VOLUME XXXV AUGUST, 1935 No. 3

THE EFFECTIVE RADIATING SURFACE OF THE HUMAN BODY

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In a uniform enclosure the heat loss by radiation from a freely exposed heated cylinder varies directly as its surface area. The loss per unit of surface area is given by Stefan's well-known equation, and depends on the emissivity of the surface and on the difference between the fourth powers of the absolute temperatures of the surface of the cylinder and the surrounding surfaces.

For the calculation of the heat loss by radiation from the human body it is necessary to know (i) the radiation per unit area of body surface, and (ii) the area of the radiating surface. The surface of the clothed, and even of the nude, human body varies in temperature in different parts, but a knowledge of the average radiation intensity from the whole surface can be obtained by means of a radiation thermopile. The chief difficulty in estimating the total radiation loss is that of ascertaining the area of effective radiating surface, for the radiating surface exposed varies with the posture of the body.

A close approximation to the true surface area of the human body is given by the height-weight formula of Du Bois and Du Bois (1916):

$$A = W^{0\cdot425} \times H^{0\cdot725} \times 71\cdot85,$$

where A is the surface area in sq. cm., W is the body weight in kg., and H is the height in cm.

It is usual to express the results of metabolism determinations in terms of the surface area as ascertained by this equation, but in studies of the effects of the thermal environment on body heat loss some allowance must be made for the effects of posture on the surface area effective for heat dissipation. When the body is in a crouching posture its effective radiating surface is distinctly less than when the person is standing normally, and still less than when the legs and arms are outstretched. Similarly, the surface freely exposed to convection effects is less when the body is in a huddled posture. On the other hand, one effect of clothing is to increase the surface area.

Previous workers have drawn attention to the question of effective radiating surface. Fishenden and Willgress (1925) mention the Du Bois equation, and go on to say that the effective surface for radiation and convection is much less than the total surface. Barker (1932) assumes that a person whose total surface area is 21 sq. ft. has an effective radiating surface of 15 sq. ft., while the whole 21 sq. ft. is effective for convection losses. It may well be that the effective convection surface is somewhat greater than the surface which is effective for radiation, but in normal postures it will almost invariably happen that some areas of the body surface are in contact and thus protect each other from convection losses.

The electrical capacity method

Bohnenkamp and his collaborators lay great stress on the necessity for ascertaining the effective radiating surface of the body. They point out that the total loss by radiation should be calculated by integrating the radiation loss over the whole surface of the body, and they describe a method by which the projection surface of the body can be estimated by photographing it from various angles (Bohnenkamp and Ernst, 1931). This method involves a considerable amount of labour, and a simpler method of estimating the effective radiating surface is put forward by Bohnenkamp and Pasquay (1931). The electrical capacity of the subject is measured, and from this measurement the effective radiating capacity is calculated. Examples are given showing that for the same subject very different values are obtained when the posture is varied.

This method has been criticised by Deighton (1933), who points out that the connection between surface area and electrical capacity depends on the assumption that the surface of a human being is a perfect electrical conductor, insulated, and not containing within itself any source of E.M.F. Insulation can be more or less achieved, but neither of the other assumptions is strictly true. "Hence", says Deighton, "the measurement of radiation loss per unit of Bohnenkamp-surface *may* be almost as indefinite really as measuring sugar by number of lumps; it may, however, also turn out to share the common convenience of this enumeration of slipshod units."

Bohnenkamp and Pasquay's method may generally give a fair estimate of the effective radiating surface, but an example drawn from their paper shows that considerable errors may arise. Details are given of a male subject 168 cm. tall and weighing 61 kg. (total surface area by the Du Bois equation = 16,900 sq. cm.). By the electrical capacity method his effective radiating surface was 13,900 sq. cm. when in the normal posture (Grundstellung), 6150 sq. cm. when cramped up, and 24,500 sq. cm. when the arms and legs were outstretched. It is difficult to see how the radiating surface with the arms and legs outstretched can be nearly twice as great as the area in the basal posture. The effective radiating surface cannot be greater than the total surface area, which for the nude subject is calculated to be 16,900 sq. cm.

The effective radiating surface area given for the cramped posture is also an impossible one, as can be shown from a consideration of the subject's body weight and specific gravity. Bohnenkamp and Schmäh (1931) find that the specific gravity of a normal man is about 1·095, while that of a woman is about 1·07; and Mumford (1927) says that the specific gravity of the body ranges from 0·95 to 1·12. Now Bohnenkamp's subject weighed 61 kg., and with a specific gravity of 1·12 (Mumford's maximum value, and a more favourable figure than Bohnenkamp's) this represents a minimum body volume of 54,460 c.c. A sphere of this volume has a surface area of 6950 sq. cm., and this is the minimum radiating surface which could possibly be presented by Bohnenkamp's subject; so that in this case, with the most favourable assumptions, the electrical capacity method gives an area which is 12 per cent. too small.

THE APPLICATION OF SIMPSON'S RULE

For the estimation of the body-surface area of animals, Deighton (1932) advocates an adaptation of Simpson's rule, with many measurements of perimeter, combined with photographs of side and plan views.

The writer has used the simple application of Simpson's rule as a ready method of estimating the effective radiating surface of the body. Measurements were made on two nude male subjects, (*a*) when standing in the "attention" position, and (*b*) when crouched so as to present the least possible radiating surface. Further measurements were made on the same subjects when wearing their customary clothing and standing in the "attention" position. The overall girth was measured at intervals of 10 cm. of height, and the mean girth multiplied by the height. This gave the area of the vertical projection surface, and an addition was made for the estimated horizontal projection area.

The figures relating to the two subjects are given below:

	Subject A	Subject B
Height (cm.)	171	164
Weight, naked (kg.)	59·9	62·8
Total surface area, Du Bois (sq. cm.)	17,010	16,840
Estimated effective radiating surface:		
(*a*) Standing, clothed (sq. cm.)	17,680	17,370
(*b*) Standing, nude (sq. cm.)	13,950	14,120
(*c*) Crouching, nude (sq. cm.)	11,270	12,950

Estimated in the way described, the effective radiating surface for the two clothed subjects was very nearly the same as the total surface of the naked body calculated from the Du Bois equation. Bohnenkamp and Pasquay give an example of one subject (height 170·5 cm., weight 62·5 kg.) whose effective surface area measured by the electrical capacity method was 13,100 sq. cm. when unclothed, and 17,100 sq. cm. when clothed. For this subject the Du Bois formula gives a total surface area of 17,200 sq. cm. These results suggest that, for a normal standing posture, no serious error results from assuming that the effective radiating surface of the clothed subject is of about the same area as that given by the Du Bois equation for the skin area.

The estimates for the nude, crouching subjects are only 19 and 8 per cent. less than those for the same subjects when standing nude. These small reductions are very different from the 56 per cent. reduction noted by Bohnenkamp and Pasquay in their similar comparison.

Summary

The effects of posture and clothing on the effective radiating surface of the body are discussed. Some results obtained by Bohnenkamp and Pasquay by their electrical capacity method are criticised, and measurements made by the application of Simpson's rule are described.

The conclusion is reached that no serious error results from assuming that the effective radiating surface of the clothed subject, when in a normal standing posture, is of about the same area as that given by the Du Bois equation for skin area.

In two nude subjects, crouching in the most cramped position possible, the estimated radiating surface was reduced by 19 and 8 per cent. as compared with a standing posture.

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(*MS. received for publication* 8. v. 1935.—Ed.)