9. A building has a U-value of 0.5 W/m^2.K and a total exposed surface area of 384 m^2. The building is subjected to an external load (only sensible) of 2 kW and an internal load of 1.2 kW (sensible). If the required internal temperature is 25^{o}C, state whether a cooling system is required or a heating system is required when the external temperature is 3^{o}C. How the results will change, if the U-value of the building is reduced to 0.36 W/m.K?

Ans.: From energy balance,

$$\mathbf{T_{out,bal} = T_{in} - \frac{(Q_{solar} + Q_{int})_{sensible}}{UA} = 25 - \frac{(2+1.2)x1000}{0.5\,x\,384} = 8.33^o\,C}$$

Since the outdoor temperature at balance point is greater than the external temperature ($T_{ext} < T_{out,bal}$);

the building requires heating (Ans.)

When the U-value of the building is reduced to 0.36 W/m.K, the new balanced outdoor temperature is given by:

$$\mathbf{T_{out,bal} = T_{in} - \frac{(Q_{solar} + Q_{int})_{sensible}}{UA} = 25 - \frac{(2+1.2)x1000}{0.36\,x\,384} = 1.85^o\,C}$$

Since now the outdoor temperature at balance point is smaller than the external temperature ($T_{ext} > T_{out,bal}$);

the building now requires cooling (Ans.)

The above example shows that adding more insulation to a building extends the cooling season and reduces the heating season.

10. An air conditioned room that stands on a well ventilated basement measures 3 m wide, 3 m high and 6 m deep. One of the two 3 m walls faces west and contains a double glazed glass window of size 1.5 m by 1.5 m, mounted flush with the wall with no external shading. There are no heat gains through the walls other than the one facing west. Calculate the sensible, latent and total heat gains on the room, room sensible heat factor from the following information. What is the required cooling capacity?

Inside conditions	:	$25^{\circ}C$ dry bulb, 50 percent RH
Outside conditions	:	$43^{\circ}C$ dry bulb, $24^{\circ}C$ wet bulb
U-value for wall	:	$1.78\ W/m^2.K$
U-value for roof	:	$1.316\ W/m^2.K$
U-value for floor	:	$1.2\ W/m^2.K$
Effective Temp. Difference (ETD) for wall:		$25^{\circ}C$
Effective Temp. Difference (ETD) for roof:		$30^{\circ}C$
U-value for glass	;	$3.12\ W/m^2.K$
Solar Heat Gain (SHG) of glass	;	$300\ W/m^2$
Internal Shading Coefficient (SC) of glass:		0.86
Occupancy	:	4 (90 W sensible heat/person) (40 W latent heat/person)
Lighting load	:	$33\ W/m^2$ of floor area
Appliance load	:	600 W (Sensible) + 300 W(latent)
Infiltration	:	0.5 Air Changes per Hour
Barometric pressure		101 kPa

Ans.: From psychrometric chart,

For the inside conditions of 25ºC dry bulb, 50 percent RH:

$$\mathbf{W_i = 9,9167 \times 10^{-3}\ kgw/kgda}$$

For the outside conditions of 43ºC dry bulb, 24ºC wet bulb:

$$\mathbf{W_o = 0.0107\ kgw/kgda,\ density\ of\ dry\ air = 1.095\ kg/m^3}$$

External loads:

a) Heat transfer rate through the walls: Since only west wall measuring 3m x 3m with a glass windows of 1.5m x 1.5m is exposed; the heat transfer rate through this wall is given by:

$$\mathbf{Q_{wall} = U_{wall}A_{wall}ETD_{wall} = 1.78 \times (9-2.25) \times 25 = 300.38\ W\ (Sensible)}$$

b) Heat transfer rate through roof:

$$\mathbf{Q_{roof} = U_{roof}A_{roof}ETD_{roof} = 1.316 \times 18 \times 30 = 710.6\ W\ (Sensible)}$$

c) Heat transfer rate through floor: Since the room stands on a well-ventilated basement, we can assume the conditions in the basement to be same as that of the outside (i.e., 43°C dry bulb and 24°C wet bulb), since the floor is not exposed to solar radiation, the driving temperature difference for the roof is the temperature difference between the outdoor and indoor, hence:

$$\mathbf{Q_{floor} = U_{floor}A_{floor}ETD_{floor} = 1.2 \times 18 \times 18 = 388.8\ W\ (Sensible)}$$

d) Heat transfer rate through glass: This consists of the radiative as well as conductive components. Since no information is available on the value of CLF, it is taken as 1.0. Hence the total heat transfer rate through the glass window is given by:

$$\mathbf{Q_{glass} = A_{glass}\ [U_{glass}(T_o - T_i) + SHGF_{max}SC] = 2.25[3.12 \times 18 + 300 \times 0.86] = 706.9\ W}$$

(Sensible)

e) Heat transfer due to infiltration: The infiltration rate is 0.5 ACH, converting this into mass flow rate, the infiltration rate in kg/s is given by:

m_{inf} = density of air x (ACH x volume of the room)/3600 = 1.095 x (0.5 x 3x3x6)/3600

$$\mathbf{m_{inf} = 8.2125 \times 10^{-3}\ kg/s}$$

Sensible heat transfer rate due to infiltration, $Q_{s,inf;}$

$$Q_{s,inf} = m_{inf}c_{pm}(T_o - T_i) = 8.2125 \times 10^{-3} \times 1021.6 \times (43 - 25) = 151 \text{ W (Sensible)}$$

Latent heat transfer rate due to infiltration, $Q_{l,inf}$:

$$Q_{l,inf} = m_{inf}h_{fg}(W_o - W_i) = 8.8125\times10^{-3} \times 2501\times10^{3}(0.0107 - 0.0099) = 16.4 \text{ W (latent)}$$

Internal loads:

a) Load due to occupants: The sensible and latent load due to occupants are:

$$Q_{s,occ} = \text{no.of occupants} \times SHG = 4 \times 90 = 360 \text{ W}$$

$$Q_{l,occ} = \text{no.of occupants} \times LHG = 4 \times 40 = 160 \text{ W}$$

b) Load due to lighting: Assuming a CLF value of 1.0, the load due to lighting is:

$$Q_{lights} = 33 \times \text{floor area} = 33 \times 18 = 594 \text{ W (Sensible)}$$

c) Load due to appliance:

$$Q_{s,app} = 600 \text{ W (Sensible)}$$

$$Q_{l,app} = 300 \text{ W (Latent)}$$

Total sensible and latent loads are obtained by summing-up all the sensible and latent load components (both external as well as internal) as:

$$Q_{s,total} = 300.38+710.6+388.8+706.9+151+360+594+600 = 3811.68 \text{ W} \qquad \text{(Ans.)}$$

$$Q_{l,total} = 16.4+160+300 = 476.4 \text{ W} \qquad \text{(Ans.)}$$

Total load on the building is:

$$Q_{total} = Q_{s,total} + Q_{l,total} = 3811.68 + 476.4 = 4288.08 \text{ W} \qquad \text{(Ans.)}$$

Room Sensible Heat Factor (RSHF) is given by:

$$RSHF = Q_{s,total}/Q_{total} = 3811.68/4288.08 = 0.889 \qquad \text{(Ans.)}$$

To calculate the required cooling capacity, one has to know the losses in return air ducts. Ventilation may be neglected as the infiltration can take care of the small ventilation requirement. Hence using a safety factor of 1.25, the required cooling capacity is:

$$\text{Required cooling capacity} = 4288.08 \times 1.25 = 5360.1 \text{ W} \approx 1.5 \text{ TR} \qquad \text{(Ans.)}$$