sweat output is automatically limited by the body to that amount which satisfies the required value of E. With restricted evaporation, however, there is excessive sweating; the body becomes fully wetted and a maximum evaporative cooling rate is established which does not increase with further sweating. This maximum evaporative cooling rate E_{max} has been established experimentally and can be calculated by the equation:

$$E_{max} = K_e A V^{0.4}(P_s - P_a) = 10V^{0.4}(P_s - P_a) \quad (5)$$

where

K_e = coefficient of heat exchange by evaporation, Btu per (hour)(square foot)(unit velocity)(millimeter of mercury vapor-pressure difference).

10 = $K_e \times A$ for average size man, fully wetted.

P_s = vapor pressure of water at skin temperature, millimeters of mercury.

P_a = partial pressure of water vapor in ambient air, millimeters of mercury.

A combination of Equations 4 and 5 yields Equation 6 which is a statement of the maximum thermal conditions under which man can maintain heat balance, giving proper recognition to internal heat production M, skin temperature t_s and to all four of the thermal characteristics of the environment:

$$M + 22(t_a - t_s) + 2\sqrt{V}(t_a - t_s) = 10V^{0.4}(P_s - P_a) \quad (6)$$

Equation 6 provides a rational basis on which to construct a heat stress index and to establish thermal standards for different industrial work situations.

Two physiological criteria are important in fixing the limit of sustained heat exposure:

1. The increase in body heat content must not exceed a certain level. Practically, this is reflected in the rise in skin temperature. This temperature may be limited to 95 F.

2. Thermal balance must be accomplished with a rate of sweating not greater than one liter per hour (equivalent to evaporative cooling of 2400 Btu per hr). Studies on young acclimatized subjects have shown that this maximum rate of sweating can be maintained over a workday without undue strain or physiological cost.

The Heat Stress Index (HSI) proposed by Belding and Hatch* makes use of these criteria together with the previous biophysical equations. A so-called *standard* young man, in good physical condition and acclimatized to heat, can safely engage in simple physical work over a normal eight-hour day in a particular thermal environment so long as his skin temperature does not exceed 95 F and he maintains thermal balance with a sweat rate not exceeding 1 liter per hr. By definition, this degree of stress has an (HSI) value of 100 and is given by any combination of $M + R + C$ which is balanced by E_{max} within their defined limits. For other situations where E_{req} is greater or less than E_{max} ($\lesseqgtr 2400$ Btu per hr), the value of (HSI) is proportionately different from 100:

$$(HSI) = 100 \times \frac{E_{req}}{E_{max} \lesseqgtr 2400} \quad (7)$$

By using the globe thermometer temperature (see Chapter 52) of the environment to represent the combined effects of mean radiant temperature and air temperature, the Heat Stress Index chart Fig. 1 has been constructed, to permit quick determination of (HSI) when M, t_s, t_a, t_{wb}, and air velocity are given. The procedure for finding (HSI) will be obvious by following the dash line in Fig. 1.

The Heat Stress Index was developed from research experience with young men in good physical condition and well acclimatized to heat. Table 2 assigns suggested physiological meaning to (HSI) values above and below 100, for older men as well as the standard young man and, also, for various kinds of jobs which differ in their demands upon mental and physical effort. From these it becomes possible to select (HSI) levels appropriate to each work situation.

The Heat Stress Index (HSI) differs from the Effective Temperature (ET) scale in the rational rather than subjective basis of its construction. Practically, the commonly recommended ET = 80 F for heavy work at moderately high air velocity agrees very well with the (HSI) limit of 100 for acclimatized young men. In Fig. 2 are shown the combinations of dry- and wet-bulb temperature (air and wall temperature alike) for three different air velocities and three

Table 2 .... Evaluation of Index of Heat Stress

Index of Heat Stress	Physiological and Hygienic Implications of 8-Hr Exposures to Various Heat Stresses
−20	Mild cold strain. This condition frequently exists in
−10	areas where men recover from exposure to heat.
0	No thermal strain.
+10	Mild to moderate heat strain. Where a job involves
20	higher intellectual functions, dexterity, or alert-
30	ness, subtle to substantial decrements in performance may be expected. In performance of heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
40	Severe heat strain, involving a threat to health unless
50	men are physically fit. Break-in period required
60	for men not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
70	Very severe heat strain. Only a small percentage of the
80	population may be expected to qualify for this work.
90	Personnel should be selected (a) by medical examination and (b) by trial on the job (after acclimatization). Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is highly desirable, and may be expected to decrease the health hazard while increasing efficiency on the job. Slight "indisposition" which in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
100	The maximum strain tolerated daily by fit, acclimatized young men.

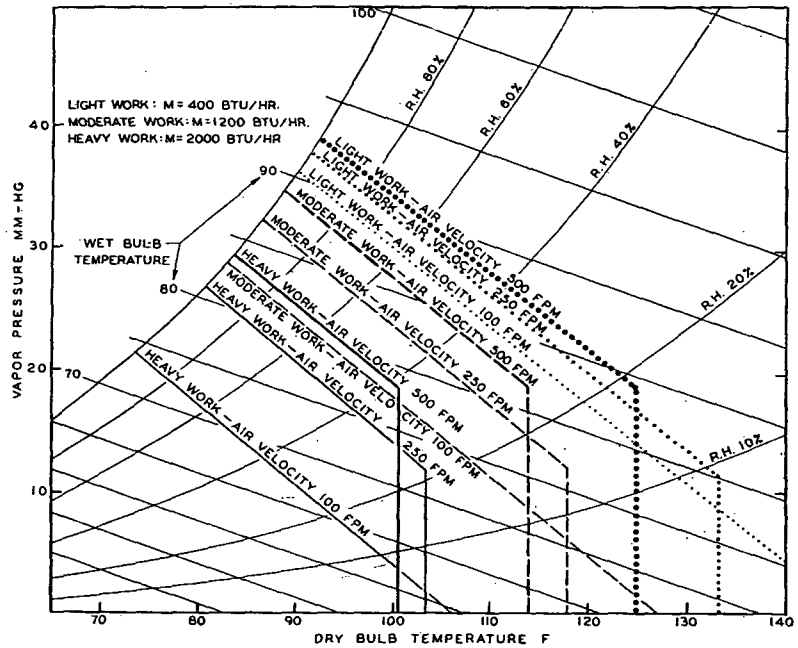

Fig. 2 .... Conditions for Stress 100 at Three Grades of Work and Three Air Velocities

different grades of work, all of which give (HSI) = 100. Points representing ET = 80 F with an air velocity of 300 fpm are also shown for comparison.

CONTROL OF HEAT EXPOSURES

Measures for control of heat exposures will be treated under the following headings: Control at Source, Local Exhaust Ventilation, Radiation Shielding, General Ventilation, Dilution Ventilation, Local Relief Ventilation.

Control at Source

The magnitude of heat exposure can be reduced by insulating hot equipment, locating such equipment most favorably (in zones of good general ventilation within buildings or even outdoors), covering steaming water tanks, providing covered drains for direct removal of hot water, and maintaining tight joints and valves where steam may escape. This method is an obvious one and requires no particular comment other than to emphasize the benefits to be derived from elimination of heat sources wherever possible.

Local Exhaust Ventilation

The natural convection column of heated air rising from a hot process may be captured by means of ventilated enclosures or exhaust hoods and removed with a minimum of dilution by air from the surrounding space when local exhaust ventilation can be used. Chapter 52 provides detailed information on the design of exhaust hoods and duct systems for local exhaust.

Radiation Shielding

In some industries, commonly referred to as the hot industries, there are many hot objects and surfaces such as furnaces, ovens, furnace flues and stacks, boilers, molten material, and hot ingots of metal, castings, or forgings and, in consequence, the major environmental heat load is in the form of radiant heat. Since air temperature has no significant influence on the flow of radiant heat, ventilation is of no help in controlling such exposures. The only effective control is the direct one of decreasing the amount of radiant heat im-