

Lesson

35

Cooling And Heating

Load Calculations

- Estimation Of Required

Cooling/Heating

Capacity

The specific objectives of this chapter are to:

1. Introduction to load calculations (*Section 35.1*)
2. Differences between conventional cooling and heating load calculation methodologies (*Section 35.2*)
3. Methods of estimating cooling and heating loads on buildings such as rules-of-thumb, semi-empirical methods etc. (*Section 35.3*)
4. Cooling load calculations using CLTD/CLF method (*Section 35.4*)
5. Estimation of the cooling capacity of the system (*Section 35.5*)
6. Heating load calculations (*Section 35.6*)

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

1. Explain the differences between conventional cooling and heating load calculations
2. List commonly used methods for estimating cooling loads
3. Estimate the internal and external cooling loads on a building by separating sensible and latent parts using CLTD/CLF method from building specifications, design indoor and outdoor conditions, occupancy etc.
4. Estimate the required cooling capacity of the coil by taking into account the bypass factor of the coil, ventilation requirements etc.
5. Explain briefly the procedure for estimating heating loads

35.1. Introduction:

As mentioned in an earlier chapter, heating and cooling load calculations are carried out to estimate the required capacity of heating and cooling systems, which can maintain the required conditions in the conditioned space. To estimate the required cooling or heating capacities, one has to have information regarding the design indoor and outdoor conditions, specifications of the building, specifications of the conditioned space (such as the occupancy, activity level, various appliances and equipment used etc.) and any special requirements of the particular application. For comfort applications, the required indoor conditions are fixed by the criterion of thermal comfort, while for industrial or commercial applications the required indoor conditions are fixed by the particular processes being performed or the products being stored. As discussed in an earlier chapter, the design outdoor conditions are chosen based on design dry bulb and coincident wet bulb temperatures for peak summer or winter months for cooling and heating load calculations, respectively.

35.2. Heating versus cooling load calculations:

As the name implies, **heating load calculations** are carried out to estimate the heat loss from the building in winter so as to arrive at required **heating capacities**. Normally during winter months the peak heating load occurs before sunrise and the outdoor conditions do not vary significantly throughout the winter season. In addition, internal heat sources such as occupants or appliances are beneficial as they compensate some of the heat losses. As a result, normally, the heat load calculations are carried out assuming steady state conditions (no solar radiation and steady outdoor conditions) and neglecting internal heat sources. This is a simple but conservative approach that leads to slight overestimation of the heating capacity. For more accurate estimation of heating loads, one has to take into the thermal capacity of the walls and internal heat sources, which makes the problem more complicated.

For estimating **cooling loads**, one has to consider the unsteady state processes, as the peak cooling load occurs during the day time and the outside conditions also vary significantly throughout the day due to solar radiation. In addition, all internal sources add on to the cooling loads and neglecting them would lead to underestimation of the required cooling capacity and the possibility of not being able to maintain the required indoor conditions. Thus cooling load calculations are inherently more complicated as it involves solving unsteady equations with unsteady boundary conditions and internal heat sources.

For any building there exists a **balance point** at which the solar radiation (Q_{solar}) and internal heat generation rate (Q_{int}) exactly balance the heat losses from the building. Thus from sensible heat balance equation, at balanced condition:

$$(Q_{\text{solar}} + Q_{\text{int}})_{\text{sensible}} = UA(T_{\text{in}} - T_{\text{out}}) \quad (35.1)$$

where UA is the product of overall heat transfer coefficient and heat transfer area of the building, T_{in} is the required indoor temperature and T_{out} is the outdoor temperature.

From the above equation, the outside temperature at balanced condition ($T_{\text{out,bal}}$) is given by:

$$T_{\text{out,bal}} = T_{\text{in}} - \frac{(Q_{\text{solar}} + Q_{\text{int}})_{\text{sensible}}}{UA} \quad (35.2)$$

If the outdoor temperature is greater than the balanced outdoor temperature given by the above equation, i.e., when $T_{\text{out}} > T_{\text{out,bal}}$, then there is a **need for cooling** the building. On the other hand, when the outdoor temperature is less than the balanced outdoor temperature, i.e., when $T_{\text{out}} < T_{\text{out,bal}}$, then there is a **need for heating** the building. When the outdoor temperature exactly equals the balanced outdoor temperature, i.e., when $T_{\text{out}} = T_{\text{out,bal}}$, then there is **no need for either cooling or heating** the building

For residential buildings (with fewer internal heat sources), the balanced outdoor temperature may vary from 10 to 18°C. As discussed before, this means that if the balanced outdoor temperature is 18°C, then a cooling system is required when the outdoor temperature exceeds 18°C. This implies that buildings need cooling not only during summer but also during spring and fall as well. If the building is well insulated (small UA) and/or internal loads are high, then from the energy balance equation (35.2), the balanced outdoor temperature will reduce leading to extended cooling season and shortened heating season. Thus a smaller balanced outdoor temperature implies higher cooling requirements and smaller heating requirements, and vice versa. For commercial buildings with large internal loads and relatively smaller heat transfer areas, the balanced outdoor temperature can be as low as 2°C, implying a lengthy cooling season and a small heating season. If there are no internal heat sources and if the solar radiation is negligible, then from the heat balance equation, $T_{out,bal} = T_{in}$, this implies that if the outside temperature exceeds the required inside temperature (say, 25°C for comfort) then there is a need for cooling otherwise there is a need for heating. Thus depending upon the specific conditions of the building, the need for either cooling system or a heating system depends. This also implies a need for optimizing the building insulation depending upon outdoor conditions and building heat generation so that one can use during certain periods free cooling provided by the environment without using any external cooling system.

35.3. Methods of estimating cooling and heating loads:

Generally, heating and cooling load calculations **involve a systematic, stepwise procedure**, using which one can arrive at the required system capacity by taking into account all the building energy flows. In practice, a variety of methods ranging from simple rules-of-thumb to complex Transfer Function Methods are used in practice to arrive at the building loads. For example, typical rules-of-thumb methods for cooling loads specify the required cooling capacity based on the floor area or occupancy. Table 35.1 shows typical data on required cooling capacities based on the floor area or application. Such rules-of-thumb are useful in preliminary estimation of the equipment size and cost. The main conceptual drawback of rules-of-thumb methods is the presumption that the building design will not make any difference. Thus the rules for a badly designed building are typically the same as for a good design.

Sl.no	Application	Required cooling capacity (TR) for 1000 ft ² of floor area
1.	Office buildings: External zones	<u>25% glass:</u> 3.5 TR <u>50% glass:</u> 4.5 TR <u>75% glass:</u> 5.0 TR
	Internal zones	2.8 TR
2.	Computer rooms	6.0 – 12.0 TR
3.	Hotels Bedrooms	<u>Single room:</u> 0.6 TR per room <u>Double room:</u> 1.0 TR per room
	Restaurants	5.0 - 9.0 TR
4.	Department stores Basement & ground floors	4.5 – 5.0 TR
	Upper floors	3.5 – 4.5 TR
5.	Shops	5.0 TR
6.	Banks	4.5 – 5.5 TR
7.	Theatres & Auditoriums	0.07 TR per seat

Table 35.1: Required cooling capacities for various applications based on rules-of-thumb (Croome and Roberts, 1981)

More accurate load estimation methods involve a combination of analytical methods and empirical results obtained from actual data, for example the use of Cooling Load Temperature Difference (**CLTD**) for estimating fabric heat gain and the use of Solar Heat Gain Factor (**SHGF**) for estimating heat transfer through fenestration. These methods are very widely used by air conditioning engineers as they yield reasonably accurate results and estimations can be carried out manually in a relatively short time. Over the years, more accurate methods that require the use of computers have been developed for estimating cooling loads, e.g. the **Transfer Function Method** (TFM). Since these methods are expensive and time consuming they are generally used for estimating cooling loads of large commercial or institutional buildings. ASHRAE suggests different methods for estimating cooling and heating loads based on applications, such as for residences, for commercial buildings etc.

35.4. Cooling load calculations:

As mentioned before, load calculations involve a systematic and stepwise procedure that takes into account all the relevant building energy flows. The cooling load experienced by a building varies in magnitude from zero (no cooling required) to a maximum value. The design cooling load is a load near the maximum magnitude, but is not normally the maximum. Design cooling load takes into account all the loads experienced by a building under a specific set of assumed conditions.

The assumptions behind design cooling load are as follows:

1. Design outside conditions are selected from a long-term statistical database. The conditions will not necessarily represent any actual year, but are representative of the location of the building. Design data for outside conditions for various locations of the world have been collected and are available in tabular form in various handbooks.
2. The load on the building due to solar radiation is estimated for clear sky conditions.
3. The building *occupancy* is assumed to be *at full design capacity*.
4. All building equipment and appliances are considered to be operating at a reasonably representative capacity.

The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment, and lights. The load due to heat transfer through the envelope is called as **external load**, while all other loads are called as **internal loads**. The percentage of external versus internal load varies with building type, site climate, and building design. The total cooling load on any building consists of both **sensible** as well as **latent** load components. The sensible load affects dry bulb temperature, while the latent load affects the moisture content of the conditioned space.

Buildings may be classified as **externally loaded and internally loaded**. In externally loaded buildings the cooling load on the building is mainly due to heat transfer between the surroundings and the internal conditioned space. Since the surrounding conditions are highly variable in any given day, the **cooling load of an externally loaded building varies widely**. In internally loaded buildings the cooling load is mainly due to internal heat generating sources such as occupants or appliances or processes. In general the heat generation due to internal heat sources may remain fairly constant, and since the heat transfer from the variable surroundings is much less compared to the internal heat sources, the **cooling load of an internally loaded building remains fairly constant**. Obviously from energy efficiency and economics points of view, the system design strategy for an externally loaded building should be different from an internally loaded building. Hence, prior knowledge of whether the building is externally loaded or internally loaded is essential for effective system design.

As mentioned before, the total cooling load on a building consists of external as well as internal loads. The external loads consist of heat transfer by conduction through the building walls, roof, floor, doors etc, heat transfer by radiation through fenestration such as windows and skylights. All these are sensible heat transfers. In addition to these the external load also consists of heat transfer due to infiltration, which consists of both sensible as well as latent components. The heat transfer due to ventilation is not a load on the building but a load on the system. The various internal loads consist of sensible and latent heat transfer due to occupants, products, processes and appliances, sensible heat transfer due to lighting and other equipment. Figure 35.1 shows various components that constitute the cooling load on a building.

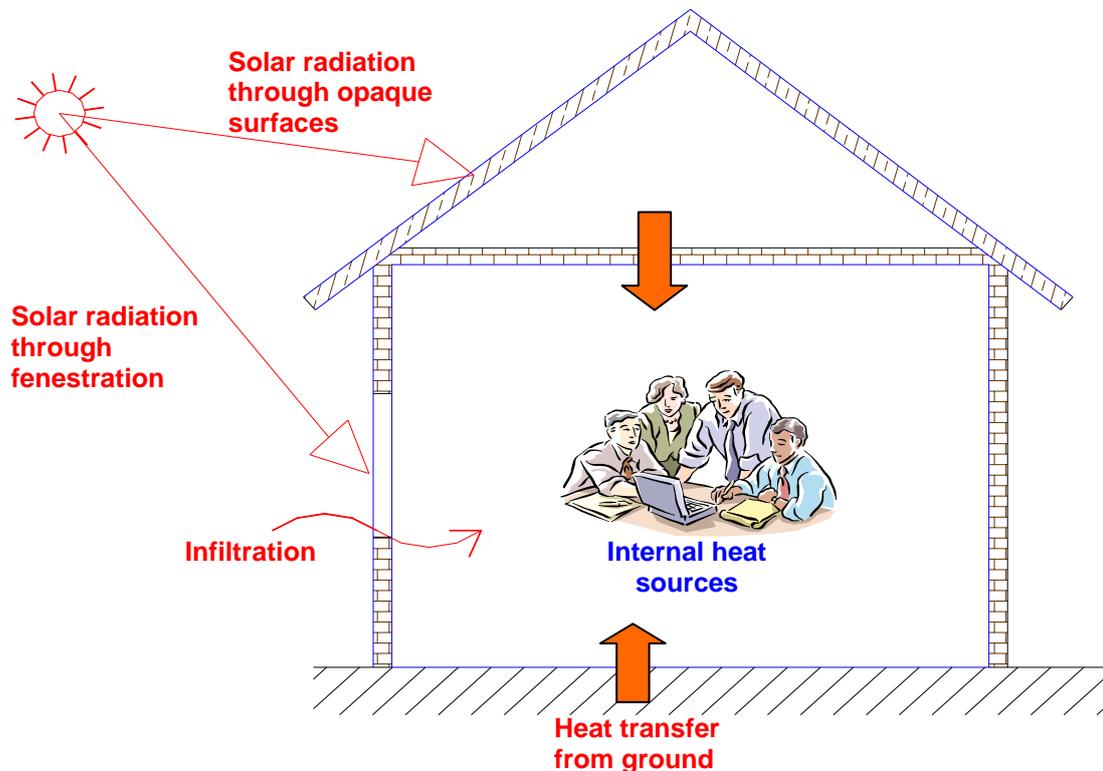


Fig.35.1: Various cooling load components

Estimation of cooling load involves estimation of each of the above components from the given data. In the present chapter, the cooling load calculations are carried out based on the CLTD/CLF method suggested by ASHRAE. For more advanced methods such as TFM, the reader should refer to ASHRAE and other handbooks.

35.4.1. Estimation of external loads:

a) Heat transfer through opaque surfaces: This is a sensible heat transfer process. The heat transfer rate through opaque surfaces such as walls, roof, floor, doors etc. is given by:

$$Q_{\text{opaque}} = U.A.CLTD \quad (35.3)$$

where U is the overall heat transfer coefficient and A is the heat transfer area of the surface on the side of the conditioned space. CLTD is the cooling load temperature difference.

For sunlit surfaces, CLTD has to be obtained **from the CLTD tables** as discussed in the previous chapter. Adjustment to the values obtained from the table is needed if actual conditions are different from those based on which the CLTD tables are prepared.

For surfaces which are not sunlit or which have negligible thermal mass (such as doors), the CLTD value is simply equal to the **temperature difference across the wall or roof**. For example, for external doors the CLTD value is simply equal to the difference between the design outdoor and indoor dry bulb temperatures, $T_{out}-T_{in}$.

For **interior air conditioned rooms surrounded by non-air conditioned spaces**, the CLTD of the interior walls is equal to the temperature difference between the surrounding non-air conditioned space and the conditioned space. Obviously, if an air conditioned room is surrounded by other air conditioned rooms, with all of them at the same temperature, the CLTD values of the walls of the interior room will be zero.

Estimation of **CLTD values of floor and roof with false ceiling** could be tricky. For floors standing on ground, one has to use the temperature of the ground for estimating CLTD. However, the ground temperature depends on the location and varies with time. ASHRAE suggests suitable temperature difference values for estimating heat transfer through ground. If the floor stands on a basement or on the roof of another room, then the CLTD values for the floor are the temperature difference across the floor (i.e., difference between the temperature of the basement or room below and the conditioned space). This discussion also holds good for roofs which have non-air conditioned rooms above them. For **sunlit roofs with false ceiling**, the U value may be obtained by assuming the false ceiling to be an air space. However, the CLTD values obtained from the tables may not exactly fit the specific roof. Then one has to use his judgement and select suitable CLTD values.

b) Heat transfer through fenestration: Heat transfer through transparent surface such as a window, includes heat transfer by conduction due to temperature difference across the window and heat transfer due to solar radiation through the window. The heat transfer through the window by convection is calculated using Eq.(35.3), with CLTD being equal to the temperature difference across the window and A equal to the total area of the window. The heat transfer due to solar radiation through the window is given by:

$$Q_{trans} = A_{unshaded} \cdot SHGF_{max} \cdot SC \cdot CLF \quad (35.4)$$

where $A_{unshaded}$ is the area exposed to solar radiation, $SHGF_{max}$ and SC are the maximum Solar Heat Gain Factor and Shading Coefficient, respectively, and **CLF** is the **Cooling Load Factor**. As discussed in a previous chapter, the unshaded area has to be obtained from the dimensions of the external shade and solar geometry. $SHGF_{max}$ and SC are obtained from ASHRAE tables based on the orientation of the window, location, month of the year and the type of glass and internal shading device.

The **Cooling Load Factor (CLF)** accounts for the fact that all the radiant energy that enters the conditioned space at a particular time does not become a part of the cooling load¹ instantly. As solar radiation enters the conditioned space, only a negligible portion of it is absorbed by the air particles in the conditioned space instantaneously leading to a minute change in its temperature. Most of the radiation is first absorbed by the internal surfaces, which include ceiling, floor, internal walls, furniture etc. Due to the large but finite thermal capacity of the roof, floor, walls etc., their temperature increases slowly due to absorption of solar radiation. As the surface temperature increases, heat transfer takes place between these surfaces and the air in the conditioned space. Depending upon the thermal capacity of the wall and the outside temperature, some of the absorbed energy due to solar radiation may be conducted to the outer surface and may be lost to the outdoors. Only that fraction of the solar radiation that is transferred to the air in the conditioned space becomes a load on the building, the heat transferred to the outside is not a part of the cooling load. Thus it can be seen that the **radiation heat transfer introduces a time lag and also a decrement factor** depending upon the dynamic characteristics of the surfaces. Due to the time lag, the effect of radiation will be felt even when the source of radiation, in this case the sun is removed. The CLF values for various surfaces have been calculated as functions of solar time and orientation and are available in the form of tables in ASHRAE Handbooks. Table 35.2 gives typical CLF values for glass with interior shading.

Solar Time, h	Direction the sunlit window is facing								
	N	NE	E	SE	S	SW	W	NW	Horiz.
6	0.73	0.56	0.47	0.30	0.09	0.07	0.06	0.07	0.12
7	0.66	0.76	0.72	0.57	0.16	0.11	0.09	0.11	0.27
8	0.65	0.74	0.80	0.74	0.23	0.14	0.11	0.14	0.44
9	0.73	0.58	0.76	0.81	0.38	0.16	0.13	0.17	0.59
10	0.80	0.37	0.62	0.79	0.58	0.19	0.15	0.19	0.72
11	0.86	0.29	0.41	0.68	0.75	0.22	0.16	0.20	0.81
12	0.89	0.27	0.27	0.49	0.83	0.38	0.17	0.21	0.85
13	0.89	0.26	0.26	0.33	0.80	0.59	0.31	0.22	0.85
14	0.86	0.24	0.24	0.28	0.68	0.75	0.53	0.30	0.81
15	0.82	0.22	0.22	0.25	0.50	0.83	0.72	0.52	0.71
16	0.75	0.20	0.20	0.22	0.35	0.81	0.82	0.73	0.58
17	0.78	0.16	0.16	0.18	0.27	0.69	0.81	0.82	0.42
18	0.91	0.12	0.12	0.13	0.19	0.45	0.61	0.69	0.25

Table 35.2: Cooling Load Factor (CLF) for glass with interior shading and located in north latitudes (ASHRAE)

c) Heat transfer due to infiltration: Heat transfer due to infiltration consists of both sensible as well as latent components. The sensible heat transfer rate due to infiltration is given by:

¹ At any point of time, cooling load may be equated to the heat transfer rate to the air in the conditioned space. If heat is transferred to the walls or other solid objects, then it does not become a part of the cooling load at that instant

$$Q_{s,inf} = \dot{m}_o c_{p,m} (T_o - T_i) = \dot{V}_o \rho_o c_{p,m} (T_o - T_i) \quad (35.5)$$

where \dot{V}_o is the infiltration rate (in m^3/s), ρ_o and $c_{p,m}$ are the density and specific heat of the moist, infiltrated air, respectively. T_o and T_i are the outdoor and indoor dry bulb temperatures.

The latent heat transfer rate due to infiltration is given by:

$$Q_{l,inf} = \dot{m}_o h_{fg} (W_o - W_i) = \dot{V}_o \rho_o h_{fg} (W_o - W_i) \quad (35.6)$$

where h_{fg} is the latent heat of vaporization of water, W_o and W_i are the outdoor and indoor humidity ratio, respectively.

As discussed in an earlier chapter, the infiltration rate depends upon several factors such as the tightness of the building that includes the walls, windows, doors etc and the prevailing wind speed and direction. As mentioned before, the infiltration rate is obtained by using either the air change method or the crack method.

The infiltration rate by air change method is given by:

$$\dot{V}_o = (ACH).V / 3600 \quad m^3 / s \quad (35.7)$$

where **ACH is the number of air changes per hour** and **V is the gross volume of the conditioned space** in m^3 . Normally the ACH value varies from 0.5 ACH for tight and well-sealed buildings to about 2.0 for loose and poorly sealed buildings. For modern buildings the ACH value may be as low as 0.2 ACH. Thus depending upon the age and condition of the building an appropriate ACH value has to be chose, using which the infiltration rate can be calculated.

The infiltration rate by the crack method is given by:

$$\dot{V}_o = A.C.\Delta P^n \quad m^3 / s \quad (35.8)$$

where **A is the effective leakage area of the cracks**, **C is a flow coefficient** which depends on the type of the crack and the nature of the flow in the crack, **ΔP is the difference between outside and inside pressure ($P_o - P_i$)** and **n is an exponent** whose value depends on the nature of the flow in the crack. The value of n varies between 0.4 to 1.0, i.e., $0.4 \leq n \leq 1.0$. The pressure difference **ΔP** arises due to pressure difference due to the wind (**ΔP_{wind}**), pressure difference due to the stack effect (**ΔP_{stack}**) and pressure difference due to building pressurization (**ΔP_{bld}**), i.e.,

$$\Delta P = \Delta P_{wind} + \Delta P_{stack} + \Delta P_{bld} \quad (35.9)$$

Semi-empirical expressions have been obtained for evaluating pressure difference due to wind and stack effects as functions of prevailing wind velocity and direction, inside and outside temperatures, building dimensions and geometry etc.

Representative values of infiltration rate for different types of windows, doors walls etc. have been measured and are available in tabular form in air conditioning design handbooks.

d) Miscellaneous external loads: In addition to the above loads, if the cooling coil has a positive by-pass factor ($BPF > 0$), then some amount of ventilation air directly enters the conditioned space, in which case it becomes a part of the building cooling load. The **sensible and latent heat transfer rates due to the by-passed ventilation air** can be calculated using equations (35.5) and (35.6) by replacing \dot{V}_o with $\dot{V}_{vent} \cdot BPF$, where \dot{V}_{vent} is the ventilation rate and BPF is the by-pass factor of the cooling coil.

In addition to this, **sensible and latent heat transfer to the building due to heat transfer and air leakage in the supply ducts**. A safety factor is usually provided to account for this depending upon the specific details of the supply air ducts.

If the supply duct consists of supply air fan with motor, then **power input to the fan** becomes a part of the external sensible load on the building. If the duct consists of the electric motor, which drives the fan, then the efficiency of the fan motor also must be taken into account while calculating the cooling load. Most of the times, the power input to the fan is not known *a priori* as the amount of supply air required is not known at this stage. To take this factor into account, initially it is assumed that the supply fan adds about 5% of the room sensible cooling load and cooling loads are then estimated. Then this value is corrected in the end when the actual fan selection is done.

35.4.2. Estimation of internal loads:

The internal loads consist of load due to occupants, due to lighting, due to equipment and appliances and due to products stored or processes being performed in the conditioned space.

a) Load due to occupants: The internal cooling load due to occupants consists of both sensible and latent heat components. The rate at which the sensible and latent heat transfer take place depends mainly on the population and activity level of the occupants. Since a portion of the heat transferred by the occupants is in the form of radiation, a Cooling Load Factor (CLF) should be used similar to that used for radiation heat transfer through fenestration. Thus the sensible heat transfer to the conditioned space due to the occupants is given by the equation:

$$Q_{s, occupants} = (\text{No. of people}) \cdot (\text{Sensible heat gain/person}) \cdot CLF \quad (35.10)$$

Table 35.3 shows typical values of total heat gain from the occupants and also the sensible heat gain fraction as a function of activity in an air conditioned space. However, it should be noted that the fraction of the total heat gain that is sensible depends on the conditions of the indoor environment. If the conditioned space temperature is higher, then the fraction of total heat gain that is sensible decreases and the latent heat gain increases, and vice versa.

Activity	Total heat gain, W	Sensible heat gain fraction
Sleeping	70	0.75
Seated, quiet	100	0.60
Standing	150	0.50
Walking @ 3.5 kmph	305	0.35
Office work	150	0.55
Teaching	175	0.50
Industrial work	300 to 600	0.35

Table 35.3: Total heat gain, sensible heat gain fraction from occupants

The value of Cooling Load Factor (CLF) for occupants depends on the hours after the entry of the occupants into the conditioned space, the total hours spent in the conditioned space and type of the building. Values of CLF have been obtained for different types of buildings and have been tabulated in ASHRAE handbooks.

Since the latent heat gain from the occupants is instantaneous the CLF for latent heat gain is 1.0, thus the latent heat gain due to occupants is given by:

$$Q_{l,occupants} = (\text{No. of people})(\text{Latent heat gain/person}) \quad (35.11)$$

b) Load due to lighting: Lighting adds sensible heat to the conditioned space. Since the heat transferred from the lighting system consists of both radiation and convection, a Cooling Load Factor is used to account for the time lag. Thus the cooling load due to lighting system is given by:

$$Q_{s,lighting} = (\text{Installed wattage})(\text{Usage Factor})(\text{Ballast factor})\text{CLF} \quad (35.12)$$

The usage factor accounts for any lamps that are installed but are not switched on at the time at which load calculations are performed. The ballast factor takes into account the load imposed by ballasts used in fluorescent lights. A typical ballast factor value of 1.25 is taken for fluorescent lights, while it is equal to 1.0 for incandescent lamps. The values of CLF as a function of the number of hours after the lights are turned on, type of lighting fixtures and the hours of operation of the lights are available in the form of tables in ASHRAE handbooks.

c) Internal loads due to equipment and appliances: The equipment and appliances used in the conditioned space may add both sensible as well as latent loads to the conditioned space. Again, the sensible load may be in the form of radiation and/or convection. Thus the internal sensible load due to equipment and appliances is given by:

$$Q_{s,appliance} = (\text{Installed wattage}) \cdot (\text{Usage Factor}) \cdot \text{CLF} \quad (35.13)$$

The installed wattage and usage factor depend on the type of the appliance or equipment. The CLF values are available in the form of tables in ASHARE handbooks.

The latent load due to appliances is given by:

$$Q_{l,appliance} = (\text{Installed wattage}) \cdot (\text{Latent heat fraction}) \quad (35.11)$$

Table 35.4 shows typical load of various types of appliances.

Appliance	Sensible load, W	Latent load, W	Total load, W
Coffee brewer, 0.5 gallons	265	65	330
Coffee warmer, 0.5 gallons	71	27	98
Toaster, 360 slices/h	1500	382	1882
Food warmer/m ² plate area	1150	1150	2300

Table 35.4: Typical appliance load (C.P. Arora)

For other equipment such as computers, printers etc, the load is in the form of sensible heat transfer and is estimated based on the rated power consumption. The CLF value for these equipment may be taken as 1.0 as the radiative heat transfer from these equipment is generally negligible due to smaller operating temperatures. When the equipment are run by electric motors which are also kept inside the conditioned space, then the efficiency of the electric motor must be taken into account. Though the estimation of cooling load due to appliance and equipment appears to be simple as given by the equations, a large amount of uncertainty is introduced on account of the usage factor and the difference between rated (nameplate) power consumption at full loads and actual power consumption at part loads. Estimation using nameplate power input may lead to overestimation of the loads, if the equipment operates at part load conditions most of the time.

If the conditioned space is used for storing products (e.g. cold storage) or for carrying out certain processes, then the sensible and latent heat released by these specific products and or the processes must be added to the internal cooling loads. The sensible and latent heat release rate of a wide variety of live and dead products commonly stored in cold storages are available in air conditioning and refrigeration handbooks. Using these tables, one can estimate the required cooling capacity of cold storages.

Thus using the above equations one can estimate the sensible ($Q_{s,r}$), latent ($Q_{l,r}$) and total cooling load ($Q_{t,r}$) on the buildings. Since the load due to sunlit

surfaces varies as a function of solar time, it is preferable to calculate the cooling loads at different solar times and choose the maximum load for estimating the system capacity. From the sensible and total cooling loads one can calculate the Room Sensible Heat Factor (RSHF) for the building. As discussed in an earlier chapter, from the RSHF value and the required indoor conditions one can draw the RSHF line on the psychrometric chart and fix the condition of the supply air.

35.5. Estimation of the cooling capacity of the system:

In order to find the required cooling capacity of the system, one has to take into account the **sensible and latent loads due to ventilation, leakage losses** in the return air ducts and heat added due to **return air fan** (if any).

37.5.1. Load on the system due to ventilated air:

Figure 35.2 shows a schematic of an air conditioning system with the cooling coil, supply and return ducts, ventilation and fans. The cooling coil has a by-pass factor X . Then the cooling load on the coil due to sensible heat transfer of the ventilated air is given by:

$$Q_{s,vent} = \dot{m}_{vent} (1 - X) \cdot c_{p,m} (T_o - T_i) = \dot{V}_{vent} \rho_o (1 - X) \cdot c_{p,m} (T_o - T_i) \quad (35.12)$$

where \dot{m}_{vent} and \dot{V}_{vent} are the mass and volumetric flow rates of the ventilated air and X is the by-pass factor of the coil.

The latent heat load on the coil due to ventilation is given by:

$$Q_{l,vent} = \dot{m}_{vent} (1 - X) \cdot h_{fg} (W_o - W_i) = \dot{V}_{vent} \rho_o (1 - X) \cdot h_{fg} (W_o - W_i) \quad (35.13)$$

where W_o and W_i are the humidity ratios of the ambient and conditioned air, respectively and h_{fg} is the latent heat of vapourization of water.

35.4.2. Load on the coil due to leakage in return air duct and due to return air fan:

If there is leakage of air and heat from or to the return air duct, additional capacity has to be provided by the cooling coil to take care of this. The sensible heat transfer to the return duct due to heat transfer from the surroundings to the return duct depends on the surface area of the duct that is exposed to outside air ($A_{exposed}$), amount of insulation (U_{ins}) and temperature difference between outdoor air and return air, i.e.,

$$Q_{s,duct} = U_{ins} \cdot A_{exposed} (T_o - T_i) \quad (35.14)$$

The amount of sensible and latent heat transfer rates due to air leakage from or to the system depends on the effectiveness of the sealing provided and the

condition of the outdoor air and return air. Since the load due to return air duct including the return air fan ($Q_{\text{return duct}}$) are not known a priori an initial value (e.g. as a fraction of total building cooling load) is assumed and calculations are performed. This value is modified at the end by taking into account the actual leakage losses

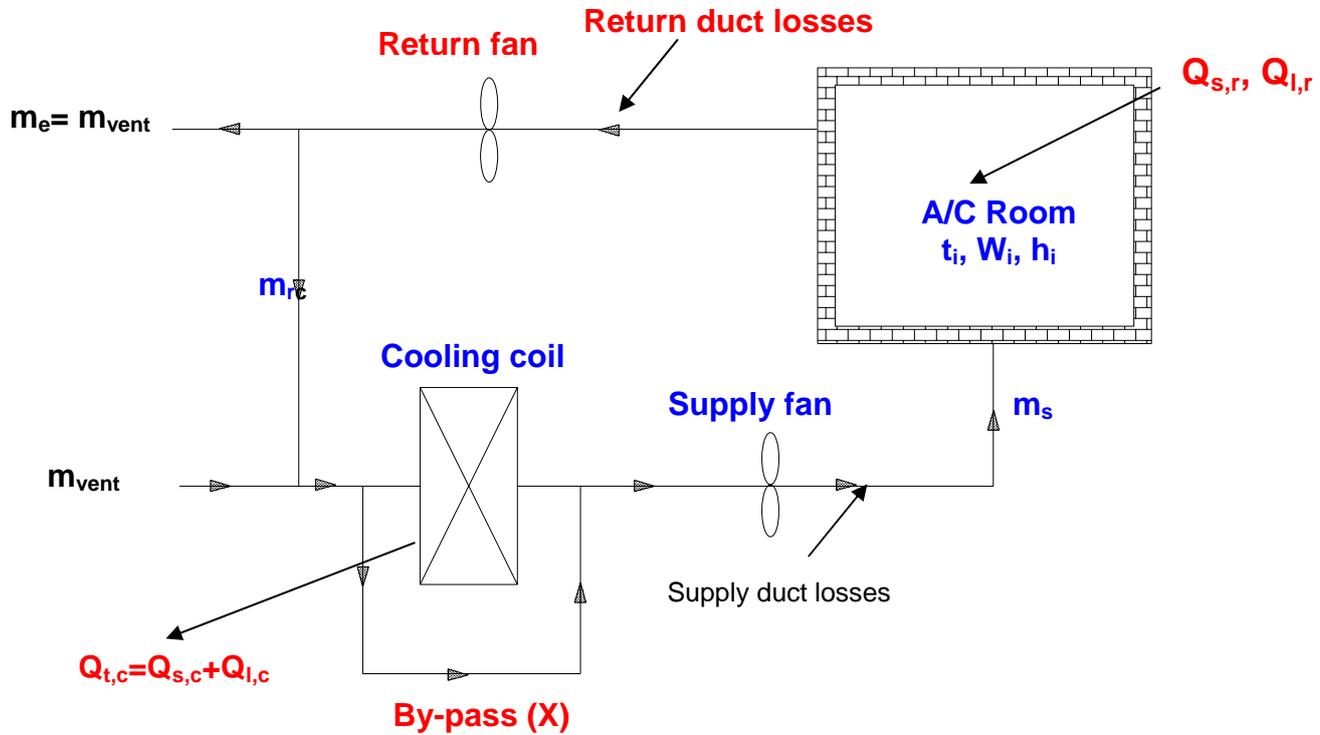


Fig.35.2: A typical summer air conditioning system with a cooling coil of non-zero by-pass factor

and return fan power consumption.

Now the total sensible load on the coil ($Q_{s,c}$) is obtained by summing up the total sensible load on the building ($Q_{s,r}$), sensible load due to ventilation ($Q_{s,vent}$) and sensible load due to return air duct and fan ($Q_{s,return duct}$), that is:

$$Q_{s,c} = Q_{s,r} + Q_{s,vent} + Q_{s,return duct} \quad (35.15)$$

Similarly the total latent load on the coil ($Q_{l,c}$) is obtained by summing up the total latent load on the building ($Q_{l,r}$), latent load due to ventilation ($Q_{l,vent}$) and latent load due to return air duct and fan ($Q_{l,return duct}$), that is:

$$Q_{l,c} = Q_{l,r} + Q_{l,vent} + Q_{l,return duct} \quad (35.15)$$

Finally the required cooling capacity of the system which is equal to the total load on the coil is obtained from the equation:

$$\text{Required cooling capacity, } Q_{t,c} = Q_{s,c} + Q_{l,c} \quad (35.16)$$

One can also calculate the sensible heat factor for the coil (CSHF) and draw the process line on the psychrometric chart and find the required coil Apparatus Dew

Point Temperature (coil ADP) from the above data as discussed in an earlier chapter.

As mentioned, the method discussed above is based on CLTD/CLF as suggested by ASHRAE. It can be seen that with the aid of suitable input data and building specifications one can manually estimate the cooling load on the building and the required cooling capacity of the system. A suitable **safety factor** is normally used in the end to account for uncertainties in occupants, equipment, external infiltration, external conditions etc. This relatively simple method offers reasonably accurate results for most of the buildings. However, it should be noted that the data available in ASHRAE handbooks (e.g. CLTD tables, SHGF tables) have been obtained for a specific set of conditions. Hence, any variation from these conditions introduces some amount of error. Though this is generally taken care by the safety factor (i.e., by selecting a slightly oversized cooling system), for more accurate results one has to resort actual building simulation taking into account on all relevant factors that affect the cooling load. However, this could be highly complex mathematically and hence time consuming and expensive. The additional cost and effort may be justified for large buildings with large amount of cooling loads, but may not be justified for small buildings. Thus depending upon the specific case one has to select suitable load calculation method.

35.6 Heating load calculations:

As mentioned before, conventionally **steady state conditions** are assumed for estimating the building heating loads and the internal heat sources are neglected. Then the procedure for heating load calculations becomes fairly simple. One has to estimate only the sensible and latent heat losses from the building walls, roof, ground, windows, doors, due to infiltration and ventilation. Equations similar to those used for cooling load calculations are used with the difference that the **CLTD values are simply replaced by the design temperature difference between the conditioned space and outdoors**. Since a steady state is assumed, the required heating capacity of the system is equal to the total heat loss from the building. As already mentioned, by this method, the calculated heating system capacity will always be more than the actual required cooling capacity. However, the difference may not be very high as long as the internal heat generation is not very large (i.e., when the building is not internally loaded). However, when the internal heat generation rate is large and/or when the building has large thermal capacity with a possibility of storing solar energy during day time, then using more rigorous unsteady approach by taking the internal heat sources into account yields significantly small heating small capacities and hence low initial costs. Hence, once again depending on the specific case one has to select a suitable and economically justifiable method for estimating heating loads.

Questions and answers:

1. Which of the following statements are TRUE?

- a) Steady state methods are justified in case of heating load calculations as the outside temperatures during winter are normally very low
- b) Steady state methods are justified in case of heating load calculations as the peak load normally occurs before sunrise
- c) Steady state methods are justified in case of heating load calculations as the outside temperature variation is normally low during winter months
- d) Neglecting internal heat sources while calculating heating loads underestimates the required capacity

Ans.: b) and c)

2. Which of the following statements are TRUE?

- a) An all year air conditioning system has to be switched from winter mode to summer mode as the outdoor temperature exceeds the outdoor temperature at balance point
- b) An all year air conditioning system has to be switched from summer mode to winter mode as the outdoor temperature exceeds the outdoor temperature at balance point
- c) The outdoor temperature at balance point increases as the amount of insulation increases
- d) The outdoor temperature at balance point decreases as the amount of insulation increases

Ans.: a) and d)

3. Which of the following statements are TRUE?

- a) Methods based on rules-of-thumb are not always useful as they are not based on practical systems
- b) Methods based on rules-of-thumb are not always useful as they do not distinguish between a good building design and a bad building design
- c) Methods based on Transfer Function Method are not always useful as they do not yield accurate results
- d) Methods based on Transfer Function Method are not always useful as they are complex and time consuming

Ans.: b) and d)

4. Which of the following statements are TRUE?

- a) An internally loaded building requires a system with variable cooling capacity
- b) An externally loaded building requires a system with variable cooling capacity
- c) An auditorium is a good example of an internally loaded building
- d) A residence is a good example of an internally loaded building

Ans.: b) and d)

5. Which of the following statements are TRUE?

- a) External loads consist of only sensible components, where as internal loads consist of both sensible and latent components
- b) Both external and internal loads consist of sensible as well as latent components
- c) Fabric heat gain consists of both sensible and latent components
- d) Heat transfer due to occupancy consists of both sensible and latent components

Ans.: b) and d)

6. Which of the following statements are TRUE?

- a) Cooling Load Factor is used for radiative component only
- b) Cooling Load Factor is used for both radiative as well as convective components
- c) The value of cooling load factor always lies between 0 and 1
- d) The cooling load factor increases as the thermal capacity of the walls increase

Ans.: a) and c)

7. Which of the following statements are TRUE?

- a) Infiltration load is a part of the building load
- b) Infiltration load is not a part of the building load
- c) Infiltration rate increases as the pressure difference across the building decreases
- d) Infiltration rate is uncontrollable

Ans.: a)

8. Which of the following statements are TRUE?

- a) Ventilation is to be considered while calculating load on the coil, not on buildings
- b) Ventilation is to be considered while calculating load on the coil, not on buildings only when the by-pass factor of the cooling coil is zero
- c) Ventilation is to be considered while calculating load on the coil, not on buildings only when the by-pass factor of the cooling coil is non-zero
- d) Losses in supply duct are a part of the building load, while losses in return duct are a part of the coil load

Ans.: b) and d)

9. A building has a U-value of $0.5 \text{ W/m}^2\cdot\text{K}$ 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°C , state

whether a cooling system is required or a heating system is required when the external temperature is 3°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,

$$T_{\text{out,bal}} = T_{\text{in}} - \frac{(Q_{\text{solar}} + Q_{\text{int}})_{\text{sensible}}}{UA} = 25 - \frac{(2 + 1.2) \times 1000}{0.5 \times 384} = 8.33^{\circ}\text{C}$$

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

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:

$$T_{\text{out,bal}} = T_{\text{in}} - \frac{(Q_{\text{solar}} + Q_{\text{int}})_{\text{sensible}}}{UA} = 25 - \frac{(2 + 1.2) \times 1000}{0.36 \times 384} = 1.85^{\circ}\text{C}$$

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

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°C dry bulb, 50 percent RH
Outside conditions	:	43°C dry bulb, 24°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°C
Effective Temp. Difference (ETD) for roof:		30°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 25°C dry bulb, 50 percent RH:

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

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

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

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:

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

b) Heat transfer rate through roof:

$$Q_{\text{roof}} = U_{\text{roof}} A_{\text{roof}} \text{ETD}_{\text{roof}} = 1.316 \times 18 \times 30 = 710.6 \text{ W (Sensible)}$$

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:

$$Q_{\text{floor}} = U_{\text{floor}} A_{\text{floor}} \text{ETD}_{\text{floor}} = 1.2 \times 18 \times 18 = 388.8 \text{ W (Sensible)}$$

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:

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

(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:

$$m_{\text{inf}} = \text{density of air} \times (\text{ACH} \times \text{volume of the room})/3600 = 1.095 \times (0.5 \times 3 \times 3 \times 6)/3600$$

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

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, $Q_{l,inf}$:

$$Q_{l,inf} = m_{inf}h_{fg}(W_o - W_i) = 8.8125 \times 10^{-3} \times 2501 \times 10^3(0.0107 - 0.0099) = 16.4 \text{ W (sensible)}$$

Internal loads:

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

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

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

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:

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

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

Total load on the building is:

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

Room Sensible Heat Factor (RSHF) is given by:

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

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:

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