high, but operating costs might be cut to the vanishing point.

Such an idea may bring a smile, but it is now becoming almost respectable, for the Massachusetts Institute of Technology has begun some experimentation along this line.

Photochemical Reactions. The foregoing suggest some interesting ideas, but with the exception of heating buildings, they do not seem to come within a gunshot of practicality. I have saved what I consider to be the best idea until the last. Namely, men should try to do efficiently what nature has been doing inefficiently for a billion years—utilize photochemical reactions. The basis of all life is some simple photochemical reaction as

$$H_2O + CO_2 + \text{Radiant Energy} = \underset{\text{Formaldehyde}}{HCHO} + O_2$$

The formaldehyde may be thought of as forming simple sugars, which then serve as the basic material for the multitude of complex compounds in plants. I realize that the actual photochemical reaction is much more complicated than this and that the formaldehyde theory is no longer tenable, but I am using this as the simplest picture to illustrate the point. What we should like to do would be to take some such simple compound as formaldehyde formed with the help of radiant energy, put it in an electrochemical cell, expose it to oxygen, and then reverse the above reaction and get back the stored energy as electrical energy—at high efficiency. Formaldehyde *can* be oxidized in a cell in a basic solution to give formic acid and a small amount of electrical energy. Perhaps all that is needed is a proper catalyst to complete the oxidation to CO_2 and water and get back nearly all the stored energy.

The catalyst which nature used for performing the photosynthesis of the above equation is chlorophyll. That's the best catalyst known, but it's very poor. Plants are very inefficient storers of energy. Even the most luxuriant plants have an energy storage efficiency of less than 2 per cent. We ought to be able to do a lot better than that.

It's a wide-open field, this study of photosynthesis and the study of oxidation cells which will reverse the reaction. That's the reason it's hopeful. The systems which might be used would not have to be limited to organic compounds. It may well be that inorganic compounds offer the most hope. The satisfactory system would need to be one that is as light-sensitive as the chemicals on a photographic film, as easily reversible as a lead storage cell. If such a photochemical-electrical system can be developed the problem of energy capture and storage would be solved. The storage of the energy would be simply that of storing chemical compounds. We're used to doing that with coal.

CONCLUSION

Some day the photochemical approach to energy utilization will either be solved or definitely proved impracticable. In view of our own energy resources it may seem foolish to start working on it now. But it may not be too early to start. If we wait too long we may be caught short as energy supplies dwindle. Moreover, many parts of the world already suffer from insufficient energy. Many international problems might disappear if every group of people could fully utilize the energy falling on its roof-tops.

Enough energy falls on about 200 square miles of an arid region like the Mohave Desert to supply the United States. When we become ingenious enough to efficiently utilize the energy treasure wherever it may fall, we may solve many of our economic problems. It might be a little hard on the railroads that haul coal, but every one else would benefit.

A PRACTICAL SYSTEM OF UNITS FOR THE DESCRIPTION OF THE HEAT EXCHANGE OF MAN WITH HIS ENVIRONMENT

By Drs. A. P. GAGGE, Yale University; A. C. BURTON, University of Toronto, and H. C. BAZETT, University of Pennsylvania

THERE are three groups interested in the thermal exchanges of the human body, namely, the heating engineers, the physicians and the physiologists. In the English-speaking countries each of these groups by training uses a different set of physical units. The heating engineer uses B.T.U., square feet and °F., the physician calories, square meters and °F., and the physiologist calories, square meters and °C. Consequently they find it difficult to make themselves mutually understandable when discussing their common interest of heat exchange. It is our proposal to present a system of units such that all three groups may think in terms of a common and at the same time a practical system.

Thermal comfort in any environment is dependent on many variables. There is evidence that in the final analysis comfort is dependent largely upon skin temperature. The optimal average skin temperature for comfort appears to be 92° F (33° C). Such an average skin temperature may be maintained in spite of exposure to cold if the clothing is properly chosen in relation to activity. Temperature regulation can be attained under less favorable conditions by adjustments of the skin circulation and evaporation of water when skin temperature may have higher or lower levels. Optimal comfort, however, is not achieved in the presence of such adjustments.

If thermal equilibrium is to be attained without the necessity of these physiological adjustments, it is obvious that the three factors concerned for a balance at an assumed optimal skin temperature are the rate of heat production of the body (dependent on the degree of muscular activity), the insulating value of the clothing and the environmental temperature. Consequently, the use of practical units for thermal activity and for insulation would provide a uniform system to describe comfortable conditions in relation to the heat exchange of man with his environment.

The proposed thermal activity unit may be defined as 50 calories per hour per square meter of the surface area of the individual (or 18.5 B.T.U./Hr./Sq.Ft.). This is approximately the metabolism of a subject resting in a sitting position under conditions of thermal comfort. This unit may be called 1 *met,* and may be utilized by any of the groups, regardless of the other system of units employed.

The unit for thermal insulation of clothing is logically the amount of insulation necessary to maintain in comfort such a sitting-resting subject in a normally ventilated room (air movement 20 ft/min or 10 cm/sec) at a temperature of 70° F (21° C) and a humidity of the air which is less than 50 per cent. This unit of insulation may be called 1 *clo.* Since, in the conditions outlined above, thermal equilibrium is maintained, the insulating value of 1 clo can be expressed and defined in terms of the common system of units.

Thermal insulation is the resistance offered to flow of heat, just as electrical insulation is related to flow of electricity. It is measured by the ratio of the difference in temperature between two surfaces, to the flow of heat per unit area that results. Thermal insulations thus estimated and expressed in clo units, may be treated mathematically just as are the comparable electrical resistances expressed in ohms. For men in the conditions already specified, it may be assumed that 24 per cent. of the resting metabolic heat is dissipated by evaporation of insensible perspiration. The remaining heat transmitted through the clothing is, therefore, 38 (76 per cent. of 50) Cals./Hr./Sq.M. The difference in temperature concerned is 33°–21° C. Then the total insulation, which is the sum of the insulation of the clothing, I_{Cl}, and that of the ambient air, I_A, is given in metric units by the equation

$$I_{Cl} + I_A = \frac{33 - 21}{38} = 0.32 \frac{°C.}{\text{Cals./Hr./Sq. M.}}$$

From previous work[1] at the John B. Pierce Laboratory, the insulation of the air in metric units at the air movement cited is

$$0.14 \frac{°C.}{\text{Cals./Hr./Sq. M.}}$$

Consequently, the insulation of the clothing, which is equal by definition to 1 clo, is

$$0.32 - 0.14 = 0.18 \frac{°C.}{\text{Cals./Hr./Sq. M.}}$$

The clo unit is therefore defined as

$$0.18 \frac{°C.}{\text{Cals./Hr./Sq. M.}} \text{ or } 0.88 \frac{°F.}{\text{B.T.U./Hr./Sq. Ft.}}$$

In general, the relation between the insulation of the clothing, I_{Cl}, that of the ambient air, I_A, the heat production, M, the evaporated loss, E, and the temperature of the air, T_A, for optimal comfort expressed in Met and Clo units is

$$I_{Cl} + I_A = \frac{33° - T_A}{9.0\ (M-E)}, \text{ for °C.,}$$

or

$$= \frac{92° - T_A}{16.2\ (M-E)}, \text{ for °F.}$$

These equations hold only for muscular activity when no external work is accomplished. When the latter is the case the work performed, W, must also be subtracted in the denominator from the total heat production, M.

The value of I_A varies with the surrounding air movement, whether this be produced by wind or the activity of the subject. The variations in I_A so produced are indicated in Table I. Since the heat loss

TABLE I

VARIATIONS IN INSULATION OF AMBIENT AIR IN CLO UNITS

Air movement	Resting sitting	Level walking		
		Slow	Normal	Fast
Normal indoors (20 F.P.M.)	.78	.37	.33	.29
Drafty indoors (100 F.P.M.)	.40	.32	.29	.26
Normal outdoors (5 M.P.H.)	.30	.24	.22	.20
Windy outdoors (20 M.P.H.)	.19	.18	.17	.16

is determined by the total insulation, it is obvious that the effect of variations in I_A produced by air movement is less important, the heavier the clothing. It may also be seen that the total insulation of the air plus normal clothing is reduced 33 per cent. if the subject changes from sitting indoors to sitting out-of-doors on a windy day. On the other hand, if the subject is doing level walking the reduction is only 12 per cent.

It is now possible to predict what are the optimal temperatures for persons wearing normal clothing (1

[1] Winslow, Gagge and Herrington, *Am. Jour. Physiol.*, 131: 79, 1940.

clo) engaged in the following degrees of exercise. It is assumed, for purposes of analysis, that 24 per cent. of the total energy production is lost by evaporation, and that, as before, the optimal skin temperature for comfort in exercise is 92° (33° C). Neither of these assumptions are likely to be precisely true. The optimal temperatures are given in Table II.

TABLE II

OPTIMAL TEMPERATURES FOR COMFORT WITH EXERCISE IN NORMAL CLOTHING

Place	Resting sitting M = 1	Slow level walking M = 2	Normal level walking M = 3	Fast level walking M = 4
Normal indoors.	70.0° F	58.4° F	43.0° F	28.5° F
Drafty indoors..	74.8°	59.6°	45.6°	30.0°
Normal outdoors	76.0°	61.5°	47.0°	33.0°
Windy outdoors	77.6°	63.2°	48.8°	35.0°

It may be deduced from Table II that if the external temperature is much above that indicated, normal equilibrium can only be attained by increasing the evaporative heat loss through sweating. The amount of such increase can be approximately estimated. For instance, if an individual is walking fast indoors (producing 4 mets) at a temperature of 58.4° F, at which only 2 mets can be dissipated with comfort, the additional 2 mets must be lost by evaporation. (For more precise predictions, the changes in insulation of the ambient air with activity would have to be considered.)

Also the ideal amount of clothing, in clos, necessary for comfort for various degrees of rest and exercise in different outdoor environmental temperatures may be predicted as shown in Table III.

The net efficiency of the human body in performing external work does not exceed 20 per cent., *i.e.,* in doing ½ met of external work the extra heat production will be at least 2½ mets, and the total will rise to at least 3½ mets. In many cases the efficiency is far less, as in level walking where the heat production rises to several mets without the accomplishment of any external work. Using the figure of 20 per cent., the maximum clothing that could be worn in comfort in a given task may be calculated. For example, a mountaineer weighing 160 pounds, surface area 1.9 square meters, climbing at the rate of 1,250 feet per hour, would accomplish a mean rate of work of 0.75 mets. The minimal total metabolism would be 4.75 mets, and the heat to be lost 4.0 mets. Since fast level walking has been assumed as equivalent to 4 mets, it may be seen from Table III that at an external temperature of 30° F without wind, the maximal clothing he could wear for comfort would be about 1 clo.

TABLE III

IDEAL CLOTHING FOR COMFORT

Environmental temperature	Resting sitting	Slow level walking	Normal level walking	Fast level walking
70° F—Normal outdoors	1.5	.7	.4	.3
50° F— " "	3.1	1.5	.9	.7
30° F— " "	4.7	2.3	1.5	1.1
0° F— " "	7.2	3.5	2.3	1.7

The advantage of using the practical units, *met* and *clo,* instead of the classical metric and British units is that they describe energy and insulation values in terms of familiar concepts. One *clo* approximately is the value of the insulation of one's everyday clothing (and incidentally of a heavy top coat alone). The additional insulation conferred by top coats, etc., may be expressed in these units. One met unit varies in absolute amount with the size of the individual. For a man of average size it is approximately equivalent to the heat generated by a 100-watt lamp. Thus, speaking in units associated with one's normal experience, the engineers, the physicians and the physiologists should be able to use their individual training more effectively in a common effort to solve current problems of heating and ventilation, as well as those of the physiological adjustments associated with the maintenance of heat balance.

OBITUARY

FRANK BURR MALLORY

DR. FRANK BURR MALLORY died at his home in Brookline, Mass., on September 27, at the age of 78. Dr. Mallory was born in Cleveland, Ohio, on November 12, 1862. He graduated from Harvard College in 1886 with the degree of A.B. He received his A.M. and M.D. from Harvard Medical School in 1890. He became associated with Harvard Medical School in 1890, first as assistant in histology, later as assistant in pathology. He was appointed assistant professor of pathology in 1896, associate professor in 1901 and professor in 1928. He retired with the title of emeritus professor in 1932. He joined the pathological staff of the Boston City Hospital in 1891 and was made pathologist in 1908. In 1932, at the age of 70, he retired, becoming consulting pathologist.

Dr. Mallory received the honorary degree of Sc.D. from Tufts College in 1928 and from Boston University in 1932. He was awarded the Kober medal in 1935 by the Association of American Physicians for outstanding service in pathology. In the same year he received the gold-headed cane from the American Association of Pathologists and Bacteriologists. This cane was presented to the association by Dr. Harold