SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 81, NUMBER 6

A STUDY OF BODY RADIATION

BY
L. B. ALDRICH

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CITY OF WASHINGTON
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INTRODUCTION

The following is a report submitted to the New York Commission on Ventilation, covering experiments conducted by the Smithsonian Institution under a grant of $1000 from the Commission.

The *raison d'être* of the experiments here described is explained in the following quotation from A Preliminary Note on Radiant Body-heat and the School Ventilation Problem, by T. J. Duffield, Executive Secretary, New York Commission on Ventilation:

> Satisfactory temperature conditions in the classroom can be established and maintained only when the loss of body heat from each pupil is not interfered with by similar processes of his neighbors or other bodies. In the classroom, the pupil loses heat by evaporation, convection (including conduction), and radiation. It is only through thorough consideration of each of these types of body heat loss that we can hope to determine logical standards of floor and air space per pupil for classrooms.
>
> The heat required to evaporate the moisture both in the lungs and from the body surface is a real loss as far as the pupil is concerned, but the heat-loss by evaporation does not enter into the problem of ventilation, because the heat has disappeared in the form of *latent heat of vaporization.* Modern ventilation—using that term in the strict sense—can cope successfully with the problem of removing the *convected* heat, which, under normal conditions of school-room construction and occupancy, is transferred by *conduction* to the air which surrounds the body. The air, thus heated, expands, rises and may be readily removed and replaced by cooler air. In these ways, two of the three forms of body heat loss are accomplished, but concerning the third form—*radiation*—very little experimental work appears to have been done. . . . .
>
> . . . . The heat loss by radiation can be cared for only if artificial sources of radiant heat in the classroom are properly shielded, and if adequate floor space per pupil in the seating section is provided.
>
> Just what the area of this space should be is a matter requiring further study, but, by reason of the different factors affected, it is evident that the provision of additional air space by making ceilings higher cannot compensate for inadequate floor space. The amount of body heat loss by radiation and the thermal gradients for pupils of different average ages must be investigated before standards of floor space in classroom design can be established scientifically and logically.

After a conference with Dr. C. G. Abbot, Secretary of the Smithsonian Institution, the New York Commission on Ventilation in June, 1927, made a grant of $1000 to the Institution to carry out a study of body heat loss by radiation. The prosecution of this study was delegated by Dr. Abbot to the writer. In a letter dated July 20, 1927, Mr. Duffield, Executive Secretary of the New York Commission on Ventilation, says:

> Our problems, as we appreciate them are two:
>
> (1) We want to know the amount of body heat loss by radiation and its relation to the total under various conditions of air temperature, and if they

would have any influence under varying conditions of humidity and air motion as well. Of course we are primarily interested in this as it affects the normally clothed school child, but I feel that this study should be extended to include adults as well, in order that we may make a definite contribution to our knowledge concerning the relative importance of the different types of heat loss under varying external conditions.

(2) We are greatly interested in the thermal heat gradients about pupils normally clothed under conditions prevailing in the school rooms where the average pupil is surrounded by his radiant neighbors, distance from him 20 to 24 inches. This matter should be studied at various temperatures ranging from 60° to 70° F. and if the findings of the first study warrant it, under various conditions of humidity and rates of air change as well.

As a preliminary, in order to discover what criteria govern the spacing of children in classrooms, the following letter, signed by the Acting Secretary of the Smithsonian Institution, was sent in August, 1927, to the superintendents of schools in ten of the larger cities of the United States:

At the suggestion of the New York Commission on Ventilation, the Smithsonian Institution is conducting a research concerning the amount of body heat loss by radiation, particularly as it affects children in the classroom.

As an aid to this research, the Institution would greatly appreciate your kindness in replying to the following three queries:

(1) In the schools under your supervision, what considerations were factors in establishing the space allotted to each individual in the classrooms?

(2) In particular, was any consideration given to the loss of heat by radiation from the individual pupils?

(3) Are the radiators or other artificial heat sources in classrooms shielded to prevent direct radiation to the pupils?

Your coöperation is earnestly hoped for.

Seven replies were received. To question (1), all seven answered that the classrooms were of certain standard sizes, determined generally by state law. To question (2), all seven replied no. To question (3), six answered no and one yes. This correspondence makes it evident that as yet the question of radiation exchange between pupils and surrounding objects has been given practically no consideration in designing classrooms.

DR. ABBOT'S EXPERIMENTS IN 1921

In the spring of 1921, Dr. Abbot conducted a series of experiments on the radiation from the nude body. This work was carried out at the invitation of Dr. F. G. Benedict in the Nutrition Laboratory of the Carnegie Institution in Boston. A description of this work and summary of Dr. Abbot's results, since they have not been previously published, are with his permission incorporated here.

In 1920 the Smithsonian Astrophysical Observatory designed and built a new instrument for the measurement of radiation called the "melikeron." It is essentially different from the ordinary type of radiation instrument such as the pyranometer, pyrgeometer, bolometer, etc., in that radiation is absorbed not upon a flat surface but by a device shaped like a honeycomb. This makes the melikeron, by virtue of its form, approximately a "black body," capable of absorbing practically all radiation falling upon it. A detailed description of the instrument and tests made upon it are given in Smithsonian Miscel-

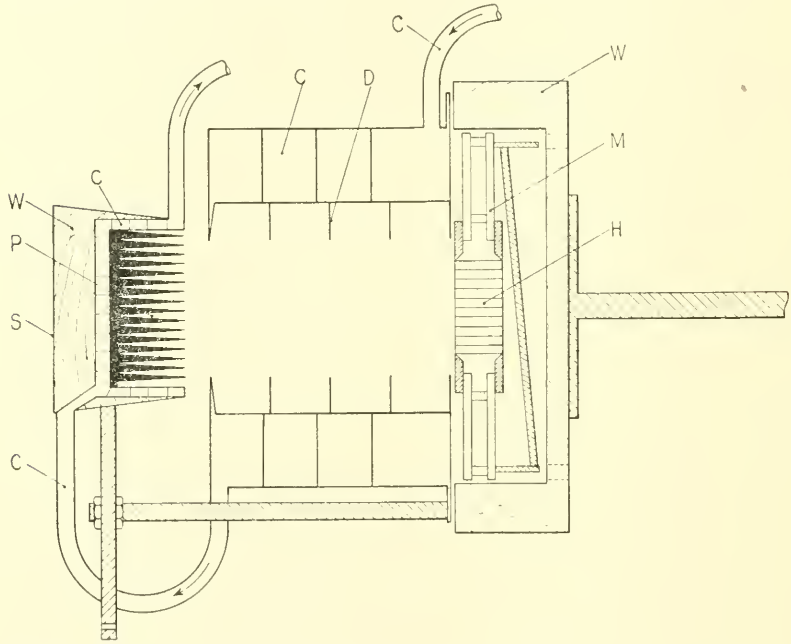

FIG. 1.—Melikeron and mounting, showing special water-circulating vestibule and water-circulating, "pin-cushion" shutter.

W—Wooden insulator.
M—Melikeron.
S—Shutter.
H—Honeycomb absorber.
D—Metal diaphragms.
C—Circulating water.
P—Blackened metal points.

laneous Collections, Vol. 72, No. 13. Being well adapted to the measurement of long wave radiation such as is emitted by bodies at low temperature, Melikeron No. 1 was chosen by Dr. Abbot for his measurements on the radiation from a nude subject in Dr. Benedict's laboratory. A special mounting was made, with the melikeron enclosed in a wooden case to keep air currents away. The front was provided with a diaphragmed vestibule through which water circulated. The diaphragms helped to prevent convection currents from reaching the honeycomb and also limited the radiation received to a known solid angle. A water circulating shutter completed the mounting. The side of the shutter exposed to the melikeron consisted of a large number of projecting metallic points and resembled a "pin-cushion." This made the shutter as well as the melikeron an approximately "black body" by virtue of its form. The vestibule and shutter are shown in cross-section in figure 1.

The melikeron and mounting were securely clamped to the round of a chair back. Observations were made upon the nude subject standing or sitting before the instrument so that the skin was about 15 mm. from the shutter. Direct skin temperature measurements were made at the same positions and as nearly as possible at the same time by Dr. Benedict, using his rubber-backed thermoelement device described in his paper, "The temperature of the human skin" (Asher-Spiro's Ergebnisse der Physiologie, Supplement-Band, 1925).

To abstract from Dr. Abbot's notes—

Suppose the temperature of the "pin-cushion" shutter is $T_0 = 273 + t_0$. Its radiation is $\sigma T_0^4 = 8.20 \times 10^{-11} \times (273 + t_0)^4$ in small calories per sq. cm. per minute (Stefan-Boltzmann formula, see Smithsonian Physical Tables, p. 247). This applies to radiation to a whole hemisphere. The jacket surrounding the melikeron limits the radiation to a circular opening 3.66 cm. in diameter and 7.03 cm. from the absorbing surface of the melikeron. It is necessary to determine what part of the total radiation from a whole hemisphere enters through this opening. See figure 9.

Let O be the center of the absorbing surface of the melikeron, and AB the opening in the jacket. Then the area of the opening AB will be

$$\int_{\theta=0}^{\theta=\theta} (2\pi\rho \sin\theta)\rho d\theta$$

and the radiation received on the horizontal surface at O will be proportional to

$$\int_{\theta=0}^{=\theta} 2\pi\rho \sin\theta\rho d\theta \cos\theta$$

$$= 2\pi\rho^2 \int_0^\theta \sin\theta\cos\theta d\theta = \pi\rho^2 \sin^2\theta$$

For the whole hemisphere this becomes $\pi\rho^2$

The part of the total radiation entering the vestibule is the ratio

$$\frac{\pi\rho^2 \sin^2\theta}{\pi\rho^2} = \sin^2\theta$$

For diameter 3.66 cm. and $\rho' = 7.03$ cm.,

$$\sin^2\theta = \frac{(1.83)^2}{(1.83)^2 + (7.03)^2} = .06347$$

NOTE.—In certain experiments on the hand (see Table A) a smaller opening was used having diameter 2.42 cm. For this, $\sin^2\theta = .02877$.

The paper referred to above (Smithsonian Misc. Coll., Vol. 72, No. 13) gives the constant of melikeron No. 1 as 2.45. That is, by multiplying 2.45 by the square of the current, in amperes, required to compensate, we obtain, in calories per sq. cm. per minute, the difference in radiation between the shutter and whatever object is exposed on removing the shutter. The difference in radiation between the "pin-cushion" shutter and the skin would be

$$R = 2.45 \frac{C^2}{\sin^2\theta}$$

A shunted voltmeter of 49.3 ohms resistance was used to measure the current, hence

$$R = \frac{2.45}{(49.3)^2} \frac{V^2}{\sin^2\theta} = \frac{.001008V^2}{\sin^2\theta}$$

where V = voltmeter reading in volts.

The shutter being a black body at temperature t_0 C., radiates

$$8.20 + 10^{-11}(273 + t_0)^4$$

Then the skin radiates

$$8.20 \times 10^{-11}(273 + t_0)^4 + .001008 \frac{V^2}{\sin^2\theta}$$

if we neglect the radiation which appears to arise in the skin, but really is reflected by the skin into the instrument and was emitted by the walls of the room, the vestibule of the melikeron, and so forth. If the skin was a perfect radiator or "black body" this reflection correction would be zero.

We may get a line on this by computing the temperature of the skin, assuming it "black" and comparing with observed temperatures taken directly.

If T_1 = absolute temperature of skin

T_0 = absolute temperature of pin-cushion shutter,

Skin radiation $= \sigma T_1^4$

Shutter radiation $= \sigma T_0^4$

$$\text{Then } R = .001008 \frac{V^2}{\sin^2\theta} = \sigma(T_1^4 - T_0^4)$$

$$T_1^4 = T_0^4 + .001008 \frac{V^2}{\sigma\sin^2\theta} = T_0^4 + 1.939V^2 \times 10^8$$

for the large aperture and,

$$= T_0^4 + 4.27V^2 \times 10^8$$

for the small aperture.

The observations and computed temperatures are recorded in table A. The part of the body exposed to the melikeron is shown in the table by the position number. Interpretation of these numbers is given in figure 7.

As explained on page 8 of the paper on the melikeron, a check on the ability of Melikeron No. 1 to absorb completely low temperature radiation was made. The mean result of the test yielded a value for the constant

$$\sigma = 8.49 \times 10^{-11}$$

Again in April, 1921, after returning from the Boston work, Dr. Abbot made a similar test. The mean of 3 values gave

$$\sigma = 8.58 \times 10^{-11}$$

These values would tend to show that the constant 2.45 for Melikeron No. 1 is perhaps a little too high.

PRELIMINARY EXPERIMENTS IN STILL AIR

In the preceding we have described experiments by Drs. Abbot and Benedict in Boston in 1921. All the subsequent experiments described in this report were performed by the writer at the Smithsonian Institution in Washington. The first series of experiments was more or less preliminary in nature. They were carried out in the large laboratory room of the Astrophysical Observatory under somewhat unsatisfactory conditions as regards the control of wall and room temperatures.

As in the Abbot-Benedict work, two instruments, one for the direct measurement of radiation, and one for measurement of surface temperatures were used. Melikeron No. 2 replaced No. 1 previously used, but the same water circulating vestibule and "pin-cushion" shutter were retained. On November 28, 1927, a test of Melikeron No. 2 was made, as had been done for No. 1, by exposing to a black body at a known low temperature. Five determinations gave the following values for σ

$$
\begin{array}{r}
8.10 \times 10^{-11} \\
8.23 \\
8.23 \\
8.42 \\
8.84 \\
\hline
\text{Mean } 8.36 \times 10^{-11}
\end{array}
$$

The melikeron was clamped in a vertical position at a convenient height (about 1 m.) and remained unchanged throughout the work. The subject stood or sat in front of the instrument so that the part of skin or clothing exposed was about 5 to 10 cm. from the shutter. In the first trials, water directly from the tap was circulated through vestibule and shutter. The difference in temperature, however, between the surrounding air and the shutter and vestibule produced a

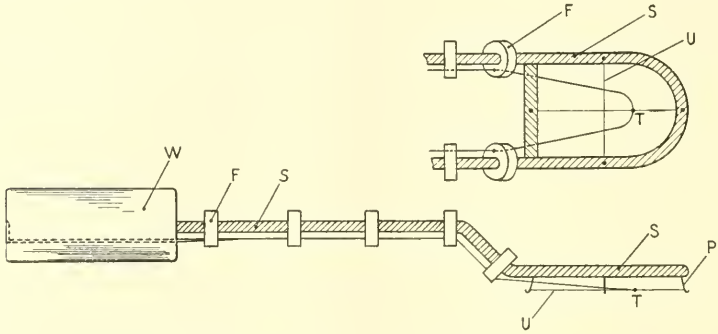

FIG. 2.—Thermoelement device for measuring surface temperatures.

F—Fibre rings.
S—German silver frame.
W—Wooden handle.
P—Spring steel projection
U—Silk thread.
T—Thermoelement.

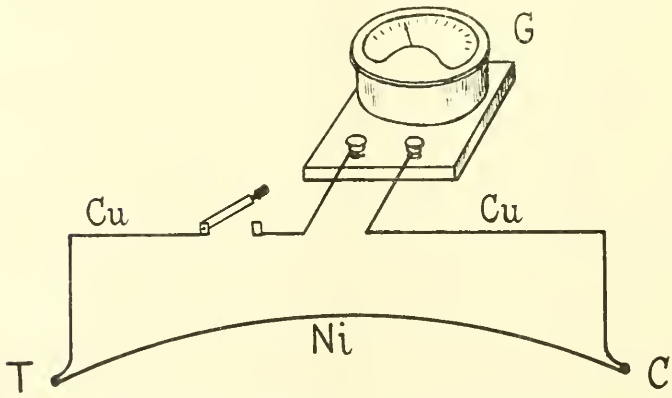

FIG. 3.—Diagram of electrical connections of copper-nickel thermoelement.

G—Galvanometer.
T—Thermoelement junction.
C—Constant temperature junction.

convection effect which altered as the shutter opened and closed and introduced an error resulting in too large values. Fifty feet of block tin pipe was then coiled and placed in a tank of water kept at room temperature. The tap water passed through this just before entering the instrument. Mercury thermometers measured the temperature of the circulating water before entering the vestibule and after leaving the shutter. The mean was used as the shutter temperature.

For the direct measurement of skin and clothing temperatures, a special device was prepared with the help of Mr. Kramer, the Observatory mechanician, and embodying Dr. Abbot's suggestions. The device is shown in figure 2. It consists of a specially mounted copper-nickel thermoelement of fine drawn wire. A frame of German silver is bent as shown in the figure and fastened in a wooden handle, *W*. Two silk threads are stretched to form a cross between the four spring-wire posts, *p*. The thermoelement wires are fastened sym-

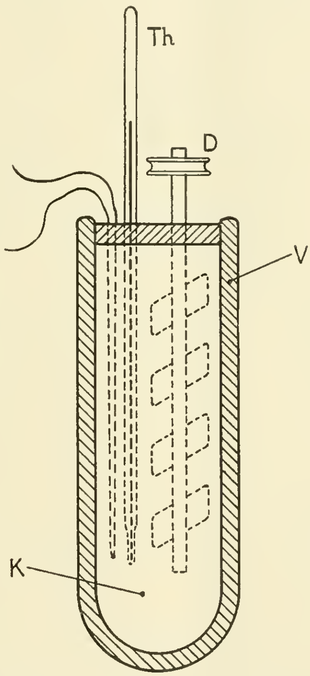

FIG. 4.—Bath for constant temperature junction.
Th—Thermometer.
D—Stirring device.
K—Kerosene bath.
V—Vacuum flask.

metrically to these silk threads with the junction straddling the lengthwise thread. The wires lead out through fibre rings, *F*, and through the wooden handle. The copper wire (see fig. 3) leads through a switch to a sensitive type Leeds and Northrup D'Arsonval galvanometer and thence to the constant temperature junction in a stirred kerosene bath as shown in figure 4. The Cu-Ni wires are sufficiently long so that all desired positions can be reached without moving the constant temperature bath. Holding the device by the wooden handle, one presses lightly the four prongs of spring wire *p* upon the surface whose temperature is desired. This places the junction in excellent contact with the surface. There is no backing to the junction save a single silk thread, and thus no possibility of heat piling up and causing too high temperatures. For about $\frac{1}{2}$ cm. on each side of the junc-

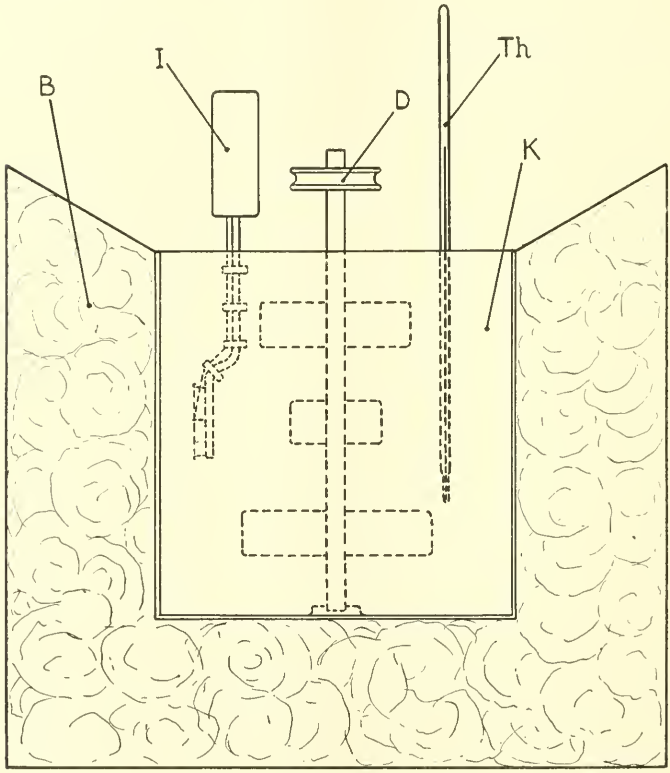

FIG. 5.—Calibrating bath.
I—Thermoelement device.
B—Insulation of cotton batting.

tion, the wire also touches the surface and assumes the surface temperature, thus eliminating error due to cooling of the junction by conduction along the wires.

Instead of a potentiometer for measuring microvolts, the thermoelement was calibrated by plotting galvanometer deflections directly against temperature differences between the two junctions. A kerosene bath (fig. 5) was prepared in which the thermoelement device was immersed. By a series of changes of the temperatures of both baths a plot (fig. 6) of the relationship between galvanometer deflection and temperature difference was made. By carefully keeping the whole set-up—galvanometer, scale distance, electrical resistance and

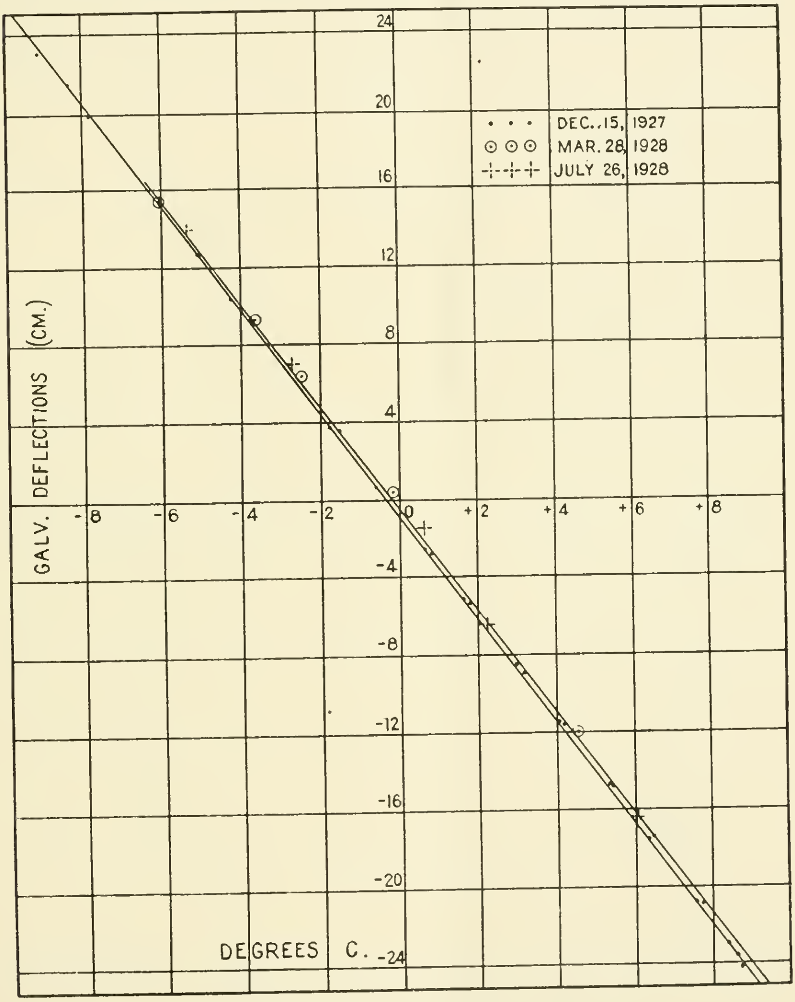

FIG. 6.—Thermoelement calibration curve.

contacts, etc.—unchanged, negligible change was found in the calibration curves made at the beginning, during and at the end of the experiments. It is probable that the calibration curve is accurate to 0°.1 C. To avoid error from lack of uniformity of the galvanometer scale, the zero of the galvanometer was always kept exactly at the middle of the scale.

Ten subjects were chosen, 3 adults and 7 children. Each subject wore ordinary clothing. No attempt was made to minimize metabolism, either by rest or diet before the measurements. The subject stood or sat, exposing to the melikeron in succession some 10 different places

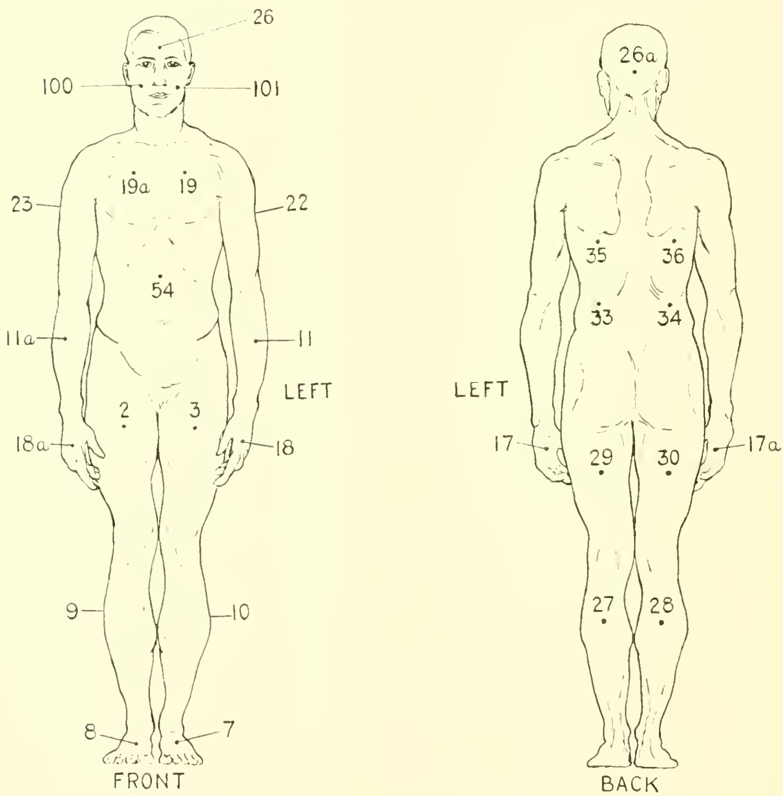

Fig. 7.—Sketch showing body position numbers.

on the body, usually 3 places on the exposed skin, 1 on the hair, 1 on the shoes, and 5 on the clothed parts. Figure 7, adapted from a similar figure kindly furnished by Dr. Benedict, gives a series of numbers corresponding to definite places measured. A single melikeron measurement required from 5 to 10 minutes, for the instrument is sluggish and requires careful adjustment of the compensating current. Immediately following each melikeron measurement the skin temperature was determined with the thermoelement device upon the same part of the skin or clothing. Usually 3 independent measures of the temperature were made, since each required less than ½ minute, and the mean used.

The observations are summarized in table B. The application of the Stefan formula to obtain the computed temperatures was the same as described under the Abbot-Benedict experiments, except that for Melikeron No. 2 the constants are altered.

Thus (see fig. 9, also pages 5 to 6),

$$R=\sigma(T_1^4-T_0^4)\sin^2\theta$$

where

$R=$ (constant Melik. No. 2) $\times C^2$

$=4.0\times$ (current in amperes)^2

$\sigma=8.20\times 10^{-11}$

$T_1=$ absolute temperature of radiator

$T_0=$ absolute temperature of melikeron shutter

$$\sin^2\theta=\frac{r^2}{\rho^2}=\frac{r^2}{r^2+\rho'^2}=\frac{(1.83)^2}{(1.83)^2+(7.2)^2}=.0606$$

$$\text{Then } T_1^4=T_0^4+\frac{4.0\times C^2}{8.20\times .0606\times 10^{-11}}=T_0^4+8.05C^2\times 10^{11}$$

From this equation, the value of T_1, the absolute temperature of the surface measured, is determined.

In examining tables A and B, we find that the 4th power formula applied to the measurements on either skin or clothing yields values as great or slightly greater than the observed temperatures. This is evidence that the skin and clothing radiate as a black body at the low temperatures measured. Cobet and Bramigk (Ueber Messung der Wärmestralung der menschlichen Haut und ihre klinische Bedeutung, Deutsches Archiv für klinische Medizin, Vol. 144, p. 45 to 60) confirm this result on the skin, and Leonard Hill (The Science of Ventilation and Open Air Treatment, British Govt. Report, 1919, Medical Research Commission) finds both skin and clothing nearly black body radiators for low temperature radiation.

In table B, the values in the *Radiation Summary* were obtained by the application of Stefan's formula to the mean temperatures given under *Temp. Summary*. For example, in table B1, we have given

Estimated wall temp. $=21^\circ\!.0$

Mean skin temp. $=33^\circ\!.7$

Then

$$R=\sigma(T_1^4-T_0^4)$$

$$=8.20\times 10^{-11}[(273+33.7)^4-(273+21.0)^4]$$

$$=.1131 \text{ calories per sq. cm. per minute.}$$

The value of the *Total Radiation* of the subject is obtained somewhat empirically as follows: The total surface area (see Notes on Tables, p. 26) is divided into sections

skin area, girls 8%, boys 7%
hair 5%
clothing, girls 78%, boys 79%
shoes 9% (if boots, 10% and clothing 78%)

The average skin radiation per sq. cm., as just determined, is multiplied by the corresponding number of centimeters of exposed skin, and similarly for clothing, hair, and shoe areas, and the sum taken. Since part of this total is ineffective, due to the area between the legs and under the arms not radiating to a full hemisphere of wall, this total radiation is reduced 8%. Dividing this result by the number of sq. m. surface area gives the value recorded under *Total Radiation.*

PRELIMINARY CALORIMETER EXPERIMENTS

The total radiation values of table B appeared much too large when compared with the basal metabolism values. The total energy production or metabolism must at all times equal the total energy loss. Exclusive of a small loss through urine and faeces and the warming of air and food taken in, there are three ways in which the body loses heat, namely, by radiation, by convection (including conduction), and by evaporation of water from lungs and skin. Du Bois states (Basal Metabolism in Health and Disease, ed. 1927, p. 400) that for a room temperature 22° to 25° C. and relative humidity 30 to 50%, the loss by vaporization of water from lungs and skin is about 24% of the total loss. By analogy with work done on the cooling of wires and blackened spheres we would expect the body convection loss to be at least as great as the radiation loss. For example, on p. 251, Smithsonian Physical Tables, 7th Ed., McFarlane finds the total loss of
least as great as the radiation loss. For example, on p. 251, Smith-
to a blackened enclosure at 14° is .00266 gram calories per second, or .1596 calories per minute. On page 247 the difference in radiation between a black body at 24° C. and one at 14° is $918-801=117$ gram cal. per sq. cm. per 24 hours or .0813 calories per sq. cm. per minute.

Then the per cent of radiation loss of the blackened sphere (which, to be sure, at these low temperatures radiates decidedly less than the "black body") is

$$\frac{.0813}{.1596}=51\%, \text{ convection loss}=49\%$$

It is of course true that the actual energy production of each of the ten subjects was materially greater than that shown by the basal metabolism values. Yet even when adequate allowance is made for this, the radiation loss seemed to be an unexpectedly large proportion of the total energy production.

After conference with Dr. Abbot and several members of the New York Commission on Ventilation, a series of experiments was started with the hope of shedding some light on the amount of body convection loss. These experiments proved that convection was, indeed, less than had been anticipated, but the close approach of total radiation to basal metabolism remains surprising.

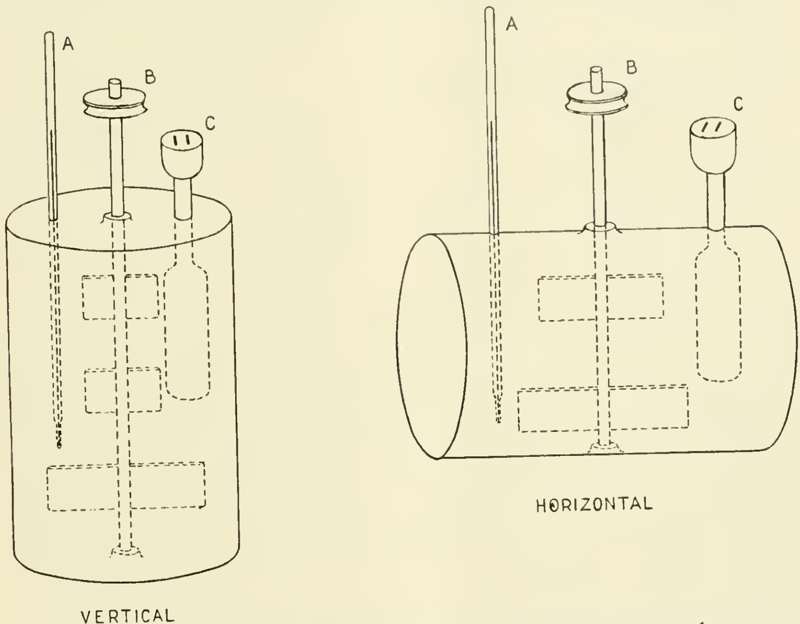

FIG. 8.—Cylindrical copper calorimeters, each 38 cm. long and 30.5 cm. diameter, filled with water and completely covered with tight fitting jackets consisting of one thickness of brown canton-flannel cloth.

A—Thermometer.
B—Stirring device.
C—Electrical heating element.

Two calorimeters were prepared of thin sheet copper, cylindrical in shape, each 38 cm. long by 30.5 cm. in diameter. One was mounted vertically and the other horizontally, each supported on four rubber blocks on the top of four metal rods. This permitted free convection and radiation on all sides but the rate of cooling of the vertical calorimeter might well be less than that of the horizontal because the warm convection currents rising from below would more closely bathe the sides in the vertical form. Appropriate stirring and heating devices were inserted as shown in figure 8. Each was filled with a known amount of water, and the outside completely covered with a tight fitting jacket consisting of a single thickness of brown canton-flannel cloth. The purpose of the shape and covering of the calorimeters was to simulate the clothed human body. Heat was lost from the calorimeter only by radiation and convection, and the total loss of heat per hour could be accurately determined from the rate of change in temperature of the water and the water equivalent of the calorimeter. A series of tests was made with each calorimeter, and in each test the radiation loss was determined with the melikeron and with the thermoelement, following exactly the method described above as applied to human subjects.

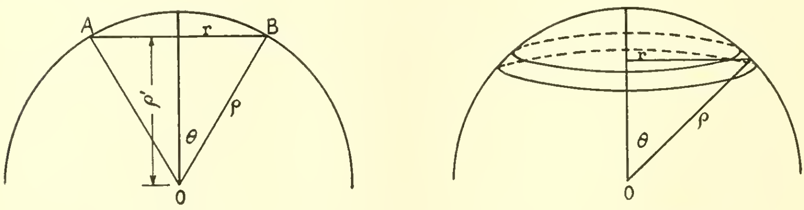

Fig. 9.—Diagram for computing solid angle exposed to melikeron.

The results of the preliminary tests are given in table C. Several interesting points appear. First, the radiation loss of the horizontal calorimeter is 6 or 7% less than in the vertical. This indicates that the shape of the calorimeter is important in determining the amount of the convection and helps to account for the difference in convection between the sphere 50% and the cylinders 70 to 80%. As noted above, however, this discrepancy is also in part due to the less perfect radiating properties of lamp-black than of porous cloth. Second, in the test of March 3, with air motion of about 300 feet per minute the radiation is only 47% and the convection increased to 53%. Third, with no cloth cover, the test of March 26 shows only 34% radiated from the copper surface in still air. This is an indication of the low emissivity of the metal surface as compared with the cloth.

CALORIMETER TESTS WITH CLOTH WALLS

A weakness in the experiments thus far has been the impossibility of accurately knowing the mean temperature of the walls to which the subjects or calorimeters are radiating. A very helpful letter from Prof. Phelps of the New York Commission dated March 27, 1928, suggested the possibility of standardizing the wall conditions by surrounding the subject with cloth draperies whose temperature, closely that of the air in the room, could be determined with the same thermoelement used on the subject. This suggestion seemed especially feasible since our results indicate that cloth radiates nearly as a black body. Accordingly, brown canton-flannel cloth was hung forming a curtained room 2½ meters high and 1½ by 2 meters in area, enclosing the calorimeter and with the melikeron mounting projecting through the curtain. The same cloth also formed the ceiling and floor. For part of the tests a current of air of known velocity from an electric fan outside the curtain was admitted through a hole in the cloth. The air velocity at the calorimeter was measured with a Katathermometer, an instrument invented by Prof. Leonard Hill, of England (see The Science of Ventilation and Open Air Treatment, British Govt. Report, 1919), and serving admirably for this purpose. The motor of the electric fan was run on storage batteries to insure a more constant air current. The Katathermometer was kindly furnished by Mr. Duffield, of the New York Commission.

The results of these tests are found in table D. Table F is a condensed summary of both tables C and D. From these tables a number of conclusions can be drawn:

(1) The amount radiated from the horizontal cylindrical calorimeter is about 7% less than from the vertical cylindrical calorimeter.

(2) The estimated wall temperatures in the preliminary calorimeter experiments are too low. From this cause the amount radiated should probably be lowered at least 10%. Much more weight can be placed in the measured wall temperatures of the cloth walls.

(3) For air motions greater than 75 feet per minute, the melikeron is unsatisfactory for use. An irregular drift of the galvanometer zero due probably to small fluctuating convection currents makes the instrument unreliable.

(4) In the preliminary experiments the melikeron gives appreciably higher results than the thermoelement, and in the second set of experiments this discrepancy disappears. The cause of this is explained in the following section.

RELATIONSHIP BETWEEN MELIKERON AND THERMOELEMENT RESULTS

In the preceding experiments, recorded in tables B, C, D and E, we have 265 comparisons of temperatures determined directly by thermoelement and computed from the radiation as measured with the melikeron, and including skin, clothing, hair, shoes, wall, and cloth-covered calorimeter temperatures. By a study of these comparisons we can determine their relationship, with a view to using only the thermoelement in a new series of experiments. The thermoelement is much quicker and easier to use than the melikeron. Also it offers no difficulty in air currents where the melikeron becomes unusable.

Table G is a summary of this kind. The first trials with the water jacketed melikeron indicated a minus correction (see page 8) when the water jacket temperature was less than room temperature. The water jacket temperatures are therefore given in all the tables and the differences Room Temperature minus Water Jacket Temperature are recorded in table G. Examination discloses a rough equality between the differences Melikeron minus Thermoelement and Room Temperature minus Water Jacket Temperature. In the wall temperatures no difference is noted between melikeron and thermoelement—which is as we might expect since the wall is always close to room temperature, and the melikeron reading is very small. In the measurements at air velocities greater than 130 feet per minute there is decided disagreement—which we know is due to the unsatisfactory performance of the melikeron in air currents. Of the remaining observations, the difference Melikeron minus Thermoelement on the skin is much larger than in any other group. For comparison, all the other groups, viz., clothing, hair, shoes, and calorimeter, are united in one group at the bottom. From the algebraic mean of Room T. minus Water J. T. in this group,
when Room T. minus Water J. T. = $^\circ.82$, Melik. minus Therm. = $^\circ.80$ that is, the melikeron calculated temperature is in error by as much as the water jacket differs in temperature from the wall. Hence we may conclude that on the skin, when Room T.—Water J. T. = 0,

$$\text{Melik.—Therm.} = 1^\circ.91 - 0^\circ.67 = 1^\circ.24.$$

Again from the arithmetical mean of Room T.—Water J. T.,

when Room T.—Water J. T. = $1^\circ.14$, Melik.—Therm. = $^\circ.80$

from which on the skin, when Room T.—Water J. T. = 0,

$$\text{Melik.—Therm.} = 1^\circ.91 - \frac{1.31}{1.14} \times {}^\circ.80 = 1^\circ.00$$

A mean of all clothing, hair, shoes, and calorimeter (Melik.—Therm.) differences whose (Room T.—Water J. T.) differences are less than $1^\circ.0$ gives

No. of observations	Melik.—therm. difference	Room T.—water J. T. difference (algebraic)
30	$^\circ.51$	$^\circ.39$

Calorimeter tests alone give

8	.20	.24

These results confirm the preceding conclusion that the melikeron computed temperatures are in error by just as much as the water jacket differs in temperature from the wall. Summarizing the above evidence, it appears that when the Room T. minus the Water J. T. is zero, the Melikeron and Thermoelement temperatures on clothing, hair, shoes, and calorimeter agree with each other within $^\circ\!.1$. On the skin, however, when the Room T. minus the Water J. T. is zero the melikeron computed temperatures are approximately $1^\circ\!.1$ greater than the thermoelement temperatures. Dr. Abbot's skin measurements of 1921 at Boston (see table A) give evidence of the same thing—that on the skin the melikeron computed temperatures are higher than those measured directly with the thermoelement. A mean of 53 of his values in table A gives

$$\text{Melikeron minus Thermoelement} = 1^\circ\!.9$$

As an explanation for the persistently larger melikeron temperatures on the skin, Dr. Abbot suggests that since the skin is porous and the internal temperature of the body is higher than that of the surface, the melikeron sees into a deeper layer than that reached by the thermoelement.

EXPERIMENTS ON TEN SUBJECTS IN STILL AND IN MOVING AIR

A second series of experiments on human subjects was begun on May 30, 1928. It included 8 children of school age and 2 adults. Three similar sets of observations were taken on each subject, first in still air, second with moderate air motion, and third with faster air motion. As before, the air motion was produced by an electric fan three meters away, the motor of which ran on storage batteries. Air velocities were again measured with the Hill Katathermometer. Each subject was placed inside the same curtained room described under the calorimeter experiments. Skin, clothing and wall temperatures were measured with the thermoelement device. Exactly the same body and wall positions were measured on each subject. A complete set included 7 observations on the exposed skin, 15 on the clothing, 1 on the hair, 2 on the shoes, and 10 on the walls. The skin temperatures were then corrected to the melikeron scale by increasing the thermoelement skin temperatures $1^\circ\!.1$ as explained in the previous section. The observations were grouped and summarized as shown in table E. Following exactly the method described on page 13, Stefan's 4th power formula was applied to the various groups and values of the total radiation determined as given in table E.

Unlike the first series of experiments on 10 subjects (see table B), this second series was carried out in midsummer. Fortunately the room was equipped with refrigerating pipes so that the room temperatures were kept fairly normal and comfortable. These pipes were entirely outside of the curtained room where experiments were made.

Attention is called to the summaries of table E data contained in tables H, J and K. Table H divides the air velocities into four groups and shows how, with the room and wall temperatures remaining nearly constant, the calories of radiation loss progressively decrease as the air motion increases. Table J gives for each subject, in calories per sq. m. of body surface, the basal metabolism and the loss of heat by radiation; also the ratios between these two quantities. These ratios are also arranged according to increasing room temperatures. A marked decrease in the ratio occurs with increasing room (and with it the wall) temperatures. Table K is a summary showing the changes in skin and clothing temperatures with varying air velocities, dividing the changes into three groups, namely, temperature changes on the side of the subject toward the fan, perpendicular to it, and away from it. A drop in temperature occurs in all three groups, with the greatest drop on the side toward the fan. In the other two groups the drop is only about one half as great. On the side towards the fan the clothing temperature drop is about one third greater than the skin temperature drop.

GENERAL DISCUSSION

We have presented the results of three series of experiments on the radiation loss of human subjects, and a fourth series on the radiation loss from specially prepared calorimeters. The first series gave the results of Drs. Abbot and Benedict on the radiation and skin temperatures of a nude subject when the room temperature was held at 15° and again when it was held at 26°. It is interesting to note the change in radiation loss in these two different cases. On March 31, when the room temperature was 15°, the thermoelement skin temperature (mean of 87 values, many of which are not included in table A) was 27°.2, and on April 1, when the room temperature was 26°.0 (mean of 40 values), was 30°.8. The black body temperatures, computed from the melikeron values and the Stefan formula, were March 31 (mean of 20 values) 28°.2, and on April 1 (mean of 12 values) 33°.4. Dr. Benedict estimated the wall temperature on April 1 to be 26°, and it is probable that on March 31 the wall temperature was at least as low as 15°. (Outside temperature was 8°.6.) Assuming these wall temperatures we can compute from the Stefan formula the average radiation per sq. cm. per minute from the body. It results as follows:

March 31, from thermoelement, .1003 cal., from melikeron, .1109 cal.
April 1, from thermoelement, .0432 cal., from melikeron, .0673 cal.

Thus the body actually radiated in the order of twice as much when the walls were at 15° as when the walls were at 26°. The best work in basal metabolism indicates that an individual's metabolism remains practically unchanged through this range of room temperature. A very considerable readjustment, perhaps of water vapor loss, must take place to compensate for the large change in radiation.

Let us compare the two series of experiments on human subjects recorded in tables B and E. Each series included 10 individual subjects, composed of adults and children of school age, of both sexes and all normally clothed. The first series was performed in midwinter, the second series in midsummer. During the first, the mean relative humidity was 43% and during the second 62%. In each series determinations were made on each subject of the total loss of heat by radiation in still air. The second of the two series deserves greater weight for two reasons:

(1) Cloth walls were used and the mean wall temperature determined from actual measurements with the thermoelement.

(2) A greater number of skin and clothing temperatures were measured since only the thermoelement was used.

In the first series the subject radiated to the walls, windows, and furniture of the room. Their mean temperature was estimated from the room temperature, after a study, on a typical day, of the relationship between the room temperature and that of the walls, windows, and furniture. From this study it was concluded that the mean wall temperature was probably °5 below room temperature. This arbitrary correction was adopted for all the preliminary 10 subjects and also for the preliminary calorimeter experiments (see table C). It is remarked on page 17 under (2) that the estimated wall temperatures in the table C data are probably too low. The reason for this can be seen from the fact that the table C data were obtained in the spring, whereas the table B data were taken in midwinter. The mean outside temperature was 11°0 for table C, and 3°5 for table B. It is evident that with a warmer temperature outside, the °5 difference between room and wall temperature was too great. On the other hand, on examining the data of the typical day from which the arbitrary °5 correction was determined, I find that the outside temperature was 2° and that the mean wall temperature was in reality 1°0 below room temperature. The arbitrary correction was made °5 because I erroneously thought the mean outside temperature was considerably above 2°. It is probable then that since the mean outside temperature was actually only 1°.5 above that of the measured day, the wall temperatures of table B should have been several tenths degree lower. As explained on pages 18 to 19, there is also another correction to be made in table B, due to the difference Room Temp.—Water Jacket Temp. This correction requires a lowering of the skin and clothing temperatures of about the same magnitude as the wall temperature correction just mentioned. It is a fortunate accident that the difference in temperature between the body surface and the walls thus remains nearly the same and the mean radiation values in table B remain unchanged.

Table L compares the means of the two series, tables B and E. The total radiation is greater in the first series due to the lower mean room temperature. The adult basal metabolism (determined from Du Bois' chart) is higher in the first series because the 3 adults were two male and one female, average age 31, whereas in the second series the adults were both female and average age 43. The work of many investigators agrees in placing the basal metabolism per sq. m. of body surface of adults considerably lower than that of children. Yet the radiation losses in tables B and E show no such change as between adults and children. In table L the ratios

$$\frac{\text{Radiation loss}}{\text{Basal metabolism}}$$

are in each case higher for adults than children. This is difficult to explain.

At normal indoor temperatures, in still air and with the subject normally clothed and at rest, the major heat losses would be distributed as follows: The loss by evaporation of water from lungs and skin (as stated by Du Bois, see page 14) is 24% of the total. The convection loss, assuming it is similar to that of the cloth-covered vertical calorimeter, is $\frac{2}{3}$ of the radiation loss. Or,

Water vapor loss	= 24% of the total
Radiation loss	= 46% of the total
Convection loss	= 30% of the total

It is interesting to compare this with a statement by Rubner (see page 20, Leonard Hill, The Science of Ventilation and Open Air Treatment) that " for an average man, in still air, the loss of heat is distributed as follows: Warming of inspired air, 35; warming the food, 42; evaporation of water, 558; convection loss, 823; radiation, 1181; total loss, 2700 kg. calories."

In considering the method by which the total radiation values are obtained in these experiments, there will perhaps be question concerning the correctness of the empirical division of the body surface into skin, clothing, shoe, and hair areas, as well as the 8% reduction for ineffective radiation between legs and under arms. Yet these factors may be altered through a considerable range and not materially alter the final result. The radiation loss will still be nearly the same magnitude.

It has been a matter of surprise to the writer that the literature covering calorimetry experiments on the total energy consumption of human subjects makes so little mention of the surrounding temperatures to which the subject radiates; also that in the comparisons between direct and indirect calorimetry the temperatures used are nearly the same throughout. It was my privilege on March 21, 1928, accompanied by Prof. Phelps, of the New York Commission, to visit the Bellevue Hospital laboratory of Dr. Du Bois, to talk with him and see the operation of the Sage calorimeter which, under the skilful manipulation of Dr. Du Bois and his assistants, has added a new chapter to our knowledge of metabolism in health and disease. The visit was of especial interest in that Dr. Stefansson, the explorer, was present for a metabolism test to determine the effect of an exclusively meat diet. Dr. Du Bois explained that the reason all his experiments had been carried out at nearly the same temperature was because of the intricacy of the apparatus and the difficulty of redetermining all the constants for each set of temperatures. He agreed that it was important to compare direct and indirect calorimetry at other temperatures and indicated that he hoped to find opportunity to do so.

Incidentally in the course of these experiments, rough tests were made with the thermoelement device to see how rapidly its temperature falls off as the thermoelement recedes from the skin or clothing. The thermoelement has a bright metal surface and consequently its temperature is but little affected by absorption of radiation. The tests show that, in moving the device horizontally away from the body, as soon as actual contact is broken between thermoelement and skin or clothing, the thermoelement temperature falls rapidly almost to room temperature and then gradually declines to room temperature as the thermoelement recedes. At 30 cm. distance no effect of the presence of the body could be detected in still air. There would be a marked effect of course if the thermoelement were held over the body instead of at the side, or if the thermoelement had a better emissivity so that its temperature would be raised by a larger absorption of radiation.

SUMMARY OF RESULTS.

The concrete results of these experiments are briefly summarized:

(1) The radiation from the skin and clothing is approximately that of a "black body" or perfect radiator.

(2) Skin temperatures computed from melikeron radiation measurements are about 1° C. higher than skin temperatures measured directly with the thermoelement. This is not true on clothing or calorimeters. Apparently the melikeron sees deeper into the pores of the skin.

(3) A cloth-covered, vertical, cylindrical calorimeter at body temperature loses in still air 60% by radiation, 40% by convection. A similar horizontal calorimeter loses 54% by radiation, 46% by convection. The human body convection loss is probably similar to this, that is, the convection loss is roughly one third less than the radiation loss, in still air and normal room temperatures.

(4) Increasing air motion rapidly decreases the percentage radiation loss and increases the convectional. With the vertical calorimeter:

Air motion	% radiation loss
0	60
75 ft. per min.	41
130 ft. per min.	35
190 ft. per min.	25

(5) Total body radiation similarly decreases with air motion:

Air motion	Radiation loss (mean for 10 subjects)
0 to 50 ft. per min.	30.7 large cal. per sq. m. per hour
50 to 100	29.3
100 to 150	25.7
180 to 250	23.2

(6) Increase in room temperature (which also means increase in wall temperature) produces a progressive lowering of radiation loss. The ratio

$$\frac{\text{Radiation loss}}{\text{Basal metabolism}}$$

decreases with increase of room and wall temperature:

	Room temp.	Radiation loss / Basal metabolism
Table I	21°.3	.80 (mean of 10 subjects)
	24.1	.75 (mean of 10 subjects)
Table J	22.1	.84 (mean of 3 subjects)
	24.5	.74 (mean of 4 subjects)
	25.6	.66 (mean of 3 subjects)

(7) Keeping room and wall temperatures unchanged, the temperature of skin and clothing decreases with increasing air motion,

the decrease being greatest on the side facing the wind and about one half as great on the side away from the wind. The clothing temperature drop on the side towards the wind is about one third greater than the corresponding skin temperature drop. Summary of 10 subjects:

Air motion (ft. per min.)	Skin temp. drop— Away from wind	Skin temp. drop— Towards wind	Clothing temp. drop— Away from wind	Clothing temp. drop— Towards wind	Clothing temp. drop— Perpendicular to wind
0 to 100	−°.4	− °.8	−°.6	− 1°.3	−°.5
100 to 250	−.7	− 1.2	−.4	− 1.7	−.5

(8) At normal indoor temperature, in still air and with the subject normally clothed and at rest, body heat losses are distributed as follows:

Evaporation of water	24%
Radiation	46%
Convection	30%

(9) Tests with the thermoelement show that the air temperature falls to room temperature very rapidly as the distance from the body increases. That is, there is a steep temperature gradient in the first centimeter or so from the body surface. With the thermoelement 30 cm. away no effect of the presence of the body could be detected.

(10) The Abbot-Benedict work (table A) indicates that the radiation loss from a nude subject is about twice as great for a room temperature of 15° as it is for a room temperature of 26°. This evidence does not entirely support the "suit of clothes" theory referred to by Du Bois. In explanation of this theory, he says (p. 385, 1927 ed. "Basal Metabolism"): "A constriction of the peripheral blood vessels (occurs) and the amount of heat carried to the surface is relatively small in proportion to the heat produced. . . . The patient really changes his integument into a suit of clothes and withdraws the zone where the blood is cooled from the skin to a level some distance below the surface."

(11) Normal fluctuations in humidity indoors produce negligible effect upon the radiation loss. This is to be expected. Our bodies, about 300° Absolute, radiate almost wholly between the wavelengths 4μ and 50μ with a maximum at 10μ. Water vapor absorption is so strong for much of this range and so nearly negligible near the maximum, 10μ, that its possible effect is nearly fully produced even by the humidity of an ordinary room. Thus the effect of changes of quantity of water vapor in the ordinary room is small. Were the air of the room exceedingly dry, changes might be noticeable.

Interesting and important questions concerning the comfort and welfare of children in classrooms are inadequately answered today. It is hoped that this report may in some degree help towards a better understanding of these problems.

NOTES ON TABLES

Temperatures are given in centigrade degrees.

Air velocities are in feet per minute.

Surface areas are determined from Du Bois' height-weight chart (Archives of Internal Medicine, Vol. 17, p. 865, 1916).

Basal metabolism values are taken from Du Bois' "Basal Metabolism in Health and Disease," edition 1927, p. 145.

In table E, Wall *A, B, C, D, E,* refer to definite places on the canton-flannel curtains hung around the subject and forming the walls to which the subject is radiating. Places *A, B,* and *D* are on the sides, *C* on the ceiling and *E* on the floor. Position numbers followed by an asterisk are taken on the skin because of short sleeves or low socks.

In table E also, skin temperatures in the three columns on the right are just as read from the thermoelement device. In the summary on the left they have been corrected to the melikeron scale by the addition of 1°.1 as explained in the text.

TABLE A.—*Abbot-Benedict Observations*

SUBJECT: Miss W, nude

March 30, 1921

Time	Pos.	Temp. Water Jacket	Observed Temp. (thermo-element)	Temp. Computed from Radiation	Remarks
1 33	19	21°1	32°8	34°1	Pos. 14 cm. below 19.
38	..	20.8	33.0	33.0	
45	19a	19.8	31.6	31.8	Pos. 14 cm. below 19a.
2 05	55	19.3	32.7	40.7	
10	..	19.1	32.5	36.8	
18	..	19.1	31.9	39.6	
29	54	19.1	33.0	34.2	Pos. 10 cm. to left of 54.
35	..	....	32.7	34.2	
45	55	19.5	31.2	36.6	
58	54	19.7	32.2	33.3	Pos. 10 cm. to left of 54.
3 21	32	20.0	27.8	28.4	Standing facing window, holding iron post to steady herself.
27	31	19.7	27.2	29.3	
38	30	19.2	27.7	30.6	Pos. 2 cm. below 30.
..	34	18.9	30.3	33.7	Pos. 6 cm. above 34.
53	45	18.7	27.6	30.2	
4 01	46	18.4	27.7	29.9	
12	14	18.7	32.1	34.6	
20	28	18.8	26.6	26.4	
March 31, 1921. Room Temp. 15.0 C. Outside Temp. 8.6 C.					
.....	..	17.6	30.9	32.2	Dr. B.'s hand.
.....	..	20.8	15.2	29.9	Floor.
.....	..	19.4	....	28.7	45 toward wall and ceiling.
10 23	14	17.7	32.0	33.4	Miss W., subject.
34	46	17.4	26.7	29.8	
39	46	17.2	26.0	27.0	
45	14	17.2	29.6	32.5	
53	46	17.2	25.1	26.5	
56	14	17.1	29.5	31.7	
11 02	46	17.2	25.4	26.8	
10	..	17.3	....	21.5	Toward ceiling.
17	14	17.3	29.2	31.4	
23	46	17.3	24.0	25.2	
30	32	17.4	22.6	23.9	
34	30	17.4	24.5	26.1	
39	3	17.4	24.2	26.1	
42	28	17.6	22.9	24.5	
47	34	17.6	27.1	29.1	
57	53	17.8	29.0	31.8	

TABLE A (continued)

March 31, 1921 (continued)

Time	Pos.	Temp. Water Jacket	Observed Temp. (thermo-element)	Temp. Computed from Radiation	Remarks
12 02	54	17°.9	26°.5	28°.4	
10	55	17.9	25.3	26.1	
21	55	18.2	25.6	26.8	Subject lying down, melikeron held over her.
27	54	18.3	25.7	28.0	
30	53	18.3	28.9	29.8	
2 00	..	20.8	35.4	39.3	Dr. M., subject, Rt. hand is made into a tube resting in left. Hands taken apart for skin temp., so that both palms were exposed.
.....	..	20.8	35.5	37.7	Palms not exposed, position held.
April 1, 1921. SUBJECT: Miss W. Room Temp. held at 26.0 Outside 4.2					
9 56	14	25.3	33.7	35.0	Sitting.
10 01	46	24.6	29.8	31.7	Standing.
10	14	23.9	33.3	35.9	Sitting.
17	46	23.2	29.7	31.7	Standing.
24	34	22.9	31.9	33.7	
30	2	22.6	30.2	31.9	Standing on stool.
36	29	22.4	30.0	31.8	
40	32	22.2	28.1	30.0	
53	53	21.9	32.5	34.7	
11 05	54	21.6	31.2	35.3	
12	54	21.3	31.4	34.9	
21	53	20.9	31.9	34.5	
2 55	..	24.5	34.4	34.7	Dr. M, subject, Rt. hand made into a tube resting in left. Melikeron opposite hole made by hand. Thermoelement with rubber back inserted in hole made by hand.
.....	..	....	36.1	....	Opened hands and clapped them together again with thermoelement between.
3 01	..	23.4	....	33.3	Hands in position of tube.
03	..	22.9	....	33.3	Hands in position of tube.
06	..	....	34.5	....	No rubber back. Mean of 13 values.
12	..	21.6	....	34.2	
14	..	....	35.7	....	No rubber back. Mean of 10 values.
41	..	20.1	35.0	35.7	Hands made into tube.
50	..	20.0	35.2	35.6	

Table B.—*Observations and Results of Preliminary Experiments on Ten Subjects*

Table B1

Date: Jan. 18, 1928.
Subject: S. A.
Sex: Male.
Age: 7 yrs.
Weight: 25.5 kg.
Height: 124 cm.
Surface Area: .95 sq. m.
Clothing: Green, wool suit, cotton stockings.

Air temperature outdoors, 10°.
Relative humidity indoors, 40%.
Room temperature, 21°.5.

Temperature Summary

Kind	No. Values	Temp. computed from Stefan formula °
Skin	3	33.7
Clothing	5	28.5
Hair	1	29.9
Shoes	(est.)	25.6
Wall	(est.)	21.0

Radiation Summary

	Calories per sq. cm. per min.
Skin	.1131
Clothing	.0653
Hair	.0779
Shoes	.0396

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18a	19.5	32.0	34.0
26a	19.5	27.3	29.9
100	19.6	30.4	33.2
54	19.6	23.8	28.6
11	19.5	27.4	28.9
int. wall	19.5	21.2	21.2
34	19.5	25.0	27.7
30	19.5	23.8	27.2
10	19.4	27.7	30.3
int. wall	19.4	21.1	20.9
101	19.4	31.0	34.0

Total Radiation

36.9 large calories per sq. meter per hour.

Basal Metabolism

43 large calories per sq. meter per hour.

TABLE B2

DATE: Jan. 21, 1928.
SUBJECT: M. W.
SEX: Female
AGE: 11 yrs.
WEIGHT: 28.1 kg.
HEIGHT: 140 cm.
SURFACE AREA: 1.07 sq. m.
CLOTHING: Red, wool dress, cotton stockings.

Air temperature outdoors, —2°.8.
Relative humidity indoors 32%.
Room temperature 22°.1.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	4	33.0
Clothing	5	26.7
Hair	2	27.4
Shoes	(est.)	24.0
Wall	(est.)	21.6

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1012
Clothing	.0440
Hair	.0502
Shoes	.0207

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
int. wall	20.7	21.9	21.7
18a	20.7	32.3	33.4
26a	20.7	30.1	28.4
100	20.7	31.9	32.9
54	20.7	24.6	26.0
11	20.7	25.7	26.7
int. wall	20.7	21.9	21.7
34	20.7	26.0	26.3
9	20.7	27.7	28.6
18a	20.7	31.4	32.2
26a	20.7	27.0	26.4
int. wall	20.7	21.9	21.7
100	20.8	31.2	33.6
54	20.8	24.7	26.1

TOTAL RADIATION

25.8 large calories per sq. meter per hour.

BASAL METABOLISM

44 large calories per sq. meter per hour.

TABLE B3

DATE: Jan. 28, 1928.
SUBJECT: J. S.
SEX: Male
AGE: 12 yrs.
WEIGHT: 46.2 kg.
HEIGHT: 158 cm.
SURFACE AREA: 1.44 sq. m.
CLOTHING: Cotton waist, corduroy trousers, high, red rubber boots. (Snow storm outside)

Air temperature outdoors —4°.4.
Relative humidity indoors 37%.
Room temperature 19°.7.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula
Skin	4	32.2
Clothing	5	26.8
Hair	1	29.4
Shoes	2	24.2
Wall	(est.)	19.2

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1135
Clothing	.0642
Hair	.0878
Shoes	.0420

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18a	19.2	30.8	32.5
100	19.2	30.4	32.3
26a	19.2	24.1	29.4
11	19.1	28.6	25.4
54	19.1	30.1	29.0
33	19.2	25.2	27.0
2	19.1	24.7	25.7
29	19.1	25.1	26.7
int. wall	19.1	19.4	19.5
10	19.2	22.4	23.7
8	19.2	23.7	24.8
int. wall	19.2	19.3	19.6
18a	19.1	29.5	31.5
100	19.1	29.7	32.4

TOTAL RADIATION

36.7 large calories per sq. meter per hour.

BASAL METABOLISM

44 large calories per sq. meter per hour.

TABLE B4

DATE: Jan. 31, 1928.
SUBJECT: S. W.
SEX: Male.
AGE: 6 yrs.
WEIGHT: 18.2 kg.
HEIGHT: 111 cm.
SURFACE AREA: .76 sq. m.
CLOTHING: Cotton waist, wool trousers, cotton stockings.

Air temperature outdoors 0°.
Relative humidity indoors 46%.
Room temperature 21°.8.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	3	34.0
Clothing	6	27.7
Hair	1	32.0
Shoes	1	25.6
Wall	(est.)	21.3

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1134
Clothing	.0562
Hair	.0950
Shoes	.0372

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
black velvet	19.8	21.0	20.5
18a	19.9	32.3	33.6
100	19.9	30.6	33.6
26a	19.9	30.6	32.0
54	19.9	27.2	28.7
11	19.9	28.2	28.7
33	19.9	25.6	27.2
int. wall	19.9	21.3	21.6
2	19.9	25.8	25.2
29	19.9	25.7	26.8
10	20.0	29.2	29.8
7	20.0	23.0	25.6
18a	20.0	32.0	34.8
int. wall	19.9	21.2	21.3

TOTAL RADIATION

33.3 large calories per sq. meter per hour.

BASAL METABOLISM

44 large calories per sq. meter per hour.

TABLE B5

DATE: Feb. 4, 1928.
SUBJECT: E. L.
SEX: Female.
AGE: 8 yrs.
WEIGHT: 24 kg.
HEIGHT: 127 cm.
SURFACE AREA: .93 sq. m.
CLOTHING: Cotton dress and stockings.

Air temperature outdoors 13°.4.
Relative humidity indoors 46%.
Room temperature 22°.4.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	4	34.7
Clothing	5	28.6
Hair	1	28.7
Shoes	1	28.6
Wall	(est.)	21.9

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1152
Clothing	.0592
Hair	.0598
Shoes	.0592

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18	20.9	32.1	35.1
100	20.9	31.5	34.3
26a	20.9	27.9	28.7
54	20.9	28.6	30.3
11	20.9	29.2	29.0
33	20.9	25.0	27.0
2	20.9	25.0	25.4
10	20.9	29.4	31.5
8	20.9	27.1	28.6
int. wall	20.9	22.4	21.7
18	20.9	32.2	35.7
101	20.9	31.5	33.7

TOTAL RADIATION

35.2 large calories per sq. meter per hour.

BASAL METABOLISM

42 large calories per sq. meter per hour.

TABLE B6

DATE: Feb. 4, 1928.
SUBJECT: R. S.
SEX: Male.
AGE: 10 yrs.
WEIGHT: 31.8 kg.
HEIGHT: 138 cm.
SURFACE AREA: 1.10 sq. m.
CLOTHING: Cotton waist, grey, wool trousers, stockings.

Air temperature outdoors 8°.3.
Relative humidity indoors 46%.
Room temperature 21°.4.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	3	34.4
Clothing	6	27.5
Hair	1	28.4
Shoes	1	25.7
Wall	(est.)	20.9

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1203
Clothing	.0566
Hair	.0652
Shoes	.0420

TOTAL RADIATION

33.1 large calories per sq. meter per hour

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18	20.6	33.0	35.1
100	20.5	30.8	35.1
26a	20.4	27.6	28.4
54	20.6	25.9	28.6
11	20.8	28.0	27.7
33	20.9	27.5	27.2
int. wall	20.9	21.2	21.3
29	20.9	25.3	26.5
2	20.9	25.7	25.8
10	20.9	28.0	29.5
8	20.9	23.4	25.7
101	20.9	30.5	33.3
int. wall	20.8	21.6	21.5

BASAL METABOLISM

42 large calories per sq. meter per hour.

TABLE B7

DATE: Feb. 11, 1928.
SUBJECT: P. L.
SEX: Female.
AGE: 8 yrs.
WEIGHT: 25.9 kg.
HEIGHT: 129 cm.
SURFACE AREA: .96 sq. m.
CLOTHING: Cotton dress, short sleeves, cotton stockings.

Air temperature outdoors 6°.
Relative humidity indoors 46%.
Room temperature 21°.9.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	2	34.8
Clothing	6	26.8
Hair	1	27.7
Shoes	1	25.1
Wall	(est.)	21.4

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1204
Clothing	.0465
Hair	.0555
Shoes	.0315

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
101	20.9	29.7(?)	35.2
18	20.9	32.8	34.5
26a	20.9	27.9	27.7
54	20.9	25.6	26.7
22	20.9	27.4	29.0
34	20.9	25.3	25.1
2	20.9	24.0	25.1
29	20.9	25.1	24.8
10	20.9	29.1	30.3
7	20.9	25.1	25.1

TOTAL RADIATION

28.1 large calories per sq. meter per hour.

BASAL METABOLISM

42 large calories per sq. meter per hour.

Table B8

Date: Dec. 13, 1927.
Subject: M. M.
Sex: Female.
Age: 27 yrs.
Weight: 61.3 kg.
Height: 165 cm.
Surface Area: 1.67 sq. m.
Clothing: Dark silk dress, silk stockings.

Air temperature outdoors ——
Relative humidity indoors 59%.
Room temperature 22°.6.

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18	19.9	31.0	31.4
26a	19.9	26.3	26.6
100	19.9	34.4	....
54	19.9	28.8	31.6
11	19.9	29.7	31.9
34	19.9	27.7	28.2
30	19.9	26.0	27.4

Temperature Summary

Kind	No. Values	Temp. computed from Stefan formula °
Skin	2	31.4
Clothing	4	29.8
Hair	1	26.6
Shoes	(est.)	27.0
Wall	(est.)	22.1

Radiation Summary

	Calories per sq. cm. per min.
Skin	.0830
Clothing	.0676
Hair	.0390
Shoes	.0426

Total Radiation

35.9 large calories per sq. meter per hour.

Basal Metabolism

37 large calories per sq. meter per hour.

TABLE B9

DATE: Dec. 9, 1927.
SUBJECT: K. B.
SEX: Male.
AGE: 21 yrs.
WEIGHT: 61.3 kg.
HEIGHT: 173 cm.
SURFACE AREA: 1.73 sq. m.
CLOTHING: Woolen shirt and trousers, thick leather boots.

Air temperature outdoors, —2°.8.
Relative humidity indoors 38%.
Room temperature 18.4.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	5	30.5
Clothing	4	26.0
Hair	(est.)	27.0
Shoes	1	23.6
Wall	(est.)	17.9

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.1077
Clothing	.0681
Hair	.0766
Shoes	.0473

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
101	20.4	29.5	31.4
18	20.3	27.1	29.7
19	20.4	25.2	27.5
11	20.4	25.9	25.5
3	20.4	24.6	25.0
10	20.5	23.1	23.6
101	20.5	30.6	33.0
18	20.5	25.9	25.7
10	22.6	24.3	26.1
18	22.6	32.5	33.8

TOTAL RADIATION

38.2 large calories per sq. meter per hour.

BASAL METABOLISM

39.7 large calories per sq. meter per hour.

TABLE B10

DATE: Dec. 21, 1927.
SUBJECT: L. A.
SEX: Male.
AGE: 45 yrs.
WEIGHT: 74.6 kg.
HEIGHT: 179 cm.
SURFACE AREA: 1.93 sq. m.
CLOTHING: Dark wool suit.

Air temperature outdoors . .
Relative humidity indoors 37%.
Room temperature 21°.3.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. computed from Stefan formula °
Skin	1	31.6
Clothing	1	27.2
Hair	1	29.4
Shoes	(est.)	24.5
Wall	(est.)	20.8

RADIATION SUMMARY

	Calories per sq. cm. per min.
Skin	.0950
Clothing	.0552
Hair	.0752
Shoes	.0317

Place	Water Jacket Temp. °	Temp. by Thermo-Element °	Temp. computed from Stefan Formula °
18a	19.3	33.9	31.6
26a	19.3	31.7	29.4
11a	19.3	25.0	27.2

TOTAL RADIATION

31.4 large calories per sq. meter per hour.

BASAL METABOLISM

39.7 large calories per sq. meter per hour.

TABLE C.—*Preliminary Tests of Cylindrical Copper Calorimeters, Cloth-covered*

	Vertical	Horizontal
Amount of copper	2.91 kg.	2.60 kg.
Amount of brass	1.50	.50
Amount of water	26.70	27.20
Total water equivalent	27.05 kg.	27.48 kg.
Area of calorimeter	5103. sq. cm.	5103. sq. cm.

Date 1928	Calorimeter	Room Temp.	Outside Temp.	Air Velocity (feet per min.)	Mean Temp. Cal. Water	Melik. Water Jacket Temp.	Loss of Heat in calories per hour (large cal.)
Feb. 29	Vert.	21°.9	11°.7	0	30°.4	20.8	21°.36
Mar. 1	Vert.	23.7	8.9	0	32.1	22.2	19.57
Mar. 3	Vert.	22.9	6.7	about 300	32.0	20.4	38.42
Mar. 15	Horiz.	24.5	14.4	0	32.0	24.3	19.63
Mar. 16	Horiz.	22.0	3.3	0	32.4	22.7	27.75
Mar. 26	Horiz.	25.5	17.2	0	32.5	22.6	12.86 (no cloth cover)
Apr. 21	Vert.	24.1	8.3	0	37.5	22.7	
Apr. 25	Vert.	22.8	13.9	0	31.7	19.0	
Apr. 25	Vert.	23.5	15.0	0	31.7	22.6	

Date 1928	Estimated Wall Temp.	No. Values	Mean Temp. Cal. Surface (Thermo-element)	No. Values	Mean Temp. Cal. Surface (computed from Melik.)	Loss by Radiation (in large cal. per hour)	% Radiated
Feb. 29	21.4	11	27.0	5	28.2	17.07	80.
Mar. 1	23.2	12	29.0	4	29.1	15.83	81.
Mar. 3	22.4	17	25.6	6	29.2	18.25	47.
Mar. 15	24.1	18	29.0	6	29.3	14.00	71.
Mar. 16	21.5	18	28.4	6	29.5	21.45	77.
Mar. 26	25.1	18	30.7	4	26.7	4.41	34.
Apr. 21	....	28	32.2	4	32.7	.....	...
Apr. 25	....	27	28.1	4	30.2	.....	...
Apr. 25	....	27	28.6	4	29.4	.....	...

TABLE D.—*Tests of Vertical Calorimeter, Cloth-covered, Surrounded by Cloth Walls*

Date 1928	Room Temp.	Out-side Temp.	Air Vel. (feet per min.)	Mean Temp. Cal. Water	Melik. Water Jacket Temp.	Loss of Heat in large cal. per hour	Mean Wall Temp.	No. of places wall temp. measured
Apr. 27	21°6	9°4	0	34°2	21°3	31.80	22°0	19
Apr. 27	21.4	9.4	0	32.0	21.4	24.70	22.2	16
Apr. 28	22.4	8.9	0	30.9	22.5	21.95	22.9	18
May 1	23.9	20.6	0	34.5	23.1	25.40	24.7	13
May 1	23.9	20.6	130	33.9	23.2	33.50	24.6	11
May 3	24.7	27.2	0	31.2	24.2	15.70	26.0	10
May 3	25.0	27.2	75	30.9	24.2	16.75	25.9	9
May 5	28.5	33.9	75	39.5	28.5	34.05	29.9	12
May 5	28.8	33.9	130	38.8	28.5	35.15	29.7	12
May 7	24.4	20.0	190	36.4	25.6	47.60	25.0	12
May 7	24.4	20.0	190	35.6	25.4	43.80	25.0	12

Date 1928	Mean Temp. Cal. Surface (Thermo-element) °	No. of places meas-ured	Mean Temp. Cal. Surface (com-puted from Melik.) °	No. of places meas-ured	Loss by Radiation in large cal. per hour: Melik.	Loss by Radiation in large cal. per hour: Thermo-element	% Radiated: Melik.	% Radiated: Thermo-element
Apr. 27	29.5	26	29.1	4	18.95	20.06	59.5	63.2
Apr. 27	28.1	24	28.1	4	15.70	15.70	63.5	63.5
Apr. 28	27.9	22	28.2	4	14.13	13.40	64.4	61.2
May 1	30.5	16	30.6	4	16.07	15.64	63.3	61.6
May 1	29.2	22	30.6	4	16.43	12.54	49.0	37.4
May 3	28.9	8	29.3	4	8.88	7.93	56.5	50.5
May 3	28.5	9	28.2	4	6.17	6.94	36.8	41.5
May 5	34.7	16	34.7	4	13.84	13.84	40.7	40.7
May 5	33.7	16	33.8	4	11.55	11.30	32.8	32.2
May 7	29.1	16	31.4	3	17.70	11.04	37.2	23.2
May 7	29.2	16	31.7	3	18.50	11.42	42.2	26.1

TABLE E.—*Observations and Results of Experiments on Ten Subjects in Still and in Moving Air*

TABLE E1

DATE: May 30, 1928.
SUBJECT: S. A.
SEX: Male.
AGE: 7 yrs. 5 mos.
WEIGHT: 24 kg.
HEIGHT: 127 cm.
SURFACE AREA: .93 sq. m.
CLOTHING: Woolen sweater, cotton trousers, socks.

Air temperature outdoors, 21°.1.
Relative humidity indoors, 56%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	130 °	180 °
Skin	7	34.1	32.3	31.1
Clothing	15	28.4	27.3	26.3
Hair	1	33.8	34.2	32.4
Shoes	2	26.2	27.4	25.2
Wall	10	21.1	22.0	21.3
Room	2	19.8	21.3	20.9

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	130	180
Skin	.1157	.0915	.0865
Clothing	.0641	.0457	.0433
Hair	.1131	.1094	.0990
Shoes	.0444	.0468	.0337

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	38.6
130	29.4
180	27.2

Place	Temperatures at Air Velocity 0 °	130 °	180 °
room	19.7	21.1	20.9
wall A	19.0	21.4	21.0
B	20.8	21.3	21.2
C	21.7	23.4	21.9
D	20.8	21.6	21.1
E	19.4	20.6	19.4
26	34.6	35.0	33.6
100	30.8	30.2	30.1
101	32.3	29.7	29.5
19a	27.8	26.7	24.1
19	28.3	24.8	23.6
54	28.0	25.1	23.6
2	29.5	28.5	23.5
3	28.8	27.7	27.0
23	29.5	28.5	27.0
22	27.6	27.3	27.9
18	33.1	30.2	30.0
18a	32.5	30.8	29.9
17	33.4	31.7	30.5
17a	34.1	30.5	29.7
9	26.9	27.9	27.7
10	26.9	26.3	24.8
8	26.9	27.4	25.0
7	25.6	27.5	25.5
26a	33.8	34.2	32.4
35	29.1	27.3	26.7
36	28.6	27.3	27.5
29	30.4	30.0	29.3
30	30.5	27.2	27.5
27	27.4	27.3	26.8
28	27.3	27.8	26.4
wall A	22.1	22.5	21.3
B	22.1	22.9	20.4
C	23.6	....	24.4
D	21.7	22.8	21.6
E	19.8	21.1	20.9
room	19.9	21.5	21.0

TABLE E2

DATE: July 12, 1928.
SUBJECT: S. W.
SEX: Male.
AGE: 6 yrs. 6 mos.
WEIGHT: 18 kg.
HEIGHT: 116 cm.
SURFACE AREA: .78 sq. m.
CLOTHING: Tan cotton suit, socks.
Air temperature outdoors, 27°.0.
Relative humidity indoors, 68%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	15 °	50 °
Skin	11	34.4	33.8	33.7
Clothing	11	31.8	31.4	30.2
Hair	1	35.1	33.6	32.7
Shoes	2	28.4	28.2	28.1
Wall	10	26.0	24.5	23.9
Room	2	25.1	23.3	23.1

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	15	50
Skin	.0766	.0838	.0878
Hair	.0835	.0818	.0785
Clothing	.0521	.0619	.0552
Shoes	.0215	.0327	.0362

TOTAL RADIATION

Air Vel.	Calories per hour per sq. meter
0	29.3
15	34.4
50	32.1

Place	Temperatures at Air Velocity 0 °	15 °	50 °
room	24.9	23.2	23.0
wall A	25.7	23.9	23.7
B	25.7	23.8	23.3
C	26.0	24.3	23.7
D	25.6	24.0	23.4
E	25.1	23.9	23.5
26	35.6	35.5	35.0
100	32.0	31.7	31.9
101	33.1	33.3	32.3
19a	33.2	33.2	32.3
19	32.6	32.9	31.7
54	30.2	31.7	32.1
2	29.5	30.7	28.8
3	32.0	30.0	28.7
23	32.5	31.8	31.2
22	32.6	32.1	31.7
18	34.8	34.4	33.8
18a	33.9	33.8	33.3
17	35.1	33.3	34.6
17a	34.3	33.3	33.6
9*	32.4	30.3	31.6
10*	32.4	31.5	31.0
8	28.7	29.0	28.3
7	28.2	27.4	27.9
26a	35.1	33.6	32.7
35	33.1	32.0	29.3
36	32.0	32.2	30.5
29	29.9	29.0	27.9
30	31.9	30.0	27.8
27*	31.6	30.9	31.0
28*	31.3	32.1	30.5
wall A	26.6	25.4	24.7
B	26.6	25.1	24.1
C	26.7	25.7	24.9
D	26.2	24.3	23.9
E	25.8	24.3	24.1
room	25.3	23.3	23.1

TABLE E3

DATE: July 12, 1928.
SUBJECT: M. W.
SEX: Female.
AGE: 11 yrs. 5 mos.
WEIGHT: 27.5 kg.
HEIGHT: 143 cm.
SURFACE AREA: 1.07 sq. m.
CLOTHING: Light cotton dress, socks.
Air temperature outdoors, 27.0.
Relative humidity indoors, 68%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	15 °	50 °
Skin	7	35.0	35.1	34.0
Clothing	15	31.6	31.1	30.2
Hair	1	33.8	33.4	31.8
Shoes	2	31.3	29.6	27.6
Wall	10	25.7	24.5	24.2
Room	2	24.5	23.2	23.2

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	15	50
Skin	.0851	.0965	.0882
Clothing	.0525	.0587	.0528
Hair	.0730	.0803	.0677
Shoes	.0498	.0447	.0296

TOTAL RADIATION

Air Vel.	Calories per hour per sq. meter
0	31.0
15	34.2
50	30.2

Place	Temperatures at Air Velocity 0 °	15 °	50 °
room	25.0	23.3	23.2
wall A	25.7	24.3	24.0
B	25.5	23.9	23.7
C	26.1	24.8	24.6
D	25.6	24.0	23.6
E	25.3	24.0	23.9
26	34.9	34.6	34.5
100	33.7	33.5	32.8
101	32.6	32.5	32.0
19a	32.6	33.0	33.0
19	33.1	32.6	31.9
54	33.9	33.4	33.4
2	31.6	28.4	28.2
3	31.3	28.9	28.1
23	31.9	31.4	31.0
22	31.9	31.8	31.1
18	33.6	33.6	32.7
18a	34.2	33.8	32.6
17	34.4	35.0	32.5
17a	34.2	35.2	32.9
9	31.7	30.7	31.5
10	31.9	32.2	31.0
8	31.1	30.0	27.6
7	31.6	29.2	27.6
26a	33.8	33.4	31.8
35	33.4	32.7	30.5
36	30.0	33.0	31.5
29	29.8	29.1	27.6
30	29.0	29.2	25.9
27	30.8	29.5	29.2
28	31.7	30.6	29.7
wall A	26.3	25.2	24.6
B	25.7	25.0	24.2
C	26.1	25.3	25.1
D	25.3	24.3	24.1
E	25.2	24.3	23.9
room	24.0	23.0	23.2

TABLE E4

DATE: July 14, 1928.
SUBJECT: T. L.
SEX: Male.
AGE: 14 yrs. 3 mos.
WEIGHT: 43.5 kg.
HEIGHT: 152 cm.
SURFACE AREA: 1.36 sq. m.
CLOTHING: Cotton waist, black woolen trousers, canvas shoes, high socks.

Air temperature outdoors, 27°.8.
Relative humidity indoors, 68%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0	84	136
		°	°	°
Skin	7	34.3	33.4	32.1
Clothing	15	30.3	29.3	29.2
Hair	1	31.1	31.4	29.6
Shoes	2	28.4	29.1	27.9
Wall	10	23.8	23.5	23.2
Room	2	22.5	22.7	22.8

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	84	136
Skin	.0943	.0892	.0790
Clothing	.0569	.0509	.0527
Hair	.0647	.0708	.0558
Shoes	.0405	.0491	.0414

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	32.5
84	30.2
136	29.7

Place	Temperatures at Air Velocity 0	84	136
	°	°	°
room	22.4	22.6	22.8
wall A	23.8	23.4	23.1
B	23.2	22.8	22.8
C	23.8	23.3	23.3
D	23.3	22.9	22.8
E	23.4	23.3	22.9
26	33.9	32.6	33.0
100	31.2	30.7	29.8
101	31.7	31.1	30.0
19a	31.2	30.5	31.0
19	31.1	30.6	30.5
54	29.2	30.1	29.4
2	28.7	28.2	28.7
3	27.7	26.9	28.6
23	31.1	30.8	29.6
22	31.6	30.1	31.1
18	33.2	33.1	31.1
18a	33.3	32.5	30.8
17	34.7	33.7	32.0
17a	34.6	32.7	30.1
9	30.8	30.5	30.5
10	31.7	31.0	30.7
8	28.2	29.1	28.2
7	28.6	29.1	27.7
26a	31.1	31.4	29.6
35	30.3	28.1	28.1
36	31.2	29.6	28.1
29	28.7	27.5	26.2
30	29.9	27.5	27.3
27	30.3	29.4	29.2
28	30.5	30.1	28.7
wall A	24.6	23.4	23.7
B	23.9	23.7	22.3
C	24.6	24.0	23.7
D	23.9	23.5	23.1
E	24.0	24.3	24.6
room	22.6	22.9	22.8

TABLE E5

DATE: July 18, 1928
SUBJECT: P. L.
SEX: Female
AGE: 8 yrs. 5 mos.
WEIGHT: 26 kg.
HEIGHT: 131 cm.
SURFACE AREA: .98 sq. m.
CLOTHING: Light, cotton dress, high socks.
Air temperature outdoors, 28° to 33°.
Relative humidity indoors, 61%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	97 °	235 °
Skin	7	34.2	34.4	33.6
Clothing	15	30.8	30.3	29.9
Hair	1	32.5	32.2	31.4
Shoes	2	29.4	29.2	28.1
Wall	10	25.2	25.1	25.5
Room	2	24.1	24.3	24.6

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	97	235
Skin	.0818	.0850	.0734
Clothing	.0502	.0463	.0359
Hair	.0658	.0643	.0536
Shoes	.0374	.0368	.0231

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	29.0
97	27.4
235	21.4

Place	Temperatures at Air Velocity 0 °	97 °	235 °
room	24.2	24.1	24.5
wall A	25.0	24.6	24.7
B	24.9	24.5	25.0
C	25.9	25.5	26.2
D	24.7	24.5	25.5
E	24.4	24.4	25.3
26	34.5	34.6	34.4
100	31.5	31.7	31.1
101	31.6	31.3	31.1
19a	32.0	29.9	29.5
19	31.5	31.4	31.2
54	30.8	30.6	31.2
2	28.9	30.2	30.5
3	29.8	31.4	29.0
23	31.7	31.1	31.0
22	32.0	30.9	30.1
18	33.0	33.4	32.1
18a	32.6	33.8	32.9
17	34.9	33.8	33.3
17a	33.5	34.6	32.6
9	29.8	30.5	30.0
10	31.1	30.5	31.2
8	29.4	29.2	28.2
7	29.4	29.2	28.0
26a	32.5	32.2	31.4
35	31.9	30.0	29.8
36	32.7	30.4	31.8
29	30.0	29.6	26.6
30	29.4	27.9	26.9
27	30.0	29.6	29.2
28	30.1	29.8	29.8
wall A	26.0	25.6	25.4
B	25.3	25.3	25.5
C	26.3	26.4	26.6
D	25.1	25.0	25.3
E	24.6	24.9	25.4
room	24.0	24.5	24.8

TABLE E6

DATE: July 18, 1928.
SUBJECT: M. A.
SEX: Female.
AGE: 55 yrs.
WEIGHT: 64.5 kg.
HEIGHT: 167 cm.
SURFACE AREA: 1.73 sq. m.
CLOTHING: Light, cotton dress, black stockings.
Air temperature outdoors, 28° to 33°.
Relative humidity indoors, 61%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	97 °	235 °
Skin	7	35.1	34.6	34.2
Clothing	15	31.1	30.7	30.5
Hair	1	28.4	26.7	27.5
Shoes	2	29.2	29.3	28.3
Wall	10	25.5	25.3	25.3
Room	2	24.0	24.2	24.6

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	97	235
Skin	.0883	.0853	.0812
Clothing	.0504	.0490	.0464
Hair	.0262	.0126	.0194
Shoes	.0332	.0356	.0268

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	28.0
97	26.8
235	25.2

Place	Temperatures at Air Velocity 0 °	97 °	235 °
room	24.0	24.1	24.5
wall A	24.9	24.6	24.7
B	25.0	25.0	25.0
C	26.1	26.2	26.5
D	24.7	24.6	24.9
E	24.1	24.3	24.3
26	33.8	33.3	33.2
100	32.3	32.2	32.0
101	32.4	31.9	31.6
19a	30.4	29.9	30.1
19	30.7	30.2	30.7
54	31.3	30.9	31.6
2	29.1	30.1	31.1
3	30.0	30.4	32.0
23	31.3	31.3	30.6
22	30.9	30.3	30.1
18	34.7	33.7	33.1
18a	33.6	33.0	33.1
17	35.8	35.5	34.1
17a	35.5	34.6	34.5
9	31.2	31.3	31.7
10	31.4	31.5	30.7
8	29.2	29.5	27.5
7	29.1	29.2	29.2
26a	28.4	26.7	27.5
35	32.0	30.4	29.2
36	31.7	31.0	29.6
29	31.8	30.6	29.9
30	31.8	30.6	29.3
27	31.1	31.3	30.7
28	31.2	31.2	30.4
wall A	28.1	25.7	25.2
B	26.0	25.8	25.9
C	26.7	26.8	27.0
D	25.1	25.3	25.2
E	24.5	24.9	24.6
room	24.0	24.4	24.7

TABLE E7

DATE: July 19, 1928.
SUBJECT: M. B.
SEX: Female.
AGE: 4 yrs. 8 mos.
WEIGHT: 15 kg.
HEIGHT: 100 cm.
SURFACE AREA: .65 sq. m.
CLOTHING: Light, cotton dress, no sleeves, high socks.

Air temperature outdoors, 29° to 33°.
Relative humidity indoors, 58%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0 °	140 °	235 °
Skin	9	33.7	34.2	34.4
Clothing	13	31.2	30.7	30.4
Hair	1	32.0	29.7	29.0
Shoes	2	29.0	29.2	28.9
Wall	10	25.6	25.8	25.9
Room	2	24.6	24.9	25.2

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	140	235
Skin	.0696	.0764	.0772
Clothing	.0505	.0442	.0398
Hair	.0578	.0346	.0272
Shoes	.0302	.0302	.0265

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	28.1
140	25.2
235	23.1

Place	Temperatures at Air Velocity 0 °	140 °	235 °
room	24.5	24.4	24.9
wall A	25.3	25.2	25.3
B	25.1	25.2	25.8
C	26.1	26.3	26.6
D	25.1	25.2	25.4
E	24.8	25.0	25.1
26	32.2	33.7	33.8
100	32.0	32.6	32.6
101	32.4	32.7	32.9
19a	32.0	30.7	30.6
19	31.2	30.1	30.7
54	30.9	32.5	32.3
2	31.6	30.1	31.7
3	30.8	29.9	31.1
23*	32.0	32.1	32.5
22*	32.0	32.0	32.6
18	32.4	32.8	33.6
18a	32.4	33.1	33.6
17	34.1	33.9	34.4
17a	33.9	34.7	33.7
9	31.0	31.3	30.3
10	32.1	31.9	31.1
8	28.4	28.9	29.8
7	29.7	29.6	28.0
26a	32.0	29.7	29.0
35	30.7	29.8	28.8
36	31.8	32.1	31.5
29	31.2	29.2	28.3
30	30.2	29.8	28.6
27	31.1	31.1	29.8
28	31.2	30.5	30.3
wall A	26.1	26.2	26.1
B	26.1	26.3	26.3
C	26.8	27.0	27.0
D	25.6	25.8	25.9
E	25.2	25.6	25.3
room	24.7	25.4	25.6

TABLE E8

DATE: July 19, 1928.
SUBJECT: G. B.
SEX: Female.
AGE: 30 yrs.
WEIGHT: 59 kg.
HEIGHT: 157 cm.
SURFACE AREA: 1.59 sq. m.
CLOTHING: Light, cotton dress, short sleeves, tan stockings.

Air temperature outdoors, 29° to 33°.
Relative humidity indoors, 58%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0	140	235
		°	°	°
Skin	7	34.9	34.1	33.5
Clothing	15	31.6	30.8	30.3
Hair	1	31.9	31.1	30.4
Shoes	2	30.6	29.8	30.5
Wall	10	26.0	25.9	26.0
Room	2	24.8	25.1	25.4

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	140	235
Skin	.0821	.0738	.0680
Clothing	.0502	.0437	.0380
Hair	.0534	.0463	.0392
Shoes	.0412	.0341	.0398

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	28.9
140	25.2
235	22.6

Place	Temperatures at Air Velocity 0	140	235
	°	°	°
room	25.0	24.9	25.1
wall A	25.6	25.3	25.4
B	25.7	25.4	25.5
C	26.8	26.6	26.8
D	25.6	25.4	25.6
E	25.2	24.9	25.1
26	33.8	33.5	33.5
100	33.4	32.6	32.9
101	33.2	32.4	32.5
19a	32.0	32.7	32.3
19	32.0	32.0	32.1
54	30.9	31.0	30.7
2	30.9	31.0	28.8
3	31.2	29.3	29.4
23	32.9	31.8	31.3
22	32.8	32.3	31.2
18	33.5	33.1	32.2
18a	33.0	32.8	32.0
17	34.8	33.5	31.9
17a	34.7	32.8	31.9
9	31.5	31.0	30.7
10	32.2	31.5	31.2
8	30.6	29.8	30.3
7	30.6	29.8	30.8
26a	31.9	31.1	30.4
35	32.6	31.5	31.0
36	32.7	31.8	31.5
29	30.1	26.5	26.9
30	29.8	27.8	27.4
27	31.3	30.5	29.9
28	31.2	31.2	30.3
wall A	26.6	26.5	26.1
B	26.5	26.6	26.3
C	27.1	27.1	27.2
D	25.8	26.0	26.1
E	25.4	25.4	25.7
room	24.6	25.3	25.7

TABLE E9

DATE: July 20, 1928.
SUBJECT: E. L.
SEX: Female.
AGE: 8 yrs. 5 mos.
WEIGHT: 24 kg.
HEIGHT: 129 cm.
SURFACE AREA: .94 sq. m.
CLOTHING: Light, cotton dress, no sleeves, high socks.

Air temperature outdoors, 32° to 35°.6.
Relative humidity indoors, 60%.

TEMPERATURE SUMMARY

Kind	No. Values	Temp. at air vel. 0	145	245
		°	°	°
Skin	9	34.9	34.3	34.6
Clothing	13	31.8	30.8	30.7
Hair	1	33.3	30.2	30.9
Shoes	2	31.8	30.5	30.6
Wall	10	27.1	26.9	27.2
Room	2	26.0	26.1	26.4

RADIATION SUMMARY

	Calories per sq. cm. per min. at air vel. 0	145	245
Skin	.0729	.0673	.0583
Clothing	.0430	.0352	.0320
Hair	.0567	.0294	.0340
Shoes	.0430	.0319	.0307

TOTAL RADIATION

Air vel.	Calories per hour per sq. meter
0	25.8
145	20.8
245	19.0

Place	Temperatures at Air Velocity 0	145	245
	°	°	°
room	25.7	25.9	26.2
wall A	26.6	26.4	26.6
B	27.1	26.5	26.9
C	28.4	27.4	27.8
D	26.8	26.4	26.8
E	26.5	26.2	26.6
26	35.1	34.6	34.7
100	33.0	32.3	33.0
101	33.1	32.5	33.0
19a	30.8	30.0	30.2
19	31.6	30.7	31.4
54	33.0	32.4	32.5
2	31.6	30.8	30.3
3	30.4	29.9	30.7
23*	32.5	32.2	32.5
22*	32.6	32.1	33.0
18	34.1	33.4	34.1
18a	34.4	34.2	34.0
17	34.8	33.7	33.8
17a	35.0	33.8	33.6
9	32.5	32.5	31.4
10	32.6	32.3	31.6
8	31.9	29.3	30.3
7	31.6	31.8	30.9
26a	33.3	30.2	30.9
35	31.8	31.1	30.3
36	31.8	30.7	31.3
29	32.6	27.7	28.0
30	31.1	28.5	29.2
27	31.9	31.3	31.4
28	32.1	32.1	31.3
wall A	27.3	27.1	27.2
B	27.0	27.1	27.5
C	27.9	28.0	28.3
D	26.8	26.9	27.0
E	26.5	26.6	27.3
room	26.3	26.4	26.6

Table E10

Date: July 20, 1928.
Subject: J. C.
Sex: Male.
Age: 10 yrs. 11 mos.
Weight: 35 kg.
Height: 135 cm.
Surface Area: 1.14 sq. m.
Clothing: Cotton waist, golf knickers, high socks.
Air temperature outdoors, 32° to 35°.6.
Relative humidity indoors, 60%.

Temperature Summary

Kind	No. Values	Temp. at air vel. 0 (°)	145 (°)	245 (°)
Skin	7	35.2	34.8	34.5
Clothing	15	32.8	32.2	31.9
Hair	1	34.0	34.1	32.3
Shoes	2	32.0	31.9	32.2
Wall	10	26.9	27.2	27.3
Room	2	25.8	26.3	26.7

Radiation Summary

	Calories per sq. cm. per min. at air vel. 0	145	245
Skin	.0768	.0703	.0664
Clothing	.0533	.0457	.0425
Hair	.0647	.0629	.0458
Shoes	.0462	.0431	.0451

Total Radiation

Air vel.	Calories per hour per sq. meter
0	30.0
145	26.3
245	24.4

Place	Temperatures at Air Velocity 0 (°)	145 (°)	245 (°)
room	25.6	26.1	26.5
wall A	26.6	26.7	26.9
B	26.4	26.8	27.2
C	27.4	27.9	28.0
D	26.5	26.7	27.0
E	26.3	26.5	26.9
26	34.5	34.0	33.9
100	34.0	33.4	33.5
101	33.4	33.2	33.4
19a	33.7	33.6	33.1
19	33.3	33.0	33.3
54	33.4	33.3	34.0
2	32.2	32.0	30.8
3	31.9	31.2	32.2
23	33.1	32.7	32.8
22	32.9	32.8	32.5
18	34.2	33.8	33.1
18a	34.0	34.4	32.7
17	34.1	33.3	33.6
17a	34.8	33.9	33.7
9	32.0	30.8	31.0
10	32.3	32.2	31.7
8	32.1	32.0	31.8
7	31.9	31.8	32.7
26a	34.0	34.1	32.3
35	34.1	31.9	32.8
36	34.5	33.1	32.0
29	32.1	31.4	30.2
30	32.7	31.5	30.1
27	31.4	31.5	30.9
28	31.9	32.1	31.4
wall A	27.3	27.4	27.2
B	27.0	27.4	27.5
C	27.8	28.6	28.1
D	26.8	27.2	27.1
E	26.7	26.9	27.1
room	26.0	26.6	27.0

TABLE F.—*Summary of Cloth-covered Calorimeter Tests*

Calorimeter	Wall Temp.	Air Vel.	Per cent Radiated by Melik.	Per cent Radiated by Thermoelement	No. of Tests
Preliminary tests—					
Vertical	Estimated	0	80	72	5
Horizontal	Estimated	0	74	65	2
Final tests with cloth walls—					
Vertical	Measured	0	61	60	5
Vertical	Measured	75	39	41	2
Vertical	Measured	130	41	35	2
Vertical	Measured	190	40	25	2

TABLE G.—*Summary Comparing all Thermoelement Temperatures with Corresponding Temperatures Computed from Melikeron Values Given in Tables B, C and D*

Place	No. of Observations	Average difference Melik.—Thermo.	Average difference Room temp.—Water Jacket temp. Algebraic Mean	Average difference Room temp.—Water Jacket temp. Arithmetic Mean
Skin	37	1°.91	°.67	1°.31
Clothing	49	1.12	1.16	1.45
Hair	9	.30	1.61	1.61
Shoes	8	1.39	.43	1.20
Wall	15	.03	1.37	1.37
Cloth-covered Cal. in still air	52	.56	.82	.95
moving air <130 ft	16	.37	—.4	.7
>190 ft	12	2.8	.2	1.6
Clothing, Hair, Shoes	67	1.10	1.12	1.40
Clothing, Hair, Shoes, Cal. <130 ft.	135	.80	.82	1.14

TABLE H.—*Summary Taken from Observations Recorded in Table E*

Subject	Room Temp.	Wall Temp.	Radiation Loss large calories per hour per sq. meter
In still air—	°	°	
S. A.	19.8	21.1	38.6
S. W.	25.1	26.0	29.3
M. W.	24.5	25.7	31.0
T. L.	22.5	23.8	32.5
P. L.	24.1	25.2	29.0
M. A.	24.0	25.5	28.0
M. B.	24.6	25.6	28.1
G. B.	24.8	26.0	28.9
E. L.	26.0	27.1	25.8
J. C.	25.8	26.9	30.0
Air vel. <50 ft.—	°	°	
S. W.	23.3	24.5	34.4
M. W.	23.2	24.5	34.2
Air vel. 50 to 100 ft.—	°	°	
S. W.	23.1	23.9	32.1
M. W.	23.2	24.2	30.2
T. L.	22.7	23.5	30.2
P. L.	24.3	25.1	27.4
M. A.	24.2	25.3	26.8
Air vel. 100 to 150 ft.—	°	°	
S. A.	21.3	22.4	29.4
T. L.	22.8	23.2	29.7
M. B.	24.9	25.8	25.2
G. B.	25.1	25.9	25.2
E. L.	26.1	26.9	20.8
J. C.	26.3	27.2	26.3
Air vel. 180 to 250 ft.—	°	°	
S. A.	20.9	21.3	27.2
P. L.	24.6	25.5	21.4
M. A.	24.6	25.3	25.2
M. B.	25.2	25.9	23.1
G. B.	25.4	26.0	22.6
E. L.	26.4	27.2	19.0
J. C.	26.7	27.3	24.4

MEANS—

Air Vel.	No. of Determinations	Room Temp.	Wall Temp.	Radiation Loss, large cal. per hr. per sq. m.
		°	°	
<50	12	23.9	25.2	30.7
50 to 100	5	23.5	24.4	29.3
100 to 150	6	24.4	25.2	25.7
180 to 250	7	24.8	25.5	23.2

TABLE J.—*Summary from Observations Given in Table E, for Still Air*

1928	Subject	Age	Sex	Room Temp.	Basal Metab. (large cal. per sq. m. per hour)	Loss by Radiation (large cal. per sq. m. per hour)	Rad. Loss / Basal Met.
May 30	S. A.	7	M	19°8	43	38.6	.90
July 12	S. W.	6	M	25.1	44	29.3	.67
July 12	M. W.	11	F	24.5	40	31.0	.77
July 14	T. L.	14	M	22.5	41	32.5	.79
July 18	P. L.	8	F	24.1	41	29.0	.71
July 18	M. A.	55	F	24.0	34	28.0	.82
July 19	M. B.	5	F	24.6	42	28.1	.67
July 19	G. B.	30	F	24.8	35	28.9	.83
July 20	E. L.	8	F	26.0	42	25.8	.61
July 20	J. C.	11	M	25.8	42	30.0	.71

Arranged according to increasing room temperatures:

Subject	Room Temp.	Radiation Loss / Basal Metabolism	
S. A.	19.8	.90	
T. L.	22.5	.79	.84
M. A.	24.0	.82	
P. L.	24.1	.71	
M. W.	24.5	.77	.74
M. B.	24.6	.67	
G. B.	24.8	.83	
S. W.	25.1	.67	
J. C.	25.8	.71	.66
E. L.	26.0	.61	

TABLE K.—*Summary of Drop in Temperature of Skin and Clothing due to Increased Air Motion, from Observations Given in Table E*

(*Each number is the mean of from 3 to 6 values*)

Subject	Air Vel. (Feet per min.)	Skin: Away from fan °	Skin: Towards fan °	Skin: Side °	Clothing: Away from fan °	Clothing: Towards fan °	Clothing: Side °
S. A.	100 to 150	—1.7	—1.5	.....	—1.1	—1.9	+ .3
	180 to 250	—2.9	—2.1	.....	—1.5	—3.9	— .9
S. W.	0 to 50	— .2	— .9	—1.5	+ .2	— .9	0
	50 to 100	— .6	—1.0	—2.2	— .8	—2.8	— .3
M. W.	0 to 50	— .2	+ .4	.....	—1.2	— .1	— .8
	50 to 100	— .9	—1.8	.....	—1.6	—1.7	—1.7
T. L.	50 to 100	— .7	— .9	.....	— .3	—1.4	— .2
	100 to 150	—1.8	—2.9	.....	0	—2.2	— .7
P. L.	50 to 100	+ .4	— .1	.....	+ .1	—1.2	— .4
	180 to 250	— .3	—1.2	.....	— .3	—1.7	— .9
M. A.	50 to 100	— .6	—1.0	.....	0	— .8	0
	180 to 250	— .8	—1.2	.....	+ .8	—1.8	— .5
M. B.	100 to 150	+ .7	— .6	0	— .6	— .6	+ .1
	180 to 250	+1.0	+ .3	+ .5	0	—1.5	— .5
G. B.	100 to 150	— .5	—1.3	.....	— .2	—1.4	— .8
	180 to 250	— .8	—2.4	.....	— .7	—1.8	— .9
E. L.	100 to 150	— .5	—1.8	— .4	— .7	—1.7	— .6
	180 to 250	— .1	—1.6	+ .2	— .5	—1.7	—1.1
J. C.	100 to 150	— .2	— .5	.....	— .3	— .9	— .4
	180 to 250	— .7	—1.1	.....	— .2	—1.6	— .3
MEANS—							
	0 to 50	— .2	— .2	.....	— .5	— .5	— .4
	50 to 100	— .5	—1.0	.....	— .6	—1.6	— .5
	100 to 150	— .7	—1.4	.....	— .5	—1.5	— 4
	180 to 250	— 7	—1.3	.....	— .3	—2.0	— .7
	0 to 100	— .4	— .8	.....	— .6	—1.3	— .5
	100 to 250	— .7	—1.2	.....	— .4	—1.7	— .5

From Table H, Mean change in Room Temp. from still air to air motion = +°.2. Mean change in Wall Temp. from still air to air motion = —°.2.

TABLE L.—*Summary of the Two Series of Ten Subjects* (*Tables B and E*)

Series	Dates	Range of Room T.	Mean of Room T.	Range of Relative Humidity	Mean	Kind	Total Radiation	Basal Metabolism	Radiation / Bas. Met.
First	Dec. 9	18°.4	21°.3	32%	43%	Adult	35.2	39	.90
	to	to	......	to	......	Children	32.7	43	.76
	Feb. 11	22.6	......	59%	......	All	33.5	42	.80
Second	May 30	19.8	24.1	56%	62%	Adult	28.4	34.5	.82
	to	to	......	to	......	Children	30.5	42	.73
	July 20	26.0	......	68%	......	All	30.1	40.5	.75

Radiation and basal metabolism values are given in large calories per hour per sq. meter of body surface.