8 RADIATION

8.1 Introduction

The sun is a powerful source of heat and in Winter it can be usefully used to offset heat losses from buildings. When initially considering sunlight as a design generator, its physical nature was not considered. However, if designers are to predict the thermal response of buildings to sunlight, then a little more needs to be understood about the nature of Sunlight.

Electromagnetic radiation is a physical phenomenon that is able to transport energy through space and some materials. There are a number of types of electromagnetic radiation and most of us are familiar with their names, e.g. X-rays, Ultra Violet, and Microwaves etc. Each of these radiations emanate from different scales of physical system and they principally interact with physical systems that are of a comparable scale. For our purposes the most significant difference between them is that they have different wavelengths and the wavelengths associated with different radiations is indicated in Figure 8.1.

Physical System	Nuclear	Inner Electron	Outer Electron		Molecular
Wavelength in m.	10^{-14}	10^{-10}	10^{-6}		10^{-2}
Type of radiation	γ-rays	X-rays	U.V	Light	Infrared

Figure 8.1 Types of radiation

Radiation travels through the vacuum of space at a speed of 3×10^8 m/s and the relation between speed, wavelength and frequency is the same as with any wavelike phenomenon, and is shown in Figure 8.2.

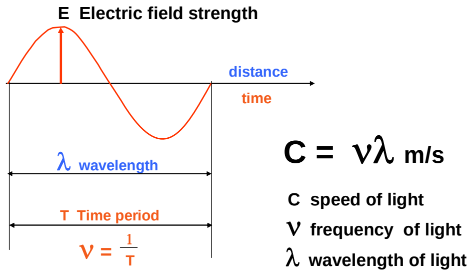


Figure 8.2 Wavelength & Frequency

The speed of light in a vacuum is denoted by c,
Wavelength is denoted by the Greek symbol λ, (lambda)
Frequency is denoted by the Greek symbol ν, (nu)

8.2 Spectroradiometric curve

A source of radiation may emit different amounts of radiation at different wavelengths. The power of radiation emitted at different wavelengths is shown graphically by plotting on a Spectroradiometric curve shown Figure 8.3.

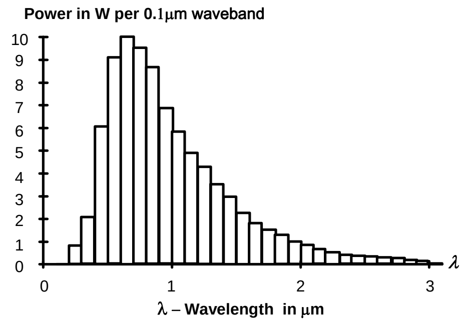


Figure 8.3 Spectroradiometric Curve

Here the power emitted at the different wavelengths is plotted against wavelength. The power emitted must be measured over some defined bandwidth $\Delta\lambda$, and in the curve of Figure 8.3 this is 0.1μm.

The power of the radiation emitted by the source is measured in Watts and is usually denoted by the upper case Greek symbol, Φ_e (phi). The suffix e is used to make clear that the radiation being considered is from the whole of the electromagnetic spectrum.

The total power of the radiation source may be found by summing up the power emitted at all the wavelengths. This will be the total area under the spectroradiometric curve shown in Figure 8.3.

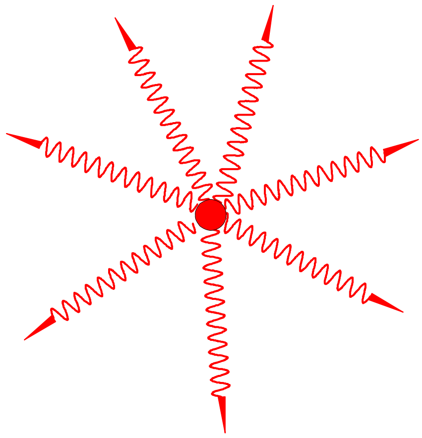
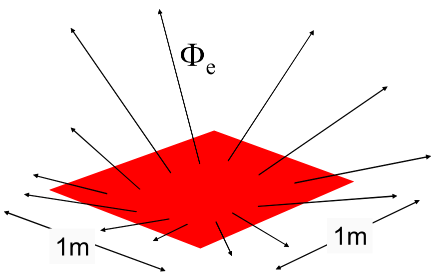


Figure 8.4 Point source



Radiant Exitance, $M_e = \frac{\Phi_e}{A_s}$ W/m^2

Figure 8.5 Radiant Exitance

This is just the sum of the individual contributions of power from all the different wavelengths. This procedure can be simply described using Greek symbol Σ, (Sigma) which represents the operation of – summing together the individual parts.

The total power of radiation will therefore be given by:

$$\Phi_e = \sum_{\lambda=0}^{\lambda=\infty} \Phi_{e\lambda} \quad \text{W}$$

Where:

Φ_e is the power of the radiation source in W,
$\Phi_{e\lambda}$ is the power radiated over bandwidth $\Delta\lambda$ at wavelength λ,
$\Delta\lambda$ is the bandwidth over which the power is measured,
λ is the wavelength at which the power is measured.

8.3 Radiant Exitance

The source of radiation could be a point source, such as is shown in Figure 8.4 where Φ_e Watt are radiated in all directions.

Another source of radiation could be a plane surface where each square metre of surface emits Φ_e W. Such a surface radiation source is described as having a particular Radiant Exitance denoted by the symbol M_e, in W/m^2. Figure 8.5 shows the concept graphically.

Radiant Exitance, $M_e = \frac{\Phi_e}{A_S}$ W/m^2

Where:

M_e radiant exitance of surface in W/m^2,
Φ_e is the power of radiated by the surface in W,
A_S is the area of the surface in m^2.

8.3.1 Radiant Exitance of Plankian radiator

All bodies above a temperature of absolute zero emit electromagnetic radiation. There is a class of bodies known as 'Plankian radiators' that emit the maximum possible amount of radiation dictated by the laws of physics. The Radiant Exitance M_e^{th}, of this theoretical surface depends only upon its absolute temperature and the formula describing its radiant exitance is,

$$M_e^{th} = \sigma T^4 \quad \text{W/m}^2 \qquad 1$$

Where,

M_e^{th} is the Radiant Exitance of the Plankian surface
σ is Stefan-Boltzmann constant = 56·7 x 10^{-12}, (sigma)
T is absolute temperature in Kelvin.

Not only will the total power output of radiation change as the temperature changes, but the nature of the radiation will also change, i.e. the proportion of power radiated at different wavelengths will change. Because a Plankian radiator is a theoretical construct it is possible to calculate its Radiant Exitance at different wavelengths, the symbol $M^{th}_{e_\lambda}$ is used for this quantity. For information, but NOT for learning, the formula for the spectral radiant exitance $M^{th}_{e_\lambda}$ is given in Figure 8.6.

$$M^{Th}_{e_\lambda} = \frac{\lambda^{-5} 3.74 \times 10^{-19}}{e^{\frac{0.01439}{\lambda T}} - 1} \qquad kW/m^2\mu m$$

$M^{Th}_{e_\lambda}$ Theoretical Spectral Radiant exitance in kW/m²µm

λ Wave length in μm

T Absolute temperature in Kelvin

Figure 8.6 Spectral Exitance

The values obtained by applying this formula are shown in Figure 8.7. You should notice that the curves are shown in a slightly different way to that which is normally used. I have used a logarithmic scale for Spectral Radiant Exitance in order that one scale only is needed for different wavelengths. A number of curves have been plotted for a range of absolute temperatures between 300K and 6000K. Two points can be made from this diagram:

1) there is a higher exitance at all wavelengths as temperature increases,

2) the wavelength at which the maximum exitance occurs shortens as the temperature increases.

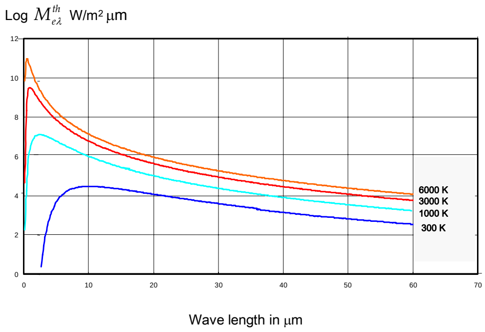


Figure 8.7 Spectral Exitance

The significance of the two extreme temperatures are that 300K represents a surface temperature of 27°C which is near the surface temperature of a human body and also room surfaces, and 6000K is the temperature of the photosphere of the sun and defines the spectrum of sunlight.

Using equation 1 to calculate the radiant exitance at these two temperatures gives the following values:

Temperature in Kelvin	M_e - Radiant Exitance in W/m²
300	418
6000	10×10^7

Figure 8.8 shows the spectrums for a 300K and a 6000K surface plotted on two different linear scales of spectral radiant exitance. Note that the 6000K output continues beyond 5µm but that the values are too small to show on the exitance scale. Also note the different range of wavelengths covered by the 300K and 6000K outputs.

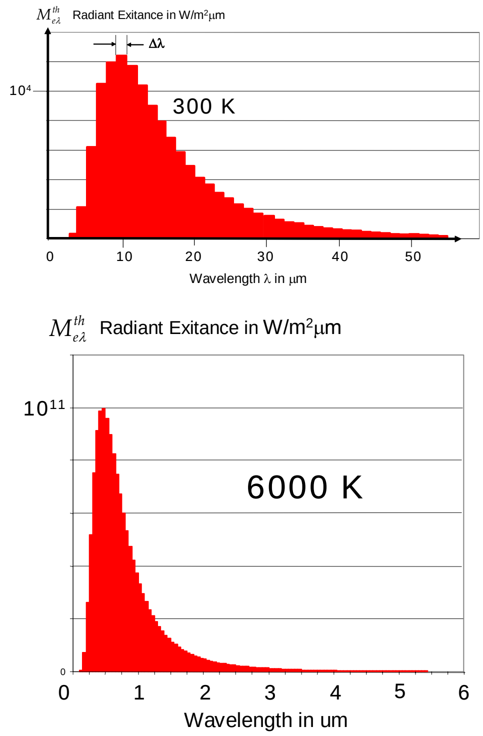


Figure 8.8 Spectral Exitances

8.3.2 Radiant exitance of real surfaces

A real surface will always emit less radiation than a Plankian radiator. The proportion of radiation emitted by a real surface compared to that from a theoretical Plankian surface is called the emissivity and is denoted by the Greek symbol ε, (epsilon). It might be that a Plankian radiator could be described as a surface that has an emissivity of 1.

The radiant exitance of a real surface might then be evaluated by using the formula:

$$M_e = \varepsilon\sigma T^4 \text{ W/m}^2.$$

Where ε is the emissivity of the real surface. The emissivity ε of the surface simply describes how effective is the surface at radiating energy. A surface with a high emissivity is good at radiating energy whilst a low emissivity surface will be poor at emitting radiation.

In principle the emissivity of a real surface might evaluated by measuring the radiant exitance of the surface and comparing it with the radiant exitance of a theoretical Plankian radiator i.e.,

$$\varepsilon = \frac{M_e}{M_e^{th}}.$$

There are two aspects to this experiment that complicate matters. One is of passing interest, but the other is of vital importance to the building designer.

First, it is found that emissivity is not constant when the experiment is conducted at different temperatures. However, because the temperature of most building surfaces varies only a little, then this aspect can be ignored.

More importantly, the emissivity of surfaces is found to vary with wavelength. This means that a surface may differently interact with radiation of different wavelengths.

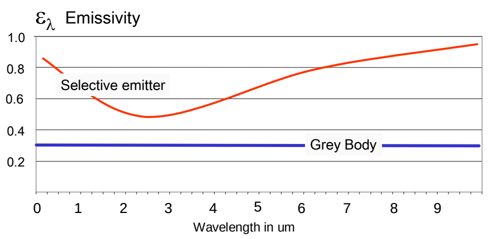


Figure 8.9 Spectral Emissivity

The emissivity at given wavelength λ is denoted by ε_λ. A surface that has a constant emissivity that is less than 1 is known as a grey body. A surface where the emissivity changes with wavelength is known as a 'selective emitter'. Figure 8.9 shows a graph of emissivity against wavelength for a grey surface and selective emitter.

Selective emitters are very useful because they allow the properties of glass to be modified in ways that save energy.

8.4 Irradiance (Intensity)

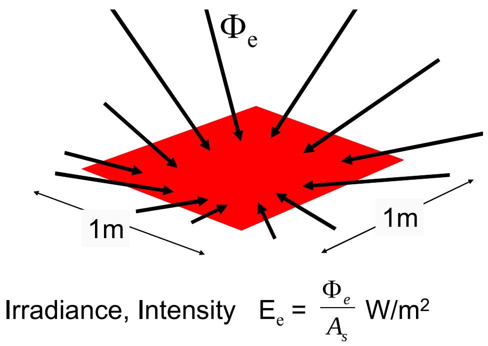


Figure 8.10 Irradiance

When radiation is incident upon a surface there will be a concentration of radiant power spread over an area. The power of radiation incident per unit area is known as Irradiance and it is denoted by the symbol E_e and is measured in W/m². Figure 8.10 shows the concept graphically.

$$E_e = \frac{\Phi_e}{A_S} \quad \text{W/m}^2$$

Where:

M_e irradiance of the surface in W/m²,
Φ_e power of radiation incident on the surface in W,
A_S is the area over which the radiation is incident in m².

It is important to realise that this concept is given a different name by different authors. I shall use the term Irradiance as it is the term agreed internationally by the CIE. Also, it avoids confusion with a term used in lighting design. However, in many books written by people whose education is from a physics background, the term Intensity is used.

8.5 Properties of glass

Consider a pane of glass shown in Figure 8.11. Of the incident radiation, one part will be reflected, another part will be absorbed by the glass and rest will be transmitted through the glass. The respective proportion of each part is:

Reflectance - ρ (rho) is used,
Absorptance – α (alpha) is used,
Transmittance - τ (tau) is used.

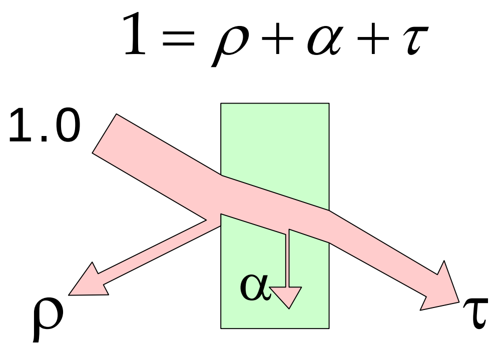


Figure 8.11 Glass

All of the incident radiation must be either reflected, absorbed or transmitted and therefore,

$$\rho + \alpha + \tau = 1\,.$$

If the glass did not transmit radiation then $\tau = 0$. In this case the above relation would become,

$$\rho + \alpha = 1\,,$$

and

$$\alpha = 1 - \rho\,.$$

Relation between absorptance and emissivity

Consider the situation shown in Figure 8.12 where a sphere is enclosed within a cavity where there is a vacuum. Because the sphere is suspended in an airless cavity the only means of heat transfer is by radiation. If no heat is input to the cavity surface or the sphere then over a period of time the sphere and the cavity surface will attain equilibrium and be at the same temperature.

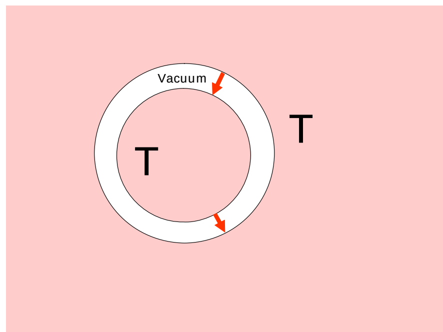


Figure 8.12 Sphere in vacuum

As the sphere is in equilibrium, then it may be concluded that it is emitting as much radiation as it is absorbing and therefore,

$$\varepsilon = \alpha\,.$$

To be absolutely correct this should be written as,

$$\varepsilon_\lambda = \alpha_\lambda\,.$$

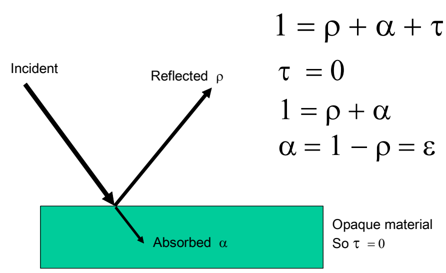


Figure 8.13 Opaque surface

Consider a pane of glass shown in Figure 8.13. If the glass is opaque, i.e. it does not transmit radiation and therefore τ = 0, then it follows that if the surface has a low emissivity then the absorptance will also be low and therefore the reflectance will be high. Contrary wise, a high emissivity will result in a low reflectance.

8.6 Sunlight

8.6.1 The effect of the atmosphere

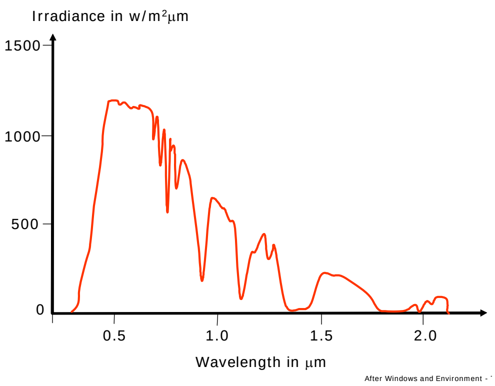


Figure 8.14 – Effects of air

External to the Earth's atmosphere the irradiance on a surface normal to the sunlight is approximately 1300 Watts/m². In passing through the atmosphere, sunlight is absorbed and the longer the path travelled in air the greater is the proportion absorbed. Gases within the atmosphere absorb some wavelengths more than others and therefore the smooth spectral curve of a Plankian distribution at 6000K is changed to something more akin to that shown in Figure 8.

Because of the increased absorption the irradiance of sunlight on a surface normal to the sun will reduce as the altitude of the sun lessens and it approaches the horizon; see Figure 8.15.

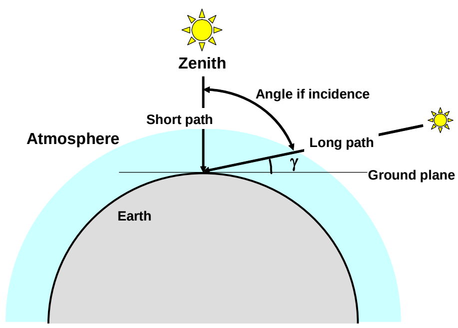


Figure 8.15 Air paths

At heights above sea level the reduced path length through air increases the irradiance from sunlight.

8.6.2 Effect of oblique incidence

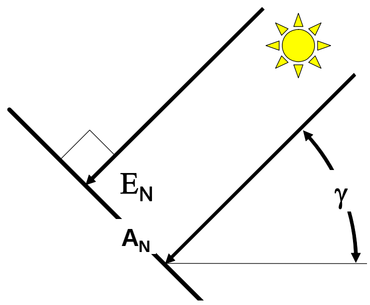


Figure 8.16 Normal incidence

The irradiance of sunlight upon a surface will depend upon its angle of incidence. Where a surface is normal to the sun's rays there will be a maximum irradiance as shown in Figure 8.16. Obliquely incident sunlight will be spread over a larger area than normally incident sunlight and therefore irradiance falls as the angle of incidence increases as shown in Figure 8.17.

Thus the irradiance at a point P on the ground can be written as,

$$E_{eP} = E_{eN} \times \cos i \quad \text{W/m}^2,$$

Where:

- E_{eP} irradiance on ground at P,
- E_{eN} irradiance normal to the sun,
- i angle of incidence of sunlight on ground plane.

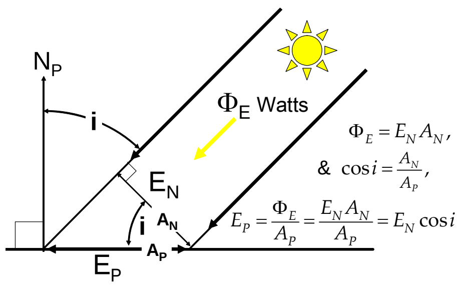


Figure 8.17 Oblique irradiance

There are various ways that can be used to calculate the irradiance from the sun. Each of these may include rather different ways to take into account the turbidity of the atmosphere, the level of air pollution, the altitude of the location above sea level etc. However, in this preliminary course I will only introduce an approximate graphical method using the stereographic projection. This graphical representation has many advantages and will allow you to gain a good appreciation of the solar gain that is likely to be expected on different facades.

8.6.3 Spectral Irradiance

Earlier in Figure 8.?? the spectrum of sunlight was shown after it had passed through the atmosphere. However, for the purpose of these notes the various absorptions will be ignored and the spectrum of sunlight will be shown as that from a surface of 6000K.

Additionally, the sunlight will be considered in terms of its normal spectral irradiance per micrometre at ground level. The reason for showing the sunlight in this way is that a direct comparison can be made with the spectral irradiance per μm received from an extended surface at room temperature. The spectral irradiances of sunlight and an extended source at room temperature are shown in Figure 8.18.

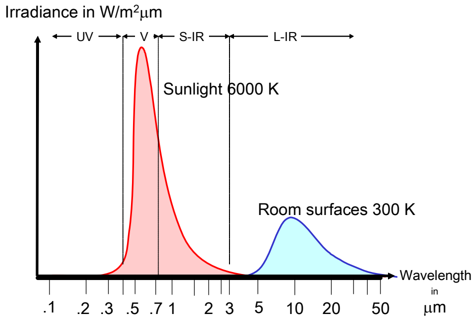


Figure 8.18 Spectral Irradiances

The area under the Sunlight curve gives a total irradiance of about 1000 W/m² and from the room surfaces of about 400 W/m².

The radiations can be divided into 4 different bands as classified by Figure 8.19. Sunlight comprises radiation principally in three bands:

Type of Radiation	Wavelengths in μm
Ultra Violet	0.1 – 0.4
Visible Light	0.4 – 0.7
Short wave infra-red	0.7 – 3.0
Long wave infra-red	3 – 50

Figure 8.19 Types of radiation

3% Ultra Violet with wavelengths between 0.3μm to 0.4μm,
50% Visible with wavelengths between 0.4μm and 0.7μm,
45% Short-wave Infra Red with wavelengths between 0.7μm and 3μm.

The radiation from the room surfaces lies principally within the Long-wave Infra Red with wavelengths between 3μm and 50μm.

This difference in the wavelengths between the radiation emitted by Sunlight and the radiation emitted by cooler surfaces at about room temperature is of crucial concern to us all.

The Earth's atmosphere is transparent to light and the short wave Infra-red radiation in Sunlight, but it is opaque to the Long wave Infra-red emitted by the Earth's surface. Therefore as is shown diagrammatically in Figure 8.20, the long-wave Infra-red from the Earth is absorbed by the atmosphere which consequently warms up. This warm atmosphere then itself radiates out to space, but also back to Earth, returning power to the surface that otherwise would have been directly radiated to space.

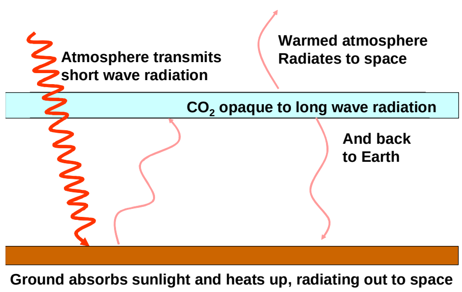


Figure 8.20 Green House effect

Glass also absorbs long-wave Infra-red and therefore the action of the atmosphere is similar in nature to that experienced in greenhouses, hence the association of the 'green-house' effect with increased atmospheric levels of CO_2 which also absorbs long-wave Infra-red radiation.

The radiative properties of glass can be further improved by coating the inside surface of glass with a layer that has a low emissivity in the long-wave Infra-red. Low emissivity means high reflectance and so the long-wave radiation emitted by the warm surfaces in a room is reflected back into the room.

8.7 Building response to solar radiation

The single most important factor affecting the response of a building to sunlight is the insolation. Insolation is the term used to describe sunlight entering into a building or room. It will depend upon a number of factors:

- Irradiance at the face of the window
- Area of glazing
- Shading provided by reveals and any '*brise soleil*'
- Transmission characteristics of glazing
- Transmission characteristics of internal blinds

The second most important factor is the '*thermal inertia*' of the building. This describes the ability of the building to absorb and store thermal energy or heat. It will be partly determined by how well the heat can pass into the building materials and partly by the capacity of the building to store heat.

All materials store heat as their temperature is increased and this property is known as Specific Heat. A short list of the specific heats of some building materials are given in Figure 8.21.

Material	Specific Heat
Water	4.2 kJ/kgK
Brickwork	0.8 kJ/kgK
Concrete	1.0 kJ/kgK
Wood	1.2 kJ/kgK
Expanded polystyrene	1.4 kJ/kgK
Aluminium	0.9 kJ/kgK
Steel	0.5 kJ/kgK
Air	1.0 kJ/kgK

Figure 8.21 – Specific heats

The energy or heat stored in a building element will therefore be given by:

$$Q = mass \times specific\,heat \times temperature\,rise \quad \text{in kJ.}$$

Where it is the volume of substance that is known, then this must be converted into the appropriate mass by applying:

$$mass = volume \times density \quad \text{in kg}$$

Sunlight incident upon an internal building surface and absorbed will raise the temperature of the surface. If the heat absorbed cannot be conducted into the structure then additional radiation falling on the surface will further increase the surface temperature. This will increase the radiant temperature in the room and also heat the air in contact with the surface which then will be convected into the room and increase the air temperature. Heat taken into the structure will ensure the increase in surface temperature is limited, thus preventing excessive radiant temperatures and immediate transfers of heat to the air in the room. However, long continued exposure to sunlight and high temperatures may raise the surface temperatures in the room. The high radiant temperatures that this causes may well make a room uncomfortably hot.

Although sunlight will be absorbed by the external surfaces of buildings and some of this will eventually find its way into the building to provide an internal heat gain, this will generally be of minor significance compared to the radiation that enters through the windows and roof lights.

The simplest and most efficient way of utilising solar energy is to use windows as schematically shown in Figure 22. They allow sunlight into the building to directly heat room surfaces. However, care is needed to ensure that some form of shading is provided which can be used to limit insolation in summer months when there could be overheating. It is often the case that different degrees of insolation are appropriate for different times in the year and on different facades of the building. Incorporating this variability into the façade can be quite a challenge, for it is unlikely that it can be achieved without affecting the appearance of the building. Indeed, the need to control insolation can be a major factor determining the look of the façade.

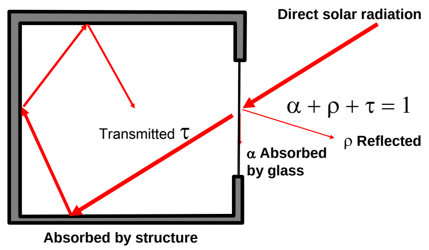


Figure 22 – Insolation

If the glass absorbs sunlight then it will become hotter. Because the air moves more quickly outside than inside it is assumed that the heat that is absorbed will be preferentially released outside in the ratio of 2 to 1 as shown in Figure 23.

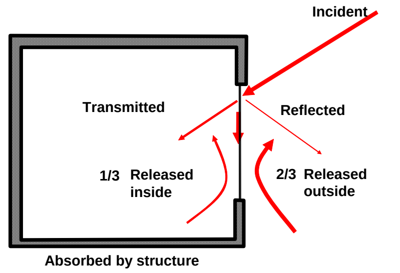


Figure 23 – 2/3rds of heat goes outdoors

Be careful when using sun spaces to harvest solar energy and then distribute the collected heat through a building. This will invariably make the sun space uninhabitable in summer. It is difficult to successfully utilise a space for living and to use it as a collector that will be able to harvest energy to distribute through a building.

Internal shading devices such as shown in Figure 24 may not be appropriate for all circumstances. This is because although the sunlight is prevented from directly entering the building structure the shading device has little mass and heats up very quickly. This will then directly heat the air in the room. Often it happens that in a morning the blinds are left up and the structure absorbs a good quantity of heat. However, eventually the room starts to heat up and occupants then lower the Venetian blinds. However, these rapidly heat up and then very quickly raise the air temperature in the room making conditions quite uncomfortable. The advice is that blinds need to be deployed before the room becomes too hot.

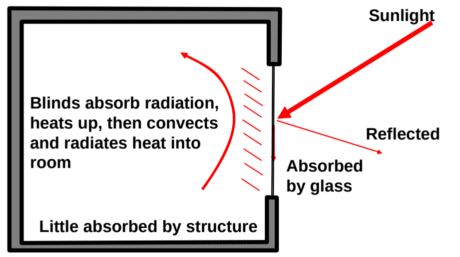


Figure 24 – Internal shading

One way of overcoming this problem is to use external blinds as shown in Figure 25. The heat absorbed by the shading is then released outside and does not become an internal solar gain. The disadvantage of external blinds is that they are often not very robust and are easily damaged by vandals and also adverse weather conditions.

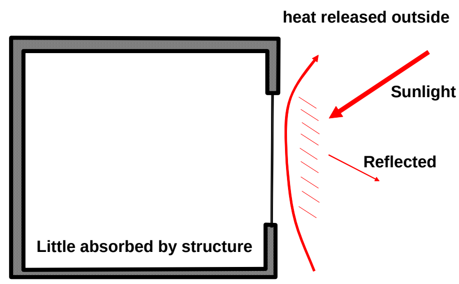


Figure 25 – Externall shading

Clearly, one important aspect of controlling the internal environment in a building is to provide the building with a reasonable degree of thermal inertia or thermal mass – (*mass* x *specific heat*). However, for the mass of the structure to be able to absorb heat it needs to be in contact with the room air or exposed to the sunlight directly. Adding false ceilings and carpets as shown in Figure 26 can insulate the structure from the internal gains and sunlight, and make what is imagined to be a heavyweight building into a light weight building. Thus a massive building might end up with a short thermal response time because it is insulated form the interior.

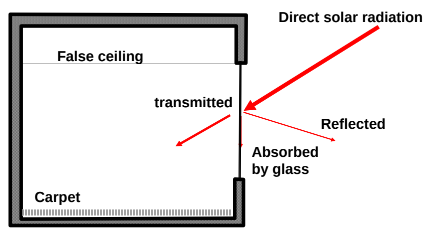


Figure 26 –Insulating structure

8.7.1 Graphically determining Irradiance

The irradiance (Intensity) on a surface from sunlight can be found by using a graphical methodology. This was mentioned earlier and it is important that if you are to fully exploit the benefits of the method you need to 'see' the three dimensional aspect of the stereographic projections.

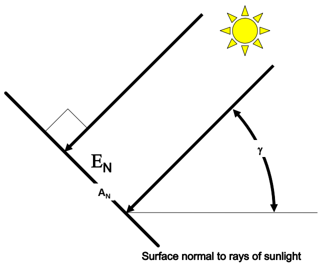


Figure 27 –Irradiance Normal to sun

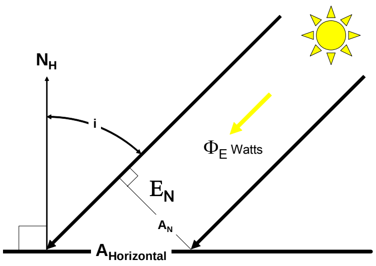


Figure 28 –Irradiance on a horizontal plane

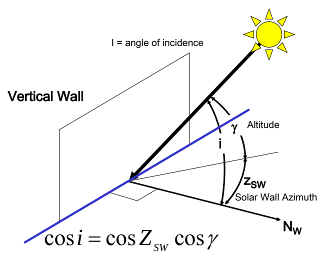
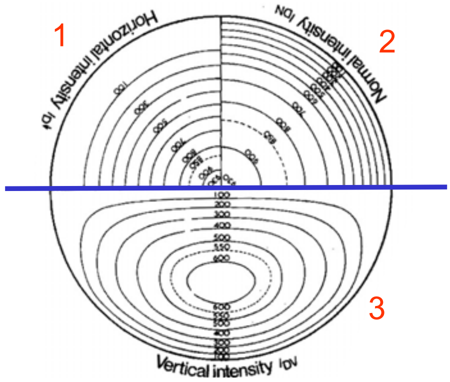
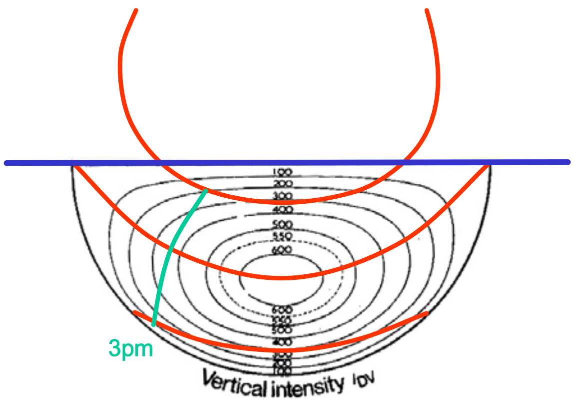


Figure 29 –Irradiance on a vertical plane

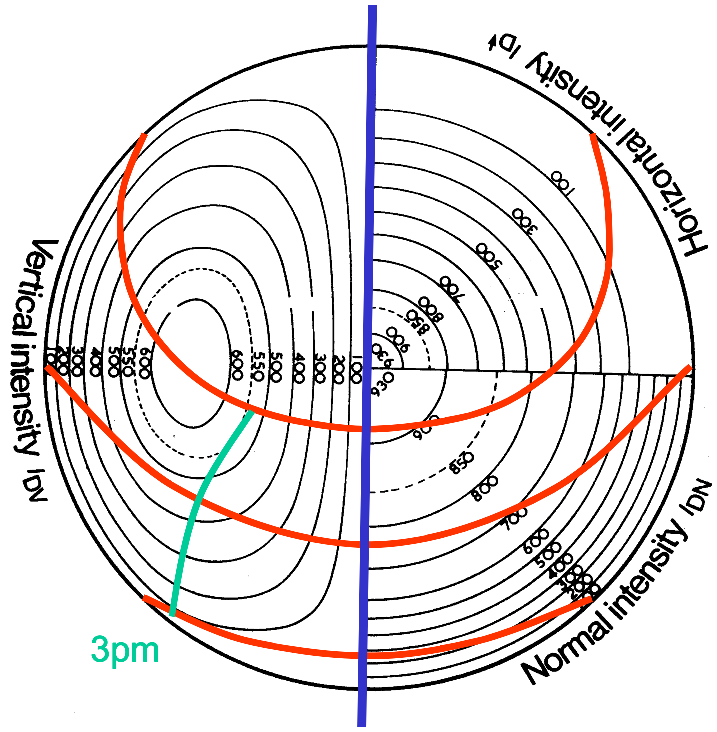


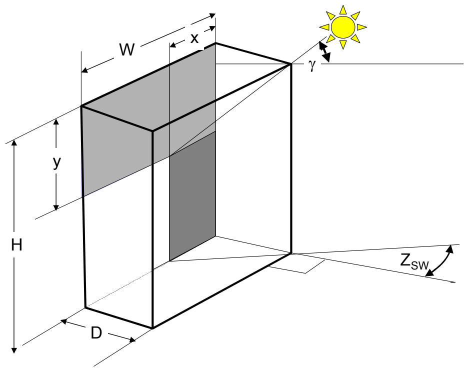
Above is a protractor that when used in conjunction with a stereographic sunpath diagram, can determine the irradiance from sunlight on three different planes. These three planes are, Normal to the sun, a Horizontal plane such as the ground or roof and a Vertical plane orientated with the base of the wall along the blue line. The three planes are shown respectively in Figures 27, 28 and 29

The top left quadrant of the protractor is used to determine the irradiance from the sun on a horizontal surface; the top right quadrant is used to determine the irradiance normal to the sun, and the lower half is used to determine the irradiance on a vertical surface that has a direction indicated by the blue line.



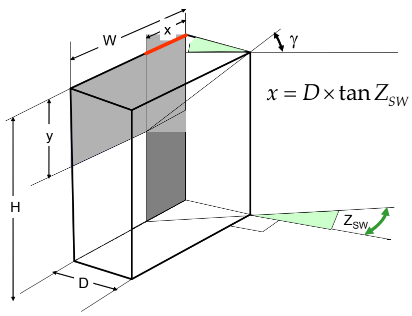
The example above shows a sunpath diagram overlain on the protractor orientated to indicate a south facing wall. It can be noted that at 3pm at the equinoxes the irradiance on a south facing wall is approximately 370 W/m².





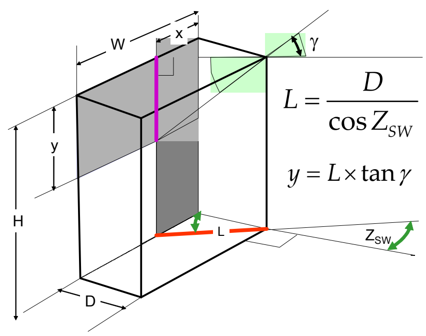
In the second example above, it can be seen that the vertical irradiance protractor has been orientated due west. The irradiance on the vertical surface of the west facing wall at 3pm solar time on the Equinoxes can be read off to be 450 W/m².

8.7.2 Effects of Shading



For the simple case of a window set back into a wall, the degree of shading provided by the reveals is calculated without too much difficulty. However, it should be noted that the transmittance will depend upon the relative position of the sun to the window. It therefore changes throughout the day.

The horizontal component of the angle that the sun's rays make with the normal to the wall is known as the Solar-Wall Azimuth, shown in the Figure as Z_{SW}.



Of the radiation that passes through the opening in the wall, it is that proportion of radiation that actually strikes the window plane that gives the transmittance of the shading device,

$$\tau_{SD} = \frac{\text{Area of the unshaded part of window}}{\text{Total area of the window}}$$

$$= \frac{(W-x)(H-y)}{WH}$$

The values of x and y are obtained by application of simple geometry.

8.7.3 Glass transmission

This can be calculated accurately, but it is usual to use the glass transmission at Normal angles of incidence, shown in the table below. In fact, just like transmittance through window reveals, the transmittance changes with the relative position of the sun, but this is often ignored. However, if one is modelling the energy inputs through the day in order to simulate the action of the building physics, then it would need to be taken into consideration.

	Solar Radiant Heat				Shading Coefficient		
	Direct Transmittance	Reflectance	Absorptance	Total Transmittance	Short Wavelength	Long Wavelength	Total
Single pane of Optifloat clear							
4mm	0.82	0.07	0.11	0.85	0.94	0.04	0.98
6mm	0.78	0.07	0.15	0.82	0.90	0.04	0.94
Single pane of Optifloat (Green)							
4mm 78/68	0.58	0.05	0.37	0.68	0.67	0.11	0.78
6mm 72/59	0.46	0.05	0.49	0.59	0.53	0.14	0.67
Single pane of Eclipse (Silver)							
6mm 33/50	0.43	0.28	0.29	0.50	0.49	0.09	0.58
Single pane of Suncool (Silver)							
6mm 10/20	0.08	0.32	0.60	0.20	0.09	0.14	0.23

$$R = \frac{M A_T}{A_f m_f + A_c m_c + A_i m_i + 2A_e m_e}$$

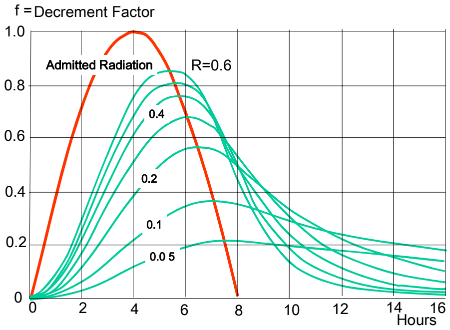
R = Response Factor

M = 25

A_T = Total surface area

m = Surface mass

$_{f,c\,i\,e}$ = floor,ceiling, internal, external wall



8.7.4 Effect of structure

The more massive a building the more the structure will absorb heat without increasing much in temperature. The corollary of this is that the less the heat is absorbed into the structure, the greater will be the increase in temperature of the surfaces in the room. This will cause a high radiant component to people occupying the space and also rapidly heat up the air in the room. This means that the solar gains are quickly converted into higher air temperatures within the room.

This effect can be roughly estimated by using a response factor method. The immediacy with which the solar gain is transferred into a space can be estimated by a response factor. The more lightweight a space, the more immediate and larger is the response of the air temperature to the effects of solar gain. A response factor R is calculated as shown in the margin, and this response factor is then used with the figure giving Decrement Factors to estimate the degree to which the maximum solar gain is reduced by the absorption of heat by the structure i.e. decrement factor.

$$(\text{Solar Gain})_{\text{Time T}} = (\text{Solar Gain})_{\text{MAX}} \times (\text{Decrement Factor})_{\text{Time T}}$$

The rise in temperature that a particular solar gain will cause when there is a given ventilation rate is estimated by using the equation shown in the margin.

$$\text{Ventilation Loss} = \frac{N V (T_{ai} - T_{ao})}{3} \text{ Watts}$$

N = air changes per hour

V = Volume of the room

T_{ai} = inside air temperature

T_{ao} = outside air temperature

$$\Delta T = \frac{3 \text{ (Solar Gain in Watts)}}{N V}$$

ΔT = Increase in air temperature due to solar gain