gives off only sensible and radiant heat without adding moisture to the air. The heat load on exposed workers is thereby increased but the rate of cooling by evaporation of sweat is not reduced. Heat balance may be maintained although this will be at the expense, perhaps, of excessive sweating. In the warm-moist situation, the wet process gives off principally latent heat. There may be no significant rise in the heat load on the worker but the increase in moisture content of the air will seriously reduce the heat loss by evaporation of sweat. The warm-moist situation is potentially more hazardous than the hot-dry.

Examples of hot-dry work situations are seen around hot furnaces, forges, metal-extruding and rolling mills, glass-forming machines, and the like. Typical of warm-moist operations are laundries, dye houses, and deep mines where water is extensively used for dust control.

The industrial heat problem varies in magnitude with local climatic conditions. Solar heat gain and an elevated outdoor temperature will increase the heat load at the work place but these contributions may not be very important compared with the locally generated heat of the process itself. The moisture content of the outdoor air, on the other hand, is a most important climatic factor affecting hot-dry work situations and on a moist summer day will seriously restrict evaporative cooling. For the warm-moist job, in contrast, solar heat gain and elevated outdoor temperature are the more important, since, compared with the moisture release on the job, that contributed by the outdoor air will be of little significance.

Thermal Standards for Industrial Work Areas

The work situations considered here are those in which the attainment of simple thermal comfort is not always practicable. The heat stress must be kept below the level of outright hazard, but how much below? On what criteria should the specifications for control be based? How should the standards be varied in recognition of the differing demands and work rates from one kind of job to another? What differences exist between older and younger workers or between workers with differing degrees of physical fitness? To what extent can periods of heat exposure be offset by alternating periods of recovery? How is this expressed in terms of design of the control measures? These and other questions arise in the analysis of an industrial heat problem and must be considered by the design engineer and others before specifications are fixed. As there is no single set of thermal standards applicable to all work situations, failure to give proper recognition to the many facets of the problem can result in inadequate control measures.

Biophysical Basis for Fixing Thermal Standards

Under conditions of thermal comfort, the rate of internal heat production (metabolism) is just balanced by the rate of heat loss to the environment. This comfortable balance is maintained without active sweating, with optimum skin and deep-body temperatures and without unusual load upon the heart. At the upper limits of physiological tolerance to sustained heat exposure, thermal balance may also be established, but this is accomplished only with active sweating, elevated skin and body temperatures, and accelerated heart rate. The limit is fixed by the maximum permissible degree to which these indexes of physiological strain—sweating, body temperature, and heart rate—can be safely elevated. For practical work situations in industry, the permissible limits of these indexes must be set below the absolute physiological maxima.

The thermal relationship between man and his environment is dependent upon four independently variable thermal characteristics of the environment: air temperature, radiant temperature, moisture content of the air, and air velocity. These may combine in various ways, together with the rate of internal heat production, to create widely different degrees of heat stress. The need is to provide a rational basis for combining them into a single index that will predict the magnitude of the heat stress and will serve also as a basis for fixing permissible limits of exposure.

A start is made with the heat balance equation:

$$M \pm R \pm C = B + E \pm \Delta S \qquad (1)$$

where

M = metabolic rate.
R = rate of heat exchange with environment by radiation.
C = rate of heat exchange with environment by convection.
B = rate of heat loss from body in exhaled air.
E = rate of heat loss from body by evaporation of sweat.
ΔS = rate of change in heat content of body.

Terms on the left side of Equation 1 represent the heat load; those on the right represent the heat loss together with the heat storage or withdrawal from the body. R and C are positive when the environmental temperature is above skin temperature and negative when below.

In practice, B and ΔS are of small magnitude compared with the others and can be neglected. For a condition of heat balance, therefore, Equation 1 may be written:

$$M \pm R \pm C = E_{req} \qquad (2)$$

E_{req} = required rate of evaporation of sweat to maintain heat balance.

M can be measured by standard physiological techniques or estimated for a given work situation by reference to Table 1. On both theoretical and experimental grounds, R and C can be calculated with reasonable accuracy by means of standard equations of heat exchange:

$$R = K_r A_r (t_w - t_s) = 22(t_w - t_s) \qquad (3)$$

$$C = K_c \sqrt{V} A (t_a - t_s) = 2\sqrt{V}(t_a - t_s) \qquad (4)$$

where

K_r = coefficient of radiant heat exchange, Btu per (hour)(square foot)(Fahrenheit degree temperature difference).
This coefficient varies in value; depending on the mean radiant temperature of the surroundings, t_w.
A_r = radiation area of body, square feet.
It differs with body position and is around 0.8 of total body surface for a standing man.
22 = $K_r \times A_r$ for average size man with moderately high mean radiant temperature, t_w.
K_c = coefficient of convective heat exchange, Btu per (hour)(square foot)(unit velocity)(Fahrenheit degree temperature difference).
A = surface area of body, square feet.
2 = $K_c \times A$, for average size man.
V = effective velocity of air movement, feet per minute.
t_w = (black-body equivalent) mean radiant temperature of environment, Fahrenheit.
t_a = ambient air temperature, Fahrenheit.
t_s = skin temperature, Fahrenheit.