body becomes warmer. M is always positive, and E is always negative. R and C are positive when the surface of the body is above that of walls and air, respectively, and negative when the surface of the body is cooler than walls or air.

The human body possesses remarkable powers of adaptation to a range of atmospheric conditions around an ideal optimum where storage is zero, and metabolism and skin and tissue temperature are at optimum values. 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). Under cold conditions, shivering or other muscular movements increase metabolism, which is, again, a reaction favorable to temperature regulation; but under very hot conditions metabolism also rises and this reaction is obviously harmful and indicates failure of the entire regulative process. 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 mechanisms of adjustment are complex and the reactions involved in a cold and in a hot environment are radically different in nature. Therefore, any attempt to formulate simple engineering relationships covering the entire thermal scale are obviously doomed to failure.

In a certain middle range, normal and easy physiological regulation occurs by slight changes in the distribution of blood between the skin and the inner organs; here, heat loss and heat gain balance and a sensation of comfort is experienced. Above this range, the blood capillaries in the skin become dilated, allowing more blood to flow into the skin, and thus increase its temperature and consequently its heat loss. If this method of cooling is not in itself sufficient, the stimulus is extended to the sweat glands which allow water to pass through the surface of the skin, where it is evaporated. This method of cooling is the most effective of all, as long as the humidity of the air is sufficiently low to allow for evaporation. In high humidities, where the difference between the dew-point temperature of the air and body temperature is not sufficient to allow rapid evaporation, equally good results may be obtained by increasing air movement. The body, under hot conditions, is in the *zone of evaporative regulation*, and for moderately extreme conditions perfect balance between heat production and heat loss may be attained, although at the cost of considerable discomfort.

In a cold environment, where environmental conditions are such as to remove heat too rapidly, the organism adapts in some degree by constricting the blood vessels of the skin, increasing the insulation of the body. The lowered surface temperature of the skin decreases heat loss which obviously depends on the differential between the temperature of

the skin and of the environment. This adaptation is, however, partial and incomplete, and the temperature of the body tissues falls, with accompanying discomfort and ultimate danger of serious chill. The process may go on for many hours. This is known as the *zone of body cooling*. The normal tendency of the individual is to move about and increase metabolism through muscular activity and thus balance the excessive heat demand of the environment.

These phenomena are important and a graph indicating the reactions of lightly-clothed human subjects in a semi-reclining position is shown in

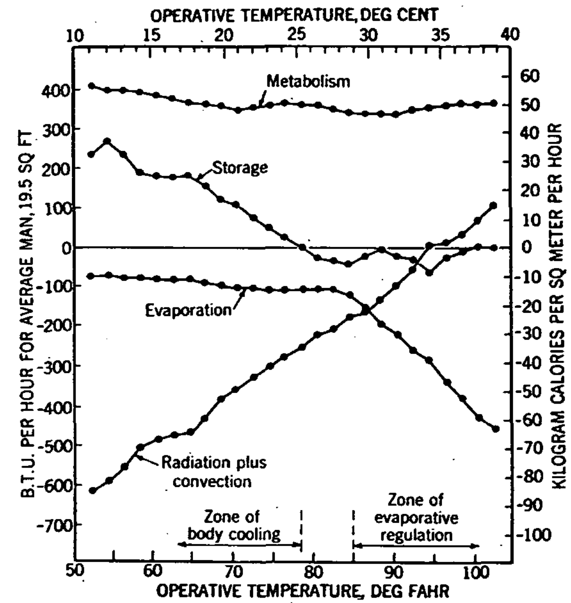

Fig. 1. Relation Between Metabolism, Storage, Evaporation, Radiation Plus Convection, and Operative Temperature for the Clothed Subject

Fig. 1. The air movement was minimal and relative humidity between 40 and 50 per cent. The abscissae are *operative temperatures* which represent the combined effect of air and wall temperatures[9], the ordinates, heat loss per unit of body surface. The following phenomena are obvious:

1. Metabolism (for a given subject) remains approximately constant within the range of operative temperatures employed, and rises slightly below 70 F.

2. At a critical temperature of 85 F the heat produced by metabolism (roughly 50 kilogram-calories per square meter per hour) is balanced by the heat loss due to evaporation and to radiation plus convection; these two major components accounting for about 25 kilogram-calories each. Storage is zero; that is, the body tissues show no change in temperature.

[9]A.S.H.V.E. Research Report No. 1107—Recent Advances in Physiological Knowledge and Their Bearing on Ventilation Practice, by C.-E. A. Winslow, T. Bedford, E. F. DuBois, R. W. Keeton, A. Missenard, R. R. Sayers, and C. Tasker (A.S.H.V.E. Transactions, Vol. 45, 1939, p. 111).