I. Effects of Heat on Man

The varying effects of heat on employees are portrayed in Figure 1.[1] Increasing degrees of psychological disturbance are noted as the level of thermal stress goes up above the comfort zone, and some of the well-known consequences are noted on the chart. These range from purely subjective discomfort to demonstrable impairment of efficiency in the performance of mental tasks. A further increase in heat load results in a higher order of psycho-physiological disturbance with an increase in frequency of errors, higher accident frequency, and reduced efficiency in the performance of skilled physical tasks. At still higher levels of

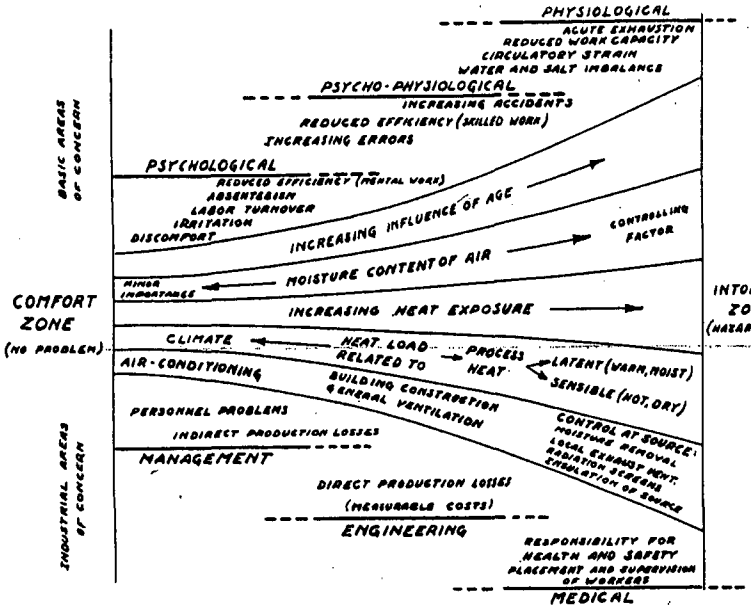

Figure 1. Effects of heat on man, ranging from no effect (comfort) to extreme physiological breakdown (heat exhaustion, stroke, death).

exposure there is a definite loss of work capacity with disturbance of physiological well-being, strain upon the heart and circulatory system, and overloading of the mechanisms of water and salt balance in the body. These disturbances culminate in acute heat exhaustion or stroke and may terminate fatally.

In parallel with the three (overlapping) categories of response to heat, psycho-

[1] T. F. Hatch, Standards for industrial heat control, in symposium on "Man and His Relationships to Air," *Heating, Piping, Air Conditioning*, **23**, 140–142 (April, 1951).

logical, psycho-physiological, and physiological, the areas of primary responsibility for fixing limits of exposure are also shown on the chart. At the lower levels of thermal stress there is no demonstrable effect on health. The consequences of heat exposure are reflected in personnel problems and indirect production losses. In the middle zone, still without evidence of direct ill-effects upon employees, the cost of thermal stress is reflected in increased production costs, and these must be compared with cost of heat control to determine the extent to which thermal stress is to be reduced. This is the concern of industrial and production engineering. It is the top zone of physiological disturbance with which we are concerned here. Thermal standards are required that will insure safe working conditions for the normal industrial population working at the rates and for the periods of time necessary to the performance of their tasks without physiological distress or impairment to health.

II. Physiological Limits of Heat Exposure

Body heat balance is a physiological requirement for comfort and health. Under normal conditions of comfort, the rate of heat production (metabolism) is just balanced by heat loss to the environment (see Chapter VIII). This comfortable balance is maintained without active sweating and with optimum skin and deep-body temperatures. An increase in heat production with work must be offset by an equal increase in rate of heat loss, which is accomplished by sweating and evaporative cooling. In environments above skin temperature, heat is brought to the body by radiation and convection, and this quantity together with the metabolic heat must be eliminated by the sole remaining avenue, evaporative cooling. Owing to his flexible sweating mechanism, man can dispose of substantial amounts of heat in this manner. An upper limit of evaporative cooling is reached, however, when the body surface becomes fully wetted.[2] If the metabolic heat plus that received from the environment exceeds the maximum evaporative capacity, the body must heat up. With the rise in skin temperature the external heat load goes down and evaporative cooling capacity increases so that thermal balance may be re-established at an elevated body temperature. A modest rise is physiologically acceptable, but any substantial increase in body temperature is accompanied by serious strain.

A. HALDANE'S WET-BULB TEMPERATURE LIMITS

The necessity to maintain heat balance at an acceptable level of body temperature has long been recognized as one criterion for fixing limits to heat exposure. Early observations were made by Haldane in 1905.[3] He defined the limit of endurance as the most extreme heat exposure that could be withstood without

[2] A. P. Gagge, A new physiological variable associated with sensible and insensible perspiration, *Am. J. Physiol.*, **120**, 277 (1937).

[3] J. J. Haldane, The influence of high air temperatures, *J. Hyg.*, **5**, 494 (1905).