

stored or given off, accompanied by a rise or fall in body temperature. Under ordinary circumstances (when the dew-point of the air is below the body surface temperature) the evaporation loss,  $E$ , is always positive; that is, heat from metabolism supplies this loss.  $R$  and  $C$  are positive when the surface temperature of the body is above that of the walls and air, and negative when it is cooler.

The human body possesses remarkable powers of adaptation to a narrow range of atmospheric conditions around an ideal optimum where storage is zero, and metabolism and skin and tissue temperature are at optimum values. Under these conditions, the body experiences a sensation of comfort. As skin temperature and body-tissue temperature rise or fall above or below an optimum, complex adaptive mechanisms come into play, chiefly associated with redistribution of blood supply between the skin and deeper tissues (in a cold environment) and with sweat secretion (in a hot environment). These reactions are governed by nervous or chemical stimuli from both skin and internal tissues. Nerves from the skin, for example, carry the sense impressions to the brain and the response comes back over another set of nerves, the motor nerves, to the musculature and to all the active tissues in the body, including the endocrine glands. In this way, a two-sided mechanism controls the body temperature by (1) regulation of internal heat production (chemical regulation), and (2) regulation of heat loss by means of automatic variation in the rate of cutaneous circulation and the operation of the sweat glands (physical regulation). The reactions involved in cold and in hot environments are on the whole radically different in nature. The mechanisms of adjustment involved are extremely complex and, while they are receiving considerable study, a complete understanding of their operation is still lacking.

Some of the phenomena of body temperature control are shown graphically in Fig. 1. The dotted curves, from a study at the *John B. Pierce Laboratory of Hygiene*<sup>11</sup>, are for subjects lightly clothed in a semi-reclining position and give the relation between the dry-bulb temperature of the environment (with about 45 per cent relative humidity) and the metabolic rate, the rate of heat dissipation by radiation and convection combined, and the latent heat loss due to evaporation of perspiration and moisture from the respiratory tract. The smooth line curves from the work of the A.S.H.V.E. Research Laboratory<sup>10</sup> give the same relationships for healthy, male subjects (18 to 24 years of age), seated at rest and normally clothed for winter-heated and air conditioned occupancy. The data for the semi-reclining subjects also include the rate of heat storage (either positive or negative) due to a rise or fall in body temperature. For the normally clothed subjects, a curve gives the total heat loss (that is, the sum of the radiation, convection and evaporative losses). Here, storage is given by the difference between the metabolism and total heat loss.

The small difference between the metabolic or heat production rates for the two types of subjects may be accounted for by the difference in activity. Heat exchange between the body and the environment by radiation and convection is greater for the lightly clothed subject, both for cool conditions where there is considerable heat loss, and for very warm conditions where there is sensible transfer from the atmosphere to the body. The two curves for evaporative loss serve to show how physiological control uses evaporation of perspiration to maintain equilibrium, particularly at high temperatures. Below about 75 F for the normally clothed subject,

and below about 85 F for the lightly clothed subject, evaporation loss is minimal and probably due to uncontrolled evaporation from the relatively dry skin and from the respiratory tract. Above these temperatures control is obtained by the availability of perspiration for evaporation. The difference in the curves above 75 F is probably largely determined by the difference in clothing and activity. Above temperatures from 95 to 100 F (the probable average outside surface temperature of the clothed body) the combined effect of radiation and convection causes a change from positive to negative. Slightly above this temperature even the greatly increased latent heat loss ceases to take care of the rate of heat production plus the negative radiation and convection loss, and heat storage occurs with a consequent rise in body temperature. Above this range, even

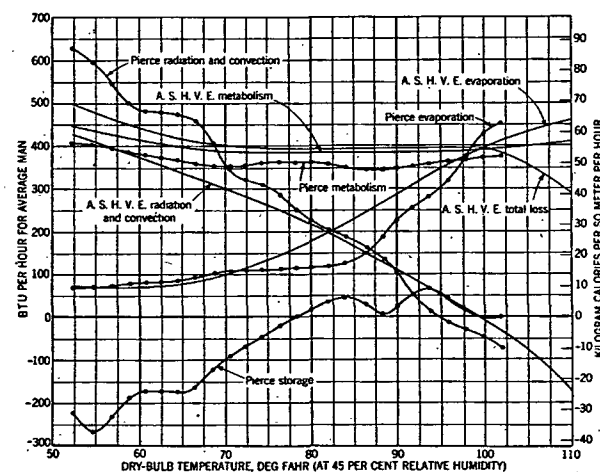


FIG. 1. RELATION BETWEEN METABOLISM, STORAGE, EVAPORATION, RADIATION PLUS CONVECTION, AND OPERATIVE TEMPERATURE FOR THE CLOTHED SUBJECT

though there is inability to dissipate heat rapidly enough, metabolism actually increases. This may be accounted for by the predominance of the purely chemical laws of increased chemical reaction with rise in temperature, over physiological control, and indicates the point where a breakdown in thermal equilibrium begins. For higher temperatures life can only survive to the point where these accelerated processes will result in a rise in body temperature to the limiting level of from 106 to 108 F.

Air movement is an important factor in increasing heat loss by either convection or evaporation. The result is accomplished through removal of hot humid air from near the body surface and replacing it with cooler and relatively drier air. This is an important factor in maintaining thermal equilibrium either for persons at rest or at work in hot, humid conditions. For conditions in the comfort zone and below, excessive velocities (particularly localized drafts) should be avoided since differential cooling of one area of the body may produce surprisingly unpleasant reactions in quite different parts of the body. In one experiment<sup>12</sup> it was shown that the application of an ice pack to an area of 60 sq cm. on the back of the neck for 15 min caused a drop of 17 F in the skin temperature