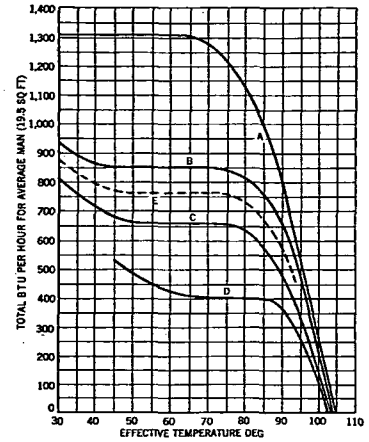


[a] Curve A—Persons working, metabolic rate 1310 Btu per hour. Curve B—Persons working, metabolic rate 850 Btu per hour. Curve C—Persons working, metabolic rate 660 Btu per hour. Curve D—Persons seated at rest, metabolic rate of 400 Btu per hour. Curves B and D based on test data covering a wide temperature range. Curves A and C based on test data at an Effective Temperature of 70 and extrapolation of Curves B and D. All curves are averages of values for high and low relative humidities; variation due to humidity is small.

Fig. 5 . . . . Relation Between Total Heat Loss from the Human Body and Effective Temperature for Still Air[a, 14]

importance of unit rise in MRT. Under ordinary *still air* conditions the effects of air temperature and MRT appear to be interdependent. Various authorities give 0.3 to 1 deg increase of room temperature to compensate for 1 deg depression of the MRT.

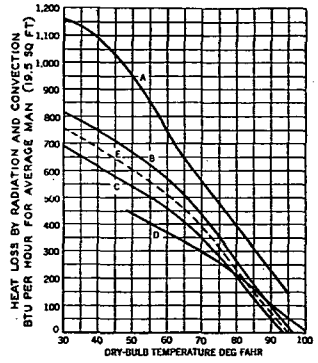
APPLICATION OF PHYSIOLOGIC PRINCIPLES TO AIR-CONDITIONING PROBLEMS

In order to estimate cooling loads in occupied spaces it is necessary to know the metabolic rate (heat production) of man. This has been studied extensively, and found to remain relatively constant per unit of body surface area in a subject fasting and resting quietly after a good night's sleep. The rate is high in children, and diminishes gradually with age; it increases in certain diseases and in the presence of fever. The metabolic rate is somewhat lower in women. Heat production goes up sharply with work and varies widely in different persons doing the same work. Figs. 5, 6, and 7 and Table 27 of Chapter 13 give sufficient basic data for estimating heat production and heat loss under various conditions.

EFFECTIVE TEMPERATURE INDEX AND COMFORT ZONES

There is no precise physiologic observation by which comfort can be evaluated. Mean skin temperature offers some promise. The zone of thermal neutrality differs with clothing, season, activity, and all the other factors controlling heat production (Table 4). The comfort zone is very similar to the zone of thermal neutrality.

Sensations of warmth or cold depend not only on the temperature of the surrounding air as registered by a dry-bulb thermometer, but also upon the temperature indicated by a wet-bulb thermometer, upon air movement, and upon radiation effects. Dry air at a relatively high temperature may feel cooler than air of lower temperature with a high moisture content. Air motion makes any moderate condition feel cooler. Radiation to cold or from warm surfaces is another important factor under certain conditions affecting the comfort reaction of the individual.



[a] See footnote a, Fig. 5.

Fig. 6 . . . . Relation Between Radiation and Convection Loss from the Human Body and Dry-Bulb Temperature for Still Air[a, 14]

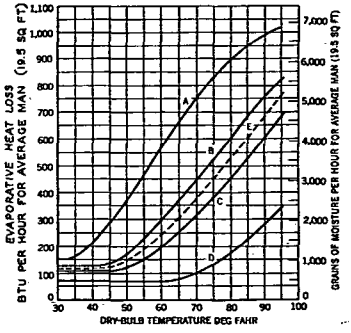
Combinations of temperature, humidity, and air movement which induce the same feeling of warmth are called thermo-equivalent conditions. A series of studies[22] at the ASHAE Research Laboratory established the equivalent conditions for practical use. This scale of thermo-equivalent conditions not only indicates the sensation of warmth, but also to a considerable degree determines the physiological *effects* on the body induced by heat or cold. For this reason, it is called the *effective temperature* scale or index, and it denotes sensory heat level.

Effective temperature is an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement. It was determined by trained subjects who compared the relative warmth of various air conditions in two adjoining conditioned rooms by passing back and forth from one room to the other.

The numerical value of the index for any given air conditions is fixed by the temperature of slowly moving (15 to

25 fpm air movement) saturated air which induces a like sensation of warmth or cold. Thus, any air condition has an effective temperature of 60 deg when it induces a sensation of warmth like that experienced in slowly moving air at 60 F saturated with moisture. The *effective temperature index* cannot be measured directly, but is determined from dry- and wet-bulb temperatures and air motion observations by reference to an Effective Temperature Chart (see Figs. 8, 9, and 10) or tables.

Fig. 8 gives the effective temperature for any combination of dry- and wet-bulb temperatures for *still air* (15 to 25 fpm) conditions. Charts similar to Fig. 8 for air velocities of 100 and 300 fpm have been presented in earlier editions of THE GUIDE, e.g., 1939. Fig. 9 is another form of effective



[a] See footnote a, Fig. 5.

Fig. 7 . . . . Evaporative Heat and Moisture Loss from the Human Body in Relation to Dry-Bulb Temperature for Still Air Conditions[a, 14]

temperature chart embodying all three variables: dry-bulb and wet-bulb temperatures, and air velocity.

As stated previously, effective temperature is an index of the degree of warmth experienced by the body. An effective temperature line is, therefore, a line defining the various combinations of conditions which will induce like sensations of warmth. It does not necessarily follow that like sensations of comfort will also be experienced along the entire length of an effective temperature line. Some degree of discomfort is likely to be experienced at very high or very low relative humidities, regardless of the effective temperature. It has also been found that the optimum effective temperature varies with the season, and is lower in winter than in summer.

Tests[14] made at the ASHAE Research Laboratory in very hot conditions, with subjects doing light work, were in very close agreement with the effective temperature chart. Other work[23] under similar environmental conditions, but with subjects walking 3 mph and carrying 20 lb packs, indicated that the effective temperature lines should be more nearly horizontal. It therefore appears that the slope of the ET lines may vary, depending upon the rate of work being performed.

Table 4 . . . . Comparison of Comfort Ranges With Zone of Thermal Neutrality

Investigators	Effective Temperature: Optimum Line	Effective Temperature: Range	Operative Temp Range	Remarks
Comfort Zone				
Houghten and Yaglou	66	63–71	...	Winter nonbasal; at rest, normally clothed. Men and women.
Yaglou and Drinker	71	66–75	...	Summer nonbasal; at rest and normally clothed. Men.
Yaglou	72.5	66–82	...	Entire year; nonbasal; at rest and stripped to waist. Men.
Keeton et al	75	74–76	...	Entire year; basal, nude. Steady state (9 hr exposure). Men and women.
Zone of Thermal Neutrality				
DuBois and Hardy	75	73.2–76.9	...	Basal; nude; men.
	71.8	64.8–76.0	...	Basal; clothed; men.
Winslow, Herrington, and Gagge	...	...	84.0–87.8	Nonbasal; at rest; nude; men.
	...	...	74 –84	Nonbasal; at rest; clothed; men.

Fig. 10 shows the ASHAE Comfort Chart[24] as published since 1950. The areas and arrows indicating the summer and winter comfort zones on the previous charts have been removed. The summer comfort zone was removed because it extended to temperatures where too large a percentage of the people would be uncomfortable. The winter comfort zone was removed for the same reason, and because of inadequate data in later studies.

The distribution curve, showing the percent of people feeling comfortable at various effective temperatures in *summer*, indicates that a maximum of 98 percent of the people were comfortable at 71 ET. The study was conducted with relative humidities between 30 and 70 percent.

The distribution curve shown on the previously used chart, showing the percent of people feeling comfortable at various effective temperatures in the *winter*, was based on research prior to 1932. This curve indicated that at 66 ET a maximum number of people were comfortable. Later studies[25] by the ASHAE Research Laboratory indicated that a maximum of 97.7 percent of the people were comfortable at 68 ET, and this finding has been confirmed by current practice.[26] However, adequate data from the later studies were available only for the ET range of 65 to 69, as presented in Fig. 10. The studies should be extended to cover a wider range. The lighter weight clothing, probably worn in the later studies, accounts for the higher desirable ET.