in clothing and activity. Above temperatures from 95 to 100 F (probably that of the average outside surface of the clothed body) radiation and convection combined changes from positive to negative, and slightly above this temperature even the greatly increased latent heat loss ceases to suffice to take care of the rate of heat production and the negative radiation and convection loss, and storage or a rise in body temperature is the consequence. Above this range, even though there is inability to dissipate heat rapidly enough, metabolism actually increases, which 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 a recent experiment[17] 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 of the fingers and that this low temperature of the fingers persisted for one hour after the ice pack was removed.

## ADAPTATION TO HOT CONDITIONS

It will be observed from Fig. 1 that a zone ranging from about 70 to 80 F, at 45 per cent relative humidity (or from 66 to 74 deg ET) the body is adequately able to maintain equilibrium through control of radiation and convection losses combined, and evaporative loss. This corresponds to the zone over which the largest percentage of persons find optimum comfort. For higher temperatures, up to an upper limit in the neighborhood of 100 F, at 45 per cent relative humidity (or approximately 87 deg ET) control is obtained through availability of perspiration on the body surface for evaporation. While a fair degree of temperature equilibrium is maintained over this range it is nevertheless obtained with considerable discomfort.

Studies at the *John B. Pierce Laboratory of Hygiene*[18] have indicated the relation between discomfort and the degree of wetting of the body surface by perspiration for lightly clothed subjects in a semi-reclining position, and the investigators there have designated this as the *zone of evaporative regulation*. Work of the A.S.H.V.E. Research Laboratory[19] over the past two decades has made available data on the relation between sensible perspiration and the atmospheric environment for normal persons at rest and at work.

[17]The Relative Influence of Radiation and Convection Upon the Temperature Regulation of the Clothed Body, by C.-E. A. Winslow, L. P. Herrington and A. P. Gagge (*American Journal of Physiology*, Vol. 124, October, 1938, p. 51).

[18]Relations Between Atmospheric Conditions, Physiological Reactions, and Sensations of Pleasantness, by C.-E. A. Winslow, L. P. Herrington and A. P. Gagge (*American Journal of Hygiene*, Vol. 26, July, 1937, p. 102). The Reactions of the Clothed Human Body to Variations in Atmospheric Humidity, by C.-E. A. Winslow, L. P. Herrington and A. P. Gagge (*American Journal of Physiology*, Vol. 124, December, 1938, p. 692).

[19]Loc. Cit. Note 13.



For colder conditions below 70 F, with 45 per cent relative humidity (or about 66 deg ET) thermal equilibrium is maintained, first, by the amount of clothing worn; second, and to a smaller extent, by limiting availability of heat at the surface by decreasing peripheral blood circulation, which results in a drop in skin temperature; and third, by an increase in the metabolic rate. Here again, while thermal equilibrium is fairly well maintained, any drop in the skin temperature is accompanied by a certain degree of discomfort.

Studies at the A.S.H.V.E. Research Laboratory[20] and elsewhere[21] during the past two decades have made available a mass of information dealing with the physiological effects of hot atmospheres on workers and means to alleviate the distress and hazards associated therewith. This interest has been termed *air conditioning in industry*, or *the effects of hot atmospheres in industrial hygiene*, and is a growing factor in air conditioning applications. Table 2 gives some of the physiological responses of men at rest and at work, to hot environments. Recent physiological studies[22] indicate that frequent and continued exposure of workers to hot environments results in not only violent but subtle physiological derangement, affecting

TABLE 2. PHYSIOLOGICAL RESPONSES TO HEAT OF MEN AT REST AND AT WORK[a]

| Effective Temp | Actual Cheek Temp (Deg Fahr) | Men at Rest | | | Men at Work 90,000 ft-lb of Work per Hour | | | |
|---|---|---|---|---|---|---|---|---|
| | | Rise in Rectal Temp (Deg Fahr per Hr) | Increase in Pulse Rate (Beats per Min per Hr) | Approximate Loss in Body Weight by Perspiration (Lb per Hr) | Total Work Accomplished (Ft-Lb) | Rise in Body Temp (Deg Fahr per Hr) | Increase in Pulse Rate (Beats per Min per Hr) | Approximate Loss in Body Wt by Perspiration (Lb per Hr) |
| 60 | ------ | ------ | ------ | ------ | 225,000 | 0.0 | 6 | 0.5 |
| 70 | ------ | 0.0 | 0 | 0.2 | 225,000 | 0.1 | 7 | 0.6 |
| 80 | 96.1 | 0.0 | 0 | 0.3 | 209,000 | 0.3 | 11 | 0.8 |
| 85 | 96.6 | 0.1 | 1 | 0.4 | 190,000 | 0.6 | 17 | 1.1 |
| 90 | 97.0 | 0.3 | 4 | 0.5 | 153,000 | 1.2 | 31 | 1.5 |
| 95 | 97.6 | 0.9 | 15 | 0.9 | 102,000 | 2.3 | 61 | 2.0 |
| 100 | 99.6 | 2.2 | 40 | 1.7 | 67,000 | 4.0[b] | 103[b] | 2.7[b] |
| 105 | 104.7 | 4.0 | 83 | 2.7 | 49,000 | 6.0[b] | 158[b] | 3.5[b] |
| 110 | ------ | 5.9[b] | 137[b] | 4.0[b] | 37,000 | 8.5[b] | 237[b] | 4.4[b] |

[a]Data by A.S.H.V.E. Research Laboratory.
[b]Computed value from exposures lasting less than one hour.

[20]A.S.H.V.E. RESEARCH REPORT No. 654—Some Physiological Reactions to High Temperatures and Humidities, by W. J. McConnell and F. C. Houghten (A.S.H.V.E. TRANSACTIONS, Vol. 29, 1923, p. 129). A.S.H.V.E. RESEARCH REPORT No. 672—Further Study of Physiological Reactions, by W. J. McConnell, F. C. Houghten and F. M. Phillips (A.S.H.V.E. TRANSACTIONS, Vol. 29, 1923, p. 353). A.S.H.V.E. RESEARCH REPORT No. 690—Air Motion, High Temperatures and Various Humidities—Reactions on Human Beings, by W. J. McConnell, F. C. Houghten and C. P. Yaglou (A.S.H.V.E. TRANSACTIONS, Vol. 30, 1924, p. 167). A.S.H.V.E. RESEARCH REPORT No. 718—Work Tests Conducted in Atmospheres of High Temperatures and Various Humidities in Still and Moving Air, by W. J. McConnell and C. P. Yaglou (A.S.H.V.E. TRANSACTIONS, Vol. 31, 1925, p. 101). A.S.H.V.E. RESEARCH REPORT No. 719—Basal Metabolism Before and After Exposure to High Temperatures and Various Humidities, by W. J. McConnell, C. P. Yaglou and W. B. Fulton (A.S.H.V.E. TRANSACTIONS, Vol. 31, 1925, p. 123). A.S.H.V.E. RESEARCH REPORT No. 908—Heat and Moisture Losses from Men at Work and Application to Air Conditioning Problems, by F. C. Houghten, W. W. Teague, W. E. Miller and W. P. Yant (A.S.H.V.E. TRANSACTIONS, Vol. 37, 1931, p. 541). A.S.H.V.E. RESEARCH REPORT No. 1106—Air Conditioning in Industry—Physiological Reactions of Individual Workers to High Effective Temperatures, by W. L. Fleisher, A. E. Stacey, Jr., F. C. Houghten and M. B. Ferderber (A.S.H.V.E. TRANSACTIONS, Vol. 45, 1939, p. 59). A.S.H.V.E. RESEARCH REPORT No. 1153—Seasonal Variation in Reactions to Hot Atmospheres, by F. C. Houghten, A. A. Rosenberg and M. B. Ferderber (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 185). Physiologic Effects of Hot Atmospheres, by F. C. Houghten, M. B. Ferderber and A. A. Rosenberg (*Industrial Medicine*, January, 1940, p. 7).

[21]A.S.H.V.E. RESEARCH REPORT No. 1151—The Peripheral Type of Circulatory Failure in Experimental Heat Exhaustion, by R. W. Keeton, F. K. Hick, Nathaniel Glickman and M. M. Montgomery (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 157).

[22]A.S.H.V.E. RESEARCH REPORT No. 1153—Seasonal Variation in Reactions to Hot Atmospheres, by F. C. Houghten, A. A. Rosenberg and M. B. Ferderber (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 185).