this PPS must be taken into account by regional planning bodies in the preparation of revisions to Regional Spatial Strategies, by the Mayor of London in relation to the spatial development strategy for London, and by local planning authorities in the preparation of local development documents.

PPS7 Sustainable Development in Rural Areas
It sets out the government's planning policies for rural areas, which local authorities should have regard to when preparing local development documents and when taking planning decisions.

PPG8 Telecommunications
This PPG gives guidance on planning for telecommunications development, including radio masts and towers, antennas of all kinds, radio equipment housing, public call boxes, cabinets, polls and overhead wires.

PPS9 Biodiversity and Geological Conservation
PPS9 sets out planning policies on protection of biodiversity and geological conservation through the planning system. These policies complement, but do not replace or override, other national planning policies and should be read in conjunction with other relevant statements of national planning policy.

PPS10 Waste Management
This Planning Policy Statement forms part of the national waste management plan for the UK.

PPS12 Local Spatial Planning
This revised PPS12 puts in place the national policy framework for creating local development frameworks and concentrates on the key policy framework.

PPG13 Transport
This PPG's objectives are to integrate planning and transport at the national, regional, strategic and local level and to promote more sustainable transport choices both for carrying people and for moving freight.

PPG14 Development on Unstable Land
This PPG explains briefly the effects of land instability on development and land use. The responsibilities of the various parties to development are considered and the need for instability to be taken into account in the planning process is emphasised.

PPG17 Sport and Recreation
This PPG describes the role of the planning system in assessing opportunities and needs for sport and recreation provision and safeguarding open space which has recreational value.

PPG18 Enforcing Planning Control
This PPG introduces new and improved enforcement powers given to local planning authorities (LPAs) by the Planning and Compensation Act 1991. The note outlines the general approach to enforcement, including the primary responsibility of LPAs in the matter and the decisive issue of whether a breach of planning control would unacceptably affect public amenity or the existing use of land and buildings meriting protection in the public interest.

PPG19 Outdoor Advertisement Control
This PPG explains that the main purpose of the advertisement control system is to help those involved in outdoor advertising to contribute positively to the appearance of an attractive environment in cities, towns and the countryside.

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PPS22 Renewable Energy
It sets out the government's planning policies for renewable energy, which planning authorities should have regard to when preparing local development documents and when taking planning decisions.

PPS23 Planning and Pollution Control
The policies in this statement and the advice in the accompanying Annexes (Annex 1: Pollution Control, Air and Water Quality and Annex 2: Development on Land Affected by Contamination) should be taken into account by Regional Planning Bodies (RPBs) and Local Planning Authorities (LPAs) in preparing Regional Spatial Strategies (RSSs) and Local Development Documents (LDDs) – referred to in this Statement as 'development plans'.

PPG24 Planning and Noise
This PPG guides local authorities in England on the use of their planning powers to minimise the adverse impact of noise. It outlines the considerations to be taken into account in determining planning applications both for noise-sensitive developments and for those activities which generate noise.

PPS25 Development and Flood Risk
Planning Policy Statement 25 (PPS25) sets out government policy on development and flood risk.

Minerals policy statements and minerals planning guidance for England
Minerals planning guidance notes (MPGs) and their replacements, minerals policy statements (MPSs), set out the government's policy on minerals and planning issues and provide advice and guidance to local authorities and the minerals industry on policies and the operation of the planning system with regard to minerals.

Marine Minerals Guidance
Marine Minerals Guidance Notes (MMGs) set out the government's policies and procedures on the extraction of minerals by dredging from the seabed in English marine waters.

Good Practice Guides
Good practice guidance is issued by 'Communities and Local Government' to augment policy and advise on the best way of achieving certain technical outcomes.

Case study: Hammarby Sjöstad – a unique environmental project in Stockholm
The water has inspired the name of the entire project – the town around the lake Hammarby Sjö. The first drawings of what would become Hammarby Sjöstad were pencilled in back in 1990. The idea was to showcase a unique opportunity – expanding the inner city with a focus on the water, while converting an old industrial and harbour area into a modern neighbourhood. Once fully built, Hammarby Sjöstad will have 11,000 residential units for just over 25,000 people and a total of about 35,000 people will live and work in the area. Hammarby Sjöstad will be fully built by 2015. Around 1200 homes per year are being constructed by three appointed developers who are responsible for their proportion of infrastructure costs borne by Stockholm Council at the outset of the project. The site had been acquired by the City as part of its bid for the Olympic Games 2004 and this ownership facilitated comprehensive planned development.

Architecture and urban design
Hammarby Sjöstad is Stockholm's biggest urban development project for many years. The area's location as a natural continuation of Stockholm's inner city has helped shape the infrastructure, planning and design of the buildings. This expansion has involved extensive reconstructions of the infrastructure, with traffic barriers removed and the old industrial and terminal areas phased out, concentrated or given a new purpose.

The next phases
The areas around Sickla Udde, Sickla Kaj and Sickla Kanal are now fully developed. The next phases involve Hammarby Gård (1,000 apartments), Redaren and Sjöfarten (500 apartments), Lugnet (650 apartments), Henriksdalshamnen (850 apartments) and Sjöstadsporten (260 apartments with 15 000 m^2 office space and 15 250 m^2 hotel space). All of these areas offer a range of zoning types. The expansion of Hammarby Sjöstad coincides with the development of the area's municipal and commercial services, and with increased investment in public transport.

The history of Hammarby Sjö
In the 1800s, Sickla was a popular destination for excursions by the inhabitants of the Södermalm district of southern Stockholm, and was popularly known as 'Eastern Söder's Pearl'. The area was partially destroyed when the Hammarbyleden highway was built, and the seabed of the Lugnet bay area was filled in with excavated soil, rocks and refuse as part of the planned port area. The plans, however, came to nothing and the land was made available for storage depots and industrial use. But no single company or industry established itself in the area: instead, a shantytown began to grow up, and the area eventually became a small-scale industrial area. Constant threats of demolition meant the buildings in the area were of a temporary nature, largely consisting of a range of corrugated steel shacks. The shantytown lasted until 1998, when it was demolished to make way for Hammarby Sjöstad.

Soil decontamination
The shantytown left numerous environmental 'nasties' in the soil, so to ensure that no one is exposed to any risks in conjunction with service work in the future, e.g. repair work on pipes, or tree planting, the City of Stockholm Environment & Health Administration is monitoring the soil decontamination work throughout Hammarby Sjöstad, ensuring that the requisite standards are met to avoid harming either the environment or people's health. On Sickla Udde alone, the earth excavated contained 130 tonnes of oils and grease, and 180 tonnes of heavy metals.

ENVIRONMENTAL GOALS FOR LAND USAGE IN HAMMARBY SJÖSTAD

- Open space standard: There shall be at least 15 m^2 of courtyard space and a total of 25–30 m^2 of courtyard space and park area within 300 m of every apartment (equiv. 100 m^2 BTA).
- At least 15 per cent of the courtyard space shall be sunlit for at least 4–5 hours at the spring and autumn equinoxes.
- Development of undeveloped green public spaces shall be compensated for in the form of biotopes that benefit the biological diversity in the immediate area.
- Natural areas of particular value shall be protected from development.

Twice as eco-friendly
Right from the start, the city has imposed strict environmental requirements on buildings, technical installations and the traffic environment. The goal of the entire environmental programme is to halve the total environmental impact in comparison with an area built in the early 1990s. Another way of putting it is that the buildings in Hammarby Sjöstad will be twice as eco-friendly as a normal building. The architecture is modern, with the focus on sustainable materials such as glass, wood, steel and stone, and the ground was thoroughly decontaminated before building work began. Adapting the area to an environmentally friendly one has also entailed a heavy investment in green public spaces, with maintenance plans for the oak forest, a reed park with wooden jetties, a

broad avenue, and several large parks. Attractive forms of public transport are also offered, such as light rail link, boat traffic and access to a carpool.

THE CITY OF STOCKHOLM'S ENVIRONMENTAL GOALS FOR HAMMARBY SJÖSTAD

Land usage: sanitary redevelopment, reuse and transformation of old brownfield sites into attractive residential areas with beautiful parks and green public spaces.

Transportation: fast, attractive public transport, combined with carpool and beautiful cycle paths, in order to reduce private car usage.

Building materials: healthy, dry and environmentally sound.

Energy: renewable fuels, biogas products and reuse of waste heat coupled with efficient energy consumption in buildings.

Water and sewage: as clean and efficient as possible – both input and output – with the aid of new technology for water saving and sewage treatment.

Waste: thoroughly sorted in practical systems, with material and energy recycling maximised wherever possible.

An avenue linking the city district's new green public spaces and forming green corridors runs all the way through the southern part of Hammarby Sjöstad. The parks to the south of Hammarby Sjö are all linked to the major green public spaces of the Nacka nature reserve and Årsta forest, and form green wedges into the heart of Hammarby Sjöstad. The Nacka nature reserve is linked to the town area by means of ecoducts – planted viaducts – over the Södra Länken highway. New parks in northern Hammarby Sjöstad have been linked up with the Vitaberg park and the Stora Blecktorn park. Existing vegetation has been saved. The natural environment along the shores of Sickla Udde has been recreated using new trees and reed beds. The oak forest on Sickla Udde has been thinned and the living oaks and dead trees that have been left in place together form attractive environments for many species of insect and bird. The parks are intended to be attractive environments and serve as footpaths for people, but are also intended to serve as dispersal corridors and living environments for animals and plants.

Transportation imposes a heavy environmental burden in a densely built-up city district which is why Sjöstaden offers energy saving and attractive alternatives to private car usage. The aim was for 80 per cent of residents' and workers' journeys to be by public transport, on foot or by bicycle by the year 2010.

ENVIRONMENTAL GOALS FOR TRANSPORTATION IN HAMMARBY SJÖSTAD

- 80 per cent of residents' and workers' journeys shall be by public transport, on foot or by bicycle by the year 2010.
- At least 15 per cent of the households in Hammarby Sjöstad shall be signed up to the carpool by 2010.
- At least 5 per cent of the area's workplaces shall be signed up to carpools by 2010.
- 100 per cent of heavy transportation shall be by vehicles that meet current environmental zone requirements.

Light rail link

Substantial investments have been made in public transport in the area, both in the form of the new light rail link 'Tvärbanan' and bus traffic. Public transport has a central route running through Sjöstaden, with four stops along the avenue that connects one side of the city district to the other.

Ferry

Sjöstaden has ferry links. The ferry, which traffics Hammarby Sjö between the southern and northern sides of Sjöstaden, is run by the City of Stockholm and is free to use. The ferry runs 365 days of the year from early in the morning until late at night.

Carpool

A carpool open to both residents and those working here has been launched in the area. Around 10 per cent of households have joined the carpool to date, and there are 25–35 carpool cars parked in the area, with the number varying according to demand. Around 75 per cent of the cars are bifuel cars. The aim was for at least 15 per cent of households and at least 5 per cent of the Hammarby Sjöstad workplaces to be signed up to the carpool by 2010.

Environmental consideration across the board

Environmental consideration is the key for all of the materials used. This applies both to the visible materials used in the facades and on the ground as well as to the materials used in the internal parts of the buildings – their shells, installations and equipment. The guiding principle throughout has been to use tried and tested, sustainable materials and eco-certified products, and to avoid any use of chemical products or construction materials that contain hazardous substances. Rainwater must not be contaminated with metals or oils en route to Hammarby Sjö, which is why facade or roofing materials that could release heavy metals or other hazardous substances have been avoided, and why eco-friendly oil has been used for the footpaths along Sickla Canal and stainless steel has been used for the cycle bridge.

Eco-inspections

Everyone who builds in Hammarby Sjöstad must check and declare their chemical products and construction materials before work on their project begins, and eco-inspections are conducted regularly throughout the construction process.

ENVIRONMENTAL GOALS FOR CONSTRUCTION MATERIALS IN HAMMARBY SJÖSTAD

- Routines shall be drawn up for choosing the best materials from resource-related, environmental and health protection viewpoints, before the planning work begins.
- Pressure-treated timber may not be used.
- Copper may not be used as ducting material in horizontal or vertical piping trunks in the tap water system, either indoors or out. This does not apply to wet rooms and their connections within the apartment.
- Galvanised materials in the external environment shall be surface-treated.
- Use of newly extracted gravel and sand shall be minimised.
- Recycled materials shall be used wherever it is indicated for environmental and health reasons, provided that it is technically and economically feasible.

One of the goals of Hammarby Sjöstad is for the district to be a healthy place for people to live, a place that stimulates the body and soul, and hence a place that offers opportunities for exercise, sports and culture.

Exercise and sports

Sjöstaden has a number of exercise and sports facilities, such as Hammarbybacken, a slalom ski slope with amazing views. The sports facility at Hammarbyhöjden, near the southern side of Hammarbybacken is an important asset, not least for school and youth sports activities. The foot of the slope is also home to the valuable Nacka nature reserve. A sports hall with a large exercise facility has been built in Sjöstaden, and this positive feature is echoed in the annual Sjöstad Games held on Sweden's National Day under the administration of Hammarby IF sports association. Sjöstaden has numerous footpaths and cycle paths alongside the canals, as well as many attractive paths for strolling through a variety of green public spaces in the district. There are also cycle paths along Sjöstaden's main through-road.

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Culture
A variety of different types of cultural activity are also important in terms of overall health. Cultural outlets in Hammarby Sjöstad include not only the Fryshuset social and cultural centre, but Kulturama, which offers tuition in a wide range of Arts for students of all ages, along with a library, not forgetting the cultural centre that will be opening soon.

Integrated planning with an eco-focus
The real key to the district's success is the integrated masterplanning work that was carried out before the area was developed. All of the various authorities and administrations that normally get involved in the various stages of the process sat down and drew up the plan for the new conceptual approach that would result in Hammarby Sjöstad. The integrated planning work carried out from the start was – and still is – unique. And the results were – and will continue to be – visible in Hammarby Sjöstad. The goal was to create a residential environment based on sustainable resource usage, where energy consumption and waste production are minimised, and resource saving and recycling are simultaneously maximised. Sjöstaden is home to exciting new technical solutions for energy supply and energy usage, a pilot sewage treatment plant facility where new technology will be tested, and a practical automated waste disposal system for waste management. One tried and tested example of integration solutions comes in the form of the heat extracted from the treated wastewater, which is used to produce district heating and, from the waste product of this process, district cooling.

Masterplanning guidance
Planning documents contain detailed spatial, landscape, height, fenestration, apartment size, balcony area, material and colour requirements to be followed by the developer teams for each area.

The Hammarby model – a unique eco-cycle
The integrated environmental solutions can be followed through an eco-cycle that has become known as the Hammarby model. The eco-cycle handles energy, waste, water and sewage for housing, offices and other commercial activities in Hammarby Sjöstad. The eco-cycle is also designed to act as a role model for the development of equivalent technological systems in big cities. The Hammarby model, along with explanatory texts, and the various sections of the cycle – namely energy, water and sewage, and waste – are presented on the following pages.

Sustainable and renewable energy
The City of Stockholm has always been well ahead of its time when it comes to finding new and renewable energy sources to make the city a better place to live in. For several decades now, Stockholm has been shifting over to using district heating to heat buildings. Hammarby Sjöstad has brought things one step further through the installation of various kinds of energy supply. New technology is being used as part of exciting development projects in Hammarby Sjöstad, e.g. as fuel cells, solar cells, and solar panels. The purpose is partly to test the new technology and partly to demonstrate methods of building a sustainable city. When the construction work on Hammarby Sjöstad is completed, the area's residents will produce half of all the energy they need. They will do this by utilising the energy present in treated wastewater and the energy to be found in the sorted-at-source combustible waste.

THE CITY OF STOCKHOLM'S ENVIRONMENTAL GOALS FOR ENERGY IN HAMMARBY SJÖSTAD
The goals relate to the sum of all the energy bought to heat the buildings and operate them each year. Household electricity is not included.

- District heating connection with exhaust air systems: 100, of which 20 kWh electricity/m^2 UFA
- District heating connection with heat extraction systems: 80, of which 25 kWh electricity/m^2 UFA
- The entire heating supply shall be based on waste energy or renewable energy sources.
- Electricity shall be 'Good Environmental Choice'-labelled, or equivalent.

Eco-friendly energy, district heating and district cooling

DISTRICT HEATING
The Högdalen combined heat and power plant uses sorted, combustible waste as an energy source (fuel) to produce electricity and district heating. Renewable energy sources are used wherever possible in order to spare the environment. Another example of sustainable heat supply is the Hammarby heat plant which extracts waste heat from the treated wastewater from the Henriksdal wastewater treatment plant.

DISTRICT COOLING
Stockholm's focus on centralised production of district heating and district cooling makes the city a world leader in this field. District cooling in Stockholm has developed over a decade into the world's largest system of its kind. From the cooled and treated wastewater that leaves the Hammarby plant's heat pumps, heat is exchanged into cooling in the water that circulates in the district cooling network in Hammarby Sjöstad. Cooling is, in other words, purely and simply a waste product from the production of district heating.

The sun provides energy and heats water
A variety of different kinds of energy supply are being tried out in Sjöstaden. Hammarby Sjöstad has several solar cell installations which capture the energy of the sun's light and convert into electrical power. Solar cells have been installed on several facades and roofs in Sjöstaden. The more effective the solar cells and the bigger the area they cover, the more effective the installation is. To date, solar cells have mainly taken the form of test projects from an energy viewpoint in urban environments. Two of the buildings on Sickla Kanalgata, for example, have been fitted with solar cells that are contributing to the buildings' energy supply by providing the energy needed for their public areas. Solar panels have also been fitted to the roof of one of Sjöstaden's larger apartment blocks.

Solar cells
Solar cells capture the sun's luminous energy and convert it into electrical power. The energy from a 1 m^2 solar cell module provides approximately 100 kWh/year, which corresponds to the domestic electricity requirement for 3 m^2 residential floor space.

Solar panels
On the roof of the Viken block, 390 m^2 of south-facing solar panels have been installed. These panels capture the warm rays of the sun and use them to heat the building's hot water supply. The solar panels produce half of the energy required to meet the building's annual hot water requirement.

Less water and cleaner sewage
Water consumption shall be reduced to streets with more than 8,000 vehicles per day shall be treated. One of Hammarby Sjöstad's goals is to reduce water consumption by 50 per cent: 200 litres/person/day is normally used in Stockholm, but the real aim is to reduce this figure to 100 litres/person/day. Thanks to eco-friendly installations (energy class A washing machines and dishwashers, low flush toilets and air mixer taps), consumption levels are currently

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approximately 150 litres/person/day. It is even more important to reduce the amount of heavy metals and non-biodegradable chemicals present in wastewater, because this will result in fewer contaminants being dispersed into the Stockholm archipelago via the treated wastewater, and will also give a better residual product, known as sludge, which can be reused on agricultural land. The strategy to systematically work with customers and society to reduce the amount of chemicals flushed into the wastewater system is called the Upstream approach. The Upstream approach is now endorsed by many wastewater companies throughout Europe as being part of their core business. By monitoring the wastewater, one can see whether campaigns in this area have any effect on the quality of the wastewater. In the spring of 2005, for example, a campaign to reduce the use of the bactericide Triclosan was conducted. Triclosan is an environmentally hazardous substance present in certain toothpastes and which there is no need whatsoever for ordinary consumers to use. Analyses of the wastewater before and after the campaign show that the amounts of Triclosan present had fallen.

THE CITY OF STOCKHOLM'S ENVIRONMENTAL GOALS FOR WATER AND SEWAGE IN HAMMARBY SJÖSTAD

- 95 per cent of the phosphorus in wastewater shall be reusable on agricultural land.
- The quantity of heavy metals and other environmentally harmful substances shall be 50 per cent lower in the wastewater from the area than in the wastewater from the rest of Stockholm.
- Lifecycle analyses (LCA) shall be carried out to determine the suitability, from an energy and emissions viewpoint, of returning nitrogen to agricultural land and of utilising the chemical energy present in the wastewater.
- Drainage water shall be connected to the storm water network and not to the wastewater network.
- Storm water shall primarily be treated locally.
- The nitrogen content of the purified wastewater shall not exceed 6 mg/litre and the phosphorus content shall not exceed 0.15 mg/litre.
- Storm water from streets with more than 8,000 vehicles per day shall be treated.

Sjöstadsverket – our own wastewater treatment plant with cutting edge technology evaluated in different processes

A new test wastewater treatment plant, Sjöstadsverket, has been built to evaluate new technology in the field of wastewater treatment. The first stage of Sjöstadsverket has four separate treatment lines for wastewater from the equivalent of 600 people in Hammarby Sjöstad. The various lines are being evaluated and a basis for decision-making for stage two – which may possibly see a water treatment plant built for the whole of Hammarby Sjöstad – will also be generated. The treatment lines under evaluation contain chemical, physical and biological processes that are run as efficiently as possible. The goal is both to treat the wastewater and to recycle resources from the wastewater with as little input of external resources, such as electrical energy and chemicals, as possible.

Cleaner biosolids and nutrient recycling

The buildings and infrastructure in Hammarby Sjöstad have been planned and built with great care when it comes to the choice of construction and building materials, and the processing of wastewater and refuse, for example. By avoiding the use of certain metals and plastics in the buildings, by ensuring that rainwater and snowmelt are treated and drained separately, and by providing residents with information, e.g. the importance of eco-labelled household chemicals, it can be ensured that households' wastewater is relatively clean. The wastewater that goes to the local wastewater treatment plant comes solely from housing in the area, and does not come from storm water and industries. This means that right from the start, the wastewater contains a minimum of contaminants, which makes it easier to treat and for the nutrients it contains to be reclaimed and, hopefully, be reusable on agricultural land. The environmental goal is for 95 per cent of the phosphorus to be separated out and recycled for agricultural use, and for the level of heavy metals and other hazardous substances to be reduced by 50 per cent. The treated sewage has to meet exceptionally high standards.

Biogas and biosolids extracted

Biogas is extracted from the digestion of sewage sludge. At the wastewater treatment plant, organic material is separated out from the wastewater in the form of sludge. The sludge is carried to large digestion tanks, where it is digested. Biogas, which is the most environmentally friendly form of fuel currently available, is produced during the digestion process. The biogas produced is primarily used as vehicle fuel, e.g. in inner city buses, garbage trucks and taxis. Biogas is also used in approximately 1,000 gas stoves in Hammarby Sjöstad. Once the digestion process is completed, the sludge – the biosolid – can be used as a fertiliser since it is nutritionally rich with a high phosphorus content. Stockholm Water sends biosolids to northern Sweden, where they are used as filling material in mines that have been closed down.

Architectonic storm water solutions

All storm water, rainwater and snowmelt is treated locally in a variety of ways, and the system is referred to collectively as LOD (the Swedish acronym for 'local storm water treatment'). Storm water from developed areas is infiltrated into the ground or drained to Sickla Canal, Hammarby Canal or Danvik Canal. A storm water canal runs through the park Sjöstadsparterren (the Sjöstaden parterre). The water runs from the surrounding buildings and courtyards via numerous small gutters and is then carried on to Hammarby Sjö through a water ladder designed by the artist, Dag Birkeland.

Green roofs

The green roofs seen on some of the buildings in Sjöstaden are another link in the local storm water treatment (LOD) chain. Their task is to collect the rainwater, delay it and evaporate it. At the same time, the small, dense sedum plants form living green areas in the cityscape.

Rainwater from the streets is treated locally

Rainwater and snowmelt from the streets is collected and treated in a variety of different ways in Sjöstaden. The most common way involves draining the water into special basins, and Sjöstaden has two closed settling tanks. The water is allowed to remain in the tanks for several hours, to allow the contaminants to sink to the bottom (settling), and is then drained out into the canals. Mårtensdal has an open storm water basin where the surface of the water can be seen. Here, the soil and plants in the area can handle the contaminants from dirty water when it sinks down into the ground water.

Waste must be reduced and recycled

These days waste is no longer just waste. It is a resource that is being utilised more and more. New things are being produced from recycled materials, allowing more economical use of nature's resources. A lot of things improve when everyone separates their waste, and if the waste is to be handled properly, everyone must do their bit. When you separate waste, you help ensure that hazardous substances are not incinerated along with the rest of the refuse bags. Extraction of virgin raw materials is reduced, when the recycled materials can be used instead. This makes waste into a resource that can be used for materials recycling and energy recovery. Quantities of domestic waste are reduced, and the refuse collection personnel's working environment improves.

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THE CITY OF STOCKHOLM'S ENVIRONMENTAL GOALS FOR WASTE IN HAMMARBY SJÖSTAD

Energy shall be extracted from 99 per cent by weight of all domestic waste from which energy can be recovered by 2010. Reuse or recycling shall, however, be prioritised.

- The amount of domestic waste generated shall be reduced by at least 15 per cent by weight between 2005 and 2010.
- The amount of domestic bulky waste disposed of in landfill sites shall be reduced by 10 per cent by weight between 2005 and 2010.
- The amount of hazardous waste generated shall be reduced by 50 per cent by weight between 2005 and 2010.
- Residents shall be given the opportunity to separate their waste at source into the following fractions:
  - Materials with a producer responsibility, within the building
  - Separated food waste and 'refuse bags', within the building
  - Bulky waste, within the building
  - Hazardous waste, in the local area
- By 2010, 80 per cent of food waste by weight shall be handed in for biological treatment which utilises its component nutrients for plant cultivation and also utilises its energy content.
- A maximum of 60 per cent (vehicle km) of waste transports and transportation of recycled materials within the area shall involve the use of heavy vehicles, in comparison with the amount transported using conventional waste management transportation.
- A maximum of 10 per cent by weight of the total waste generated during the construction phase shall comprise waste that is disposed of in landfill sites.

Waste is separated at source and recycled or used to produce heating and electricity

THREE-LEVEL WASTE MANAGEMENT

In Hammarby Sjöstad, there are three different levels of waste management: building-based, block-based, and area-based: building-based separating at source. The heaviest and bulkiest waste is separated into fractions and deposited in different refuse chutes in or adjacent to the buildings.

- Combustible waste. Things made of plastic, paper and other forms of non-packaging are placed in ordinary plastic bags.
- Food waste. Food product waste is placed in bags made of corn starch which, unlike plastic bags, are biodegradable.
- Newspapers, catalogues, paper, etc. left loose, not packed.

BLOCK-BASED RECYCLING ROOMS

The types of waste that do not belong in the building-based refuse chutes can be left in block-based recycling rooms:

- Glass, paper, plastic and metal packaging.
- Bulky waste, e.g. old furniture.
- Electrical and electronic waste. Items that require an electric socket or batteries to function, as well as light bulbs, fluorescent tubes and low-energy light bulbs.
- Some of the recycling rooms also have containers for textiles.

AREA-BASED HAZARDOUS WASTE COLLECTION POINT

Waste that constitutes a danger to people and the environment, such as paint, varnish and glue residues, nail polish, solvents or cleaning agents, batteries and chemicals must never be placed in domestic waste or poured down the drain. It must be separated out and handed in at the hazardous waste collection point in GlashusEtt, the area's environmental information centre.

WHERE DOES THE WASTE GO?

- Combustible waste is transported to the Högdalenverket plant in southern Stockholm where it is incinerated and recycled as heating and electricity.
- Food waste is transported to Sofielund in Huddinge where it is composted and turned into soil. The ultimate aim is for food waste to be converted into biogas and bio-fertilisers.
- Newspapers are delivered to paper recycling companies and then sent on to paper mills where they are turned into new paper.
- Packaging. Paper, metal, glass and plastic packaging is recycled as new packaging or as other products.
- Bulky waste. Metal is recycled, combustible bulky waste is incinerated and recycled as heating and electricity. Non-combustible waste is disposed of in landfill sites.
- Electrical and electronic waste is disassembled and the materials are recycled. Leftover material is disposed of in landfill sites.

The automated waste disposal system reduces transport in the area

MOBILE AUTOMATED WASTE DISPOSAL SYSTEM

The waste collected in the mobile automated waste disposal system ends up in underground tanks that are emptied by a refuse collection vehicle equipped with a vacuum suction system. There are separated tanks for each fraction: combustible domestic waste and food waste. The refuse collection vehicle stops at docking points where several buildings' waste tanks are emptied simultaneously, but only one fraction at a time per collection round.

STATIONARY AUTOMATED WASTE DISPOSAL SYSTEM

All refuse chutes are linked by underground pipes to a central collection station to which they are carried by vacuum suction. The collection station houses an advanced control system that sends the various fractions to the right container. There is a large container for each fraction: combustible domestic waste, food waste and newspapers. The systems reduce transport in the area, which means the air is kept cleaner than when traditional refuse collection techniques are employed. In addition, the work environment for the refuse collection workers is improved when heavy lifting is avoided and there is a noticeable improvement in children's safety.

GlashusEtt is the area's environmental information centre

ENVIRONMENTAL INFORMATION CENTRE

The design and content of GlashusEtt make it the natural focal point for information on environmental issues in Hammarby Sjöstad. This knowledge centre also provides Stockholm with a natural hub for demonstrating the links between modern technology and a better environment in an atmosphere of harmony with exciting new architecture. The centre is also responsible for its own website – www.hammarbysjostad.se.

EXHIBITIONS – STUDY VISITS

The environmental information centre is tasked with spreading knowledge through study visits, exhibitions and demonstrations of the Hammarby Model and new eco-friendly technology. National and international visitors come to Sjöstaden to see not only how the City of Stockholm has planned the new city district, but also how an eco-minded approach has characterised the entire Sjöstaden planning process that went into making it the sustainable city.

CONFERENCE ROOMS

GlashusEtt's conference rooms are used, in part, to receive visitors, but they also function as a meeting place for discussions and conversations about the sustainable city. GlashusEtt is also used as a teaching centre for a variety of different courses on environmental

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and urban planning, public meetings, politicians' meetings and customer meetings.

EXPORTING ENVIRONMENTAL TECHNOLOGY

GlashusEtt also plays a very important role in exporting environmental technology. A very close cooperation is taking place with a range of authorities tasked with promoting environmental exports, such as Stockholm Business Region, the Swedish Ministry for Foreign Affairs, and the Swedish Trade Council. In just a short period of time, Hammarby Sjöstad has become one of the world's most high profile examples of sustainable urban development and is mentioned in specialist publications worldwide. Sjöstaden is visited by over 10,000 industry representatives and decision makers every year. Significant urban projects in Toronto, London, Paris and several cities in China have been influenced by the expertise and technology that forms the basis for its success.

Hammarby Sjöstad's own eco-cycle

ENERGY

- Combustible waste is converted into district heating and electricity.
- Biofuel from nature is converted into district heating and electricity.
- Heat from treated wastewater is converted into district heating and district cooling.
- Solar cells convert solar energy into electricity.
- Solar panels utilise solar energy to heat water.
- Electricity must be a 'Good Environmental Choice' product, or equivalent.

WATER AND SEWAGE

- Water consumption is reduced through the use of eco-friendly installations, low flush toilets and air mixer taps.
- A pilot wastewater treatment plant has been built specifically for the area in order to evaluate new sewage treatment techniques.
- Digestion is used to extract biogas from the sewage sludge.
- The digested biosolids can be used for fertilisation.
- Rainwater from yards and roofs is drained into Hammarby Sjö, rather than into the wastewater treatment plant.
- Rainwater from streets is treated locally using settling basins and then drained into Hammarby Sjö, rather than being drained into the wastewater treatment plant.

WASTE

- An automated waste disposal system with various deposit chutes, a blockbased system of recycling rooms and an area-based environmental station system help the residents sort their waste.
- Organic waste is converted/digested into biosolids and used as fertiliser.
- Combustible waste is converted into district heating and electricity.
- All recyclable material is sent for recycling: newspapers, glass, cardboard, metal, etc.
- Hazardous waste is incinerated or recycled.

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29 Museums, art galleries and temporary exhibition spaces

Geoffrey Matthews, with additional information (case study) by Pamela Buxton

CI/Sfb:75

Geoffrey Matthews is a museum consultant. Pamela Buxton is editor of the fifth edition of the Metric Handbook

KEY POINTS:
- *Flexibility and potential for expansion is a priority*
- *Design must enhance visitor orientation*
- *Digital media brings new challenges and opportunities*

Contents

1 Introduction
2 Area data
3 General planning
4 Exhibition and collection storage spaces
5 Interpretation, communication and display
6 Environment and conservation
7 Security and services
8 Case study
9 Bibliography

1 INTRODUCTION

1.1 Scope

Museums are defined by the Museums Association in the UK as institutions that collect, safeguard and make accessible artefacts and specimens, which they hold in trust for society. They enable people to explore these collections for inspiration, learning and enjoyment.

The design of museums, art galleries and the temporary exhibition spaces associated with similar organisations involves the housing of a wide range of functions broadly indicated in the common definitions of a museum. Museums, however, vary considerably in size, organisation and purpose. It is important therefore to consider the particular context and features that characterise a museum in the process of developing concepts.

1.2 Collections

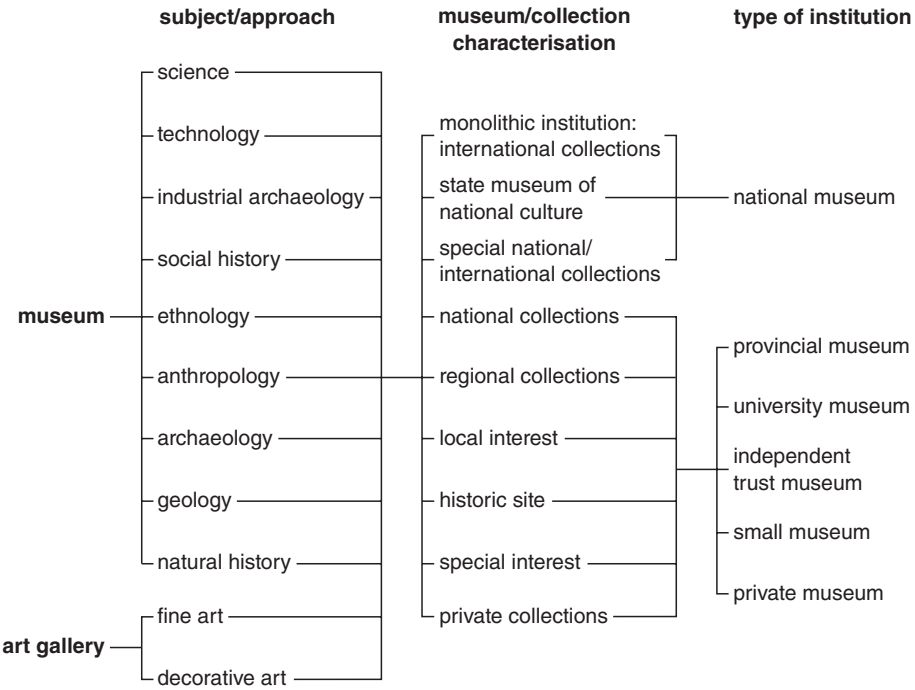
Collections in national museums are very large and varied in material and generally of international importance. The National Maritime Museum in Greenwich, for example, houses collections of machinery, boats, costumes, medals, ship models, paintings, silver, weapons and scientific instruments, among many other types of material. Such museums are staffed by a wide range of highly qualified experts in collection management, research, conservation, public relations and marketing.

In some local and private museums collections are small, specific in material content and of specialist or local interest. Many such museums have only one qualified curator to oversee management of the collections and public services, and many of the specialist functions may be provided by outside bodies such as the Area Museum Councils. Figure 29.1 shows a typology of museums based on subject/museological approach, collection characterisation and type of institution.

2 AREA DATA

2.1 Design guidelines

There is no convenient formula for determining the areas to be devoted to the different functions. The client's intentions in respect



29.1 *A museum typology based on: museological approach/interpretive discipline; collection characterisation; and institution characterisation*

of public access to collections, information and staff, and of commitment to research and conservation will provide an initial guide and most major museums, for example the Victoria and Albert Museum, will have their own design guidelines.

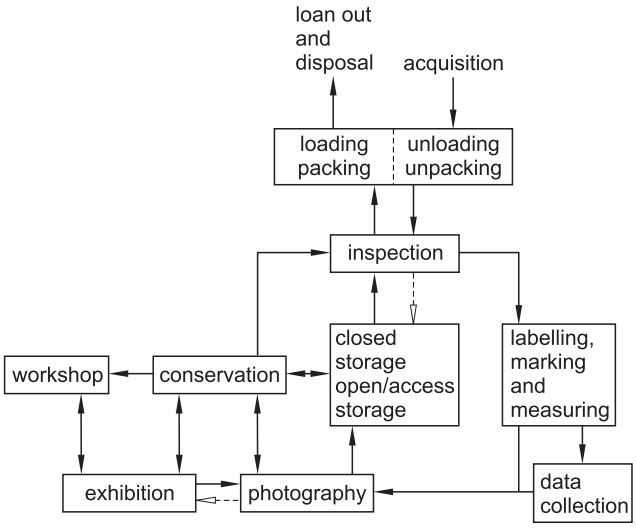
2.2 Storage

Some museums may have only a small proportion of the permanent collections on public exhibition at any one time, the bulk remaining in storage and accessible for research and conservation purposes only. Well-serviced temporary exhibition space may be a priority in such cases. Other museums may have smaller collections attractive enough to the visiting public to warrant the development of sophisticated exhibitions with a designed life of several years. In such cases storage space may be needed primarily for the expansion of the collections, and considerable effort may be made to develop educational programmes.

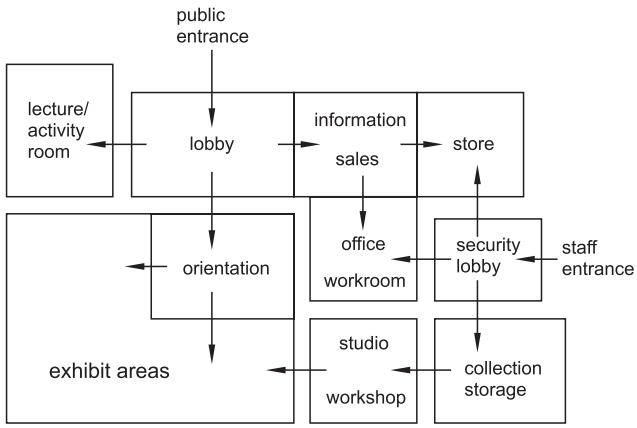
3 GENERAL PLANNING

3.1 Organisation

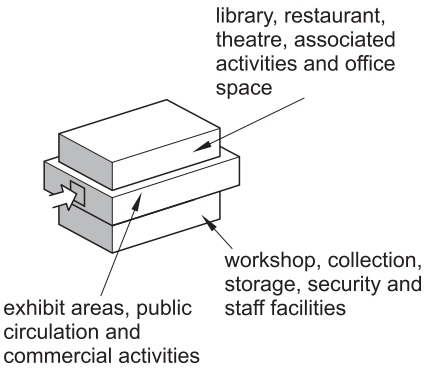
The relationships between functions are common to all museums and art galleries. The flow diagram in Figure 29.2 shows collection item movements in the operation of collection services, but note that not every operation necessarily requires a separate space, and some services may be provided by outside agencies. As far as possible, collection movement and public circulation should be kept separate. Figure 29.3 shows one approach to zoning and expansion based on this principle. Figure 29.4 shows a possible layout for a small museum in which interpretive exhibitions and educational programmes are central to its operation. Where a museum is to be developed around a large-scale permanent installation this should be integrated into the interpretive scheme at an early stage. Examples are Jorvik Viking Centre's archaeological site and the National Railway Museum's turntables.



29.2 *Flow diagram of collection item movements in the operation of collection services: exhibitions, conservation and collections management*



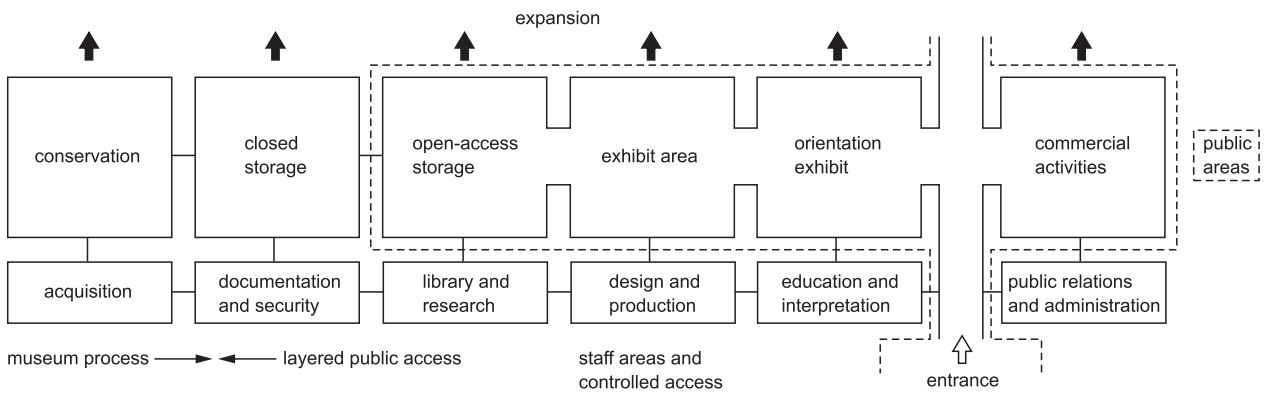
29.4 *A possible layout diagram for a small museum*



29.5 *Two basic massing concepts that allow public areas to be organised on one level*

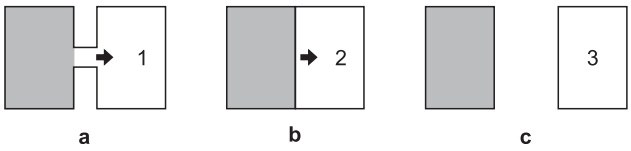
3.2 Flexibility

Museums are long-term developments: concepts for layout and massing should therefore be capable of expansion in all areas and a degree of internal rearrangement, particularly in work and ancillary areas. Figure 29.5 shows possible massing concepts and Figure 29.6 illustrates the three methods of expansion.



29.3 *A layout concept showing a clear relationship between museum functions and an approach to zoning and expansion*

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29.6 *Three modes of expansion: a Block addition; b Extension; c New building*

4 EXHIBITION AND COLLECTION STORAGE SPACES

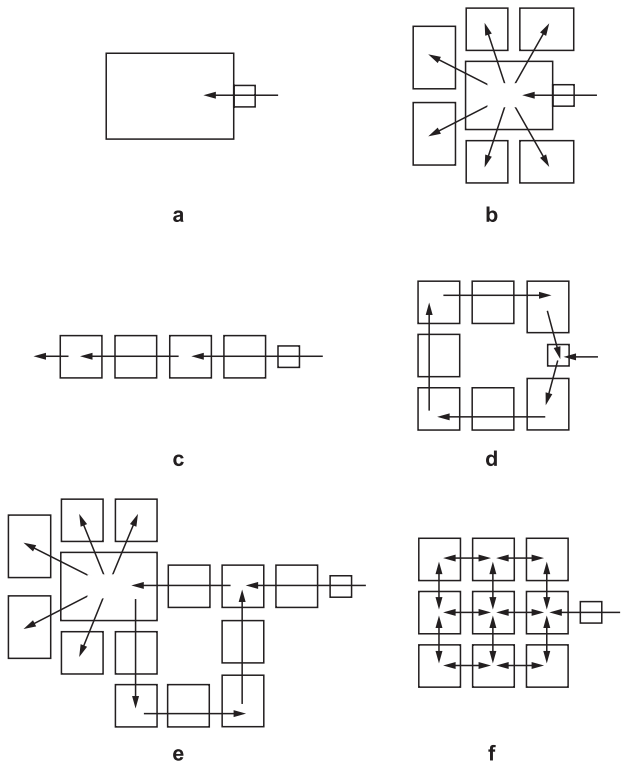
4.1 Layout

The layout of public areas in a museum, Figure 29.7, may be based on a simple concept of free circulation around a single open-plan exhibition space, Figure 29.7a, or on more complex concepts related to generic interpretive structures. It is important to consider the nature of the narratives appropriate to the museum's objects of interest. The storyline of an exhibition may be translated into:

- a *linear* arrangement of spaces with beginning, middle and end, Figure 29.7c;
- a *loop* where the essentially linear storyline leads naturally back to the beginning, Figure 29.7d;
- an arrangement of *core and satellites* where each theme or detailed treatment of a subject leads back to a central introductory or orientational area, Figure 29.7b;
- a more *complex* scheme combining linear, loop and core-satellite arrangement of spaces which is specifically structured to account for more or less stable relationships between collections and interpretive themes, Figure 29.7e; or
- a *labyrinthine* arrangement where the relationships between areas can be varied from exhibition to exhibition by managing the public circulation, Figure 29.7f.

4.2 Orientation

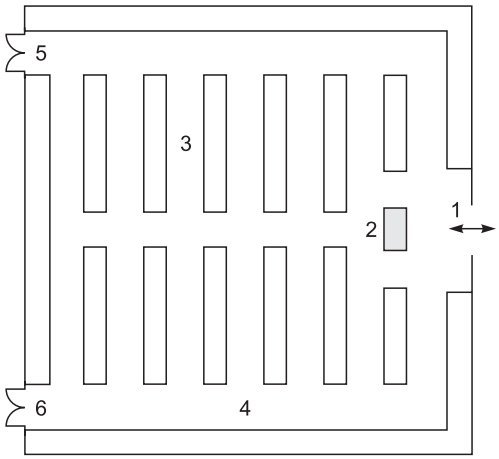
In any arrangement of exhibition spaces considers the problem of orientation; at the entrance to the museum and at key decision points in the museum, information and visible clues should be provided to enable the visitor to grasp the organisation of the collections, the interpretive scheme and the public services offered by the museum. The aim of orientation is not only easy understanding of the building layout but more crucially to facilitate access to collections, information and museum services.



29.7 *Generic plans for exhibit and open-access storage areas: a Open plan; b Core + satellites; c Linear procession; d Loop; e Complex; f Labyrinth*

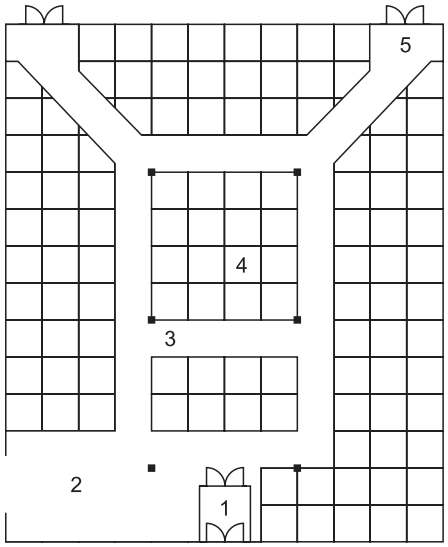
4.3 Storage

Many museums carefully control access to all collection storage spaces. However, it is increasingly worth considering the provision of open-access storage areas particularly for collection study. The former requires that storage areas are made secure and that visitors are closely supervised. Open access, on the other hand, requires that secure forms of storage equipment and furniture are arranged in very compact layouts. Figure 29.8 shows a typical layout for a storage area fitted out with ranks of secure display cases. Figure 29.9 shows a secure storage area with open-floor storage for larger collection items.



29.8 *Method of layout in open-access storage areas*

1 *Entrance from main exhibit areas*
2 *Orientation point*
3 *Ranks of cases glazed on all sides*
4 *Full-height wall cases*
5 *Fire exit*
6 *Controlled access to staff areas and secure storage*



29.9 *Grid system for open-floor secure storage area*

1 *Controlled entrance lobby*
2 *Inspection area*
3 *Clear aisles*
4 *Grid marked on floor, e.g. 1.5 m squares lettered in one direction, numbered in the other*
5 *Fire exit*

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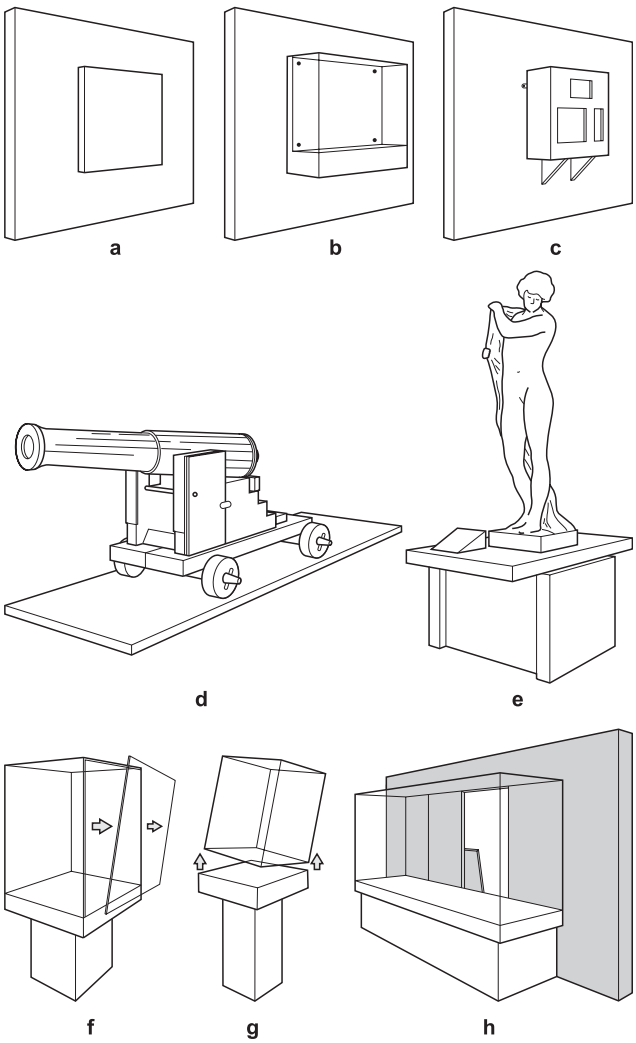
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5 INTERPRETATION, COMMUNICATION AND DISPLAY

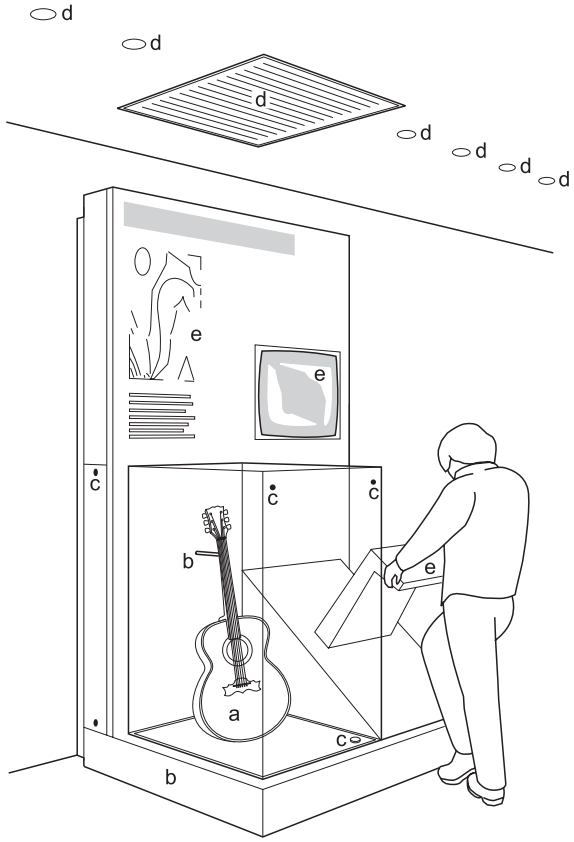
5.1 Strategy

The communications strategy of the museum should be determined at an early stage. The relative importance and coordination of exhibition, education, publication, live interpretation and other forms of direct communication with the public are the essential factors that will determine the interface between staff and public. It is not sufficient to consider only the relationship between visitor and displayed collections; a wide variety of media are now used in museum exhibitions to enrich interpretation and facilitate communication with the visiting public – graphic display, audio-visual, theatre, video, computer graphics, digital media, animatronics, tableau and reconstruction, and working environments. Once beyond the stage of producing a general scheme it is important to consult an exhibition designer and a museum consultant to explore the matrix of interactions between people, information and collections that must be accommodated.

A wide range of academic expertise may be brought to bear in the interpretation of collections for exhibition purposes. Within the framework that the initial consultations provide, informed decisions may be made regarding the interpretive process and techniques, and the choice of media and types of exhibit to be employed. Figure 29.10 shows a broad typology of exhibit and media installations, and Figure 29.11 indicates the physical elements associated with exhibits. A design for a temporary exhibition at the Museum of London is shown in Figure 29.12. Reference should be made to the anthropometric data in Chapter 2 in determining coordinating dimensions; for example, the range of eye levels represented in the visiting population.



29.10 *Exhibits may be of four basic types: a, b, c Hanging or wall mounted; d, e Free-standing and open exhibits; f, g, h Contained exhibits and display cases*



29.11 *Each of exhibit types in 29.10 may have any combination of the following elements: a Item or items from the collection; b Fixing mount, support or plinth; c Preservation: protection of vulnerable or removable parts, lock, alarm, barrier, glazing, thermo-hygrometer (contained exhibits may have buffering material against changes in relative humidity); d Lighting; e Interpretive material: label, graphic information, sound, audio-visual, kinetic device, interactive device*

6 ENVIRONMENT AND CONSERVATION

6.1 Relative humidity and temperature

Special consideration must be given to proper control of relative humidity, temperature and air pollution in all collection areas of a museum or art gallery. This includes: exhibition areas; collection storage; and conservation, display and photographic work areas. Passive, low-tech approaches may be considered where climate and the inertia of the building allow. Full air conditioning may be required to cope with climatic extremes, even in this case the building envelope should provide a sufficient buffering effect to prevent sudden changes in relative humidity during periods of repair or maintenance. Figure 29.13 shows suitable conditions in museums, while Table I gives the ranges of museum interior temperature and relative humidity recommended in various climatic zones.

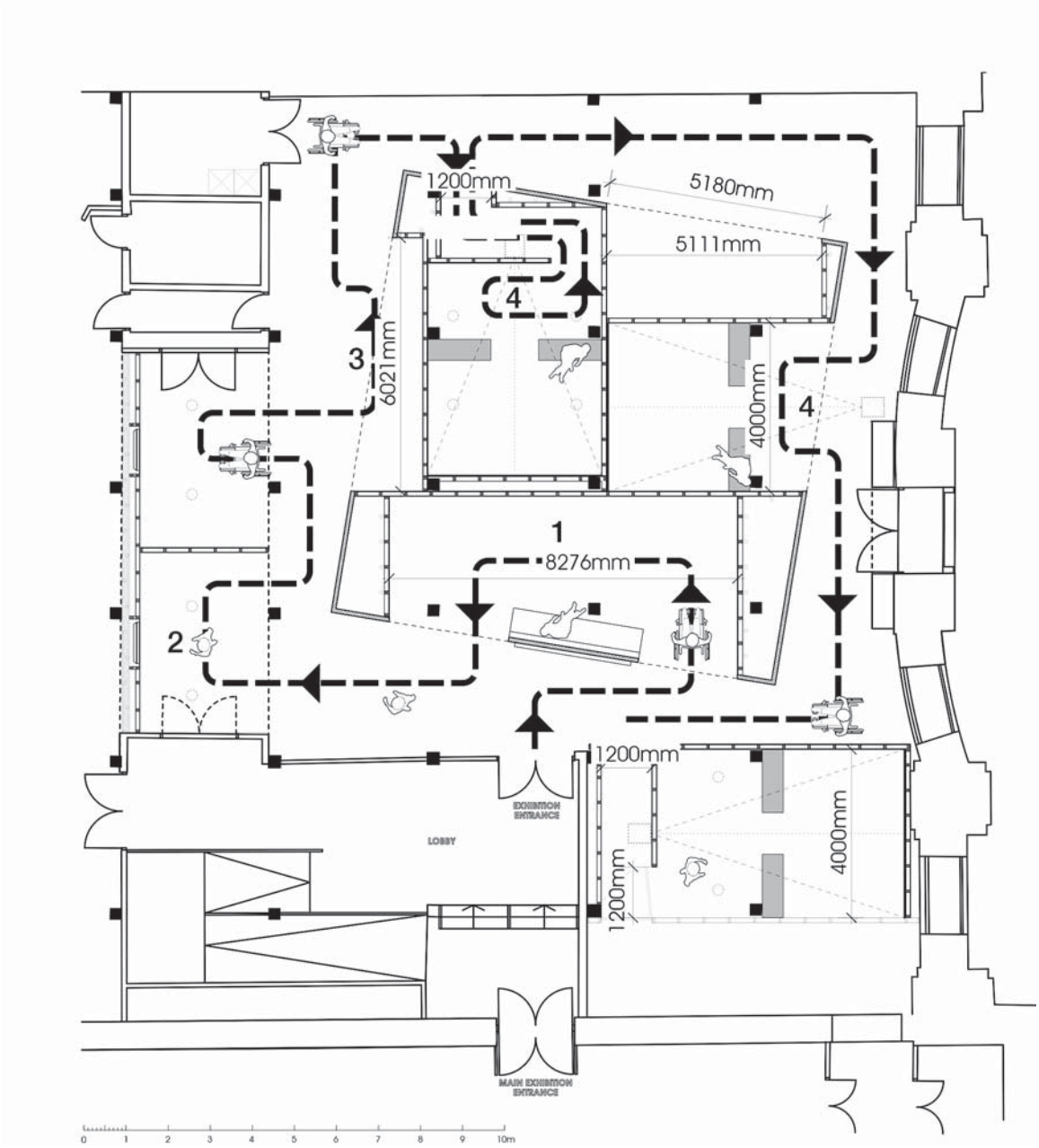
6.2 Air pollution

Information about local air quality should be sought and used to decide on the appropriate approach to control. If air filtration is necessary it should not be of the electrostatic type, as malfunction can result in the generation of highly damaging ozone levels.

6.3 Light and lighting

Museum lighting is a complex subject. It is important, particularly in art museums, to determine a clear policy on the approach to natural and artificial lighting. Direct sunlight should not fall on any collection item and UV radiation must be effectively eliminated from all light reaching a collection item: at the higher energy end of the spectrum light is very effective in initiating chemical change in vulnerable materials. The maximum light dosage recommended for different categories of collection item is summarised in

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29.12 *Layout for the Estuary temporary exhibition at the Museum of London Docklands, designed by Urban Salon. Key 1, Open space for fine art exhibits; 2, Enclosed space for screen based video artists; 3, Long open flat surfacing for a series of flat works; 4, Staggered entrance for minimal light and sound spill for projection artists*

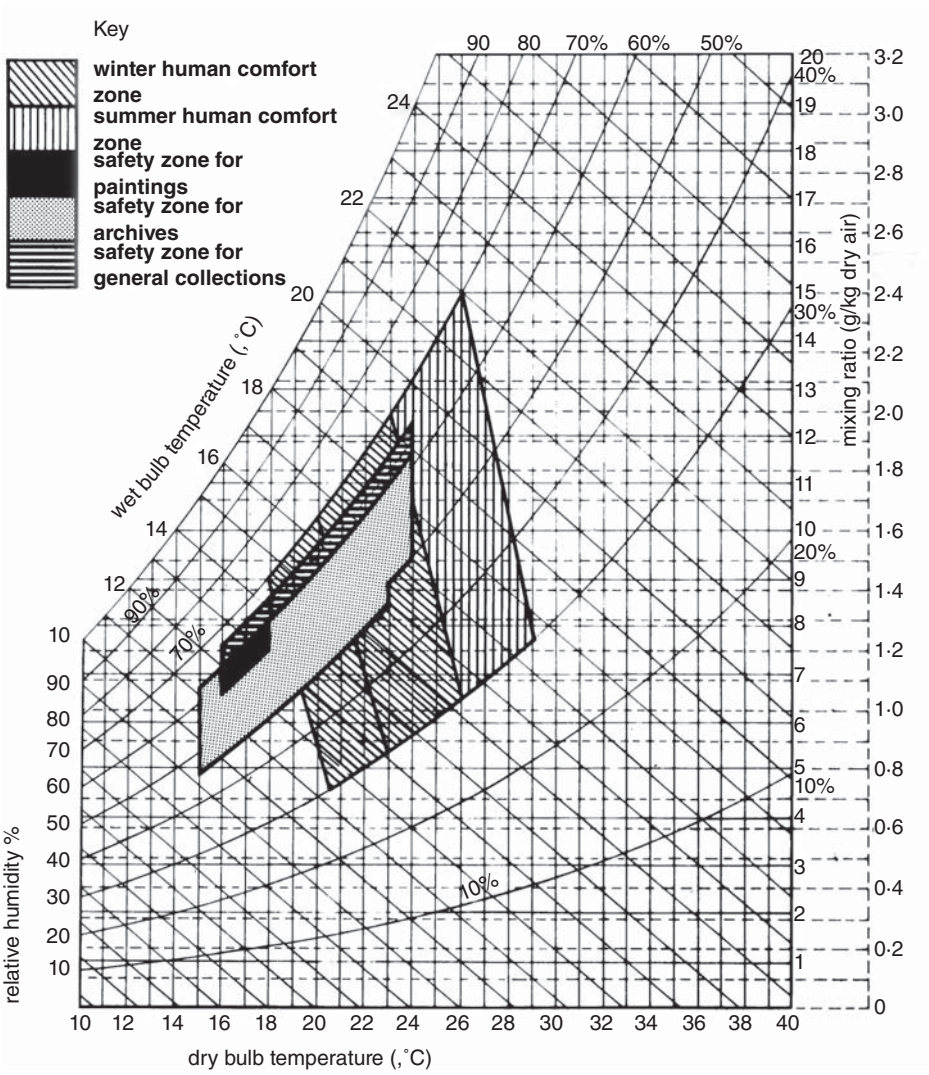
Table I Recommended temperatures and relative humidities in various climatic zones

Climate	Temp (°C)	RH (%)	Notes
Humid tropics	20–22	65	Acceptable for mixed collections. However, RH too high for iron and chloride-containing bronzes. Air circulation very important
Temperate coastal and other non-arid regions	20–22	55	Widely recommended for paintings, furniture, and wooden sculpture in Europe, satisfactory for mixed collections. May cause condensation and frosting difficulties in old buildings, especially inland Europe and northern North America
Temperate inland regions	20–22	45–50	A compromise for mixed collections and where condensation may be a problem. May be best level for textiles and paper exposed to light
Arid regions	20–22	40–45	Acceptable for display of local material. Ideal for metal-only collections

Table II Recommended maximum light dosages

Type of collection	Dosage (kilolux-h)	Notes
Objects specially sensitive to light, e.g. textiles, costumes, watercolours, tapestries, prints and drawings, manuscripts, miniatures, paintings in distemper media, wallpapers, gouache, dyed leather. Most natural history items, including botanical specimens, fur and feathers	200	Usually only possible to achieve with artificial lighting
Oil and tempera paintings, undyed leather, horn, bone and ivory, oriental lacquer	650	If a daylight component is used great reduction of UV is necessary
Objects insensitive to light, e.g. metal, stone, glass, ceramics, jewellery, enamel, and objects in which colour change is not of high importance	950	Higher dosage is possible but usually unnecessary

Table II. These dosages are normally achieved by limiting the level of illumination on collection items during visiting hours to 50 lux per annum on the most sensitive material such as paper, textile,



29.13 *Psychrometric chart showing safety and comfort zones for museums, art galleries and archives wheelchair viewers. Digital captions and audio points are 700 mm off finished floor level.*

watercolour and 200 lux on other sensitive materials such as wood, leather, and oil paint.

The eye has a limited ability to adapt to changes in brightness, and as the visitor moves through the museum sudden changes in lighting levels and extreme contrasts of brightness in the field of view should be avoided. However, a reasonable range of contrast should be maintained in conditions of low illumination to prevent a dull effect and possible problems of visual accommodation.

6.4 Acoustics and zoning

The transport of sound through structure should be controlled. Functional zones should be provided with surface or sub-surface materials that dampen impact sounds and isolating cavities to interrupt the structural transmission of sound. Noise levels should be controlled within zones by appropriate choices of material finishes on floors, walls and ceilings, and the shaping of interior spaces to prevent flutter and unwanted amplifying effects. To generalise and simplify, the penetration of low-frequency sound is lessened by structural mass, of middle frequencies by diffusing and absorbing surfaces, and of high-frequency sound by the elimination of small-scale air gaps in doors, windows and partition walls.

7 SECURITY AND SERVICES

7.1 Security

Many security problems can be avoided by keeping the number of access points to the site and to the building to a minimum. The ideal is one public entrance monitored by information staff and/or attendants, and one staff entrance controlled by the security staff responsible for key control and the checking of deliveries and outside contractors. Security staffing is also considerably more effective and economic if all exhibition and open storage areas are on one level.

7.2 Secure areas

The health and safety of the public and the staff and collection security are the prime considerations in determining the zoning of the museum into secure areas. During open hours it may be sufficient to separate public and staff areas. When the museum is closed to the public it is normal to secure more specific zones, for example:

1 Entrance, orientation/information, shop, café and toilets/cloakrooms.
2 Temporary and permanent exhibitions – in larger museums subdivided into several secure exhibit areas.
3 Educational facilities, lecture theatre, study collections.
4 Offices: administration, curatorial, conservation, design, etc.
5 Conservation workshops, laboratories, photographic facilities.
6 Collection storage, security staff areas, collection packing and inspection areas.
7 Exhibition and maintenance workshops.

7.3 Services

For general guidance see appropriate chapters in this book. In addition, special consideration should be given to minimising the risk

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to the collections when locating service installations and routing service ducts. For example, water and waste pipes should not be routed near collection storage and exhibition areas.

Risk management is also greatly enhanced if a separate heating/air conditioning system or independent control system is provided in collection areas.

8 CASE STUDY

Project: The Dr Susan Weber Furniture Gallery, Victoria and Albert Museum, South Kensington, London

Design: Nord Architecture

8.1 Introduction

The Victoria and Albert Museum commissioned Nord Architecture to design a 720sq m permanent gallery for furniture and fabrication techniques. Completed in 2012 with a budget of £1.4 million, the Dr Susan Weber Gallery shows more than 250 objects from the past 500 years.

8.2 Site

The site was a 72 m x 10 m gallery within the Grade I listed Aston Webb interior. The listing meant that all work had to be fully reversible, and required planning and listed building consent for the introduction of new air handling plant. Internally, the original interior cabinetry had to be removed and stored off site.

8.3 Challenges

The biggest challenge was creating a display solution that would allow so many diverse exhibits to sit well together. Another issue was the gallery plan. Since the gallery can be entered at either end, the content needed to legible in both directions. Also, the narrow shape of the plan meant that careful consideration of visitor flow was required while at the same time maintaining ample viewing distances from the objects. Because of the length and linear nature of the gallery, it was important to provide a varied rhythm of experience in order to retain interest.

Exacting conservation strategies were also required to respond to light sensitive content, with a maximum average annual daylight exposure of 50 –70 lux stipulated. For a top lit gallery on a north-south axis, this implied extensive solar shading.

8.4 Design solution

The arrangement of objects was given a tripartite hierarchy to aid legibility. A chronological display created a spine to the exhibition along the centre of the gallery, Figure 29.14. Around the perimeter



29.15 *Completed gallery, with display portals down either side*

walls, objects were divided into sections, each addressing a distinct manufacturing technique, Figure 29.15.

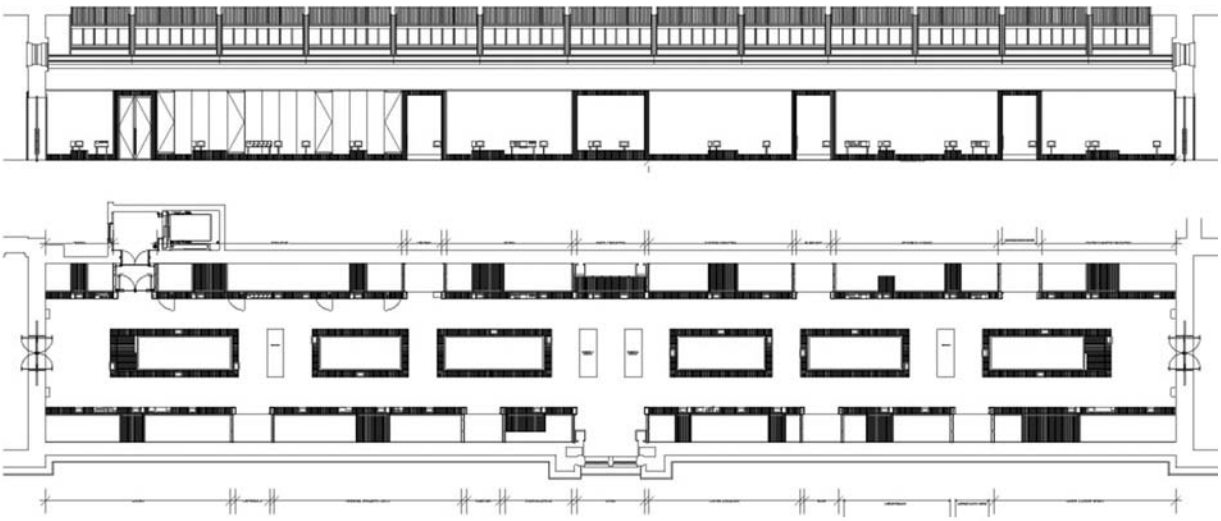
To provide buffering between each display and variety within the linear display, a series of framed openings or portals each measuring 1800 mm x 3650 mm, was inserted along the length of the gallery, each focusing on an individual furniture maker. The portals followed the height, width and thickness of the existing black marble door architraves at either end of the gallery. This allowed them to be read as a perceptual 'doorway' inviting the visitor to enter the world of the maker, Figure 29.16.

A monochrome colour scheme created a holistic backdrop to the multitude of timber objects and materials. Ebonised oak strip was used throughout to form the plinths, portals and frieze. To contrast with this, white Corian linings were used for display space, cabinet linings and plinth tops.

Displays were kept to 350 mm off finished floor level to provide a suitable height for wheelchair viewers. Digital captions and audio points are 700 mm off finished floor level.

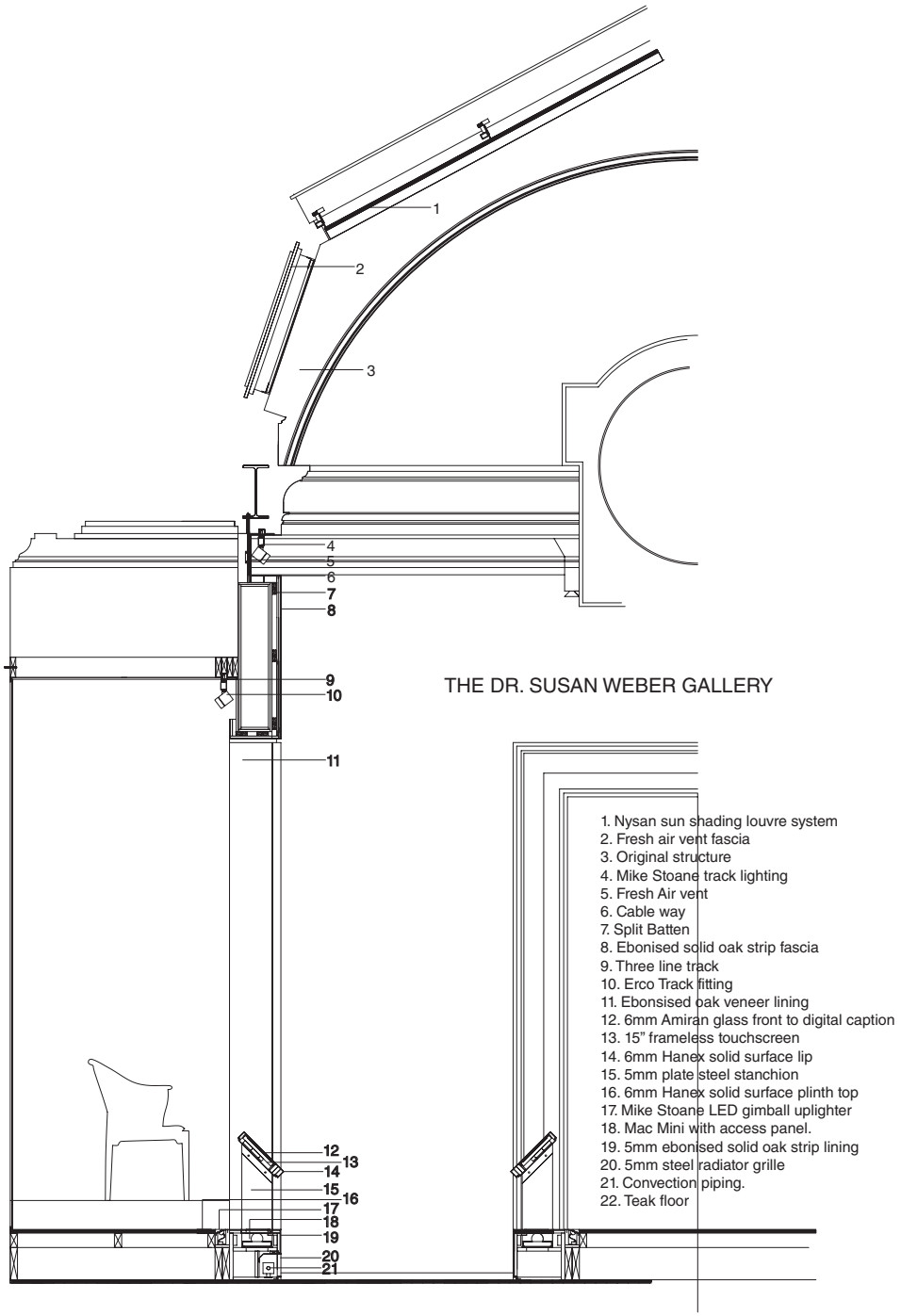
8.5 Interpretation

Each technique display was given a dedicated interpretive ledge to introduce the visitor to the process behind the technique. Films/touch objects/samples/illustrations and historical precedents were collated in groups to impart better understanding of the technique from the perspective of the maker. To limit captioning, digital touch labels were introduced within bespoke housings – the first digital labels at the museum.



29.14 *Section (top) and plan, showing perimeter wall displays and central plinths*

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29.16 *Detail of display portal*

Each portal incorporated an audio point with a selection of recordings from architects and designers describing the maker's relevance today. At the centre of the gallery, two interactive workbenches allow visitors to explore materials and their production processes.

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