1 Built environment

Learning objectives

Study of this chapter will enable the reader to:

1. relate human physiological needs to the internal and external environment;
2. understand the ways in which heat exchange between the body and its surroundings takes place;
3. calculate indoor and outdoor thermal comfort equations;
4. identify essential instruments for measuring the environment;
5. understand the thermal environment terminology used by design engineers;
6. recognize the problems of experimental work;
7. make reliable technical reports based on his or her own work and not to copy the work of others;
8. understand and use the factors that influence indoor air quality;
9. calculate fresh air ventilation rate;
10. know the instrumentation used for indoor environmental monitoring.

Key terms and concepts

air velocity 9; allowed exposure time 14; atmospheric pollutants 4; *clo* value 8; comfort equation 8; conduction, convection, radiation and evaporation 3; data logger 11; decipol 4; dry-bulb air temperature 15; dry resultant temperature 20; environmental temperature 19; equivalent wind chill temperature 13; globe temperature 16; heat stress index 14; humidity 3; infrared scanner 19; Kata thermometer 17; mean radiant temperature 9; metabolic rate 8; odorants 4; olf 4; olfactory 4; operative temperature 20; percentage of people dissatisfied 11; pitot-static tube 18; predicted mean vote 11; sling psychrometer 15; thermistor anemometer 17; thermocouple 18; thermohygrograph 17; trend 11; vane anemometer 17; vapour pressure 8; wet-bulb globe temperature 15; wet-bulb temperature 15; wind chill index 13.

Introduction

The building is an enclosure for the benefit of human habitation, work or recreation; in some cases, the ruling criteria are those demanded by an industrial need, such as machinery, products stored or computer equipment. Much construction work is undertaken outdoors, where the climate influences human working effectiveness and can lead to health risk.

The way in which the design engineer calculates measurement scales and interaction with human requirements is investigated.

World energy supply and demand

Many countries have become rich in material possessions by rapidly exploiting technological advances in energy supply and use. The human ability to extract enormous amounts of natural energy from the earth has enabled rapid travel to all parts of the globe, and space, and has kept habitable structures warm or cool as desired. Buildings are maintained with a standard of comfort, in all aspects of the word, at high energy cost. Large parts of the globe are much poorer in terms of their standard of living, and it is incumbent upon those nations possessing knowledge to act responsibly with regard to the resources they use now, how they plan for future development, and what technology is sold to developing nations. The building industry as a whole can learn from the history of energy usage to promote only those systems making the best use of available power. Economical use of energy with services installations is crucially important in this respect, as is designing new buildings that are energy-efficient. The designer's responsibility for energy use ceases after construction is completed and the defects liability period ends. The building owner, or user, pays for energy use in continuum. The energy cost, whether this be low or high, of using the facility, has been welded into place. Many years pass before anyone becomes brave enough to consider retrofit energy-saving measures. Demand-side minimization of energy use becomes the responsibility of all of us in the construction industry as well as us being personal consumers in our homes and transportation. The alternative is the ever-increasing requirement for supply-side public power supply installations. The word sustainability is recently popular; evaluating what it means to the building services industry becomes a real challenge to us all.

The building as an environmental filter

One of people's basic needs is to maintain a constant body temperature while the metabolism regulates heat flows from the body to compensate for changes in the environment. We have become expert in fine-tuning the environmental conditions produced by the climate in relation to the properties of the building envelope to avoid discomfort. A simple tent or cave may be sufficient to filter out the worst of adverse weather conditions, but the ability of this type of shelter to respond to favourable heat gains or cooling breezes may be too fast or too slow to maintain comfort.

Outside of the tropics, latitudes beyond 23.5° from the equator, houses may be advantageously oriented towards the sun to take advantage of solar heat gains, which will be stored in the dense parts of the structure and later released into the rooms to help offset heat losses to the cool external air during winter. Buildings within the tropical zone require large overhanging roofs and shutters over the windows to exclude as much solar radiation as possible and to shade the rooms. Thus the building envelope acts to moderate extremes of climate, and by suitable design of illumination and ventilation openings, together with heating, cooling and humidity controls, a stable internal environment can be matched to the use of the building.

Basic needs for human comfort

The building services engineer is involved with every part of the interface between the building and its occupant. Visually, colours rendered by natural and artificial illumination are produced by combinations of decor and windows. The acoustic environment is largely attributed to the success achieved in producing the required temperatures with quiet services equipment, all of which is part of the thermal control and transportation arrangements. Energy consumption for thermally based systems is the main concern, and close coordination between client, architect and engineer is vitally important.

Heat transfer between the human body and its surroundings can be summarized as follows.

Conduction

Points of contact with the structure are made with furniture and the floor. Clothing normally has a substantial thermal insulation value and discomfort should be avoided.

Convection

Heat removed from the body by natural convection currents in the room air, or fast-moving airstreams produced by ventilation fans or external wind pressure, is a major source of cooling. The body's response to a cool air environment is to restrict blood circulation to the skin to conserve deep tissue temperature, involuntary reflex action, shivering, if necessary, and in extreme cases inevitable lowering of body temperature. This last state of hypothermia can lead to loss of life and is a particular concern in relation to elderly people.

Radiation

Radiation heat transfer takes place between the body and its surroundings. The direction of heat transfer may be either way, but normally a minor part of the total body heat loss takes place by this method. Radiation between skin and clothing surfaces and the room depends on the fourth power of the absolute surface temperature, the emissivity, the surface area and the geometric configuration of the emitting and receiving areas. Thus a moving person will experience changes in comfort level depending on the location of the hot and cold surfaces in the room, even though air temperature and speed may be constant.

Some source of radiant heat is essential for comfort, particularly for sedentary occupations, and hot-water central heating radiators, direct fuel-fired appliances and most electrical heaters provide this. The elderly find particular difficulty in keeping warm when they are relatively immobile, and convective heating alone is unlikely to be satisfactory. A source of radiant heat provides rapid heat transfer and a focal point, easy manual control and quick heat-up periods. Severe cases of underheating can be counteracted by placing aluminium foil screens in positions where they can reflect radiation onto the rear of the chair.

Overheating from sunshine can also cause discomfort and glare, and tolerance levels for radiant heating systems have been established.

Evaporation

Humid air is exhaled, and further transfer of moisture from the body takes place by evaporation from the skin and through clothing. Maintenance of a steady rate of moisture removal from the body is essential, and this is a mass transfer process depending on air humidity, temperature and speed as well as variables such as clothing and activity.

Ventilation

The quality of the air in a building depends upon the quantity, type and dispersal of atmospheric pollutants (Awbi, 1991, p. 27). Some of these, odorants, can be detected by the olfactory receptors in the nose. These are the odours, vapours and gases that ingress from the outdoor environment and are released from humans, animals, flora, furnishings and the structural components of the building. Solid particles of dust, pollen and other contaminants often have little or no smell. These might be seen in occasional shafts of sunlight, and become visible when they have settled. Cleaning fluids such as ammonia, cigarette smoke, hair spray, deodorants and perfumes can be most noticeable. The inflow of diesel exhaust fumes, road tar, paint vapours and creosote creates unpleasantly noticeable pollution, even when of short duration. The presence of harmful pollutants such as carbon monoxide and radon gases is not detectable by the occupant. Indoor air quality may be said to be acceptable when not more than 50% of the occupants can detect any odour. Pollutants may still be present even if not noticeable by most occupants. The nasal cavity also reacts to pollutants with the general chemical sense of irritation. Olfactory response adapts to pollutants over time making people less sensitive to them while irritation increases with time (Chartered Institution of Building Services Engineers, CIBSE Guide A).

Professor Ole Fanger has introduced units of subjective assessment for odorants only. The olf quantifies the concentration of odorous pollutants. The decipol is the evaluation of the pollutant as determined by the recipient through the olfactory sensations from the nose. One olf is the emission rate of biological effluents from one standard person, or the equivalent from other sources. One decipol is the pollution caused by one standard person when ventilated with 10 l/s of unpolluted air. The number of olfs corresponding to different levels of human activity is shown in Table 1.1 (Fanger, 1988).

Office accommodation normally has one person for each 10 m^2 of floor area, so the biological effluent pollution load produced by normal occupancy is 0.1 olf/m^2. Smokers, building and furnishing materials and ventilation systems add to the pollution load. The average pollution in an existing building that has 40% of the occupants as smokers produces a load G of 0.7 olf/m^2. A low-pollution building with an absence of smoking has a load G of 0.2 olf/m^2. When there is complete mixing of the ventilation air with the air in the room, the rate of supply of outdoor air that is necessary to maintain the required standard of air quality is found from

$$Q = \frac{10 \times G}{C_i - C_o} \text{ l/s}$$

where C_i is the perceived air pollution within the enclosure (decipol), C_o is the perceived air pollution of outdoor air, usually 0.05 decipol but which may rise to 0.3 in a city with moderate pollution, and G is the concentration of pollution in the enclosure and the ventilation system (olf).

Table 1.1 Olf values for human activities.

Human activity	*Number of olfs*
Sedentary	1
Active	5
Highly active	11
Average for a smoker	6
During smoking	25

The perceived air pollution C_i within the enclosure is found from the percentage of the occupants who are dissatisfied with the conditions, *PD*, from

$$C_i = \frac{112}{(5.98 - \ln PD)^4} \text{ decipol}$$

where *PD* is the percentage of the occupants who are dissatisfied (ASHRAE (1985) recommend 20%), and ln = logarithm to base *e* ($\log_e$).

EXAMPLE 1.1

Calculate the outdoor air ventilation rate, from the Fanger method, that is required to satisfy 75% of the occupants of a commercial building where none of them are smokers. The building is located on the edge of a large town in the UK.

To satisfy 75% of the occupants, 25% are dissatisfied, so *PD* is 25%.

$$\begin{aligned} C_i &= \frac{112}{(5.98 - \ln 25)^4} \text{ decipol} \\ &= \frac{112}{(5.98 - 3.219)^4} \text{ decipol} \\ &= \frac{112}{(2.761)^4} \text{ decipol} \\ &= 1.93 \text{ decipol} \end{aligned}$$

For an existing building with no smokers, $G = 0.2$ olf/m^2. $C_o = 0.05$ decipol for clean suburban air. For 1 m^2 of office floor area

$$\begin{aligned} Q &= \frac{10 \times G}{C_i - C_o} \text{ l/s m}^2 \\ &= \frac{10 \times 0.2}{1.93 - 0.05} \text{ l/s m}^2 \\ &= 1.07 \text{ l/s m}^2 \end{aligned}$$

EXAMPLE 1.2

A new aerobics gymnasium is being designed for the basement of a commercial building in the City of Manchester. The room is to be 15 m long, 12 m wide and 3 m high. It has no exterior windows. There will be between 10 and 40 simultaneous users of the facility. There will not be any smoking and all the furnishings and building materials will have the low-pollution emission of 0.1 olf/m^2. At peak usage, all the occupants will be highly active. Calculate the outdoor air ventilation rate, from the Fanger method, that will be required so that 75% of the occupants will be satisfied. Recommend how the outdoor air ventilation system could be controlled for energy economy and comfort. Recommend an acceptable solution for the client.

(a) At full occupancy (40 people), to satisfy 75% of the occupants, 25% (10 people) are dissatisfied, so $PD = 25\%$.

$$C_i = \frac{112}{(5.98 - \ln 25)^4} \text{ decipol}$$
$$= 1.93 \text{ decipol}$$

The low-pollution building produces 0.1 olf/m^2.
At peak usage, there will be 40 people each producing 11 olf, from Table 1.1.

$$\text{gymnasium floor area} = 15 \text{ m} \times 12 \text{ m} = 180 \text{ m}^2$$

$$\text{pollution load } G = 0.1 \text{ olf/m}^2 + \frac{40 \text{ people} \times 11 \text{ olf/person}}{180 \text{ m}^2}$$
$$= 0.1 + 2.44 \text{ olf/m}^2$$
$$= 2.54 \text{ olf/m}^2$$

$C_o = 0.3$ decipol for vitiated city air that enters the basement from street level. For 1 m^2 of gymnasium floor area,

$$Q = \frac{10 \times G}{C_i - C_o} \text{ l/s m}^2$$
$$= \frac{10 \times 2.54}{1.93 - 0.3} \text{ l/s m}^2$$
$$= 15.6 \text{ l/s m}^2$$

For the whole gymnasium,

$$Q = 180 \text{ m}^2 \times 15.61 \text{ l/s m}^2$$
$$= 2808 \text{ l/s}$$

the room volume

$$V = 15 \text{ m} \times 12 \text{ m} \times 3 \text{ m}$$
$$= 540 \text{ m}^3$$

air change rate

$$N = 2808 \frac{\text{l}}{\text{s}} \times \frac{1 \text{ m}^3}{10^3 \text{ l}} \times \frac{1 \text{ air change}}{540 \text{ m}^3} \times \frac{3600 \text{ s}}{1 \text{ h}}$$
$$= \frac{2808 \times 3600}{10^3 \times 540} \text{ air changes/h}$$
$$= 18.7 \text{ air changes/h}$$

This is a high air change rate and will result in large heating and cooling costs during winter and summer if the thermal conditions are to remain within acceptable ranges for the activity. The number of room occupants who can be satisfied with the air quality will need to be reduced. Air quality, here, refers to maintaining a low enough level of odours so that the occupants are satisfied. Alternative solutions to supplying 100% outdoor air into the basement are available.

(b) When the gymnasium has 10 occupants with 75% satisfaction, 3 people are dissatisfied, so *PD* is 25%, C_i is 1.93 decipol, *G* is 0.71 olf/m^2 when C_o is 0.3 decipol, *Q* becomes 4.4 l/s m^2, 792 l/s for the whole room and *N* is 5.3 air change/h.

(c) The supply of outside air into the gymnasium is required to comply with the minimum of 10 l/s per person (CIBSE Guide A).

$$\text{Minimum outside air supply } Q_o = 40 \text{ people} \times \frac{10}{\text{person}}\ \frac{\text{l}}{\text{s}}$$

$$= 400 \text{ l/s}$$

$$\text{Air change rate } N = 400\ \frac{\text{l}}{\text{s}} \times \frac{1\ \text{m}^3}{10^3\ \text{l}} \times \frac{1 \text{ air change}}{540\ \text{m}^3} \times \frac{3600\ \text{s}}{1\ \text{h}}$$

$$= \frac{400 \times 3600}{10^3 \times 540} \text{ air changes/h}$$

$$= 2.7 \text{ air changes/h}$$

(d) The air change rates of outdoor air that are, apparently, needed to satisfy the Fanger odour air quality criteria vary from zero, when the gymnasium is unoccupied, to 5.3 per hour when 10 people use the gymnasium, to 18.7 per hour when 40 people use the room. The minimum required outdoor air supply is 400 l/s; this corresponds to a room air change rate of 2.7 per hour when 40 people are using the gymnasium. Mechanical ventilation will be needed owing to the location of the room. The design engineer will recommend a minimum energy use by recirculating the maximum amount of room air and minimizing the use of outdoor air to match the room occupancy. All the incoming outdoor air can be passed through a flat-plate heat exchanger to recover heat that is being discharged to the atmosphere through the exhaust air duct, if this is possible for the duct installation. When the room is unoccupied, the outside air supply can be closed with a motorized damper. The number of occupants in the gymnasium can be detected from a carbon dioxide sensor in the extract air duct, which can be used to control the opening of the outside air motorized damper as well as the supply air and return air fan speeds. The varying air flow rates can be provided with a system of supply-and-extract air fans that have variable performance. Each fan can have a variable-speed electric motor which has its supply frequency controlled between 0 and 50 Hz from an inverter drive. The outdoor air that is supplied into the gymnasium can be heated to around 16°C in winter and cooled to 20°C in summer, for thermal comfort. When lower than the Fanger-recommended outside air intake quantities are used, that will normally be always, the odour air quality can be improved by passing the return air through an activated carbon filter or by injecting a deodorant spray into the supply air duct. Whichever alternative is selected, the energy-conscious design engineer will minimize the use of outside air to ventilate the room. Those using the gymnasium are fairly unlikely to find the presence of some body odour totally unacceptable. Significant energy savings will be achieved by the use of carbon dioxide sensing of the occupants in a gymnasium that is used intermittently each day. The outside air damper will remain closed whenever the room is unoccupied and it will only open in response to the actual occupancy level.

Table 1.2 Comparison of ventilation rates for offices.

Data source	*Ventilation rate*	
	(l/s m²)	*(l/s per person)*
Fanger equation	5	50
ASHRAE	0.7	7
BS5925	1.3	13
DIN 1946	1.9	19
CIBSE, office	1.3	10

Awbi (1991, p. 31) shows a comparison between the current standards for ventilation with outdoor air. They are based upon one person for each 10 m^2 of office floor area, the standard person and activity plus some smoking. To these, recommendations (CIBSE Guide A) have been added, as shown in Table 1.2. The general recommendation is 10 l/s per person. Where less is attempted, measurement of return air CO_2 content may be applied to ensure adequate air quality.

Other applications are taken on their merits: for example, toilets 5 air changes/h, bathrooms 15 l/s and kitchen 60 l/s in dwellings (CIBSE Guide A). The designer needs to evaluate all the aspects of the need for outdoor air ventilation. These include the heating and cooling plant loads that will be generated, the potential for energy recovery between the incoming fresh air and outgoing air at room temperature, avoidance of draughts in the occupied rooms, the variation of load with the occupancy level and the ability to utilize outdoor air to provide free cooling to the building when the outdoor air is between 10°C and 20°C (Chadderton, 1997a, p. 5).

Comfort equation

The fundamental purpose of heating or cooling an occupied space is to maintain constant body temperature. Regulation of personal comfort is achieved by clothing choice, and a successful building can be said to be one where 5% or less of its occupants complain. Definitive work was done by Fanger (1972) to produce a complete mathematical statement of the heat transfer between the body and its surroundings, and then to conduct subjective tests and produce guidelines for building and engineering designers. Fanger's comfort equation is of the form

$$f(H, clo, v, t_r, t_a, p_s) = 0$$

that is, a balance, where f represents a mathematical function connecting all the variables contained in the brackets, H is the internal heat production in the human body, clo is the thermal insulation value of clothing, v is the air velocity, t_r is the mean radiant temperature, t_a is the air temperature and p_s the atmospheric vapour pressure.

The energy released per unit time in the human body by oxidation processes is known as the metabolic rate M. Some of this can be converted into useful mechanical work W, so that

$$M = H + W$$

The mechanical efficiency of the body is given by

$$\frac{W}{M} \times 100\%$$

and this varies from zero while reading this book to a maximum of 20% during heavy physical work.

Internal heat production H varies from 35 W/m^2 (watts per square metre of body surface) while sleeping to 440 W/m^2 during maximum exertion. The thermal insulation value of clothing is expressed in *clo* units. One *clo* unit is equal to the total thermal resistance from the skin to the outer surface divided by 0.18. It is worth noting that 1 *tog* = 0.645 *clo*. Values of *clo* vary from zero when nude through 1 when wearing a normal business suit to 4 for a polar suit.

Moving-air velocity in normally occupied rooms will be between 0 and 2 m/s (metres per second), where the upper figure relates to a significantly uncomfortable hot or cold draught. Still air conditions are most unlikely to occur, as convection currents from people and warmed surfaces will promote some circulation. Room air movement patterns should be variable rather than monotonous, and ventilation of every part of the space is most important.

The mean radiant temperature is a measure of radiation heat transfers taking place between various surfaces and has an important bearing on thermal comfort. Heat transfer Q_r by radiation from a warm emitting surface to a receiving plane is given by

$$Q_r = \frac{5.67}{10^8} A_1 F_1 E_1 E_2 (T_1^4 - T_2^4) \text{ W}$$

where E_1 and E_2 are surface emissivities, which range from 0.04 for polished aluminium to 0.96 for matt black paint, and T_1 and T_2 are the absolute temperatures of the emitting and receiving surfaces in Kelvin (°C + 273). F_1 is the configuration factor denoting the orientation of and distance between the two surfaces. Flat parallel surfaces are evaluated using

$$A_1 F_1 = \frac{A_1 A_2}{\pi l^2}$$

where A_1 and A_2 are the surface areas (m^2) and l is the distance between the surfaces (m). This only fits the simplest cases, such as radiation across the cavity in a wall. Other real problems become geometrically rigorous and complex.

EXAMPLE 1.3

A hot-water central heating system has a ceiling-mounted radiant panel of surface area 8.0 m^2 and a surface temperature of 70°C. It faces a person 1.1 m away whose upward projected body surface area and temperature are 0.3 m^2 and 21°C respectively. The surface emissivities of the radiator and the person are 0.85 and 0.90 respectively. Calculate the radiant heat transfer.

$$A_1 F_1 = \frac{8.0 \text{ m}^2 \times 0.3 \text{ m}^2}{\pi (1.1^2 \text{ m}^2)} = 0.63 \text{ m}^2$$

$$T_1 = (273 + 70)\text{K} = 343 \text{ K}$$

$$T_2 = (273 + 21)\text{K} = 294 \text{ K}$$

$$Q_r = \frac{5.67}{10^8} \times 0.63 \times 0.85 \times 0.90 \times (343^4 - 294^4)\text{W}$$

$$= 174 \text{ W}$$

Because of the complexity of such calculations for a heated room, an approximation to the mean radiant temperature t_r is often made that estimates its value for the geometric centre of the room volume:

$$t_r \cong t_m = \frac{A_1 t_{s1} + A_2 t_{s2} + \cdots + A_n t_{sn}}{A_1 + A_2 + \cdots + A_n}$$

Thus t_m is seen to be the average room surface temperature weighted in proportion to the surface area, room geometry and point of measurement; n is the number of surfaces.

EXAMPLE 1.4

A room is heated with under floor low-temperature hot-water pipework and the winter data shown in Table 1.3 were found during site measurements.

Table 1.3 Data for Example 1.4.

Surface	*Area (m^2)*	*Average surface temperature (°C)*
Window	12	2
Outside wall	24	12
Inner walls	30	16
Ceiling	22	24
Floor	22	30

Estimate the mean radiant temperature of the room at the centre of its volume.

$\sum A$ and $\sum At_s$ are calculated as shown in Table 1.4. Then

$$\begin{aligned} t_m &\cong \frac{\sum(At_s)}{\sum A} \\ &= \frac{1980}{110} \\ &= 18°\text{C} \end{aligned}$$

Air temperature t_a is that recorded by a mercury-in-glass dry-bulb thermometer freely exposed to the air stream; thermometer is usually in a sling psychrometer.

Table 1.4 Calculations for Example 1.4.

Surface	*Area A (m^2)*	*t_s (°C)*	*At_s*
Window	12	2	24
Outside wall	24	12	288
Inner walls	30	16	480
Ceiling	22	24	528
Floor	22	30	660
	$\sum A = 110$		$\sum(At_s) = 1980$

Atmospheric vapour pressure *p* is that part of the barometric pressure produced by the water vapour in humid air. Standard atmospheric pressure at sea level is 1013.25 mb (millibars) and this comprises about 993.0 mb from the weight of dry gases and 20.25 mb from the water vapour, depending on the values of barometric pressure, air temperature and humidity.

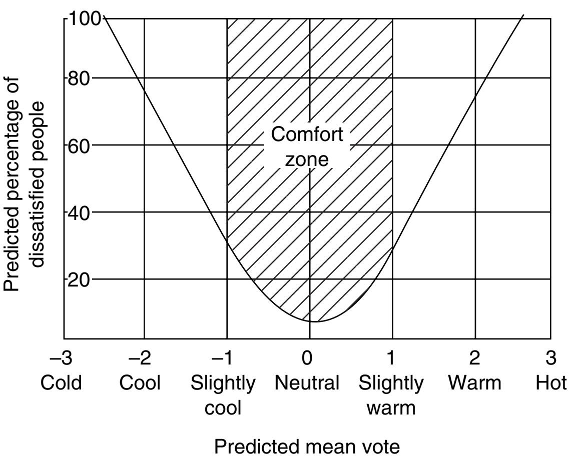
The comfort equation balances to zero when heat transfers between the body and surroundings are stable. This is the thermally neutral condition when there are no feelings of discomfort. It is unlikely to be satisfied for a group of people, and a comfort zone is used to specify the range of acceptable levels for the majority.

Comfort measurement

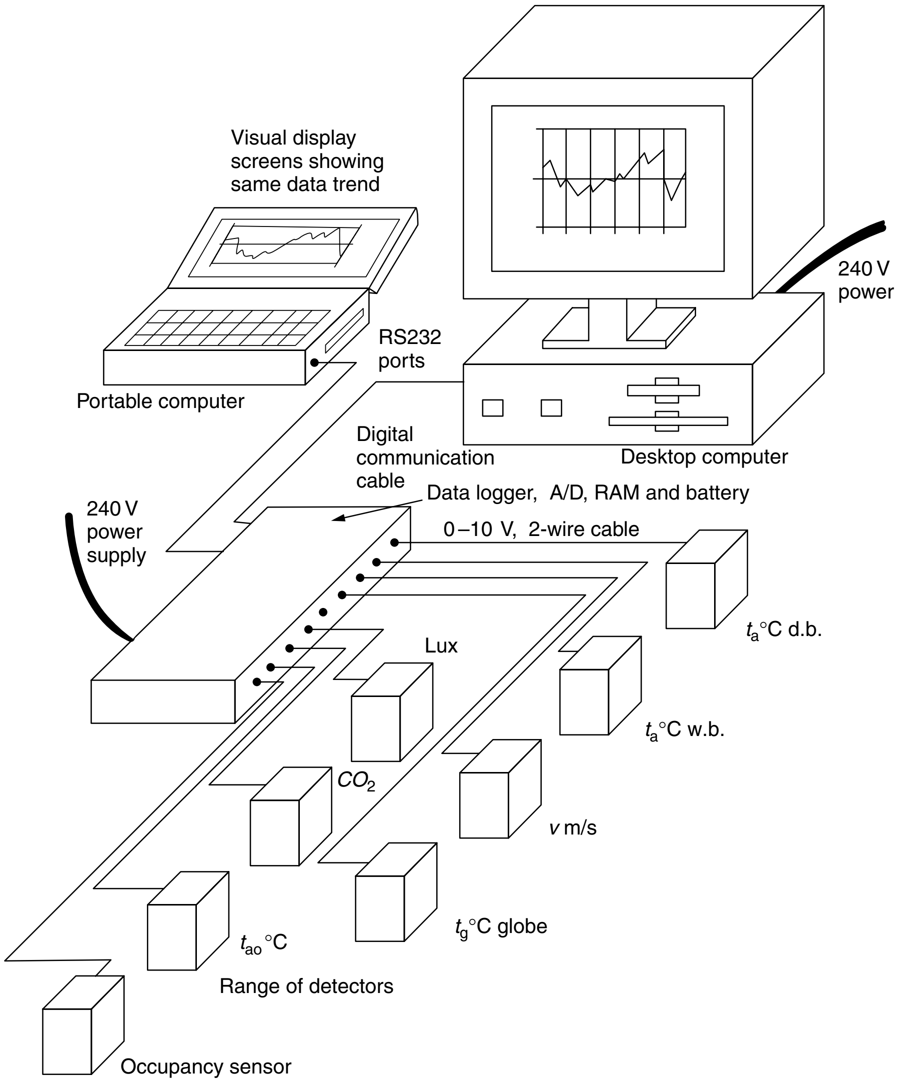
Figure 1.1 shows the percentage of people dissatisfied (*PPD*) and predicted mean vote (*PMV*) that are used for the assessment of indoor thermal environments, from Fanger. The chart demonstrates that dissatisfaction among less than one-third of the occupants is achieved in indoor environments within the slightly cool to slightly warm categories. Personal variation in clothing, sedentary position and control over the microclimate being the final control mechanism.

A thermal comfort analogue computer may be used to make this assessment with an ellipsoidal-shaped sensor that is around the size of a straight banana. This shape has the same mathematical relationship between its heat loss by radiation and convection as the human body.

To obtain values of temperature, velocity, carbon dioxide and humidity in the atmosphere, each is measured separately as 0–10 V or 0–20 mA analogue signals, converted into digital bytes with an analogue-to-digital converter and then stored in a data logger in random access memory. Numerous readings are easily retained in memory for later access through a desktop or portable computer. Lists of data numbers and their time of occurrence can be stored on hard and floppy disks for processing with dedicated software or any spreadsheet program. Graphical output can show the history of the recorded temperature, or other variable, during a period of time. Such graphs are termed trends. The software can be programmed to take readings at, say, intervals of 2 s or longer, or only whenever a significant change takes place. Figure 1.2 shows the schematic arrangement of a data-logging system with a trend display of room air temperature. Figure 1.3 is a photograph of a portable data-logging cart created to assess existing building conditions.



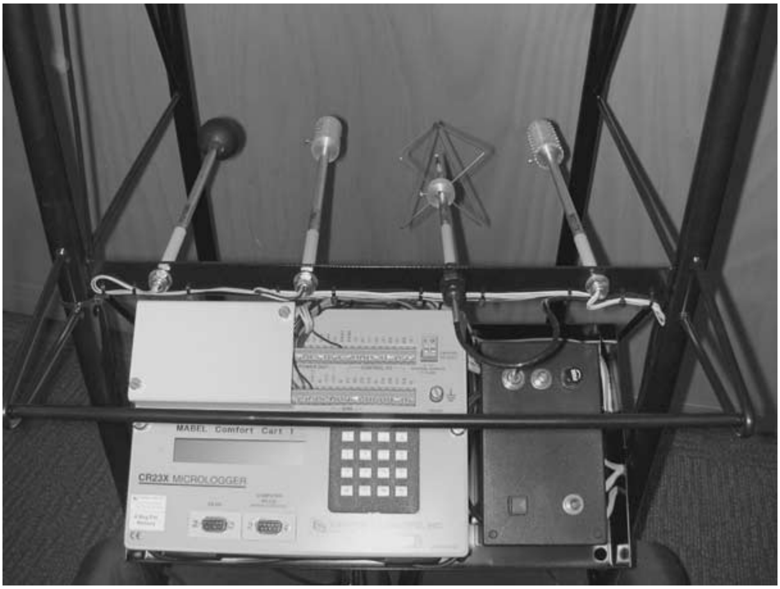
1.1 *PPD* versus *PMV*.



1.2 Multi-channel data logger linked to desktop and portable computers.

The sensors, from left to right, are globe temperature, relative humidity, air velocity and air dry-bulb temperature.

Research results indicate that nationality, geographic origin, location, age, sex and body build have no significant effect on basic comfort requirements. The achievement of acceptable comfort levels for the variety of activities that are conducted in offices, factories, schools, hospitals and homes can be very expensive in terms of building and services construction and energy costs. In practice, compromise solutions are made that satisfy most requirements for the majority of the occupants.



1.3 Thermal comfort data logger (reproduced by courtesy of Mobile Architecture and Built Environment Laboratory, Deakin University, Geelong).

External environments

Extremes of external climate are mainly of concern to construction workers in severe environments. There are two main indices: wind chill index (*WCI*) and heat stress index (*HSI*). Wind chill index measures the cooling effect on the body of a moving air stream, given by:

$$WCI = (10.45 + 10\sqrt{v} - v)(33 - t_a)$$

Wind speed v is in metres per second; the equation can be used for values of up to 22.0 m/s (79 km/h (kilometres per hour)). Frostbite should be avoided if the wind chill index is less than 1400 at an air temperature of −10.0°C d.b. during a maximum exposure of 30 min. A convenient use of the wind chill index is to calculate the equivalent wind chill temperature (*EWCT*), which is the air temperature, calculated from measured data, that would provide the same chilling effect but at an air velocity of 1.78 m/s (6.4 km/h):

$$EWCT = (-0.045WCI + 33)°\text{C}$$

EXAMPLE 1.5

A winter day in northern England has an outdoor air velocity measured as 25.2 km/h (7 m/s) and the sling psychrometer air temperature showed −2.5°C d.b. Find the wind chill index and the equivalent wind chill temperature.

$$v = 7 \text{ m/s} \quad t_a = -2.5°\text{C}$$

$$WCI = (10.45 + 10\sqrt{7} - 7)[33 - (-2.5)]$$

$$WCI = 1061.7$$

$$EWCT = (-0.045 \times 1061.7 + 33)°\text{C}$$

$$EWCT = -14.8°\text{C}$$

Construction workers in hot climates are exposed to heat hazards, and severe cases will lead to an inevitable increase in body temperature. This is the zone of unacceptable body heating. In its attempt to dissipate the metabolic heat produced, which cannot be transferred to the high-temperature environment, the body raises its temperature to compensate. The symptoms are fatigue, headache, dizziness, vomiting, irritability, fainting and failure of normal blood circulation to cope with the problem. Heat exhaustion of this sort can normally be counteracted by removal to a cool place. Cramp may occur as a result of loss of some body salts. Salt tablets can be taken to redress the balance. Heatstroke occurs if the body temperature rises to 40.6°C (normal body temperature is 36.9°C), and in this condition sweating ceases, the body enters a comatose state, brain damage can occur and death is imminent.

The heat stress index is a measure of the maximum elevation of sweat rate, body temperature and heart rate that can be tolerated (Belding and Hatch, 1955):

$$HSI = \frac{E_{req}}{E_{max}} \times 100 \quad \text{(this is a ratio and not a percentage)}$$

where $E_{req} = M - Q_r - Q_c$ is the required evaporative cooling, $Q_r = 4.4(35 - t_r)$ is the heat lost from the clothed body by radiation, $Q_c = 4.6\, v^{0.60}(35 - t_a)$ is the heat lost from the clothed body by convection and $E_{max} = 7.6\, v^{0.60}(56 - p_a)$ is the maximum available evaporative cooling.

The numerical value of the heat stress index can be related to practical circumstances as shown in Table 1.5. The allowed exposure time (*AET*) is given by

$$AET = \frac{2440}{E_{req} - E_{max}} \text{ min}$$

When the heat stress index is less than 100.0, the exposure time is unrestricted. The heat stress index reduces and the allowed exposure time increases when a prevailing wind or fans produce extra cooling.

Table 1.5 Evaluation of heat stress index.

Heat stress index	*Response to 8-h exposure*
−20	Mild cold strain
0	Neutral
10–30	Mild strain
40–60	Unsuitable for mental effort
70–90	Selected personnel
100	Maximum possible for a fit acclimatized young man

EXAMPLE 1.6

A construction worker is exposed to conditions of 38°C d.b. and 24% saturation in the shade in city centre Melbourne. Metabolic rate is 320 W/m^2 while lifting and placing structural formwork. Local air movement is 0.25 m/s. Find the heat stress index and the allowed exposure time. Assume that $t_r = t_a$. The atmospheric vapour pressure p_a is 16.74 mb.

$$E_{req} = 320 - 4.4(35 - 38) - 4.6 \times 0.25^{0.60}(35 - 38)$$
$$= 339.2 \text{ W/m}^2$$
$$E_{max} = 7.6 \times 0.25^{0.60}(56 - 16.74)$$
$$= 129.9 \text{ W/m}^2$$
$$HSI = \frac{339.2}{129.9} \times 100$$
$$= 261.1$$
$$AET = \frac{2440}{339.2 - 129.9} \text{ min}$$
$$= 11.7 \text{ min}$$

By providing increased air movement around the construction worker with a portable fan, an elevation of v to 1.5 m/s would reduce the heat stress index to below 100 and make exposure time unrestricted.

Environmental measurements

Measurement of air temperature and humidity is accurately made by using both dry- and wet-bulb mercury-in-glass thermometers in a sling psychrometer, otherwise called whirling hygrometer, Figure 1.4. The dry-bulb thermometer defines the air temperature t_a°C d.b. and evaporation of water from the cotton wick cools the wet-bulb thermometer; its reading is known as the wet-bulb temperature t_a°C w.b. The difference between dry- and wet-bulb temperatures is the wet-bulb depression. Temperatures are sometimes symbolized by θ (theta) (CIBSE Guide A).

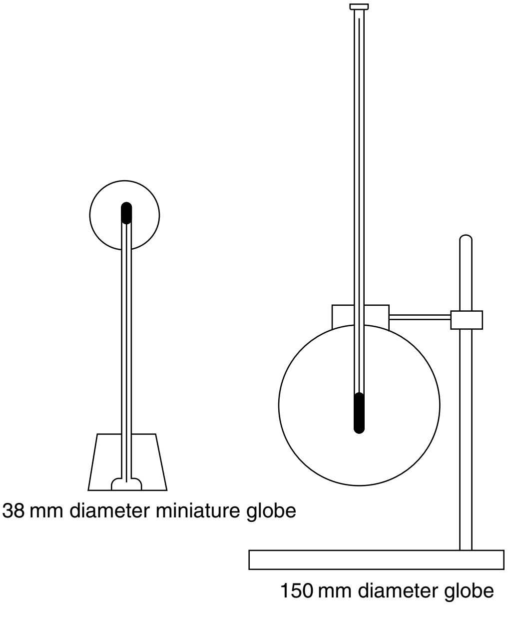
In order to find the mean radiant temperature t_r, the dry-bulb temperature t_a and the air velocity v in m/s are measured, and the empirical relationship

$$t_r = t_g(1 + 2.35\sqrt{v}) - 2.35 t_a \sqrt{v}$$

where t_g is the globe temperature, is used. The globe temperature is measured at the centre of a blackened globe of diameter 150 mm suspended at the measurement location. Figure 1.5 shows the large and small globe thermometers used. The resultant temperature, found using a globe of diameter 100 mm, can be used, and t_r can be calculated by replacing 2.35 with 3.17 in the previous formula.

Wet-bulb globe temperature, *WBGT*, is used for assessment of warm humid environments for health and safety at work conditions. It is found from air wet-bulb t_a°C w.b., globe t_g°C and air dry-bulb t_a°C d.b. in weighted amounts to give greater emphasis to humidity. It is humidity that causes significant heat stress, while hot dry air flow is efficient at removing bodily heat

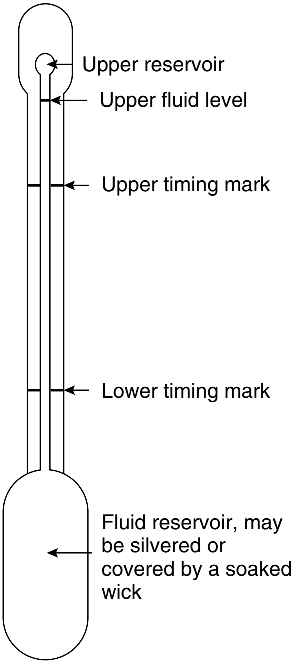
1.4 Sling psychrometer or whirling hygrometer (reproduced by courtesy of Casella CEL Ltd).



1.5 Large and small globe thermometers.

production. When local air temperature approaches core body temperature, the sole remaining mechanism for bodily heat removal is evaporation from breath and skin; that is, when there is no handy swimming pool.

$$WBGT = 0.7t_a°\text{C w.b.} + 0.2t_g°\text{C} + 0.1t_a°\text{C d.b.}$$

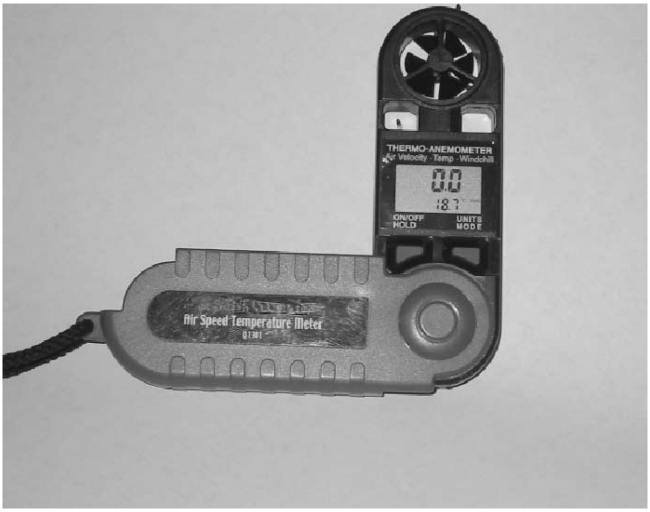


1.6 Kata thermometer.

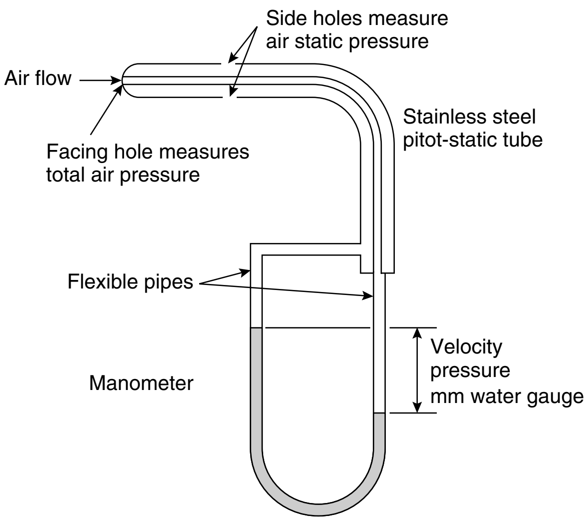
The Kata thermometer shown in Fig. 1.6 is used to measure the cooling power of room air movements and air velocity. The thermometer is heated by immersing the large bulb in hot water until the alcohol enters the upper reservoir. The bulb is dried, and the Kata thermometer is suspended at the location being investigated. The time taken for the meniscus to fall between the two marks on the stem is noted, the operation is repeated twice and the average time of cooling is found. A Kata factor, which is the amount of heat lost from the bulb surface during cooling (typically 475 mcal/cm^2 of bulb surface as the thermometer cools through 2.8°C), is inscribed on the stem. The cooling power is defined as the Kata factor divided by the average cooling time in seconds. A cooling power of around 10 is suitable for sedentary occupation. Wet-bulb Kata readings can also be taken, and these include humidity effects. A nomogram or formula can be used to find the air velocity at that location.

Direct-reading air velocity measuring instruments are shown in Figs. 1.7 and 1.8. Rotating vane anemometers are used to measure airstreams through ventilation grilles, where the rotational speed of the blades is magnetically counted. Thermistor and hot-wire anemometers utilize the air stream cooling effect on the probe; the latter type is mainly used for research work. Duct air flow rates are found by inserting a pitot-static tube into the airway, taking up to 48 velocity readings at locations specified in BS 848: Part 1: 1980 and evaluating the air volume flow rate from the average air velocity found from all the readings.

The term for air humidity is percentage saturation, and the most reliable method of measurement is to take dry- and wet-bulb air temperature readings using a sling psychrometer and referring to a psychrometric chart (Chapter 5). Hair hygrometers can be used to display percentage saturation. A combined clockwork-driven thermohygrograph can be used to monitor air dry-bulb and humidity room conditions over a period of days, but electronic data loggers are currently preferred. Permanent monitoring and control requires an electronic sensor utilizing a



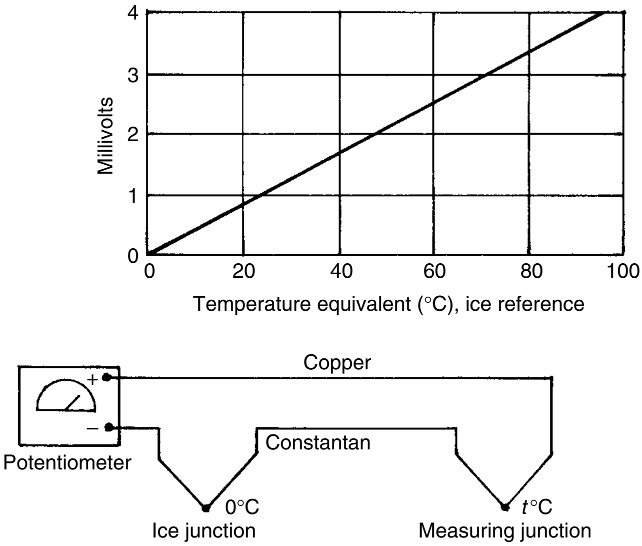
1.7 Thermistor anemometer.



1.8 Pitot-static tube and U-tube manometer.

hygroscopic salt covering a coil of wire. The output signal from this unit depends on the amount of moisture absorbed by the sensor.

Thermocouple temperature-sensing enables supervision of large numbers of locations by manual or automatic scanning. Inaccessible areas can be reached by installing thermocouple wires during construction or by drilling. Figure 1.9 shows the basic construction of a copper–constantan thermocouple circuit. The small electrical voltages caused between the junctions of dissimilar metals at different temperatures produce an electron flow, and thus the potential difference between the wires can be measured and calibrated into temperature. Surface temperature measurements can be made using portable instruments to check the integrity of thermal insulation (Chapter 3) or in experimental investigations into the thermal transmittance of building components using multi-channel recording systems.



1.9 Basic thermocouple circuit and calibration graph.

Non-touch temperature sensors receive infrared heat radiation emitted from all surfaces that are above absolute zero, and they are calibrated to give the surface temperature. Small areas can be surveyed with portable gun instruments and large scans can be performed by mobile television camera equipment, which produces temperature contour maps. Ground-level or aerial surveys are used to detect energy waste from non-existent, inadequate or damaged thermal insulation in homes, in factories or where there are buried pipes in district heating systems.

Environmental temperature

Heat losses from buildings and the conditions required for thermal comfort both depend on the mean radiant temperature and the air temperature. The environmental temperature t_{ei} combines these two measures:

$$t_{ei} = 0.667t_r + 0.333t_{ai}$$

EXAMPLE 1.7

An open-plan office is designed for sedentary occupation and is to have general air movement not exceeding 0.25 m/s and an air temperature of 22°C d.b., in winter. It is expected that a globe temperature of 20°C would be found at the centre of the room volume. What would be the mean radiant, resultant and environmental temperatures?

$$\begin{aligned} t_r &= t_g(1 + 2.35\sqrt{v}) - 2.35t_a\sqrt{v} \\ &= 20(1 + 2.35 \times \sqrt{0.25}) - 2.35 \times 22 \times \sqrt{0.25} \\ &= 17.6°\text{C} \end{aligned}$$

$$t_{res} = t_g(1 + 3.17\sqrt{v}) - 3.17t_a\sqrt{v}$$
$$= 20(1 + 3.17 \times \sqrt{0.25}) - 3.17 \times 22 \times \sqrt{0.25}$$
$$= 16.8°C$$
$$t_{ei} = 0.667t_r + 0.333t_{ai}$$
$$= 0.667 \times 17.6 + 0.333 \times 22$$
$$= 19.1°C$$

Operative temperature

Operative temperature, t_c, is that recorded in the centre of a 40 mm diameter blackened globe freely exposed to room air. Sufficient time is needed for stabilization of the radiant and convective heat transfers to take place with the thermometer, thermocouple or thermistor temperature sensor in the globe. When taking readings, realize that room conditions may be varying due to movement of people, solar heat gains, air movement or the room temperature control system. During normal room conditions of low air velocity and where mean radiant and air temperatures are very close, operative, air dry-bulb and dry resultant temperatures, t_{res}, are substantially equal. Well-insulated modern buildings having small areas of glazing have the effect of raising room mean radiant temperature close to the air dry bulb. Dry resultant temperature is the temperature recorded by a thermometer at the centre of a 100 mm diameter blackened globe. Operative temperature is now recommended for use as that specified for comfort conditions in the internal environment. Comfortable values range from 21°C for a residential living room through 18°C for a bedroom or lecture room to 16°C in passageways. It is related to the mean radiant, air and resultant temperatures and the air velocity v m/s by:

$$t_c = t_{res} = \frac{t_r + t_{ai}\sqrt{10v}}{1 + \sqrt{10v}}$$

In normally occupied rooms the air temperature and the mean radiant temperature should be within a few degrees of each other. The air velocity within a habitable space should be barely discernible, in the region of 0.1 m/s. Under these conditions the dry resultant temperature at the centre of the room is

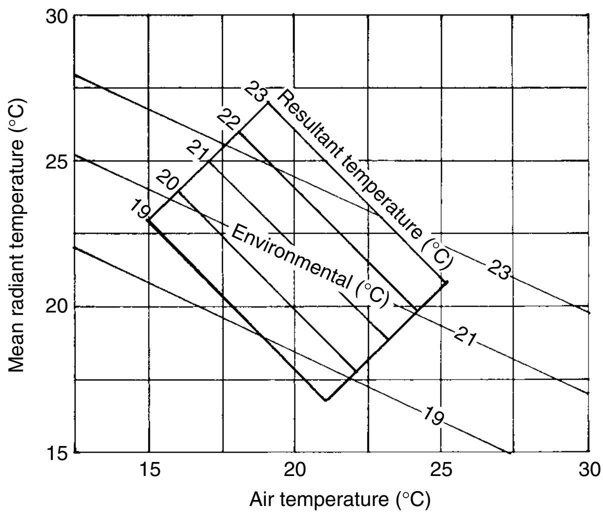
$$t_c = t_{res} = 0.5t_{ai} + 0.5t_m$$

There should be no significant effect upon comfort conditions when t_c is within 1.5°C of its design value; this allows for some flexibility in the actual value of the mean radiant and air temperatures and the air velocity due to the occupants changing position within the room, or to weather variations.

Comfort criteria

The main comfort criteria for sedentary occupants in buildings in climates similar to that of the British Isles are as follows.

1. Operative temperature should be in the range 19–23°C depending on room use.
2. A feeling of freshness is produced when the mean radiant temperature is slightly above air temperature. A significant amount of radiant heating is needed in order to achieve this.



1.10 Sedentary comfort zone.

3. Air temperature and the mean radiant temperature should be approximately the same. Large differences cause either radiant overheating or excessive heat loss from the body to the environment, as would be experienced during occupation of a glasshouse through seasonal variations.
4. Percentage saturation should be in the range 40–70%.
5. Maximum air velocity at the neck should be 0.1 m/s for a moving-air temperature of 20°C d.b. Both hot and cold draughts are to be avoided. Data are available for other temperature and velocity combinations.
6. Variable air velocity and direction are preferable to unchanging values of these variables. This is achieved by changes in natural ventilation from prevailing wind, movement of people around the building, on–off or high–low thermostatic operation of fan-assisted heaters or variable-volume air-conditioning systems.
7. The minimum quantity of fresh air for room use that will remove probable contamination is 10 l/s per person.
8. Mechanical ventilation systems should provide at least 4 air changes/h to avoid stagnant pockets and ensure good air circulation.
9. Incoming fresh air can be filtered to maintain a clean dust-free internal environment.
10. The difference between room air temperatures at head and foot levels should be no more than 1°C.
11. Ventilation air quantity can be determined by some other controlling parameter: for example, removal of smoke, fumes or dust, solar or other heat gains and dilution of noxious fumes.

Figure 1.10 shows a comfort zone, and it can be seen that the data for the previous example produce an acceptable office environment.

Experimental work

Various measurements of the thermal environment can be made using relatively simple equipment, and some suggestions for practical projects are listed here. It is most important to take great care with observation of the conditions being measured. Record all the relevant details: time of day, date, external weather, temperatures, air speeds, solar radiation, number of people, clothing, activity level, heating and cooling room terminal units and outlets and, most important of all, where the data measurements are being taken. Take digital photographs of the measuring instruments and everything done, if the occupants allow; permission is very important. Do not take all the readings near a draughty window and then claim that the results show average room conditions.

1. Effects of room air temperature gradients on comfort: measure floor-to-ceiling air temperature gradients with a multi-channel thermocouple probe and discuss their effects on the comfort conditions encountered.
2. Room air velocity distribution: produce velocity contours for different parts of the room and compare with observed comfort conditions.
3. Measure the Kata cooling power and air velocity, the globe temperature and the dry-bulb air temperature. Compute the other temperature scales and compare with subjective assessments of the conditions.
4. Make and test a thermocouple temperature-measuring circuit with copper–constantan wire and an accurate potentiometer. Build junctions into walls and building structures, plot their temperature profiles and calculate their thermal transmittances.

Questions

Descriptive answers must be made in your own words based on a thorough understanding of the subject. Copied work displays a noticeable discontinuity of style between your own production and the reference material. Also, the work has not been fully comprehended if it can only be answered by copying. The ability to pass on reliable and concise information is a vitally important part of business and government work, and you should realize that as much practice and experience as possible is needed to become an effective communicator.

1. List and discuss the factors affecting thermal comfort.
2. List the factors involved in making buildings work in terms of sustainability.
3. Define sustainability in relation to the construction and use of habitable buildings.
4. Write notes on what you understand by the word sustainability for building services engineers and users of services installations.
5. Discuss the following statement: ‘a building acts as an environmental filter’.
6. State how extremes of heat and cold affect the workers on a site, what environmental measurements can be taken, and the corrective actions possible to ensure safe and healthy working conditions.
7. Describe how an investigation into the thermal comfort provided in a building can be measured. State which instruments would be used and give reasons.
8. Describe with the aid of sketches how each of the following instruments functions: dry-bulb thermometer, wet-bulb thermometer, globe thermometer, Kata thermometer, vane anemometer, thermocouple and infrared scanner.
9. Describe how heating, cooling and humidity control systems interact with the building to provide a comfortable environment.
10. A survey of a heated room revealed the information given in Table 1.6. The dry-bulb air temperature is 19°C. Estimate the mean radiant and environmental temperatures and assess the thermal comfort conditions for sedentary occupation. State any remedial measures that may need to be taken.

Table 1.6 Data for Question 10.

Surface	*Area (m^2)*	*Average surface temperature (°C)*
Window	7	0
Outside	20	10
Inner wall	28	17
Ceiling	30	23
Floor	30	12

11. A hot-water central heating system has a radiator of surface area 4.5 m^2 and a surface temperature of 76°C. It faces a person 2.25 m away whose body surface area and temperature are 1 m^2 and 21°C respectively. The surface emissivities of the radiator and the person are 0.85 and 0.90 respectively. Calculate the radiant heat transfer.
12. A radiant panel at high level in an industrial facility has a surface area of 20.0 m^2 and an average surface temperature of 165°C. It faces a steel work bench 3.2 m directly below whose surface area and temperature are 8 m^2 and 26°C respectively. The surface emissivities of the radiator and the bench are 0.85 and 0.90 respectively. Calculate the radiant heat transfer. What danger may be produced?
13. A gas-fired radiant tube overhead heating system has a surface area 20.0 m^2 and a surface temperature of 225°C. Workers are 3.5 m below. Each person has an upward projected surface area and temperature of 0.25 m^2 and 25°C respectively. The surface emissivities of the radiant tube and the person are 0.90. Calculate the radiant heat transfer.
14. A room is heated with a hot-water panel radiator and the data shown in Table 1.7 were found during site measurements. Estimate the mean radiant temperature of the room at the centre of its volume.

Table 1.7 Data for Question 14.

Surface	*Average surface temperature (°C)*	*Area (m^2)*
Window	8	8
Radiator	70	4
Outside wall	12	20
Inner walls	17	24
Ceiling	24	20
Floor	11	20

15. A refrigerated food cold room is maintained at –4°C with ammonia refrigerant fan coil units. Site measurements found the data given in Table 1.8. Estimate the mean radiant temperature of the room at the centre of its volume.

Table 1.8 Data for Question 15.

Surface	*Average surface temperature (°C)*	*Area (m^2)*
Doors	5	10
Walls	−1	310
Ceiling	3	450
Floor	2	400

16. An hotel lounge remains at 24°C with air conditioning. Measurements found the data given in Table 1.9. Estimate the mean radiant temperature of the room at the centre of its volume.

Table 1.9 Data for Question 16.

Surface	*Average surface temperature (°C)*	*Area (m^2)*
Window	12	20
Outside wall	14	90
Inner walls	18	110
Ceiling	26	150
Floor	12	150

17. A building site in Manchester was exposed to a wind velocity measured at 5.2 m/s and the sling psychrometer air temperature showed –2°C d.b. Find the wind chill index and the equivalent wind chill temperature.
18. An exposed hill top has the air velocity measured at 15 km/h, 4.2 m/s and the sling psychrometer air temperature showed −1.5°C d.b. Find the wind chill index and the equivalent wind chill temperature.
19. An underground tunnel has an air velocity of 45 km/h (12.5 m/s) during full traffic flow in a European city in winter. The sling psychrometer air temperature showed −1.2°C d.b. Find the wind chill index and the equivalent wind chill temperature.
20. Compare the wind chill index and the equivalent wind chill temperature on two sites operated by workers wearing similar clothes.
    Site A: air velocity, 5 m/s; air temperature, 2.0°C d.b.
    Site B: air velocity, 0.6 m/s; air temperature, −10°C d.b.
21. A scaffold erector works in air at −5°C d.b. and 20% saturation with a metabolic rate of 300 W/m^2. The wind velocity gusts up to 2.5 m/s. Given that the atmospheric vapour pressure is 0.8 mb, calculate the heat stress index produced. Assume that $t_r = t_a$.
22. Site work is being conducted in bright sunshine when the air peaks at 35°C d.b. and 20% saturation at 3 p.m. A worker's metabolic rate is 280 W/m^2. Atmospheric vapour pressure is 12 mb and the air speed is 0.8 m/s. Calculate the heat stress index produced and comment on the conditions. Assume that $t_r = t_a$.
23. A construction surveyor is exposed to conditions of 35°C d.b., 22°C w.b. and 22% saturation in the sunshine in the Middle East. His metabolic rate is 300 W/m^2 while moving and using instruments. Local air movement is 0.2 m/s. Find the heat stress index and the allowed exposure time. Assume that $t_r = t_a$. Atmospheric vapour pressure p_a is 17.56 mb.
24. An air-conditioning unit maintenance technician works on roof-mounted fan coil units in a hot climate. Outside air conditions are 40°C d.b., 25.7°C w.b. and 30% saturation in the sunshine. His metabolic rate is 340 W/m^2 while working and climbing external ladders. Local air movement is 15 km/h (4.2 m/s). Find the heat stress index and the allowed exposure time. Assume that $t_r = t_a$. Atmospheric vapour pressure p_a is 23.3 mb.
25. An air-conditioning ductwork technician works indoors on a building site in a hot humid climate. There is no local cooling or mechanical ventilation available during construction work. Outside air conditions are 36°C d.b., 31.2°C w.b. and 70% saturation. Indoor conditions are about the same as outdoor air as walls are incomplete. His metabolic rate is 360 W/m^2 while working out of the sunshine. Local air movement is 0.3 m/s. Find the

heat stress index and the allowed exposure time. Assume that $t_r = t_a$. Atmospheric vapour pressure p_a is 42.34 mb.

26. Measurements in an office showed that the general air movement amounted to 0.25 m/s at a temperature of 23°C d.b. The globe temperature was 19°C. Calculate the mean radiant and environmental temperatures, and discover whether room conditions are within the comfort zone.
27. An open-plan office is designed for sedentary occupation and is to have general air movement not exceeding 0.2 m/s and an air temperature of 22°C d.b., in winter. It is expected that a globe temperature of 20°C would be found at the centre of the room volume. What would be the mean radiant, resultant, environmental and operative temperatures?
28. A lecture theatre is designed for sedentary occupation and is to have general air movement not exceeding 0.5 m/s and an air temperature of 21°C d.b., in winter. It is expected that a globe temperature of 18°C would be found at the centre of the room volume. What would be the mean radiant, resultant, environmental and operative temperatures?
29. A conference room is designed for sedentary occupation and is to have general air movement not exceeding 0.35 m/s and an air temperature of 24°C d.b., in summer. It is expected that a globe temperature of 21°C would be found at the centre of the room volume. What would be the mean radiant, resultant, environmental and operative temperatures?
30. List the temperatures used to describe comfort conditions and explain how they are relevant for room users.
31. Survey the factors affecting thermal comfort and explain what they mean.
32. Explain how a building filters the external climate.
33. Explain the meaning of the terms olf and decipol and state how they are used in the design of ventilation systems.
34. Which of these is where indoor odours, vapours and gases come from? More than one correct answer.

    1. The air-conditioning systems.
    2. Ingress from outdoor environment.
    3. The basement car park of the building.
    4. Humans, animals, plants and furnishings within the building.
    5. Dust, pollen and materials in waste paper bins.

35. Which of these is where indoor odours, vapours and gases come from? More than one correct answer.

    1. Cleaning fluids used overnight.
    2. New furniture, carpets, floor coverings, sealants and adhesives.
    3. Old furniture, carpets and floor coverings.
    4. Personal hygiene products.
    5. Cigarette smoke, diesel engine exhaust, road tar, painting work being done and creosote used on roofing.

36. Which of these is where indoor odours, vapours and gases come from? More than one correct answer.

    1. Radon gas emanating from the ground beneath the building.
    2. Carbon monoxide from traffic.
    3. People, our clothes and what we put on our skin.
    4. Passively acquired cigarette smoke prior to entry into the office building.
    5. Last night’s spicy meal.

37. Are any of these correct for biological effluent? More than one correct answer.
    1. Is too complicated to be measured.
    2. Comes from many sources within the working environment.
    3. From one office worker in a 10.0 m^2working space is standardized at 1.0 olf.
    4. Is counteracted by plants within the occupied building, particularly with open atria.
    5. We walk into the building with odours on our clothes.
38. Are any of these incorrect for biological loading? More than one correct answer.
    1. From one office worker is around 0.10 olf/m^2.
    2. Of a smoker while smoking is around 25.0 olf/m^2.
    3. Of a smoker when not smoking is around 6.0 olf/m^2.
    4. Within a gymnasium in use is around 11.0 olf/m^2.
    5. Within a low-pollution office building with an absence of smoking is around 0.20 olf/m^2.
39. Satisfactory air quality may be deemed when:
    1. 100% of the full-time occupants are satisfied.
    2. 85% of the full-time occupants are satisfied.
    3. 50% of the full-time occupants are satisfied.
    4. Complaints cease.
    5. Odours have been eliminated.
40. Which of these are correct for excellent air quality in a building? More than one correct answer.
    1. May need very high room air change rates.
    2. May need outside air to be collected from the roof of a tall city centre building.
    3. May be unachievable where the building is located in a polluted outdoor industrial environment.
    4. Can be improved with air filtering equipment.
    5. Is mainly impractical due to its high cost.
41. State two uses for the Kata thermometer.
42. Where are thermocouples used? What are their advantages?
43. How can heat leakages due to inadequate thermal insulation and damaged pipes or cables be detected?
44. What is the function of environmental temperature?
45. A high-temperature gas-fired radiant heater is used to provide warmth for site workers. The heater has a red-hot area of 300 mm × 500 mm at a temperature of 700°C. A worker of surface area 1 m^2 and temperature 12.0°C is 2.5 m from the heater. Surface emissivities are 1.0 for the heater and 0.9 for the worker. Calculate the radiant heat transfer to the worker.
46. State the factors that are taken into account when designing for the provision of ventilation with outdoor air.
47. Write a technical report on the aspects of the provision of outdoor air for the ventilation of the following:
    1. commercial building that has offices, retail shops and a pedestrian atrium;
    2. an underground high-security manufacturing and storage facility for nuclear materials;
    3. a large open-plan metal-fabrication factory;
    4. a college or university;

5. an hotel;
6. a sports centre that has swimming, weight training, aerobics, racquet courts and restaurant facilities.

48. Explain the meaning of the terms olf and decipol and state how they are used in the design of ventilation systems.
49. List the atmospheric pollutants that are likely to be present within normally occupied buildings. Identify those pollutants that are used for the design of the ventilation system, the filtration equipment, acoustic insulation and general maintenance during occupation.
50. A 10-storey office building is located in Birmingham city centre alongside a highway that has continual, heavy traffic density. The building has 30 m of road frontage, is 20 m deep and each floor is 3 m high. The occupancy averages one person for each 10 m^2 of floor area. Calculate the outdoor air ventilation rate, from the Fanger method, that is required to satisfy 85% of the occupants of an office where it is expected that none of them are smokers. State the recommended location for the fresh air intake and discharge louvres. The office occupants can be taken as mainly sedentary. The interior has a low-pollution load of around 0.20 olf/m^2.
51. Calculate the outdoor air ventilation rate, from the Fanger method, that is required to satisfy 80% of the occupants of an office where it is expected that none of them are smokers. It is located in a county area close to a rural town in the UK.
52. Calculate the outdoor air ventilation rate, from the Fanger method, that is required to satisfy 95% of the occupants of an office where it is expected that none of them are smokers. It is located in a city in the UK.
53. Calculate the outdoor air ventilation rate, from the Fanger method, that is required to satisfy 50% of the occupants of an office where it is expected that none of them are smokers. It is located in a county area close to a rural town in the UK.
54. A new conference room is being designed for an inner city in the UK. The room is to be 20 m long, 12 m wide and 4 m high. Windows are not openable. The conference room is to seat 30 adults. There will not be any smoking and all the furnishings and building materials will have the low-pollution emission of 0.1 olf/m^2. Calculate the outdoor air ventilation rate, from the Fanger method, that will be required so that 90% of the occupants will be satisfied.
55. A new office area for 8 workstations in a commercial building in the City of Southampton is to be 10 m long, 8 m wide and 3 m high. There will not be any smoking and all the furnishings and building materials will have the low-pollution emission of 0.1 olf/m^2. Calculate the outdoor air ventilation rate, from the Fanger method, that will be required so that 80% of the occupants will be satisfied.
56. A lecture theatre is being designed for a rural campus. The theatre is to be 22 m long, 16 m wide and 4.5 m high. It has no exterior windows. Potential occupancy is 100. There will not be any smoking and all the furnishings and building materials will have the low-pollution emission of 0.2 olf/m^2. Calculate the outdoor air ventilation rate, from the Fanger method, that will be required so that 50% of the occupants will not complain. Is this a suitable design?
57. An open-plan office is being designed for a city centre development. Each floor is 50 m long, 25 m wide and 3.5 m high and is to have 100 workstations for the occupants. Use the data from Table 1.2 to evaluate the outdoor ventilation air requirement from the different authorities for this application for one floor. What is the maximum room air change rate that could be produced?
58. A new lecture theatre is being designed for the Bournemouth City University. The theatre is to be 25 m long, 12 m wide and 5 m high. It has no exterior windows. The peak occupancy can be 125 and can be considered to be sedentary. There will not be any smoking, the

building has a low-pollution load of 0.1 olf/m^2 and each occupant creates a load of 1 olf. The external atmosphere is considered to have a low-pollution count. Calculate the outdoor air ventilation rate, from the Fanger method, that will be required so that 90% of the occupants will be satisfied. Recommend how the outdoor air ventilation system could be controlled for energy economy and comfort.

59. Discuss the difference between the Fanger method of assessing the provision of outdoor air with that based on the supply of a fixed quantity, such as 10 l/s per person. State the implications for the energy used in heating and cooling the supply of outdoor air for both systems.
60. Explain, with the aid of sketches, how the ventilation design can be arranged to minimize the use of outdoor air in the provision of acceptable indoor air quality and temperature control for human thermal comfort. The reader can make use of Chapter 5 in answering this question.
61. New instruments for measuring and recording environmental variables such as air temperature, velocity, relative humidity, air quality and thermal comfort become increasingly available. Conduct a search for such devices and write a brief description for the benefit of assessing their relative usefulness to your own work. You may wish to limit the range of equipment to just one type, such as air temperature measurement, in compiling the information for reporting. Make a recommendation for purchase, with reasons, as if it were for your own organization to use.
62. Explain with practical examples why continuous logging of environmental variables is useful to the engineer. You may decide to concentrate on one variable and provide data from a logging instrument to demonstrate its usefulness.
63. State why continuous logging is of value to the energy audit engineer, environmental system design engineer, building designer and building occupants, giving reasons for your statements.
64. Which of these correctly describes how heat transfers within buildings? More than one answer is correct.

    1. Radiation through the concrete floor.
    2. Convection currents within room air.
    3. Conduction between the occupants and the surfaces of the building.
    4. Conduction through solid building materials.
    5. Radiation across a wall cavity when there is aluminium foil-faced sisalization.

65. What is included in *WBGT*?

    1. It does not exist.
    2. Water basic (demand) and gross (heat) transfers for a building.
    3. Wet-bulb temperature, globe temperature and dry-bulb air temperature.
    4. Wet-bulb gradient temperature.
    5. Wet-bulb ground temperature

66. Where does poor indoor air quality come from? More than one correct answer.

    1. Toxic substances that occupants bring into the building by hand or on their clothing.
    2. Inward leakage of outdoor air.
    3. Insufficient fresh air ventilation quantity.
    4. Volatile organic compounds released into the building air from furnishings, cleaning fluids and electro-mechanical equipment.
    5. Lack of adequate air filtration systems.

67. Thermal comfort zone is:

    1. Where everyone is satisfied.
    2. All data falls within one standard deviation of the ideal conditions.
    3. Where the predicted mean vote of all occupants fall within the slightly cool to slightly warm band.
    4. When the environmental temperature is correct for the application.
    5. When nobody complains.

68. Which are correct about cold outdoor climates? More than one correct answer.

    1. Wind chill index found from local air velocity and dry-bulb air temperature.
    2. Frost bite occurs at a wind chill index of 900.
    3. Frost bite can happen at any negative Celsius air temperature.
    4. Frost bite should be avoided if wind chill index, *WCI*, is less than 1400 at an air temperature of –10°C d.b. during a 30 min exposure.
    5. Adequate clothing always avoids frost bite.

69. Which does not apply to heat stroke in a hot climate?

    1. To avoid it, get into a swimming pool.
    2. Occurs at a body temperature of 40.6°C.
    3. Sweating ceases.
    4. Body becomes involuntarily hyperactive.
    5. Body becomes comatose, brain damage from reduced blood supply and death is imminent.

70. Which is a correct meaning for comfort criteria?

    1. 95% of occupants are satisfied with the dry-bulb air temperature.
    2. Mean radiant temperature just below the air dry-bulb temperature in winter.
    3. Dry resultant temperature in the range 19–23°C.
    4. Dry resultant temperature in the range 24–26°C in summer.
    5. Dry-bulb air temperature in the range 15–26°C depending upon room application and season.

71. Which is not an appropriate statement for moving air comfort criteria?

    1. Variable air velocity and temperature is preferred.
    2. Varying the air velocity during the occupied day is impossible.
    3. Varying air velocity during the working day may require the supply air fan to have a variable-speed control.
    4. Low-energy buildings with natural ventilation systems have air velocity variations due to changes in prevailing winds.
    5. Low-energy buildings may have active systems to vary air movement around occupants.

72. Which is the function of the human body thermoregulatory system?

    1. Maintains comfort when heat gains to the body exceed its ability to lose heat.
    2. Provides alarm signals to prompt appropriate response.
    3. Stops blood temperature rising too high.
    4. Averages heat gains and losses between extremities to maintain comfort.
    5. Attempts to maintain energy balance and maintain 37°C core temperature.

73. What was the earlier name for operative temperature regarding comfort assessment?

    1. Wet resultant temperature.
    2. Wet-bulb globe temperature.
    3. Dry resultant temperature.
    4. Environmental temperature.
    5. Dry-bulb air temperature.

74. In well-insulated buildings having modest glazing areas and little air movement, which will operative temperature be closest to?

    1. Globe temperature.
    2. Mean radiant temperature.
    3. Wet-bulb temperature.
    4. Dry-bulb air temperature.
    5. Environmental temperature.

75. Which of these working environments may lead to construction worker heat stress?

    1. High radiant heat load, outdoor work, outdoor air 25°C d.b. and low humidity.
    2. Indoor work in confined space, outdoor air 24°C d.b., high humidity and adequate ventilation.
    3. Clear blue sky, outdoor air 35°C d.b., 20°C w.b., little wind, all work conducted in a deep underground mining tunnel.
    4. Clear blue sky, outdoor air 29°C d.b., high humidity, little wind, all work conducted beneath concrete floor slabs with no perimeter walling.
    5. Completely cloudy sky, high air dry-bulb temperature, strong wind from inland and high humidity.