Thermal environment and human comfort

Hutcheon, N. B.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000835
Canadian Building Digest, 1968-06

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 102

Thermal Environment and Human Comfort

Originally published June 1968

N.B. Hutcheon

Please note

The importance of being able to describe thermal environment in relation to the welfare and the comfort of people needs little emphasis. Such matters are commonly the concern of the medical profession and of the air-conditioning engineer who must design equipment to produce the desired conditions. They should also be appreciated by the building designer who inevitably influences the thermal aspects of the environment, directly or indirectly. Owners and tenants too can benefit from a better appreciation of the factors involved, the reasons for dissatisfactions that sometimes arise, and the corrective measures, if any, that may be considered.

The most commonly used index of comfort is air temperature. There are, however, a number of other factors involved. The physical aspects of any environmental situation are usually far from simple. They may differ widely from one case to the next and even be variable with time. Then there are the complications of the physiology of the human body. Added to this, different people may respond differently to the same conditions.

It is useful to recognize that the human body is warm-blooded and that it must maintain a body temperature within very close limits. It uses food as a fuel, converting it into energy. Some of this energy may leave the body in the form of external work done; the balance represents heat production within the body and is available for the maintenance of body temperature. As the body must produce heat continuously, it must also lose it at a rate that provides control of body temperature. An understanding of the thermal environment can therefore best be developed by considering how it influences the ability of the human body to maintain a suitable rate of heat loss. Comfort may be regarded both physically and physiologically as a condition of thermal neutrality under which the body need not strain to reduce or increase heat loss.

The human body maintains a basic minimum rate of heat production at about 250 Btu/hr during sleep, the heat equivalent of about 75 watts, and about 400 Btu/hr (120 watts) when awake but sedentary. As bodily activity increases, the rate of oxidation of food, with its attendant release of energy, must increase. The level of heat production for light work will be about 650 Btu/hr (190 watts), the extreme value for heavy work, about 2400 Btu/hr (700 watts).

It is possible to recognize the main ways in which the body will lose heat and to relate them in a simple equation as follows:

$$H = S + E + R + C$$

where

H = rate of internal heat production

S = rate of heat storage in the body

E = rate of loss by evaporation

R = rate of radiant energy exchange with surroundings

C = rate of loss by convection

The equation indicates simply that the internal heat production must be in balance with the four ways in which it may be disposed. Some heat may be stored, or drawn from storage within the body, with a corresponding change in body temperature over short periods. Most of the heat, however, must be rejected from the body surfaces through convection losses to the surrounding air, by radiation exchanges with surrounding surfaces, and by the evaporation of perspiration from the skin when required. Although not listed specifically, there will be a loss of heat through the heat and water vapour added to the air involved in respiration.

The body involuntarily makes adjustments that influence these processes by increasing or decreasing the rate of heat loss as required. It can attempt to induce evaporation by pouring out perspiration on the skin when it is too warm. It can attempt to vary convective and radiative losses by increasing or decreasing the peripheral blood circulation which raises or lowers skin temperature. Whether or not these measures are effective depends on the temperature, moisture content and motion of the air, and the temperature of the surrounding surfaces. The amount of clothing becomes a major factor also since it is interposed between the skin and the influence of the surroundings and becomes involved in the convective, evaporative, and radiative losses for those areas of the body that are covered.

The effects of varying pertinent environmental factors can now be described. Increasing the air temperature tends to reduce convective and radiative losses and to increase evaporative losses under sweating conditions. If air temperature rises above skin or clothing surface temperature there will be a heat gain rather than a heat loss by convection, and this must be offset by increased losses in other ways.

Perspiration and respiration components of the evaporative loss are dependent upon the rate at which water is actually evaporated. This depends in turn upon the degree of saturation of the air, which may be measured in terms of relative humidity. Thus, there can be no evaporative loss with air saturated at 98°F, regardless of the rate of perspiration unless the body temperature rises above normal. On the other hand, under conditions that lead to comfort, with only light activity the main evaporative loss is that from the lungs, with little or no contribution from perspiration, at least until the upper limits of comfort are reached.

A net heat exchange by radiation takes place between any two surfaces when there is a difference in temperature between them. In summer the exterior wall and window surfaces of a room may be appreciably higher than air temperature, while in winter the reverse situation may exist. Thus, the net radiation exchange between a body and the surrounding room surfaces can vary independently of convective losses.

Air motion is another factor that can have a marked effect. Increased air speed over the body and clothing surfaces can increase convective losses and, when there is perspiration, the evaporative losses as well. Thus, under conditions of high temperature and high humidity, discomfort can often be greatly reduced by increasing the air flow. It is of more than passing interest to note that under these conditions even high air speeds can be pleasant. With cooler conditions, however, even small localized air circulation may give rise to complaints of drafts.

Comfort Index and Effective Temperature

Air temperature alone is not the only determinant of the thermal influence of room conditions and should not be expected to correlate well with thermal sensations of comfort under all conditions. The other factors that have been discussed can also influence the heat losses from the human body. Various attempts have been made to produce a single index that would adequately describe some or all of the pertinent conditions, so that all situations described by the same value of the index might be expected to produce the same comfort condition.

The comfort index most widely known and used on this continent is that developed by the American Society of Heating and Ventilating Engineers many years ago. It took account, in its basic form, of air temperature, relative humidity, and air motion only. Radiation effects were neglected, i.e., all surrounding surface temperatures were assumed to be at air temperature. Correlations were obtained from the reactions of a large number of subjects, who moved back and forth between test rooms maintained at slightly different conditions and were asked to compare sensations of warmth. Those conditions producing the same thermal sensations of comfort were assigned the same value, this being taken as the air temperature at 100 per cent relative humidity that produced the same sensation. The index thus obtained was called Effective Temperature, and in the final compilation in the well known Comfort Chart only those values pertinent to an average or normal air movement from 15 to 25 feet per minute, as normally found in rooms, was used. Thus, Effective Temperature as commonly used combines only air temperature and relative humidity.

A marked influence of relative humidity was found. The value in summer at which 97 per cent of the subjects were comfortable was 71 degrees Effective Temperature, which corresponds to conditions of 82 degrees at 10 per cent, 76 degrees at 50 per cent and 71 degrees at 100 per cent relative humidity. Correspondingly, the value for winter conditions at which the greatest proportion of subjects was comfortable was about 68 degrees, which can be obtained with 78 degrees at 10 per cent and 72 degrees at 50 per cent relative humidity.

More careful work at a later date on a smaller number of subjects has failed to show any influence of relative humidity upon thermal sensations of comfort with light activities, and prolonged exposure to the same conditions, for temperatures and humidities at and below those normally considered comfortable. A dry bulb temperature of 77 degrees was rated as comfortable, and no influence of relative humidity below 70 per cent was found. Above 70 per cent there was some influence, increasing with increasing humidity. At 71 degrees, which was rated as slightly cool, no effect of relative humidity was found below 90 per cent, the upper value for the tests. A temperature of 82 degrees was rated as slightly warm, with a relative humidity effect beginning at 50 per cent and increasing above this. The corresponding temperature for the same comfort at 90 per cent was 79 degrees.

Although there is now no reason so far as optimum comfort is concerned to select one relative humidity in preference to another over a fairly wide range, one proposition favouring lower relative humidities in summer air-conditioning has been made. It has been pointed out that when there are occupants in a space such as a ballroom engaged in a range of activity from sitting to vigorous dancing, the best compromise for the comfort of all will be achieved by maintaining relative humidities on the low side, thus providing those who are active with a greater possibility to eliminate body heat by evaporation without affecting the comfort of those who are sedentary.

Radiation Effects

The role of radiation effects has already been mentioned. They generally rise from the surrounding physical environment and are not directly under the control of the air-conditioning system. Thus they can introduce a very definite limit on the extent to which air-conditioning can produce uniform comfort conditions.

Consider a simple case of a heated object similar to a human body located in the centre of a room in which all enclosing surfaces are at the same temperature as the air. If the room surfaces are all lowered by 1 degree without changing air temperature there will be an increase in the net radiative heat loss from the body. The body heat balance may be maintained as before if the air temperature is now raised, resulting in a compensating decrease in convective heat loss. The required increase in air temperature for these conditions may be taken as roughly equal to the change in room surface temperature, that is, 1 degree.

The case just considered is greatly simplified but does serve to illustrate that a thermal balance can be maintained if the air temperature is adjusted to compensate for a change in the temperature of the enclosing surfaces. Conversely, constant thermal balances cannot be maintained under different radiation effects unless the convective heat exchange can be adjusted to suit. This can be done by adjusting temperature as already indicated, but may also be done within limits by adjustments to air flow over the body.

Actual situations involving people can become much more complex, however, with respect to both radiative and convective effects. The enclosing surfaces of occupied spaces will seldom all be at one temperature. In addition, there may be concentrated radiating sources, including lights, radiators, and heaters of various kinds. The direct rays of the sun provide strong radiation effects, involving short-wave radiation. Window surfaces or blinds heated by the sun may be up to 30 F deg above air temperature and thus become important radiators of long-wave radiation. Correspondingly, glass surfaces in winter can be as much as 30 F deg below room temperature. All exterior walls are also, to a lesser degree, dependent on their over-all heat transmission characteristics, likely to be above air temperature at times in summer and below in winter.

Interior walls, floors and ceilings having no outdoor exposure will usually be within a degree or two of air temperature, and will exchange energy by radiation with heated or cooled exterior walls and windows and any hot or cold bodies in the room. When the bounding surfaces of a space are at different temperatures the calculation of radiation exchanges with an object in the space can become quite complicated. It is not enough to calculate the average surface temperature of the enclosure, although this gives a first rough approximation, because the radiative exchange depends upon the areas and relative positions of the surfaces involved. Thus the radiation exchange with a body may vary with its position in the room when there is unbalanced radiation. The concept of mean radiant temperature is useful, this being the equivalent uniform surface temperature that would produce the same radiation exchange as the actual situation.

When the mean radiant temperature is variable throughout a space it will not be possible to provide exact compensation for it by adjusting room temperature. This would require the maintenance of different but controlled air temperatures throughout the space. Exterior walls with large glass areas may produce mean radiant temperatures differing from air temperature by several degrees at locations near outside walls, while the differences at more remote positions may be one degree or less. Quite good results could be provided by using compensating radiation, so that cold surfaces would be balanced by warm heating panels and vice versa. This is seldom done intentionally and the old-fashioned radiator under the window, although it offered some advantage in this way, has been discarded in favour of convectors.

Study of the physics of the thermal environment serves mainly to identify and to provide an understanding of the external factors that will influence the body heat balance. The physiological response to various conditions provides a further great field for research, but it must be carried out on people. Much remains to be studied despite the many tests that have already been made. Objective instrumental measurements can be used. The assessment of comfort, however, must finally be related to the subjective reactions of people, and experiments are required in which people become the meters.

Many experiments with people were required to establish the ASHRAE Comfort Chart already described. Many more have been conducted since that time, and many still remain to be done to establish firm relations even in such limited areas as comfort conditions for people engaged in light work or at rest in air-conditioned buildings.

A Standard for Thermal Comfort Conditions designated 55-66 has been produced and published by ASHRAE. The limited situations covered by the Standard are a salutary reminder of the extreme difficulty of the subject, and the reservations regarding its application deserve special attention. It is the only Standard of its kind currently available, and provides a basis for specifying or assessing thermal comfort conditions, within the limitations set out. It deals in particular with the effects of different radiation conditions that could not be taken into account in the Comfort Chart based on Effective Temperatures.

Compensating adjustments equivalent to a change in air temperature of several degrees may be required for positions in a room close to large hot or cold window or wall areas. This

Standard does not recognize any influence of relative humidity, within normal limits, upon thermal comfort, while setting an upper limit of 60 per cent for air-conditioned occupied space.

For further discussion of the conditions covered by the Standard and for situations in which effects of the thermal environment other than comfort are of interest, the reader is referred in the first instance to the pertinent Chapters of the current issue of the ASHRAE Handbook of Fundamentals. A discussion of comfort in relation to air-conditioning, from which portions of this Digest have been reproduced, is to be found in NRC 8625, Air Conditioning and Comfort. An annotated bibliography on the literature up to 1960 is included in NRC 5514, Man and His Thermal Environment.