

# Chapter Five

## Heating Load Calculation

Heating loads are the thermal energy that must be supplied to the interior of a building in order to maintain the desired comfort conditions. There are two kinds of heat losses; (1) the heat transmitted through the walls, ceiling, floor, glass, or other surfaces, and (2) the heat required to warm outdoor air entering the space.

The actual heat loss problem is transient because the outdoor temperature, wind velocity, and sunlight are constantly changing, but during the coldest months, however sustained periods of very cold, cloudy, and stormy weather with relatively small variation in outdoor temperature may occur. In this situation heat loss from the space will be relatively constant and maximum. Therefore for design purposes the heat loss is usually estimated for steady- state heat transfer for some reasonable design temperature.

Heat loss (gain) calculations by the (BTU) or (kW) method is an accurate process of determining the heat transmission through building materials. The established (U) factors of combinations of building materials gives a simple corrected method of determining the loss of heat from a building.

With the cost of material continually rising, accurate heat loss is a must. Systems can be designed to do the job efficiently without the long used *safety factor*. The safety factor is only a "cost more" factor.

### Conductivity for Plan Wall and Steady State

Fourier equation;

$$q = - KA \, dT/dx \rightarrow q = - dT/(dx/KA) \dots\dots\dots (5.1)$$

Where:

q: heat flow (kW)

dT: thermal potential difference (°C)

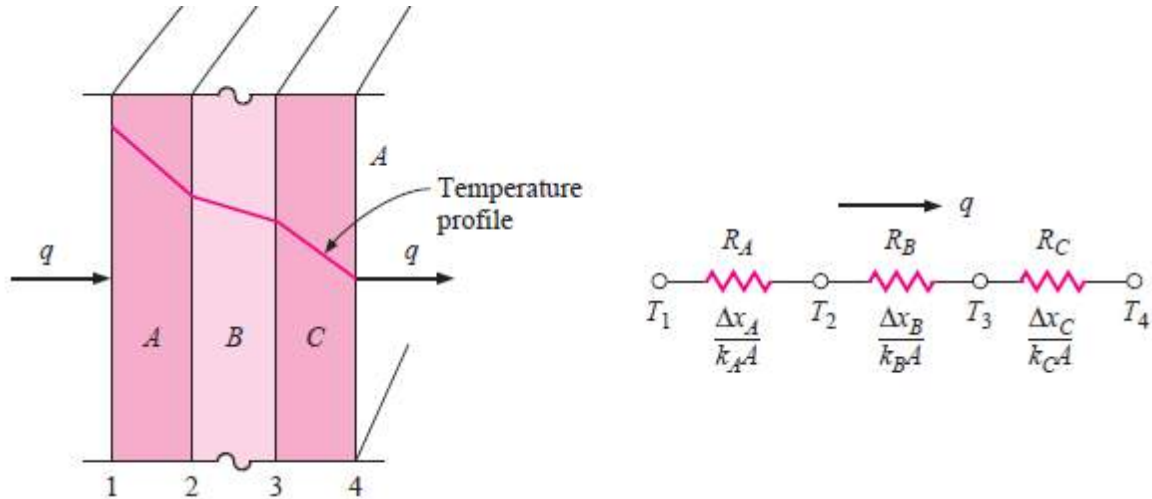
dx: wall thickness (m)

K: thermal conductivity (W/m.°C)

A: perpendicular area (m<sup>2</sup>)

We can say that;  $R_{th} = dx/KA$

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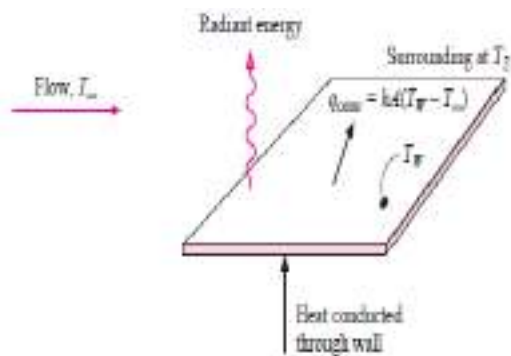
**Figure 5.1 One-dimensional heat transfer through a composite wall and electrical analogy.**

The temperature gradients in the three materials are shown in the Fig.5.1, and the heat flow may be written

$$q = -K_A A (T_2 - T_1) / \Delta x_A = -K_B A (T_3 - T_2) / \Delta x_B = -K_C A (T_4 - T_3) / \Delta x_C \dots\dots\dots (5.2)$$

$$q = (T_1 - T_4) / (\Delta x_A / K_A A + \Delta x_B / K_B A + \Delta x_C / K_C A) \\ = \Delta T_{\text{overall}} / \Sigma R_{\text{th}} \dots\dots\dots (5.3)$$

## Convection heat transfer



**Figure 5.2 Convection heat transfer.**

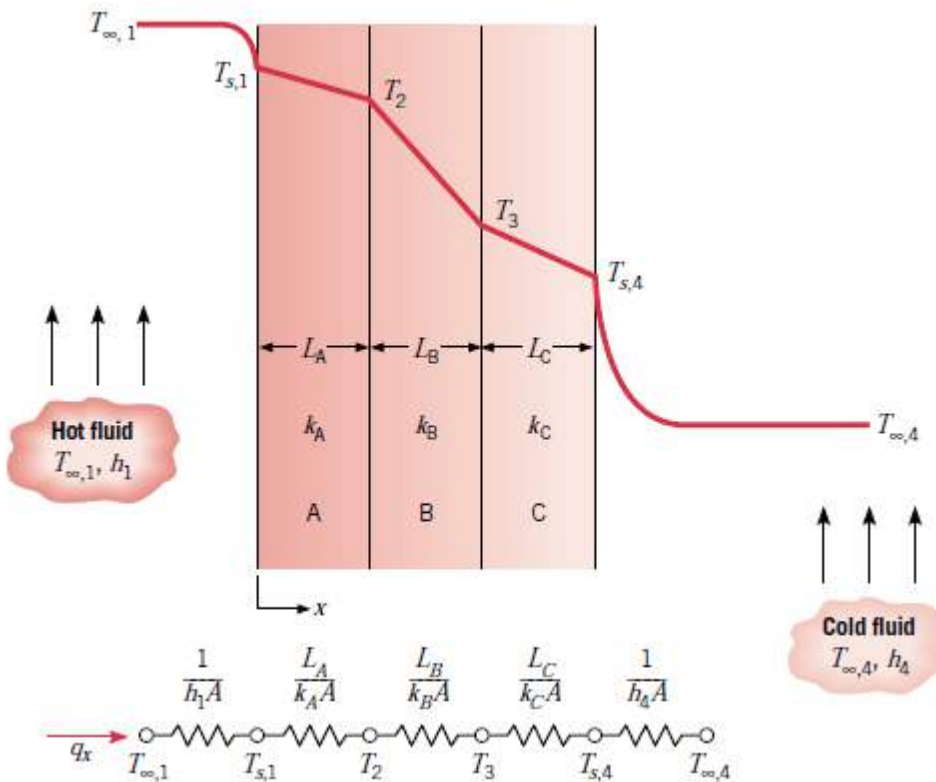
$$q = hA(T_w - T_f) \dots\dots\dots (5.4)$$

where; A is the surface area

$q = \Delta T / (1/h A)$ , where  $(1/h A)$  is the convection thermal resistance.

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## Overall heat transfer coefficient



**Figure 5.3 Equivalent thermal circuit for series composite wall.**

$$q = \Delta T_{\text{overall}} / \Sigma R_{\text{th}}$$

$$\Delta T_{\text{overall}} = T_i - T_o$$

$$\Sigma R_{\text{th}} = R_i + R_A + R_B + R_C + R_o$$

Equation of heat transfer can be written as;

$$q = U A \Delta T_{\text{overall}} \dots\dots\dots (5.5)$$

Where

U is the overall heat transfer coefficient =  $1 / \Sigma R_{\text{th}}$

To determine how much heat is lost through the walls, we have "U" factors for different types of construction. A "U" factor tells us how many (kW's) are transmitted to the colder (hotter) outside for one square meter of area with a difference of one degree between the outside surface and inside surface of the walls, windows, roofs or ceilings.

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## Definitions

1. "U" – Coefficient of heat transmission (overall): The amount of heat transmitted from air to air per square meter of the wall, roof, or ceiling for a difference in temperature of one degree centigrade between the air on the inside and outside (winter) of the wall, floor, roof or ceiling.
2. "K" – Conductivity: The amount of heat (W) transmitted through one square meter of a homogeneous material one meter thick for a difference in temperature of one degree centigrade between two surfaces of the material.
3. "C" – Conductance: The amount of heat (W) transmitted from surface to surface through one square meter of material or construction for a difference in temperature of one degree centigrade between the two surfaces. This is not per meter or centimeter of thickness, but for thickness shown.
4. "f<sub>o</sub>" – Outside film coefficient: The outside combined surface loss due to radiation and convection, with a 5 or 10 km/h (or more) wind velocity. The amount of heat (W) for one square meter of surface for a temperature difference of one degree centigrade (W/m<sup>2</sup>.°C).
5. "f<sub>i</sub>" – Inside film coefficient: The combined inside surface loss due to radiation and convection, with still air (W/m<sup>2</sup>.°C).
6. "a" – Thermal conductance of an air space: The amount of heat (W) transmitted through one square meter of surface for a difference in temperature of one degree centigrade (W/m<sup>2</sup>.°C).
7. "R" – This is the reciprocal of conductivity and conductance, or the overall heat transfer coefficient "U".

The total resistance "R" to heat flow through a wall is equal numerically to the sum of the resistance in series.

$$U_{Tot} = 1/R_{Tot}$$

$$R = 1/C, \quad R = 1/a, \quad R = 1/f, \quad R = X/K$$

$$U_{Tot} = 1/\Sigma R = 1/(1/f_i + 1/a + X_1/K_1 + X_2/K_2 + \text{-----} + 1/f_o)$$

## Example:

A wall consist of 10 cm face brick with 15 cm concrete and 1.3 cm cement plaster. The outdoor temperature is -7°C, and the wind velocity is 24 km/h, while the indoor space temperature is 25°C. Calculate:

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- (a) Thermal resistance of the wall    (b) Overall heat transfer coefficient  
(c ) Rate of heat transfer through the wall    (d) Rate of heat transfer when neglect the thermal resistance of the air layers.

### Solution:

Use the table of thermal conductivity of building materials to find the following:

For face brick                       $K_b = 1.30 \text{ W/m}^\circ\text{C}$

For concrete                       $K_c = 1.73 \text{ W/m}^\circ\text{C}$

For cement plaster               $K_p = 0.721 \text{ W/m}^\circ\text{C}$

$$f_i = 8.29 \text{ W/m}^2\cdot^\circ\text{C}, \quad f_o = 34.1 \text{ W/m}^2\cdot^\circ\text{C}$$

- (a) The total thermal resistance ( $\Sigma R_{th}$ )

$$\begin{aligned}\Sigma R_{th} &= 1/f_o + X_b/K_b + X_c/K_c + X_p/K_p + 1/f_i \\ &= 1/34.1 + 0.1/1.30 + 0.15/1.73 + 0.013/0.721 + 1/8.29 \\ &= 0.332 \text{ m}^2\cdot^\circ\text{C/W}\end{aligned}$$

- (b) The overall heat transfer coefficient (U)

$$U = 1/\Sigma R_{th} = 1/0.332 = 3.012 \text{ W/m}^2\cdot^\circ\text{C}$$

- (c ) The rate of heat transfer through the wall ( $q/A$ )

$$q/A = U (T_i - T_o) = (3.012) (25 - (-7)) = 96.384 \text{ W/m}^2$$

$$\Sigma R_{th} = X_b/K_b + X_c/K_c + X_p/K_p$$

$$= 0.1/1.30 + 0.15/1.73 + 0.013/0.721 = 0.182 \text{ m}^2\cdot^\circ\text{C/W}$$

$$q/A = (1/0.182) (25 + 7) = 175.82 \text{ W/m}^2$$

### Example:

Door made of wood sheet and contains a glass in the middle, which represent 80% of the door area. The thickness of the door is 40 mm and the room temperature is  $22^\circ\text{C}$ , while the outdoor temperature is  $5^\circ\text{C}$ . Determine the rate of heat loss from the room, if the dimensions of the door are 2 m x 1 m.

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### Solution:

$$\text{Door area} = 2 \times 1 = 2 \text{ m}^2$$

$$\text{Wood area} = 0.2 \times 2 = 0.4 \text{ m}^2$$

$$\text{Glass area} = 0.8 \times 2 = 1.6 \text{ m}^2$$

$$K_W = 0.159 \text{ W/m}^\circ\text{C}, \quad C_g^* = 6.25 \text{ W/m}^2^\circ\text{C}$$

Rate of heat transfer through the wood of the door:

$$\begin{aligned} \Sigma R_{th} &= 1/f_o + X_W/K_W + 1/f_i \\ &= 0.121 + (0.04/0.159) + 0.029 = 0.402 \text{ m}^2^\circ\text{C/W} \end{aligned}$$

$$q_w = (1/0.402) \times 0.4 \times (22 - 5) = 16.9 \text{ W}$$

Rate of heat transfer through the glass:

$$q_g = U.A.(t_i - t_o) = 6.25 \times 1.6 \times (22 - 5) = 170 \text{ W}$$

Then the total heat loss through the door:

$$q_d = q_w + q_g = 16.9 + 170 = 186.9 \text{ W}.$$

### The Temperature of the Surface of the Wall

It is important to know that the inside and outside air temperature is not equal to wall surface temperature. So in case when the temperature of inside wall surface reaches or below the dew point of indoor space temperature, it will causes to condensate the water vapor and may be defect this wall (especially in the winter). It is important to make a chick about this point.

### Example:

An external wall consist of three layers, layer A ( $X= 5 \text{ cm}$ ,  $K= 0.4 \text{ W/m.K}$ ), layer B ( $X= 24 \text{ cm}$ ,  $K= 0.6 \text{ W/m.K}$ ), layer C ( $X= 5 \text{ cm}$ ,  $K= 0.8 \text{ W/m.K}$ ). If the indoor space condition is  $20^\circ\text{C}$  DBT and  $14^\circ\text{C}$  WBT, and the outdoor temperature is  $-15^\circ\text{C}$ . Chick is the vapor condensate on the inner surface of the wall or not?

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### Solution:

We must find the temperature of the inner surface ( $T_w$ ) and compare it with the dew point of the air space, which is  $10.5^\circ\text{C}$

$$\begin{aligned} U &= 1/\Sigma R_{th} = 1/(1/f_i + X_A/K_A + X_B/K_B + X_C/K_C + 1/f_o) \\ &= 1/(1/8.29 + 0.05/0.4 + 0.24/0.6 + 0.05/0.8 + 1/34.1) = 1.36 \text{ W/m}^2.\text{C} \\ q &= U.A.(T_i - T_o) = 1.36 \times 1 \times (20 - 15) = 47.6 \text{ W/m}^2 \end{aligned}$$

Also

$$q = f_i (T_i - T_s) \quad \text{where; } T_s \text{ is the inner surface temperature}$$

$$47.6 = 8.29 \times (20 - T_s) \rightarrow T_s = 14.26^\circ\text{C}$$

The inner surface temperature is greater than the dew point, so the vapor will not condenses.

### Example:

A wall was constructed of hollow concrete blocks ( $C = 5.11 \text{ W/m}^2.\text{C}$ ). The indoor condition is  $20^\circ\text{C}$  DBT and  $14^\circ\text{C}$  WBT, when the outdoor air temperature is  $-15^\circ\text{C}$  and the wind velocity is  $24 \text{ km/h}$  in winter. Determine the inner surface temperature, and show if the vapor condenses on it or no.

### Solution:

The dew point for the indoor air from the psychrometric chart is  $9.3^\circ\text{C}$

$$\Sigma R_{th} = 1/f_i + 1/C + 1/f_o = (1/8.29) + (1/5.11) + (1/34.1) = 0.346 \text{ m}^2\text{C/W}$$

$$R_f/R_t = \Delta T_f/\Delta T_t$$

$$0.121/0.346 = (20 - T_s)/(20 + 15)$$

$$T_s = 7.8^\circ\text{C}$$

The inner surface temperature is lower than the dew point, so the vapor will condenses.

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## Infiltration

All structures have some air leakage or infiltration. This means a heat loss because the cold dry outdoor air must be heated to the inside design temperature and moisture must be added to increase the humidity to the design value. The heat required to increase the temperature is given by

$$q_s = m \cdot C_p (T_i - T_o) \dots\dots\dots (5.6)$$

Where

$q_s$ : sensible heat loss

$m$ : mass flow rate of the infiltration air

$C_p$ : specific heat of moist air

Infiltration is usually estimated on the basis of volume flow rate at outdoor conditions.

Then equation 5.6 become:

$$q_s = (V/v) C_p (T_i - T_o) = 1.22 V \cdot (T_i - T_o) \dots\dots\dots (5.7)$$

Where

$V$ : infiltration volume flow rate ( $m^3/s$ )

$v$  : specific volume ( $m^3/kg$ )

The latent heat required to humidify the air is given by

$$q_L = m \cdot (W_i - W_o) h_{fg} \dots\dots\dots (5.8)$$

$$= (V/v) (W_i - W_o) h_{fg} = 3010 V \cdot (W_i - W_o) \dots\dots\dots (5.9)$$

Where

$(W_i - W_o)$ : the difference in design moisture ratio ( $kg/kg_{d.a}$ )

$h_{fg}$ : the latent heat of vaporization at indoor condition ( $J/kg$ ) or ( $kJ/kg$ )

More than one method is used in estimating air infiltration in building structures.

### 1. Air Change Method

Experience and judgment are required to obtain satisfactory results with this method. Experienced engineers will often simple make an assumption of the number of air changes per hour (ACH) that a building will experience based on their appraisal of the building type,



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construction, and use. The range will usually be from 0.5 ACH (very low) to 2.0 ACH (very high). This approach is usually satisfactory for design load calculation but not recommended for the beginner.

In practice, the following values of air changes per hour can be used with reasonable precision for rooms with the extent of windows and external doors given.

No windows or exterior doors	0.5
Exterior doors or windows on one side	1
Exterior doors or windows on two sides	1.5
Exterior doors or windows on three sides	2
Entrance halls	2

### **2. Crack Method**

The flow (leak) through an opening is proportional to the area of the cracks, the type of the cracks, and the pressure difference across the crack.

$$V \cdot = A.C.\Delta P^n \dots\dots\dots (5.10)$$

Where

A: effective leak area of the cracks

C: flow coefficient, which depends on the type of crack and the nature of the flow in the crack.

$\Delta P$ : outside – inside pressure difference ( $P_o - P_i$ )

N: Exponent that depends on the nature of the flow in the crack  $0.4 < n < 1.0$ .

The following table gives the leakage rates through cracks in doors on the windward side for different wind velocities and different door constructions.

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Type of door	m <sup>3</sup> per linear meter of crack					
	Wind velocity, km/h					
	8	16	24	32	40	48
Glass door, good installation						
3.2 mm crack	0.3	0.6	0.9	1.21	1.49	1.77
Average installation						
4.76 mm crack	0.45	0.93	1.3	1.86	2.23	2.7
Poor installation						
6.4 mm crack	0.6	1.21	1.77	2.42	2.42	3.53
Ordinary wood or metal door						
well fitted W-stripped	0.04	0.06	0.08	0.12	0.16	0.2
well fitted now W-stripped	0.08	0.11	0.17	0.24	0.31	0.39
Poorly fitted						
Now W-stripped	0.08	0.21	0.34	0.48	0.61	0.78
Factory door 3.2 mm crack	0.3	0.6	0.9	1.21	1.49	1.77

### **Example:**

Find the sensible heat loss due to infiltration outdoor air at -6°C into a heated house through an aluminum window (2 m x 1.2 m), which has double swinging parts the width of each is 0.5 m, and a fixed glass in the middle. The temperature of the air inside the house is 22°C.

### **Solution:**

Crack length =  $2[(1.2 + 0.5) \times 2] = 6.8 \text{ m}$

ASHRAE Handbook, 1981 gives value of 0.77 (l/s. m) infiltration air through aluminum windows when the air velocity is 40 km/h.

$$V \cdot = (0.77/1000) \times 6.8 = 0.00524 \text{ m}^3/\text{s}$$

And from equation 5.7

$$q_s = 1.22 V \cdot (T_i - T_o) = 1.22 (0.00524)(22 + 6) = 0.179 \text{ kW}.$$

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## Ventilation

The introduction of outdoor air for ventilation of conditional spaces is necessary to dilute the odors given off by people, smoking and other internal air contaminates.

The amount of ventilation required varies primarily with the total number of people, the ceiling height and the number of people smoking. People give off body odors which required a minimum of 5 cfm (2.36 l/s) per person. When people smoke, the additional odors given off by cigarettes or cigars requires a minimum of 15 to 25 cfm (7 – 12 l/s) per person. In special gathering rooms with heavy smoking, 30 to 50 cfm (15 – 24 l/s) per person is recommended.

Tables 4.7 and 4.8 are used to determine the minimum and recommended ventilation air quantity for several applications.

The sensible and latent heating loads from ventilation air can be estimated by the following equations

$$q_s = (V/v) C_p (T_i - T_o) = 1.22 V \cdot (T_i - T_o) \dots\dots\dots (5.10)$$

$$q_L = (V/v) (W_i - W_o) h_{fg} = 3010 V \cdot (W_i - W_o) \dots\dots\dots (5.11)$$

V: ventilation volume flow rate (m<sup>3</sup>/s)

### Example:

An auditorium seats 1000 people. The space design conditions are 21°C and 40% RH, and outdoor design conditions 5°C DBT and 60% RH. What is the heating load due to ventilation.

### Solution:

From table 4.8 the minimum ventilation air per person to be 5.5 l/s

Total ventilation air = 5.5 x 1000 = 5500 l/s = 5.5 m<sup>3</sup>/s

$$q_s = (V/v) C_p (T_i - T_o) = 1.22 V \cdot (T_i - T_o) = 1.22 (5.5)(21 - 5)$$

$W_i = 0.0061$  kg/kg dry air ,  $W_o = 0.0034$  kg/kg dry air [ from the psychrometric chart at the inner and outer design conditions]

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$$q_L = (V/v) (W_i - W_o) h_{fg} = 3010 V \cdot (W_i - W_o) \\ = 3010 (5.5)(0.0061 - 0.0034) = 44.7 \text{ kW}$$

Then the total heating load due to ventilation

$$Q_v = 107.36 + 44.7 = 152.06 \text{ kW}$$

### Heat Losses from Air Ducts

The losses of a duct system can be considerable when the ducts are not in the conditioned space. Proper insulation will reduce these losses but cannot completely eliminate them. The losses may be estimated using the following relation

$$q_D = U \cdot A_s \cdot \Delta T_m \dots\dots\dots (5.12)$$

where

U: overall heat transfer coefficient (W/m<sup>2</sup>°C)

A<sub>s</sub>: outside duct surface area (m<sup>2</sup>)

ΔT<sub>m</sub>: mean temperature difference between the air in the duct and the environment.

### Example:

Estimate the heat losses from 0.5 m<sup>3</sup>/s of air at 50°C round duct 8 m in length. The duct has 25 mm (1 in) of fibrous glass insulation and the overall heat transfer coefficient is 1.1357 W/m<sup>2</sup>.°C. The environment temperature is -10°C and the duct diameter is 400 mm.

### Solution:

Equation 5.12 will be used to estimate the heat losses

$$\Delta T_m = T_s - T_o = 50 - (-10) = 60^\circ\text{C}$$

The surface area of the duct is

$$A_s = \pi \cdot D \cdot L = \pi (0.4 + 0.05)(8) = 11.3 \text{ m}^2$$

$$\text{Then, } q_D = 1.1357 (11.3)(60) = 770 \text{ W} = 0.77 \text{ kW}$$

the temperature of air leaving the duct may be computed from

$$q = m \cdot C_p (T_2 - T_1) = V \cdot \rho \cdot C_p (T_2 - T_1)$$

$$T_2 = T_1 + q / (V \cdot \rho \cdot C_p) = 50 + (-0.77 / 0.5 \times 1.2 \times 1.017) = 48.7^\circ\text{C}$$

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Minimum insulation of supply and return duct is presently specified by ASHRAE standards as follows:

All duct system shall be insulated to provide a thermal resistance, excluding film resistance, of

$$R = \Delta T / 47.3 \text{ (m}^2\text{°C/W)}$$

Where,  $\Delta T = T_{\text{duct}} - T_{\text{surrounding}}$

Heat losses from the supply ducts become part of the space heating load and should be summed with transmission and infiltration heat losses.

Heat losses from the return ducts are not a part of the space heat loss, but should added to the heating equipment load.

### **Air Required for Space Heating**

The air quantity is computed from

$$q_s = m \cdot C_p (T_s - T_r) = 1.22 \dot{V} \cdot (T_s - T_r) \dots\dots\dots (5.13)$$

$$\dot{V} = q_s / [1.22(T_s - T_r)]$$

Where

$\dot{V}$ : volume flow rate of supplied air, m<sup>3</sup>/s

$v$ : specific volume of supplied air, m<sup>3</sup>/kg

$T_s$ : temperature of supplied air, °C

$T_r$ : temperature of room (conditioned space), °C

The temperature difference ( $T_s - T_r$ ) is normally less than 10°C. It can be considered as a temperature difference about 6°C is suitable for most of the comfort air conditioning applications in Arab region.

After the total air flow rate required for the complete structure has been determine. The next step is to allocate the correct portion of the air to each room or space. Air quantity for each room should be apportioned according to the heating load for the space; therefore

$$\dot{V}_{\text{rn}} = \dot{V} \cdot (q_{\text{rn}} / q_t) \dots\dots\dots (5.14)$$

Where;  $q_{\text{rn}}$ : total heat loss of room(n), W

$\dot{V}_{\text{rn}}$ : volume flow rate of air supply to room(n), m<sup>3</sup>/s

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### Exercises:

1. The dimensions of the outer wall of a room are 6 m x 3 m, and it contains a glass window of dimensions 2 m x 1.5 m. The wall is made up of 24 cm brick with 10 cm face brick and 2 cm of a gypsum layer from the inside. The indoor air temperature is 20°C, while the outdoor air temperature and wind velocity are 5°C and 24 km/h respectively. Calculate:

(a) The total heat loss from the wall and the window together.

(b) The temperature of the inner surface of the wall.

2. An external wall is made of 100 mm common brick, with 40 mm gypsum plaster. What is the thickness of rock wool insulation ( $K = 0.04 \text{ W/m} \cdot ^\circ\text{C}$ ) to reduce the rate of heat loss by 80%.

3. The room conditions in winter are 22°C DBT and 40% RH. Infiltration air at 1°C DBT and 50% RH enters the room at a rate of 0.006 m<sup>3</sup>/s.

(a) Calculate the rate of water that must be evaporating to maintain the room conditions.

(b) Calculate the amount of heat required to vaporize the water at the above rate.

4. A building wall consists of 25 cm concrete ( $K = 1.75 \text{ W/m} \cdot \text{K}$ ) and 1.9 cm plaster ( $K = 0.87 \text{ W/m} \cdot \text{K}$ ) on the inside surface. The outside and inside surface heat-transfer coefficients can be taken as 34 and 9.4 W/m<sup>2</sup>K respectively. The outside temperature is -18°C, while the room is held at 23.5°C DBT and 16.8°C WBT.

(a) What is the temperature on the inside wall surface.

(b) Will the moisture condense on the wall.

(c) How many layers of 1.25 cm thick fiber-board insulation ( $K = 0.048 \text{ W/m} \cdot \text{K}$ ) should be applied on the inside wall surface to prevent moisture to condense on it.

5. A residential house contains a reception room and a family room and two-bedroom. The heating load of the listed rooms are; 5.5 kW, 3.5 kW and 4.2 kW for each bedroom respectively. The inside required temperature is 21°C. Find the rates of hot air which required for every room.

# Chapter Six

## Cooling Load Calculation

A large number of variables are considered in making cooling load calculations than heating load calculations. In both situations the actual heat loss or gain is a transient one. In design for cooling, however, transient analysis must be used if satisfactory results are to be obtained. This is because the instantaneous heat gain into a conditioned space is quite variable with time, primarily because of the strong transient effect created by the hourly variation in solar radiation.

### 6.1 Heating Gain and Cooling Load

It is important to differentiating between heat gains and cooling load. Heat gain is the rate at which energy is transferred to or generated within a space. Heat gains usually occur in the following forms:

- a. Solar radiation through openings.
- b. Heat conduction through boundaries with convection and radiation from the inner surface into the space.
- c. Sensible heat convection and radiation from internal objects.
- d. Ventilation (outside) and infiltration air.
- e. Latent heat gain generated within the space.

Figure 6.1 shows the heat gain sources in summer.

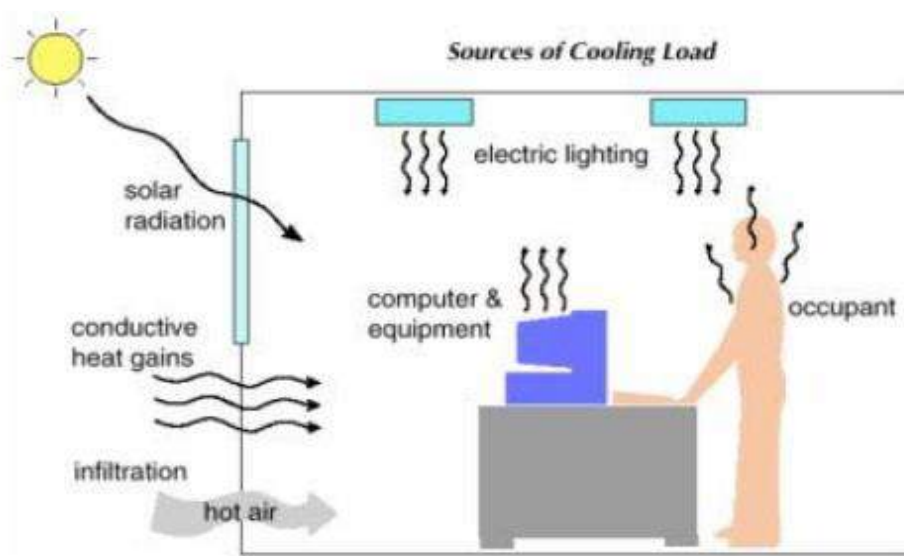


Fig. 6.1 Sources of heat gain.

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The space cooling load is the rate at which heat must remove from a space to maintain the temperature and humidity at the design values. The space cooling load will generally differ from the space heat gain at any instant of time.

The heat storage characteristics of the structure and interior objects determine the thermal lag and therefor the relationship between heat gain and cooling load.

Figure 6.2 shows the relation between the heat gain and cooling load and the effect of the mass of the structure. The attenuation and delay of the peak load gain is very evident especially for heavy construction.

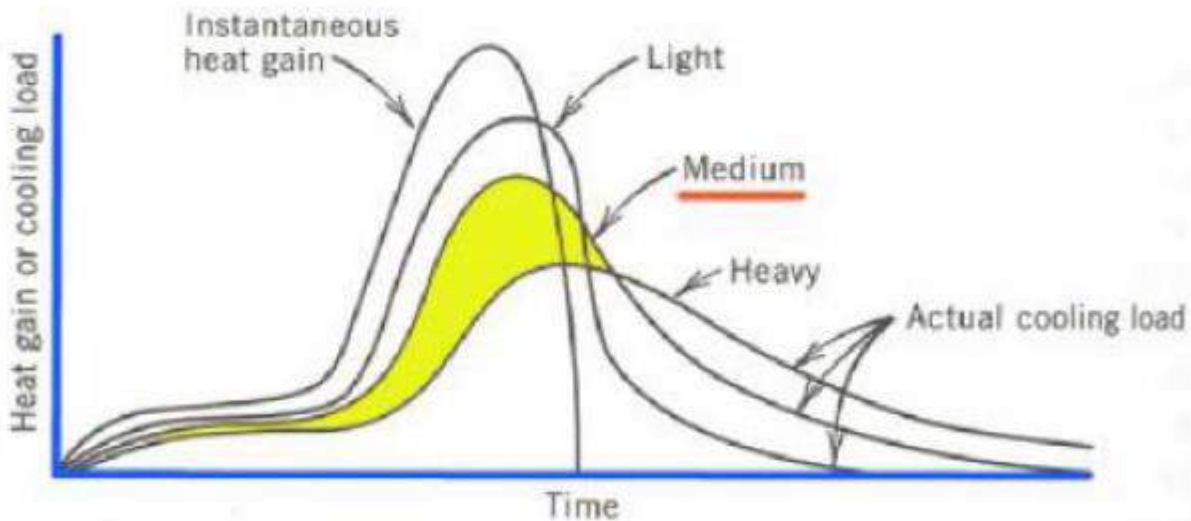


Figure 6.2 Relation between heat gain and cooling load.

## 6.2 Solar Air Temperature

In the first instance, heat transfer through a wall depends on the rate at which heat enters its outer surface. The concept of 'Sol-air temperature' has been in use for some time as an aid to the determination of the initial rate of entry of heat. It is defined as the value of the outside air temperature which would, in the absence of all radiation exchanges, give the same rate of heat flow into the outer surface of the wall as the actual combination of temperature differences and radiation exchanges really does.

The sol-air temperature,  $t_{eo}$ , otherwise termed the outside environmental temperature, is used in the following equation

$$Q' = h_{so}(t_{eo} - t_{so}) \quad \text{-----} \quad (6.1)$$



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where  $Q'$  = rate of heat entry into the outer surface, in  $\text{W m}^{-2}$

$h_{so}$  = outside surface heat transfer coefficient, in  $\text{W m}^{-2} \text{K}^{-1}$

$t_{eo}$  = sol-air temperature, in  $^{\circ}\text{C}$

$t_{so}$  = outside surface temperature, in  $^{\circ}\text{C}$

$Q'$  can be expressed in another way which does not involve the use of the sol-air temperature:

$$Q' = \alpha I_{\delta} + \alpha' I_s + h_{so}(t_o - t_{so}) + R \quad \dots\dots\dots (6.2)$$

In this basic heat entry equation,  $\alpha$  and  $\alpha'$  are the absorption coefficients (usually about the same value) for direct,  $I_{\delta}$ , and scattered,  $I_s$ , radiation which is normally incident on the wall surface.  $R$  is a remainder term which covers the complicated long wavelength heat exchanges by radiation between the wall and nearby surfaces. The value of  $R$  is difficult to assess; in all probability it is quite small and, if neglected, results in little error.

Equations (6.1) and (6.2) can be combined to yield an expression for  $t_{eo}$  in useful form:

$$t_{eo} = t_o + \frac{\alpha I_{\delta} + \alpha' I_s + R}{h_{so}} \quad \dots\dots\dots (6.3)$$

If  $\alpha'$  is made equal to  $\alpha$ , and  $R$  is ignored, this expression becomes

$$t_{eo} = t_o + \frac{\alpha(I_{\delta} + I_s)}{h_{so}} \quad \dots\dots\dots (6.4)$$

## 6.3 Cooling Load Calculation Methods

For a thorough calculation of the zones and whole-building loads, one of the following three methods should be employed:

- a. Transfer Function Method (TFM): This is the most complex of the methods proposed by ASHRAE and requires the use of a computer program or advanced spreadsheet.
- b. Cooling Load Temperature Differential/Cooling Load Factors (CLTD/CLF): This method is derived from the TFM method and uses tabulated data to simplify the calculation process. The method can be fairly easily transferred into simple spreadsheet programs but has some limitations due to the use of tabulated data.
- c. Total Equivalent Temperature Differential/Time-Averaging (TETD/TA): This was the preferred method for hand or simple spreadsheet calculation before the introduction of the CLTD/CLF method.

These three methods are well documented in ASHRAE Handbook Fundamentals, 2001.

# Chapter Six

## The CLTD Method

The CLTD method accounts for the thermal response in the heat transfer through the wall or roof, as well as the response due to radiation of part of the energy from the interior surface of the wall to objects and surfaces within the space. The CLTD method makes use of (a) the temperature difference in the case of walls and roofs and (b) the cooling load factors (CLF) in the case of solar heat gain through windows and internal heat sources, that is,

$$Q = U \times A \times \text{CLTD}_c \dots\dots\dots (6.5)$$

Where

Q: is the net room conduction heat gain through roof, wall or glass (W)

A: is the area of roof, wall or glass (m<sup>2</sup>)

U: is the overall heat transfer coefficient (W/m<sup>2</sup>.K)

CLTD<sub>c</sub>: is the cooling load temperature difference (°C)

### CLTD/CLF calculation

#### - Walls and roofs

To account for the temperature and the solar variations, the concept of cooling load temperature difference (CLTD) is introduced. The CLTD is a steady-state representation of the complex heat transfer involving actual temperature difference between indoors and outdoors, mass and solar radiation by the building materials, and of time of day. Table 6.1 lists the types of the walls according to installation structural, while Table 6.2 gives the values of CLTDs for different groups of sunlit walls. Table 6.3 lists the CLTDs values for thirteen type of roofs for the typical cooling design day. The following relation makes corrections in the CLTDs listed in the Tables 6.2 and 6.3 for walls and roofs respectively for deviations in design and solar conditions as follows:

$$\text{CLTD}_c = [(\text{CLTD} + \text{LM})k + (25.5 - T_r) + (T_{o,m} - 29.4)]f \dots\dots\dots (6.6)$$

Where

CLTD<sub>c</sub>: is the corrected value of CLTD

LM: is latitude-month correction from Table (6.4)