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

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

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:

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

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

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 work day without undue strain or physiological cost.

The Heat Stress Index (HSI) proposed by Belding and Hatch[3] 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} (≤ 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_g, 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 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, and providing covered drains for direct removal of hot water, 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 45 provides detailed