Lecture 7

Comfort and Inside Design Conditions

.1 Metabolism and comfort

The human body differs from the insentient machine in tolerating only a narrow band of temperature (36°C to 38°C) and in having an appreciation of comfort. Defining the latter is not easy because of its subjective nature: in the long run a person's comfort can only be assessed by posing the question, 'Are you comfortable?' Even then the individual may have difficulty in phrasing a satisfactory answer. Establishing a numerical scale of comfort, interpreted from simple physical measurements, has not proved straightforward although Fanger (1972) has proposed a comfort equation (see section 4.7) that allows the determination of thermal comfort in terms of activity, clothing, dry-bulb temperature, the mean radiant temperature of the surrounding surfaces, relative humidity and air velocity.

The body eats and digests food which, through the intake of oxygen by breathing, is converted into energy for useful work with the liberation of heat and the emission of waste products. The chemical changes occurring in the liver and other parts of the body, and muscular contraction, release thermal energy which is transported throughout the body by the circulation of the blood so that it can be lost to the outside world and the temperature of the deep tissues kept at comparatively constant value (about 37.2°C) if good health is to be preserved. The efficiency of the body—defined as $W/(M - 44)$, where W is the rate of working, M the metabolic rate of energy production for the particular activity and 44 W m^{-2} is the basal metabolic rate per unit area of bodily surface—is not very great, varying from 0 per cent when at rest to a maximum of about 20 per cent when walking up a one in four gradient at 10 km h^{-1}. So most of the energy produced by the bodily metabolism must be dissipated as heat to the environment.

In good health, the thermo-regulatory system of the body exercises automatic control over the deep tissue temperature by establishing a correct thermal balance between the body and its surroundings. Apart from the matter of good health the comfort of an individual also depends on this balance and it might therefore be interpreted as the ease with which such a thermal equilibrium is achieved. ASHRAE Comfort Standard 55–74 goes further and defines comfort as '... that state of mind which expresses satisfaction with the thermal environment ...' but points out that most research work regards comfort as a subjective sensation that is expressed by an individual, when questioned, as neither slightly warm nor slightly cool.

.2 Bodily mechanisms of heat transfer and thermostatic control

Heat is exchanged between the body and its environment by four modes: evaporation (E), radiation (R), convection (C) and, to an insignificant extent because of the small area of contact usually involved, conduction. There is also a small loss by the rejection of excreta but this is generally ignored. A heat balance equation can be written if we include an additional element, S, representing the positive or negative storage of heat in the body that would cause the deep tissue temperature to rise or fall:

$$M - W = E + R + C + S \tag{4.1}$$

For a normally clothed, healthy human being in a comfortable environment and engaged in a non-strenuous activity, S is zero and the thermo-regulatory system of the body is able to modify the losses by radiation and convection to maintain a stable, satisfactory temperature. Evaporative losses occur in three ways: by the exhalation of saturated water vapour from the lungs, by a continual normal process of insensible perspiration, and by an emergency mechanism of sweating. Insensible perspiration results from body fluids oozing through the skin under osmotic pressure according to Whitehouse *et al.* (1932) and forming microscopic droplets on the surface which, because of their small size, evaporate virtually instantaneously, not being felt or seen and hence termed insensible. Sweating is entirely different and in comfortable conditions should not occur: if body temperature tends to rise the thermo-regulatory system increases the evaporative loss by operating sweat glands selectively and flooding strategic surfaces. In extreme cases the body is entirely covered with sweat that must evaporate on the skin to give a cooling effect—if it rolls off or is absorbed by clothing its cooling influence will be nullified or much reduced.

Evaporative loss is a function of the difference in vapour pressure between the water on the skin and that of the ambient air. It also depends on the relative velocity of airflow over the wet surface. The two following equations are sometimes useful to solve numerical problems although equation (4.2), for parallel airflow over a lake surface (or the like) is considered to give an underestimate. Equation (4.3) describes the case of transverse airflow, as across a wet-bulb thermometer.

$$\text{Evaporative loss (W m}^{-2}\text{)} = (0.0885 + 0.0779v)(p_w - p_s) \tag{4.2}$$

$$\text{Evaporative loss (W m}^{-2}\text{)} = (0.018\,73 + 0.1614v)(p_w - p_s) \tag{4.3}$$

where the relative air velocity, v, is in m s^{-1} and p_w and p_s, the vapour pressures of the water and the ambient air respectively, are in Pa.

Losses occur by radiation if the skin temperature exceeds that of the surrounding surfaces and by convection if it is greater than the ambient dry-bulb. The average temperature of the surrounding surfaces is termed the mean radiant temperature, T_{rm}, and is defined as: the surface temperature of that sphere which, if it surrounded the point in question, would radiate to it the same quantity of heat as the room surfaces around the point actually do. The mean radiant temperature thus varies from place to place throughout the room. Bodily surface temperature is influenced by the type of clothing worn, its extent, the activity of the individual, the performance of the thermo-regulatory system and the rate of heat loss to the environment. Signals are sent by nerve impulses from the brain in response to changes in blood temperature to regulate the flow of heat from the warmer, deep tissues of the body to the cooler, surface tissues. This regulation is done two ways: by changing the rate of sweat production and by dilating or constricting the blood vessels (the vascular system) beneath the skin. Vaso-dilation increases the flow of blood to the surface and so the flow of heat from the deeper tissues. Conversely, vaso-constriction reduces the flow of blood, the skin temperature and the bodily heat loss. A skin temperature exceeding 45°C or less than 18°C triggers a response of pain according to ASHRAE (1997) and subjective sensations for mean skin temperatures of sedentary workers are: 33.3°C comfortable, 31°C uncomfortably cold, 30°C shivering cold and 29°C extremely cold. For a more strenuous activity such temperatures might be reported as comfortable. A skin temperature of 20°C on the hand may be considered uncomfortably cold, one of 15°C extremely cold and 5°C painful. Higher ambient air temperatures than the skin temperatures mentioned can be borne because of the insulating effect of the air surrounding the surfaces of the body and some tolerances quoted given by ASHRAE (1989) are: 50 minutes at 82°C, 33 minutes at 93°C and 24 minutes at 115°C, for lightly clad persons in surroundings with dew points less than 30°C. Tolerance decreases rapidly as the dew point approaches 36°C. A rise in body temperature of a few degrees, because of ill-health or inadequate heat loss, is serious with possibly fatal results at above 46°C when the thermo-regulation control centre in the brain may be irreversibly damaged: sweating can cease and vaso-constriction become uncontrolled with the onset of heat production by shivering. On the other hand, a fall in the deep temperature of the body to below 35°C can also cause a loss of control by the thermo-regulation system and although recovery from a temperature as low as 18°C has occurred, according to ASHRAE (1989), 28°C is taken as the lower survival limit. The normal response of the body to a fall in temperature after vaso-constriction is the generation of heat by muscular tension and, subsequently, by involuntary work or shivering.

According to Gagge *et al.* (1938) experimental evidence shows that unclothed and lightly clad people can be comfortable at operative temperatures (see section 4.8) of 30°C and 27°C, respectively. These temperatures are the mid-points of narrow ranges (29°C to 31°C and 25°C to 29°C) within which there is no change of evaporative loss and no body cooling or heating, the deep tissue temperature being maintained at a constant value without physiological effort. Above and below these ranges are zones of vaso-motor regulation against cold and heat wherein the control system of the body can keep the deep tissue temperature constant (albeit with some change in skin temperature) by vaso-constriction and dilation, respectively. Below the cold zone muscular tension etc. takes over until eventually deep temperature can only be maintained at a satisfactory level by putting on more clothing. At the upper end of the range of operative temperatures the zone of control over heat is much smaller and vaso-dilation only suffices until the skin temperature approaches to within 1°C of the deep body temperature, after which the sweat glands must work if the thermal balance between the person and the environment is to be maintained.

It follows from the foregoing that skin temperature and evaporative cooling from the skin will have a significant influence on comfort. Belding and Hatch (1955) defined a heat stress index as the ratio of the total evaporation loss in bodily thermal equilibrium to the maximum loss by evaporation if the skin were entirely wetted by regulatory sweating, is sometimes used. The ASHRAE scale of effective temperature (see section 4.8) makes use of the concept of heat stress.

.3 Metabolic rates

Mackean (1977) expresses metabolism as 'All the chemical changes going on in the cells of an organism.' In the context of air conditioning the interest lies mainly in the quantities of sensible and latent heat dissipated by the body to its environment as a consequence of these changes and in accordance with equation (4.1). People vary in shape, surface area and mass, thus research workers currently prefer to express heat emission from the body in terms of the met unit, equal to 58.2 W m^{-2}. The related body surface area is difficult to measure but a favoured equation for its expression, developed by Du Bois and Du Bois (1916), defines it as the Du Bois surface area, A_D, where

$$A_D = 0.202 m^{0.425} h^{0.725} \quad (4.4)$$

in which m is the body mass in kg and h its height in m. Using equation (4.4) a man of 70 kg (11 stone) with a height of 1.8 m (5′ 11″) has a surface area of 1.9 m^2. One met unit is often taken as corresponding to 100 W, approximately, representing the emission from a resting adult.

The metabolic rate depends on the activity and varies from about 84 W for a person of 1.8 m^2 surface area, as a basal rate, to a maximum of about 1200 W for a normal, healthy young man. Although trained athletes can work at maxima as high as 2000 W, an ordinary person can only maintain some 50 per cent of his maximum output continuously for any length of time. The maximum possible decays with age to roughly 700 W at the age of 70 years. Women have maximum levels at approximately 70 per cent of these values and children less still, because of their smaller surface areas, but for estimating the emission of heat from a mixed group of people the proportions of the normal male output taken by ASHRAE (1989) for women and children are usually 85 per cent and 75 per cent, respectively. Conservative values, as used for heat gain calculations, are quoted in Table 7.16, but more exact figures for different activities are given in Table 4.1.

Table 4.1 Typical metabolic rates for various activities, according to ASHRAE (1997)

Activity	Total heat production in watts
Sleeping	72
Sitting quietly	108
Standing (relaxed)	126
Walking on a level surface at 6.4 km/h (4 mph)	396
Reading (seated)	99
Writing	108
Typing	117
Dancing	82–256

The total heat productions are for continuous activity by an adult having a Du Bois surface area of 1.8 m^2. The figures are in good agreement with those published in the *CIBSE Guide* (1999), A1, Environmental criteria for design.

.4 Clothing

The loss of heat from the body and the feeling of individual comfort in a given environment is much affected by the clothing worn and in a room with a mixed population of men and women wearing different garb, comfort for everyone may be almost impossible to achieve. There also appears to be a seasonal pattern in the clothing worn, according to Berglund

(1980), which prevails even if the temperature of the working environment is virtually constant throughout the year, lighter garments of less thermal insulation value being worn in the summer.

The unit used to describe the thermal insulating quality of the clothing worn is the clo with a physical value of 0.155 $m^2\,K\,W^{-1}$. Table 4.2 lists some thermal resistances proposed by Berglund (1980) for individual items, to be combined by equation (4.5), according to McCullough and Jones (1984).

$$I_{clo} = 0.835\ \Sigma I_{clui} + 0.161 \qquad (4.5)$$

where I_{clui} is the effective thermal insulation of garment i, and I_{clo} is the thermal insulation of the total clothing ensemble.

Table 4.2 Thermal resistances for some items of clothing according to Berglund (1980)

Men	clo	Women	clo
Sleeveless singlet	0.06	Bra and pants	0.05
T-shirt	0.09	Half slip	0.13
Underpants	0.05	Full slip	0.19
Shirt, light-weight, short sleeves	0.14	Blouse, light-weight	0.20 (*a*)
Shirt, light-weight, long sleeves	0.22	Blouse, heavy-weight	0.29 (*a*)
Waistcoat, light-weight	0.15	Dress, light-weight	0.22 (*a*, *b*)
Waistcoat, heavy-weight	0.29	Dress, heavy-weight	0.70 (*a*, *b*)
Trousers, light-weight	0.26	Skirt, light-weight	0.10 (*b*)
Trousers, heavy-weight	0.32	Skirt, heavy-weight	0.22 (*b*)
Sweater, light-weight	0.20 (*a*)	Slacks, light-weight	0.26
Sweater, heavy-weight	0.37 (*a*)	Slacks, heavy-weight	0.44
Jacket, light-weight	0.22	Sweater, light-weight	0.17 (*a*)
Jacket, heavy-weight	0.49	Sweater, heavy-weight	0.37 (*a*)
Ankle socks	0.04	Jacket, light-weight	0.17
Knee socks	0.10	Jacket, heavy-weight	0.37
Shoes	0.04	Stockings or tights	0.01
Boots	0.08	Sandals	0.02
		Shoes	0.04
		Boots	0.08

(*a*) Deduct 10% if sleeveless or short sleeved.
(*b*) Add 5% if below knee length; deduct 5% if above knee length.

It is reckoned by ASHRAE (1997) that total clo-values cannot be estimated to be better than 20 per cent accuracy and this should be borne in mind. ASHRAE (1997) quote clo-values that are a little less than the figures given in Table 4.2.

EXAMPLE 4.1

Estimate the insulation value of the clothing of a man dressed as follows:
(*a*) T-shirt, underpants, light-weight trousers, ankle socks and shoes,
(*b*) Sleeveless singlet, underpants, long-sleeved shirt, heavy-weight trousers, jacket and waistcoat, knee-length socks and shoes.

Answers

(i) Using Table 4.2 the sum of the individual items of clothing is 0.09 + 0.05 + 0.26 + 0.04 + 0.04 = 0.48 and by equation (4.5) we have $0.835 \times 0.48 + 0.161 = 0.56$ clo.
(ii) The sum of the individual items is 0.06 + 0.05 + 0.22 + 0.32 + 0.49 + 0.29 + 0.10 + 0.04 = 1.57 and by equation (4.5) we have $0.835 \times 1.57 + 0.161 = 1.47$ clo.

Similar calculations for the light and heavy extremes of women's clothing yield figures of about 0.6 and 1.3 clo. We might therefore conclude that 1 clo represents average clothing for a man and perhaps 0.9 clo for a woman. It is not surprising that achieving satisfactory conditions of comfort for an air conditioned room with a mixed population sometimes proves difficult. It has been suggested by Berglund (1980) that the comfort of a clothed individual corresponds to a decrease in ambient dry-bulb of about 0.5°C for each clothing increase of 0.1 clo but this can only be true over a limited range of temperature. For sedentary workers a realistic lower limit for a period of more than one hour is about 18.5°C, provided the air movement is imperceptible, as it might be in a room that was only heated and not mechanically ventilated or air conditioned. In air conditioned rooms with typical air change rates of 5 to 20 per hour air movement is not imperceptible at such a low temperature, no matter how well the air distribution system is designed. For air conditioned rooms the realistic lower limit is 20°C in the UK and even then it will be unsatisfactorily cool for some of the occupants.

The intensity of air turbulence (T_u) is relevant to a sensation of draught and is defined by ASHRAE (1997) and Fanger (1987) as

$$T_u = 100(V_{sd}/V) \tag{4.6}$$

where V_{sd} is the standard deviation of the local air velocity, measured by an omnidirectional anemometer with a time constant of 0.2 s, and V is the mean air velocity in m s^{-1}. The value of T_u is used in equation (4.7) to predict the percentage of people dissatisfied (PD) because of the presence of the draught:

$$\mathrm{PD} = (34 - t_a)(V - 0.05)^{0.62}(0.37VT_u + 3.14) \tag{4.7}$$

where t_a is the dry-bulb temperature of the air.

The equation is relevant for $20°\mathrm{C} < t_a < 26°\mathrm{C}$ and for $0.05 < V < 0.5$ m s^{-1}, according to ASHRAE (1997). As an example, this reference shows that, for an air temperature of 22°C with a mean air speed of 0.25 m s^{-1} and a turbulence intensity of 2 or 3 per cent, it is still likely that 15 per cent of the people will be dissatisfied. Fanger *et al.* (1988) have shown that discomfort depends also on the frequency of fluctuation of the draught, people being particularly sensitive to the range from 0.3 to 0.6 Hz.

.5 Environmental influences on comfort

From the foregoing it can be inferred that the body maintains a thermal equilibrium with the environment by heat exchanges involving evaporation (about 25 per cent), radiation (about 45 per cent) and convection (about 30 per cent), referred to an environment of approximately 18.5°C and 50 per cent relative humidity for a normally clothed, sedentary person. The figure for evaporation covers respiration and insensible perspiration, without sweating. It further follows that there are four properties of the environment that influence comfort by modifying the contributions of these three modes of heat transfer:

2.4 Factors affecting Human Comfort

In designing winter or summer air conditioning system, the designer should be well conversant with a number of factors which physiologically affect human comfort. The important factors are as follows:

1. Effective temperature, 2. Heat production and regulation in human body, 3. Heat and moisture losses from the human body, 4. Moisture content of air, *5.* Quality and quantity of air. 6. Air motion, 7. Hot and cold surfaces, and 8. Air stratification.

These factors are discussed, in detail, in the following articles:

2.5 Effective Temperature

The degree of warmth or cold felt by a human body depends mainly on the following three factors:

1. Dry bulb temperature, 2. Relative humidity, and 3. Air velocity.

In order to evaluate the combined effect of these factors, the term *effective temperature* is employed. It is defined as that index which correlates the combined effects of air temperature, relative humidity and air velocity on the human body. The numerical value of effective temperature is made equal to the temperature of still *(i.e.* 5 to 8 *m/min* air velocity) saturated air, which produces the same sensation of warmth or coolness as produced under the given conditions.

The practical application of the concept of effective temperature is presented by the comfort *chart,* as shown in Fig. 2.1. This chart is the result of research made on different kinds of people subjected to wide range of environmental temperature, relative humidity and air movement by the American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE). It is applicable to reasonably still air (5 to 8 *m/min* air velocity) to situations where the occupants are seated at rest or doing light work and to spaces whose enclosing surfaces are at a mean temperature equal to the air dry bulb temperature.

In the comfort chart, as shown in Fig. 2.1, the dry bulb temperature is taken as abscissa and the wet bulb temperature as ordinates. The relative humidity lines are replotted from the psychrometric chart. The statistically prepared graphs corresponding to summer and winter season are also superimposed. These graphs have effective temperature scale as abscissa and % of people feeling comfortable as ordinate.

A close study of the chart reveals that the several combinations of wet and dry bulb temperatures with different relative humidities will produce the same effective temperature. However, all points located on a given effective temperature line do not indicate conditions of equal comfort or discomfort. The extremely high or low relative humidities may produce conditions of discomfort regardless of the existent effective temperature. The moist desirable relative humidity range lies between 30 and 70 per cent. When the relative humidity is much below *30* per cent, the mucous membranes and the skin surface become too dry for comfort and health. On the other hand, if the relative humidity is above *70* per cent, there is a tendency for a clammy or sticky sensation to develop. The curves at the top and bottom, as shown in Fig. 2.1, indicate the percentages of person participating in tests, who found various effective temperatures satisfactory for comfort.

The comfort chart shows the range for both summer and winter condition within which a condition of comfort exists for most people. For summer conditions, the chart indicates that a maximum of *98* percent people felt comfortable for an effective temperature of *21.6ºC*. For winter conditions, chart indicates that an effective temperature of *20ºC* was desired by *97.7* percent people. It has been found that for comfort, women require *0.5ºC* higher effective temperature than men. All men and women above 40 years of age prefer *0.5ºC* higher effective temperature than the persons below *40* years of age.

It may be noted that the comfort chart, as shown in Fig. 2.1, does not take into account the variations in comfort conditions when there are wide variations in the mean radiant temperature (MRT). In the range of *26.5ºC*, a rise of *0.5ºC* in mean radiant temperature above the room dry bulb temperature raises the effective temperature by *0.5ºC*. The effect of mean radiant temperature on comfort is less pronounced at high temperatures than at low temperatures.

Note: From the comfort chart, we see that for a point corresponding to dry bulb temperature of 2.5ºC, wet bulb temperature of 12.5ºC and relative humidity of 60%, the effective temperature is 16ºC. Now for the same feeling of comfort and warmth, there is another point on 100% relative humidity line at which dry bulb temperature and wet bulb temperature are both equal to 16º C. Thus both have an effective temperature of 16ºC.

The comfort conditions for persons at work vary with the rate of work and the amount of clothing worn. In general, the greater the degree of activity, the lower the effective temperature necessary for comfort.

Fig. 2.2 shows the variation in effective temperature with different air velocities. We see that for the atmospheric conditions of 24ºC dry bulb temperature and 16ºC wet bulb temperature correspond to about *21ºC* with nominally still air (velocity *6 m/min*) and it is about *17ºC* at an air velocity of *210 m/min*. The same effective temperature is observed at higher dry bulb and wet bulb temperatures with higher velocities. The case is reversed after *37.8ºC* as in that case higher velocities will increase sensible heat flow from air to body and will decrease comfort. The same effective temperature means same feeling of warmth, but it does not mean same comfort.

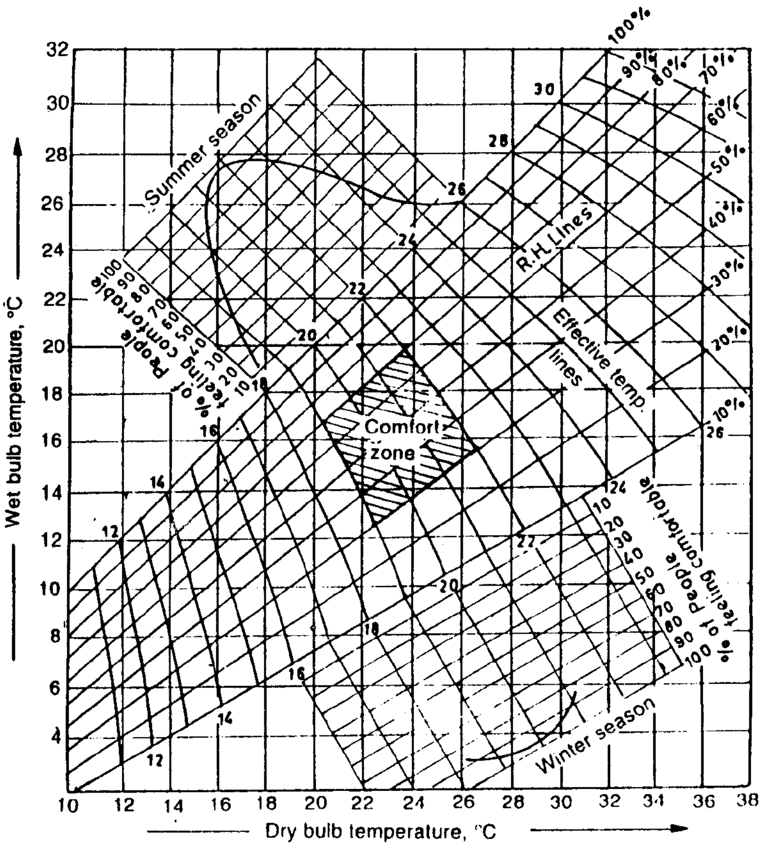


Fig. 2.1:. Comfort chart for still air (air velocities from 5 to 8 *m /min*).

2.6 Modified Comfort Chart

The comfort chart, as shown in Fig. 2.1, has become obsolete now a days due to its short comings of over exaggeration of humidity at lower temperature and under estimation of humidity at heat tolerance level. The modified comfort chart according to ASHRAE is shown in Fig. 2.3 and it is commonly used these days. This chart was developed on the basis of research done in 1963 by the institute for environmental research at Kansas State University. The mean radiant temperature was kept equal to dry bulb temperature and air velocity was less than 0.17 *m/s.*

2.7 Heat Production and Regulation in Human Body

The human body acts like a heat engine which gets its energy from the combustion of food within the body. The process of combustion (called *metabolism)* produces heat and energy due to the oxidation of products in the body by oxygen obtained from inhaled air. The rate of heat production depends upon the individual's health, his physical activity and his environment. The rate at which the body produces heat is termed as *metabolic rate.* The heat production from a normal healthy person when asleep (called *basal metabolic rate)* is about 60 watts and it is about ten times more for a person carrying out sustained very hard work.

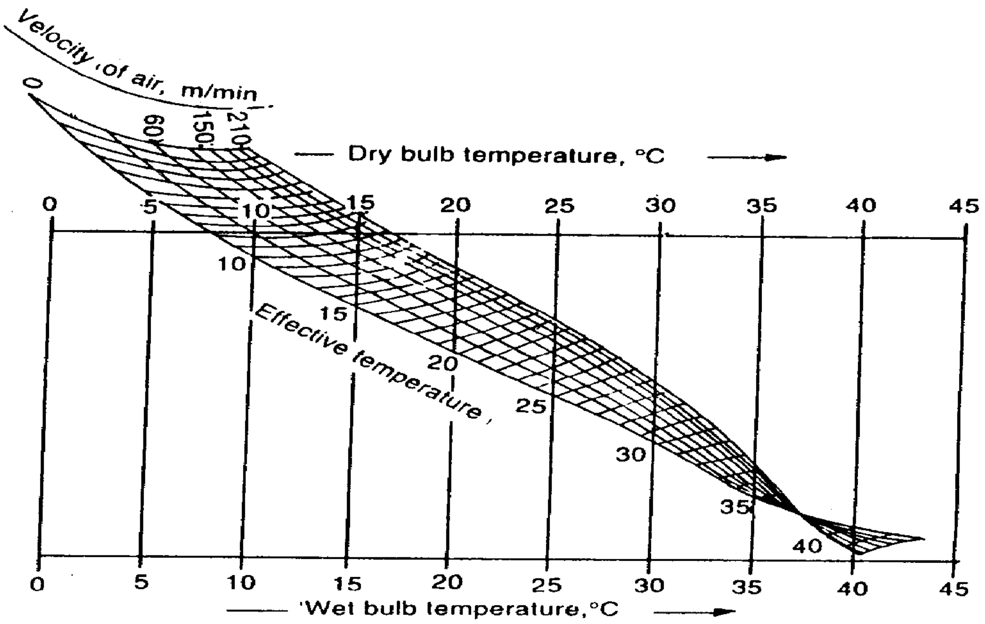


Fig. 2.2. Variation of effective temperature with air velocity.

Since the body has a thermal efficiency of *20* per cent, therefore the remaining 80 per cent of the heat must be rejected to the surrounding environment, otherwise accumulation of heat results which causes discomfort. The rate and the manner of rejection of heat is controlled by the automatic regulation system of a human body.

In order to effect the loss of heat from the body to produce cold, the body may react to bring more blood to the capillaries in the skin. The heat losses from the skin, now, may take place by radiation, convection and by evaporation. When the process of radiation or convection or both fails to produce necessary loss of heat, the sweat glands become more active and more moisture is deposited on the skin, carrying heat away as it evaporates . it may be noted that when the temperature of surrounding air and objects is below the blood temperature, the heat is removed by radiation and convection. On the other hand, when the temperature of surrounding air is above the blood temperature, the heat is removed by evaporation only. In case the body fails to throw off the requisite amount of heat, the blood temperature rises. This results in the accumulation of heat which will cause discomfort.

The human body attempts to maintain its temperature when exposed to cold by the withdrawal of blood from the outer portions of the skin, by decreased blood circulation and by an increased rate of metabolism.

2.8 Heat and Moisture Losses from the Human Body

The heat is given off from the human body as either sensible or latent heat or both. In order to design any air conditioning system for spaces which human bodies are to occupy, it is necessary to know the rates at which these two forms of heat are given off under different conditions of air temperature and bodily activity.

Fig. 2.4a shows the graph between sensible heat loss by radiation and convection for an average man and the dry bulb temperature for different types of activity. Fig. 2.4*b* shows the graph between the latent heat loss by evaporation for an average man and dry bulb temperature for different type of activity.

The total heat loss from the human body under varying effective temperatures is shown in Fig. 2.4*c*. From curve *D*, which applies to men at rest, we see that from about *19ºC* to *30ºC* effective temperature, the heat loss is constant. At the lower effective temperature, the heat dissipation increases which results in a feeling of coolness. At higher effective temperature, the ability to lose heat rapidly decreases resulting in severe discomfort. The curves *A, B, C* and *D* shown in Fig. 2.4 represents as follows

Curve A — Men working at the rate of 90 *kN.m/h*
Curve B — Men working at the rate of *45 kN.m/h*
Curve C — Men working at the rate of 22.5 *kN.m/h*
Curve D — Men at rest.

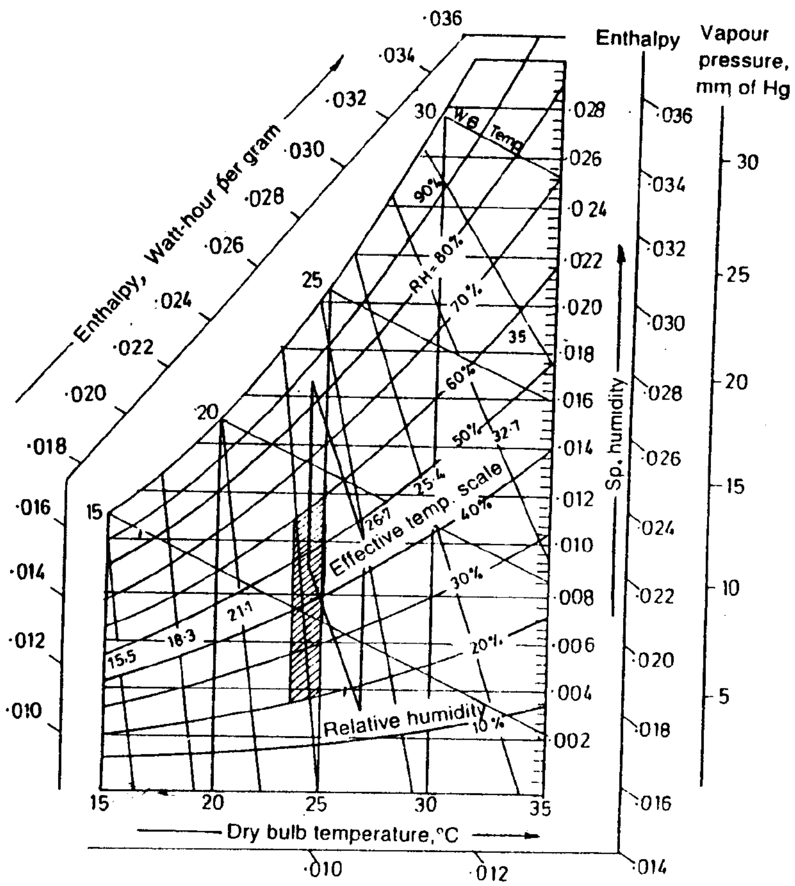
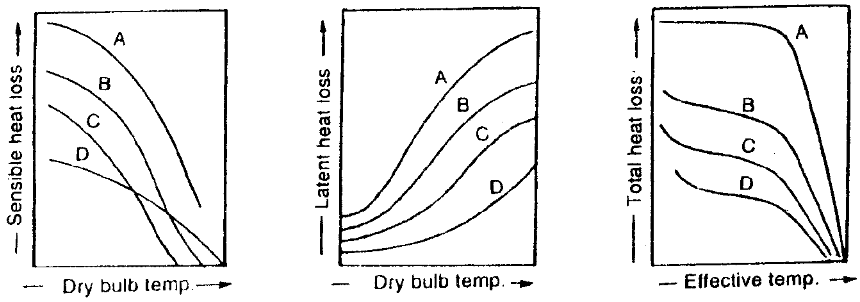


Fig. 2.3. Modified comfort chart.



(a) Relation between sensible heat loss from the human body and dry bulb temperature for still air.

(b) relation between latent heat loss from the human body and dry bulb temperature for still air.

(c) relation between total heat loss from the human body and effective temperature for still air.

Fig. 2.4

2.9 Moisture Content of Air

We have seen in Art. *2.5* that the dry bulb temperature, relative humidity and air motion are interrelated. The moisture content of outside air during winter is generally low and it is above the average during summer, because the capacity of the air to carry moisture is dependent upon its dry bulb temperature. This means that in winter, if the cold outside air having a low moisture content leaks into the conditioned space, it will cause a low relative humidity unless moisture is added to the air by the process of humidification. In summer, the reverse will take place unless moisture is removed from the inside air by the dehumidification process. Thus, while designing an air conditioning system, the proper dry bulb temperature for either summer or winter must be selected in accordance with the practical consideration of relative humidities which are feasible. In general, for winter conditions in the average residence, relative humidities above *35* to *40* per cent are not practical. In summer comfort cooling, the air of the occupied space should not have a relative humidity above *60* per cent. With these limitations, the necessary dry bulb temperature for the air may be determined from the comfort chart.

2.10 Quality and Quantity of Air

The air in an occupied space should, at all times, be free from toxic, unhealthful or disagreeable fumes such as carbon dioxide. It should also be free from dust and odour. In order to obtain these conditions, enough clean outside air must always be supplied to an occupied space to counteract or adequately dilute the sources of contamination.

The concentration of odour in a room depends upon many factors such as dietary and hygienic habits of occupants, type and amount of outdoor air supplied, room volume per occupant and types of odour sources. In general, when there is no smoking in a room, $1\, m^3/min$ per person of outside air will take care of all the conditions. But when smoking takes place in a room, *1.5* m^3/min per person of outside air is necessary. In most air conditioning systems, a large amount of air is recirculated over and above the required amount of outside air to satisfy the minimum ventilation conditions in regard to odour and purity. For general application, a minimum of *0.3* m^3/min of outside air per person, mixed with *0.6* m^3/min of recirculated air is good.

2.11 Air Motion

The air motion which includes the distribution of air is very important to maintain uniform temperature in the conditioned space. No air conditioning system is satisfactory unless the air handled is properly circulated and distributed. Ordinarily, the air velocity in the occupied zone should not exceed *8* to *12 m/min*. The air velocities in the space above the occupied zone should be very high in order to produce good distribution of air in the occupied zone, provided that the air in motion does not produce any objectionable noise. The flow of air should be preferably towards the faces of the individuals rather than from the rear in the occupied zone. Also for the proper and perfect distribution of air in the air conditioned space, down flow should be preferred instead of up flow. The air motion without proper air distribution produces local cooling sensation known as *draft.*

2.12 Cold and Hot Surfaces

The cold or hot objects in a conditioned space may cause discomfort to the occupants. A single glass of large area when exposed to the outdoor air during winter will produce discomfort to the occupants of a room by absorbing heat from them by radiation. On the other hand, a ceiling that is warmer than the room air during summer causes discomfort. Thus, in the designing of an air conditioning system, the temperature of the surfaces to which the body may be exposed must be given considerable importance.

2.13 Air Stratification

When air is heated, its density decreases and thus it rises to the upper part of the confined space. This results in a considerable variation in the temperatures between the floor and ceiling levels. The movement of the air to produce the temperature gradient from floor to ceiling is termed as *air stratification.* In order to achieve comfortable conditions in the occupied space, the air conditioning system must be designed to reduce the air stratification to a minimum.

2.14 Factors Affecting Optimum Effective Temperature

The important factors which affect the optimum effective temperature are as follows:

1. Climatic and seasonal differences

It is a known fact that the people living in colder climates feel comfortable at a lower effective temperatures than those living in warmer regions. There is a relationship between the optimum indoor effective temperature and the optimum outdoor temperature, which changes with seasons. We see from the comfort chart (Fig. 2.1) that in winter the optimum effective temperature is 19^oC whereas in summer this temperature is 22^oC.

2. Clothing

It is another important factor which affects the optimum effective temperature. It may be noted that the person with light clothing need less optimum temperature than a person with heavy clothing.

3. Age and Sex

We have already discussed that the women of all ages require higher effective temperature (about 0.5^oC) than men. Similar is the case with young and old people. The children also need higher effective temperature than adults. Thus, the maternity halls are always kept at an effective temperature of *2* to 3^oC higher than the effective temperature used for adults.

4. Duration of stay

It has been established that if the stay in a room is shorter (as in the case of persons going to banks), then higher effective temperature is required than that needed for long stay (as in the case of persons working in an office).

5. Kind of activity

When the activity of the person is heavy such as people working in a factory, dancing hall, then low effective temperature is needed than for the people sitting in cinema hall or auditorium.

6. Density of occupants

The effect of body radiant heat from person to person particularly in a densely occupied space like auditorium is large enough which require a slight lower effective temperature.