

Lesson

33

Cooling And Heating

Load Calculations

-Solar Radiation

Through Fenestration

- Ventilation And

Infiltration

The specific objectives of this lesson are to discuss:

1. Need for fenestration in buildings and effects of fenestration on air conditioning systems (*Section 33.1*)
2. Estimation of heat transfer rate into buildings through fenestration, concepts of Solar Heat Gain Factor (SHGF) and Shading Coefficient (*Section 33.2*)
3. Effect of external shading, calculation of shaded area of fenestrations, estimation of heat transfer rate through windows with overhangs (*Section 33.3*)
4. Need for ventilation and recommended ventilation rates (*Section 33.4*)
5. Infiltration and causes for infiltration (*Section 33.5*)
6. Estimation of heat transfer rate due to infiltration and ventilation (*Section 33.6*)

At the end of the lecture, the student should be able to:

1. Define fenestration and explain the need for fenestration and its effect on air conditioning
2. Calculate heat transfer rate due to fenestration using SHGF tables and shading coefficients
3. Calculate the dimensions of shadow cast on windows with overhangs and estimate the heat transfer rate through shaded windows
4. Explain the need for ventilation and select suitable ventilation rates
5. Define infiltration and explain the causes for infiltration
6. Calculate the heat transfer rates due to infiltration and ventilation

33.1. Solar radiation through fenestration:

Fenestration refers to any glazed (transparent) apertures in a building, such as glass doors, windows, skylights etc. Fenestration is required in a building as it provides:

- a) Daylight, heat and outside air
- b) Visual communication to the outside world
- c) Aesthetics, and
- d) Escape route in case of fires in low-rise buildings

Because of their transparency, fenestrations transmit solar radiation into the building. Heat transfer through transparent surfaces is distinctly different from heat transfer through opaque surfaces. When solar radiation is incident on an opaque building wall, a part of it is absorbed while the remaining part is reflected back. As will be shown later, only a fraction of the radiation absorbed by the opaque surface is transferred to the interiors of the building. However, in case of transparent surfaces, a major portion of the solar radiation is transmitted directly to the interiors of the building, while the remaining small fraction is absorbed and/or reflected back. Thus the fenestration or glazed surfaces contribute a major part of cooling load of a building. The energy transfer due to fenestration depends on the characteristics of the surface and its orientation, weather and solar radiation conditions. A careful design of fenestration can reduce the building energy consumption considerably.

33.2. Estimation of solar radiation through fenestration:

Figure 33.1 shows an **unshaded window** made of **clear plastic glass**. As shown in the figure, the properties of this glass for solar radiation are: **transmittivity (τ) = 0.80**, **reflectivity (ρ) = 0.08** and **absorptivity (α) = 0.12**. Thus out of 100% of solar radiation incident on the glass, 80% is directly transmitted to the indoors, 12% is absorbed by the glass (**which increases the temperature of the glass**) and the remaining 8% is reflected back. Of the 12% absorbed by the glass which leads to increase in its temperature, about 4% is transferred to the indoors by convection heat transfer and the remaining 8% is lost to the outdoors by convection and radiation. Thus out of 100% radiation, 84% is transmitted to the interiors of the building. Of course, these figures are for a clear plate glass only. For other types of glass, the values will be different.

Assuming the transmittivity and absorptivity of the surface same for direct, diffuse and reflected components of solar radiation, the amount of solar radiation passing through a transparent surface can be written as:

$$Q_{sg} = A(\tau \cdot I_t + N \cdot \alpha \cdot I_t) \quad (33.1)$$

where:

- A = Area of the surface exposed to radiation
- I_t = Total radiation incident on the surface
- τ = Transmittivity of glass for direct, diffuse and reflected radiations
- α = Absorptivity of glass for direct, diffuse and reflected radiations

N = Fraction of absorbed radiation transferred to the indoors by conduction and convection

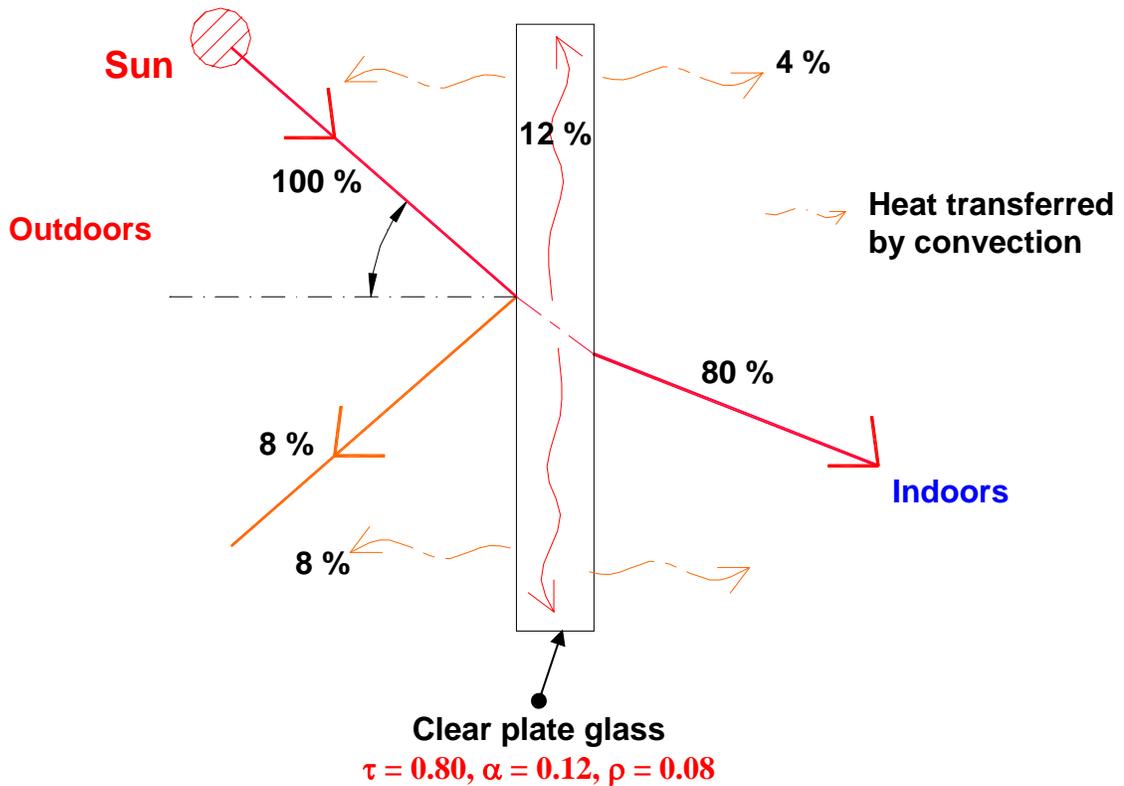


Fig.33.1: Radiation properties of clear plate glass

In the above equation, the total incident radiation consists of direct, diffuse and reflected radiation, and it is assumed that the values of transmittivity and absorptivity are same for all the three types of radiation. Under steady state conditions it can be shown that the fraction of absorbed radiation transferred to the indoors, i.e., N is equal to:

$$N = \frac{U}{h_o} \tag{33.2}$$

where U is the overall heat transfer coefficient, which takes into account the external heat transfer coefficient, the conduction resistance offered by the glass and the internal heat transfer coefficient, and h_o is the external heat transfer coefficient.

From the above two equations, we can write:

$$Q_{sg} = A \left[I_t \left(\tau + \frac{\alpha U}{h_o} \right) \right] \tag{33.3}$$

The term in square brackets for a single sheet, clear window glass (reference) is called as **Solar Heat Gain Factor (SHGF)**, i.e.,

$$\text{SHGF} = \left[I_t \left(\tau + \frac{\alpha U}{h_o} \right) \right]_{ss} \quad (33.4)$$

Thus SHGF is the heat flux due to solar radiation through the reference glass (SS). The maximum SHGF values for different latitudes, months and orientations have been obtained and are available in the form of Tables in ASHRAE handbooks. For example, Table 33.1 taken from ASHRAE Fundamentals shows the maximum SHGF values in W/m^2 for 32° N latitude for different months and orientations (direction a glass is facing).

Month	Orientation of the surface					
	N/shade	NE/NW	E/W	SE/SW	S	Horizontal
December	69	69	510	775	795	500
Jan, Nov	75	90	550	785	775	555
Feb, Oct	85	205	645	780	700	685
Mar, Sept	100	330	695	700	545	780
April, Aug	115	450	700	580	355	845
May, July	120	530	685	480	230	865
June	140	555	675	440	190	870

Table 33.1: Maximum SHGF factor for sunlit glass located at 32° N (W/m^2)

The first column in the table gives the maximum SHGF values of a **north facing glass or a glass shaded from solar radiation and oriented in any direction**. Again it can be observed that, a glass facing south is desirable from cooling and heating loads points of view as it allows maximum heat transfer in winter (reduces required heating capacity) and minimum heat transfer in summer (reduces required cooling capacity). Similar tables are available for other latitudes also in ASHRAE Handbooks.

For fenestrations other than the reference SS glass, a **Shading Coefficient (SC)** is defined such that the heat transfer due to solar radiation is given by:

$$Q_{sg} = A \cdot (\text{SHGF}_{\max}) \cdot (\text{SC}) \quad (33.5)$$

The shading coefficient depends upon the type of the glass and the type of internal shading devices. Typical values of SC for different types of glass with

different types of internal shading devices have been measured and are tabulated in ASHRAE Handbooks. Table 33.2 taken from ASHRAE Fundamentals shows typical values of shading coefficients.

Type of glass	Thickness mm	No internal shading	Shading Coefficient, SC			
			Venetian blinds		Roller shades	
			Medium	Light	Dark	Light
<u>Single glass</u> Regular	3	1.00	0.64	0.55	0.59	0.25
<u>Single glass</u> Plate	6-12	0.95	0.64	0.55	0.59	0.25
<u>Single glass</u> Heat absorbing	6	0.70	0.57	0.53	0.40	0.30
<u>Double glass</u> Regular	3	0.90	0.57	0.51	0.60	0.25
<u>Double glass</u> Plate	6	0.83	0.57	0.51	0.60	0.25
<u>Double glass</u> Reflective	6	0.2-0.4	0.2-0.33	-	-	-

Table 33.2: Shading coefficients for different types of glass and internal shading

It can be inferred from the above table that the heat transferred through the glass due to solar radiation can be reduced considerably using suitable internal shadings, however, this will also reduce the amount of sunlight entering into the interior space. Values of SC for different types of curtains have also been evaluated and are available in ASHRAE handbooks. Thus from the type of the sunlit glass, its location and orientation and the type of internal shading one can calculate the maximum heat transfer rate due to solar radiation.

33.3. Effect of external shading:

The solar radiation incident on a glazed window can be reduced considerably by using external shadings. The external shading reduces the area of the window exposed to solar radiation, and thereby reduces the heat transmission into the building. A very common method of providing external shading is to use overhangs. The principle of overhangs for solar heat gain control is known for thousands of years. Fixed overhangs are among the simplest, yet an effective method to control the solar heat gain into a building. By proper design of the overhangs it is possible to block the solar radiation during summer and allow it into the building during winter.

Figure 33.2 shows an inset window of height H , width W and depth of the inset d . Without overhang, the area exposed to solar radiation is $H \times W$, however, with overhang the area exposed is only $x \times y$. The hatched portion in the figure shows the area that is under shade, and hence is not experiencing any direct solar radiation. Thus the solar radiation transmitted into the building with overhang is given by:

$$Q_{sg} = A_{\text{unshaded}} \cdot (\text{SHGF}_{\text{max}}) \cdot (\text{SC}) = (x \cdot y) \cdot (\text{SHGF}_{\text{max}}) \cdot \text{SC} \quad (33.6)$$

Using solar geometry the area of the window that is not shaded at any location at a particular instant can be calculated. It can be shown that x and y are given by:

$$x = W - d(\tan \alpha) \quad (33.7)$$

$$y = H - d \left(\frac{\tan \beta}{\cos \alpha} \right) \quad (33.8)$$

where β is the altitude angle and α is the wall solar azimuth angle.

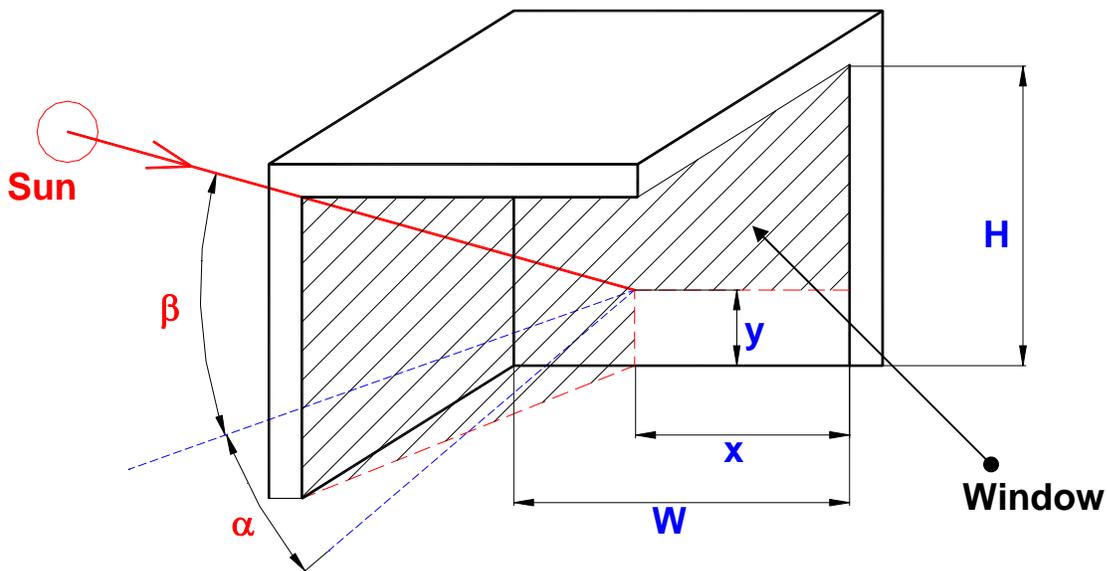


Fig.33.2: Shadow cast by an inset window

It should be noted that the overhang provides shade against direct solar radiation only and cannot prevent diffuse and reflected radiation. Thus for the shaded portion, the $SHGF_{max}$ values corresponding to the north facing window in Table 33.1 should be selected.

Using a separation between the top of the window and the overhang, it is possible to completely shade the window in summer and completely unshade it in winter. Complete shading of the window can be provided by selecting infinite combinations of overhang width (W_o) and separation dimensions (S), as shown in Fig.33.3. It should however be noticed that for complete shading as the separation distance S increases, the width of the overhang W_o should also increase and vice versa. ASHRAE defines a **Shade Line Factor (SLF)** which is the ratio of the distance a shadow falls below the edge of an overhang to the width of the overhang. Thus from the knowledge of the SLF and the dimensions of the window with overhang, one can calculate the unshaded area. The average SLF values for 5 hours of maximum on August 21st for different latitudes and orientations of the window are presented in tabular form by ASHRAE.

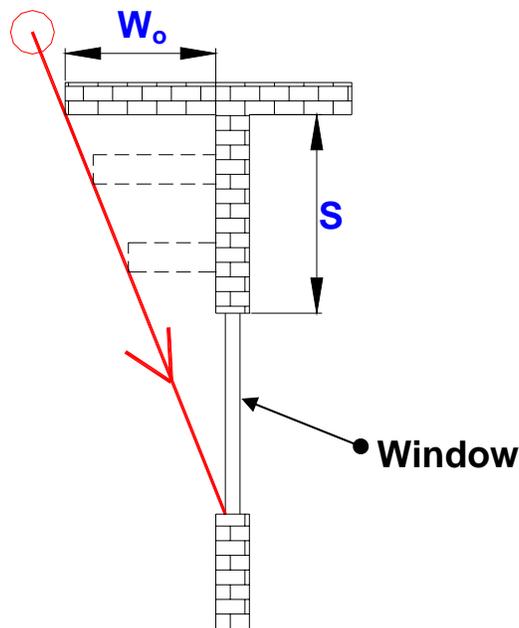


Fig.33.3: Variation of overhang width with separation for complete shading

Though overhangs, if properly designed can lead to significant reduction in solar heat gain during summer, they do have certain limitations. These are:

- a) An external overhang provides protection against direct solar radiation only. It cannot reduce diffuse and reflection radiations. In fact, sometimes, the external overhang may actually reflect the ground radiation onto the window.

- b) The reflectivity of the glazed surfaces increases and transmittivity reduces with angle of incidence. Thus in summer when the angle of incidence on a vertical surface is large, most of the solar radiation incident on the glazed surface is reflected back and only about 40% of the incident radiation is transmitted into the building. In such cases, the provision of overhang can take care at the most only 40% of the incident radiation.
- c) For practical purposes, overhangs are truly effective for windows facing 30–45° of south. During mornings and evenings when the sun is striking the east and west walls and is so low in the sky that overhangs can provide only minimum protection.

In spite of the above limitations, a fixed overhang is frequently used as in addition to reducing the direct solar radiation, it also provides protection against rain. The dimensions of the overhang have to be selected depending upon whether passive solar heating in winter is more important or shading in summer. It is also possible to use adjustable overhangs in place of fixed overhangs. However, though the adjustable overhangs are more flexible, and hence can provide greater benefit both in summer and winter, these are not so frequently used due to the operational difficulties and design complexities.

33.4. Ventilation for Indoor Air Quality (IAQ):

The quality of air inside the conditioned space should be such that it provides a healthy and comfortable indoor environment. Air inside the conditioned space is polluted by both internal as well as external sources. The pollutants consist of odours, various gases, volatile organic compounds (VOCs) and particulate matter. The internal sources of pollution include the occupants (who consume oxygen and release carbon dioxide and also emit odors), furniture, appliances etc, while the external sources are due to impure outdoor air. **Indoor Air Quality (IAQ)** can be controlled by the removal of the contaminants in the air or by diluting the air. The purpose of ventilation is to dilute the air inside the conditioned space. Ventilation may be defined as the “**supply of fresh air to the conditioned space either by natural or by mechanical means for the purpose of maintaining acceptable indoor air quality**”. Generally ventilation air consists of fresh outdoor air plus any re-circulated air that has been treated. If the outdoor air itself is not pure, then it also has to be treated before supplying it to the conditioned space.

Though the minimum amount of air required for breathing purposes is small (about 0.2 litres per second per person), the actual ventilation air required is much larger as in addition to supplying oxygen to the occupants, the ventilation air must:

- a) Dilute the odours inside the occupied space to a socially acceptable level
- b) Maintain carbon dioxide concentration at a satisfactory level
- c) Pressurizing the escape routes in the event of fire

33.4.1. Estimation of minimum outdoor air required for ventilation:

Ventilation is one of the major contributors to total cooling and heating load on the system. From energy conservation point of view, it is important select the ventilation requirements suitably. The amount of air required for ventilation purposes depends on several factors such as: application, activity level, extent of cigarette smoking, presence of combustion sources etc. After several studies stretched over several years, standards for minimum ventilation requirements have been formulated. For example, **ASHRAE standard 62-1989** provides a guideline for minimum ventilation requirements. Table 33.3 provides typical outdoor (OD) air requirement for the purpose of ventilation:

Function	Occupancy per 100 m ² floor area	OD air requirement per person (L/s)	
		Smoking	Non-smoking
Offices	7	10	2.5
Operation theatres	20	-	15
Lobbies	30	7.5	2.5
Class rooms	50	-	8.0
Meeting places	60	17.5	3.5

Table 33.3: Typical outdoor air requirements for ventilation

It can be observed from the above table that the ventilation requirement increases with the occupancy. It can also be seen that the required amount of OD air increases significantly if smoking is permitted in the conditioned space.

33.5. Infiltration:

Infiltration may be defined as the uncontrolled entry of untreated, outdoor air directly into the conditioned space. Infiltration of outdoor air into the indoors takes place due to wind and stack effects. The **wind effect** refers to the entry of outdoor air due to the pressure difference developed across the building due to winds blowing outside the building. The **stack effect** refers to the entry of outdoor air due to buoyancy effects caused by temperature difference between the indoor and outdoors. Though infiltration brings in outdoor air into the building similar to ventilation, in many commercial buildings efforts are made to minimize it, as it is uncontrolled and uncertain. Some of the means employed to control infiltration include use of vestibules or revolving doors, use of air curtains, building pressurization and sealing of windows and doors. It is very difficult to estimate the exact amount of infiltration as it depends on several factors such as the type and age of the building, indoor and outdoor conditions (wind velocity and

direction, outdoor temperature and humidity etc.). However, several methods have been proposed to estimate the amount of infiltration air. Sometimes, based on type of construction, buildings are classified into loose, average or tight, and infiltration is specified in terms of number of air changes per hour (ACH). One ACH is equal to the airflow rate equal to the internal volume of the occupied space per hour. The ACH values are related to the outside wind velocity and the temperature difference between the indoor and outdoors. Infiltration rates are also obtained for different types of doors and windows and are available in the form of tables in air conditioning handbooks.

33.6. Heating and cooling loads due to ventilation and infiltration:

Due to ventilation and infiltration, buildings gain energy in summer and loose energy in winter. The energy gained or lost consists of both sensible and latent parts, as in general the temperature and moisture content of indoor and outdoors are different both in winter and winter.

The sensible heat transfer rate due to ventilation and infiltration, $Q_{s,vi}$ is given by:

$$Q_{s,vi} = \dot{m}_o c_{p,m} (T_o - T_i) = \dot{V}_o \rho_o c_{p,m} (T_o - T_i) \quad (33.9)$$

The latent heat transfer rate due to ventilation and infiltration, $Q_{l,vi}$ is given by:

$$Q_{l,vi} = \dot{m}_o h_{fg} (W_o - W_i) = \dot{V}_o \rho_o h_{fg} (W_o - W_i) \quad (33.10)$$

In the above equations:

\dot{m}_o and \dot{V}_o are the mass flow rate and volumetric flow rates of outdoor air due to ventilation and infiltration, $c_{p,m}$ is the average specific heat of moist air, h_{fg} is the latent heat of vaporization of water, T_o and T_i are the outdoor and indoor dry bulb temperatures and W_o and W_i are the outdoor and indoor humidity ratios. Thus from known indoor and outdoor conditions and computed or selected values of ventilation and infiltration rates, one can calculate the cooling and heating loads on the building. The sensible and latent heat transfer rates as given by the equations above will be positive during summer (heat gains) and negative during winter (heat losses).

Though the expressions for heat transfer rates are same for both ventilation and infiltration, there is a difference as far as the location of these loads are considered. While heat loss or gain due to infiltration adds directly to the building cooling or heating load, heat loss or gain due to ventilation adds to the equipment load. These aspects will be discussed in a later Chapter.

Questions & answers:

1. Which of the following statements are TRUE?

- a) Fenestration is important in buildings as it provides visual communication to the outside world
- b) Heat transfer through fenestration generally forms a small part of the total building load
- c) Heat transfer due to fenestration depends only on the properties of the transparent material
- d) Fenestration is undesirable and hence should be minimized

Ans.: a)

2. Which of the following statements are TRUE?

- a) External shading of windows is taken care of by using a shading coefficient
- b) Internal shading of windows is taken care of by using a shading coefficient
- c) The shading coefficient for the reference SS glass is 0.0
- d) The shading coefficient for the reference SS glass is 1.0

Ans.: b) and d)

3. Which of the following statements are TRUE for northern hemisphere?

- a) Providing fenestration on northern side of the building is beneficial from summer cooling and winter heating points of view
- b) Providing fenestration on southern side of the building is beneficial from summer cooling and winter heating points of view
- c) On an average, the heat transfer due to fenestration is maximum for east and west facing windows
- d) On an average, the heat transfer rate due to fenestration is minimum for north facing windows

Ans.: b), c) and d)

4. Which of the following statements are TRUE?

- a) Compared to external shadings, internal shadings are beneficial as they do not allow the radiation into the buildings
- b) Compared to internal shadings, external shadings are beneficial as they block the radiation outside the window itself
- c) The effectiveness of external shading at a particular varies from day to day and from time to time
- d) External shadings are effective for east and west facing windows

Ans.: b) and c)

5. Which of the following statements are TRUE?

- a) Ventilation is required for supply of oxygen for breathing only
- b) Ventilation is uncontrolled, while infiltration is controlled
- c) Ventilation requirement depends on occupancy and also on activity level
- d) All of the above

Ans.: c)

6. Calculate the maximum heat transfer rate through a 1.5 m² area, unshaded, regular double glass facing south during the months of June and December without internal shading and with internal shading consisting of light venetian blinds. Location 32°N

Ans.: For the month of June the SHGF_{max} from Table 33.1 is 190 W/m². Using the values of shading coefficients from Table 33.2, the heat transfer rate is:

Without internal shading (SC = 0.9):

$$Q_{sg} = A.(SHGF_{max}).(SC) = 1.5 \times 190 \times 0.9 = 256.5 \text{ W} \quad (\text{Ans.})$$

With internal shading (SC = 0.51):

$$Q_{sg} = A.(SHGF_{max}).(SC) = 1.5 \times 190 \times 0.51 = 145.35 \text{ W} \quad (\text{Ans.})$$

These values for the month of December (SHGF_{max} = 795 W/m²) are:

Without internal shading: $Q_{sg} = 1073.25 \text{ W}$ **(Ans.)**

With internal shading: $Q_{sg} = 608.175 \text{ W}$ **(Ans.)**

7. Calculate energy transmitted into a building at 3 P.M on July 21st due to solar radiation through a south facing window made of regular single glass. The dimensions of the window are height 2 m, width 1.5 m and the depth of inset 0.3 m. Find the energy transmitted if there is no overhang.

Ans.: From the above data the altitude angle β and wall solar azimuth angle α are found to be:

$$\beta = 48.23^\circ, \alpha = 39.87^\circ$$

Therefore area of the unshaded portion = x X y, where x and y are given by:

$$x = W - d(\tan \alpha) = 1.5 - 0.3(\tan 39.87) = 1.249 \text{ m}$$

$$y = H - d \left(\frac{\tan \beta}{\cos \alpha} \right) = 2.0 - 0.3 \left(\frac{\tan 48.23}{\cos 39.87} \right) = 1.562 \text{ m}$$

∴ The heat transmission rate into the building through the unshaded portion Q_{us} is given by:

$$Q_{us} = (x \cdot y) \cdot (SHGF_{max}) \cdot SC = (1.249 \times 1.562) \times 230 \times 1.0 = 448.7 \text{ W}$$

The heat transmission rate into the building through the shaded portion Q_{ss} is given by:

$$Q_{ss} = (W \cdot H - x \cdot y) \cdot (SHGF_{max} \cdot N) \cdot SC = (1.049) \times 120 \times 1.0 = 125.9 \text{ W}$$

Hence the total amount of radiation transmitted into the building, Q_{sg} is given by:

$$Q_{sg} = Q_{us} + Q_{ss} = 574.6 \text{ W} \quad (\text{Ans.})$$

Without overhang the heat transmission rate is:

$$Q_{sg} = (W \times H) SHGF_{max} = 690 \text{ W} \quad (\text{Ans.})$$

Thus there is a reduction of 115.4 W (16.7%) due to external shading. Of course, these values will be different for different periods.

8. A large air conditioned building with a total internal volume of 1,00,000 m³ is maintained at 25°C (DBT) and 50% RH, while the outside conditions are 35°C and 45% RH. It has a design occupancy of 10,000 people, all non-smoking. The infiltration rate through the building is equal to 1.0 ACH. Estimate the heat transfer rate due to ventilation and infiltration. Assume the barometric pressure to be 1 atm.

Ans.: From psychrometric chart:

For inside conditions: 24°C (DBT) and 50% RH:

$$W_i = 0.0093 \text{ kgw/kgda}, h_i = 47.656 \text{ kJ/kgda}$$

For outside conditions: 35°C (DBT) and 45% RH:

$$W_o = 0.01594 \text{ kgw/kgda}, h_o = 75.875 \text{ kJ/kgda} \text{ and } v_a = 0.89519 \text{ m}^3/\text{kg}$$

Heat transfer due to ventilation:

From Table 33.3, assume a ventilation requirement of **3.5 l/s/person**. Hence the total OD air required is:

$$V_{o,v} = 3.5 \times 10,000 = 35000 \text{ l/s} = 35 \text{ m}^3/\text{s}$$

Hence the mass flow rate of ventilated air is:

$$m_{o,v} = 35 / 0.89519 = 39.1 \text{ kg/s}$$

Sensible heat transfer rate due to ventilation is given by:

$$Q_{s,v} = m_{o,v} c_{pm} (t_o - t_i) = 39.1 \times 1.0216 \times (35 - 25) = 399.5 \text{ kW}$$

Latent heat transfer rate due to ventilation is given by:

$$Q_{l,v} = m_{o,v} h_{fg} (W_o - W_i) = 39.1 \times 2501 \times (0.01594 - 0.0093) = 649.3 \text{ kW}$$

Hence total heat transfer rate due to ventilation is:

$$Q_{t,v} = Q_{s,v} + Q_{l,v} = 1048.8 \text{ kW} \quad (\text{Ans.})$$

Heat transfer rate due to infiltration:

$$\text{Infiltration rate, } V_{inf} = 1 \text{ ACH} = 1,00,000/3600 = 27.78 \text{ m}^3/\text{s}$$

Hence mass flow rate of infiltrated air is:

$$m_{inf} = V_{inf}/v_a = 27.78/0.89519 = 31 \text{ kg/s}$$

Hence using expressions similar to ventilation, the sensible, latent and total heat transfer rates due to infiltration are found to be:

$$Q_{s,inf} = 316.7 \text{ kW} \quad (\text{Ans.})$$

$$Q_{l,inf} = 514.8 \text{ kW} \quad (\text{Ans.})$$

$$Q_{t,inf} = 831.5 \text{ kW} \quad (\text{Ans.})$$

It can be seen from the above example that the total load on the air conditioning system is very high (= 1880.3 kW = 534.6 TR).