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.

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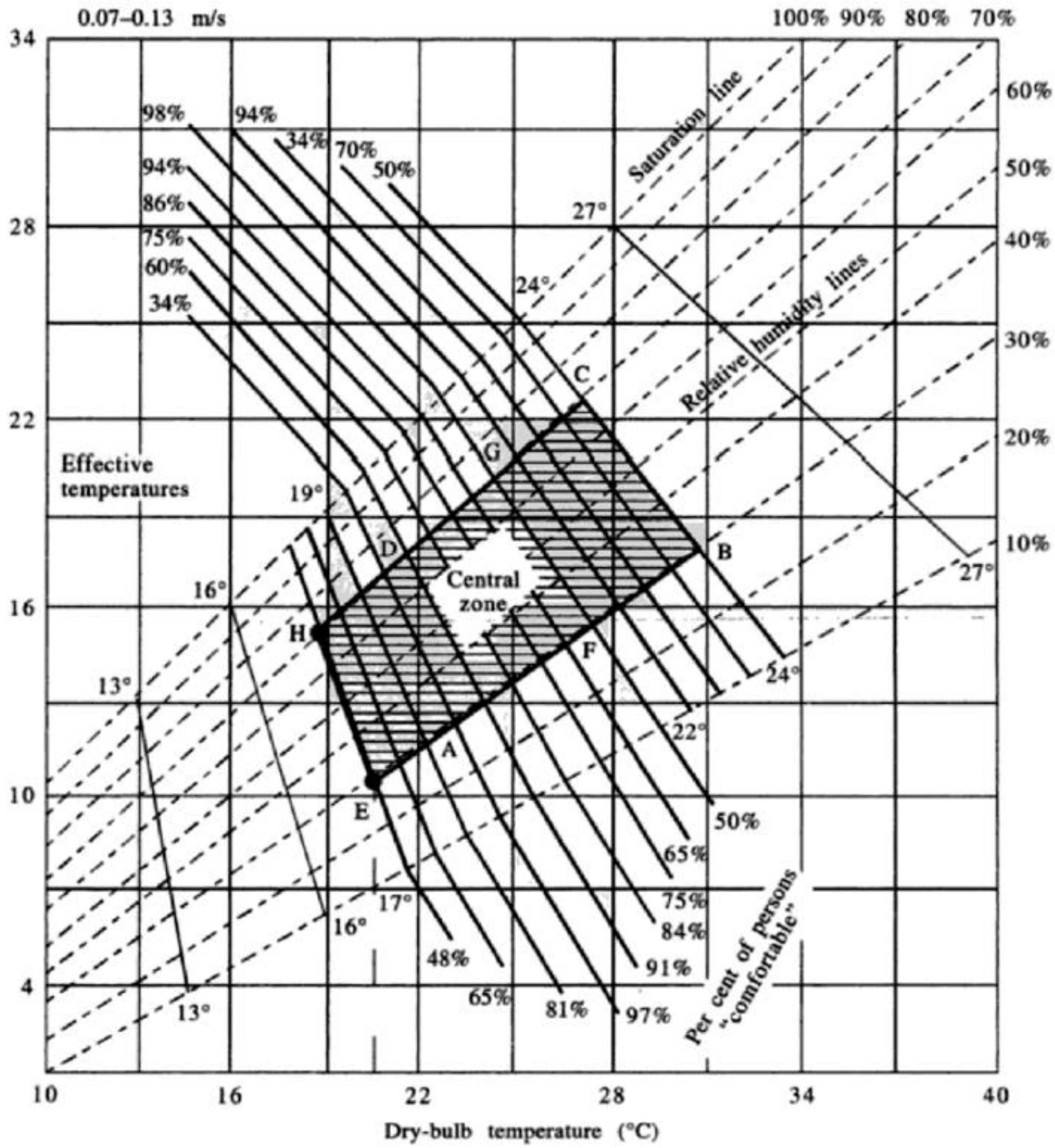

Typical comfort chart

Sumer comfort condition is found between (22-27^oC) ET, with100% occupants comfortable at (21^oC) ET.

Winter comfort conditions between (18-21°F) ET. With 100% occupants comfortable at (19-20°C) ET.

c. Corrective effective temperature:
   Takes account of radiation in addition to the above. Employs 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.

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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 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:

$$\dot{Q} + \dot{W} = M.A_{skin} \qquad (1)$$

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,

$$S = (M\text{-}W) - E \pm R \pm C \qquad (2)$$

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 3.1). 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

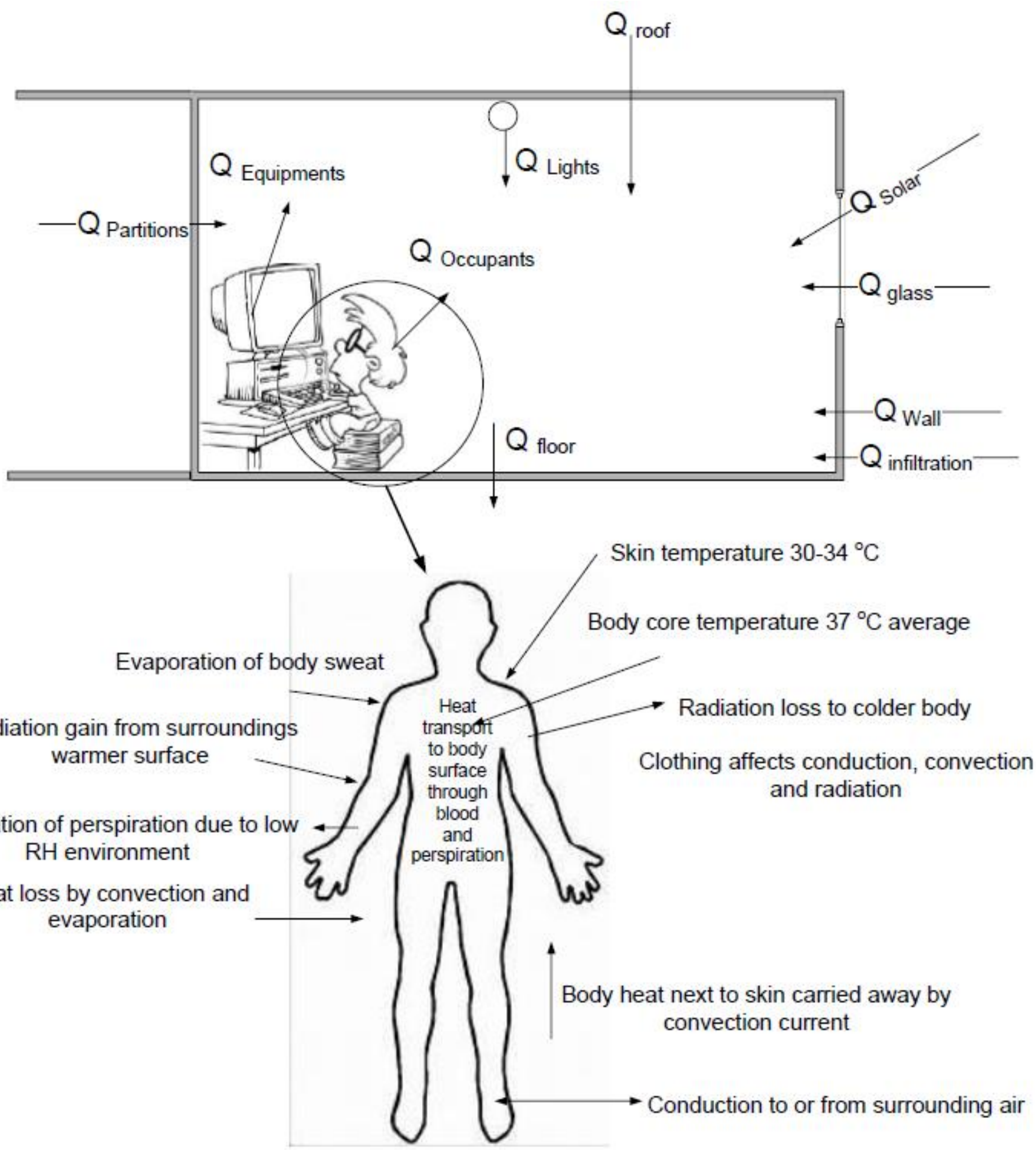

Figure 1 several modes of heat exchange

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/m^2. 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 clo = $0.155 km^2/W$.