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TEMPERATURE AND HUMIDITY

SOLVING THE PROBLEM OF KEEPING PEOPLE HAPPY

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The ideal environment for thermal comfort, defined as a lack of awareness of the thermal environment, is when the thermoregulatory system is not being asked to do too much and is operating well within its capacity. For a sedentary person wearing a light suit or its equivalent the environment for comfort is a dry bulb temperature of about 22°C, a relative humidity between about 40 and 60%, a radiant temperature of about22° and a wind speed of about 0.15 m/s. It is important to keep people 'happy' because with discomfort and stress comes inefficiency, loss of productivity and an increase in accidnet rates.

There are four environmental variables associated with comfort and two personal variables.

The four environmental factors

- The temperature of the air, referred to as the dry bulb temperature (tdb), is directly related to the loss or gain of heat by the body. If the air temperature is at the same temperature as the skin heat will not pass into or out of the air but any departure from skin temperature and heat will flow down the temperature gradient. The flow of heat is partly controlled by the static boundary layer of air over the skin but the thinner it is the faster the heat will flow and as the boundary layer thickness is determined by the wind which erodes it, wind speed has a pronounced affect on sensible heat exchange between the body and the environment. In practice, due to the effect of clothing in creating a thick boundary layer for cold conditions and the evaporation of sweat in hot conditions, man can work between - 40° C and + 40° C with work at + 50° C even being possible.

- The water content of the air is normally determined by measuring the wet bulb temperature (twb), that is the temperature of a thermometer with the bulb covered with a wet wick over which air is blowing to remove the boundary layer. The bulb is also shielded from radiation.

  The speed at which the water evaporates from the bulb is determined by the vapour pressure gradient between the wet bulb and the air. The greater the gradient the faster the water evaporates and the colder the thermometer becomes in relation to the dry bulb thermometer. From the two temperatures it is possible to determine the amount of water vapour in the air that is its absolute humidity in grammes of water per Kg of air the vapour pressure and the relative humidity as a percentage of the water present over what the air could hold at saturation. Both the absolute and relative humidity are relevant to the effects of water vapour on people, micro-organisms, materials, dusts and gases.

The natural wet bulb which only has the natural air movement over it and is not shielded from radiation, cannot be used for determining the humidity of the air. Its use is in determining the wet bulb globe temperature index of the environment.

- o The radiant temperature of the working environment is seldom measured directly and is normally referred to as the globe thermometer temperature (tg). The idea is that the black globe heats up or cools down according to the amount of radiation it is receiving and the globe temperature and the difference between the tdb and tg indicates the magnitude and direction of the radiant exchange between a person and the environment. If the globe temperature is corrected for convective heat loss the mean radiant temperature of the environment can be calculated.

  Globe temperatures of 60°C+ can be measured out of doors when the sun is shining. The solar load can be about 1Kw/m .

- o Air movement with its effect on the thickness of the static boundary layer over the skin and on the air trapped by clothing has a very marked affect on heat exchange by convection and evaporation.

Humidity and its relevance

The rate of evaporation of sweat or water from the skin and clothing of a person is determined by the vapour pressure gradient between the skin and the ambient air. The boundary layer imposes a resistance to the movement of water molecules so if it is eroded by wind the evaporation can take place more quickly. Clothing by establishing and enhancing the boundary layer and which in some cases may be impermeable to air and water vapour may reduce the rate of evaporation from the skin, in some cases to zero.

When not sweating people are not normally aware of the relative humidity from values as low as 10% up to 70% possibly more. Comfort values are normally quoted as 40 - 70%. There are chronic effects of low relative humidities both to the skin and respiratory tract. As materials react to changes in relative humidity with dust in particular being much more easily raised from surfaces, low humidities are associated with throat, skin and eye irritation produced by the dust. Electrostatic charges are also built up leading to shocks and insect bite like bumps on the lower leg.

Some micro organisms will thrive or survive depending on the RH. In confined spaces water vapour will rapidly accumulate as sweat evaporates from the occupants. With low ambient vapour pressure levels as occur in winter problems may not arise but in summer, particularly when humid air moves across the country serious problems can arise. Above a wet bulb temperature of 27 C increasing heat problems must be expected.

Personal factors

The six factors concerned with the thermal state of the body consist of the four environmental factors above plus the work rate or heat production of the person and the clothing worn. The heat produced by the body has to be lost via convection, radiation and evaporation and the clothing of course impedes the loss which may be to the good in cold environments or detrimental in warm environments. When doing physical work a person may produce up to 500 watts of heat possibly more. The resistance of the clothing to the flow of heat through it is often described in terms of clo units with cotton coveralls being 1 clo. In doing a risk analysis of work in the heat the clo value of the clothing and its resistance to water vapour transfer have to be taken into account.

Criteria for standards

For comfort whilst sedentary it is normally assumed that a person is not sweating. However, as the environment gets warmer or the person increases the work rate sooner or later sweating will be required in order to prevent the body temperature rising. At first only a small percentage of the total skin area will be wetted but as the thermal stress increases the percent wetted area will rise towards 100%. For a given workrate the percentage wetted area will be determined by the absolute humidity and the wind speed. Clothing will also affect the wetted surface area for if an impermeable garment blocks out say 40% of the skin all the evaporation has to take place from the remaining skin. If the wetted area was 40% effectively 80% is now used up leaving 20 in reserve instead of 60%.

The amount of sweat a person can produce is limited and at one time 1 litre per hour was considered a limiting value. The ISO now suggest 800ml/hr as the limit for an acclimatised person. Heart rate likewise has a limit and although it is capable of reaching values of 220- age in years a 110 bpm is the upper TWA for work in the heat.

There is a relationship between body temperature and sweat rate with sweat rate reaching its maximum at about 38° to 38.2°C. A deep body temperature of 38°C is therefore also used as a physiological standard.

Subjective responses are used widely for assessing comfort conditions with the most common scale being the ASHRAE seven point scale of thermal sensation - hot, warm, slightly warm, neutral, slightly cool, cool and cold.

Heat balance equation

Historically many subjective and physiological indices of comfort and thermal stress were developed. Some are still used such as the effective temperature and the WBGT indices. There are however indices based on the rational approach of the heat balance equation.

$$M + Conv + Cond + R + Evap + S = 0$$

In this equation the evaporation is that required to balance the equation, Ereq. There is however not only a limit to the amount of sweat a person can produce but a limit to the amount the environment will accept, Emax.

Emax is = Ar Ce (Ps-Pa) w/m
7.0 V (56-Pa) clothed
11.7 V (56-Pa) unclothed

With upper limit of 390 w/m Pa mb. If Ereq is placed over Emex ie Ereq/Emax x 100 a value called the heat stress index (HSI) is derived. An HSI value of 100 indicates a wetted skin surface of 100%.

Comfort equation

Fanger in 1970 published a book on thermal comfort in which he developed the detail of the heat balance equation and defined the conditions for thermal comfort as -

$$ts = 35.7 - 0.032 \frac{H}{Adu} \ (°C)$$

$$Esw = 0.42 \ Adu \ \frac{H}{Adu} \qquad Kcal/hr$$

where H = metabolic rate
Adu = skin surface area
ts = mean skin temperature
Esw = sweat rate

The two equations define the skin temperature and sweat rate for thermal comfort against work rate. The development of practical importance is from this equation the predicted mean vote index (PMV) and the predicted percent dissatisfier (PPD). The PMV is derived from a detailed calculation of the body heat balance and prediction of mean skin temperature and evaporation necessary to maintain heat balance. By comparing the predicted physiological values with the responses of subjects in thermal comfort, the model is capable of assessing the degree of discomfort expressed as the PMV that the experimental subjects would have experienced in the actual environment.

To put it another way if the dry bulb temperature, humidity, activity level, clothing clo value and air movement are measured, with dry bulb = mean radiant temperature, it is possible to determine the PMV and the PPD for the environment in question.

One of the important virtues of the rational approach to heat stress and comfort is that the various control options can be evaluated, for example changing air temperature, wind speed or clothing level. In theory control can be achieved by changing one or more of the six factors. It is of particular value when people working at different levels or some are wearing protective clothing are in the same working area.

Wet bulb globe temperature index

This index is probably the most widely used one for thermal stress, it is simple, easy to use and comes with one control option - rest periods - built into it. The main problems often arise with the measurement of the environment. The latest versions in the ACGIH Threshold Limit Values booklet deal with the acclimatized and unacclimatized states and various levels of clothing.

What can go wrong

In the comfort zone problems can arise with any one of the environmental variables with air temperature and humidity being the main problems as the ambient environment moves between the seasonal extremes. Excess air velocity near inlets and radiant temperatures above or below air temperatures can arise on outside walls and near windows. Low RH can lead to dust generation particularly in buildings with plenty of dust such as libraries and theatres. Air movements can move out of control if ventilation systems are not balanced and adjusted. Always approach a problem systematically ascertaining how many staff and who is uncomfortable and why. Even in the ideal environment some will feel cool and others warm. Do not respond to one person complaining unless the complaint relates to something specific to their work station.

People working at different levels and having to wear specific workwear or protective clothing in a common work area may lead to problems that are difficult to resolve. If seasonal heat or cold is a problem plan how to deal with it in advance. For people working in the cold, keep them physically active if possible otherwise it is very difficult to keep them comfortable and warm, rest areas may be required.

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