

## Introduction

We all know about global warming and that we are running out of fossil fuels. We know that we need to reduce consumption of our finite resources of gas, coal and oil and most countries now realise that we also need to reduce emissions of Greenhouse Gases, for example Carbon Dioxide (CO<sub>2</sub>). What you might not realise is that in the UK, buildings account for approximately 50% of total annual CO<sub>2</sub> emissions. These emissions are produced during the construction, operation and demolition of buildings.

As a [Mechanical Building Services Engineer \[Link 1a\]](#) I am primarily concerned with the design of [Mechanical Building Services Systems \[Link 2a\]](#) that are [energy efficient \[Link 3a\]](#) or 'green' [\[Link 4a\]](#) and with making sure that the people inside the buildings are happy – that they're not too hot or too cold. I do this by ensuring that the conditions inside the buildings are correct for the activity being carried out. An office will have different requirements to a school or a house or a factory

[\[Link 1a\]](#)

A Mechanical Building Services Engineer is responsible for the design of the systems that control the internal environmental within a building – that is the heating, cooling, ventilation and façade systems and the design of all the equipment and distribution systems, such as boilers and pipes, that go with them.

[\[Link 2a\]](#)

The heating, cooling and ventilation systems.

[\[Link 3a\]](#)

By Energy Efficient we mean a building that uses as little energy as possible to power the building services systems within it, thus reducing consumption of fossil fuels. Or it could be a building that uses [renewable energy \[Link 1b\]](#) sources to power it instead of fossil fuels. Or it could be a building that is designed in such a way that we can reduce or even eliminate the need for the building services systems.

[\[Link 1b\]](#)

For example solar or wind power.

[\[Link 4a\]](#)

A green building is one that has as little impact on the environment as possible. This could effect the choice of materials used, the location of the building and its use. It will also effect the choice of the environmental systems within the building and the fuel source used to power these systems.

The following article is going to concentrate on the energy used by the [Mechanical Building Services Systems \[Link 2a\]](#) during the operation of the building and how we can design a building in such a way as to reduce the amount of energy used.

## Why do buildings use energy?

Energy is used in the construction of buildings, during the creation of the materials to be used, in transporting the materials to the building site and during the construction process itself. Energy is also used in the demolition of a building at the end of its life. When analysing how much energy a building uses and how much it contributes to CO<sub>2</sub> emissions it is necessary to consider its whole lifecycle, which includes the energy to create and destroy it as well as that to use it.

However, we are going to concentrate on the energy that is used in a building during its [operating life \[Link 5a\]](#) and more specifically the energy used by the [Mechanical Building Services Systems \[Link 2a\]](#) and how incorporating [energy efficient \[Link 3a\]](#) principles into the design of the building can reduce the amount of energy used.

[Link 5a]

The time during which the building is occupied and used for the purpose that it was designed for.

We need to design a building to ensure that the people that use the building are comfortable [Link 6a] inside it.

[Link 6a]

Comfort is a measure of how happy people will be in a space. Professor P O Fanger [Link 2b] developed comfort criteria [Link 3b] based on various factors including the temperature in the space, the clothing that the occupants are wearing and the activity that they are carrying out.

Imagine that you are sitting still in a room wearing shorts and a T-shirt – in the winter – you are likely to feel a bit cold! However if you were wearing jeans and a jumper you would probably feel comfortable. Now imagine that you're still wearing those jeans and jumper but you are asked to run around the room – I bet you feel far too hot now!

Making sure a space is comfortable is about designing the right environment for the activity that is going to be carried out in it and for what people are likely to be wearing to do it. However, everyone is different and some of you might feel quite comfortable sitting in that room in shorts in the winter – and this is what makes comfort a very difficult thing to define and to design for!

Other things to think about when considering occupant comfort are factors such as the amount of daylight in a room, can people see outside and do the occupants have any control, for example can people open the windows or are they able to switch the heating on or off? All these contribute to how much a person will like being in the building.

[Link 2b]

Professor Fanger developed the model for assessing Thermal Comfort. He is Director of the International Centre for Indoor Environment and Energy. He has received numerous awards for his outstanding contribution to Building Services Engineering based on his development of criteria for human comfort, health and productivity.

[Link 3b]

If a group of people are all in the same room, it is extremely unlikely, due to biological differences, that all of them will feel comfortable.

The most important variables which influence Thermal Comfort are:

Activity level [Link 1c]  
Thermal resistance of clothing [Link 2c]  
Air temperature [Link 3c]  
Mean radiant temperature [Link 4c]  
Relative air velocity [Link 5c]  
Relative humidity [Link 6c]

The predicted level of Comfort in a space can be described in two ways:

### **Predicted Mean Vote (PMV)**

This is an index that has been derived to make a prediction of how comfortable a person is based on the above criteria. The following scale is used:

-3 cold  
-2 cool  
-1 slightly cool  
0 neutral  
+1 slightly warm  
+2 warm  
+3 hot

From experiments enough data is now available that for given criteria the PMV of people in a space can be estimated. From this an equation to calculate PMV has been derived, however it is rather complicated and in practice we generally calculate it using computer analysis software.

#### **Percentage People Dissatisfied (PPD)**

PMV allows us to see whether a group of people will be mainly too warm or too cool, however what does a PMV of +2 really mean – it means that an ‘average person’ will be warm, but it doesn’t tell us how many people will be slightly warm or hot.

As people who are uncomfortable are more likely to complain, it is important when analysing a particular design to quantify how many people will be ‘dissatisfied’, that is uncomfortable.

Again a relationship has been found using experimental data using the results for the PMV for the space. PPD increases the more the PMV deviates from neutral. In practice this is also determined using computer analysis software.

[Link 1c]

What are you doing in the space and so, how much heat is your body producing?

[Link 2c]

How warm is your clothing? A woolly jumper has more thermal resistance than a T-shirt!

[Link 3c]

Simply the air temperature in the space – the same type of temperature measurement as you get in a weather forecast.

[Link 4c]

Mean radiant temperature is the mean temperature of all the surfaces that are surrounding you. A warm surface will radiate heat to you – the mean radiant temperature assesses the temperature of all the surfaces that your body can ‘see’ and determines the average radiant temperature that you will feel.

[Link 5c]

Is the space draughty or stuffy?

[Link 6c]

Is the air in the space moist, making you feel ‘sticky’ or is it dry, making you mouth and throat dry?

A **heating system** [Link 7a] is required to keep the building at a comfortable temperature when the temperature outside falls to a temperature that would not be comfortable to live/work in. This system could be as simple as the radiators in your house.

[Link 7a]

For example a boiler that produces hot water to serve radiators.

A **cooling system** [Link 8a] may be required to keep the building a comfortable temperature when the temperature outside rises to a temperature that would not be comfortable to live/work in. This will depend on the function of the building and the climate in which you are building.

[Link 8a]

For example a chiller that produces cold water that can then be used to serve cooling units in a space, much in the same way that radiators use hot water to provide heat to a space.

A ventilation system [Link 9a] may be required to provide a fresh air supply for the people using the building. This could be as simple as opening the windows, but in some buildings this is not possible and therefore a mechanical system ventilation system will be required.

[Link 9a]

For example an air handling unit which contains fans that can move air around a building allowing air to be supplied to all areas. At certain times of the year this air may need to be heated (using the hot water from the boilers) or cooled (using the cold water from the chillers).

### How much energy will a building use?

In order to determine how much energy a building will use we need to consider what the building is made from (what materials), what the heat loss [Link 10a] will be, how much solar radiation [Link 11a] will hit the building (and therefore what the associated heat gain [Link 10b] will be) and what sort of internal loads [Link 12a] will be present within the building.

[Link 10a]

Heat loss occurs through the walls, roof and floor of a building and the amount of this heat loss is determined by the properties of the materials used in the construction of the building and the temperature difference between inside and outside.

The thermal properties of a material are expressed in terms of its thermal resistance. For solid materials, such as concrete, stone and glass, heat is transmitted by conduction [Link 4b]. The thermal resistance [Link 5b] is directly proportional to the thickness of the material.

For materials such as insulation, where there are air gaps in the material, heat may be transmitted by a combination of solid and gaseous conduction, convection [Link 6b] and radiation [Link 7b].

Different building materials have different conductivities and these are detailed in The Chartered Institution of Building Services Engineers technical literature – specifically in 'Environmental Design - Guide A'.

For example glass conducts more heat than concrete, while insulation materials have a far lower conductivity than concrete. Insulation is used to limit the heat loss through walls and roofs by including it in the layers of materials which make up a wall or roof.

Once we know the individual properties of a material we can calculate the thermal properties of the whole construction element, for example a wall that comprises layers of different materials. This is called its Thermal Transmittance or its U-Value [Link 8b].

Multiplying the U-value of the construction by its area gives us the rate of heat loss per unit of temperature difference between inside and outside. This then allows you to calculate the Total Fabric Heat Loss [Link 9b].

Heat will also be required to combat air infiltration in to the space. The amount of infiltration will be depend on how 'leaky' the construction is. To calculate the heat loss due to infiltration we need to know the amount of air that is leaking in, and we generally make an estimate based on the type of construction being used. Then we can calculate the Total Infiltration Heat Loss [Link 10b].

A way of reducing the heating load associated with infiltration is to design and detail the building with air tightness in mind. By this we mean that the building construction details are such that they minimise the amount of air that can pass through them – that is they aren't leaky!

The calculation of the fabric and infiltration losses allows us to determine the amount of heating required for the building.

[Link 4b]

Conduction is the transfer of heat through a substance resulting from a difference in temperature between different parts of the substance. Molecules in the substance vibrate against neighbouring molecules, from regions of higher temperature to regions of lower temperature. The rate of heat flow between two regions is proportional to the temperature difference between them and the heat conductivity of the substance.

[Link 5b]

$$\text{Thermal Resistance} = \frac{\text{Thickness}}{\text{Thermal conductivity}}$$

[Link 6b]

Convection happens because fluids/gases expand when heated and thus undergo a decrease in density. As a result, the warmer, less dense portion of the fluid will tend to rise through the surrounding cooler fluid. If heat continues to be supplied, the cooler fluid that flows in to replace the rising warmer fluid will also become heated and also rise. Thus a convection current is established in the fluid, transferring heat through it.

[Link 7b]

Radiation is a term applied to the emission and transmission of energy through space or through a material medium.

[Link 8b]

$$U\text{-Value} = \frac{1}{\text{Total Thermal Resistance}} \\ \text{Rsi} + \_R + \text{Rso}$$

Where Rsi is the Internal Surface Resistance and Rso is the Outside Surface Resistance. Traditional UK values for these are defined in British Standards.  $\_R$  is the sum of the resistances of all the materials within the construction.

[Link 9b]

Total Fabric Heat Loss is dependant on the temperature differential between inside and outside and is calculated as follows:

$$\text{Total Fabric Heat Loss} = \text{U-Value} \times \text{Area} \times \text{Temperature Difference}$$

[Link 10b]

Total Infiltration Heat Loss is dependant the amount of air that leaks into a space, that is how leaky the construction is, and on the temperature differential between inside and outside and is calculated as follows:

$$\text{Total Infiltration Heat Loss} = (c \times \rho \times N) \times \text{Temperature Difference}$$

3600

Where c is the specific heat capacity of the air,  $\rho$  is the density of the air and N is the air change rate i.e. how much air infiltrates per hour.

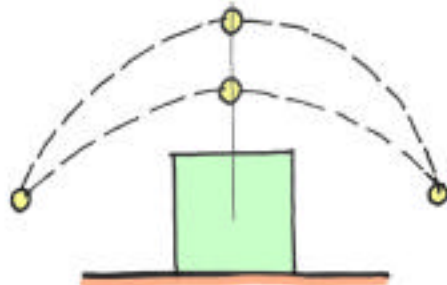
[Link 11a]

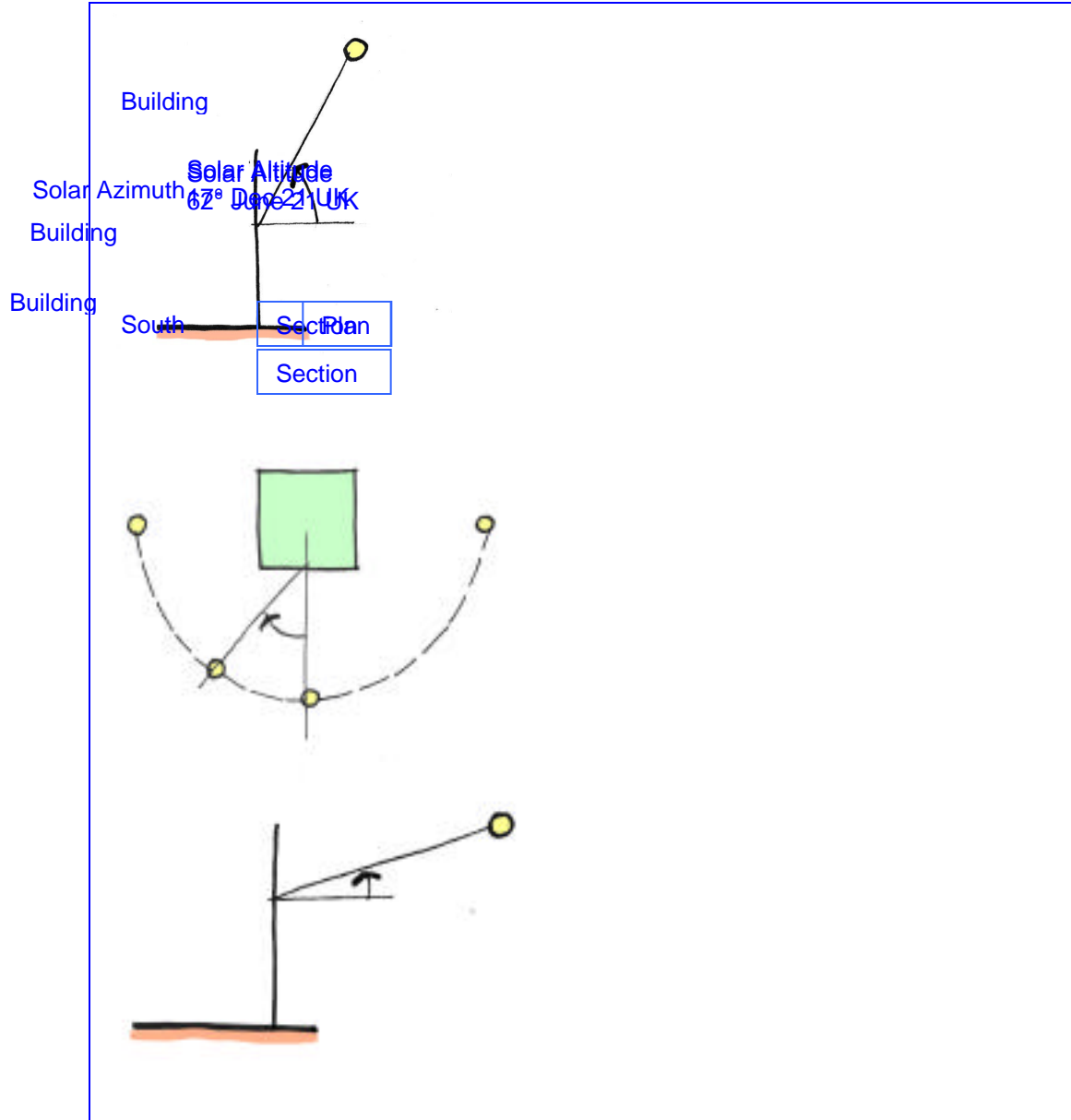
When we talk about Solar radiation [Link 11b] we mean all the types of radiation emitted by the sun. Summer

South

In order to determine the effect of this radiation on a building we need to know the intensity [Link 12b] of the radiation falling on a façade throughout the day. To help Mechanical Building Services Engineers [Link 1a] there is measured data available for many locations throughout the world that we can look up and use to determine the intensity at any given time of the day/month/year for our building. We can find this data in The Chartered Institution of Building Services Engineers technical literature – specifically in 'Environmental Design - Guide A'.

Once we know what the intensity of the sun is we need to consider the path of the sun around the building so that we can determine which part of the building the sun will be hitting at any time during the day/month/year.

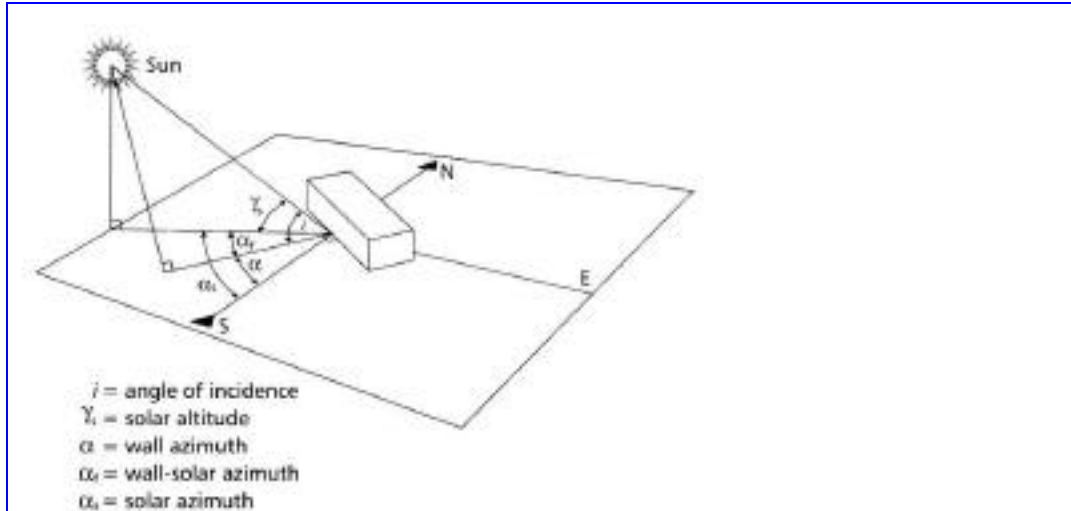




**Figure 1a** – Path of the sun through the day

The sun rises in the East and sets in the West. As the sun moves through the sky over the course of the day it gets higher in the sky, peaking on the south at lunchtime and we refer to this angle as the **solar altitude** [Link 13b]. This angle varies through the year, with the sun being much higher in the sky in the summer that it is in the winter. We refer to how far it has travelled between East and West, measured from due south, as the **solar azimuth** [Link 14b].

The location of the sun may be described by these two angles. This data is also available in tabular form in Guide A for us to refer to and use in our calculations.



**Figure 1a - Solar Geometry**

Once we know the intensity, and where the sun is in relation to our building, we can begin to look at the amount of heat that will transfer through a façade/window, the **heat gain** [Link 15b]. This will allow us to size the cooling system required to combat the gain from the sun.

The amount of this heat gain will depend on largely on the angle of incidence [Link 16b] of the solar radiation, the properties [Link 17b] of the glazing and any shading [Link 18b] used on the façade.

[Link 11b]

$$\begin{aligned}
 &\text{Solar Radiation} \\
 &= \\
 &\quad \text{Ultra-Violet} \\
 &\quad + \\
 &\quad \text{Light (visible radiation)} \\
 &\quad + \\
 &\quad \text{Infra-red (thermal radiation)}
 \end{aligned}$$

The infrared part of the solar spectrum is the main contributor to solar heat gain through a glass facade.

[Link 12b]

The intensity of the radiation is referred to as irradiance.

Irradiance

$$\begin{aligned}
 &= \\
 &\quad \text{Direct Radiation} \\
 &\quad + \\
 &\quad \text{Diffuse Radiation} \\
 &\quad + \\
 &\quad \text{Reflected Radiation}
 \end{aligned}$$

Irradiance is the radiant energy incident on a plane per unit surface area per time unit – Joule per second per metre squared = Watts per metre squared ( $W/m^2$ ).

**Direct solar radiation** is the direct radiation coming from the sun. The direct irradiance on a surface is dependent on the angle of incidence.

**Diffuse solar/sky radiation** is the scattered and reflected solar radiation coming from the whole hemisphere. It is more or less evenly distributed over the earth's surface.

The relationship between direct and diffuse is determined by the distance travelled through atmosphere to reach the earth at that point and the amount of haze and/or cloud cover

**Reflected solar radiation** is that which is reflected back at the building by any surrounding surfaces.

[Link 13b]

The angle between the horizontal plane and the sun beams

[Link 14b]

The angle between the projection of the sunbeams on the horizontal plane and the south – to the east positive and to the west negative.

[Link 15b]

The Heat Gain into a space through a window is made up of the direct radiation from the sun – the short wave, and indirect radiation from the window, long wave. It is often referred to as the Solar Gain.

Heat gains through a glass façade

=

Short wave radiation

*Emitted by the sun*

*(v. hot)*

+

Long wave radiation

*Emitted by the window (cool)*

[Link 16b]

When visible and thermal radiation hit a glass surface they are either transmitted or reflected. The exact proportions depend on the angle of incidence (the angle between a perpendicular to the window surface and the sun's rays). As this angle increases more light is reflected and less is transmitted. When determining the heat gain we are interested in the thermal radiation. Thermal radiation can also be absorbed and subsequently re-radiated [Link 12b]

[Link 17b]

The proportion of the incident thermal radiation that is actually transmitted through a window depends not only on the angle of incidence but also on the properties of the glass that is being used.

Glass performance is represented using the following characteristics:

**Direct transmission** [Link 7c]

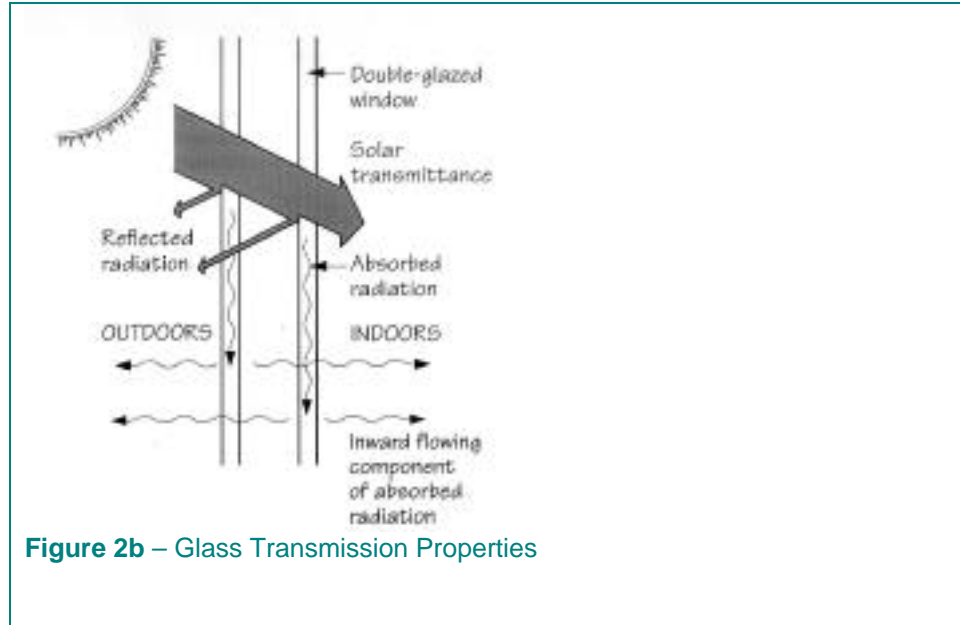
**Reflection/Reflectance** [Link 8c]

**Absorption/Absorptance** [Link 9c]

**Indirect transmission/Re-transmission** [Link 10c]

**Total Transmission** [Link 11c]

**Solar Gain Factor** [Link 12c]



**Figure 2b** – Glass Transmission Properties

[Link 7c]

The fraction/percentage of incident thermal radiation that passes through the glazing without change of wavelength, that is it remains short wave. For multi-layered glazing this includes any radiation that is reflected between the layers but still emerges on the inside of the glazing.

[Link 8c]

The fraction/percentage of the incident radiation that does not penetrate through or into the window but remains on the outside of the glazing.

[Link 9c]

The fraction/percentage of incident radiation that is not transmitted or reflected. This raises the temperature of the glazing and is then dissipated to the air on either side. The amount of heat energy released depends on the emissivity of the glass surface, that is, how much it radiates – this is the long wave component.

[Link 10c]

This is long wave radiant energy transferred from the warmed glazing to the room (due to the absorption).

[Link 11c]

The total fraction/percentage of the incident radiation that is transmitted into the room

Total Transmission

=

Direct Transmission (short wave)

+

Indirect Transmission (long wave)

[Link 12c]

This is the same as total solar transmittance but is usually only applied to glass combinations i.e. a double glazed unit – taking into account the combined properties of the two panes of glass.

[Link 18b]

Shading in this context refers to blinds, overhangs, external louvres, awnings etc. – anything that impedes the transmission of solar energy into the space.

[Link 12a]

People, lights, computers, photocopiers etc generate internal gains in a building. All of these things give off heat and the cooling systems will need to counteract this heat to maintain the temperature required in the space. A way of reducing the need for heating during the day can be to balance these internal heat gains with the heat loss from the building.

The basics of the building design and of the [building physics](#) [Link 13a] will have the biggest effect on the energy consumption from the mechanical systems

[Link 13a]

Building physics refers to the way in which the building and the materials used to construct it react to certain conditions, inside and outside the building.

### How is a building designed?

As you can see, when designing a building there are lots of things to think about. There are also a lot of people involved in the process.

The [architect](#) [Link 14a] will come up with a [concept](#) [Link 15a] for the building and then the [Design Team](#) [Link 16a] will help them optimise their ideas within the constraints of the design – that is client expectations, cost, location, use etc. In order to design a building well the whole team needs to work together to produce the best design for everyone. This may involve compromise between the various aspects of the design, for example – a building needs to look good, but it also needs to be within budget, gold taps might look great but if the client can't afford them he won't thank the team for designing them. The budget might be tight, but getting rid of the heating system to save money isn't an option! These are extreme examples, but the end product of the design process needs to fulfil all the requirements of the client and the user.

[Link 14a]

The Architect designs the form of the building and the relationships between the spaces inside. They are concerned with how the building blocks, the different rooms and functions, will fit together in 3D and how people will move around and use the spaces.

[Link 15a]

The Concept Design is the first idea of what the building will look like. This may be done for a competition or for a specific development.

Concept is the first stage of a design process that could go on for years! The basic phases of a typical building project are as follows:

[Concept Design](#) [Link 19b]

[Scheme Design](#) [Link 20b]

[Detailed Design](#) [Link 21b]

[Tender Stage](#) [Link 22b]

[Construction Stage](#) [Link 23b]

[Operation](#) [Link 24b]

[Link 19b]

The first ideas are generated without many of the details being defined. At the end of this stage there may be several ideas on the drawing board to study further.

[Link 20b]

This is the stage where the design becomes more defined. Whereas at the end of Concept there may still be a few ideas to look at, at the end of Scheme there will be one idea and this will have been defined sufficiently for a preliminary cost for the building to have been estimated.

[Link 21b]

During this stage the design will be developed to a level of detail from which it can be fully costed and then built. During this stage the building services engineers will have designed and specified the systems within the building right down to component level, that is every radiator, piece of pipe, fan, duct etc. will have been sized, drawn and detailed.

[Link 22b]

This is when the companies that would like to construct the building get involved and say how much they think it will cost them to do it. They are given the detailed design information and from this they will put together a bid to do the job. These bids are then assessed and the successful companies will join the team.

[Link 23b]

During this stage the building will actually be built. All the building services systems will be installed and tested to ensure that everything works properly.

[Link 24b]

Once the construction of the building is complete the building will be given to the Client to use.

[Link 16a]

A lot of people are involved in the design of a building, but the main players are as follows:

The Client [Link 25b]  
The Architect [Link 26b]  
Structural Engineers [Link 27b]  
Services Engineers [Link 28b]  
Specialists [Link 29b]  
Quantity Surveyor [Link 30b]

[Link 25b]

This is the guy with the money! They want a building for a specific purpose, be it a house, office, factory, school, hospital... and they want a team of people to realise this dream for them.

[Link 26b]

They are often the first people that the client speaks to and in that capacity often lead the design team, which is made up of them and the engineers and any specialists required.

[Link 27b]

They are responsible for the structural design of the building, making sure that it is stable and that it stands up!

[Link 28b]

Along with the Mechanical Building Services Engineers [Link 1a], there will also be Electrical Engineers responsible for designing the power systems to the building – providing power to all the Mechanical Services Systems, all the power sockets in the building – and for the design of the lighting systems. There are also the Public Health Engineers who are responsible for designing all the domestic water and drainage systems, for example in the toilets and kitchens.

[Link 29b]

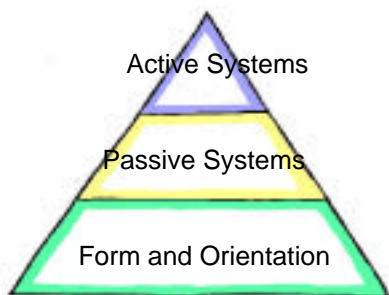
Depending on the type of building, specialist designers may be required. For example a theatre will require input from an Acoustics Engineer and many buildings will require input from a Fire Engineer.

[Link 30b]

These are the people that keep an eye on the money for the client. They are responsible for developing a budget for the building and then tracking the actual costs over the life of the project against this budget.

### What can help to make a building green?

When designing a [green building](#) [Link 4a] there are many things to consider, but we are going to concentrate on what we can do to reduce the energy consumed by the [Mechanical Building Services Systems](#) [Link 2a]. The best way to do this is to design the building in such a way that you don't need to add the building services systems to it.



**Figure 1** – The Green Pyramid

As we move up towards the top of the 'Green Pyramid', the cost and complexity of the systems increases, another reason to try and do as much with the form and orientation as possible.

The following sections describe the main areas to concentrate in the design of a building to contribute to the design of a building that is [energy efficient](#) [Link 3a].

#### Form/Shape [Section 1]

The form can effect the efficiency of building. For example, a narrow plan building lends itself to [natural ventilation](#) [Link Section 5], while a deep plan building doesn't.

A tall building has different considerations – for example openable windows can be difficult in taller buildings due to increased wind effects.

First the basics. When designing a [green building](#) [Link 4a] there are many things that we can do to reduce the energy consumption, however the best thing we can do is get the [form/shape](#) [Link Section 1] and the [orientation](#) [Link Section 2] and the [Façade Design](#) [Link Section 3] of the building right. If we can do this then we have won half the battle.

The next things to think about are passive systems, that is systems that require no power, such as [shading](#) [Link 18b] systems.

The last thing to do is add active systems, systems that require additional power, such as motorised [shading](#) [Link 18b] systems.

### Orientation [Section 2]

The [orientation \[Link 17a\]](#) of the building is very important, as this will determine the potential [solar gain \[Link 18a\]](#) from the sun into each part of the building.

For example, in an office, we could consider using more glass on the North facing side of the building as the [solar radiation \[Link 11b\]](#) hitting the north is much lower, while we might want to limit the amount of glass on the west side as low afternoon sun can cause a large [heat gain \[Link 15b\]](#) into the building. Whereas in a house we might want to face the building south-west so that we get the benefit from the gain to offset the heating load.

[Link 17a]

This relates to how the building is positioned in relation to north, east, south and west. The amount of façade that faces in a particular direction will effect the amount of sun hitting the building.

[Link 18a]

The solar gain or [heat gain \[Link 15b\]](#) refers to how much of the solar energy hitting the building actually gets into the space – the [Total Transmission \[Link 5c\]](#). Whether gain is good or bad depends on type of building and time of year. For example, in a house this gain may be beneficial in the winter, however in an office, this additional gain may be undesirable all year.

### Façade Design [Section 3]

Ultimately the design of the façade of a building is the most significant factor when considering the energy required for the [Mechanical Building Services Systems \[Link 2a\]](#). The heating and cooling required to combat the [heat loss \[Link 10a\]](#) and the [heat gain \[Link 15b\]](#) are two of the most significant elements of the total energy used by the building.

For an [energy efficient \[Link 3a\]](#) building we want to try to minimise the [solar gain \[Link 19a\]](#) in the summer while considering beneficial gain in the winter.

To minimise the gain, we need to consider the amount of glazing in the building, the type of glass that is being used and any [shading \[Link 18b\]](#) systems that are being used.

The easiest thing to review is the amount of glass in the building – obviously the less glass the less the gain there will be into the building. However, there are other things to think about when looking at the amount of glazing, for example daylight and view out of the building – both of which have an effect on the [comfort \[Link 6a\]](#) of the occupants.

The next thing to consider is the glass being used – you want a glass that will help reduce the [solar gain \[Link 18a\]](#). There are lots of different types of glass that you can buy that vary the different [properties \[Link 17b\]](#) of the glass to help to reduce the gain. We generally use double glazing systems, that is two panes of glass separated by an air filled cavity. We might then add a coating to one of the panes to increase the [reflection \[Link 2c\]](#) from it, or we might add a colour/tint which increases the [absorption \[Link 3c\]](#) of the glass. There are lots of manufacturers of glass, but a good one to have a look at to learn more about the properties of glass and the types of coating and colours that can be added is Pilkington, check out [www.pilkington.com](http://www.pilkington.com).

So, we've thought about the area of glass and the type of glass, but what if that's not enough and the [solar gain \[Link 18a\]](#) is still too high? Well, the next things to consider are [shading \[Link 18b\]](#) systems which can limit the gain into the building.

Shading can also increase the [comfort \[Link 6a\]](#) of the occupants – glass will get hot when the sun hits it and is [absorbed \[Link 3c\]](#) which creates a [radiant effect \[Link 19a\]](#) that can make people feel uncomfortable. [Glare \[Link 20a\]](#) is another issue to consider and shading can help to reduce this effect.

[Link 19a]

When you sit next to a window you feel the effect of two things - the **direct transmission** [Link 1c] of solar radiation [Link 11a] hitting you and the effect of the hot pane of glass, due to the **absorption** [Link 3c] in the glass, **radiating** [Link 7b] heat to you.

[Link 20a]

Glare refers to the brightness from the sun that can, for example, make it difficult to see your computer.

There are several different ways of providing **shading** [Link 13b] to a building.

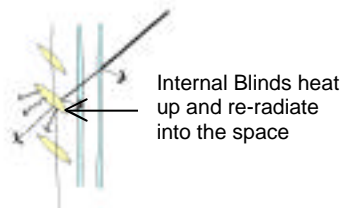


Figure 2 – Internal Blinds

#### Internal blinds:

These do not provide much shading as the **solar gain** [Link 18a] has already made it in to the room. Internal blinds can also get very hot, increasing the risk of people feeling uncomfortable when sitting next to the window due the **radiant effect** [Link 19a]. However, internal blinds can help with **glare** [Link 20a] control.

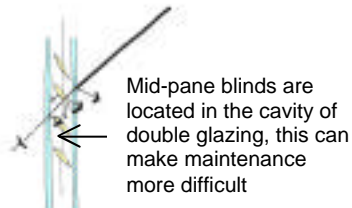


Figure 3 – Mid-pane Blinds

#### Mid pane blinds:

These are better than internal blinds at providing shading from **solar gain** [Link 18a]. There can be problems with maintenance as they are located within the cavity in the glazing. They can help with **glare** [Link 20a] control.

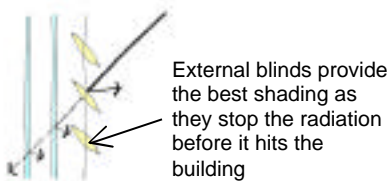


Figure 4 – External Blinds

#### External blinds/louvers:

These provide the best protection from **solar gain** [Link 18a] as they stop the majority of the **solar radiation** [Link 11a] from finding it's way into the glazing system in the first place. However they do not generally provide **glare** [Link 20a] control as they often cannot be controlled by the occupants.

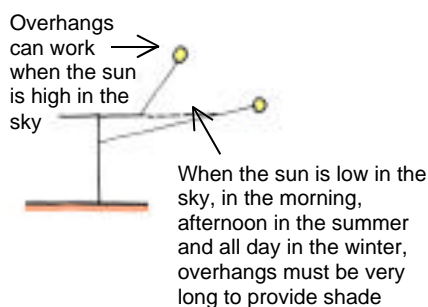


Figure 5 - Overhangs

#### Overhangs:

These will provide protection from **solar gain** [Link 18a] when the length of the overhang is long enough to cut off the sun at a particular **solar altitude** [Link 8b]. Therefore, unless the sun is very high in the sky or the overhang is very long, they are of limited benefit over the year. They do not provide **glare** [Link 20a] control.

For an **energy efficient** [Link 3a] building we also want to try to minimise the **heat loss** [Link 10a] in the winter. To minimise this loss, we need to consider the types of materials used in the building. We want to minimise the use of materials that **conduct** [Link 4b] a lot of heat and use insulating materials as much as possible. We also need to consider the **infiltration loss** [Link 10b].

Another consideration when looking at the design of the façade and the heating required is [down draughts \[Link 21a\]](#) from glazing. It is this and the fact that the heat loss itself occurs through the external walls which means that radiators are generally located against the external wall, particularly under windows.

[Link 21a]

Down draughts are caused by the cold surface of the glass. As air in the room hits this cold surface it also cools down and 'drops' down the glazing causing draughts. The cold surface of the glass can also result in a cold radiant effect – sitting next to the cold surface will make you feel cold as you lose heat to the window – as you do when you touch a cold surface.

#### Thermal Mass [Section 4]

Another thing to consider when choosing the materials used in the construction of the building is the [mass \[Link 22a\]](#) of those materials. Using lightweight and heavyweight constructions will result in different effects on the internal environment of the building.

[Link 22a]

How heavy/dense the material is.

A lightweight construction, for example a building with a lot of glass, will result in the internal environment reacting very quickly to changes in the outside temperature – imagine a greenhouse. This sort of building requires [Mechanical Building Services Systems \[Link 2a\]](#) that react very quickly to changes in temperature and this will effect your choice of systems and the amount of energy that the systems use.

A heavyweight construction, for example high density concrete or stone, will result in a far more stable internal environment as the concrete will 'dampen' [\[Link 23a\]](#) the effect of changes in outside temperature as the 'time lag' [\[Link 24a\]](#) on concrete is far higher than that for glass. Imagine being inside an old church or a castle on a summers day – even if it's really hot outside, it will still feel cold inside. The same is true in the winter – even when it's really cold outside, it will feel warmer inside.

[Link 23a]

Lessening the effect – in this case slowing the effect.

[Link 24a]

Materials will take a certain amount of time to [conduct \[Link 4b\]](#) heat through them from one surface to the other – materials like concrete have a long time lag which means that heat on the outside surface will take time to reach the inside – this effect can be used to release heat into the building later in the day when the outside temperature has dropped.

We can use this effect inside the building too, by choosing the right materials. Exposed concrete ceilings or walls can be used as a [heat sink \[Link 25a\]](#). During day excess heat in the space, for example from the [internal gains \[Link 12a\]](#), is absorbed by mass. This heat will then be released later in the day when the temperature in the space starts to drop.

[Link 25a]

Something that absorbs heat.

This effect can also be used to cool the space. Cold air is passed over the mass, cooling it down. This is often done over night in the summer. The cold slab then acts as a more efficient [heat sink \[Link 26a\]](#) during the day.

Natural Ventilation [Section 5]

Natural ventilation at it's simplest is openable windows and when considering natural ventilation you want to take advantage of the fact that hot air rises!

Natural air flow through a building depends on the pressure difference between inside and outside. This pressure difference could be due to the [wind effect \[Link 26a\]](#) on the building or it could be due to a difference in temperature between inside and outside. This is generally referred to as [stack effect \[Link 27a\]](#).

[Link 26a]  
 Wind will drive air into the building through openings on the windward side of the building due to the pressure effect of the wind hitting that side of the building. Air will then pass from this side of the building to the other where it will exit through openings on the leeward side, where the pressure will be lower.

[Link 27a]  
 Cool air is denser than warm air therefore if a building is hotter inside than it is outside, gravity will cause cold air from outside to enter through low level openings to displace the warmer inside, which escapes through openings at high level.

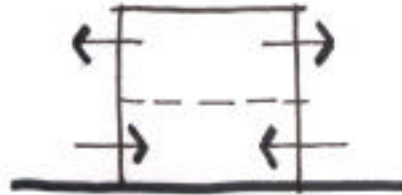
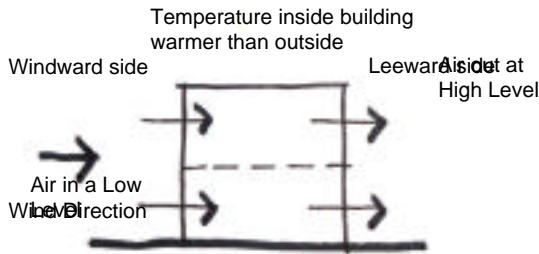


Figure 6 – Wind Driven Ventilation

Figure 7 – Temperature Driven Ventilation

Natural Ventilation systems have to be low resistance as they have no ‘power’ behind them, for example from a fan, to combat any resistance in the system.

You also need to be careful of how they are controlled, if occupants can control them then they will choose to let hot or cold air into the building, for example by opening a window. If it’s centrally controlled then tighter limits are required on the acceptable outside air temperatures that can be used – people will feel uncomfortable if hot or cold air hits them that they can’t control.

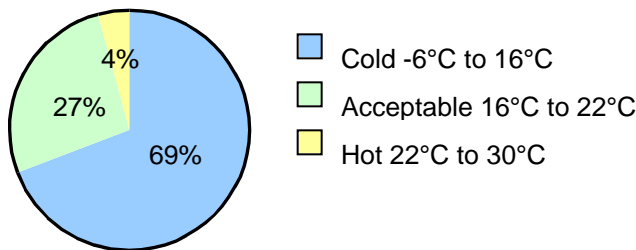


Figure 8 – Typical Temperature Frequency for London

If we look at typical year of weather data from London for example, a centrally controlled natural ventilation system could only be used for approximately 30% of the year, when the temperature is deemed to be ‘acceptable’ to supply into a space with no additional treatment, that is heating or cooling. This makes it a pretty inefficient solution!

Another consideration is the location of your building – you need to think about how noisy it is outside and what the air quality is like – if it's on a busy main road then openable windows may not be desirable!

### The future?

If we were to design the ideal 'energy efficient' [\[Link 3a\]](#) building what might it be like? How can we use the elements we've just described most efficiently in a real building? What are the limitations of applying these principles, do any of them contradict each other? For example, there is a conflict between reducing [heat loss \[Link 10a\]](#) and providing daylight.

As we've seen, to reduce [heat losses \[Link 10a\]](#) we want to reduce the use of materials that [conduct \[Link 4b\]](#), and glass conducts much more than, say, concrete. So windows allow heat to pass through them more easily than a solid wall would. This would imply that to minimise heat losses, and so heating requirements, you would want a building with very few windows. However, this means that daylight into the building would also be minimised and as we have seen, one of the factors that affects occupant [comfort \[Link 6a\]](#) is the amount of daylight into, and view from, a space.

So, designing the 'ideal' building is a complicated problem!

In the winter season we want to reduce the heating requirements of the building. To do this we can use the [thermal mass \[Link Section 4\]](#) of the building and use insulating materials in the construction rather than those that [conduct \[Link 4b\]](#) heat easily.

We also need to carefully consider the use of glass in the building, reaching a compromise between [heat loss \[Link 10a\]](#), beneficial [heat gain \[Link 15b\]](#), for example [solar gain \[Link 18a\]](#) in house may be useful as it contributes to the heating of the space thus reducing the reliance on the heating system, and daylighting whereas in an office that already has constant [internal loads \[Link 12a\]](#) this additional gain is not desirable.

In the summer season we want to reduce the cooling requirements of the building. Again we could use the [thermal mass \[Link Section 4\]](#) of the building, utilising night time cooling and the mass to stabilise the internal environment.

Again we need to carefully consider the use of glass, ensuring that areas of glazing have good [shading \[Link 18b\]](#) systems to reduce [solar gain \[Link 18a\]](#) when required.

We want to try and utilise [natural ventilation \[Link Section 5\]](#) wherever possible, throughout the year, to reduce the requirements of any ventilation system.

For example, providing openable windows, or vents in the façade, allows us to reduce the time of the year that the building requires a mechanical ventilation system. We need to consider the form of the building carefully so that it lends itself to natural ventilation, for example by designing a narrow plan building that allows more of the internal spaces to be naturally ventilated than a deep plan building would.

Designing an [energy efficient \[Link 3a\]](#) building requires us to combine many different, at times conflicting, design principles. It is this that presents us with the challenges and opportunities that make designing buildings such an exciting and rewarding experience.