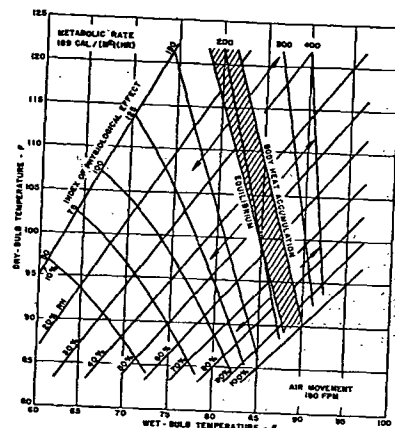




Each contour line of physiological effect indicates conditions of the environment which had equal effects on the working men.

Fig. 8 . . . The Physiological Effects of Environment on Two Clothed Men Walking at 3.5 mph up a 2.5 Percent Grade (MR 189 Cal per (M²) (hr))

ture, humidity, and movement of air upon the human body. In repeated experiments, the subjective response by groups of individuals to variations of temperature, humidity, and air movement was studied. Combinations of temperatures, humidities, and velocities, which produced the same feeling of warmth were assigned the same effective temperature value. If the temperature, humidity, and air movement are known, the effective temperature can be read from Fig. 7. The choice of chart to be used will depend upon whether the men are normally clothed or stripped to the waist. In the presence of radiant heat, as when the globe temperature exceeds the ambient temperature by more than 2 F deg, the globe temperature should be used instead of the dry-bulb temperature in computing the ET from Fig. 7. According to this scale, an ET of 78 F represents the threshold of sweating, while an ET of 90 F marks the upper limit for continuous exposure of heat-acclimatized men engaged in light activities. The upper permissible limit for moderately hard work is an ET of 85 F, and for heavy work, 80 F. In hot spaces of Naval ships (underway), an ET of 91 F is well tolerated during the usual 4-hr watches.

Limitations of Effective Temperature

The ET index is most applicable to warm atmospheres when radiation effects are not significant. This scale makes too much allowance for humidity at low temperatures and not enough allowance at high temperatures. In the presence of radiant heat, significant errors are reported if the ET index is used. Bedford¹⁰ suggested that this can be corrected by using an unheated globe thermometer, instead of the air tempera-

ture, and the given dew point, and then computing ET. It is believed that, by this modification, the error will be small if the air movement is low, but it may be considerable in high wind velocities.

Wet-Bulb Globe-Temperature Index of Yaglou (WBGT)¹¹

The Effective Temperature Index previously described requires the integration of three values: dry-bulb temperature, humidity, and air movement. Proper measurement of air movement is a most difficult procedure, requiring specialized apparatus and skilled personnel. It has been suggested, for spaces in which radiant heat is present, that an index (WBGT) can be obtained more simply by the use of wet-bulb and black-globe temperatures. With this procedure, it would not be necessary to obtain air movement measurements, since the globe temperature will automatically reflect air movement, provided that radiant heat is present. In this method, the wet-bulb temperature is multiplied by a factor (approximately 0.7), the globe temperature is multiplied by a factor (approximately 0.3), and the two are added to give a new index. This index is currently being evaluated in the field and looks promising, particularly in outdoor applications where the environment ordinarily has a radiant heat load. Results to date indicate values of the same order of significance as those obtained by more tedious methods.

Index of Physiological Effect (Ep)¹²

In the construction of this index, heat stress was evaluated from increases of heart rate, skin temperature, rectal temperature, and sweat rate of four subjects working or resting in

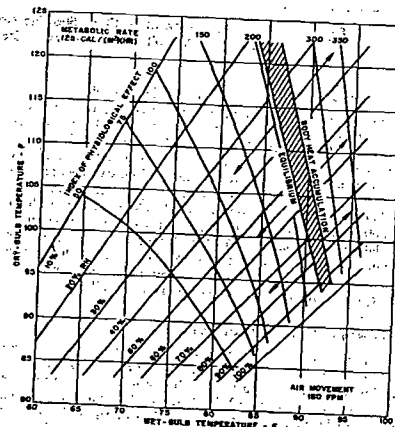


Fig. 9 . . . Physiological Effects of Environment on Two Clothed Men Walking at 2.8 mph on the Level (MR 125 Cal/(M²) (hr))

Physiological Principles

the laboratory at various temperatures and humidities, with a constant air movement of 180 fpm. Contour curves, representing lines of equal physiological strain, were plotted on charts (Figs. 8, 9, and 10). The chart to be used will depend upon the metabolic rate involved. If the dry-bulb and wet-bulb temperatures and the approximate metabolic rate are known, it is possible to estimate Ep values in the range of 50 to 400. Thermal equilibrium is possible when the Ep value is under 200; heat begins to accumulate in the body when Ep exceeds 250; and conditions become intolerable with Ep values of over 400. Ep has certain distinct advantages and disadvantages, compared with ET. For this reason it is desirable to use both indices for checking one against the other.

The Predicted Four-Hour Sweat Rate (P4SR)¹³

The predicted four-hour sweat rate uses only the rate of sweating as a criterion of heat stress in environments that are hot enough to cause sweating. On the basis of British experimental work, empirical nomograms have been developed for predicting the probable amount of sweat in liters that would be secreted over a 4-hour period by fit, acclimatized men. These nomograms incorporated environmental factors, metabolic rate, and the amount of clothing worn. A P4SR of 4.5 liters was provisionally adopted as the upper limit of tolerance for physically fit men. On the basis of this value, less severe conditions can be evaluated. This method of determining thermal stress is difficult to apply in the field and is primarily a research tool.

The Belding-Hatch Heat Stress Index (HSI)¹⁴

The Belding-Hatch index expresses the heat load in terms of the amount of sweat which must be evaporated in order to

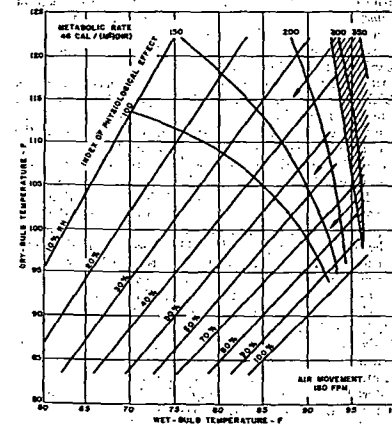


Fig. 10 . . . Physiological Effects of Environment on Two Men Sitting at Rest in Shorts (MR 46 Cal/(M²) (hr))

Table 3 . . . Estimates of Energy Metabolism (M) of Various Types of Activity

(Values apply for a 154 lb man, and do not include rest periods)

Kind of Work	Activity	M Btu/hr
Light Work	Sleeping	250
	Sitting quietly	400
	Sitting, moderate arm and trunk movements (e.g., desk work, typing)	450-550
	Sitting, moderate arm and leg movements (e.g., playing organ, driving car in traffic)	550-650
	Standing, light work at machine or bench, mostly arms	550-650
Moderate Work	Sitting, heavy arm and leg movements	650-800
	Standing, light work at machine or bench, some walking about	650-750
	Standing, moderate work at machine or bench, some walking about	750-1000
	Walking about, with moderate lifting or pushing	1000-1400
Heavy Work	Intermittent heavy lifting, pushing or pulling (e.g., pick and shovel work)	1500-2000
	Hardest sustained work	2000-2400

maintain heat balance at an arbitrarily assumed skin temperature of 95 F. The evaporation rate required is estimated from the metabolic rate and body heat loss by radiation and convection, using empirical equations or nomographs. By comparing this rate with the maximum evaporative capacity of the atmosphere on a man whose skin is at a temperature of 95 F, and is completely wet with perspiration, it is possible to evaluate the heat stress and resulting strain by the difference between the rates or by their ratio. Although this index may have future possibilities with new facts coming to light, it, too, is primarily a research tool at present. Tables 3 and 4, and Fig. 11, are included for informational purposes. It should be noted that several factors incorporated in this index are currently under study and may need modification (convection factor, evaporation factor).

ENVIRONMENTAL CONDITIONS AND COMFORT

As has been previously indicated, changes in body temperature or pulse rate provide useful scales for evaluating the effects of thermal stress on the human body. However, there is no precise physiological observation by which comfort can be evaluated. Within the comfort zone, or the zone of thermal neutrality (Table 5), the body is able to maintain a balance between heat production and heat loss without significant changes in any of the readily-measurable indices which have been tried. Mean skin temperature was at one time thought to offer some promise, but this, too, has proven to be an unreliable index.