The loss by radiation of a given surface depends entirely upon the difference between the temperature of the body and the mean surface temperature of the surrounding walls and objects. This latter temperature is called the *mean radiant temperature* (MRT).

Because these two types of heat losses act in a supplementary manner toward each other, a required rate of heat loss can be secured by having a relatively low air temperature and a relatively high MRT, or *vice versa*. Thus, if the air is reduced from a given temperature to a lower temperature, the amount of heat lost from the body by convection is increased, and this increase can be compensated for by raising the MRT. Similarly, with a higher air temperature the same total heat loss will be maintained by a correspondingly lower MRT.

Within limits the sensation of feeling cold can be avoided in two ways; first, by raising the air temperature surrounding the body, and secondly, by allowing the thermal radiation from warm objects to impinge on the body with sufficient intensity to make up for a lower air temperature.

It is the object of a heating installation to avoid the necessity for human body adaptation and also to provide comfort for those individuals doing the least physical work. While some conditions may take care of the heat loss from the body without controlling the generation of heat within, other conditions stimulate the production of heat within us, which enables the body to respond to the environment and generate more heat to meet the conditions.

Rate of Heat Production

The normal rate of heat production in a sedentary individual is about 400 Btu[1] per hour, or (since the entire surface area of an average adult is 19.5 sq ft) about 20.5 Btu per square foot per hour. When considering radiant heating, it is necessary to calculate the radiation and the convection loss separately. The human body is of complicated shape, and radiation only takes place freely from the exposed outer surface. There are considerable portions of the body which radiate most of their heat to other portions, such as: the legs, arms, lower part of head etc. It is necessary to determine the equivalent surface of the body from which heat is radiated and a similar value for convection. The total surface for convection may be assumed as an approximate value of 19.5 sq ft and 15.5 sq ft for radiation.

The heat generated in the average human body is approximately 400 Btu per hour of which 75 per cent or 300 Btu per hour is the approximate value of the heat given off by radiation and convection. While it is difficult to differentiate the exact proportion of these two values, it is found that if the body gives off about 190 Btu per hour by radiation or 12.26 Btu per hour per square foot of radiant body surface, conditions of greatest comfort will result. This leaves 110 Btu per hour to be released by convection, or 5.64 Btu per hour per square foot of convected body surface.

[1]A.S.H.V.E. RESEARCH REPORT No. 830—Heat and Moisture Losses from the Human Body and Their Relation to Air Conditioning Problems, by F. C. Houghten, W. W. Teague, W. E. Miller, and W. P. Yant (A.S.H.V.E. TRANSACTIONS, Vol. 35, 1929, p. 245).

The loss by evaporation, which depends on the air temperature, air movement and humidity, together with the loss by respiration makes up the balance of 100 Btu per hour. All of these values are relative because the total will vary materially with change of position, occupation, age, race, etc.

The mean normal surface temperature of the human body, taken over the whole area, including not only the exposed skin surface but also surfaces of the clothes and the hair, has been very extensively used as 75 F, particularly in England where radiant heating has been practiced for nearly 30 years. However, results obtained by Aldrich[2] in rooms in which the air and wall surface temperatures were approximately 72 F gave mean values nearer 83 F than 75 F. In both England and America mean wall and air temperatures of 72 F seem to be unwarranted; so it is not unreasonable to assume that a body surface temperature lower than 83 F may eventually be accepted. Some values have already been suggested as being the most suitable for the American climate, but the accepted standard for United States practice must be ultimately derived from research and practical experience.

The mean surface temperature of an inert body which will maintain the optimum heat loss by radiation and convection in a uniform environment of a given temperature may be calculated from fundamental equations for radiation and natural convection by substituting comparable cylinders for the body. While it may be possible to produce effects on a cylinder or any other body of a particular size and shape to estimate similar effects on the human body, it should be remembered that the heat loss from the body varies greatly with movement. Every movement of the body not only alters its shape but also the velocity of the air passing over it and the surface exposed to radiation. This fact makes it difficult to compare the effect of any environment on a cylinder to that of a human body. Heilman[3] gives the following equations:

$$H_r = 0.1723\, e \left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4 \right] \qquad (1)$$

$$H_c = 1.235 \left(\frac{1}{D}\right)^{0.2} \times \left(\frac{1}{T_m}\right)^{0.181} \times \left(T_s - T_a\right)^{1.266} \qquad (2)$$

where

H_r = heat loss by radiation, Btu per square foot per hour.
H_c = heat loss by convection, Btu per square foot per hour.
T_s = absolute temperature of the body surface, degrees Fahrenheit.
T_w = absolute temperature of the walls, degrees Fahrenheit.
T_a = absolute temperature of the air, degrees Fahrenheit.
$T_m = \dfrac{T_s + T_a}{2}$
D = diameter of cylinder, inches.
e = the ratio of actual emission to black body emission.

If it is assumed that a normal adult has an average height of 5 ft 8 in.

[2]A Study of Body Radiation, by L. B. Aldrich (Smithsonian Miscellaneous Collections, Vol. 81, No. 6, December 1928).

[3]Surface Heat Transmission, by R. H. Heilman (*A.S.M.E. Transactions, Fuels and Steam Power Section*, Vol. 51, No. 22, September-December, 1929).