[13] Hecht, S., *Proc. Nat. Acad. Sci.*, **23**, 227 (1937).
[14] Federov, N. T., *C. R. Acad. Sci.* (URSS), **24**, 696 (1939).
[15] Crozier, W. J., and Holway, A. H., to be described elsewhere.
[16] Steinhardt, J., *Jour. Gen. Physiol.*, **20**, 185 (1936–1937).
[17] Hecht, S., Peskin, J. C., and Patt, M., *Ibid.*, **22**, 7 (1938–1939).
[18] Crozier, W. J., *Proc. Nat. Acad. Sci.*, **22**, 412 (1936); a fuller account of this matter will be published elsewhere.

DIFFERENCES BETWEEN MEN AND WOMEN IN THEIR RESPONSE TO HEAT AND COLD

BY JAMES D. HARDY AND EUGENE F. DU BOIS

RUSSELL SAGE INSTITUTE OF PATHOLOGY IN AFFILIATION WITH THE NEW YORK HOSPITAL AND DEPARTMENT OF MEDICINE, CORNELL UNIVERSITY MEDICAL COLLEGE

Read before the Academy, April 22, 1940

There have been a large number of publications dealing with the reactions of men to changes of environmental temperature, but very few studies with women. Just why there has been such a neglect of half our population is not clear. Air conditioning is theoretically based on physiological studies, and politeness alone would demand more consideration of the ladies. It is well known that women in light clothing tolerate a wide range in temperature. This is not due to greater fortitude or vanity but rather a better physiological adjustment.

Max Rubner in 1890 and 1902[1–3] outlined the factors concerned in the loss of heat and described the "physical regulation" through changes in heat loss or voluntary activity. He also spoke of a rise in heat production through "chemical regulation" which is induced without visible changes in the activity of the animal. In previous papers from the Russell Sage Institute of Pathology[4,5] presented before this Society we reported that the heat production of the two normal men studied by us in detail was uniform when exposed to temperatures between 22° and 35°C. This is in accordance with the findings of Wiley and Newburgh[6] in Ann Arbor, Winslow, Herrington and Gagge[7] in New Haven, and others. Martin,[8] however, did note a falling metabolism in one man during a voyage to the tropics. There have been may reports indicating that the basal metabolism of men and women is lower in the tropics, but there are several factors involved besides temperature. Miss Mason,[9] who eliminated all the factors except climate, observed that the metabolism of a group of women was 5% lower in tropical India than it was in the temperate zone. Hardy and Milhorat,[10] in a brief preliminary publication from the Russell Sage Institute of Pathology last year, demonstrated that three normal women showed a considerable drop in metabolism in a warm environment and they analyzed the differences between these women and the two men that we had studied in the same manner. In this present report we can add the results on four more women.

The men and women were studied in the respiration calorimeter of the Russell Sage Institute of Pathology[11] which is now at the New York Hospital. They came to the laboratory at 9 o'clock in the morning without breakfast, sat quietly for an hour in the calorimeter room which had been kept at the desired temperature since the previous day, undressed and entered the calorimeter which was then sealed. During the preliminary period in the box the surface temperature was measured. The first experimental period was started at about 11 o'clock, and observations were terminated either at noon or at 1 o'clock. At the end of the experiment the surface temperature was determined once more. During the experimental periods the subjects lay almost motionless on a comfortable bed made of fish net with a folded sheet under the body. There was little movement of air in the calorimeter. The two normal men were 33 and 54 years old, in good physical condition; and the seven women were artist models or technicians, in good physical condition, between the ages of 21 and 35 years, with weights of 54 kg. to 77 kg. They were all intelligent and coöperative.

The respiration calorimeter of the Russell Sage Institute of Pathology has been described many times. Since 1935 we have been using the Hardy radiometer[12] to determine skin temperature. Combining these two instruments the following quantities are measured:

(1) The rectal temperature, measured every 4 minutes
(2) The skin temperature in twenty points, at the beginning and end of each period
(3) The calorimeter temperature (wall and air), at the beginning and end of each period
(4) The total heat production during a period (usually one hour)
(5) The total heat loss by radiation and convection
(6) The total grams of water vaporized from skin and lungs
(7) The surface area of the body

From these data, according to procedures already described in detail, the following quantities could be calculated:

(1) The average skin temperature
(2) The effective radiating surface of the skin
(3) The total heat loss by radiation
(4) The total heat loss by convection
(5) The total heat loss by vaporization

(6) The heat stored in the body
(7) The conductance of the peripheral tissues of the body
(8) The cooling constant of Newton's Law of Cooling

Figure 1, which has already been described in previous publications[4,5] shows the results on the two men. It will be noted that the heat production represented by the first blank column in each group of experiments

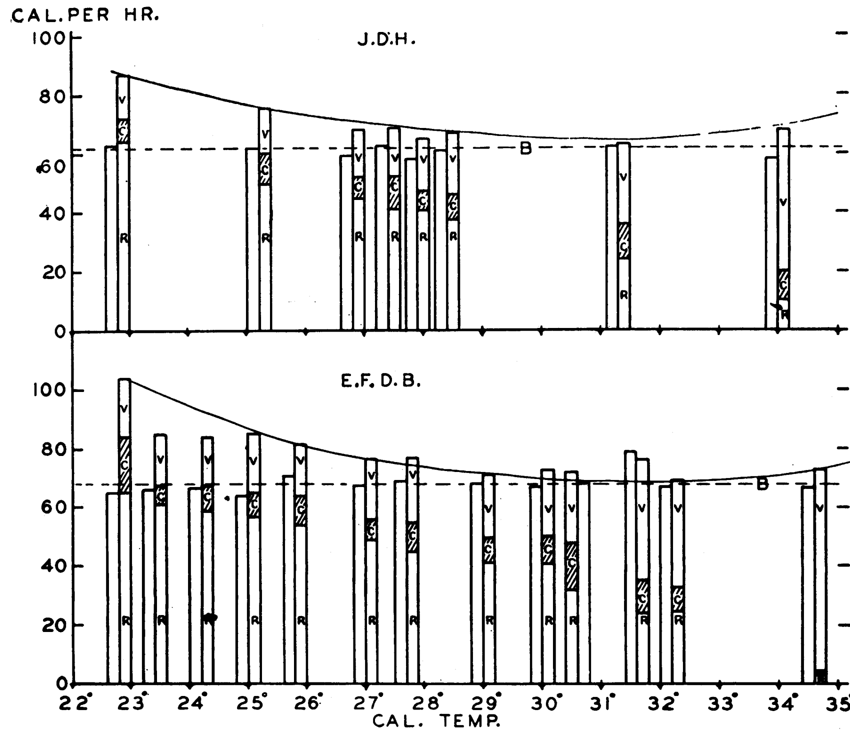

FIGURE 1

Heat production and heat loss of two normal men exposed naked in the calorimeter to temperatures between 22–35°C. The first or blank column in each experiment shows the basal heat production (*B*) which was uniform throughout the range. The second column shows heat loss divided into radiation (*R*), convection (*C*) and vaporization (*V*).

remained constant throughout the experimental range. The heat loss shown in the second column of each group exceeded the heat production in the cold zone and equalled it in the comfort zone between 29° and 31°C. Radiation (*R*), given in the lower portions of each of these heat loss columns, decreased steadily with increasing temperature until it disappeared at 35°C. when the skin temperature equalled the temperature of the wall of

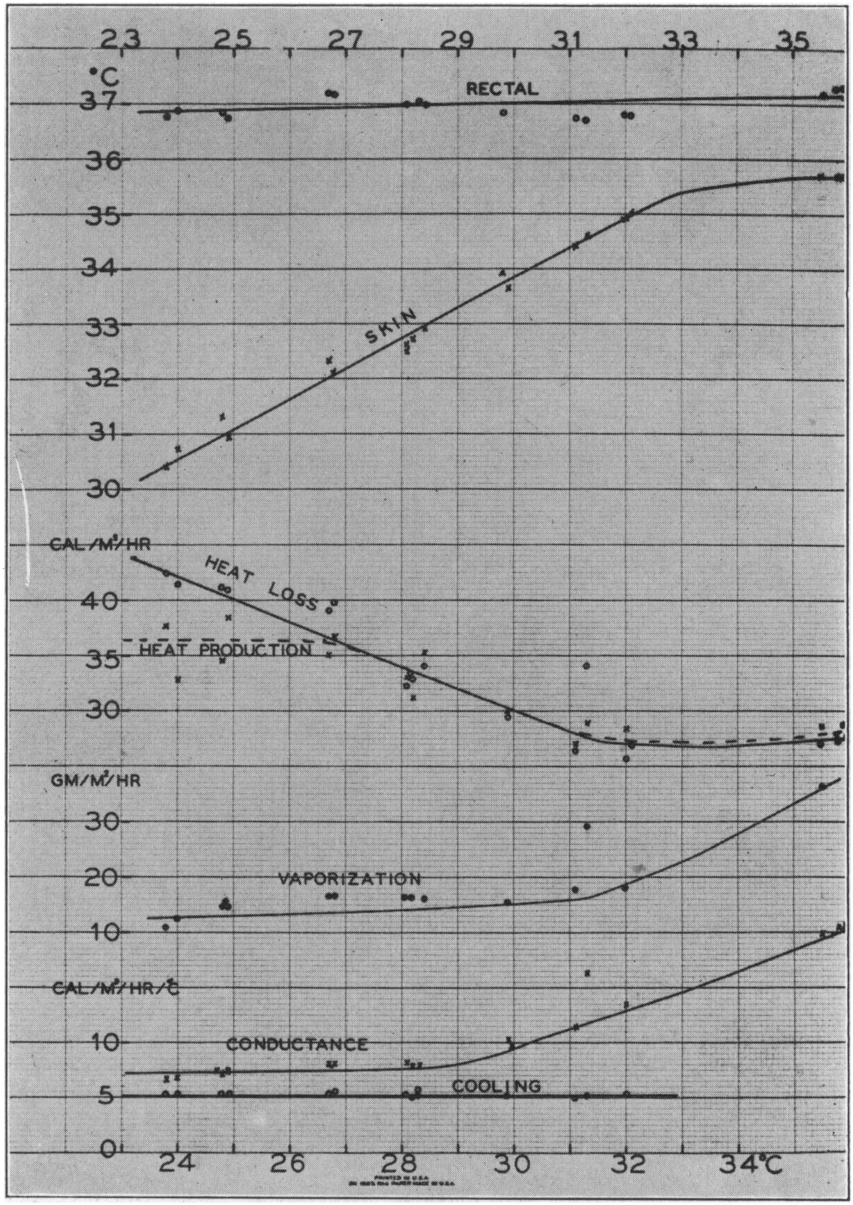

FIGURE 2

(Figures 2 and 3.) Calorimeter data obtained in two normal women showing the fall in heat production in temperatures above 27°C.

the calorimeter. Convection (*C*) played a relatively small rôle because there was slight air movement in the calorimeter and loss by convection disappeared when the air temperature was the same as the skin temperature. Vaporization (*V*) remained fairly uniform until the air temperature rose above 30°C., then increased rapidly until it assumed the whole burden of heat loss at 35°C.

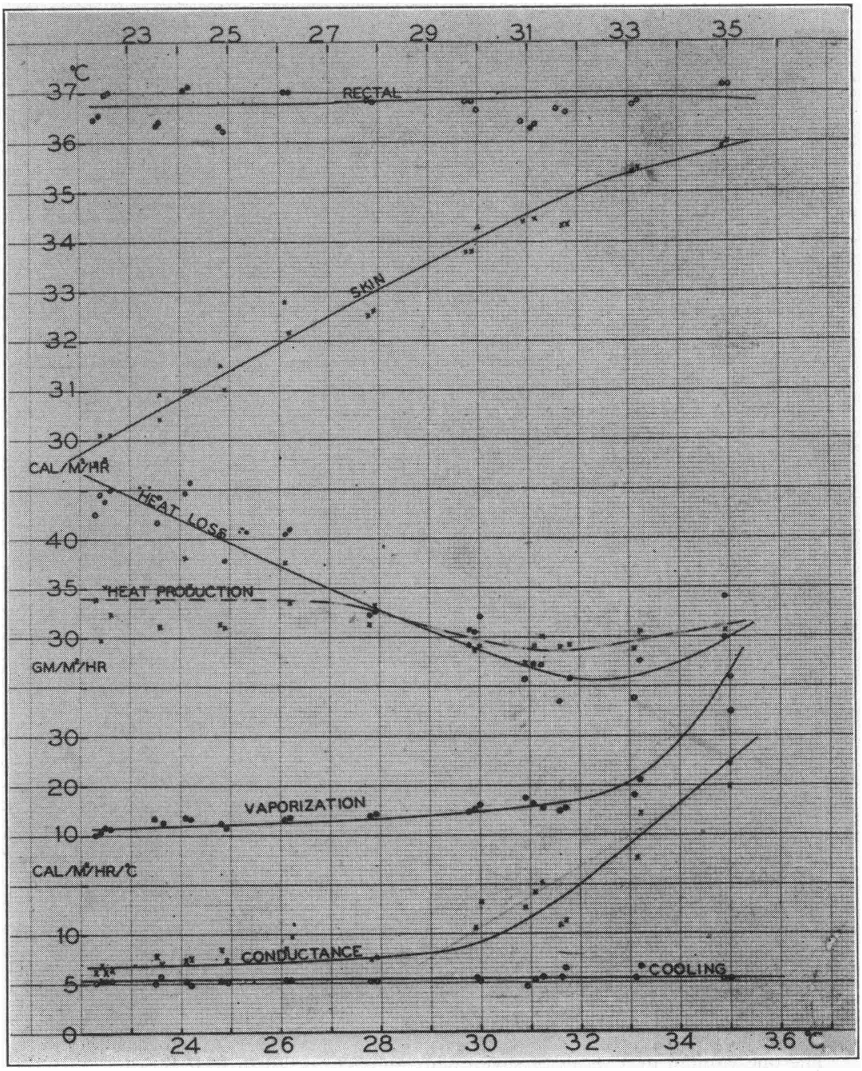

FIGURE 3

The results on three of the young women are shown in figures 2, 3 and 4. The first two demonstrate a marked fall in heat production in the warm zone. The third woman was an exception, for there was practically no

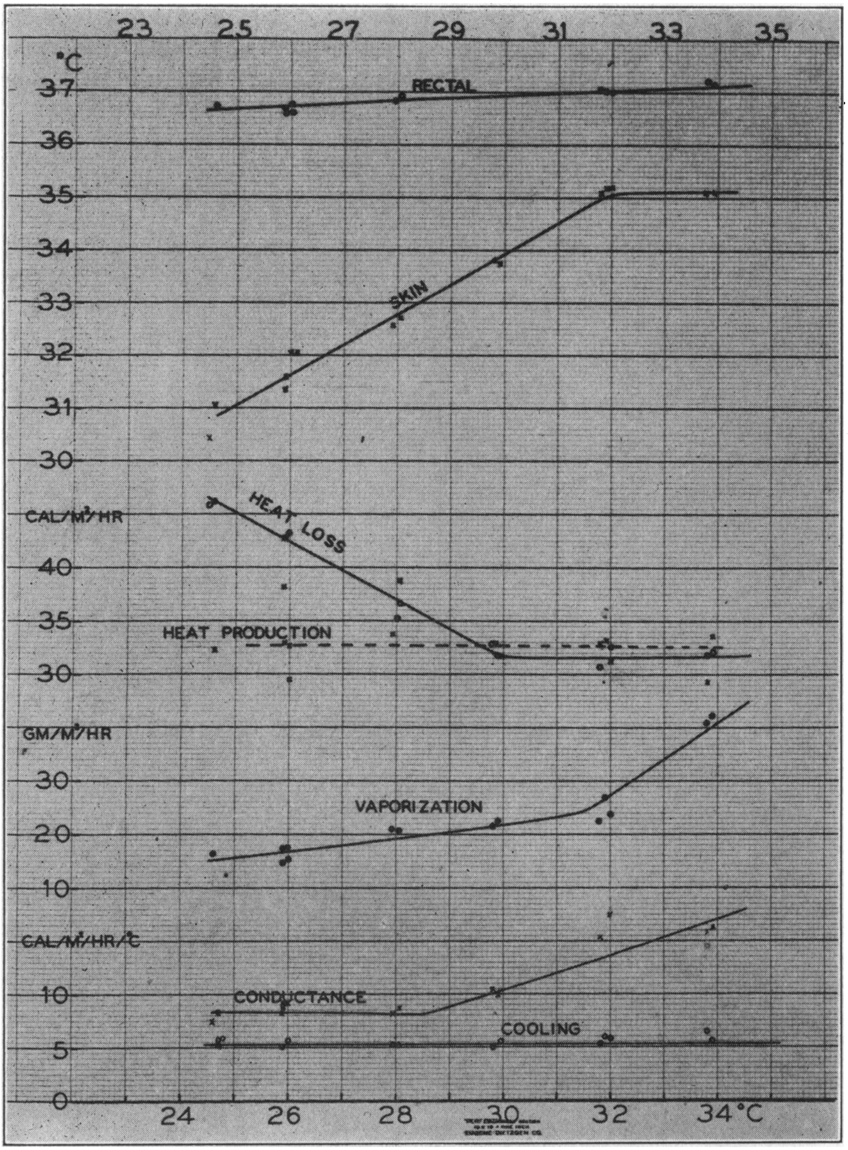

FIGURE 4

The one woman in a series of seven who showed no fall in heat production with rising temperatures.

change in heat production between air temperatures of 24.5° and 34°C. It so happens that this woman was being treated with hormones for amenorrhea. Whether or not this is significant we do not know. Figure 5

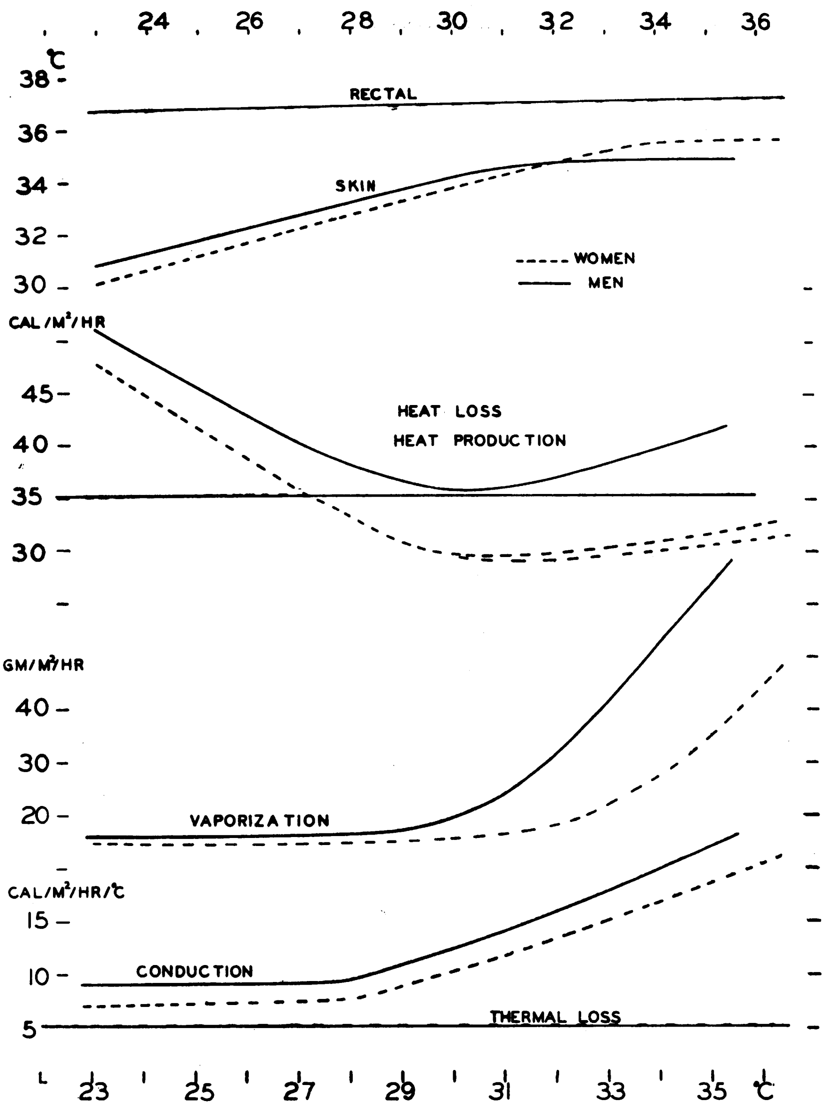

FIGURE 5

A comparison of results obtained on men and women at calorimeter temperatures between 22–35°C. Note that the dotted line showing the heat production of the women is almost exactly the same as that of the men in temperatures between 23–27°C. and then falls, almost equaling the upper dotted line which shows the heat loss in women.

shows the differences between the results obtained on the men and women. The measurements made after about $2^1/_2$ hours' exposure, naked, and motionless, to the various temperatures, are plotted according to the calorimeter temperature in degrees Centigrade. Needless to say it required many days to complete the tests on any one subject.

(1) The rectal temperatures were the same for the men and women and were both slightly lower in the cold zone as a result of exposure to the cold air. There was a spread of about 0.6°C. in the individual measurements.

(2) After exposure to the cold air for approximately $2^1/_2$ hours the average skin temperature of women was about 1.0°C. lower than that of the men. In the warmest zone skin temperatures after the same exposure were about 1.7°C. higher than those of the men. In environments colder than 33°C. the average skin temperature fell almost linearly with the calorimeter temperature so that a change of 1° in the calorimeter caused a change of 0.5° in the skin. The change in the women was greater than that observed in the men by 0.1°C. per degree fall in the environmental temperature.

(3) The heat loss for women in the cold zone was about 10% lower than that of the men on account of the lower skin temperature. In the warm zone the heat loss of most of the women was about 14–20% lower than that of the men because the women did not sweat as much.

(4) The heat production of the men was constant throughout the temperature range. In marked contrast to this the heat production of the women which was the same as that of the men in the cold zone showed a marked fall in temperatures about 27°C. Above this point the heat production of the women fell with the heat loss being almost equal to it at all times. Therefore, in temperatures from 30° to 32°C. under our standard conditions the metabolism of most of the women was 14–20% lower than that of the men.

(5) Vaporization in the cold zone is accounted for by the loss of water from the respiratory passages and by seepage of moisture through the skin. There is no appreciable activity of the sweat glands in the cold. In this zone the vaporization was approximately equal in men and women, but as the temperatures grew warmer the men started to sweat at 29°C. The women did not start until the air temperature had been raised to about 32–33°C. They did not need to sweat as soon or as much because they had lowered the production of heat in their bodies. At temperatures around 34–36°C. both sexes lost all their heat through vaporization because the skin temperature had equaled the air and wall temperatures and radiation and convection had disappeared as channels of heat loss.

(6) Conductance, (conduction, conductivity) represents the ease with which heat is transferred from the interior of the body at a temperature of 37°C. to the surface, which is at a much lower temperature. Conductance can be calculated from the total heat lost in hourly periods knowing the rectal temperature and the average skin temperature. Under all conditions heat is transferred by conduction through the skin and subcu-

taneous tissues, which are about as good insulators as cork. In the cold these tissues are almost bloodless. The lower conductance for women in the cold is due to the greater thickness of the subcutaneous tissues, and we calculate that the average difference represents a layer of fat about 4 mm. thick. We have found that fat has about the same conductance as muscle, skin or cork.

The upward swing of the curves in both sexes which begins at 28°C. is due to a new factor, the steadily increasing transport of heat by the blood stream. With rising environmental temperatures there is an increased vaso-dilatation. Although the hands and feet show the most dramatic changes in blood flow they play a relatively insignificant part since they represent only 12% of the total body surface.

(7) As an over-all check on the physical procedure and measurements we have calculated the thermal loss or constant for Newton's Law of Cooling. This represents the heat loss by radiation plus convection per unit area of skin per degree of difference between skin and air temperatures. As would be expected the constant is the same for the two sexes and does not change with calorimeter temperature. For radiation alone calculation with the Stephan-Boltzman Law gives much closer results.

In basal metabolism tests with men and women little attention has been paid to the environmental temperature as long as the patient was comfortable. It is, of course, difficult to estimate or measure the actual environmental temperature of a person who is clothed or covered with a blanket. We have not yet made determinations on clothed subjects, and it must be remembered that we have made our measurements only on persons at complete rest, naked and in an environment with minimal air movement. The results, however, indicate that it may be necessary to make changes in the standards of the normal basal metabolism, paying attention to the environmental temperature in the case of women. The lowering of the metabolism in the women in the warm zone speaks for the existence of a "chemical regulation" as described by Rubner for animals. This had never previously been established for the human species although it is generally accepted for animals. The physical regulation of temperature involves changes in the skin, sweating and other physical methods of heat loss and the changes in heat production due to exercise or unconscious tensing of the muscles. The chemical regulation is supposed to be due to some non-physical factor such as a hormone, which changes the level of heat production. The prevailing opinion is that such regulation would appear as the environment began to grow colder and would increase metabolism. Our calorimeter data favor the idea of a factor which lowers the metabolism in warm atmospheres from the standard level established in a cooler zone.

Summary.—The men and women whom we have studied under our limited standard conditions showed two points of agreement—Newton's

Law constant and the internal body temperature. In all the other adjustments to changes in the thermal environment the women have a physiological advantage. The comfort zone, in which the heat loss and heat production are equal, extends over a range of about 6° for women instead of 2–3° for men. The most important factor is the fall in heat production of women in warmer environments. Another factor is the thicker layer of insulation against cold. A third factor is a slightly better adaptation of skin temperature to meet thermal changes in the environment. In cool air women, lightly clad, may be comfortable when the men need woolen clothing. In the warm zone long before the women have started to perspire or even "glow" the men may be covered with beads of sweat. Many of these facts have been suspected for generations but all should be taken into consideration in the practice of air conditioning.

[1] Rubner, Max, "Die Beziehungen der atmosphärischen Feuchtigkeit zur Wasserdampfabgabe, *Arch. Hygiene,* **11,** 137 (1890).

[2] Rubner, Max, *Die Gesetze des Energieverbrauchs,* Leipzig and Vienna, Deutiche (1902).

[3] Lusk, G., *Science of Nutrition,* Fourth Edition, Saunders and Company, Philadelphia (1928).

[4] Hardy, J. D., and Du Bois, E. F., "Regulation of Heat Loss in the Human Body," *Proc. Nat. Acad. Sci.,* **23,** 624 (1937).

[5] Hardy, J. D., and Du Bois, E. F., "Basal Metabolism, Radiation, Convection and Vaporization at Temperatures of 22–35°C.," *Jour. Nutrit.,* **15,** 477 (1938).

[6] Wiley, F. H., and Newburgh, L. H., "The Relationship between the Environment and the Basal Insensible Loss of Weight," *Jour. Clin. Invest.,* **10,** 689 (1931).

[7] Winslow, C.-E. A., Herrington, L. P., and Gagge, A. P., "Physiological Reactions of the Human Body to Varying Environmental Temperatures," *Amer. Jour. Physiol.,* **120,** 1 (1937).

[8] Martin, C. J., "Thermal Adjustment of Man and Animals to External Conditions," *Lancet,* **219,** 617 (1930).

[9] Mason, E. D., "The Basal Metabolism of European Women in South India and the Effect of Change of Climate on European and South Indian Women," *Jour. Nutrit.,* **8,** 695 (1934).

[10] Hardy, J. D., and Milhorat, A. T., "Basal Heat Loss and Production in Women at Temperatures from 23–36°C.," *Proc. Soc. Exper. Biol. & Med.,* **41,** 94 (1939).

[11] Du Bois, E. F., *Basal Metabolism in Health and Disease,* Third Edition, Lea and Febiger, Philadelphia (1936).

[12] Hardy, J. D., "Radiation of Heat from the Human Body. An Instrument for Measuring the Radiation and the Surface Temperature of the Skin," *Jour. Clin. Invest.,* **13,** 593 (1934).