



University of Hilla

Department of Refrigeration and Air Conditioning Technologies

Fundamental of Air Conditioning and Refrigeration

Part 3

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3.1 Cooling Load Estimation and Psychometric Analysis:

Air conditioning means controlling the temperature, relative humidity, velocity and purity of air to be supplied to the air conditioned space. The air conditioned space may be for creating comfort conditions for human beings or it may be for creating conditions as per the needs of a specific industrial process.

Human body continuously generates heat at the rate varying between 100 W and 500 W depending upon the health and the activities of the individuals. Body temperature must be maintained within a narrow temperature range to avoid discomfort and danger from heat or cold stress. Therefore, heat must be dissipated in a controlled manner. Heat is neither generated uniformly throughout the body nor is it dissipated uniformly. Therefore, comfort conditions are not the same for men, women, children and old people. These also vary depending on the location and season of the year and the activities one carries out. Scientists have carried out a large number of experiments on human beings to understand the comfort conditions. As per their investigations, majority of people feel comfortable in summer at:

- 1- Dry-bulb temperature = $25 \pm 1^\circ\text{C}$
- 2- Relative humidity = $50 \pm 5\%$
- 3- Air velocity = 15 to 20 m/min

For winter season the comfort conditions are:

1. Dry-bulb temperature = $22 \pm 1^\circ\text{C}$
2. Relative humidity = 50%
3. Air velocity = 9 to 12 m/min

3-2 THERMODYNAMICS OF HUMAN BODY AND MATHEMATICAL MODEL:

The rate at which body generates heat is called the *metabolic rate*. The human body is considered a heat engine with 20% thermal efficiency. This means that if the body generates heat energy of the order of 100 W due to digestion of food, heat at the rate of 80 W must be dissipated to the surroundings. If the body does not dissipate heat at the rate, it would accumulate causing discomfort. The human body works best at a particular temperature similar to that of a heat engine. The body temperature of a healthy man is 36.9°C (98.4°F) at the skin.

A man with body temperature of 40.5°C (104.9°F) is considered serious and with 43.5°C (110°F) dead.

The rate of heat loss from human body to the atmosphere is through three modes- radiation, convection and evaporation of the moisture. The total heat loss from the body is:

$$Q = Q_r + Q_c + Q_e \quad (3.1)$$

Where Q = rate of total heat loss (watt).

Q_r , Q_c and Q_e are the heat loss due to radiation, convection and evaporation of the moisture respectively.

One feels comfortable only when the rate of heat generation due to metabolic rate is equal to the rate of heat loss to the surroundings. Hence, one can apply the first law of thermodynamics to a body as:

$$Q_m - W = Q + Q_s \quad (3.2)$$

$$Q_m - W = Q_r + Q_c + Q_e + Q_s$$

Where Q_m = metabolic rate of heat generation, in watts and it depends on the nature of food and its consumption.

W = useful rate of work in watts.

Q_s = rate of heat stored in human body in watts (for comfort, $Q_s = 0$)

(a) **Convective heat loss:** The heat loss from human body due convection is given as:

$$Q_c = UA(T_b - T_a) \quad (9.3)$$

Where **U** is the overall heat transfer coefficient ($\text{W/m}^2 - \text{K}$) between the body and the surroundings. It depends on air velocity, thermal conductivity, specific heat of air, etc.

A is the surface area of human body (m^2).

T_a and T_b are atmospheric and human body temperatures, respectively.

In winter **T_a** is less than **T_b**, heat loss takes place at a greater pace, so one may feel cold. Therefore, one has to increase the layer of insulation by wearing woolen clothes.

In summer, if **T_a** is greater than **T_b**, the only mode of heat dissipation is by evaporation of moisture. Therefore, one perspires more in summer.

(b) **Radiation heat loss:** The radiation heat loss from human body is given as:

$$Q_r = \sigma A(T_b^4 - T_a^4) \quad (9.4)$$

Where σ is the Stefan-Boltzmann constant, $5.67 \times 10^{-8} \text{ W/m}^2\text{-K}^4$.

Human body gains heat from surroundings when **T_a > T_b** and loses heat when **T_a < T_b**. The explanation as given above can also be applied here

(c) **Evaporative heat loss:** Evaporative heat loss from human body is given as:

$$Q_e = K_d A(p_s - p_v) h_{fg} K_c \quad (9.5)$$

K_d = diffusion coefficient (kg of water evaporated/ $\text{m}^2/\text{h}/\text{N}$ pressure difference).

P_s = saturation pressure of water vapor corresponding to the skin temperature.

P_v = vapor pressure of moisture present in the air.

h_{fg} = latent heat of evaporation, kJ/kg

K_c = a factor for type of clothing.

The rate of heat dissipation from body by Convection, radiation or by evaporation is affected by the quality of clothing.

3.3 EFFECTIVE TEMPERATURE

People feel comfortable only when all the three parameters, say DBT, RH and air velocity, are within certain limits as stated above. Effective temperature is a single parameter at which people feel comfortable. Effective temperature is an index of the measure of comfort.

Effective temperature (ET) is that temperature of saturated air at which people feel comfort as experienced in the actual unsaturated environment.

Effective temperature is a measure of feeling warmth or cold by the human body in response to the air temperature, RH and air motion.

Construct a constant effective temperature line say S-A on the psychrometric chart, Figure (3.1). Mark point A on the intersection of 50% RH and 25° C DBT. Draw a vertical line from x-axis corresponding to 21.7° C intersecting the saturation curve at point S. Join the points S and A indicating constant effective temperature line. This is an approximate method of obtaining a rough idea about effective temperature.

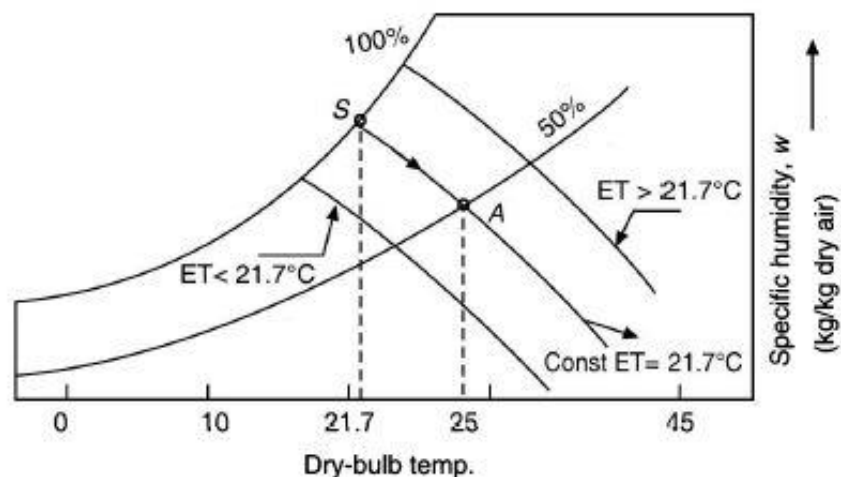


Figure 3.1 Effective temperature

As one follows the constant effective temperature line (say from point S to A), one observes that:

- Specific humidity decreases.
- DBT increases.

But human beings feel the same comfort as ET remains the same. This is because body loses more heat in the form of latent heat, i.e. by the evaporation of sweat. An increase in DBT can be compensated by increasing the air velocity to a certain extent (say 6 m/min to 18 m/min). This can also be observed in table 3.1.

Table 3.1. ET is same for different DBT and RH combinations

DBT (°C)	RH (%)	% of people feeling comfort	Effective temperature (ET)	DBT (°C)	RH (%)	% of people feeling comfort	Effective temperature (ET)
21	100	90	21	25	100	80	25
23	88			27	90		
25	76			29	80		
29	64			31	70		

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Based on this concept of equal comfort at different conditions. A comfort chart has been constructed by an international organization called ASHRAE.

3.4 HUMAN COMFORT CHART

A chart is prepared showing the percentage of people feeling comfort at different effective temperatures. The collection of data regarding the percentages of people feeling so at different effective temperatures has been tabulated by ASHRAE.

The chart that gives different percentages of people (feeling comfort at different effective temperatures) is known as comfort chart. This chart can be prepared as follows:

- 1- First the psychrometric chart is redrawn taking DBT on x-axis and WBT on y-axis.

- 2- The 100% RH line is drawn passing through the point of intersection of DBT and WBT lines; then the other relative humidity lines are drawn as shown in Figure 3.2.
- 3- The effective temperature lines are drawn on this chart taking the points from Table (3.1).
- 4- The percentage of people feeling comfortable at different effective temperatures for summer and winter conditions are also shown.
- 5- The effective temperature lines $b_{s,b}$, $b_{w,b}$, and $b_{s,b}$, show that the percentage of people feeling comfort is zero in summer.
- 6- The maximum percentage (100%) of people feeling comfort in summer is shown by the line BB.
- 7- The maximum percentage (100%) of people feeling comfort in winter is shown by the line AA.

For small values of relative humidity of air, evaporation from body surface becomes rapid causing under-cooling as well as drying of the skin. On the other hand, if the relative humidity of air is high, then the evaporation from the body practically ceases and causes high discomfort due to sticky feeling on the body surface.

Generally, for the comfort conditions and softness of the skin the most desirable relative humidity range lies between 30% and 70% as shown in Figure 9.2. Skin becomes too dry when the RH is below 30% and there is a sticky feeling when RH is above 70%.

For comfortable conditions, part of the heat loss must be in the form of latent heat (evaporation loss) to maintain the softness of the skin and to avoid the shrinking of the skin surface. The heat loss by evaporation is generally 60% and by convection 40% when the man is at rest. Their proportions change with the activity of the person.

With the RH limitations, the desired comfort condition must lie between B' B'' for summer conditions and between A' A'' for winter conditions.

This area $A' A'' B'' B'$ shown on the comfort chart is used for the year round air conditioning design.

The chart allows engineers to choose or suggest to users the most economical room conditions without jeopardizing the comfort.

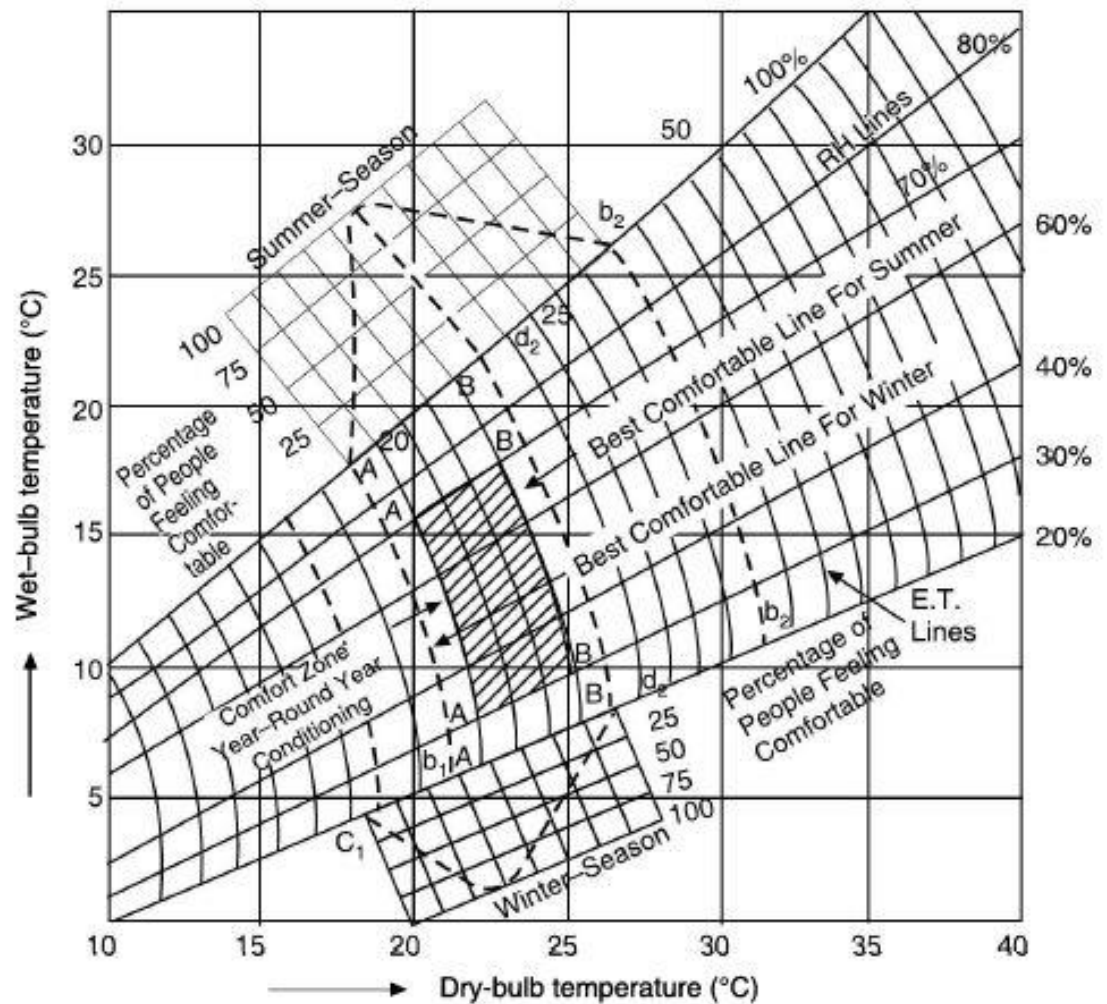


Figure 3.2 comfort chart

3.5 OUT SIDE CONDITIONS

The air conditioning load is estimated to become a base for selecting the conditioning equipment. It must take into account the heat entering into the space from outdoors on a design day, as well as the heat being generated within the space. A design day is defined as:

- 1- A day on which the DBT and WBT are peaking simultaneously.
- 2- A day when there is little or no haze in the air which reduces the solar heat.
- 3- All of the internal loads are normal.

As far as the design of an air conditioning system is concerned, the time of peak load is important. The time of a peak load at a particular location is dependent on the outdoor conditions.

The outside ambient conditions vary from place to place and season to season.

The information contained in such tables is based on the following points:

- 1- Dry-bulb temperature
- 2- Wet-bulb temperature
- 3- Moisture content grains per kg of dry air
- 4- Average daily temperature variation (average daily range)
- 5- Wind velocity (summer and winter)
- 6- Altitude of the place
- 7- Latitude angle

It is based on the hourly recorded data of dry-bulb temperature of the last 10 years. Then it is possible to choose a dry-bulb temperature which is on 1%, 2% or 5% not exceeding basis.

The highest wet-bulb temperature coincidental with the chosen dry-bulb temperature gives us the outside design conditions of that location.

3.6 SOURCE OF HEAT LOAD

The heat gain components that contribute to the room-cooling load are classified as external or internal sources. The heat sources may be of two types, namely Sensible heat load (SH load) due to increase in room temperature and Latent heat load (LH load) due to increase in moisture content of the room air.

External sources

- 1- Conduction through exterior walls, roof and glass.
- 2- Conduction through interior partitions, ceilings and floors.
- 3- Solar radiations through glass (SH load).
- 4- Infiltration—Heat from infiltration of outside air through openings of doors (SH + LH).
- 5- Ventilation—Heat from fresh outside air supplied through the system to bring freshness to the room air (SH + LH).

Internal sources

The internal load or heat generated within the space depends on the character of application. Generally, internal heat gains consist of some or all of the following items:

- 1- **Occupancy**—Human body through metabolism generates and releases heat. Heat given out by people occupying the room is (SH + LH).
- 2- **Lights**—Illuminants convert electrical into light and heat. Some of the heat is radiant and partially stored. It is in the form of SH.
- 3- **Appliances**—Restaurants, hospitals, etc. Have electrical, gas or steam appliances which release heat into open space. It may include SH and LH.
- 4- **Equipment**—Most of the equipment give out SH loads, However, some like sterilizer, coffee brewer, give out latent heat load as well.
- 5- **Products brought in**—All products brought in the open space carry SH load while some like hot dishes in a restaurant bring LH load as well.
- 6- **Electronic device**—Computing machines (computers) release heat into the air-conditioned space.

7- **Hot pipes and tanks-** Steam or hot water pipes running through the air-conditioned space or hot water tanks in the space add heat.

8- **System heat gain-** This load is due to the air-conditioned system itself. It is of three types:

- **Duct heat gain-** Cool air in the duct absorbs heat from outside atmosphere through the duct wall (SH). It has to be reduced through insulation.
- **Duct air leakage-** Air may leak while flowing through the ducts. Such leaks should be prevented. This loss of air would result in additional load (SH + LH).
- **Blower power-** The blower or fan which circulates air through the complete system releases energy (its power) in the supply air as heat (SH).

The correct estimation of the above loads is very complex. But it would be explained in subsequent sections to a certain extent.