

CALCULATING *AND ANALYSING* *BUILDING* *SERVICES*

Requirements for comfort levels in buildings



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TASK A

PART A1

A1.1 The Room Index

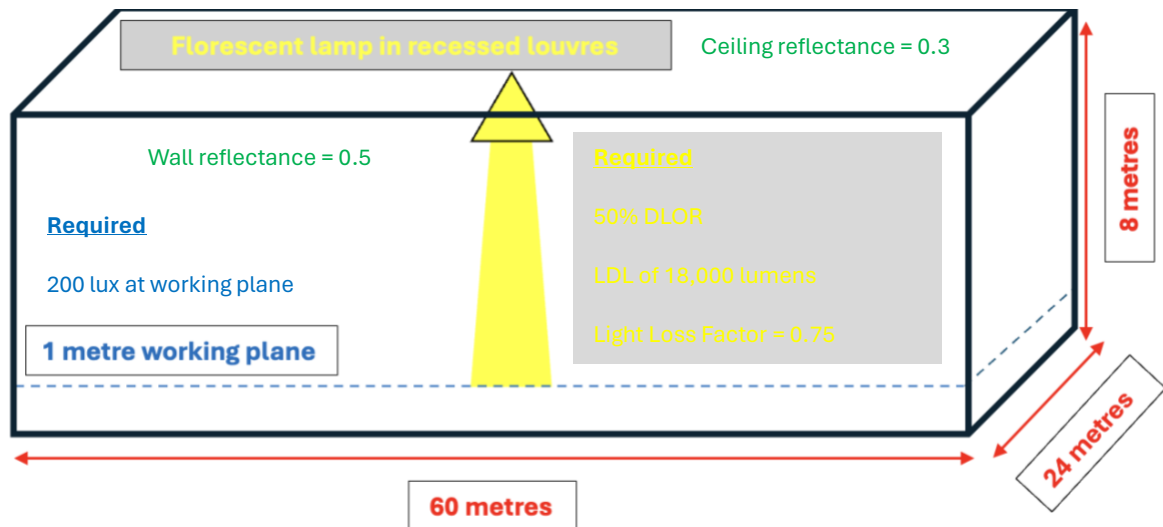


Figure A1.1.1: An unscaled dimensional diagram of the production area.

To calculate the room index of the production factory, information is extracted from figure A1.1.1 and placed in the equation below.

$${}^1RI = \frac{(L \times W)}{(H_m(L + W))}$$

The equation will appear as follows.

$$RI = \frac{(60 \times 24)}{(7 \times (60 + 24))}$$

¹ L = length of the room; W = the width of the room; H_m = the height of the luminaire measured from the working plane

To simplify the equation, the sums within the bracket have been calculated.

$$RI = \frac{1440}{7 \times 84}$$

Then multiplying the 7 and 84 to present the final sequence.

$$RI = \frac{1440}{588}$$

Now the room index can be calculated below.

$$2.4489 = \frac{1440}{588}$$

The room index is 2.4489. This figure will now be utilised in section A1.2 to identify the utilisation factor.

A1.2 The Utilisation Factor

The sum of 2.4489 is rounded up to the closest room index value that are presented in table A1.2.1, the rounded-up figure is 2.5. However, this figure alone will not identify the utilisation factor.

The production area of the factory requires fluorescent lamps in a recessed louvre, and the reflectance of the ceilings and walls in that space are 0.3 and 0.5 respectively. This additional information distinguished the utilisation factor as 0.46.

(Table A1.2.1: Applying the relevant figures to the utilisation factor sheet to identify the utilisation factor)

UTILISATION FACTOR SHEET											
Description of fitting	Typical outline LOR	Basic downward LOR%	Ceiling	0.7			Reflectances			0.3	
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3
			Room index								
Aluminium industrial reflector, aluminium or enamel high-bay reflector		70	0.6	0.39	0.36	0.33	0.39	0.36	0.33	0.39	0.35
			0.8	0.48	0.43	0.40	0.46	0.43	0.40	0.46	0.43
			1.0	0.52	0.45	0.45	0.52	0.48	0.45	0.52	0.48
			1.25	0.56	0.53	0.50	0.56	0.53	0.49	0.56	0.52
			1.5	0.60	0.57	0.54	0.59	0.57	0.53	0.59	0.57
			2.0	0.65	0.62	0.59	0.63	0.60	0.58	0.63	0.59
			2.5	0.67	0.64	0.62	0.65	0.62	0.61	0.65	0.62
			3.0	0.69	0.66	0.64	0.67	0.64	0.63	0.67	0.64
			4.0	0.71	0.68	0.67	0.69	0.67	0.65	0.69	0.66
Near-spherical diffuser, open beneath		50	0.6	0.28	0.22	0.18	0.25	0.20	0.17	0.22	0.18
			0.8	0.39	0.30	0.26	0.33	0.28	0.23	0.27	0.25
			1.0	0.43	0.36	0.32	0.38	0.34	0.29	0.31	0.29
			1.25	0.48	0.41	0.37	0.42	0.38	0.33	0.34	0.32
			1.5	0.52	0.46	0.41	0.46	0.41	0.37	0.37	0.35
			2.0	0.58	0.52	0.47	0.50	0.48	0.43	0.42	0.39
			2.5	0.62	0.56	0.52	0.54	0.50	0.47	0.45	0.42
			3.0	0.65	0.60	0.56	0.57	0.53	0.50	0.48	0.45
			4.0	0.68	0.64	0.61	0.60	0.56	0.54	0.51	0.48
Recessed louvre trough with optically designed reflecting surfaces		50	0.6	0.28	0.25		0.23	0.28	0.25	0.23	0.28
			0.8	0.34	0.31	0.28	0.33	0.30	0.28	0.33	0.30
			1.0	0.37	0.36	0.32	0.37	0.34	0.32	0.37	0.34
			1.25	0.40	0.38	0.35	0.40	0.37	0.35	0.40	0.37
			1.5	0.43	0.41	0.38	0.42	0.40	0.38	0.42	0.39
			2.0	0.46	0.44	0.42	0.45	0.43	0.41	0.44	0.42
			2.5	0.48	0.46	0.44	0.47	0.45	0.43	0.46	0.44
			3.0	0.49	0.47	0.46	0.48	0.46	0.45	0.47	0.45
			4.0	0.50	0.49	0.48	0.49	0.48	0.47	0.48	0.47
			5.0	0.51	0.50	0.49	0.50	0.49	0.48	0.49	0.48

A1.3 The Number of Lamps Required

The utilisation factor is applied to the required number of lamps equation.

$$^2N = \frac{E \times A}{F \times UF \times LLF}$$

This essay has been provided with the essential information (detailed below) to complete this equation.

E. Illuminance levels required = 200 lux.

A. Area - 60 x 24 = 1440.

F. The Average Luminous Flux per lamp = 18,000.

UF. Utilisation Factor = 0.46

LLF. Light Loss Factor = 0.75

The required number of lamps equation is now populated.

$$N = \frac{200 \times 1440}{18000 \times 0.46 \times 0.75}$$

The following sequence of the equation has multiplied the numbers to have a single value placed on either side of the equation.

² N = number of required lamps; E = the illuminance levels required in lux; A = area of the working plane in m²; F = the average luminous flux of each lamp (lm); UF = the utilisation factor; LLF = the light loss factor.

$$46.3768 = \frac{288,000}{6210}$$

It is impossible to have 46.3768 lamps therefore the figure is rounded up to 47 lamps as the minimum required sum of lamps for the factory. However, 47 being a prime number creates difficulties in distributing equal illuminance, therefore the grid layout will consist of 48 lamps.

This increase in lamps can be attributed to the 70% rule, which enables a slight adjustment to the calculated number of lights required to enable a 'best fit' scenario. The 70% alludes to the permittance of an additional 70% lux over the calculated required lux.

Part A2

A2.1 A Suitable Layout

Now that the required number of fluorescent lamps in a recessed louvres have been identified, a suitable layout is designed. The following equation is used to identify the maximum permitted spacing between lamps (S_{max}).

$$^3S_{max} = 1.5 \times H_m$$

The height of the working plane is 1 metre from the floor surface, the ceiling height is 8 metres, giving a working plane distance from the light source of 7 metres. Once multiplied by the factor of 1.5, the S_{max} is calculated as 10.5 metres.

$$10.5 = 1.5 \times 7$$

The S_{max} has a $1/2 S_{max}$ to identify the maximum permitted distance from the perimeter lamps to the walls. The equation is simply dividing the S_{max} in half giving a value of 5.25 metres.

$$5.25 = \frac{10.5}{2}$$

Nevertheless, these values are maximum distances only and can be reduced to accommodate a sufficient layout of equal illuminance, although the distance from the lamps to the wall must be as close to half of the distance between lamps as is reasonably possible.

³ H_m = the height of the luminaire measured from the working plane; 1.5 = the multipliable factor of fluorescent lamps to calculate the S_{max}

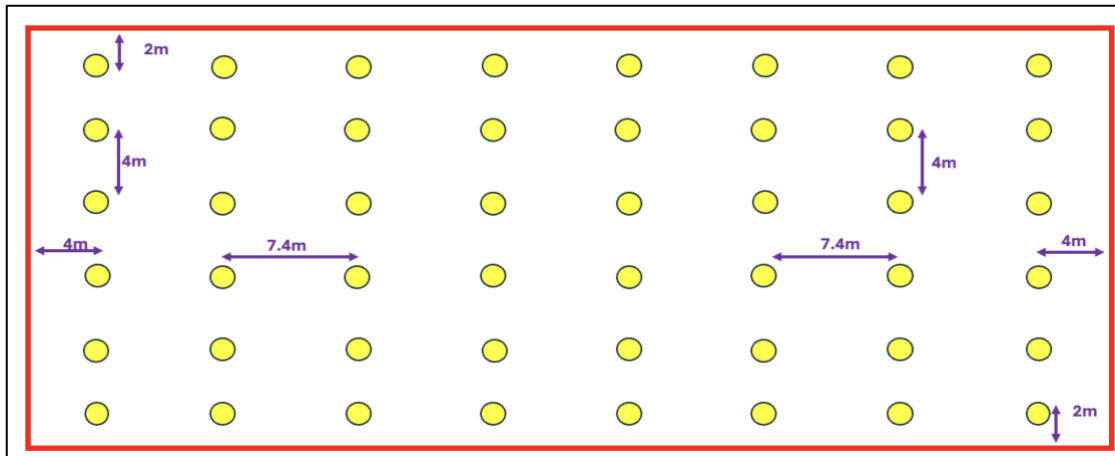


Figure A2.1.1: The suitable lighting layout. 10mm = 2 meters on A4

The layout seen in figure A2.1.1 displays 48 fluorescent lamps in recessed louvers. The spacing between each lamp is 7.4 metres horizontally and 4 metres vertically which sits within the permitted $S_{\max}$ value of 10.5 metres.

Equally, the distance between the perimeter lamps and the walls are almost perfectly half that of the distance between the lamps themselves in their respective horizontal and vertical rows satisfying the $\frac{1}{2} S_{\max}$ rule. Therefore, this layout would generate equal illuminance across the factory whilst adhering to the standard methods of a lighting layout as discussed in this section.

TASK B

Part B1

B1.1 Wavelength and Frequency of Sound

A wavelength is the horizontal length of one cycle, which is measured from one peak of the wave to the next. The transmission and changes of pressure creates sound as the wavelength travels through the air (Binggeli 2016). Sound is primarily created by impact sources where physical contact is required to generate the sound, or voices creating airborne sound waves (Lyons 2007). Nevertheless, most sounds contain a range of frequencies defined as octave bands.

The number of waves passing a particular point per second generates the frequency of the sound, measured in Hertz (Hz). Higher frequencies create high-pitched noises whilst lower frequencies create low-pitch noises. Consequently, various frequencies will differentiate in behaviour when encountering an object(s) where higher frequencies with shorter wavelengths are absorbed better than lower frequencies with longer wavelengths, although it is heavily dependent on the size of the encountered object (McMullan 2007). Furthermore, the properties of the encountered object(s) will affect the attenuation, reflectance, reverberation, and diffraction of the sound (Binggeli 2016).

B1.2 A Building's Internal Design and Service Support

Services commonly generate unwanted noise in internal environments, like water passing through pipes, or air travelling through vents that can cause airborne and impact noise. Ideally, the design of internal environments should isolate highly serviced rooms such as kitchens and bathrooms away from habitable living spaces like

bedrooms and living rooms. Nevertheless, these habitable rooms still require services therefore specific techniques to limit unwanted noise can be implemented.

Lightweight porous materials are good sound insulators through attenuating airborne sound travelling through the miniscule air pockets of the material where the energy is converted to heat (Lyons 2007). Although the insulation will be ineffective if the penetrations do not have airtight sealing (McMullan 2007). Unfortunately, the porous materials will not effectively attenuate lower frequencies, requiring thicker materials for lower frequencies.

Furthermore, service equipment can generate impact noise through mechanical vibration. To combat this, discontinuous construction techniques are implemented to isolate the source from the building envelope, like lapping services with flexible ducts to ease rigidity (Binggeli 2016) or utilising suspended service trays.

B1.3 Partition Wall

Binggeli (2016) highlights mass, resiliency, and tightness as three critical components to sound attenuation. Mass is a superior sound insulator, therefore fixing plasterboard to both sides of a lightweight frame can increase its acoustic performance. Lyons (2007) suggests using two layers of staggered plasterboard of varying thickness. However, if an object becomes too rigid, sound vibration impact can increase. To counteract rigidity, isolate the two leaves with separate timber frames (McMullan 2007) and place resilient furring channels to separate the wall finish from the wall structure allowing space for insulation in the created cavities. Any penetrations through the cavity must be sealed to airtightness. It is important to note that any rigid structure that then connects two leaves will counteract the sound attenuation of this system.

Evidently the method of construction is equally as important as the material itself, as seen with the isolation of structures and the alternation between solid, air, and hybrid

obstructions. The science behind the changing mediums of sound transmittance is to force the soundwave to interact with materials of opposing characteristics to attenuate the energy of the sound. Nevertheless, the science of the construction could also be as simple as placing windows or doors away from sources of noise such as roads (Binggeli 2016) or using compound cavity absorbers (McMallan 2007).

Any opening within a partition wall can weaken the acoustic integrity of that structure (Binggeli 2016). Therefore, when measuring the sound transmission coefficient (STC) of a structure, in other words how well it attenuates sound energy, the following equation is applied. Note that there if no unit of measurement, the calculation will produce a ratio.

$$T = \frac{\text{Transmitted sound energy}}{\text{Incident sound energy}}$$

A human ear is not energy sensitive, therefore the STC must be converted dBs. The sound reduction index (SRI) provides a dB unit of measurements.

$${}^4SRI = 10x \left(\log_{10} \left(\frac{1}{T} \right) \right)$$

Although if a composite wall comprises of multiple skins, windows, and doors, the SRI cannot be averaged for those specific areas, however the SRI can be averaged if the specific STCs are calculated prior to the SRI average and placed in the equation below.

$${}^5T_o = \frac{(T_1 \times A_1) + (T_2 \times A_2) + (T_3 \times A_3)}{A_1 + A_2 + A_3}$$

⁴ T = Transmission coefficient

⁵ T = Transmission coefficient; A = area of component

The value of the average transmission coefficient is placed back into the SRI equation to calculate the overall reduction of sound in dB for the composite structure.

B1.4 Insulation Types

Arthur Lyons (2007) compares the various insulation types commonly used in the construction industry. Insulation can be engineered to specific requirements or be as simple as loose fill blanket rolls. Nevertheless, the type of insulation used will be determined by the requirements such as attenuation of noise frequency and the suitability of that insulation to be applied to the system.

For example, modern construction techniques are reducing the thickness of domestic walls, therefore one might not want to rely on a material that is reliant on its density to attenuate sound such as lightweight aggregate concrete. The insulation of choice however, might be a mineral wool filled between staggered timber joints although the mineral wool alone will not be sufficient without two layers of staggered plasterboard fixed to an additional internal cavity which incidentally increases the thickness of the wall. This could, however increase its effectiveness at attenuating lower frequencies of sound, especially if the internal frame is lined with a battened cavity plywood lining (Binggeli 2016).

Insulation can also appear exterior to the cavity construction. Porous and panel absorbers can be fixed to faces to attenuate sound. McMullan (2007) presents the effectiveness of three panel absorber types in figure B1.4.1. A porous absorber is typically fibre glass or mineral wool with small pockets of air that reduce sound energy through viscous resistance and a panel absorber transmits sound energy as mechanical vibrations to the porous insulation material within the wall. Both attenuate sound but are effective at differing frequencies, reinforcing the paramount consensus of understanding the type of noise that a particular environment is attempting to attenuate to successfully limit unwanted noise exposure.

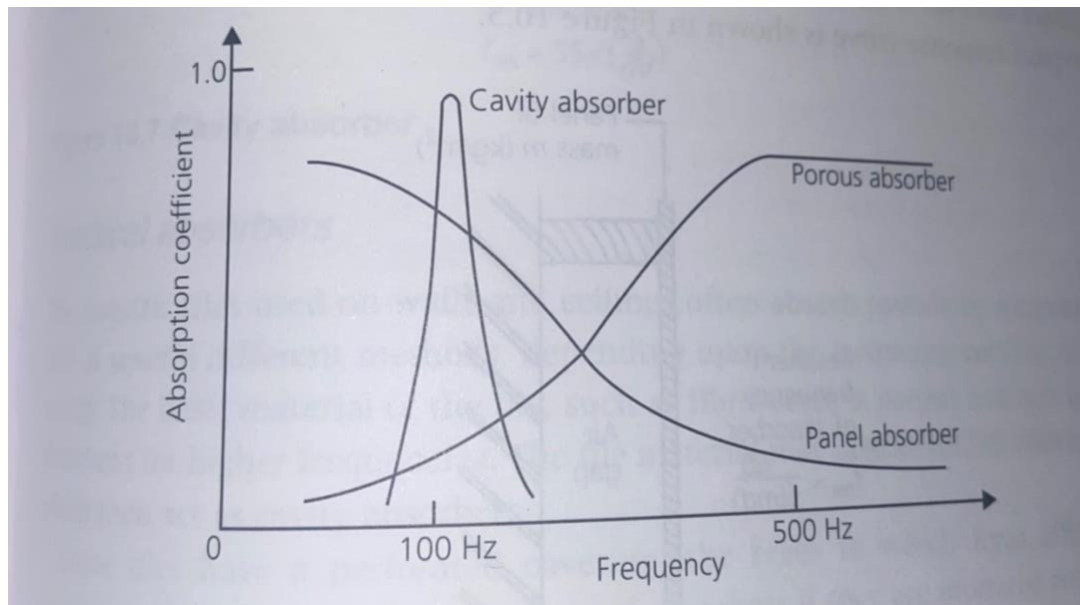


Figure B1.4 1: The absorption coefficient of sound absorbers (McMullan 2007)

PART B2

B2.1 Thermal Transmittance and Thermal Resistance

Thermal resistance and thermal transmittance are means of measuring insulating performances through two separate equations. Firstly, thermal resistance calculates how effective a material limits heat flow, i.e., a material of higher thermal resistance will reduce the flow of heat. This measurement is calculated as an ‘R-Value’, using the following equation. Where multiple R-Values exists, like composite walls all R-Values are accounted, as displayed in the second equation.

$${}^6R = \frac{d}{\lambda}$$

$$R_r = R_{si} + R_1 + R_2 + R_{so}$$

Thermal transmittance defines the conductive properties of a material, i.e., how efficient does it enable heat to traverse through the material. Thermal transmittance is calculated using a ‘U-Value’ through the following equation.

$$U = \frac{\lambda}{d}$$

The similarity of these equations creates a reciprocal relationship between R-Values and U-Values, therefore if one calculates the R-value then the U-value can be calculated and vice versa through the following equation.

$$U = \frac{1}{R}$$

⁶**R** = thermal resistance in $m^2 K/W$; **D** = thickness of the material; λ = thermal conductivity coefficient of the material (W/mK)

Example:

To demonstrate the interdependent relationships between R-Values and U-values this example will assume a flat roof room of 15m x 12m x 3m high, with an internal temperature of 24°C and an external temperature of 4°C.

Table B2.1.1: Calculating the R-Values

Items	Thickness layer 'd' (m)	Thermal Conductivity λ (W/m K)	$R = d/\lambda$ (m² K/W)	Resistance R (m² K/W)
Composite Wall				
Dulux Trade Plus Thermoacoat+ (Dulux Trade)	0.006	0.05	0.006/0.05	0.12
British Gypsum Glasroc H Tilebacker (British Gypsum 2024)	0.0125	0.3	0.0125/0.3	0.04
Aerated Concrete Block	0.115	0.11	0.115/0.11	1.045
Rockwool NyRock Cavity Slab (Rockwool)	0.05	0.032	0.05/0.032	1.5625
Clear Cavity	0.05	n/a	standard	0.18
Standard Facing Brick	0.103	0.77	0.103/0.77	0.133
Wall Resistance R_t				3.08
Composite Flat Roof				

Standard flat roof with integral insulation (<i>The Steel Construction Institute 2002</i>)	Standard	Standard	N/A	4
Flat Roof Resistance R_t				4
<u>Composite Floor</u>				
Standard Floor	Standard	Standard	N/A	4
Floor Resistance R_t				4

Table B2.1.1 calculates the R-value for each composite item. Importantly if the composite item does not provide an overall R-Value then the items should be calculated individually as illustrated above for the cavity wall. Furthermore, each item relates to different dimensions of the room which will become evident in calculating the U-Value in table B2.1.2.

Table B2.1.2 Calculating the U-Values

<u>Items</u>	R-Value <i>($m^2 K/W$)</i>	$\frac{1}{R}$	U-Value <i>($m^2 K/W$)</i>
Composite Wall	3.08	1 / 3.08	0.32
Composite Flat Roof	4	1 / 4	0.25
Composite Floor	4	1 / 4	0.25

After applying the reciprocal equation to work out the U-Values, then the values are applied to the final following equation⁷, which will be calculated in B2.1.3.

$$P = U \times A \times (\theta_1 - \theta_2)$$

Table B2.1.3: Calculating heat loss

Item	U-Value	Area (m²)	Temperature Difference (°C)	Power Loss (Watts)
Walls	0.32	162	20	1036.8
Roof	0.25	180	20	900
Floor	0.25	180	20	900
				= 2836.8

The final sum calculates the total heat loss at 2836.8W, or alternatively as 1 joule equals 1 Watt a conclusion can be drawn that the room would require 2836.8 joules per second to maintain the internal temperature of 24°C.

⁷ **P** = Heat loss (watts); **U** = U-Value; **A** = Area (m²); **θ₁ – θ₂** = Temperature difference (°C)

B2.2 Thermal Conductivity

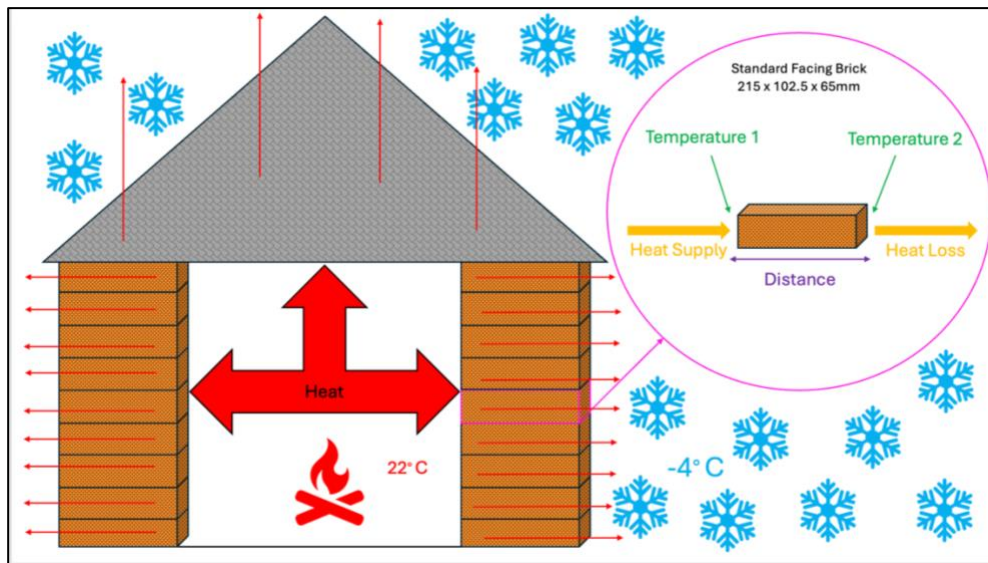


Figure B2.2.1 : Diagram illustrating the concept of heated air moving through thermal bridges to colder environments.

Thermal conductivity can be measured by calculating the rate of conduction through an object. The heat flow is expressed in Watts/mK, indicating the quantity of heat energy transferred per meter of material in every 1°C change in temperature. Utilising figure B2.2.1 as an example, one can apply the relevant information in the following equation to calculate a standard facing brick's conductivity that has a thermal conductivity of 1W/mK.

$$^8 \text{Rate of heat flow (Conductivity)} \frac{H}{t} = \frac{\lambda \times A \times (\theta_1 - \theta_2)}{d}$$

$$8.815 = \frac{1 \times 0.0220375 \times 26}{0.065}$$

⁸ H/t = rate of heat flow; λ = coefficient of thermal conductivity for that material (Watt/mK); A = Cross sectional area of the sample m^2 ; $\theta_1 - \theta_2$ = Temperature difference between the faces; D = distance between the faces (m)

A material's thickness and thermal properties are extremely influential to its conductive capabilities. Table B2.2.1 demonstrates how thickness decreases the rate of heat flow per object. For experimental fairness, the temperature difference and cross-sectional area was maintained throughout each object to clearly demonstrate the influence of thickness to the rate of heat flow.

Table B2.2.1: Comparing the thermal conductivity of rockwool, steel and brick.

Material	Thermal Conductivity (W/mK)	Cross sectional area (m²)	Temperature difference (°C)	Distance (thickness)	Rate of Heat Flow (W/mK)
Rockwool	0.35	0.25	15	10mm	131.25
Rockwool	0.35	0.25	15	30mm	35
Standard Facing Brick	1	0.25	15	10mm	375
Standard Facing Brick	1	0.25	15	30mm	125
Steel	45	0.25	15	10mm	16,875
Steel	45	0.25	15	30mm	5,625

Word Count 2,497 (excluding tables and diagrams).

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