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Applications and activities: HVAC strategies for common building types

CIBSE Guide B0



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CIBSE Guide B0: 2016



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Foreword

Guide B provides guidance on the practical design of heating, ventilation and air conditioning (HVAC) systems. It represents a consensus on what constitutes relevant good practice guidance. This has developed over more than 70 years, with the Steering Groups for each edition of the Guide expanding and pruning the content to reflect the evolution of technology and priorities.

Since the last edition of Guide B in 2005, the European Energy Performance of Buildings Directive has been introduced. This requires national building energy regulations to be based on calculations that integrate the impact of the building envelope and the building services systems, formalising what was already recognised as good design practice. In addition, the use of voluntary energy efficiency and sustainability indicators has increased.

These changes have influenced the content of Guide B, but the emphasis remains on system design. The guidance in Guide B is not in itself sufficient to cover every aspect of the effective design of HVAC systems. Energy (and carbon emission) calculations will also be needed, and a range of other environmental criteria may be specified by the client. These may, for example, include whole-life costing or assessments of embodied energy or carbon. The balance between building fabric measures and the energy efficiency of HVAC systems is important, as is the balance between energy use for lighting and for heating, ventilation and cooling. More detailed information on energy efficiency and sustainability can be found in Guides F and L respectively. The Guide does not attempt to provide step by step design procedures – these can be found in appropriate textbooks.

Structure of the Guide

Guide B deals with systems to provide heating, ventilation and air conditioning services, and is divided into several chapters which are published separately. It will usually be necessary to refer to several – perhaps all – chapters since decisions based on one service will commonly affect the provision of others.

This chapter, B0: *Applications and activities*, focuses on how different types of building and different activities within buildings influence the choice of system. This chapter is not available in printed form, but can be downloaded from the CIBSE website. For many activities and types of building, more detailed design information is available in specialist guidance.

Chapters B1 to B4 address issues relating to specific services. There are usually several possible design solutions to any situation, and the Guide does not attempt to be prescriptive but rather to highlight the strengths and weaknesses of different options.

- B1: *Heating*, including hot water systems and an annex on hydronic systems, which is also applicable to chilled water systems
- B2: *Ventilation*, including ductwork
- B3: *Air conditioning and refrigeration*
- B4: *Noise and vibration control for building services systems* (applicable to all systems)

When all chapters have been published, an index to the complete Guide B will be made available.

The focus is on application in the UK: though many aspects of the guidance apply more generally, this should not be taken for granted. The level of detail provided varies: where detailed guidance from CIBSE or other sources is readily available, Guide B is relatively brief and refers to these sources. Examples of this are the treatment in the Guide of low carbon systems such as heat pumps, solar thermal water heating and combined heat and power. On-site energy generation such as wind power and photovoltaics are not covered.

Regulatory requirements are not described in detail in the Guide – the information varies between jurisdictions and is liable to change more rapidly than the Guide can be updated. Instead, the existence of regulations is sign-posted and their general scope explained. Sometime example tables are shown, but readers should note that these are simply examples of the type of requirement that is imposed and may not be current.

While there is some discussion of relative costs, no attempt is made to provide detailed cost figures as these are too project-specific and variable with time and location.

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0 Applications and activities

0.1 Introduction

This chapter is intended as a subject introduction to engineers in training or to more experienced engineers faced with tackling an activity with which they are unfamiliar and seeking a general approach to the subject. It first summarises a number of issues that affect the selection and design of heating, ventilation and air conditioning (HVAC) systems and then highlights specific issues that relate to particular applications and activities. More detailed discussions of HVAC system selection and characteristics – and of generic issues such as acoustic and vibration control – are provided in the remainder of CIBSE Guide B. As with the rest of the Guide, the emphasis is on a UK context. Much of the guidance is applicable in countries with similar climates and regulations, but this must be carefully considered.

The types and varieties of activity undertaken within a building are often important factors in the choice and design of HVAC system(s). An ‘activity’ may relate to a single space in a building, to several spaces or to a complete building, with consequent design implications at the different scales. For instance, office activities take place not only in office buildings but also in spaces within schools, factories and many other types of building.

In many cases, the primary environmental objective is to provide satisfactory indoor environmental conditions for occupants carrying out sedentary work. In order to reduce repetition, the ‘offices’ section addresses the issues that relate to this type of activity in rather more detail than is the case under other headings.

This chapter is not a design guide but aims to highlight features that are specific to, or particularly important for, each of the activities covered. The length of text devoted to each activity or building type varies according to the complexity of the issues and to the availability of detailed design guidance. References are provided to more detailed relevant guidance and requirements. Further information and case studies can also be found in the Knowledge section of the CIBSE website. Clients may have additional requirements and regulations and standards change, therefore readers should therefore use this chapter only as an introduction.

Environmental design requirements are addressed in CIBSE Guide A: *Environmental Design* (2015) and not repeated here. The number of possible activities is large and this chapter does not claim to be comprehensive¹.

¹ CIBSE welcomes offers of suitable information relating to additional activities for future revisions of this Guide. These might cover, for example, call centres, TV studios, specialist laboratories, warehouses, museums and art galleries or prisons.

0.2 General context

0.2.1 Conflict between design objectives

A balance between conflicting design objectives has to be established, which will vary from project to project. These are not exclusively technical. For example, aesthetic and heritage considerations can be important. This balance will depend on the client’s needs, so early clarification and agreement is highly desirable. Systems should, of course, be compliant with all relevant regulations, not all of which are itemised here. Safety issues during construction and use, including smoke ventilation requirements, are fundamental.

0.2.2 The internal environment

The primary purpose of the services provided by HVAC systems is to create an acceptable indoor environment. While the environmental requirements for some activities may be determined by the needs of processes or artefacts such as paintings, there are few activities in which occupants’ needs are unimportant. Thus there is a need to create a healthy – and preferably enjoyable and productive – indoor environment for occupants’ wellbeing and to ensure acceptable levels of thermal, visual and aural comfort for occupants. For many activities occupants are sedentary and it is important that HVAC systems satisfy local and not just average room thermal comfort criteria. People differ in their preferences for temperature, humidity etc. and, in any space containing several people, some degree of dissatisfaction is inevitable. Local air velocities and radiant temperature asymmetry should be assessed as well as mean room operative temperature and availability of daylight. The provision of effective controls that are easily understood by users and building managers is essential; this is dealt with in detail in CIBSE Guide H: *Building control systems*. Indoor air quality is always important and the control of contaminants from both indoor and outdoor sources and the provision of adequate clean supply air are essential considerations. Humidity control will also be important for some systems and some applications. These questions are discussed in more detail in CIBSE Guide A, section 1.3, ‘Thermal environment’.

0.2.3 Initial and operating cost

Lifecycle cost assessment (bearing in mind future risk and uncertainty) is, in principle, always desirable. In practice, first cost is important but rarely provides the lowest lifecycle costs. Planned and reactive maintenance, replacement and disposal should be taken into account.

0.2.4 Environmental impact and energy efficiency

The need to constrain impacts on the outdoor environment – especially in terms of energy-related impacts – is an important influence on system choice and design. In particular, mandatory minimum performance requirements such as those imposed by Building Regulations and compliance guides must be complied with. Some clients, and local or other authorities, may require significantly higher environmental or other standards. This is especially important in the light of regulatory moves towards ‘low carbon’ and ‘nearly zero-energy’ buildings and the growing interest in ‘whole-life’ assessments of carbon emission and resource use.

0.3 Generic issues affecting HVAC strategy

This section is a reminder of the factors that can influence design for most or all activities.

0.3.1 Built form and scale

The orientation of a building and whether it is, for example, deep plan or shallow plan, single- or multi-storey, has one space or many, or includes atria, will strongly influence the ventilation strategies that are possible, the choice of HVAC systems and the energy consumption. Shallow plan buildings are easier than deep plan buildings to ventilate naturally and provide with daylight, but can be subject to larger and more variable solar heat gains.

Some applications, such as assembly halls and auditoria, vary greatly in scale; solutions for smaller spaces are not always appropriate for larger ones and vice versa.

0.3.2 Location

Climate, noise, outdoor air quality and level of urbanisation can all constrain the range of practicable choices of system and design strategy.

0.3.3 Range of activities

A building usually consists of more than one space, and the individual spaces may accommodate different activities with different servicing needs. For example, there may be requirements to satisfy the needs of human (or other) inhabitants, to preserve products or artefacts, or to preserve the building fabric. The number and variety of spaces and activities present within a building can be fundamental to the selection of the number and types of HVAC systems required.² In addition, a space such as a school hall may be used for different purposes and the HVAC system will need to satisfy all of the likely activities.

² The large range of activities that might be considered is illustrated by the number of standardised activities that are permitted for carbon emission calculations to support EPBD implementation in the United Kingdom.

Even if the activities in different spaces are similar, the spaces may be managed or owned by different organisations or individuals. Services design may need to reflect the division of operational and maintenance responsibilities between tenants and/or between landlord and tenant. For example, a building may predominantly consist of office spaces or retail units but these may have different tenants with different operational requirements. With shell-and-core construction, for a multi-tenanted building, services provision to each user is mainly in the hands of individual tenants.

0.3.4 Resilience to future changes

When developing an HVAC strategy, system designers should consider possible changes to a building, its environment and the uses of the spaces within it. Such changes may include changes of use of the building or of individual spaces, refurbishments and the impact of climate change (notably extreme events). Buildings tend to last longer than HVAC systems, especially the energy-using components of systems, and the ease of systems and component replacement should be considered.

0.4 Key decisions

0.4.1 Is heating needed?

This will be the case for most activities in the UK. Exceptionally, internal heat gains may be sufficient to cover all heating needs, but fresh air supply from outdoors may still require preheating. The internal heat gains from people, lights and equipment may provide sufficient gains to maintain the desired temperature, with heating only required to preheat the space from the overnight or setback temperature.

0.4.2 Is mechanical ventilation needed?

This decision is influenced by:

- location:
 - outdoor noise
 - outdoor air quality
- need for ventilation heat recovery (e.g. for energy conservation)
- the activities served:
 - are there specific indoor environment requirements (filtration, humidity control)?
 - are there process and local extract requirements that will require outside air make up?
- built form:
 - deep plan
 - height of space
 - a wish to avoid overheating without using mechanical cooling (such as enhanced thermal coupling to the building structure),

but note that mechanical cooling may be more energy-efficient.

as meeting rooms) and areas used purely for circulation, (corridors and stairwells).

0.4.3 Is cooling needed?

This decision is influenced by:

- the activities served:
 - are there specific indoor environment requirements?
 - are there high internal heat gains?
- client requirements (such as higher rental value)
- climate
- envelope design
- the design criteria for limiting summertime temperatures.

In cellular offices, internal and solar heat gains can be large so that, even in winter, some offices may require cooling whilst others require heating. The HVAC system must be able to cope with this, but simultaneous heating and cooling within a single cellular office must be prevented. It is common practice to specify internal heat gains from people and office equipment in terms of W/m^2 of floor area. Such allowances are based on average gains taken over the whole office floor area and may not be appropriate for small cellular offices. Corner offices can be subjected to particularly high solar gains at certain times of the day but at other times may have very light cooling loads. In winter, 'cold radiation' and cold draughts from large areas of glazing need to be taken into account; it may be necessary to provide supplementary low level heating depending on the U -value of the glazing and infiltration rate. The HVAC system must therefore have a large and controllable turndown ratio.

0.5 Specific activities and building types

Considerations for specific activities and building types are given below. The applications considered are as follows:

- offices (0.5.1)
- dealing rooms (0.5.2)
- supermarkets and food stores (0.5.3)
- shops and general retail premises (0.5.4)
- commercial kitchens (0.5.5)
- hotels (0.5.6)
- schools (0.5.7)
- places of assembly (0.5.8)
- dwellings (0.5.10)
- hospitals (0.5.10)
- healthcare buildings: non-surgical (0.5.11)
- sports centres (0.5.12)
- swimming pools (0.5.13)
- data centres (0.5.14)
- factories and workshops (0.5.15)
- cleanrooms (0.5.16)
- animal rooms (0.5.17)
- farms (0.5.18)
- transportation buildings and facilities (0.5.19).

With large open plan offices, the floor area should be zoned so that differences in zonal heating and cooling load density (W/m^2 of floor area) can be identified and catered for in the layout of the HVAC system. Perimeter zones will experience heat losses as well as solar heat gains whilst internal zones will be subject to internal heat gains only. For open plan offices, room air movement will limit any differences in temperature between zones. HVAC grilles and heat emitters can be set out on a uniform grid. Internal open plan spaces may have low calculated steady-state heating loads, but system sizing and operational controls should be such as to provide adequate boost to raise temperatures on cold winter mornings. Simultaneous heating and cooling is unlikely to be required except in very large open plan offices. However, should partitioning or cellular offices be erected at a later date, local under or overheating could occur. Consideration should be given to the layout and duty of heating and cooling unit emitters so that the potential for future partitioning is not unduly compromised.

The ability to incorporate cellular offices within an open plan office is particularly important when designing speculative office buildings.

0.5.1.2 Typical HVAC strategies and systems

Office accommodation may be heated and naturally ventilated, heated and mechanically ventilated or air conditioned (that is, including some form of mechanical cooling such as refrigeration). The heating may be separate to or integrated within the air conditioning system. In addition, some office accommodation may be mixed-mode, whereby natural ventilation is used to prevent overheating of the space when outdoor conditions permit, with the air conditioning operating only during the warmer months of the year.

Natural ventilation

The ability of natural ventilation to achieve satisfactory summer indoor temperatures will depend upon:

- outdoor temperature and humidity in summer
- level of heat gains (solar and internal)
- depth of floor plan.

0.5.1 Offices

0.5.1.1 Principal HVAC servicing issues

This section deals specifically with general office accommodation, which may be of open plan or cellular layout or, often, a mixture of the two. Office buildings also include areas that have special requirements, including areas with very large internal heat gains (such as dealer and server rooms), areas with only occasional occupation (such

Table 0.1 Common types of air conditioning in offices

System	Application	Features
Variable air volume	Relatively complex to design and commission. Space required for ductwork and air handling equipment. Risk of high air leakage	Best for large buildings with extensive internal zones with varying cooling loads. Can also provide heating
Fan-coil	Limited ductwork space needed. Relatively low fan consumption.	Very versatile and 4-pipe versions can provide simultaneous heating and cooling
Chilled ceiling/ passive chilled beam	Limited ductwork space needed. Relatively low fan consumption. Care needed to avoid condensation	Best for spaces without large solar gains due to limited cooling capacity Need separate heating emitters
Active chilled beam	Limited ductwork space needed. Relatively low fan consumption. Care needed to avoid condensation	Can also provide heating
Stand-alone DX room units	Can be used with natural ventilation. Poor humidity control.	Best for individual offices or meeting rooms in shallow-plan buildings Can also provide heating
Variable refrigerant flow	Can be used with natural ventilation. Poor humidity control.	Can serve multiple zones with differing loads, but limits to the number of floors on one system. Can provide simultaneous heating and cooling.

Shallow floor plan offices with moderate heat gains in temperate climates such as the UK are frequently naturally ventilated as outdoor temperatures in summer rarely exceed indoor design temperatures. Openable windows often provide the simplest solution for natural ventilation except where sited close to external sources of noise such as main roads, railways and airports. Purpose-designed vents on the quiet side of the building (or vents incorporating sound attenuation) may be suitable. These may be designed to create a draught through the stack effect so as to overcome the resistance of the air paths. Local air pollution sources, such as road traffic will also affect the location of inlet vents.

Where natural ventilation during occupied hours cannot achieve the required summer indoor design temperature, consideration should be given to the use of night cooling in conjunction with high thermal mass building elements exposed to the room air. Concrete soffits are often utilised. In existing buildings, thermal mass can be added by incorporating phase change materials.

Offices with deep floor plates are unlikely to be suitable for natural ventilation.

For further details see CIBSE AM10: *Natural ventilation in non-domestic buildings* (2005).

Heating in naturally ventilated offices can be provided by installing heat emitters within the space. These may be radiators, natural convectors, radiant panels or fan convectors, or underfloor heating. They should be selected to match the thermal characteristics of the building including radiant and convective heat output, so as to achieve good thermal comfort for the occupants without excessive energy consumption (see sections 1.4.4 and 1.4.7 in Guide B, chapter 1). Where there are large expanses of glazing, or the building is poorly insulated, heat emitters are best located on external walls, preferably below windows, so as to offset cold downdraughts and radiation draughts. However, this may restrict the placing of desks

and workstations. Occupants should be permitted some control over the heat emitters to allow for personal preferences in room temperatures in their immediate vicinity.

Mechanical ventilation

Mechanical ventilation allows the ventilation rate to be controlled. It may be provided by the simple addition of extract fans to an otherwise natural ventilation system, particularly extract vents to supplement stack effect. Such fans may be needed only during the hottest days of the year.

Alternatively, a fully ducted mechanical supply and extract ventilation system may be installed. This will give the advantage of controlling air movement within the occupied zone. In systems without mechanical cooling, the supply air volume will normally be based on the need to limit summer cooling loads, as this will exceed the fresh air ventilation rate required to dilute indoor pollutants.

The volume flow rate required to limit indoor temperatures in summer can be very high due to the small temperature difference between indoors and outdoors. This will result in high fan power. Consideration should therefore be given to variable volume control allowing the fans to be turned down in cooler weather or the system operated in mixed-mode. In buildings with relatively high effective thermal capacity, mechanical ventilation can also be operated to provide cooling through night ventilation. The use of high volume/flow mechanical ventilation or night ventilation does not, however, necessarily result in lower energy consumption than mechanical cooling: much depends on the flow rate and specific fan power of the ventilation system and the energy efficiency ratio of the cooling equipment.

Some forms of displacement ventilation/cooling use a computer room-type floor void for air circulation. Care is needed to maintain airtightness in such systems and to provide supply air at acceptable temperatures.

If the mechanical ventilation system is to operate outside the cooling season, then some form of heating of the supply air will be required and the potential for heat recovery should be investigated. The provision of heat recovery can be a cost-effective way of meeting the increasingly demanding energy performance requirements for buildings. If the heat recovery rate is not controllable (as is the case with plate heat exchangers) a bypass should be provided to allow the mechanical ventilation system to provide 'free' cooling. The supply air may be discharged into the room at close to room temperature and additional space heating provided, as with a naturally ventilated office. Alternatively, the supply air can be heated above room temperature so as to offset the room heat losses. Care needs to be taken in such cases to avoid stratification. Perimeter areas with large glazed areas or poorly insulated fabric may not be suited to this method of heating.

Air conditioning

The most commonly used (but not exclusive) types of air conditioning for offices are shown in Table 0.1.

Bibliography

Guide to Specification (BCO, 2014)

0.5.2 Dealing rooms

0.5.2.1 Principal HVAC servicing issues

HVAC systems for dealing rooms need to provide a high level of reliability, as the system is critical to the proper functioning of the building and the business conducted within it. Consequential losses arising from failure can be very significant in this type of building. Operating hours are longer than in most office environments.

Dealing rooms are characterised by much higher sensible heat gains from IT equipment and latent heat gains from people than those for general office areas, with occupation densities as high as one trading desk per 7 m².

Heat gains are typically in the order of 500 W per trading desk, but can vary between 200 and 1000 W (Pringle Brandon, 1996). Loads are a function of the IT equipment and are subject to technological developments that may also affect load intensity by making equipment more compact. It is important to calculate the required air moisture content as well as its temperature.

0.5.2.2 Typical HVAC strategies and systems

Dealing rooms will normally require air conditioning to deal with the high cooling load. Ceiling mounted system options include fan coils and variable air volume (VAV) systems. However, supplying cooling from above to deal with the heat from the equipment risks creating a large amount of air movement, thereby increasing the risk of draughts unless high induction swirl-type diffusers can be used. An alternative approach is to supply cool air directly to desktop computers through the floor void to remove the heat directly, reducing air movement in the occupied space and the risk of draughts. This approach may be used in conjunction with the fan coil units, VAV system or chilled beams/ceilings to deal with the balance of the load.

Resilience is important. There is a need to minimise disruption, to have high reliability and low maintenance requirements. Systems normally incorporate a high degree of redundancy. Risks associated with pipework and condensate leakage should be minimised.

0.5.3 Supermarkets and food stores

0.5.3.1 Principal HVAC servicing issues

Supermarkets can pose problems with maintaining acceptable levels of comfort in a large open area with varying heating/cooling needs in different zones.

It is customary to group the refrigerated chilled cabinets together for reasons of cost and to thus create an area with a net heat loss for most of the year.

The preference for retailers to have large open-fronted refrigerated display cases means the spillage of cold air can be difficult to control. Retrieving the cold air using low-level ducts is the most effective method of dealing with this effect. The rate of extraction from low level should be agreed with the display case manufacturer, so as not to disrupt the display case air flow.

Most larger supermarkets use 'remote' refrigerated cases, where they are served by central compressor plant and external condensers, and the rejected heat is removed externally. 'Integral' display cases, where the heat is rejected from the case itself, are limited to small installations.

Refrigerated cabinets will be tested to a prescribed range of temperature and humidity, e.g. BS EN ISO 23953-2: *Refrigerated display cabinets. Classification, requirements and test conditions* (BSI, 2005), which must be maintained for the cabinet to operate within range.

Large circulation areas and non-food displays may require minimal heating for most of the year and a requirement for cooling for a large part of the year. This results in the need for zoned or separate air handling plant serving different areas of the sales floor.

Local extract systems should be provided in food preparation and service areas to remove unwanted odours and heat from areas such as bakeries, hot delicatessen areas and fish serveries.

Entrance areas require additional heating, usually by over-door heaters, to offset the increased heat loss due to customer traffic. With the advances in door heater control, this is easier to control locally than was the case in the past. The most energy-efficient building design is to provide an entrance lobby with inner and outer doors.

Checkout areas need particular attention and may be treated as a separate zone due to the fact that the operators will be sedentary for considerable periods.

0.5.3.2 Typical HVAC strategies and systems

The main sales area is usually treated with one or more ducted air handling units. This can take the form of fixed fresh and return air volumes, with the return air coming from all or part of the low level extract from the refrigerated

cases. The fresh air volume should match the volume from the local extracts with an additional amount for pressurisation of the sales floor to limit draughts. The cold air retrieval from the refrigerated cases can be dealt with by separate extract units and distributed directly to other areas of the sales floor with a cooling requirement. Using this method, the size of the main air handling unit can be reduced.

The distribution of the air within the sales area can be achieved with conventional grilles/diffusers where the cold air retrieval has a de-stratifying effect to the space. Supplying air through high velocity grilles into cold aisles should be avoided as the movement of air disturbs the airflow patterns in the refrigerated cases and can cause discomfort for shoppers.

Make-up air to the extract systems can be introduced from the main sales area air handling unit, from local supply systems or from supply canopies. The latter two methods offer a reduction in energy as they only run when the area requires them, and can usually supply at a slightly lower temperature.

For food stores, the type and performance of refrigerated display cases will influence the design of the ventilation and conditioning system in a number of ways:

- display cases may require temperature and humidity levels within the space to be maintained below maximum limits
- heat losses from the space to the display cases
- display cases with integral heat rejection will provide a net heat input to the space
- the performance of display cases is susceptible to draughts from doors and ventilation systems.

Losses from refrigerated display cases can vary significantly, depending on case design. The losses can lead to a 'cold aisle' effect in refrigerated areas of a store. Refrigerated areas commonly require heating throughout the year. One means of reducing this effect is by recovering some of the cold air spilt from the display cases, which may then be used to cool other areas of the store via the ventilation system. Internal draughts into cases from the ventilation system can be avoided by the careful positioning of supply points from the ventilation and air conditioning equipment. The building should be maintained under positive pressure by ensuring that the rate of supply exceeds the rate of extract. Extracts should be positioned in the areas of high heat gain, e.g. lighting displays or hot food counters.

0.5.4 Shops and general retail premises

0.5.4.1 Principal HVAC servicing issues

Retail premises vary considerably in size and function. A shop unit may be used for a wide variety of purposes in the course of its life, meaning that the HVAC systems may need to satisfy conditions that differ markedly from those of the first occupant, and may need to be modified or replaced. The underlying requirement is to provide a comfortable environment within the occupied zone for both customers and staff (who will sometimes have very different levels of clothing). In summer this may entail balancing acceptable

indoor temperatures with the risk of unacceptable temperature differentials between the retail space and the outside circulation space (i.e. outside or covered mall).

Heat gains will be a function of the building and the specific application but will often be characterised by one or more of the following:

- transient occupancy with high peak value
- high solar gains local to large areas of glazed shop front
- high lighting gains for display purposes
- localised equipment loads, e.g. hot food counters.

Minimum fresh air supply is typically lower than that for 'occupiable' rooms, such as offices. Infiltration of air from the outside due to door opening can be a particular concern. The problem may be exacerbated if there are openings on opposite facades of a store encouraging cross-ventilation driven by wind or stack forces (e.g. if opening onto a shopping mall), or by users if the shop operates a 'doors always open' policy.

0.5.4.2 Typical HVAC strategies and systems

Heating, ventilation and air conditioning can be achieved by various methods using centralised or unitary equipment. The choice of plant is governed by the retailer's particular requirements, the availability of external plant space, the size of the retail space and the availability of services supplied by the lessor. Small shops are commonly naturally ventilated and, if necessary, cooled and heated with split air conditioning systems.

Larger, centralised systems can take the form of variable volume or constant volume systems, which may use recirculation or 'free' cooling to provide the volume necessary to enable distribution of conditioned air at an acceptable temperature. Alternatively systems supplying minimum outdoor air supply (or used with natural ventilation) such as unitary cooling, split-DX air conditioning, variable refrigerant flow (VRF) systems or 2- or 4-pipe fan coil units may be used.

It is common for units in larger retail developments to be provided with a chilled water loop for the air conditioning system. This provides users with the flexibility to provide their own heat pumps as necessary to meet their individual requirements. This type of system may also balance well with the diversity of activities undertaken by the occupier, often requiring simultaneous heating and cooling. Water loop heat pump systems can be used to meet such requirements.

Smoke extract from retail units may be installed as separate standalone systems, which act as additional safety ventilation systems, or be incorporated into the general ventilation systems, which serve the retail unit (known as 'dual purpose'). There are three possibilities in smoke extraction design each with a different purpose:

- (a) *Life safety*: systems designed to maintain tenable conditions on escape routes and other occupied areas.
- (b) *Firefighting access/property protection*: systems designed to increase visibility for, and reduce heat

exposure to, trained firefighters. This allows earlier and less hazardous attack on the fire. Such systems will help to reduce property damage by increasing fire brigade effectiveness.

- (c) *Smoke purging*: systems designed to enable smoke to be cleared from a building after a fire has been brought under control.

It is necessary to decide which, or which combination, of these three objectives is to be achieved before commencing a design. BRE Report BR 368 (BRE, 1999) should be consulted, in conjunction with BS 9999: *Code of practice for fire safety in the design, management and use of buildings* (BSI, 2008).

0.5.5 Commercial kitchens

A commercial kitchen is an environment in which food preparation takes place. This includes those in offices, hotels, restaurants and cafés. Many aspects of kitchen ventilation are subject to Local Authority requirements, which should be ascertained before starting design.

0.5.5.1 Principal HVAC servicing issues

Ventilation is the dominant HVAC requirement for commercial kitchens and is required for a number of purposes:

- To introduce sufficient clean, cool air and remove excess hot air in order for the occupants to remain healthy and, to the extent that this is possible, comfortable.
- To provide sufficient air for complete combustion in appliances to limit carbon monoxide production and to dilute and remove combustion products.
- To dilute and remove air contaminants including grease, odours, vapours and steam from the cooking process. Designers should ensure that they are aware of latest revisions to any guidance relating to this issue.

These requirements can result in air change rates of 30 to 100 per hour. More information on the ventilation of kitchens is provided in CIBSE Guide B, chapter 2.

Local ventilation must be kept clean from fat residues to avoid loss of efficiency and minimise the risk of fire.

Often it is not possible to achieve normal comfort conditions in kitchens because of the difficulties of counteracting the heat released from appliances in summer. In winter, make-up supply air can be uncomfortably cold. Under these circumstances care should be taken to ensure that acceptable working conditions are provided.

Heating is required to offset cold fresh air that replaces the extracted air. This is generally provided by a heater battery in the make-up air supply or, for small kitchens, by some local electric heaters or radiators.

0.5.5.2 Typical HVAC strategies and systems

Most HVAC strategies for commercial kitchens rely on mechanical extract ventilation by canopies or ventilated ceilings.

Kitchen extract ductwork

Kitchen extract ductwork presents a particular fire hazard, as combustible deposits such as grease are likely to accumulate on internal surfaces. Therefore, all internal surfaces of the ductwork must be smooth. Where ductwork passes to atmosphere via another fire compartment, fire resistant ductwork must be used. Depending on the daily hours of use, extract ductwork may need cleaning every 3 months and, in any case, at least annually. Access doors for cleaning must be provided at distances not exceeding 3 metres; fire dampers must not be used and the use of volume control dampers and turning vanes is not recommended.

Grease filtration

Grease filtration is essential and can be provided by either washable mesh-type or baffle-type filters. Mesh filters may be used in applications where grease production is low. They comprise a number of layers of galvanised or stainless steel mesh within a steel housing. Grease-laden air is deposited onto the non-corrosive mesh. The performance varies with use and temperature and they may need to be cleaned twice weekly to avoid grease build-up. Mesh filters provide no barrier to flame and therefore should not be used either at low level or in applications where there is a risk of fire.

Baffle filters comprise a number of interlocked vanes that, when assembled, form a two-pass grease removal device. Grease-laden air passes through the filter and, by a series of forced changes in direction and velocity, the grease becomes separated from the air stream and is deposited on vertical vanes from where it is drained-off into a collection drawer that has to be cleaned at regular intervals. The grease drawer must be isolated from the air stream otherwise re-entrainment can occur. The resistance to air flow in a baffle filter is higher than that for mesh filters but the pressure drop remains constant and blades provide a barrier in the event of a flash fire.

Kitchen exhaust fans

Kitchen exhaust fans are normally located at the building roof to avoid duct leakage smells. The discharge is normally vertically, with discharge velocities of about 15 m/s, to prevent nuisance to neighbouring properties. The design of the discharge stack should prevent downdraughts and re-entry of fumes into the building. Air discharged at high velocities can create noise and care is needed not to exceed noise limits imposed by local authorities at the site boundaries.

Replacement air

The provision of the large volumes of replacement air is important whether a canopy or ventilated ceiling extract strategy is adopted. In smaller kitchens sufficient replacement air may be drawn in naturally via ventilation grilles in walls, doors or windows. Provision should be made to prevent pest entry by using a fine mesh in the

opening. However, it may be necessary to compensate for restrictions in the airflow by increasing the size of the grille. If the kitchen is in a sealed area (i.e. not adjacent to dining areas) replacement air should comprise (typically) 85% supplied by mechanical ventilation and 15% by ingress of air from the surrounding areas. This ensures that the kitchen is maintained under a negative pressure to prevent the escape of cooking odours.

Where a non-air conditioned (but properly ventilated) restaurant adjoins the kitchen, the majority of the air may be drawn from the dining area. If the restaurant is air conditioned, air may be drawn from it at a maximum rate of 7 litre/s per person. The difference between the extract and replacement air should be provided by a separate kitchen supply system. Air drawn from adjacent areas should be clean. Avoid drawing make-up air from spaces where smoking is allowed. Where make-up air is drawn via serving hatches or counters it is recommended that air velocities do not exceed 0.25 m/s to avoid complaints of draughts. However, higher velocities may be tolerated or desirable at hot serving counters. The make-up air can be drawn-in through permanent grilles if the serving hatches are small or likely to be closed for long periods. These should be sized on the basis of an air velocity of 1.0–1.5 m/s. The incoming air from the ventilation system needs to be arranged so as not to affect adversely the performance of flues associated with open-flued gas appliances (HSE, 2012).

Recirculation systems

Designers sometimes prefer recirculation systems to extract methods. Where these are installed, regulatory authorities often impose very strict requirements to ensure compliance with the manufacturer's servicing schedule, since there is a high risk of toxic air quality contamination if inadequately maintained. With recirculation systems a complex arrangement of filters, which may include ultraviolet irradiation, electrostatic filtration and agglomeration filters, is located in the extract hood to absorb odours, combustion products, fat and particles. The extract air is then largely recirculated back into the kitchen space. As a consequence, heat and moisture, generated during cooking, is not dissipated from the kitchen and low-level discharge may be permitted by the Local Authority. Separate means are necessary to cool and dehumidify the space. This can result in substantially increased cooling requirements and resulting energy use.

Air inlets

Air inlets from mechanical ventilation supply systems can be positioned to provide cooling air above hot working locations. Extra provision may be required, either by an overhead outlet discharging cool air or by air conditioning. Free-standing fans are not recommended due to health and safety considerations and their effect on the efficiency of the designed ventilation systems. It is often not possible to fully offset heat radiated from hot plates etc. The provision of a degree of personal control can help to provide more acceptable conditions. For example, strategically placed variable geometry and direction air supply terminals, capable of operation by staff, may be provided. Some devices of this type can be fully inverted and provide an alternative horizontal air pattern. They should be robust and simple to operate.

Canopy extract

Air needs to be removed from cooking and subsidiary areas at a constant rate to take away combustion fumes and cooking odours as close to the source as possible. It is advisable that the bulk of extraction from the kitchen is via hoods above gas-fired and all other appliances capable of generating heat, water vapour, fumes and odours. Hoods should be larger than the area occupied by cooking appliances, typically by 250 to 300 mm. Canopies and ductwork need to be constructed from non-combustible materials and fabricated so as not to encourage the accumulations of dirt or grease, nor to allow condensation to drip from the canopy. The ductwork needs suitable access for cleaning and grease filters need to be readily removable for cleaning or replacement.

The amount of air extracted via the canopies should be calculated from the information supplied with the particular appliances, and not based simply on general advice or overall air change rate. Where details of the equipment are known, B&ES (formerly HVCA) specification DW/172 (B&ES, 2005) describes a method whereby each cooking appliance is allocated a thermal convection coefficient, the sum of which enables the total extract volume to be determined. The factor will vary depending on whether the appliance is fired by gas or electricity. Where the ventilation requirements of the individual cooking appliances are not available, an approximate airflow rate can be calculated from the hood face dimensions and the duct or capture velocity required. ACGIH Guide: *Industrial Ventilation: A Manual of Recommended Practice for Design* (ACGIH, 2013) provides suitable advice.

Ventilated ceiling extract

Where ventilated ceilings are used in place of canopies, the ventilation rates should be calculated taking into account room size and function. As a guide, a ventilation rate of not less than 17.5 litre/s per m² of floor area and not less than 30 air changes per hour (ACH) is advisable. A lower air change rate may be needed to avoid discomfort from draughts where the kitchen is divided into separate rooms. B&ES DW/172 recommends that a general ventilation rate of 40 ACH be used in areas of larger kitchens not treated by canopies.

Bibliography

CIBSE TM50: *Energy efficiency in commercial kitchens* (CIBSE, 2009)

0.5.6 Hotels

0.5.6.1 Principal HVAC servicing issues

There are three principal areas within a hotel: guest bedrooms (including en suite bathrooms), public areas and 'back of house' areas, each with different needs.

Guests paying directly for a service are reluctant to accept compromises in temperature, level of service or the quality of the environment that would allow reductions in energy consumption. However, running costs are usually of high importance to the operator and therefore it is important to avoid waste. To achieve this, systems need to be responsive and readily controllable. Means to turn off, or turn down,

systems when they are not required should be provided, but must be straightforward and easily managed by non-technical staff.

The level of service will depend on the type of hotel. Understanding the type and the branding of the hotel is important to choosing an appropriate system. Many hotel operators will have well-developed standard solutions. In the UK, common solutions range from heating with natural ventilation to full air conditioning. Different types of hotels will also have different occupancy rates and this can have a major impact on sizing of central plant and public space systems. A business hotel will have a full occupancy at between 1.1 and 1.3 persons/room, whereas a family or resort hotel will have a much higher occupancy, typically at least 2.0 persons/room. A rate of 2.4 persons/room may not be unreasonable for a busy budget hotel near an airport. Typically, the load patterns have morning and evening peaks.

0.5.6.2 Typical HVAC strategies and systems

Each of the three types of area has different needs and is serviced in a different manner. The diversities applied to central plant can therefore be quite high and the likely peak loads need to be carefully considered. A spreadsheet showing the combined load at hourly intervals is an effective way of reviewing how the different loads interact and can be used in design discussions with the client. It can also be used as the first step in analysing the potential for a combined heat and power (CHP) approach. Hotels, particularly those with swimming pools, are usually good candidates for CHP.

Guest bedrooms

Guest bedrooms in an air conditioned hotel often employ a 4-pipe fan coil unit, often located above the entrance lobby. The unit should be sized to allow a rapid and individual response to each room. Other common solutions are water loop heat pumps and variable refrigerant flow (VRF) systems. These have the advantage of using less riser space but may require more maintenance. Care must also be taken with refrigerant systems to ensure that the effects of a refrigerant gas leak can be dealt with safely (BS EN 378, Parts 1-4).

Controls should be simple to understand and to operate. Acceptable noise levels can also be an issue and need to be agreed with the client. Care should be taken not to oversize the system while ensuring that it remains responsive. The peak solar load is unlikely to coincide with the peak internal loads. Depending on occupancy, a peak room cooling load between 1.5 and 2.0 kW will normally be adequate for the UK. Some hotels choose to limit the energy consumption of the bedroom systems by the use of occupancy detectors, key fobs or central booking systems. These can be used to turn off electrical systems and turn down the air conditioning when guests are not in their rooms. This has been shown to make significant energy savings but care needs to be taken to ensure that guest comfort levels are not affected and that critical loads such as the minibar (if present) are not isolated.

Bathroom extract ventilation should comply with Building Regulations, but many hotels use higher values that may ensure a fresh air supply for two occupants in the room. At these higher rates, tempered air is usually supplied directly

to the room or to the fan coil unit within the room to avoid large gaps under doors or external air grilles. The supply location needs to be positioned to reduce the likelihood of draughts over the bed and in areas that may be used by the occupants when walking to and from the bathroom. The fresh air supply should be designed to take account of the fact that many UK guests will turn the air conditioning off before going to sleep and this should not, ideally, limit the incoming fresh air. It is common to keep the bedroom supply and bathroom extract systems running continuously to maintain room air quality and to ensure adequate extract from the bathroom at unusual hours. Noise levels are therefore important. Budget hotels often rely on natural ventilation, primarily through opening windows. Opening stays are usually incorporated for safety and to reduce risk from intruders, especially at ground floor level.

In guest bedrooms that are naturally ventilated and not cooled, radiators served by LTHW are most common, with direct electric panel heaters used where very low heat losses exist.

Public areas

Public areas such as reception, conference rooms, bar and restaurant areas are generally characterised by high, but variable, occupancy levels and lighting loads. The system will need to be responsive and capable of delivering high quantities of fresh air when required to do so. This will often suggest all-air systems but these need to be carefully zoned to allow individual control of spaces. Where possible, separate systems for the different areas are ideal, but multi-zone systems are also used and these are sometimes supplemented with fan coil units to provide more individual control. Constant volume systems with reheat are occasionally used but can be wasteful of energy. VAV systems are also used but should be treated with care to ensure that adequate fresh air is delivered to the space under all conditions. The design of the systems for the public areas will need to achieve ventilation rates imposed by licensing regulations. The level of occupancy to which the hotel wishes to be licensed should be agreed with the client at an early stage. These figures should be confirmed at an early stage as the operator may wish to have the hotel licensed for high densities.

Underfloor heating may be appropriate for spaces that are not air conditioned.

'Back of house' areas

'Back of house' areas for staff will require a variety of systems to suit their different uses. Typically, these areas will include managers' offices, kitchens, laundries or linen handling, staff changing, staff dining, training, IT and computer rooms. Reference should be made to the guidance given for kitchens (section 0.5.5, above) and computer rooms (section 0.5.14, below).

The general office areas will normally be treated to the same level as the public spaces, (i.e. for an air conditioned hotel they will be air conditioned). Some hotels believe in extending this to cover further areas, such as the staff dining rooms, and this needs to be clarified with the client as early as possible. It is common for the kitchens to be cooled, at least in part, so that salads, pastries and deserts can be well presented. Many hotels contract-out their laundry, but linen-handling space will still be needed.

These areas require high air change rates to remove the high levels of dust and lint that will be generated during sorting.

Increasingly, hotels have sophisticated billing and IT and audio-visual systems and therefore the computer room housing the central IT equipment and audio-visual rooms must be properly conditioned, usually independently of the main system.

0.5.7 Schools

0.5.7.1 Principal HVAC servicing issues

This section is based on CIBSE TM57: *Integrated school design* (2015), which outlines a design hierarchy and an iterative and progressive approach to the school design process, and introduces the key determinants of effective HVAC and other aspects of indoor environmental design:

- Schools are seasonal buildings and should be designed and procured as such with flexibility for extra-curricular activities without compromising energy performance.
- Schools often do not have the resources or budget to run complex HVAC systems with high operational costs; therefore integration of passive design with simpler HVAC strategies is preferable option.
- Acoustics, daylighting, ventilation to mitigate CO₂ levels and the risk of overheating are all key factors for teaching/learning spaces.

The servicing strategy will be developed around these requirements. A key requirement of a successful school design process is the need for an 'informed client' who is aware of the relationship between aspects of building services design and the likely outcome for the teaching environment in the proposed school. The Commission for Architecture and the Built Environment (CABE) developed a document entitled *Successful school design: questions to ask* (CABE, 2009). It provides an ideal source of questions for an informed client and is also a valuable checklist for designers.

Early consideration of acoustics design, which is directly a function of architectural design and surface material selection, is essential since this can avoid expensive remedial works. The following are key acoustic design issues in modern schools:

- sound insulation between spaces can be compromised by crosstalk via ventilation ducts
- use of indirect natural ventilation routes (e.g. classroom to circulation area to classroom) is often compromised by noise generation in the circulation area
- noise generated from MVHR systems.

In theory, open plan design is often proposed as a flexible alternative to separate teaching spaces, making more effective use of space and allowing different groups to interact. In practice, open plan designs can create poor acoustic environments. BB93 (EFA, 2014) provides further details.

In the winter (heating) season the ventilation system is designed to meet air quality requirements while minimizing ventilation heat loss whereas in the summer (cooling) season the ventilation system is designed to reduce the risk of overheating. Accordingly, a much higher airflow rate is required in the summer than in the winter. CIBSE TM57 outlines a wide range of mechanical, natural, or mixed mode ventilation strategies used in schools and indicates how conflicts arise from competing acoustic, lighting and ventilation design aspirations. Three natural ventilation strategies are favoured:

- single sided ventilation using louvre windows with perimeter heating
- mid-façade centre pivot windows with perimeter heating
- cross ventilation, preferably with high levels windows on opposite façades.

Mechanical ventilation is often a source of poor indoor air quality in schools: filters should be changed regularly; horizontal duct work is a dust trap and so should be cleaned frequently; ventilation grilles and diffusers should be vacuumed as often as possible.

CIBSE TM57 identifies 'performance in use' HVAC issues in modern schools, which are described below.

School buildings have to be inherently flexible, to reflect the fluctuations of school operating hours or the use of the building by the community outside of the core school period. Only the zones directly affected by the additional occupancy should be operational during the extended hours, reducing unnecessary energy usage in other zones.

From a heating perspective there are needs for:

- good control of heat output to ensure fast response to change in load (e.g. an underfloor heating may not have adequate response time)
- avoidance of draughts from natural ventilation inlets in winter
- tamper-proof heating controls.

Where a centralised system is used – commonly a centralised heating plant with zoned distribution – it is important to provide that the operation of circulation pumps and the boiler remain efficient at low loads.

A great deal of energy can be wasted overnight, in half-term breaks and during school holidays so adequate time control should be provided. A BMS will most likely be required and can significantly improve both the performance of the building and its controllability. The specification, however, must be appropriate to the scale of the building and the ability of the operators to use the system. As with other types of building, the operation of the school will not be under the direct control of the building services engineering designer but rather the facilities manager. The designer should limit the number of points to control and reduce the complexity. The BMS should offer at least the following heating system controls:

- optimum start/stop
- automatic frost protection
- zoning, allow use out of hours

- simple overrides for occasional extended hours or for holiday mode
- local thermostatic control with limited adjustment afforded to users
- weather compensation should be used where the boiler plant capacity exceeds 100 kW and may also be usefully applied to smaller heating zones, e.g. to allow for aspect zoning.

ICT equipment along with the support IT infrastructure, provided in the form of server and data hub rooms, constitute a large part of buildings' energy consumption in modern secondary schools and academies and may require cooling.

0.5.7.2 Typical HVAC strategies and systems

The most common strategy for classrooms has been the combination of natural ventilation and LPHW heating systems serving either radiators or underfloor heating, with local cooling for spaces with unavoidably high heat gains such as ICT rooms. This strategy requires a quiet outdoor environment and windows that provide adequate security.

The introduction of demanding energy requirements and concern that recommended ventilation rates are not being achieved in practice has led to an increased use of mechanical ventilation with heat recovery.

Hybrid systems that use mechanical extract combined with make-up air drawn through the façade are also used. In these systems the use of specially designed radiators or convectors with facility for make-up ventilation air to be pre-heated before delivery into space is paramount to avoid draughts in winter.

Special educational needs (SEN) schools or schools with specialist rooms, such as for hearing-impaired pupils, may need to be mechanically ventilated with heat recovery to ensure the safety of pupils and meet the more stringent indoor environmental design targets.

The high number of occupants means a low level of satisfaction. Control of the HVAC should be restricted to the teacher and a clear description of the HVAC strategies should be passed to the school's adult occupants through the handover and 'soft landings' (see www.bsria.co.uk) approach.

Low carbon requirements for schools have also resulted in an increased use of biomass, solar water heating and heat pumps (sometimes linked to the use of these facilities to support teaching).

0.5.8 Places of assembly

There are many types and sizes of places of assembly ranging from large auditoria and places of worship to smaller, more intimate performance spaces and meeting areas. The importance of each of the servicing issues and the choice of systems differs with the context.

0.5.8.1 Principal HVAC servicing issues

Assembly halls and auditoria (e.g. theatres, concert halls, conference centres, places of worship) are generally characterised by large but variable occupancy levels, relatively high floor to ceiling heights, sedentary occupation, and stringent acoustic requirements. Performance and rehearsal spaces for high-energy activities such as dance will generate correspondingly high loads.

There are a large number of specific issues that need to be addressed:

- Flexibility of the space being served and if the seating is fixed or removable.
- Acoustic control measures, including: plant location, vibration, noise break-out, fan noise, silencers, flexible connections, duct linings, noise regeneration at terminals.
- Integration of relatively large air handling plant and distribution ductwork and air terminal device selection, integration with seats.
- Occupancy patterns and part load operation.
- Zoning of the plant and air distribution (especially for large auditoria).
- Separate consideration of the needs of the auditorium and stage ventilation and cooling and lighting heat gains.
- Cooling and ventilation to control rooms etc.
- Temperature control at rear of auditorium due to reduced height.
- Background and out-of-hours heating.
- Avoidance of stratification of warm air in heating mode, e.g. by the use of de-stratification fans or variable geometry diffusers to blow air to low level for space heating and to blow air horizontally for cooling.
- Pre-occupancy boosting to raise or lower temperature ready for occupancy.
- Variability of fresh air ventilation rate for control of air quality and relative humidity.

0.5.8.2 Typical HVAC strategies and systems

Mechanical ventilation is common, though some spaces, such as places of worship, are often serviced by natural ventilation and heating. In the case of mechanical ventilation, heating and cooling is generally combined with the supply of ventilation air, subject to the supply air temperatures being acceptable to provide comfort. A natural ventilation strategy in places of assembly is typically implemented with air supply by attenuated inlet builders' work ducts at low level. Extract is by attenuated outlets at high level, relying on stack effect to ventilate and cool the area. This approach has potentially the lowest running costs but may require a number of provisions to ensure adequate airflow rate and to limit peak temperatures in summer. Particular considerations include providing suitable air paths, inlets and exhaust positions, solar protection, mass exposure and night cooling.

This may be provided by direct gas fired heaters and direct expansion (DX) cooling incorporated into the ventilation

plant. Terminal heater batteries may be required for zone control.

In refurbishing existing buildings, space and/or cost constraints can prevent all HVAC equipment being located remote from the conditioned space. To avoid the system noise level exceeding what is acceptable for some individual performances, precooling by fan coil units or similar terminals before performances and during intervals may be combined with continuous ventilation supply and extract.

Cinemas

Cinemas commonly use direct expansion heating and cooling in an air handling unit supplying air via a diffuser located under the screen. Supply air is directed diagonally upwards to a level above the rearmost of seats. Variable airflow and free cooling can be provided for energy efficiency.

Theatres and concert halls with raked seating

Theatres and concert halls with raked seating commonly use mechanical ventilation. Air is often supplied via a plenum beneath the seating with air being extracted at high level and returned to the central plant, either for heat recovery or exhausted to atmosphere. Displacement-type room air distribution strategies are often used. The advantages are that only the occupied zone is conditioned, not the entire space, and the potential for 'free' cooling is maximised as supply air temperatures are usually relatively high. Air volumes and energy consumption are usually lower than with high-level supply, although central plant sizes are normally similar. If it is impracticable or prohibitively expensive to provide under-seat plenums, high-level supply can be used. Computational fluid dynamics (CFD) modelling has been used to support air distribution design of large theatres.

Large flexible-use spaces

Large flexible-use spaces are usually serviced by mechanical ventilation with high-level supply and extract. In such spaces seating is usually removable, and it is not feasible to provide under-seat plenums.

Places of worship

Places of worship tend to be serviced with low cost, simple solutions providing heating only using LTHW underfloor heating with radiant spot heating (electric) or storage electric heaters or, possibly, gas-fired convectors providing warm air at low level to avoid stratification. Occupancy times are often relatively short so the impact of building thermal capacity on warm-up times can be particularly important. Underfloor heating, for example, may provide effective background heating but may require a longer warm-up period. Typically, spaces are high so temperature stratification can be significant and older buildings may have high infiltration rates. There are also likely to be significant aesthetic considerations.

0.5.9 Dwellings

0.5.9.1 Principal HVAC servicing issues

Dwellings require heating, hot water services and ventilation for comfort and health. Strategies are also necessary to reduce the risk of summertime overheating, particularly in modern well-insulated dwellings.

Households are known to differ widely in their use of heating systems from highly intermittent use (with short periods of high demand that can significantly exceed the steady-state heat loss) to continuous heating. The most common pattern for central heating is for two heating periods per day, but any system is likely to have different owners during its life.

Ventilation is required principally for:

- *Control of condensation:* arising from moisture, mainly generated by cooking, washing and clothes drying. The practice of drying clothes indoors can give rise to high humidity in any room. Moisture is often the dominant pollutant. The key to avoiding mould problems is to avoid a situation where the relative humidity exceeds 70% for a prolonged period, and to avoid cold bridges where surface temperatures are likely to fall below 18 °C.
- *Removal of allergens:* arising from dust mites, odours and pollutants such as volatile organic compounds (VOCs).

High rise dwellings (and other high rise buildings) impose special requirements on ventilation equipment because of the high winds to which they are exposed, and on piped water systems because of the high water pressures when a single system serves a large number of floors.

0.5.9.2 Typical HVAC strategies and systems

The term 'dwellings' applies to a wide range of building types, some of which have more similarity to non-domestic buildings than to 'traditional' housing. While the principles noted above apply generally, the general guidance below needs to be interpreted in the light of specific designs – especially for large mansions or small studio apartments.

Heating has traditionally been provided by low temperature, low pressure hydronic systems, though warm-air systems and individual room heaters can also provide a satisfactory service. The most common source of heat remains a gas boiler, either with a storage cylinder for hot water provision or, often, a combination boiler that can also provide an instantaneous hot water service. New gas boilers are required to be condensing boilers. Lower-carbon heat sources such as heat pumps are becoming more common, as is solar preheating for hot water services. Emitter sizing and controls to maintain emitter temperatures at as low a temperature as is compatible with the heat needs of spaces is desirable to maintain the efficiency of condensing boilers and heat pumps. Low emitter temperatures can be achieved through the use of floor heating or suitably sized radiators or convectors, or by employing weather-compensating water temperature control.

Individual heating systems for each dwelling are commonly provided, but communal heating, either for individual

blocks of multi-family housing or from district heating can offer advantages, especially when combined with CHP or renewable or waste energy sources. Further guidance can be found in CIBSE AM12: *Combined heat and power for buildings*.

Ventilation may be provided in several ways, all of which require careful design:

- *Natural ventilation with mechanical extract*: a common strategy has been to extract directly at source from wet zones using intermittent mechanical extract ventilation (local or whole-house) or passive stacks. Fresh supply air is brought into the living rooms and bedrooms by natural ventilation methods or induced by the negative pressure.
- *Passive stack ventilation*: a passive stack system comprises vents located in the kitchen and bathroom connected via individual near-vertical circular or rectangular ducts to ridge or tile terminals. Moist air is drawn up through the ducts by a combination of stack and wind effects.
- *Mechanical supply ventilation*: a fan unit is typically mounted in the roof space and delivers air that has been filtered and tempered by the roof space into the dwelling. The system works on the principle of continuous dilution, displacement and replacement of air in the dwelling. Air discharge from the dwelling is via purpose provided egress vents and/or leakage paths.
- *Whole-house (and local) mechanical ventilation with heat recovery (MVHR)*: this incorporates separate mechanical supply and extract networks coupled with a heat recovery unit in which waste heat from the exhaust stream is used to preheat the supply air. This approach is becoming increasingly used in new housing to meet energy efficiency targets. This system may be the only HVAC system in some integrated designs. In some cases individual room, wall mounted systems may be used instead of whole house ducted systems.

In addition to provision for minimum ventilation rates, capacity for more rapid extraction in response to moisture release within the dwelling is necessary. Humidity sensors, timer controls and even CO₂ monitors can be considered for meeting transient ventilation needs.

Balanced flue combustion appliances, which do not allow the possibility of flue gases being released into the room, are preferred for all dwellings but especially those fitted with mechanical ventilation incorporating extraction, which may generate local pressure differences.

0.5.10 Hospitals

0.5.10.1 Principal HVAC servicing issues

Hospitals and healthcare buildings can contain many types of spaces, some of which have very specific HVAC requirements. The wellbeing of patients is paramount, along with the comfort of the staff attending to them. The HVAC services should be designed in a manner to assist the treatment and recovery processes insofar as is possible. Guidance for UK hospitals is available from various sources (see section 0.5.10.3 below); regional, national and

international standards are also available, depending upon where the hospital is to be built.

All patient areas in a hospital may be regarded as infection critical and stringent requirements exist to prevent cross contamination. Odour dilution is also an important consideration.

Care is required in locating extract from isolation rooms to avoid the possibility of recirculation back into the building. In exceptional cases filters may be needed on exhaust systems.

0.5.10.2 Typical HVAC strategies and systems

In an acute hospital it is common in the UK for many areas to be entirely or partially naturally ventilated. Whilst natural ventilation is desirable, the temperature limits of HTM 03-01 (DoH, 2007) cannot generally be met by natural ventilation alone, and some form of peak temperature topping is usually required.

Mechanical ventilation systems should be of the all-fresh-air type to minimise risk of infection. In areas such as non-invasive imaging, equipment rooms and staff areas, local systems may be required, with heat recovery effected by a means where cross-contamination of airstreams cannot occur. The ease of cleaning ductwork systems is important and they should be provided with sufficient access points to ensure that adequate cleaning can be undertaken. Air terminals should be selected with ease of cleaning as a primary consideration. Relevant NHS standards for duct cleaning should be adhered to.

It is a general requirement for healthcare buildings that the building has an overall positive or neutral pressure and the extracted air replaced by treated make-up air supplied to, for example, internal areas, staff base, etc. in ward areas. Air handling plant for all medical areas should be of the 'blow-through' type with only the frost coil and pre-filter upstream of the fan to ensure that there is no inward leakage of air downstream of the coils and main filter. Ventilation systems should be fully ducted so that, if contamination occurs, only the affected rooms and associated ductwork will require cleansing. With a return air ceiling plenum, access to the void above the room would be necessary for cleaning. Condense drip trays below cooling coils should be readily accessible and removable for cleaning purposes. Services should, where possible, be located in corridor ceiling voids to minimise access requirements in clinical areas.

Each operating theatre suite should ideally be provided with its own plant but it may be acceptable to have a zoned common air handling unit serving two adjacent suites. If common air handling plant is provided for an entire operating department, a plant failure or maintenance shutdown will render the whole department inoperative. Also, it means that it would be uneconomic to operate a single theatre for emergency or maternity use out of normal hours. Special considerations are needed for infection control and operating theatres. Reference should be made to HTM-03-01 (DoH, 2007).

Certain areas have ventilation requirements that will involve specialist expertise. These include audiology rooms, where extremely low background noise levels must be achieved, and aseptic suites where low particle counts are necessary. Isolation rooms are intended to protect

patients from catching or spreading infection. Specialist guidance is available on how these rooms should be ventilated, via a protected positively pressurised lobby with extract via the en suite bathroom. The older practice of switchable 'positive and negative pressure rooms' has been found unsatisfactory.

It should not be assumed that humidification is required in all areas. The avoidance of infection and, in particular, *Legionellae* is of paramount importance, especially as many patients will have limited resistance. Humidifying of the supply air is by steam injection from plant steam if available is usually the preferred option.

There are a number of special considerations for heat emitters, notably cleanliness, deep clean requirements, the vulnerability to damage, risks posed by sharp edges and surface temperature. As a result either ceiling mounted radiant panels or low surface temperature radiators that can be deep cleaned inside and outside are usually installed in wards and general circulation/other spaces. Underfloor heating is an increasingly popular choice, especially as the low grade heat required can be provided by ground source heat pumps.

Where areas are mechanically ventilated or air conditioned the heating is usually integrated with the air conditioning units, e.g. by using active chilled beams. These should be positioned directly above and parallel to the beds in wards to avoid any possibility of drafts. They should be of the type manufactured expressly for hospitals so they can be readily cleaned. Fan coil units and split units are very difficult to clean properly and, in most cases, should only be considered as a last resort in any hospital area where clinical procedures take place, invasive or otherwise. For non-clinical areas, or mental health type environments they can be considered. Whenever the chosen HVAC solution differs from the requirements of the Healthcare Technical Memoranda (HTM) documentation derogation must be sought from the client confirming that such an approach is acceptable.

0.5.10.3 Bibliography

Note that most of the following sources only apply to the UK, and in some cases only to England:

- HTM 03-01: *Heating and ventilation systems*
- HTM 07-02: *Making energy work in healthcare*
- HTM 07-07: *Sustainable health and social care buildings*
- HTM 01: *Decontamination* (various parts)
- HTM 04: *Water systems* (various parts)
- HTM 05: *Fire safety* (various parts)
- HTM 07: *Environment and sustainability* (various parts)
- HTM 08: *Specialist services* (various parts)
- *Heatwave Plan for England 2014* (PHE, 2014)
- HBN 00-09: *Infection control in the built environment* (DoH, 2013b)
- *NHS Saving carbon and improving health* (NHS SDU, 2009)

- *Guidelines on the facilities required for minor surgical procedures and minimal access interventions* (Humphries et al., 2012)
- Model Engineering Specification C04: *Mechanical ventilation and air conditioning systems* (NHS, 1997)

0.5.11 Healthcare buildings: non-surgical

A significant proportion of the national healthcare estate is intended for the care and treatment of patients who do not require invasive procedures. Examples include mental health buildings, elderly and dementia care, residential care and primary care.

Broadly speaking, for the patient areas in residential buildings, a key aim is to provide a high degree of domesticity to the space, and this should be reflected in the design of the mechanical services. It should be noted that the limiting temperature criteria of HTM 03-01 (DoH, 2007) are likely to be applied, and since the document was aimed at the acute healthcare environment a degree of interpretation will need to be applied.

Note that NHS Trusts vary on what they will accept and as such need to be closely consulted during the design process.

All of the building types described below will have meeting areas, offices etc. for staff. Since these are non-clinical and covered elsewhere they are not considered here.

0.5.11.1 Mental health buildings

Forensic mental health premises pose specific challenges. These are hospitals where the patients are admitted under mental health legislation, and are perceived to pose a risk to themselves and in some instances others. The building(s) may require a secure boundary and other extensive security features.

Principal HVAC servicing issues

There are 'low', 'medium' and 'high' security categories for mental health buildings, but the heating and ventilation requirements are similar. Limiting the risk of self-harm, insofar as is possible, is essential and the design of the building will also take into account the minimisation of risks to staff. All exposed services, controls, sockets etc. will be required to be of a low/zero ligature-risk type and will need to be able to withstand destructive testing (the NHS has internal guidelines and will carry out the tests on-site in a mock-up). The mechanical building services for non-secure mental health facilities share many characteristics with those for secure hospitals, the key differences being concerned with security issues. In terms of heating and ventilation/comfort cooling the choice of method and distribution will usually be similar.

Day areas in these buildings will need to meet HTM temperature criteria, but in rooms where the patients are under supervision certain restrictions on access may be relaxed; this will need to be agreed with the individual Trust.

Typical HVAC strategies and systems

Underfloor heating is a preferred option in rooms where a slow response time is acceptable, e.g. bedrooms and day areas. Underfloor heating may not be feasible in rooms where furniture has to be fixed to the floor, in which case other intrinsically safe low ligature-risk options need to be considered, such as all-air or ceiling radiant panels. Alternatives may be low ligature-risk, low surface temperature radiators or ceiling radiant panels, but note the limitations on access described below. Low-ligature risk, low surface temperature radiators may also be considered if the risks of damage to the building or self-harm are perceived to be lower, but all such decisions need to be made with the full acceptance of the Trust concerned. Where a rapid response is needed, such as de-escalation rooms, a fan coil system is a possibility, but the fan coils will need to be located outside the room itself for access reasons.

In all areas where patients are left unattended ceiling access will not be possible. All high level services requiring access will need to be routed via corridors, and vertical distribution is much the better option when possible. Access to risers will also need to be from corridors and the building design should permit such access without affecting the use of the corridors. A large multi-service riser per pair of bedrooms, with sufficient space for working within, is a common solution. If it is possible for access to plant areas to be outside of the secure boundary this will greatly assist maintenance staff. It may be necessary to install security bars in large diameter ducts that penetrate the secure boundary.

It is likely that some form of peak temperature lopping will be required to meet HTM criteria. This is largely due to the necessary limits on the extent of window opening and the security measures required. This can be provided from central air handling plant ducted to the rooms and supplied via low ligature risk diffusers. Patients should preferably be given individual room temperature control with a control band, via purpose made robust wall controllers.

0.5.11.2 Dementia care

Increasingly common, these buildings strive for a domestic feel for the comfort of the residents and their family and friends. They are often built outside of direct NHS control and as such the requirements of the various Health Technical Memoranda and Health Building Notes may not always be applied. The design of the rooms, corridors and day areas will be such that memory can be triggered, and they become 'home' for those in care.

Principal HVAC servicing issues

Self-harm will probably not be a major concern, but it is still important that heating surfaces are intrinsically safe from high temperatures. Day areas will also need to be viewed as large domestic spaces, and careful design with access to outside spaces may negate the risk of overheating and hence the need for cooling.

Typical HVAC strategies and systems

Low surface temperature radiators are an option, and underfloor heating is also used, especially as it can make good use of low-grade hot water as supplied by ground

source heat pumps. Individual room control should be provided. Mechanical cooling is unlikely to be required in most areas, although this should be agreed with the Trust/care-provider.

0.5.11.3 Elderly care and residential care*Principal servicing issues*

In terms of mechanical services these facilities will share the requirements of dementia care buildings, noting that the occupants are often in good health, and simply want the comfort of knowing that help is close at hand if needed. Certain buildings, or areas within buildings, may be used for those patients who require greater clinical care, and these rooms bear a similarity with single bed hospital wards. This will need to be discussed and agreed with the Trust or care provider concerned. Should this be the case then the notes elsewhere in this section on hospital ward accommodation provide guidance as to how to proceed.

Typical HVAC strategies and systems

The solutions applied to domestic dwellings are generally appropriate.

0.5.11.4 Primary care

Primary care and general practice 'centres' are being built to meet the increasing needs for patients with non-urgent problems, in order to decrease pressure on hospital accident and emergency departments. In most cases the facilities will consist of waiting areas, consulting rooms, minor procedure and possibly low level imaging areas. The existing HTM documentation provides adequate information regarding design criteria.

Principal HVAC servicing issues

Comfort cooling or peak lopping may be required in some areas.

Typical HVAC strategies and systems

Where cooling is needed, all-air systems are preferable to fan coils, but there may be no alternative to the latter, especially for retrofits.

0.5.12 Sports centres**0.5.12.1 General**

This section deals with indoor sports facilities commonly used by the general public and schools. It does not consider venues that have large audiences such as arenas and stadia. Nor does it consider spaces where required indoor conditions are largely determined by factors other than thermal comfort, such as ice or curling rinks. Swimming pools are dealt with in section 0.5.13.

Sports facilities can include varying ranges of indoor and outdoor, multi-purpose or single-function spaces, each of which has its own needs. For example, larger centres might devote considerably more space to fitness training, often combined with an exercise studio, integral office/reception, cubicle changing, sauna, spa pool and lounge.

Principal HVAC servicing issues

HVAC systems need to provide adequate temperature control and ventilation to deal with a range of activities and occupancy levels, both of which can change rapidly. Heat and moisture gains from strenuous activities can be high, but lower-intensity activities, possibly requiring low background noise levels, are also likely. The system and controls should therefore be capable of wide variation and have the capacity to react swiftly. Humidity control is not essential provided good fresh air rates and, where necessary, comfort cooling is provided. The way that sports halls are used makes them particularly suitable for occupancy sensors or presence detectors to control heating, lighting and/or ventilation systems automatically. Consideration should be given to providing separate controls for heating and ventilation so that the space can be maintained at a comfortable temperature ready for use, and the ventilation is linked to occupancy and air quality. Nevertheless, ventilation heat recovery (with summer bypass if variable recovery rates are not possible) can often be justified by the high ventilation rates sometimes required during occupancy. In practice, sports halls may often require low levels of heating but benefit from systems that have fast response times in order to be adaptable to the needs of different user groups.

If the facility is to be used for public entertainment, the relative importance of the needs of players and watchers needs to be considered. It is not uncommon for larger spaces to be used for non-sporting activities and this should be borne in mind.

Unlike other building types, sports halls generally need to exclude solar penetration to avoid glare. Hence they are less able to benefit from solar gain as a contributor to energy efficiency. However, summer overheating can still occur due to the relatively low indoor air temperatures required for most activities.

The capital and operating costs of HVAC systems are particularly important. Heating, lighting and ventilation services can account for a significant proportion of construction costs. Energy is often the next largest item to staff cost.

0.5.12.2 Multi-purpose sports halls

Typical HVAC strategies and systems

Where a sports hall is part of a larger centre, the choice of system may be influenced by the needs of other areas. Even in the smallest project there are likely to be changing rooms and entrances that will need to be heated and ventilated and might be integrated with the hall system and give scope for shared fuel source and plant room space. Sports halls commonly have either radiant heating ceiling panels plus ventilation or combined ducted heating and ventilation systems.

Radiant heating systems should not be too close to netting and sports use within the hall. However they result in lower air temperatures, reduce stratification and provide fast response times.

High-level extract fans in the roof or walls together with appropriate means of outside air supply can often be used as a separate ventilation system and can be effective, subject to

air velocities not affecting shuttlescocks and large volumes of cold air causing high heating loads or discomfort. The noise caused by wind acting on the external damper can also be an issue.

Natural ventilation systems such as ventilation towers that utilise wind energy can also be considered. However, these will need some form of supplementary system to deal with warm windless days and some means of tempering the cold incoming air during cold winter periods. The risk of unwanted air movements needs also to be considered.

Ducted warm air systems have generally been seen as the preferred method of integrating heating and ventilation. They can give a good degree of control of air quality throughout the year and achieve good distribution and efficiency. In some instances fan convectors and unit heaters with outside air provision can provide a limited amount of ventilation, but this is generally not very substantial or effective.

Underfloor heating is sometimes used, in which case conflict with floor socket positions (including future installations) needs careful consideration. The response time to cope with varying programme needs to be considered. The thermal stability and performance of floors with under floor heating systems is discussed in Sport England design guidance note *Floors for indoor Sports* (Sport England, 2007).

Built-in local fan convectors are also seen in many older facilities.

Bibliography

Sports Halls Design & Layouts: Updated & Combined Guidance (Sport England, 2012)

0.5.12.3 Fitness suites and weight training facilities

Principal HVAC servicing issues

Effective ventilation is usually the most critical factor because of the metabolic heat gains, body odour and humidity that can rapidly occur in such spaces.

Typical HVAC strategies and systems

Mechanical ventilation or air-conditioning is usually required. Comfort cooling will be essential in many cases as heat gain is likely to be significant and strict temperature control is needed. The controls must be capable of wide variation and have the capacity to react swiftly.

0.5.12.4 Squash courts

Principal HVAC servicing issues

Squash courts should be well ventilated to keep walls free from condensation and remove the players' body heat, which can be considerable. Incoming air must not be drawn from changing rooms, bar areas, showers or any other parts of the building with high humidity levels.

Typical HVAC strategies and systems

In general, each court should have an extract fan centrally placed at high level. Fresh air can be drawn in through airbricks behind the playboard. This should be perforated to provide 10% free area. Extract fans should over-run for 15 minutes after the courts have been vacated to ensure that all stale air has been removed. Fans should be linked to the court lighting circuit where practicable. The rate of ventilation in the spectator gallery may have to be based on maximum occupancy.

0.5.12.5 Changing rooms*Principal HVAC servicing issues*

Changing rooms normally require a mechanical supply (which can also provide heating) and extract system in larger facilities. The high fresh air requirement offers the opportunity for heat recovery to be cost effective.

Typical HVAC strategies and systems

In small facilities, satisfactory conditions may be achieved with conventional radiators and convectors combined with natural ventilation or local extract fans. Floor heating is popular with users.

0.5.13 Swimming pools

This section addresses enclosed swimming pools, especially large public pools.

0.5.13.1 Principal HVAC servicing issues

The principal purposes of HVAC in swimming pools are to minimise degradation of the building fabric caused by high humidity and condensation (in all areas that are not physically segregated from the pool hall), and to provide comfort for pool users and spectators.

It is therefore important to consider evaporation rates, the expected internal surface temperatures, the integrity of vapour barriers, and the likelihood of moisture to migrating to cooler areas of the building. Adequate protection should be provided for exposed internal surfaces if maintenance and replacement costs are to be kept to a minimum.

To prevent 'fogging', the air temperature in the pool hall should be at a minimum of 1 K above the pool water temperature when the pool is in use. The recommended pool water temperature varies depending upon the activity. For competition swimming the pool is held at 26 °C. For leisure use a temperature range of 28–30 °C is more appropriate; for spas, remedial and other hot pools a pool temperature of up to 36 °C may be maintained.

Since the environmental conditions tend to create high humidity, evaporation rates from the pool and the pool surrounds should be carefully evaluated and adequate ventilation should be provided in order to:

- control humidity
- prevent condensation on inner building fabric surfaces
- maintain a satisfactory indoor environment including the prevention of down-draughts

- remove airborne pollutants
- dilute disinfectant fumes.

The use of a pool cover reduces evaporation and allows a temperature setback regime with reduced ventilation and consequent energy saving.

Air supply and extract rates should be balanced, or preferably set to maintain a marginally lower pressure in the pool hall than outside or in the adjoining accommodation. This will inhibit the migration of moisture and odour. Detectable air movement over the pool is undesirable as it causes discomfort and increases evaporation. Extract air from pool halls can be corrosive to the internal surfaces of ventilation systems.

Warmed air should be provided to maintain changing rooms at a minimum of 24 °C, and preferably supplied to give even temperature distribution if no provision is made for underfloor heating. Permanent extraction from the clothes storage area should be balanced by an air supply at a rate of 6–10 air changes per hour. A separate extract system should be provided for the WCs.

0.5.13.2 Typical HVAC strategies and systems

Ventilation systems for swimming pool halls are either 100% fresh air systems or partial recirculation systems. Both types of system are suitable for installing heat recovery or dehumidification systems. When dehumidification or cooling is provided, the extracted heat can be used for pool heating. Recirculation systems allow the fresh air supply to be adjusted while maintaining the overall supply volumes to the pool hall, hence maintaining air distribution patterns.

Savings can be made by minimising the intake of outside air for the 100% fresh air system using 2-speed or variable speed fans. However, it is essential that damper positions and control regimes are arranged to ensure adequate introduction of fresh air (30% minimum) and expulsion of contaminated air. Internal accumulations of chlorinous by-products are damaging to the building fabric and potentially dangerous to people. Therefore it is necessary to ensure a minimum ventilation rate at all times when the pool is occupied. Traditionally air supply has been at low level below windows but with modern glazing systems and *U*-values, the high level supply is possible. Supply diffusers should be placed to avoid air movement in zones occupied by bathers. Extract location is less critical but should minimise short-circuiting.

CHP is used for large pools, and ice rinks and pools may share a common site, offering opportunities for shared services.

0.5.13.3 Bibliography

Shah MM et al. (2011) 'Simplified Method of Calculating Evaporation from Swimming Pools' *HPAC Engineering Oct 1, 2011*

SPATA Factsheet 13: *Pool heating* (Andover: Swimming Pool and Allied Trades Association) (undated)

SPATA Factsheet 14: *Indoor pool climate control* (Andover: Swimming Pool and Allied Trades Association) (undated)

0.5.14 Data centres

0.5.14.1 Principal HVAC servicing issues

The size of an information technology (IT) or data centre installation can vary enormously from a few kilowatts for the small commercial user to many megawatts for those serving large data centres. Power densities and heat loads of up to 2 kW/m² are possible for a fully populated, high-density server facility. Coupled with 24/7, all-year operation, energy consumption of both IT equipment and of cooling services can therefore be extremely high. While this makes energy efficiency important it is still secondary to the key requirement for resilience of equipment and of services.

Most computer equipment requires an environment with specific ranges and maximum rates of change of temperature and humidity. There are also demanding air cleanliness requirements. Although IT equipment may produce noise levels around NR70–80, depending on power density, occupancy is intermittent.

IT equipment has a typical lifecycle of two to five years (although it may need to interact with systems that are much older) with the building and engineering plant having a much longer life expectancy. To avoid early obsolescence, system design needs to allow for future power density (increases) and different IT configurations.

A data centre will house a variety of hardware from a range of vendors in varieties of cabinets of differing power. Cabinets from some vendors may be designed to be air-, water-, or refrigerant-cooled.

0.5.14.2 Typical HVAC strategies and systems

Although the range of applications is large, the engineering solutions in many ways remain the same. The normal arrangement is to set out the computer racks in rows on a raised ventilated floor. Specialist packaged computer room air conditioning units (CRACs) are strategically located supplying conditioned air into the floor void while drawing warm stratified air from high level in the space. The air is delivered primarily between the computer racks in a 'cold aisle'.

Equipment resilience is a key issue. A minimum level of acceptable resilience would be $(N+1)$ where N equates to the number of units to meet the load. Where large numbers of CRAC units are installed this is better expressed as a percentage, for example $(N+20)$ per cent as anywhere up to 50–60 units can be provided depending on their capacity.

'Day-one' loads are generally defined as the period between practical completion and a point in time where design loads are being achieved. IT loads can be very low, especially immediately after handover and normal plant operation will require a degree of modification to achieve economic plant operation while maintaining the desired resilience level. The potential risks of condensation should not be overlooked, particularly in unoccupied or low-occupancy data halls during cooler periods of the year.

Typically, data halls would be subdivided into low-, medium- or high-diversity areas. Table 0.2 (based on CIBSE KS18: *Data centres*) shows typical cooling strategies.

Space temperatures in the order of 20–25 °C are considered acceptable with CRAC or computer room air handler (CRAH) return air temperatures around 10 °C above this. Humidity ranges of 40–60 per cent are acceptable. Some products can operate satisfactorily over the range 30–80 per cent relative humidity. Temperature swings of less than 3 °C per hour or 5 per cent swing in the humidity level are desirable to ensure optimum performance.

The set points of the cooling cycle have the biggest effect on the efficiency of refrigeration systems. Increasing these above accepted norms is often one of the largest energy savers of the facility, due to their impact on the cooling cycle and improved opportunities for free cooling.

Air cleanliness and the need for good quality filtration are paramount and the external pollution levels have a big impact. Filtration systems should include both primary and secondary filters on air handling systems with European Standards of G4 and F6/7 class of filters respectively. Air management is an important enabler for achieving energy efficiency objectives through reduced refrigeration and CRAC/CRAH fan energy requirements. Using cool air effectively is a key enabler of mechanical systems energy saving. Physical segregation of hot and cold air streams can minimise bypass and recirculation issues. Methods include cold aisle containment, hot aisle containment and the use of cabinet exhaust chimneys. These can help to minimise adjacent CRACs operating in different modes (heating or cooling) simultaneously.

The need to supply fresh air to the data hall is essential to ensure a positive pressure within the space. Exhaust air can be managed by pressure relief dampers but if gas fire suppression systems in are used then a mechanical extract system with pressure relief dampers will be essential. In the event of gas suppression discharge it will be necessary to vent the space for a period of time to remove the gas and

Table 0.2 Typical cooling strategies for data centres

Description	Power density / W/m ²	Typical cooling medium	Typical cooling system
Low density	500–900	Air	Computer room air conditioner, computer room air handling units, or all air
Medium density	900–1500	Air, chilled water, refrigerant, carbon dioxide	Hot or cold aisle containment, containment and in-row liquid cooling
High density	>150	Chilled water, refrigerant, carbon dioxide	Cabinet/rear door liquid cooling

provide safe conditions for entry – this should vent directly to atmosphere.

0.5.15 Factories and workshops

0.5.15.1 Principal HVAC servicing issues

This section considers the building services needs of production areas. These spaces may also include areas devoted to storage and distribution and to office functions, which are considered in separate sections. Warehouses and storage areas typically need only limited background heating and ventilation.

Many industrial processes have specific health and safety requirements that impinge, in particular, on ventilation needs. Minimum ventilation rates are determined by the fresh air requirements for occupants laid down in the Factories Act (HMG, 1961) and Health and Safety at Work etc. Act 1974 (HSE, 1974). However more demanding requirements are often needed to meet the ventilation requirements of the particular manufacturing processes and HSE guidance should be followed.

Industrial buildings can be broadly divided into the following categories:

- *Light manufacturing buildings* are typically 4 to 5 m high and include areas for offices, storage and dispatch. The process often makes few direct demands on the internal thermal environment, though it may give rise to specific ventilation requirements. There may be little differentiation between production, office and storage spaces. The principal needs are for thermal comfort though, for some activities, design temperatures may be lower than for sedentary work. Operating hours may be long where shift working is practiced.
- *General manufacturing buildings* may contain a very wide range of activities. Typically they are 8 m high to accommodate tall equipment, gantry cranes and local storage racking. In many cases heat gains from industrial processes will be significant or dominant. In the latter case the process demands very little of the building (e.g. it may be outside) or it may totally dominate the situation, for either quality or health and safety reasons.

An industrial building is likely to house a number of different activities, either in separate spaces or as less well-defined areas within the same space. This may result in the use of different heating, cooling or ventilation strategies in different spaces. Even with a common strategy, different spaces may have different occupation periods and this should be taken into account in the design of HVAC systems.

In heated buildings, infiltration can be a major source of heat loss, especially when frequent door opening is necessary for the supply of materials and the shipping of products. Where possible, goods doors should not be installed facing the prevailing wind or opposite each other. If this is not possible the goods loading area should be partitioned-off, with the partitioning insulated to the same level as the external wall. Other means of reducing infiltration include: rapid closing doors suitable for frequent use, either push-button or automatic; plastic strip curtains (although these are not a substitute for doors and

there are safety considerations); air curtains; or pneumatic seals around loading bays. The ventilation requirement for loading bays is for the dilution of exhaust gases in normal operation and provision for smoke extract under fire conditions.

0.5.15.2 Typical HVAC strategies and systems

In general manufacturing buildings with high heat gains from industrial processes, mechanical ventilation or active cooling may be required to maintain acceptable indoor conditions. With less dominant heat gains the servicing need is dictated primarily by the comfort and performance requirements of the people in the building but may be affected by the needs of the process, e.g. humidification for textile weaving or paper storage and humidity control for metal and chemical stores.

General industrial production areas usually require floor spaces that are largely free of fixed obstructions. Thus heating systems mounted at high level are common. These may be convective or radiant. Radiant heating, often direct gas fired (flued to outside), is particularly appropriate for spaces where relatively high infiltration rates are unavoidable, as they can provide thermal comfort with minimal heating of the air. Convective heating may be by central ducted systems, high level unit heaters or local floor-mounted cabinet heaters. Central ducted systems – often in the form of packaged roof units – are typically combined with mechanical ventilation and may be provided with solar preheating from various designs of ‘solar wall’ or with mechanical or evaporative cooling should this be needed. In high spaces, convective heating requires destratification, either by separate destratification fans or by ensuring that the supply air contains sufficient downwards momentum to reduce vertical temperature gradients.

Heat recovery may also be incorporated. Before considering heat recovery, ensure that ventilation rates are minimised and can be adequately controlled. Where the extracted air is contaminated only with particles it may be possible to filter it and return it to the workplace. This eliminates heat losses but will result in more stringent maintenance requirements. If the recycled air is hot it may be discharged back into the workplace at low level during the winter; ductwork should also be provided to allow the hot air to be rejected to outside during the summer. The use of central plant will assist in the installation and economics of heat recovery but may prejudice its controllability.

Subject to constraints imposed by industrial processes, natural ventilation can be particularly effective in industrial buildings due to the relatively high ceilings. Light manufacturing buildings are often naturally ventilated with occasional local mechanical extraction or air conditioning. The most effective ventilation will be obtained by using a combination of low and high level openings (e.g. windows and rooflights). With heat gains up to 20 W/m², simple systems can be used that may be cheaper to install than those relying on mechanical plant. With heat gains of 20–40 W/m², more sophisticated natural ventilation strategies may be required which may cost more to install. However, lifecycle costing could demonstrate the potential for overall savings due to reduced operational costs.

For optimum energy efficiency, any natural ventilation should be controllable as natural air change rates in

industrial buildings can be quite high (particularly if goods doors are left open). The correct strategy is to design the building to be as airtight as possible and to provide the required amount of ventilation by controllable means.

Mechanical extract ventilation for general factory ventilation may be provided by the use of high level extract fans (either wall or roof mounted). These are effective at removing heat but are ineffective at controlling fumes. Consider providing all mechanical ventilation systems with back-draught shutters or dampers to prevent air infiltration when the fans are not in use. Direct gas firing is a particularly efficient way of tempering large volumes of fresh air if required as make-up.

Air curtains condition the incoming air at the entrance in order to minimise cold draughts. They do not act as a physical barrier to prevent the entry of outside air but use heating energy to temper air that enters the doorway. They prevent the natural convection of warm air out of the top of a doorway being replaced by cold air at the bottom.

0.5.16 Cleanrooms

0.5.16.1 Principal HVAC servicing issues

A cleanroom is an environment where the concentration of airborne particles at designated particle size(s) are defined and controlled. Cleanrooms are used where the airborne particulate can have an impact on the quality of the product being manufactured within the space and are commonly used in the aerospace, microelectronic, pharmaceuticals, medical devices and food industries. Operating theatres, blood banks, fertility clinics and certain types of laboratory may also require cleanrooms.

Under the international system ISO 14644 (BSI, various dates), cleanrooms are graded from ISO9 for the least critical operations up to ISO1 for the most critical operations and can be classified in three states, 'as-built', 'at rest' and 'in operation'. The certification of cleanrooms under ISO 14644 requires only the airborne particulate level to be maintained, however further testing maybe required for the products quality requirements and/or, as is the case for pharmaceuticals and medical devices, meet statutory requirements set by law. Examples of other requirements include testing for:

- temperature
- humidity
- airflow
- differential pressure with respect to adjacent spaces
- recovery after shutdown
- surface contamination
- containment leak
- installed final filter leak
- electrostatic and ion generation.

The appropriate classification will often require routine monitoring as part of the quality assurance of the product quality being manufactured within the space, for example, routine qualification as part of an environmental

performance validation programme in the pharmaceutical industry.

Cleanroom ventilation is based on dilution, replacing air (and airborne particles) from inside the space with clean air fed through high efficiency filters (HEPA or ULPA) by the HVAC system. An effective cleanroom is dependent on a combination of appropriate cleanroom airflow design both inside the space and from adjacent spaces, construction with cleanable and non-shedding materials, and minimisation of particle generation within the cleanroom. The contamination control principles applied to cleanrooms can also be applied to smaller clean air devices such as clean air hoods, isolators and glove boxes.

Generally, the design of the ventilation systems for cleanrooms must take account of the following factors, which will need to be agreed with the client/user as early as possible in the design process:

- classification of the space
- the state of the space during testing, i.e. 'as built', 'at rest' or 'operational'
- nature of work, e.g. semiconductor/electronics or pharmaceutical or in some cases biological
- selecting the airflow concept to be used: unidirectional flow (formerly called laminar flow using displacement of contamination), or non-unidirectional airflow (using turbulent mixing to dilute contamination)
- access and containment strategy, for example bubble or sink airlock design
- minimum air change rates to mitigate heat gains/losses and achieve the specified cleanliness levels
- the classification of any adjacent spaces
- pressure differentials and directional air flow
- recirculation or full fresh air (full fresh air is only required where there is a risk of contamination)
- any segregation of ventilation systems
- air pressure differentials to adjacent spaces (to be $12.5 \text{ Pa} \pm 20\%$)
- room construction, fabric leakage rates and other air paths
- final filter efficiency and location (HEPA or ULPA filtration standards for efficiency and in-situ integrity testing)
- number of and locations of final filters
- room layout and geometry, including fittings and equipment
- technical and plant space requirements for air handling systems and ductwork feeding the cleanroom
- open or closed door design and interlocking requirements
- environmental control requirements.

Resilience is important for mechanical ventilation systems for cleanrooms. A high level of reliability is necessary as the system is critical to the proper functioning of the building and the business/processes conducted within it. The health

or product quality consequences of system failure in this type of space can be very significant.

0.5.16.2 Typical HVAC strategies and systems

Cleanrooms can be configured as unidirectional (UDF) or non-unidirectional airflow (non-UDF).

In UDF cleanrooms (or clean air devices) air is delivered through a bank of terminal HEPA or ULPA filters covering the whole ceiling (downflow) or on one wall (cross flow). The air is exhausted through the entire opposite surface, with air flowing in parallel lines and at uniform velocity. Thus, air makes only one pass through the room and any contamination created in the room is displaced. The air velocity from the ventilation system should be maintained within $0.45 \text{ m/s} \pm 20\%$ to prevent settling out. Airflow uniformity is essential for various critical tasks and such operations should be located to receive 'first air' from the filter source.

In non-UDF cleanrooms, air is supplied to the room by individually ducted terminal HEPA or ULPA filter modules/grilles in the ceiling, the number dependant on the amount of air required. These filter modules can be provided with diffusers to enhance turbulent mixing and improve the ventilation effectiveness for both heat gain mitigation and particle control but must be cleanable and manufactured from non-shedding materials. Air should be exhausted through grilles or through air walls located near the floor. For low grade cleanrooms (ISO9; operational) consideration can be given to a remote mounted in line HEPA filter, but should be located as close to the room as possible, and the ducting between the filter and the room must be specified to avoid particle shedding and induction of contamination from surrounding technical areas with sufficient access for cleaning.

To maintain a cleanroom's classification, very high air changes are required, typically ranging from 10 air changes per hour for an ISO Class 9 to 600 air changes per hour for an ISO class 1. Consideration should be made for technical space requirements for the air handling equipment, ductwork and utilities early in the design process. Spatial requirements should also include access for routine maintenance and testing requirements.

The final air filters are one of the major components influencing the level of cleanliness in cleanrooms, the efficiency of which will need to suit the room classification but must not be considered in isolation. Effective pre-filters should be selected to ensure long life of final filters. Variable speed fans and/ or constant air volume boxes (CAV) should be used to maintain constant airflow and pressure when filters become dirty.

Cleanrooms are very costly to construct and operate. Cleanrooms with high air change rates should be minimised (in size and volume) to avoid unnecessary energy usage and capital expenditure (for example using an isolator instead of a room). Air is normally fully air conditioned, with space conditions set to maintain both product quality and personnel comfort. Air should be re-circulated to reduce energy costs unless prohibited by contamination to meet the fresh air requirements for personnel working in the room or to offset any air removed through pressurisation of the space. Reduced air changes may also be considered but

should be proven to have no impact on the quality of the product or process by risk analysis or other suitable means.

0.5.16.3 References and Regulations

The pharmaceutical industry is highly regulated worldwide, and these regulations, known as the cGMP (current Good Manufacturing Practice) regulations, include all specific requirements for cleanrooms and clean air devices related to specific manufacturing operations to license the product manufactured to be sold into the market enforcing the cGMP's. Requirements include minimum air classifications, filtration levels, microbial surface counts, gowning requirements and recovery periods. In different parts of the world, there are similar but slightly different sets of cGMP regulations. For example the EU GMP Annex 1, and the FDA CFR 21 and associated aseptic processing guidance in the USA. There is an international effort to standardise cGMP regulations globally to ensure quicker access to life saving drugs to various parts of the world. This international collaboration is known as the International Conference for Harmonisation (ICH) and includes the regulatory bodies of the EU, the USA, Japan and other interested parties. The cGMP requirements from different regulatory groups are transposed into the pharmaceutical regulatory guidance published by the regulatory bodies and the PIC/S, WHO, ISPE and the PRC.

0.5.16.4 Bibliography

BS EN ISO 14644, Parts 1 to 10: *Cleanrooms and associated controlled environments* (various dates)

0.5.17 Animal rooms (housing and care when used in scientific procedures)

The design of facilities for the housing and care of animals used in scientific procedures is regulated by the Government and requires careful and detailed briefing along with comprehensive commissioning and verification requirements. Consultation should be undertaken with the licence holder to determine the current codes of practices and regulations and to agree the environmental conditions specific to the species to be housed and the method of localised holding.

0.5.17.1 Principal HVAC servicing issues

For precise experimental work, close control of temperature (± 0.5 – 2 K) and relative humidity ($\pm 10\%$) may be required at different conditions within the overall operational stage depending upon the species. Uniformity of the environment throughout the space is also important and in some cases the direction of air movement needs to be controlled to minimise, for example, the pollution in the spaces through which the laboratory operatives move.

Resilience is important and requirements may include standby equipment and/or safety features that are automatically initiated in the event of a failure of the main system.

The specification of the design for animal rooms would be undertaken by the holder of the premises certificate, with

the approval of the Home Office local inspector. Designers must ensure that all necessary procedures are followed. The environmental conditions and degree of control required for animal rooms depend on the species and the intended use of the facilities. The operation and maintenance of the plant needs to be considered in the context of the licensee's operational plan.

0.5.17.2 Typical HVAC strategies and systems

Full air conditioning without recirculation is often selected to minimise cross contamination, often with ventilated cage rack systems connected directly to supply and extract systems via HEPA filters.

Terminal re-heater batteries are installed in each room in order to provide individual temperature control.

Cooling/humidity control is normally provided centrally by dew-point control at the AHU and supply air terminal energy optimised by 'polling' terminal zone demands.

Where the requirements for holding are small in number, or the environmental containment hazards are high, consideration can be given to packaged environmental chambers.

0.5.17.3 Bibliography

Code of practice for the housing and care of animals used in scientific procedures (HMG, 2014)

0.5.18 Farms

0.5.18.1 Principal HVAC servicing issues

The environmental design requirements for farm animals (and poultry) relate to economics, the health and well-being of both animals and workers and regulatory requirements.

The over-riding environmental factor affecting the physiological functions of domestic animals is temperature. For most farm animals a mean daily temperature in the range 10 to 20 °C is referred to as the 'comfort zone'. However, the ideal temperature range in terms of growth or milk production is narrower and differs according to the type and age of stock. Very young animals lack fully developed temperature-regulating mechanisms and are much more sensitive to the thermal environment, so they require higher temperatures.

Buildings for farm animals fall into two main groups:

- buildings for housing 'hardy stock', such as milking-cows, breeding-pigs and sheep, that do not require any great control of environmental conditions
- buildings such as pig farrowing houses, fattening houses, veal calf houses, laying and broiler poultry houses etc., which require the environmental conditions to be controlled such that the highest possible productivity is obtained at the lowest food and management costs.

Guidance on the housing of animals on farms may be obtained from the Animal Welfare division of the

Department for Environment, Food and Rural Affairs (Defra). Reference should also be made to the Welfare of Farmed Animals (England) Regulations (Defra, 2007).

0.5.18.2 Typical HVAC strategies and systems

Hardy stock require housing only to protect them from extremes of weather, ventilation being provided by low level and ridge ventilators with protection against direct and through draughts. Care must be taken to ensure adequate ventilation in high density enclosed animal houses where forced ventilation will be necessary. Humidity is not usually a problem.

For young animals requiring close control of conditions, mechanical ventilation is essential, provided by supply and/or extract fans depending on the requirement for positive or negative pressures within the animal houses. Ventilation is required to control indoor air quality (removal of moisture and body and excrement odours) and to avoid overheating. Winter recirculation can be used to conserve heat. Safeguards must be provided against fan failure or livestock will be seriously affected during hot weather. Sophisticated control of mechanical ventilation systems can be cost-effective.

0.5.19 Transportation buildings and facilities

0.5.19.1 Airport terminals

Principal HVAC servicing issues

Terminal buildings have large low-rise open circulation areas, check-in facilities, retail outlets, offices and ancillary areas which, together with very variable occupancy, commonly generate large and variable heat gains. The sections of this chapter that relate to retail and office activities are equally relevant here. Control of solar gain is important. It is important that the ventilation/air conditioning system is able to respond to these changes. However, due to the large volume of the circulation spaces it is possible to use the building volume to dampen the effects over short periods. In busy periods or when departure patterns are disrupted, prolonged high occupancy is possible. Ventilation systems can be controlled by air quality detectors, thereby automatically reacting to passenger flows.

The system design should also incorporate sufficient zone control to accommodate the widely varying occupancy levels in different parts of the building, or even between adjacent departure gates. If available, histograms of passenger movement for departure and arrival are useful in estimating the design occupancy, but it the possibility of more intensive future use of the space should be taken into account.

Airports generally consist of one or more terminal buildings, connected by passageways to departure gates. Many terminals have telescoping loading bridges connecting the departure lounges to the aircraft. These eliminate heating and cooling problems associated with open doorways, but may themselves be sources of significant heat loss or gain.

Terminal buildings are separated by a landside/airside boundary. The HVAC systems will therefore need to consider security issues for maintenance access.

Airport terminals are buildings surrounded by aeroplanes. The aeroplanes are typically refuelled at their gate or stand and the location of air intake and exhaust has to take into consideration their impact on safety in the event of a fuel spill.

Filtering of the outdoor air with activated carbon filters should be considered to reduce the presence of noxious fumes. However, the siting of air intakes away from the aircraft jet exhausts may obviate the need for such filtration and will reduce operating costs. It may be difficult to predict whether fumes will affect the air intake location, and supply systems should incorporate facilities to enable carbon filters to be added at a later stage, if necessary. The aim of any ventilation system should be to create a positive internal pressure that will prevent the odour and pollutants from entering the buildings. The automatic control of ventilation flow to react to passenger numbers therefore needs to be given special consideration as the pressurisation requirements of the large spaces will be the limiting factor for turn down.

Typical HVAC strategies and systems

Mechanical ventilation with all-air cooling and heating is typically used, often with low-level supply diffusers, though other forms of air conditioning such as fan coils or chilled beams may be appropriate in some areas. Underfloor heating and cooling may be used in areas without air conditioning. To reduce heat losses in cold weather mechanical ventilation systems may be designed with recirculation during periods of low occupancy (to provide heat reclaim).

The form of a terminal is typically defined by the primary process of moving passengers and bags to aeroplanes (through the front of house areas), the passenger experience and maximising revenue through food and beverage and retail. The servicing strategy therefore has to minimise the impact of space requirements and routine maintenance to the primary process. Plant would therefore typically be located away from front of house or where maintenance would impact operation. High level distribution within or below ceilings is minimised where possible and equipment requiring regular maintenance located away from passenger areas.

Large airports commonly have centralised energy centres providing low or medium temperature water to many buildings, including terminals.

Airports can be critical national infrastructure facilities and may require resilient systems to be incorporated into their design. This includes the HVAC which may need to maintain conditions so that critical airport operations can continue in extreme events including fire, weather, equipment or utility failure.

0.5.19.2 Bus and railway terminals

Principal HVAC servicing issues

Where the railway tracks or bus platforms are enclosed under a canopy or buildings above, it will be necessary to

consider how the fumes produced by the locomotives are to be exhausted/diluted.

The general requirement is for engineering systems that will remove the hazards of carbon monoxide and airborne particles from vehicle exhaust emissions and prevent the build-up of vapours from fuel leaks etc.

The use of alternative fuels to diesel oil is increasing and these raise additional issues. For buses fuelled by natural gases, the normal emission rate of unburnt fuel is low. However, if the high pressure gas fuel line were to break, then a large quantity of gas would be released causing a potentially explosive atmosphere. Such a situation would require the prompt use of purging ventilation. Initially, the gas, while cold, will collect at ground level and therefore purging needs to be at this level. However, when warmed, methane tends to rise, as will unburnt methane in the exhaust gases. Therefore, potentially stagnant air zones at high level need to be eliminated.

The ventilation rate also needs to provide odour control, which would generally require a 75:1 dilution rate of outside air to bus exhaust gases. The overall rate of fume emission can be determined from considering the bus operation, terminal configuration and traffic movements. The overall ventilation required can be reduced by removing exhaust gases at the point of discharge.

Typical HVAC strategies and systems

Naturally ventilated terminals with large open ends may expose passengers to inclement weather and strong winds. Therefore, enclosed platforms with appropriate mechanical ventilation should be considered. Alternatively, enclosed passenger waiting areas can be considered for large terminals with heavy bus traffic. The waiting areas can be pressurised and heated, with normal air volumes depending on the layout and number of boarding gates.

The exhaust components from diesel engines that affect the ventilation design are particulates, carbon monoxide, hydrocarbons, oxides of nitrogen and formaldehydes. Exposure limits are given in HSE EH40 (HSE, 2011).

Bibliography

For further information see *ASHRAE Handbook—HVAC Applications* (ASHRAE, 2011), chapter 15 'Enclosed Vehicular Facilities'.

0.5.19.3 Car parks

Principal HVAC servicing issues

The general requirement is for engineering systems that will remove the hazards of carbon monoxide and airborne particles from vehicle exhaust emissions and prevent the build-up of vapours from fuel leaks.

A requirement is sometimes imposed for the maintenance of a pressurised means of escape stairwell under a 'fire condition'. Two speed fans are regularly used to achieve the higher air change rate required for pressurisation and that leads to very large fan power requirements.

Typical HVAC strategies and systems

Above-ground car parks should be provided with natural ventilation openings in the outside walls of at least 5% of the floor area. Openings on opposite sides should be provided to promote ventilation without being adversely effected by wind direction.

A hybrid ventilation system may also be provided if 2.5% aggregate of the car park floor area is provided in opposing walls such that 3 air changes per hour mechanical ventilation is sufficient for day-to-day operation, with smoke clearance achieved by natural ventilation using these permanent openings.

Mechanical ventilation is required for car parks that are enclosed or located in basements. The system should be independent of any other systems and provide 6 air changes per hour for normal operation and 10 air changes per hour in a fire condition. Extract points should be placed so as to eliminate pockets of stale air, and be distributed so that 50% of the extract is at high level and 50% at low level, with particular attention at low points and drains. Alternatively an impulse ventilation system can be provided to remove the need for distributed ductwork within a car park. These fans should be sited to ensure an even coverage of air across the car park and will still require the mechanical extract in enclosed car parks to remove the air. Mechanical supply of air should be considered to large car parks to reduce the velocity at which air enters via the available natural openings and should be considered essential for multiple-level basement or enclosed car parks to ensure freshness of air supplied to each level is achieved. The system should be divided into two parts, each connected to an independent power supply that will continue to operate in the event of mains failure. This may be achieved by dual-incoming mains supply to the system control panel and 50% stand-by extract fans.

Where many vehicle engines are likely to be running simultaneously, e.g. at exit and entrances, consideration should be given increasing the ventilation rates to maintain the acceptable contamination levels based on vehicle emissions. Limiting concentrations of exhaust pollutants are included in the HSE's guidance publication EH40: *Occupational Exposure Limits* (HSE, 2011). If separate from the general car park ventilation system, the ventilation can be controlled using carbon monoxide detectors at appropriate locations. Manned pay stations may need positive supply air, with the air intake located away from the contaminated roadways. The main car park volume however should be kept under slight negative pressure; this limits the escape of smells and pollutants to neighbouring rooms during the time of doors opening and assists in maintaining fire compartmentation during a fire when natural smoke lobbies are used (i.e. the smoke lobbies are at atmospheric pressure, therefore if the car park were to go into positive pressure smoke could be forced into the protected lobby areas).

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