body, heat is also lost through evaporation from both the body surface and the respiratory tract.

The rate of heat loss by convection depends upon the average temperature difference between the surface of the body and the surrounding air, the shape and size of the body, and the rate of air motion over the body.

The rate of heat loss by radiation depends upon the exposed surface area of the body, and upon the difference between the mean surface temperature of the body and the mean surface temperature of the surrounding walls or other objects. This latter temperature is called the mean radiant temperature (MRT).

Because these two types of heat loss supplement each other, a required rate of total heat loss can result either from a relatively low air temperature and a relatively high MRT, or vice versa. If the air temperature is reduced, the heat loss from the body by convection is increased, which can be compensated for by raising the MRT so as to decrease the heat-loss by radiation.

A heating installation should provide comfort for those individuals doing the least physical work, without causing undesirable changes either in the rate of heat generation, or in the body's heat regulating mechanism.

Rate of Heat Production

The normal rate of heat production in an average sized sedentary individual is about 400 Btu[1] per hour. When considering radiant heating, the evaporation, radiation and convection losses must be separately studied. The human body is of complicated shape, and radiation takes place freely, only from the exposed outer surface; there are considerable portions of the body such as the legs, arms, lower part of head, etc., which radiate most of their heat to other portions. 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 may be assumed as approximately 19.5 sq ft for convection and 15.5 sq ft for radiation, for an average sized individual.

The loss by evaporation and respiration depends on the temperature and area of the moist surfaces (outside and respiratory) of the body, the air temperature, air movement and humidity. In air at a temperature of 80 F, this loss for a sedentary individual of average size will be approximately 180 Btu per hour; at 70 F, about 90 Btu per hour; and at 60 F, about 60 Btu per hour. All of these values are relative, because the total will vary materially with change of position, bodily activity, age, sex, race, etc.

The balance of the heat generated in the average human body (approximately 300 Btu per hour at about 71 F room temperature) is the approximate amount of heat given off by radiation and convection. It is difficult to determine the exact proportions of these two; but it appears that if the body loses about 190 Btu per hour by radiation (or 12.25 Btu per hour per square foot of radiating body surface), the greatest comfort

[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, 1939, p. 245).

will result. This leaves about 110 Btu per hour to be lost by convection (or 5.65 Btu per hour per square foot of convecting body surface).

The mean surface temperature of the human body, including the whole area not only of exposed skin but also of clothing and hair, has been estimated variously at from 75 F (particularly in England) up to 83 F (in America). Further research and experience will be needed to finally derive the most suitable value for the American climate. The final figures will vary with sex, age, clothing, etc., but will probably come between these extremes.

The mean surface temperature of an inert body, which will cause given rates of heat loss by radiation and by convection in a uniform environment, having a given air temperature and a given mean wall temperature, may be calculated from fundamental equations for radiation and natural convection, but substituting comparable cylinders for the irregular human body.

Heilman[2] gives the following equations:

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

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

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.
$T_m = \frac{T_s + T_a}{2}$
D = diameter of cylinder, inches.
e = the ratio of actual emission to black body emission.

If it is assumed that an average adult has a height of 5 ft 8 in. and a body surface of 19.5 sq ft for convection, and 15.5 sq ft for radiation, an equivalent effect can be worked out for two cylinders, 5 ft 8 in. high by 13.15 in. diameter and 10.45 in. diameter, respectively. However, while the effects on a cylinder (of a particular size and shape) may be used to estimate average similar effects on the human body, it should be remembered that the heat loss from the body varies greatly. Every movement alters not only its shape, but also the velocity of the air passing over it and the surface exposed to radiation. This fact renders the results of any such computation only approximate.

BRITISH EQUIVALENT TEMPERATURE

The British Equivalent Temperature (BET) is the mean temperature of the entire environment which is effective in controlling the rate of sensible heat loss from a *black body* in still air when this body has a surface temperature equal to that of the human body, and a size comparable

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