Table 1 .... Minimum Odor-free Air Requirements to Remove Objectionable Body Odors Under Laboratory Conditions[1]

Type of Occupants	Air Space per Person Cu Ft	Odor-free Air Supply CFM per Person
Heating season with or without recirculation. Air not conditioned.		
Sedentary adults of average socio-economic status	100	25
	200	16
	300	12
	500	7
Laborers	200	23
Grade school children of average socio-economic status	100	29
	200	21
	300	17
	500	11
Grade school children of lower socio-economic status	200	38
Children attending private grade schools	100	22
Heating season. Air humidified by means of centrifugal humidifier. Water atomization rate 8 to 10 gph. Total air circulation 30 cfm per person.		
Sedentary adults	200	12
Summer season. Air cooled and dehumidified by means of a spray dehumidifier. Spray water changed daily. Total air circulation 30 cfm per person.		
Sedentary adults	200	<4

from heating appliances). For such conditions, the control of air temperature is the major consideration.

In more crowded rooms (large offices, large workrooms, auditoriums), where the cubic space per person is less, and it is usually impossible to admit untempered outdoor air without creating drafts, mechanical ventilation is essential.

Freedom of movement, action, and thought, together with the variability of stimuli experienced by persons under ideal conditions in the country, mountains, or seashore, undoubtedly has some stimulating effect. Various experimenters have attempted to duplicate the invigorating qualities of outdoor air by the use of ionization, ozone, or ultraviolet light.[4]

Air conditioning today provides control of most of the climatological environmental factors for the service and comfort of man. There are, however, some less well known environmental factors not presently controlled that may be of increasing importance to the engineer desiring to provide an artificial atmosphere equal in all respects to outdoor air having the most favorable qualities. Atmospheric electricity is one such factor. Under normal circumstances, the ion content of conditioned air may differ from that of outdoor air. Such devices as mechanical filters, electrostatic precipitators, ultraviolet lamps, incandescent heaters, and spray or steam-jet type humidifiers are known to alter markedly the *normal* ion density. However, research to date has failed to show any significant effect of air ionization on the comfort of normal, healthy individuals.[4] There is still much to be learned about the biological effects of air ionization, although the literature on the subject is quite extensive.[5]

Ozone in amounts of 0.01 to 0.05 ppm of air is allowable in comfort air conditioning. Above this limit, there is a pungent, unpleasant odor, and perhaps respiratory distress, depression, and stupor.[6]

PHYSICAL IMPURITIES IN AIR

Dust particles of almost any type can produce irritation of the mucous membranes of the nose and throat, if present in high concentrations. Certain dusts may be very harmful, but coal dust is well tolerated. The effects of various industrial dusts, pollens, etc., are discussed in Chapter 11.

A certain portion of the dissemination of disease in confined spaces may be due to pathogenic organisms floating in the air like dust particles. (See Chapter 10.)

While, it may be possible in some instances, to reduce the physical impurities of the air by dilution from a non-contaminated source, such a source is rarely available. Frequently, outdoor air contains a higher concentration of physical impurities than indoor air. Therefore, it is usually desirable to reduce the concentration of physical impurities by air cleaning methods. (See Chapter 36.)

THERMAL INTERCHANGES WITH ENVIRONMENT

Body temperature depends upon the balance between heat production and heat loss. Heat resulting from oxidation of food elements in the body (metabolism) maintains the body temperature well above that of the surrounding air in a cool or cold environment. At the same time, heat is constantly lost from the body by radiation, convection, and evaporation. Since, under ordinary resting conditions, the body temperature is maintained within its normal range of 97 to 99 F, the heat production must be balanced by the heat loss. During work, the body temperature may rise; afternoon temperatures of normal persons average 1 deg above the resting value of the morning, whether they are working or not.

The fundamental thermodynamic processes concerned in heat interchanges between the body and its environment may be described by the equation:

$$M = \pm S + E \pm R \pm C \qquad (1)$$

where

M = rate of metabolism, heat produced within the body.
S = rate of storage, change in intrinsic body heat.
E = rate of evaporative heat loss.
R = rate of radiative heat loss or gain.
C = rate of convective heat loss or gain.

The rate of metabolism, M, is always positive. The storage, S, may be either positive or negative, depending upon whether heat is being stored or depleted, owing to a rise or fall in body temperature. Under ordinary circumstances (when the dew point of the air is below the body surface temperature), the evaporation loss, E, is always positive, that is, heat from metabolism supplies this loss. R and C are positive when body surface temperature is above that of walls and air, and negative when it is below.

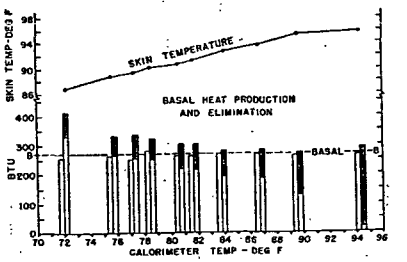
DuBois,[7] after careful calorimeter studies on a fasting, nude *man, plotted the partition* of body heat loss and heat production as a function of temperature. Fig. 1 shows some disparity between heat production and heat loss. This disparity

is S in Equation 1. In the central range of the experiments, S was quite low, and no increase in heat loss by vaporization was apparent.

Within the range of 81–86 F air temperature, with still air, there is, for a resting, nude man, a point at which his body needs to take no particular action in order to maintain its heat balance. If he is clothed, or if he is active, this point will naturally lie at a lower level. At this point, which may be termed the *neutral point* for that individual, conditions are neither too hot nor too cold. If, through a fall in air temperature or a rise in air movement, the rate of heat loss from the skin to the environment is increased, then the body must do something to counteract this heat loss. Over a certain range, the body can do this by decreasing the flow of blood through the skin. This will result in some cooling of the skin and subjacent tissues, but the temperature of the deep tissues will be maintained. The range of external conditions over which this may be achieved may be termed the *zone of vaso-motor regulation against cold.* Beyond this range, the temperature of the superficial tissues will fall still further, and that of the deep tissues will fall as well, unless some other steps are taken. The body normally does react; it increases heat production by increasing muscular tension, by shivering, or by spontaneous increase in activity.[8] As long as these reactions are adequate to meet the increased rate of heat loss to the environment, a fall in deep body temperature may be prevented. Such conditions may be said to lie in the *zone of metabolic regulation against cold.* Beyond this point, the body enters the *zone of inevitable body cooling.*

It will be seen that, in man, deep body temperature is preserved over an important range of cold external conditions, at the expense of (1) a fall in the temperature of the peripheral tissues, and (2) an increased expenditure of energy. In the first of these, the farther away superficial tissue lies from the central body mass, the more readily will its temperature fall.

On the hot side of the neutral point, there exists a *zone of vaso-motor regulation against heat,* corresponding to that against cold. The blood flow through the skin is increased when the opportunities for heat loss to the environment are restricted.[9] This increase in blood flow may double or triple the conductance of the superficial tissues over that characteristic of the neutral point, and the temperature of the skin surface may rise until it is only three degrees below that of the deep tissues. If this increase in blood flow is unable to balance the restriction in heat loss, the body has entered the next zone. Once again, the normal body takes steps to prevent a change in its deep temperature, but they are not the counterpart of the steps taken when exposed to cold. There is, in fact, very little change in heat production, beyond that resulting from a disinclination for exertion. The second *line of defense* is a powerful method of promoting heat loss, the provision of water, through the operation of the sweat glands, for evaporative cooling. As long as evaporation is adequate to restore the desired heat loss, the body is in the *zone of evaporative regulation against heat.* When evaporation ceases to be adequate, the body is in the *zone of inevitable body heating.* The body enjoys less latitude in this zone than it did in the corresponding zone on the cold side, but when the deep temperature rises more than 4 F deg, it loses its efficiency, and body temperatures above 110 F may be lethal if endured for longer than a few minutes. All factors which affect the evaporation of water from the skin affect heat regulation in the zone of evaporative regulation. Atmospheric vapor pressure and air motion are the most important of these. With dry-bulb temperature above



** Normal control, naked, in calorimeter at temperatures from 72.8 to 94.1 F. First column in each experiment represents heat production as determined by indirect calorimetry, the second column, heat elimination. The portion marked with vertical lines represents vaporization; the unmarked area, radiation, and convection. The skin temperature represents the average reading of 18 spots on the surface.*

Fig. 1 .... Heat Loss from Human Being by Evaporation and by Radiation and Convection*

body temperature, air motion facilitates evaporative heat loss by removing hot humid air from contact with the skin and replacing it with relatively drier air.

Temperature regulation in man requires an intact set of sensory nerves, a normal sympathetic nerve supply to sweat glands and blood vessels, a great many sweat glands, and a circulatory system capable of carrying heat from muscles and viscera to the skin by circulation of the blood.

Some of the phenomena of body temperature control are shown graphically in Fig. 2. The dotted curves, from a study at the John B. Pierce Laboratory of Hygiene,[10] are for subjects lightly clothed in a semi-reclining position, and give the relation between the dry-bulb temperature of the environment (with about 45 percent relative humidity) and the metabolic rate (heat production), the rate of heat dissipation by radiation and convection combined, and the latent heat loss due to evaporation from the skin and the respiratory tract. The smooth line curves from the work of the ASHRAE Research Laboratory[11] give the same relationships for healthy, male subjects (18 to 24 years of age), seated at rest and dressed in customary winter indoor clothing. The Pierce Laboratory data for the semi-reclining subjects also include the rate of heat storage (either positive or negative) due to a rise or fall in body temperature. For the normally clothed subjects, a curve gives the total heat loss, that is, the sum of the radiation, convection, and evaporative losses. Storage is given by the difference between the metabolism and total heat loss.

The small difference between the metabolic rates for the two groups of subjects may be accounted for by difference in activity. Heat exchange between the body and the environment by radiation and convection is greater for the lightly clothed subject, both for cool conditions where there is excessive heat loss, and for very warm conditions where there is transfer of heat from the atmosphere to the body. The two curves for evaporative loss serve to show how physiological control uses evaporation of sweat to maintain equilibrium at high temperatures. Below 75 F, for the normally clothed sub-