



Physiological Reactions to the Environment.

1- Factors affecting human comfort.

(In order of importance).

1. Temperature: depends on the application, season, activity, etc...
2. Humidity: is acceptable between 30-70%.
3. Air motion & distribution: air motion is necessary but drafts or excessive air motion is objectionable.
4. purity: purity means cleanliness of air from dust, fumes, toxic gases.

Human comfort is dependent on the rate of heat loss from the human body by radiation, convection and evaporation. When the rate of heat generated by metabolism is equal to heat dissipated, man is comfortable.

2- Comfort scales:

- a. Equivalent temperature: British concept which is not very popular. Black cylinder 55cm high & 20cm diameter. Power is fed to the cylinder and regulated to maintain a certain temperature on the cylinder surface to model mans loss by radiation and convection. No account of relative humidity.
- b. Effective temperature (ET): is that index which expresses the composite effect of air temperature, relative humidity and motion on the human body. The numerical value is equal to the temperature of calm (4.5-7.5 m/min) saturated air.
- c. Corrective effective temperature:
Takes account of radiation in addition to the above. Employ globe thermometer reading for the dry bulb reading (thermometer at center of blackened sphere (100mm diameter) in the effective temperature scale.
- d. Black globe temperature: Globe temperature by itself is used as an index.



3-heat loss from human body:

The amount of heat generated by the human body depends on five factors which govern or control the metabolic rate.

[a) Age. b) sex. c) health. d) degree of activity. e) motional state].

Type of heat loss are sensible and latent:

- Sensible heat loss by radiation and convection from the skin to surrounding air.
- Conduction by contact is negligible.
- Latent loss by loss of moisture with breath and sweating.

4- Ventilation requirements.

Odors, toxic fumes and smoke must be removed from a conditioned space by continuously introducing fresh outside air and by removing stale inside air. Smoking is the controlling factor in determining the rate of ventilation.

*Infiltration should be considered while determining the rate of ventilation.

* Ventilation air is never introduced into the space directly. It must be conditioned by the apparatus first.

*Infiltration air enters the space directly and is included in the space load.



Inside and Outside Design Conditions

The specific objectives of this lecture are to:

1. Describe a typical air conditioning system and discuss the need for fixing suitable indoor and outdoor design conditions.
2. Discuss the criteria used for selecting inside design conditions.
3. Define thermal comfort, metabolic rate and response of human beings to variation in body temperature
4. Present heat balance equation, equations for convective, radiative and evaporative losses from the skin, metabolic rates for various types of activities and discuss the thermo-regulatory mechanism used by human body to fight against heat and cold .
5. Discuss the factors affecting thermal comfort.
6. Discuss the various thermal indices used for evaluating indoor environment and present.

ASHRAE comfort chart, recommended inside design conditions and discuss the concept of Predicted Mean Vote (PMV) and Percent of People Dissatisfied (PPD).

7. Discuss the criteria used for selecting outside design conditions and present typical summer design conditions for major Indian cities as suggested by ASHRAE.

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

1. Explain the need for selecting design inside and outside conditions with respect to a typical air conditioning system.
2. Define thermal comfort, metabolism, metabolic rate and discuss the effects of variation in body temperatures on human beings.
3. Write the heat balance and heat transfer equations from a human body and using these equations, estimate various heat transfer rates.
4. List the factors affecting thermal comfort
5. Define the various thermal indices used in evaluating indoor environment
6. Draw the ASHRAE comfort chart and mark the comfort zones for summer and winter conditions.
7. Select suitable indoor design conditions based on comfort criteria.
8. Define PMV and PPD and explain their significance.



9. Explain the method followed for selecting suitable outside design conditions

1. Introduction:

Design and analysis of air conditioning systems involves selection of suitable inside and outside design conditions, estimation of the required capacity:

- i. of cooling or heating equipment,
- ii. selection of suitable cooling/heating system,
- iii. selecting supply conditions,
- iv. design of air transmission and distribution systems etc.

Generally, the inputs are the building specifications and its usage pattern and any other special requirements. Figure .1 shows the schematic of a basic summer air conditioning system. As shown in the figure, under a typical summer condition, the building gains sensible and latent heats from the surroundings and also due to internal heat sources (RSH and RLH).

In general, the sensible and latent heat transfer rates (GSH and GLH) on the cooling coil are larger than the building heat gains due to the need for ventilation and return duct losses.

The building heat gains depend on:

- i. the type of the building,
- ii. outside conditions and
- iii. the required inside conditions.

Hence selection of suitable inside and outside design conditions is an important step in the design and analysis of air conditioning systems.

2. Selection of inside design conditions:

The required inside design conditions depend on the intended use of the building. Air conditioning is required either for :

- i. providing suitable comfort conditions for the occupants (e.g. comfort air conditioning).
- ii. or for providing suitable conditions for storage of perishable products (e.g. in cold storage) **or**
- iii. conditions for a process to take place or for products to be manufactured (e.g. industrial air conditioning).

The required inside conditions for cold storage and industrial air conditioning applications vary widely depending on the specific requirement. However, the



required inside conditions for comfort air conditioning systems remain practically the same irrespective of the size, type, location, use of the air conditioning building etc., as this is related to the thermal comfort of the human beings.

3. Thermal comfort:

Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment". This condition is also sometimes called as "neutral condition", though in a strict sense, they are not necessarily same. A living human body may be likened to a heat engine in which the chemical energy contained in the food it consumes is continuously converted into work and heat.

4. HEAT BALANCE EQUATION

The physical basis of comfort lies in the thermal balance of the body, i.e. the heat produced by the body's metabolism must be dissipated to the environment, otherwise the body would overheat.

The total energy production rate of the body is the sum of the production rates of heat \dot{Q} and Work \dot{W} and can be written in the form:

$$\dot{Q} + \dot{W} = M \cdot A_{skin} \quad (1)$$

Where:

M is the rate of metabolic energy production per unit surface area

A_{skin} is the total surface area of skin.

The thermal balance of the body can be expressed by the equation,

$$S = (M - W) - E \pm R \pm C \quad (2)$$

Where:

$(M - W)$ is the net surplus heat to be liberated or stored (metabolic rate minus the useful rate of working).

E : the heat loss by evaporation.

R : the heat gain or loss by radiation.

C : the heat gain or loss by convection.

S : the rate at which heat is stored within the body.



Under steady-state conditions, the body remains comfortable and healthy because S is zero.

In an oppressively hot environment, the load imposed upon E , R and C may be so great that S is positive, and the body temperature will rise, eventually resulting in heat-stroke.

Heat dissipation from the body (Table 1) to the immediate surroundings occurs by several modes of heat exchange as shown in figure 1:

- Sensible heat flow from the skin.
- Latent heat flow from evaporation of sweat and from evaporation of moisture diffused through the skin.
- Sensible heat flow during respiration.
- Latent heat flow due to evaporation of moisture during respiration.

Sensible and latent heat losses from the skin are typically expressed in terms of environmental factors, skin temperature, and skin wittedness. The main independent environmental variables can be summarized as air temperature, mean radiant temperature and relative air velocity and ambient water vapour pressure.

5. THERMAL INTERCHANGE WITH ENVIRONMENT

The human body is continually gaining and producing heat as well as losing heat to its surroundings to maintain temperature equilibrium (Figure 1). Body heat gains come from two sources:

- Heat produced within the body itself as a result of metabolic processes.
- Heat gained by body from external sources, by radiation from the sun or other hot objects or surfaces, and by convection from the surrounding air.

5.1 Heat is lost from the body by:

(a) Conduction; Heat loss by conduction depends on the temperature difference between the body surface and the object with which the body is in direct contact. Heat lost by conduction from the body can be neglected as the amount of body surface in contact with an external surface is usually too small and the period of contact is short too.



(b) Convection (about 30 per cent): Heat loss due to convection takes place from the body to the air in contact with the skin or clothing. Hot air resulting from skin contact rises and is replaced by cooler air. The rate of convective heat loss is increased by a faster rate of air movement, by a lower air temperature and a higher skin temperature.

(c) Radiation (about 45 per cent): Radiant heat loss depends on the temperature of the body surface and the temperature of the opposing surfaces. Thus, the human body will radiate heat to walls, ceilings, floors, windows, and to the out-of-doors if these surfaces are at a lower temperature than the body surface. Conversely, the body gains by radiation from the sun or from any surface warmer than the skin surface. Body skin temperature ranges between 30°C and 34°C with an average of 32.2°C for a healthy person engaged in light activity.

(d) Evaporation (about 25 per cent): Heat loss by evaporation is governed by the rate of evaporation, which in turn depends on the humidity of air (the dryer the air, the faster the evaporation) and on the amount of moisture available for evaporation.



(TABLE 1): Heat output of the body in various activities

Activity	Watts
Sleeping min.	70
Sitting, moderate movement, e.g. typing on computer	160-190
Sitting, heavy arm and leg movements	190-230
Standing, moderate work, some walking	220-290
Walking, moderate lifting or pushing	290-410
Intermittent heavy lifting, digging	440-580
Hard, sustained work	580-700

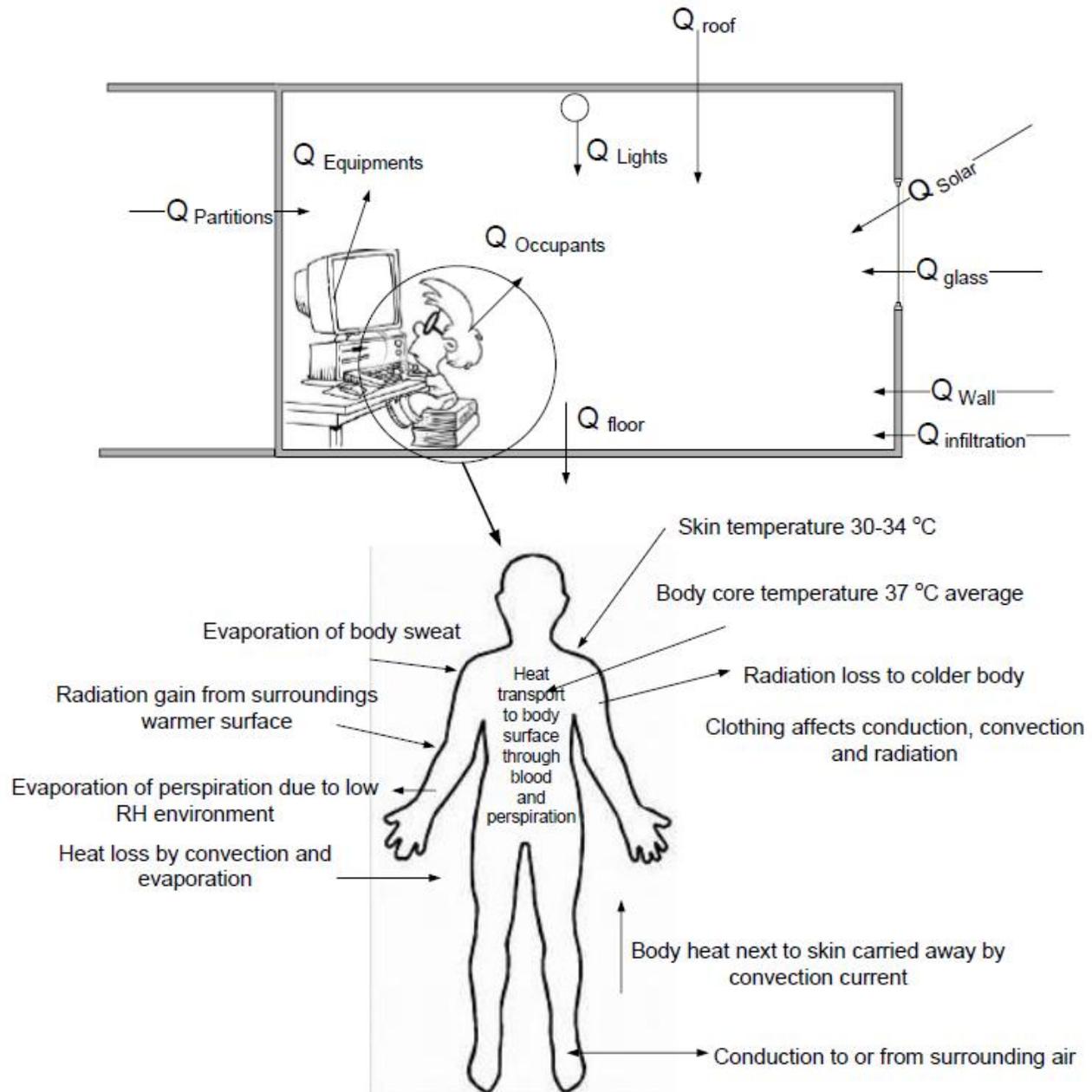


Figure 1 several modes of heat exchange



5.2 Metabolic heat generation

The unit used to measure the metabolic rate is *met*. One met represents the average heat produced by a sedentary average person at normal mean radiant temperature, i.e. 1 met = 58.2 W/m². The comfort envelope defined applies only to sedentary and slightly active (1 met), normally clothed (0.6 clo) persons at low air velocities, when the mean radiant temperature (MRT) is equal to air temperature. Table 2 lists the typical metabolic heat generation for various activities.

(TABLE 2): Typical metabolic heat generation for various activities

Activities	W/m ²	met
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking		
3.2 km/h (0.9 m/s)	115	2.0
4.3 km/h (1.2 m/s)	150	2.6
6.4 km/h (1.8 m/s)	220	3.8
Office activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1



Clothing affects comfort, since it acts as an insulation. The unit measuring the insulating effect of clothing on a human subject is *clo*, where, $1 \text{ clo} = 0.155 \text{ km}^2/\text{W}$.

6. ENVIRONMENTAL PARAMETERS AND INDICES

6.1 Environmental parameters

Environmental parameters that affect human comfort can be categorized into:

(a) directly measured parameters and (b) calculated parameters.

The following are the frequently used directly *measured psychrometric parameters*:

- Dry-bulb temperature.
- Wet-bulb temperature.
- Dew-point temperature.
- Water vapour pressure.
- Total atmospheric pressure.
- Relative humidity.
- Humidity ratio.
- Air velocity.

The mean radiant temperature is derivable and, hence, a *calculated parameter*. It is the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing non-uniform environment. Fanger identified two additional calculated parameters, which are *activity level* and *clothing*. In addition to the above, the other secondary factors such as day-to-day temperature variation, age, adaptability, sex, etc. also influence comfort.

6.2 Environmental indices

An environmental index combines two or more parameters, such as air temperature, mean radiant temperature, humidity or air velocity into a single variable. The *effective temperature* (ET*) is probably the most common environmental index and has the widest range of applications.

The *effective temperature* (ET*) is defined as the dry-bulb temperature of a uniform enclosure at 50% RH in which humans would have the same net heat



exchange by radiation, convection, and evaporation as they would in the varying humidities of the test environment.

Another approach used to evaluate the combined effect of temperature and humidity is the *Heat Stress Index*. This index is the ratio of the total evaporative heat loss required for thermal equilibrium to the maximum evaporative heat loss possible for the environment, multiplied by 100 for steady-state conditions (skin temperature is held constant at 35°C in order to limit the rise in body temperature, the sweat rate should not exceed one litre per hour to limit the loss of body fluid). The heat stress index is therefore defined as:

$$\text{Heat stress index} = \frac{\dot{Q}_E}{\dot{Q}_{E,max}} \times 100$$

\dot{Q}_E : the actual evaporation rate

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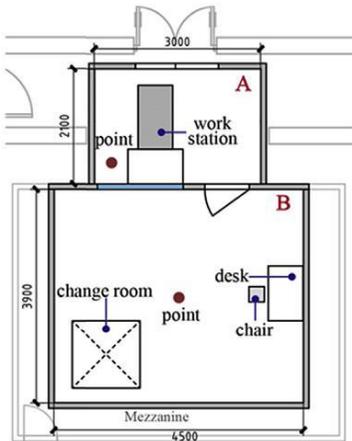
$\dot{Q}_{E,max}$: the maximum evaporative heat loss with the skin temperature at 35°C.



7. COMFORT CHARTS

In identical environments, different people perceive comfort in different ways. In the same built environment, some may feel chilly while others may feel warm. Likewise some people tend to like moist coastal climate, while others may prefer arid desert environment or cool and crisp mountain weather. Dry bulb temperature is not a reliable indication of how warm or cold an occupant will feel in a room. The effects of both relative humidity and air velocity need also to be considered.

In the same context, ASHRAE and other researchers have conducted extensive research over the years to relate the above factors to human comfort, as shown in figure 3. From the results of these tests emerged the concept of an *effective temperature*. This index is a measure of comfort which involves the combined effect of dry bulb, wet bulb, and air movement as judged by the subjects in the research studies. There were a number of different combinations of dry-bulb and relative humidity which would give the same feeling of comfort to a high percentage of the subjects for a given air velocity. All these combinations were said to have the same effective temperature, defined earlier. See figure A typical comfort chart shown in Figure 4 could then be constructed by drawing lines through the points at which **the majority of people equally clothed and equally active reported the same feeling of comfort**. These lines are called the *effective-temperature (ET)* lines. The summer-comfort zone ABCD encompasses the possible combinations of dry-bulb temperature and relative humidity which produce summer comfort for most people. It may be noted that this zone spans the range of effective temperatures from around 19 to 24°C. In a like manner, the area EFGH is the winter-comfort zone for most individuals and spans the range of effective temperature from 17°C to 22°C.



a. Chamber set-up



b. Sitting and typing



c. Standing and typing



d. Walking and typing

Figure 3a climate chamber for comfort study

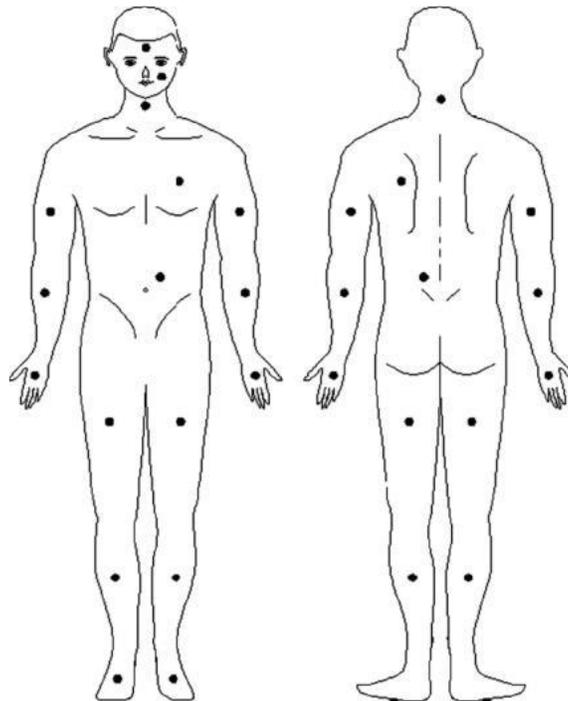


Figure 3 b, the Measurement points of local skin temperature.

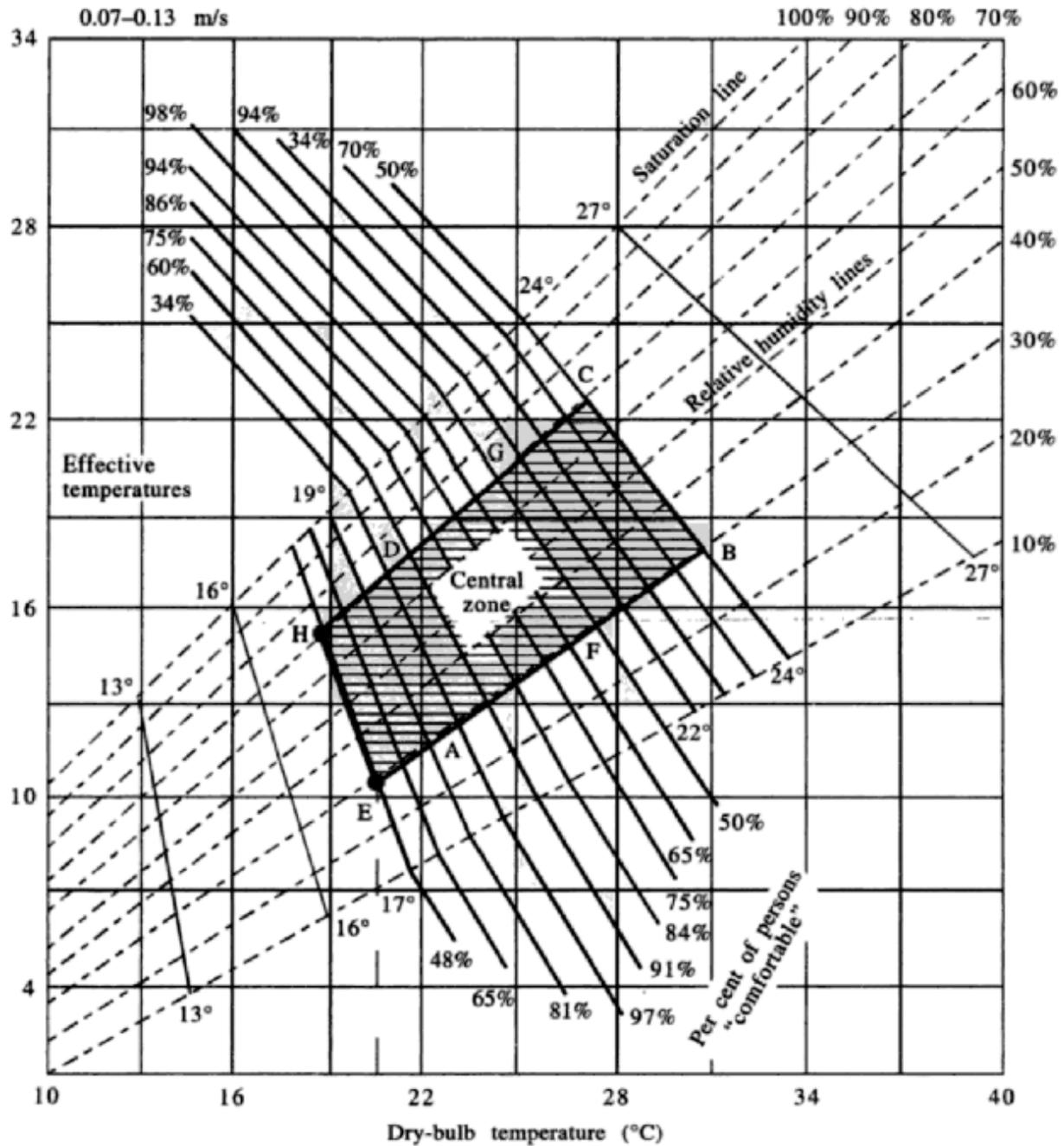


Figure 4 A typical comfort chart



8. PREDICTION OF THERMAL COMFORT

The usual comfort parameters are ambient air temperature, humidity, air motion, body activity level, and clothing. However, it has been observed that if the surrounding surfaces are below the air dry bulb temperature, comfort would occur at a higher effective temperature than that indicated by Figure 4. This implies that radiant cooling affects comfort parameters/sensation appreciably. Studies have also indicated that women of all ages prefer an effective temperature about one degree higher than that preferred by men, while both men and women over 40 years age prefer an effective temperature about one degree higher than that desired by younger people. People of all climatic regions have identical preferred temperatures. The activity level of the occupants and the duration of occupancy also affect human thermal comfort sensation.

Thermal comfort and thermal sensation can be predicted by

(a) a comfort chart.

(b) numerically by the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD).

The predicted mean vote predicts the mean response of a large group of people. This thermal comfort sensation scale as developed by Robles and Nevins is shown in Table 3.

TABLE 3 ASHRAE thermal sensation scale

+3	+2	+1	0	-1	-2	-3
Hot	warm	slightly warm	neutral	slightly cool	cool	cold

The test results have been correlated with the air dry-bulb temperature, humidity level, sex, and duration of exposure. The basic equation used to compute the PMV is:

$$PMV = a^*t + b^*p_v + c^* \quad (4)$$

where, t is the dry bulb temperature and P_v is the corresponding saturation pressure, a^* , b^* and c^* are the coefficients used for calculating PMV. The values of coefficients a^* , b^* and c^* , can be obtained from Table 4.



After calculating the PMV, the PPD is estimated for the same condition (Figure 5). The dissatisfied occupants are defined as those who do not vote either +1, 0 or -1 on the PMV scale.

The PMV-PPD model is widely used and accepted for design and field assessment of comfort conditions. It can be seen from the figure that even when the PMV is zero (i.e., no thermal load on the body) 5 % of the people are dissatisfied! When PMV is within ± 0.5 , then PPD is less than 10.

TABLE 4: Coefficients a^* , b^* and c^* used to calculate the predicted mean vote (PMV).

Exposure period	Sex	Coefficient $t(^{\circ}\text{C})$, P_v (kPa)		
		a^*	b^*	c^*
1.0	Male	0.220	0.233	-5.673
1.0	Female	0.272	0.248	-7.245
1.0	Combined	0.245	0.248	-6.475
3.0	Male	0.212	0.293	-5.949
3.0	Female	0.275	0.255	-8.622
3.0	Combined	0.243	0.278	-6.802

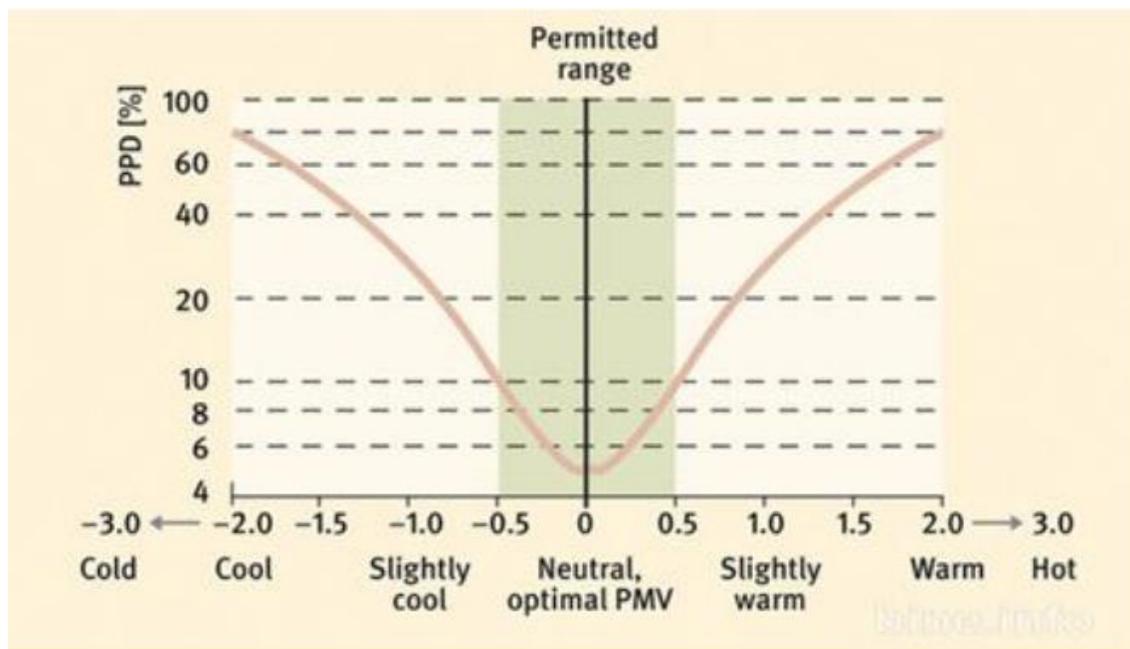




Figure 5 Percentage of room users that are dissatisfied with the existing indoor environment conditions (PPD index – predicted percentage dissatisfied) as a function of the user's average subjective evaluation of the environment (PMV index – predicted mean vote) as suggested by Fanger.

Example 1

A number of male and female subjects took part in a climate chamber test. Determine the difference between the PMV of male and that of female occupants with the air dry bulb temperature being 24°C and the dew-point temperature being 20°C, 1 hour after entry into the space.

Solution

$$PMV = a*t + b*p_v + c^* \quad (4)$$

PMV for men (using data from Table 4):

$$PMV = 0.22(24) + 0.233(2.339) - 5.673 = 0.051$$

Similarly, PMV for women:

$$PMV = 0.272(24) + 0.248(2.339) - 7.245 = -0.136$$

From the above, both males and females are predicted to be thermally neutral.

8.2 Outdoor design conditions for winter:

Similar to summer, it is not economical to design a winter air conditioning for the worst condition on record as this would give rise to very high heating capacities. Hence it is recommended that the outdoor design conditions for winter be chosen based on the values of **dry bulb temperature** that is **equaled or exceeded 99.6 or 99.0 % of total hours in a year**. Similar to summer design conditions, these values for major locations in the world are available in data books, such as AHRAE handbooks. Generally, the 99.0% value is adequate, but if the building is made of light-weight materials, poorly insulated or has considerable glass or space temperature is critical, then the 99.6% value is recommended.

Table 5 shows the ASHRAE recommended summer design conditions for some Iraqi cities.



Table 5: Outdoor design Conditions for Baghdad and Mosel.

Governor	Lat. o	Long. O	Winter		Summer						Daily rang °C
			DBT °C		DBT °C			WBT °C			
			97.5%	99%	1%	2.5%	5%	1%	2.5%	5%	
Baghdad	33°20'N	44°24'E	1.5	0	42	44	45	22	22	23	19
Mosel	36°19'N	43°09'E	0	-1.5	43.5	44.5	45.5	22	22	23	22

9. Weather and climate

How does climate differ from weather?

9.1 Weather is the current atmospheric conditions, including temperature, rainfall, wind, and humidity at a given place. If you stand outside, you can see that it's raining or windy, or sunny or cloudy. You can tell how hot it is by taking a temperature reading. Weather is what's happening right now or is likely to happen tomorrow or in the very near future.

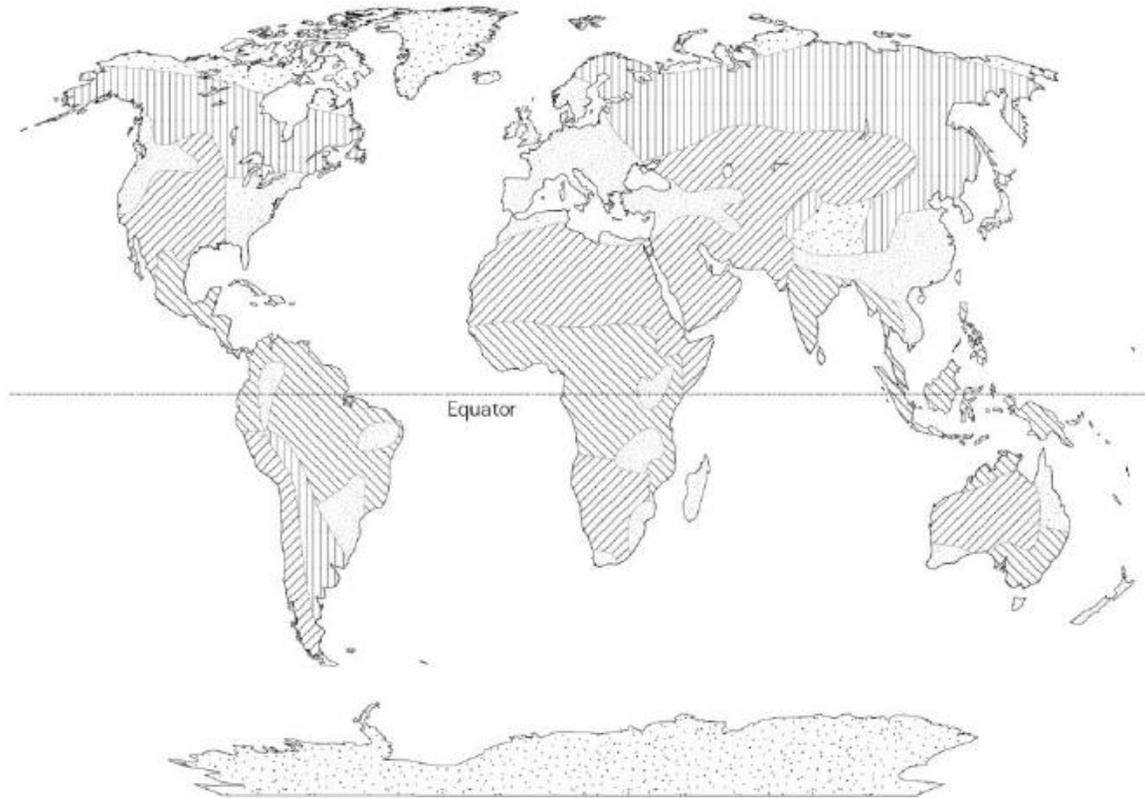
9.2 Climate, on the other hand, is the general weather conditions over a long period of time. Some meteorologists say that "climate is what you expect and weather is what you get."

According to one middle school student, "climate tells you what clothes to buy, but weather tells you what clothes to wear." Climate is sometimes referred to as "average" weather for a given area.

10. Classification of climates

The most classification of climate is the Koppen climate classification, that shown in figure 5 which classifies the world into six major groups of world climate, these groups are:

1- Cold and cool climates, 2- Warm temperature rain climate, 3- Hot dry climates (hot desert and steppe climates), 4- Composite climates, 5- Warm humid climates, and 6- Tropical upland climates.





Key

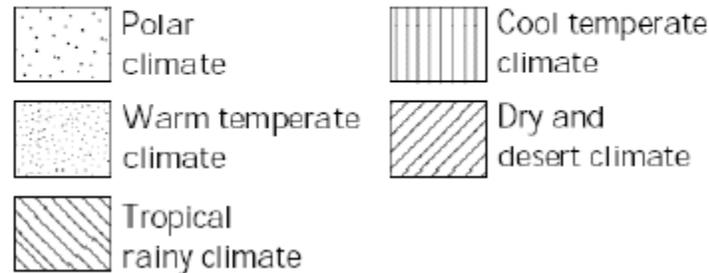


Figure 5 Koppen climate classification

11. Climate of Iraq:

11.1 Temperature.

The annual temperature rang in the arid desert is larger than in any other type of climate within tropic.

- The mean annual temperature of Baghdad is 23°C,
- the mean temperature in August is 34 °C, and January is 10 °C.
- The mean temperature for summer season is 33 °C,
- while the maximum in July is 42 °C.
- The mean monthly number of days with maximum temperature equal or exceeding to 40°C for Baghdad in August is equal to 30 day, and they are equal to 8 days when the maximums temperature equal to or exceeding 45°C.

11.2 Sky Conditions and sun shine Iraqi climate is characterized by right sunshine, high solar radiation with very little cloud cover and radiation from the ground.

11.3 Relative humidity Baghdad has mean relative humidity of 30% in summer, and 65% in winter.