abnormal rise in body temperature. For the clothed, resting man, not especially acclimatized, the maximum endurable condition for sustained exposure was 88° F. for still air saturated with moisture. Higher air temperatures were found acceptable only when the moisture content was lowered to increase evaporative cooling and thus offset the hotter air. Haldane demonstrated the benefits of air movement, reporting that with 170 f.p.m. air velocity instead of still air, the endurable temperature of saturated air was raised from 88 to 93° F. A moderate work rate was found to lower the acceptable level 10° to 78° F. for saturated air. Reasoning that the wet surface of the body and clothing would act like the wet-bulb thermometer, Haldane suggested that environments with varying dry-bulb temperatures but having the same wet-bulb temperature would be thermally and physiologically equivalent. Thus, to maintain heat balance without abnormal rise in body temperature, Haldane recommended the following maximum temperatures for clothed men not especially acclimatized: (*1*) resting, in still air—88° F., wet-bulb temperature; (*2*) resting, 170 f.p.m. air velocity—93° F., wet-bulb temperature; (*3*) moderate work, still air—78° F., wet-bulb temperature.

B. EXPOSURE LIMITS IN TERMS OF EFFECTIVE TEMPERATURE

Later, with the development of the ASHAE Effective Temperature scale (Chapter VIII), it was found that physiological limits to prevent abnormal rise in body temperature could be expressed, for different levels of activity, in terms of this scale, which combines temperature, humidity, and air motion into a single thermal index. The rate of increase in temperature and in pulse rate rose sharply in the resting man when the effective temperature, ET, was above 90° F., and the break occurred at a lower ET level for the working man. In still, saturated air the ET is the same as the wet-bulb temperature, so that a recommended ET of 90° agrees well with Haldane's earlier suggestion of 88° F., wet-bulb, for a resting man. For sedentary work (500 B.t.u./hr.) an ET of 85° was found acceptable, whereas for heavy work (1800 B.t.u./hr.) the ET of the environment should not exceed 80° F.[4] Within these limits body temperature remains below 101° F. and the heart rate less than 125 beats per minute over a normal working day.

C. PHYSIOLOGICAL LIMITS BASED ON PERFORMANCE ABILITY

At the Armored Medical Research Laboratory Eichna and associates[5] obtained more extensive data on the upper limit of tolerance to heat. Observations were limited to young men in good physical condition and well acclimatized to heat. Tests involved 4 hours' exposure (nude) walking at 3 m.p.h., equivalent to 300–400 f.p.m. air velocity, carrying a 20 pound pack (about 1200 B.t.u./hr.). The

[4] C. P. Yaglou (Chairman, APHA Committee on Atmospheric Control), Thermal standards in industry, *Am. Public Health Assoc. Yearbook, 1949–50*, pp. 131–143.

[5] L. W. Eichna, W. B. Bean, and W. B. Shell, The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments, *J. Ind. Hyg. Toxicol.* **27**, 59 (1945).

demonstrated ability or inability to complete the assigned task during the 4-hour period was used as the criterion of tolerance. "Relatively easy" environments fell along line No. 1 on the psychrometric chart shown in Figure 2. The work in these environments was easily accomplished without great effort or complaint and with all subjects alert at the completion of the work period and seemingly capable of continuing indefinitely. "Difficult" environments, in which all subjects completed the work, but only with great effort and with evidence of approaching exhaustion, are shown on a parallel line, No. 2, in Figure 2. A third parallel line defines "Impossible" environments, in which the work could be carried on only with real danger to health. The narrow differences in moisture content of the air between easy, difficult, and impossible environments are especially to be noted.

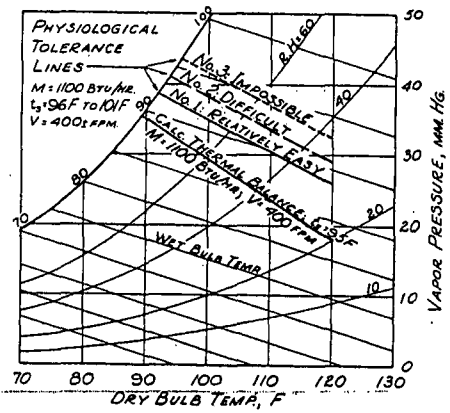

Figure 2. Lines of maximum physiological tolerance and calculated line of thermal balance, plotted on psychometric chart. Air and wall temperatures equal; air velocity, 400 f.p.m.; metabolic rate, 1100 B.t.u./hr.

D. MAXIMUM PERMISSIBLE SWEAT RATE

There are practical objections to defining limits to heat exposure in terms of environmental factors only, since a different standard is required for each work rate. McArdle *et al.*[6] have proposed using the sweat rate as a single index of heat stress to include both the work load and the external heat load. They recommend 4.5 liters output in four hours as the maximum permissible rate consistent with physiological well-being for repeated exposures to heat for acclimatized young men in good physical condition. A chart has been developed[6] from which the

[6] B. McArdle, W. Dunham, H. E. Holling, W. S. S. Ladell, J. W. Scott, M. L. Thompson, and J. S. Weiner, *The Prediction of the Physiological Effects of Warm and Hot Environments*. Royal Navy Personnel Research Committee, Med. Research Council, H. M. Stationery Office, London, October, 1947.