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.

Table 1 . . . . Estimates of Energy Metabolism (M) of Various Types of Activity

(Values apply for a 154 lb man, and do not include rest pauses)

Kind of Work	Activity	M Btu/hr
	Sleeping	250
	Sitting quietly	400
Light Work	Sitting, moderate arm and trunk movements (e.g., desk work, typing)	450–550
	Sitting, moderate arm and leg movements (e.g., playing organ, driving car in traffic)	550–650
	Standing, light work at machine or bench, mostly arms	550–650
Moderate Work	Sitting, heavy arm and leg movements	650–800
	Standing, light work at machine or bench, some walking about	650–750
	Standing, moderate work at machine or bench, some walking about	750–1000
	Walking about, with moderate lifting or pushing	1000–1400
Heavy Work	Intermittent heavy lifting, pushing or pulling (e.g., pick and shovel work)	1500–2000
	Hardest sustained work	2000–2400

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:

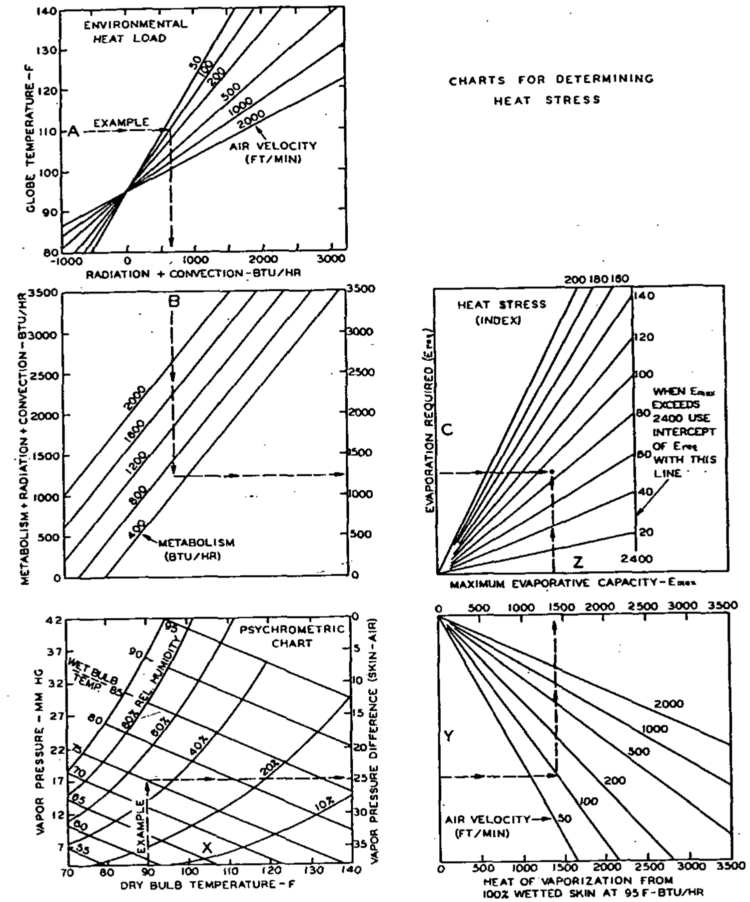
$$R = K_r A_r (t_w - t_s) = 22(t_w - t_s) \qquad (3)$$

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

where

K_r = coefficient of radiant heat exchange, Btu per (hour) (square foot) (Fahrenheit degree temperature difference).
K_r varies in value; depending on the mean radiant temperature of the surroundings, t_w.
A_r = radiation area of body, square feet.
A_r 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.

So long as there is no limitation on evaporation rate, the



Example: Determine Heat Stress Index for worker doing light arm work while standing at a bench.

Metabolism	*600 Btuh*

Environmental conditions:

Globe thermometer temperature	*110 deg*
Dry-bulb temperature	*90 F*
Wet-bulb temperature	*75 F*
Air velocity	*100 fpm*

Solution: Follow the broken lines from the globe thermometer temperature and from dry-bulb temperature to their intersection on above diagram C to read a heat stress index of 90.

Fig. 1 . . . . Flow Charts for Determining Heat Stress Index Values