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Environmental Physiology

With Special Reference to Domestic Animals

XVIII. Influence of Environmental Temperature, 0° to 105° F, on Hair and Skin Temperature of Holstein, Jersey, Brown Swiss, and Brahman Cattle, with Notes on the Thermal Properties of Hair and Skin.

H. J. THOMPSON, D. M. WORSTELL, AND SAMUEL BRODY

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INTRODUCTION

This is a continuation of Missouri Research Bulletin 481 which reported data on the effect of rising environmental temperature, 50° to 105°F, and of declining temperature, 50° to 0°F, on the skin and hair temperatures of Jersey and Holstein cows during the first two experimental periods, March 1948 to March 1949 (Fig. 1).

This report is concerned with similar data, similarly obtained, tabulated, charted, analyzed and integrated during the subsequent three periods, June 1949 to May 1950 (Fig. 1) which, however, also includes Brahman or Zebu (Indian-evolved but Texas-bred) and Brown Swiss cows and yearling heifers.

In addition, an attempt was made to estimate the numerical values of the coefficients of heat flow (and of thermal resistance) from the body to the environment, with special reference to Newton's Law of Cooling.

Descriptions of the animals and measurements taken on them were previously reported (Res. Buls. 460 and 471). The temperatures of the chamber air and surrounding surfaces (walls, floor, and ceiling) were approximately the same (Fig. 2). The humidity, about 65 per cent, and air movement, about 45 feet per minute, were approximately the same at all chamber temperatures.

The measurements were mostly for the "main body surface temperature", which was an average of back, belly, right and left sides of body, neck and rump (the position of the spots are shown in Fig. 3, Res. Bul. 481).

The chamber air temperature here used is an average of nine thermocouple readings for each cow, taken in perpendicular planes in line with the stall partitions. Reading points were at the 1.5, 4.5, and 7.5-foot levels from the floor in the feed alley, stall and litter alley. The chamber surface temperatures were taken in this same plane, i.e., floor and ceiling of the feed alley, stall and litter alley, plus one reading on each front and rear wall. These chamber surfaces, as well as the animal surface, temperatures were measured with a Hardy Radiometer (for references see Res. Bul. 481).

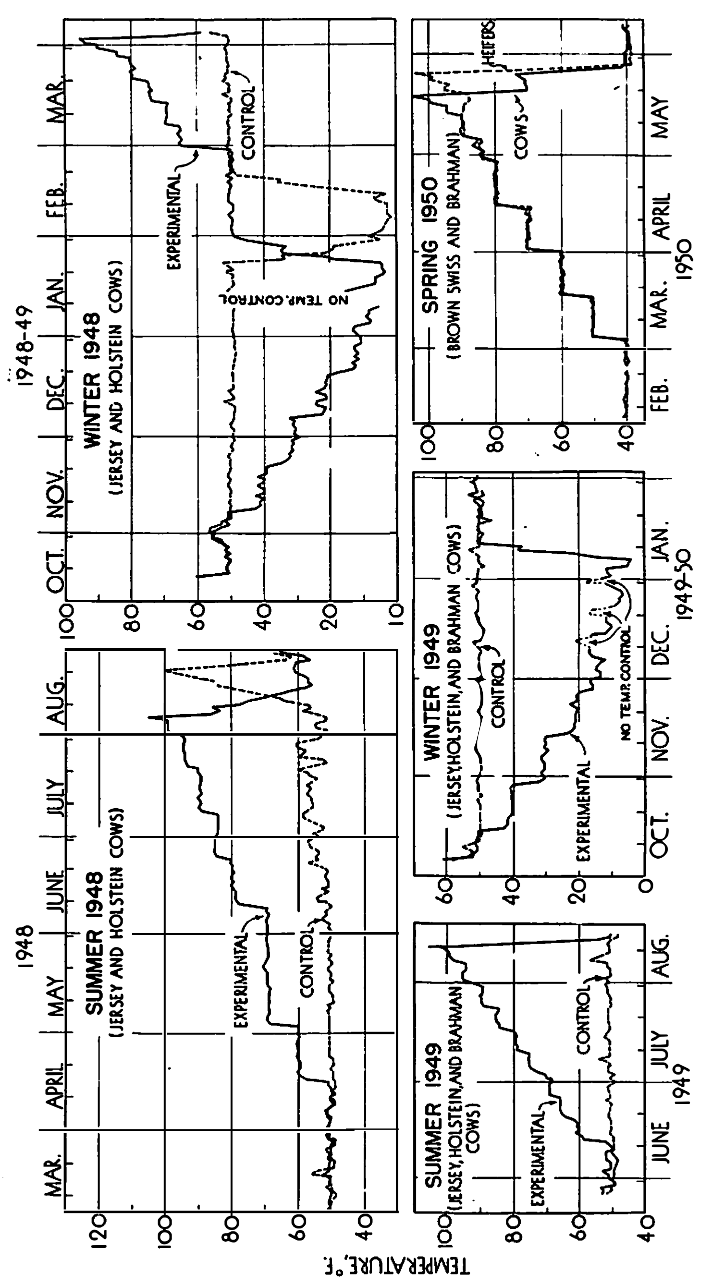

Fig. 1—Time-temperature schedule for the five experimental periods discussed in this bulletin.

NUMERICAL DATA

The basic data for skin and hair temperatures at various chamber temperatures are listed in Tables 1 and 2 in the Appendix. Table 3 gives the regression equations for the above relations; Table 4 the equations for several derived temperature differences.

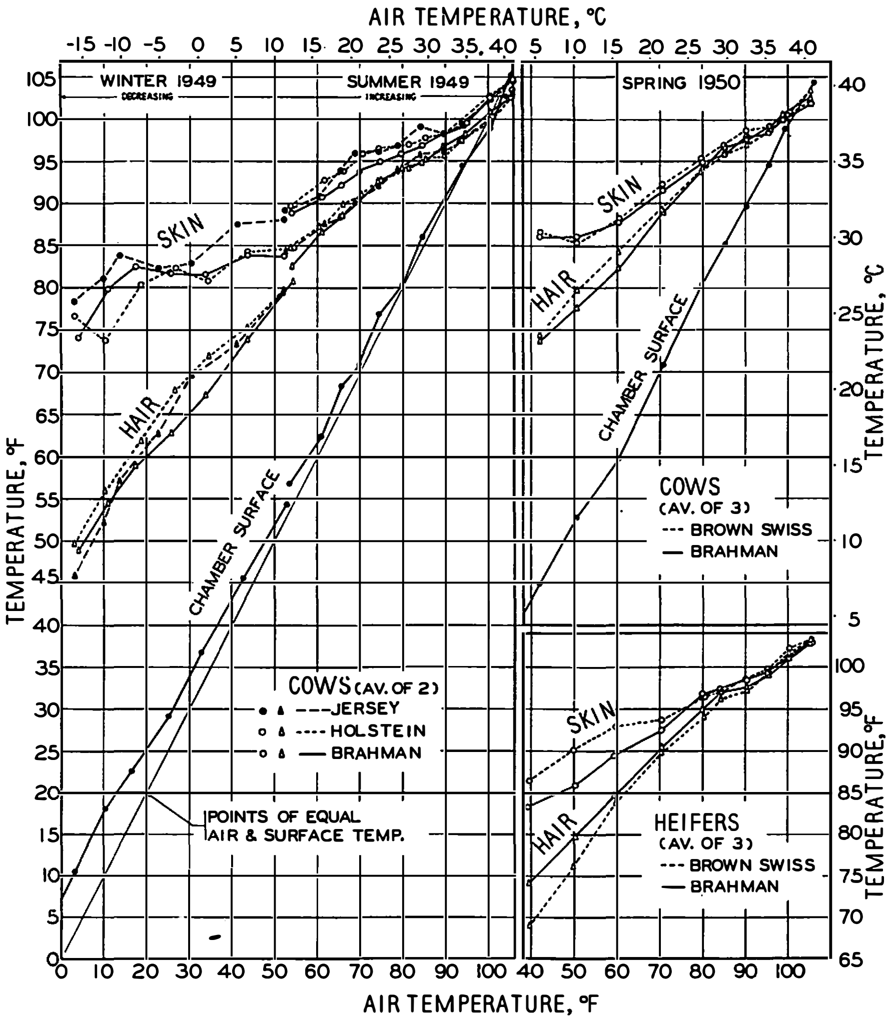

Fig. 2—Surface temperatures for the last three experimental periods: Summer 1949 and Winter 1949-50 on Jersey, Holstein, and Brahman cows (left-hand section); Spring 1950 on Brown Swiss and Brahman cows (upper right-hand section), and Brown Swiss and Brahman heifers (lower right-hand section). The skin temperature was measured with a touch thermocouple; the hair surface with a Hardy radiometer. The chamber air and surface temperatures were virtually the same; the greatest difference occurring at the lowest temperature levels.

GRAPHIC REPRESENTATIONS AND COMPARISONS OF DATA

Fig. 2 shows the skin and hair surface temperatures of the "main body" as functions of chamber-air temperatures; also chamber-*surface* and chamber-*air* temperatures plotted against the chamber air temperature to show the relations between chamber air and surface temperatures and the relations between skin, hair, and chamber temperatures.

It is commonly believed that Brahman cattle sweat more profusely and are, for this reason, more heat tolerant than European-evolved cattle. If this were the case, the Brahman skin and hair temperatures would be lower at the higher environmental temperatures than of European cattle. Fig. 2 shows no such breed difference. Indian-evolved cattle are probably more heat tolerant, not because of their greater sweating per unit surface area, but because they have 12 per cent more surface area (dewlap, navel flap, pendulous ears) per unit body weight than European cattle of the same weight, which facilitates heat dissipation by convection as well as by vaporization; and because of their lower heat production associated with lower feed consumption, milk production and growth rate; and also because of their lower basal metabolic rate than in European cattle (Res. Bul. 473).

Figs. 3 to 5 present several comparisons between the curves of the regression equations of the several sets of data. The curves with their legends are self-explanatory. A comment, however, is called for on the significance of the "breaks" in the curves at about 65°F (18°C).

Inspection of the 1948-49 curves relating body surface to chamber temperature (Res. Bul. 481) indicated a change in slope at about 65°F (18°C). This break in the slope of the body-surface temperature curve coincided with the sharp rise in the slope in the evaporative cooling curve (see upper section Fig. 3, Res. Bul. 451), both apparently reflecting the beginning of heat stress in the European-evolved cows. Changes in the temperature curves of other processes (feed consumption and milk production, and so on—see bulletin titles in the Appendix) likewise seem to begin at about this temperature in European-evolved cattle; and 10° to 15°F later in the Brahmans (see Fig. 7, Res. Bul. 479) presumably because of their greater surface area per unit weight and lower heat production, as previously explained.

INTEGRATION OF DATA WITH THE AID OF NEWTON'S LAW OF COOLING

Newton's Law of Cooling and heat dissipation: After tabulating, charting, comparing, and describing the data in Tables 1 to 5 and Figs. 1 to 7, one feels a need for their integration and generalization on a broader level, perhaps with the aid of Newton's Law of Cooling.

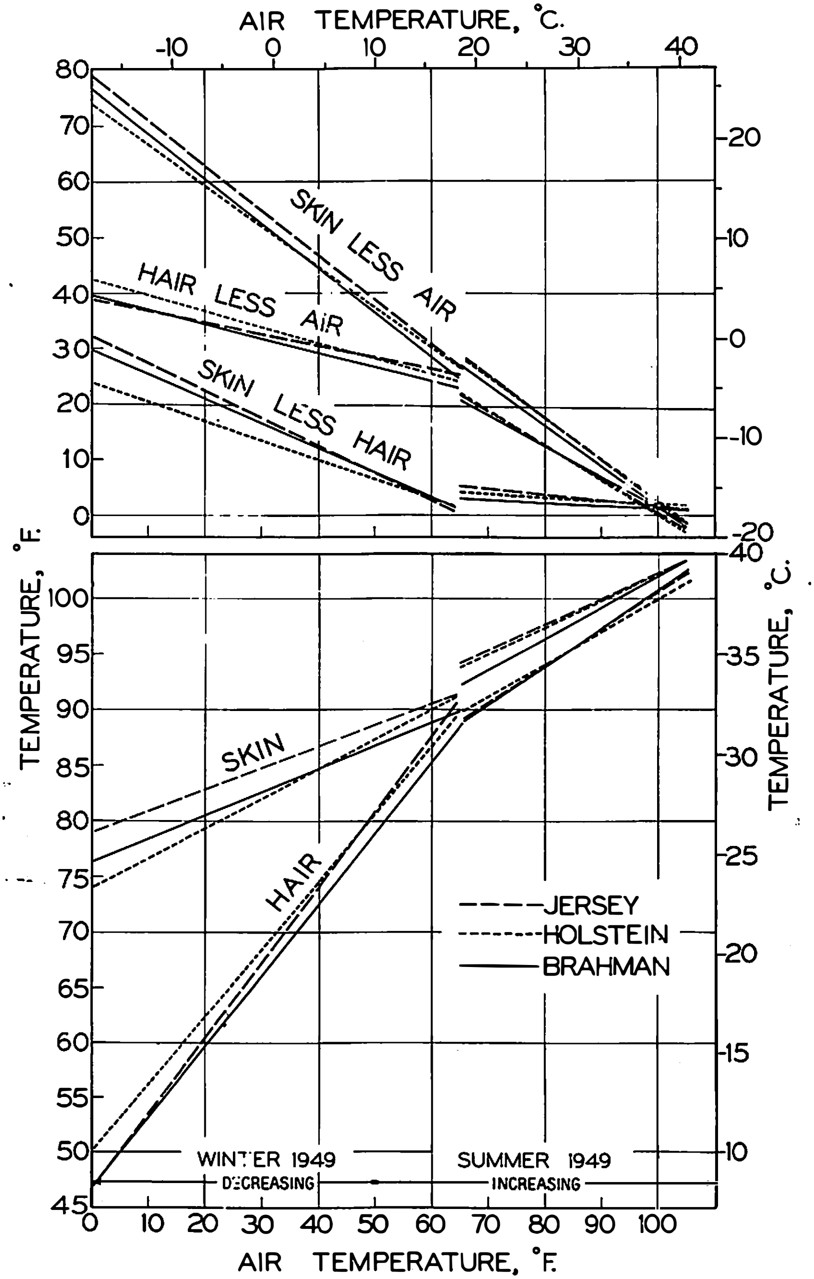

Fig. 3—The lower section, curves for regression equations given in Table 3 for the 1949 data; upper section, curves for the equations relating the difference between surface temperature and air temperature given in Table 4. "Breaks" were assumed to be at about 65°F (18°C). Note that the Jersey skin temperature appears to be higher than the Holstein or Brahman. Air temperature in these measurements taken to be the same as the chamber surface temperature as measured by radiometer.

This law, published in 1701, states that the rate of cooling of a body is directly proportional to the temperature difference, $t_1 - t_2$, between body and

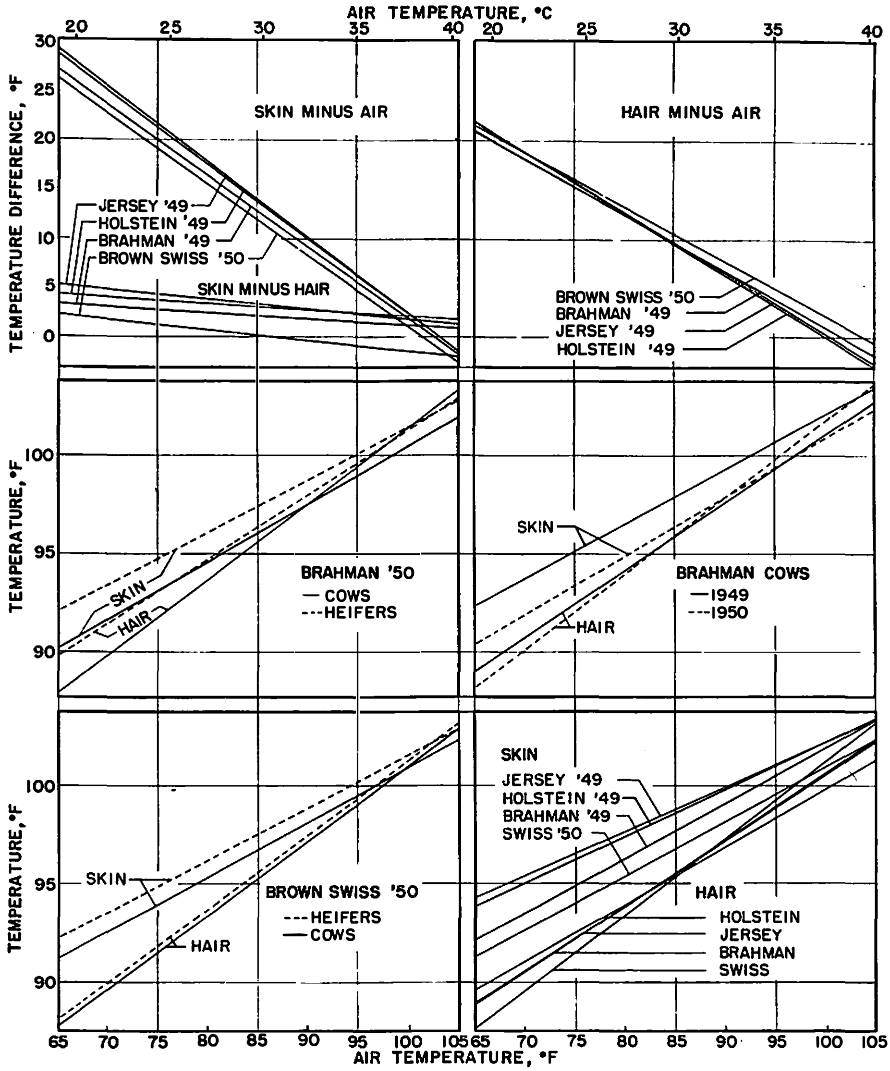

Fig. 4—Comparison of hair and skin temperatures as functions of environmental temperature 65° to 105°F. The curves represent the regression equations in Tables 3 and 4. The difference between the 1949 and 1950 curves may be due to differences in hair coats, depending on the temperature level in the preceding experimental period (see Table 5).

environment. This may be represented for a dynamic steady-state system (as in our animals) by the equation

$$H = kA\ (t_1 - t_2)t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

or, solving for k, by the equation

$$k = \frac{A}{H} / (t_1 - t_2)t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which H is the amount of heat transferred from the body of temperature t_1 and of surface area, A, to the environment of temperature t_2 in time, t; k is the coefficient of heat transfer, here expressed in terms of heat loss from the body in kg-cal per square meter surface area of animal per 1°F temperature difference between body and environment. In brief, the heat loss is here given, perhaps somewhat inconsistently, in terms of Cal/m²/hr/1°F.

Since thermal resistances are additive, it is often more convenient to discuss thermal resistance, which is the reciprocal of heat flow, k, in equations (1) and (2).

The applicability of Newton's Law of Cooling to the data was indicated in Res. Bul. 481 for equation (1) by the linear distribution of heat loss values,

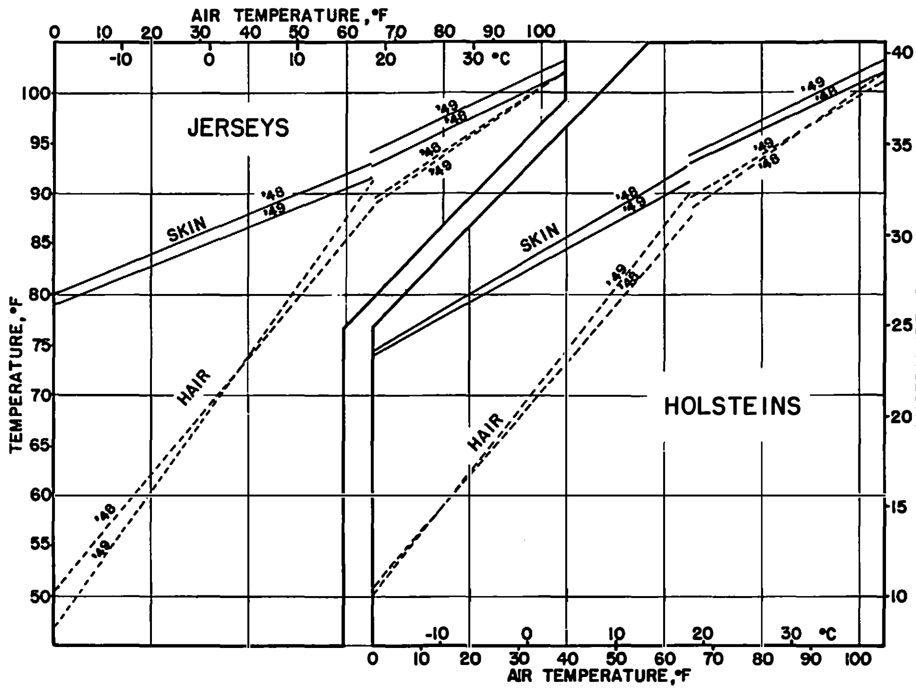

Fig. 5—Comparison of the regression curves for skin and hair surface temperatures in relation to chamber-air temperature of Holstein and Jersey cows for the 1948 data (from Res. Bul. 481) with the 1949 data (Table 3), indicating the order of agreement between data obtained at different times on different animals of the two major breeds of dairy cattle.

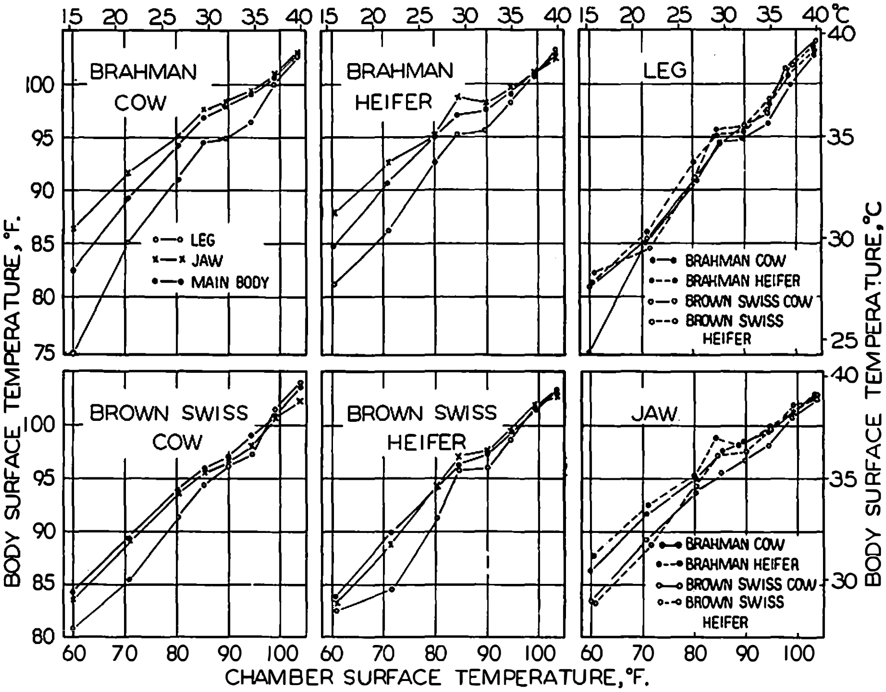

Fig. 6—Regional surface temperature differences in the animals between 60° and 105°F chamber-surface temperatures (both by radiometer) obtained during the Spring 1950. There seems to be a definite, decreasing, temperature gradient from the temperatures of the jaw to the main body, thence leg, with decreasing environmental temperature. Another report in this series shows that the lower leg temperature is only slightly above freezing at environmental temperature about 10°F, which substantiates the Irvin-Scholander Arctic Research report.[4] The "main body" temperature is the average of the six spot measurements as shown in Fig. 3, Res. Bul. 481.

Cal/m²/hr. plotted against temperature difference, $t_1 - t_2$, between body surface and environment. It is here indicated for equation (2) by the near horizontal distribution (upper left two sections of Fig. 8) of the values of *k* (heat loss, Cal/m²/hr/1°F) plotted against environmental temperature.

Categories of body temperature, conducting or insulating elements, and heat losses: Equation (1) states that the rate of heat loss is proportional to $t_1 - t_2$, the temperature difference between body and environment. But the body has many temperature levels*—hair, skin, sub-surface, rectal, respiratory tract

*Burton (J. Nutr., *9*, 261, 1935) and Hardy and DuBois (Id., *15*, 477, 1938) computed respectively, the average body temperature in man from the equations

Av. body temp. = 0.65 rectal temp. + 0.35 av. surface temp.

and

Av. body temp. = 0.80 rectal temp. + 0.20 av. surface temp.

Burton computed the heat conductance from the body interior to the surface from the equation:

$$\text{Conductance} = \frac{\text{rate of heat loss from body surface}}{\text{surface area} \times (\text{rectal less skin temp.})}$$

Hart (Can. J. Zool., 29, 224, June 1951) reported that the average body temperature of mice is about 2°C lower than the colonic temperature.

and so on; and the skin temperature is different for the "main body," legs, respiratory tract, and so on. Figs. 8 and 9 are confined to the use of the skin and hair temperature of the main body. The body has also many conducting (or insulating) elements—fur, skin, subcutaneous fat, circulatory system, and so on. Moreover, the conductivities of these elements tend to change with changing environmental temperature not only because of temperature change of these elements, but also because of acclimatization effects, such as growth of fur, changing composition of the fur, skin and other tissues, vasomotor control, and so on.

These categories of temperature differences are complicated by different categories of heat losses: (total; evaporative; non-evaporative) and by different avenues of heat losses (outer surface and respiratory surface).

The evaporative heat loss tends to be adjusted (by biologically-adaptive, or homeothermic, mechanisms) to the animal's needs, with which Newton's Law is not concerned; non-evaporative heat loss, on the other hand, is probably actuated at a given moment by purely physical mechanisms to which Newton's Law may be expected to apply.

Non-evaporative heat transfer occurs by convection, radiation, and conduction, each of which follows different "laws." Newton's Law, is, however, often applied[1] to overall heat transfer in very complex physical systems. It seems even more legitimate to apply it to non-evaporative surface cooling in animals, as in the present case, when the temperature gradient between hair surface and environment is small and the temperature of the environments, air and surfaces (walls, etc.), are virtually identical.[2]

The equation of Newton's Law of Cooling is of a general type used[1] for representing heat transfer regardless of the constancy of the coefficient, k, at different temperatures, as, for example, in computing the heat conductivity of metals which usually changes with changing temperature. It may be very instructive to use it for analytic purposes, for indicating the temperatures during which the heat flow changes, possibly the actuating mechanisms, and for computing the component heat transfers that go to make up the whole.

The distribution of the values of k will, of course, be affected by many homeothermic or acclimatizing mechanisms which compensate for the changing environmental conditions, including changes in the rates of evaporative cooling (changing "sweating" and panting), convective cooling (changing thickness and configuration of fur and whole body), heat production, and so on. For instance, the slopes of the curves in the lower-left segment Fig. 8 and lower-right segment Fig. 9 may represent mostly changes in hair length and thickness with changing environmental temperature.

[1]McAdams, W. H., "Heat Transmission," McGraw-Hill Book Co., 1942, page 3.

[2]Newburgh, L. H., Ed., "Physiology of Heat Regulation," Saunders, 1949. Burton, A. C., J. Nutr., 7, 497, 1934.

Graphic representation of heat transfer, k, and thermal resistance, l/k, as function of environmental temperature: The left segments in Fig. 8 represent the time rates of *non-evaporative* heat transfer, k, in equation (2), of hair to air, skin to air, and skin to hair plotted against environmental temperature. The distribution of the values of k (Cal/m²/hr/1°F) differs for the various categories of $t_1 - t_2$. The right segments in Fig. 8 similarly represent total heat transfer, including evaporative cooling, in equation (2) of rectal to skin, rectal to air, and rectal to hair. (Total heat loss, in this case, is equal to total heat

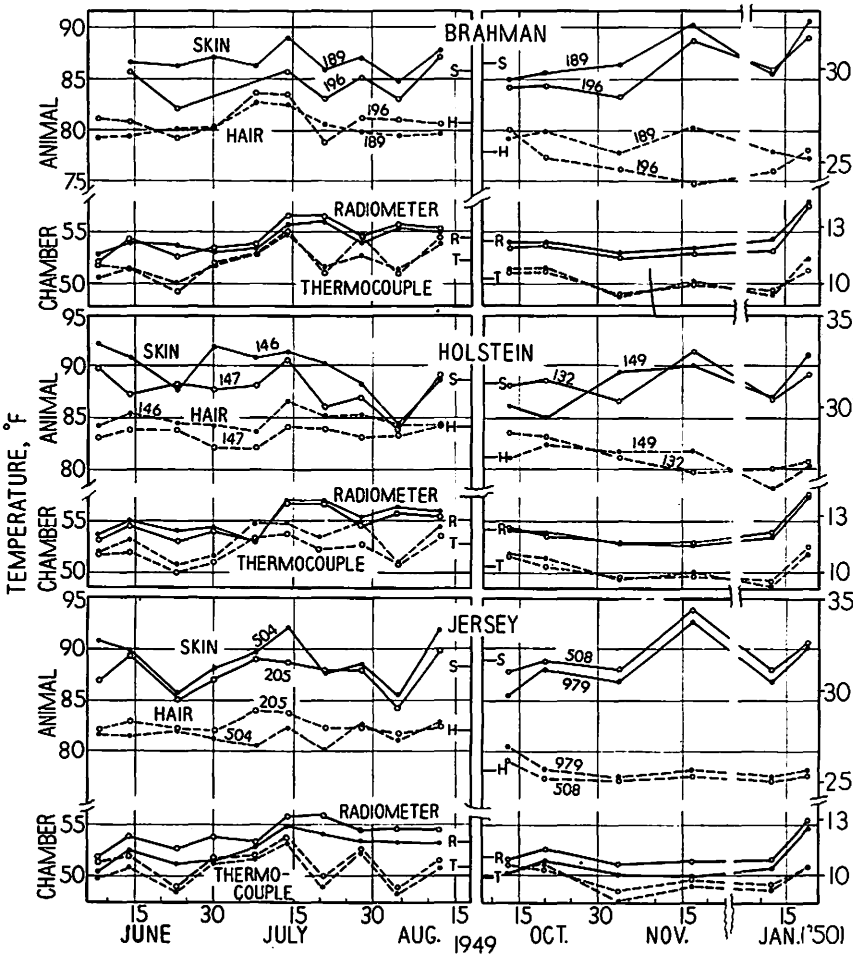

Fig. 7—Comparison of radiometer and thermocouple surface temperatures of the chamber and of three breeds of cows kept as "Controls" for the 1949 data at about 50°F and 65 per cent relative humidity. These curves indicate the order of overall fluctuations in the values here reported.

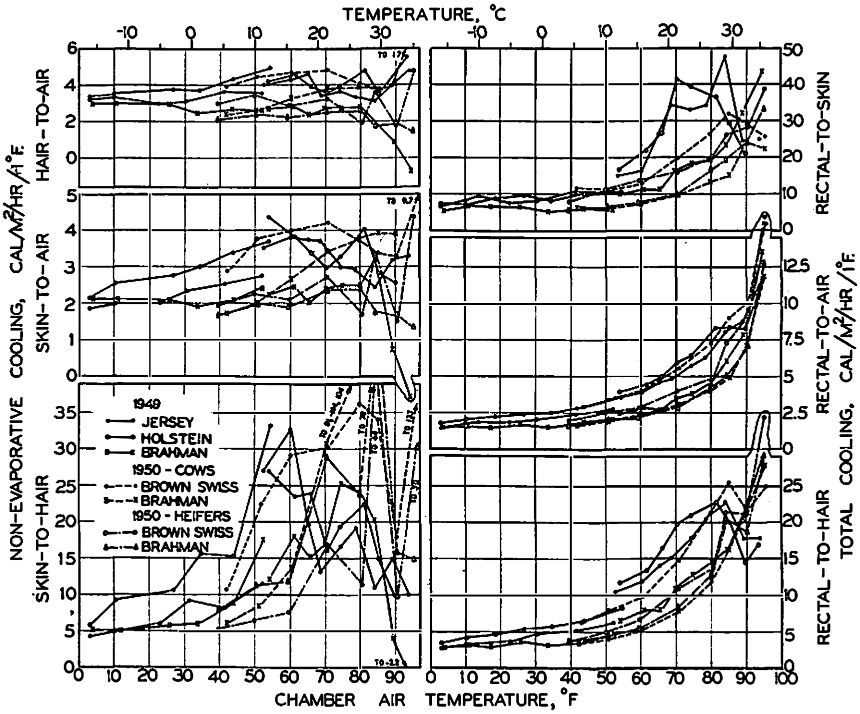

Fig. 8—Heat transfer, k, as function of environmental temperature for the indicated $t_1 - t_2$ categories.

production; the heat production values were reported by Kibler et al, in Res. Bulletins 435, 450, 464, 473.)

The hair-to-air heat transfer, upper left segment in Fig. 8, shows a satisfactorily horizontal distribution of the 7 sets of data (Holstein, Jersey, Brahman, and Brown Swiss; Brahman and Brown Swiss yearling heifers) from 0° to 85°F. The distribution of the data then became erratic partly because of increasing experimental errors and decreasing numbers of observations with increasing temperature above 85°F in the many measurements that enter into the computing of the value of k (temperature of animals and of environment, insensible weight loss, metabolic weight loss, total heat production). On the whole, the hair-air k values are distributed in a fairly orderly horizontal fashion.

Unlike the non-evaporative hair-to-air heat transfer (upper left segment, Fig. 8), which is relatively constant from 0° to 85°F environmental temperature, the non-evaporative skin-to-hair k values (bottom segment, Fig. 8), which conventionally represents hair conductance (or overall coefficient of transmission for the thickness of hair at any given temperature) increases from about

5 Cal/m²/hr/1°F at 0°F to about 60 Cal/m²/1°F at 80°F environmental temperature. This means that the change in conductance of the hair is due mostly to the change in length and thickness of the hair.

The right half of Fig. 8 presents k curves for total heat loss, including evaporative cooling; for this reason the slopes of these curves rise steeply, especially above 65°F, as previously explained. The k curves for evaporative cooling (not shown) show particularly clear-cut and striking rises in slopes beginning about 65°F (18°C).

Figure 9 shows thermal resistance, l/k, as function of environmental temperature. The left curves represent l/k resistance values of skin-to-air and rectal-to-skin, as percentages of the sum of these two resistances, or, percentage of the sum of the reciprocals of the two k values based on total heat production. The right-hand curves are similarly a percentage of the sum of two resistances based on non-evaporative k values.

The right side curves in Fig. 9 are dramatic in emphasizing the skin-to-hair decline (and therefore hair-to-air rise) in thermal resistance with rising environmental temperature. This is interesting and important from the animal shelter viewpoint as it indicates the change in overall thermal resistance due to changes in the size, number, shape and arrangement of the hairs (or coating) with time and not necessarily the change in resistance of the hair as such.

Therefore, the skin-to-hair curves in Figs. 8 and 9 do not represent literal changes in the conductivity (or resistivity) of the hair as such, but rather

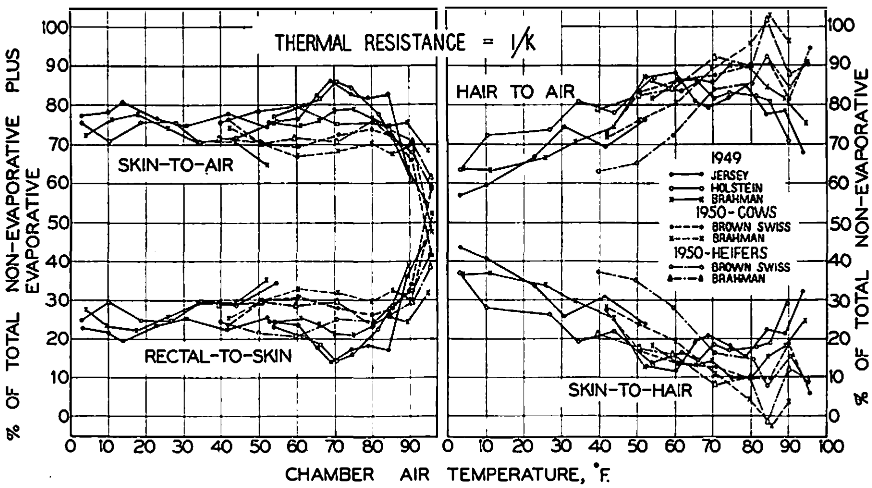

Fig. 9—Thermal resistance, l/k, as function of environmental temperature in terms of percentages of total resistance.

adaptive changes in growth and development of the fur (or coating), with changing environmental temperature.

Relative heat and cold tolerance of cattle with notes on the Irving-Scholander observations: The sharp change in slopes of the temperature curves relating evaporative cooling and related reactions (see page 6) at about 65°F (18°C) in European-evolved and at about 80°F in Indian-evolved cows illustrates the much lower heat tolerance of cattle than of man. At 105°F environmental temperature the rectal temperature of cows, both European and Indian, is from 4° to 7° above normal, whereas in man it is normal.

The opposite appears to be true for cold tolerance. While some men wore heavy clothing to work in the chambers at approximately 4°F, the larger cows appeared to be comfortable. Hay consumption increased from zero in the large, high milking cows to 35 per cent in small, low milking, European-evolved cows, and 50 per cent in the Brahman cows on lowering the temperature from 50° to 4°F. The increasing feed consumption in the cold environment may have reflected the stimulating effect of declining temperature on appetite[3] as well as the need for more fuel. There was an increase in heat production — as there must be — in proportion to feed consumption due to the increased heat increment of the extra feeding (SDA). In brief, cattle are much *more cold tolerant* and much *less heat tolerant* than man.

An interesting light was recently thrown on cold tolerance of other mammals, and also birds. One of the authors heard at the 1951 joint session of the Federation of American Society for Experimental Biology, Dr. Irving's fascinating story[4] about the observations of the ONR Arctic Research group investigating the extent and nature of cold tolerance in a large series of arctic animals, including caribou, reindeer, Dall sheep, Eskimo dogs, white and red foxes, polar and grizzly bears, as well as smaller animals—ground squirrels, hares, lemmings and gulls.

While the temperature at Point Barrow, Alaska, where the animals were captured, was only about −40°C (−40°F), arctic animals are known to live in eastern Siberia and northwestern Canada with monthly temperatures of −50° to −60°C (−58° to −76°F). These animals may thus maintain a *temperature difference* between the body interior and environment near 100°C (180°F), equivalent to the temperature difference between freezing and boiling water!

Eskimo dogs, arctic foxes, and gulls were observed to sleep in comfort on snow at −40°C, and what is most remarkable, their (near) basal heat production and rectal temperature were observed to remain constant in a respiration chamber when the temperature changed from −40° to +30°C (−40° to +86°F).

[3]Johnson, R. E., and Marks, R. M., Science, *105*, 378, 1947.
[4]Irving, L., Physiological Adaptation to Cold in Arctic and Tropic Animals. Federation Proceedings, *10*, 543, June, 1951. Scholander, P. F., Hock, R., Walters, V., Johnson, F., and Irving, L., Biol. Bull. *99*, pp. 225, 237, and 259, 1950.

Since the rectal temperature and heat production remained constant,[5] the authors inferred that the overall insulating value of the body covering (including configurational changes) must have changed eleven-fold during this change in the environmental temperature.

The inference of an eleven-fold change in the insulating value of the body covering during the environmental temperature change from +30°C (86°F) to -40°C (-40°F) is almost certainly an exaggeration resulting from the assumed insignificance of the changes in evaporative heat losses and in acclimatization. Our observations indicate (page 11, Res. Bul. 479) that while the steep rise in evaporative cooling in man begins near 85°F, the corresponding slope in the evaporative cooling curve of cattle is at about 65°F. In arctic animals, vaporization may have taken over at a still lower environmental temperature, perhaps at 0°C, and our colleague Merle L. Esmay suggested that the heat loss (as given by Scholander *et al.*[4]) appears to be a linear function of temperature gradient below the "critical temperature" because the vapor losses then attained a minimum level. Acclimitization may also have contributed to the apparent eleven-fold change in insulating value of the body covering. When our Brahman cows first arrived here, they shivered at 50°F (10°C); but following an acclimatization period they seemed to be comfortable at 5°F (-15°C) with an approximate 50 per cent increase in feed consumption and heat production.

The fact[4] that the tropical raccoon and the arctic lemming have about the same insulation yet the raccoon is very much more sensitive to declining temperature (as shown by the shape of the heat production curve), substantiates the idea that species differences in evaporative cooling (at higher temperatures) and acclimatization (to lower temperatures) are basic factors in the phenomenal temperature range during which the "basal metabolism" of the arctic animals remained constant; and it is hoped that future papers in this remarkable series by Scholander *et al.* may have data on evaporative cooling and acclimatization.

Fur or feather is an obvious heat-conserving mechanism in cold weather; but what about the gulls that normally walk about in their outdoor cages at -40° without freezing their bare feet and legs? However, a gull that was kept indoors for several months at about 20°C (68°F) was observed to freeze the web on its feet white and hard in less than one minute after it escaped through an open door into the snow at only -20°C (-4°F), so that the outer web and some of the toes became gangrenous and were lost.[4] Was the cold adaptation

[5]A fox subjected for 105 minutes to -60°C (-76°F), slept with no sign of shivering. Shivering, however, began after one hour at -70°C (-94°F); and after 5 minutes at -80°C (-112°F); but the rectal temperature remained constant during the hour of exposure to this temperature. The "critical temperature" (at which basal metabolism is increased) in the fox, perhaps, is -50°C (-60°F) in contrast to man or monkey whose critical temperature is about 27°C (80°F).

gravely reduced by the few months of indoor life? Or did the suddenness of temperature change—inability of the vasomotor response to keep up with the temperature change (independent of acclimatization)—cause this catastrophe? These questions have an important bearing on shelter problems.

While the rectal temperature in the arctic animals remained constant, the peripheral surface temperature, particularly legs and feet—bare in most birds —was greatly reduced to just above freezing; but, of course, never below freezing.[4] We observed similar reduction in feet and leg temperature in cattle (see Fig. 6; data down to 0°F are being prepared for another publication). Reducing the peripheral temperature to just above freezing (by vasoconstriction) reduces the skin conductivity and also the temperature difference between body and environment and, therefore, reduces the rate of heat loss. Species that have the coldest skin, particularly of the feet and legs (which have the greatest *specific* surface area) have the lowest heat losses, and they are thus able to withstand the lowest environmental temperatures. As such, this is an important heat-conserving mechanism, an important homeothermic adaptation. In this connection one wonders how these very low environmental temperatures affect the temperature of the respiratory tract.

The above considerations suggest that the insulating properties of a pelt—a dead skin and its fur—is but a very crude indication of the extent of physiological insulation offered by it as part of the body-temperature regulating mechanism of the normal animal; and that changes in rectal-minus-skin temperature differences are extremely important features in body temperature regulation as well as hair coating and body configuration characteristics.

SUMMARY

Surface temperature data (skin and hair) are presented in tabular, graphic, and equation form for Holstein, Jersey, and Brahman cows exposed to environmental temperatures 0° to 105°F, and for Brown Swiss cows and Brahman and Brown Swiss yearling heifers exposed from 40° to 105°F temperatures.

These data were analyzed and rationalized with the aid of Newton's Law of Cooling and attempts were made to estimate the heat transfer, k, in Newton's Law, equation (1) and (2), and thermal resistance, 1/k, of several conductive or insulative layers.

The data and analyses were integrated with the literature, particularly with the fascinating Scholander-Irving 1950-51 reports on the reaction of arctic mammals and bare-legged birds to extraordinary low environmental temperatures.

At 0°F (–18°C) chamber temperature the skin temperature of our cattle was about 75°F (24°C), and hair surface temperature about 45°F (7°C); the surface temperatures increased linearly up to environmental temperature about

65°F (18°C) when the skin temperature was about 93°F (34°C) and hair temperature about 88°F (31°C); the surface temperature continued to rise linearly beyond 65°F, showing no significant breed difference, but at a reduced slope until 105°F (40.6°C), when the temperatures of environment, skin, and hair of all the cattle merged.

The non-evaporative cooling rate, k value in Newton's Law of Cooling, was virtually constant (3 to 4 $Cal/m^2/hr/1°F$) for hair-to-air cooling but for skin-to-hair cooling it increased from about 5 $Cal/m^2/hr/1°F$ at 0°F environmental temperature to about 60 Cal. at 80°F environmental temperature. Hence, the conclusion that the hair coating plus the peripheral vasomotor control of the skin in all cattle, including Brahman, are extremely important factors in rendering cattle tolerant to very low temperatures. The low heat tolerance in cattle is due to a low threshold and narrow range in "sweating."

ABSTRACT

Surface temperature data (skin and hair) are presented for Holstein, Jersey, and Brahman cows exposed to environmental temperature 0° to 105°F, and for Brown Swiss cows and Brown Swiss and Brahman yearling heifers exposed from 40° to 105°F. The surface temperatures increased linearly until environmental temperature about 65°F, at which time it continued its linear increase but at a reduced slope; at 105°F the temperatures of environment, skin, and hair of all the cattle merge. The non-evaporative cooling rate, k value in Newton's Law of Cooling, was virtually constant for the hair-to-air cooling, but increased with increasing environmental temperature for the skin-to-hair cooling, indicating that both the peripheral vasomotor control of the skin and the change in hair coating are extremely important factors in rendering cattle tolerant to very low temperatures. The lack of tolerance to heat in cattle is due to a low threshold and narrow range in sweating.

APPENDIX

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451	VIII.	Influence of Ambient Temperature, 0° to 105°F, on Insensible Weight Loss and Moisture Vaporization in Holstein and Jersey Cattle (H. J. Thompson, et al.).
460	IX.	Milk Production and Feed and Water Consumption Responses of Brahman, Jersey, and Holstein Cows to Changes in Temperature, 50° to 105°F and 50° to 8°F (A. C. Ragsdale, et al.).
461	X.	Influence of Temperature, 5° to 95°F, on Evaporative Cooling From the Respiratory and Exterior Body Surfaces in Jersey and Holstein Cows (H. H. Kibler, et al.).
464	XI.	Effects of Temperature, 50° to 105° and 50° to 9°F, on Heat Production and Cardiorespiratory Activities in Brahman, Jersey, and Holstein Cows (H. H. Kibler, et al.).
471	XII.	Influence of Increasing Temperature, 40° to 105°F, on Milk Production in Brown Swiss Cows, and on Feed and Water Consumption and Body Weight in Brown Swiss and Brahman Cows and Heifers (A. C. Ragsdale, el al.).
473	XIII.	Influence of Increasing Temperature, 40° to 105°F, on Heat Production and Cardiorespiratory Activities in Brown Swiss and Brahman Cows and Heifers (H. H. Kibler, et al.).
479	XIV.	Influence of Temperature on Insensible Weight Loss and Moisture Vaporization in Brahman, Brown Swiss, Holstein, and Jersey Cattle (H. J. Thompson, et al.).
481	XV.	Influence of Environmental Temperature, 0° to 105°F, on Hair and Skin Temperatures and on the Partition of Heat Dissipation Between Evaporative and Non-Evaporative Cooling in Jersey and Holstein Cattle (H. J. Thompson, et al.).
484	XVI.	Effect of Increasing Temperature, 65° to 95°F, on the Reflection of Visible Radiation from the Hair of Brown Swiss and Brahman Cows (R. E. Stewart, et al.).
488	XVII.	The Influence of Temperature on Blood Composition of Cattle (Clifton Blincoe, Samuel Brody, et al.).

TABLE 1. AIR, SURFACE, AND SKIN TEMPERATURES, °F, OF HOLSTEIN, JERSEY, AND BRAHMAN CATTLE.

SUMMER 1949 (May 23 to August 15)								WINTER 1949 (Oct. 4, 1949 to Feb. 1, 1950)					
Thermocouple		Radiometer				Humidity	No.	Thermocouple		Radiometer		Humidity	No.
Chamber Air	Cow Skin*	Chamber Surface	Cow Surface*	Dewlap	Hoof	%	of Obs.	Chamber Air	Cow Skin*	Chamber Surface	Cow Surface*	%	of Obs.
						JERSEY							
52.5	89.3	55.7	84.5			65	2	52.0	88.2	54.0	79.6	67	2
60.1	91.0	61.8	87.4	88.2		70	4	41.3	87.6	43.7	73.4	56	4
65.1	94.0	67.3	88.5	89.4	88.6	73	4	30.6	83.0	34.4	69.7	59	4
68.7	96.1	70.0	90.4	90.6	87.6	76	4	22.8	82.4	27.1	62.7	60	4
74.2	96.2	75.8	92.2			71	2	13.8	83.9	20.8	57.2	62	4
78.6	97.0	79.8	94.2	95.1	93.2	65	2	10.0	81.1	17.6	52.2	65	2
84.0	99.2	85.8	95.8	96.6	95.9	65	2	3.0	78.4	11.0	45.8	66	2
89.4	98.3	90.2	96.4	96.8	96.8	68	2	50.1#	92.2	52.6	76.6	65	6
93.7	99.5	95.4	97.6	97.5	98.3	56	2						
100.3	102.4	98.7	100.0	98.8	100.6	60	2						
105.6	104.9	105.3	103.3	101.7	103.4	59	2						
51.1#	82.2	52.0	79.0	72.8	62.2	67	2						
						HOLSTEIN							
53.9	89.8	57.5	84.9			65	2	54.4	84.8	54.7	80.8	67	2
61.6	92.8	62.4	87.7	87.4		70	4	43.8	84.4	47.0	75.4	56	4
66.0	94.0	69.0	90.0	90.3	89.9	73	4	34.4	80.9	38.6	72.0	59	4
70.2	96.0	71.8	91.2	90.6	87.5	76	4	26.8	82.4	31.2	67.8	60	4
74.2	96.6	77.6	92.8			71	2	18.6	80.4	24.1	61.8	62	4
81.3	97.0	80.8	94.2	94.0	92.6	65	2	10.1	73.7	18.0	56.0	65	2
85.1	97.8	86.4	95.4	95.2	94.8	65	2	3.0	76.6	10.2	49.6	66	2
89.8	98.4	90.5	95.9	94.8	97.2	68	2	49.6#	90.6	52.4	77.6	65	6
93.1		93.8	97.6	97.2	97.8	56	2						
100.4	102.9	99.4	99.9	99.1	100.8	60	2						
105.5	104.8	106.0	103.1	102.2	103.7	59	1						
52.3#	81.6	54.7	77.5	74.4	65.6	67	1						
						BRAHMAN							
54.0	89.0	57.6	82.6			65	2	52.1	83.8	54.4	79.7	67	2
61.0	90.8	63.1	86.7	75.5		70	4	43.7	84.2	45.7	73.8	56	4
65.6	92.3	69.2	88.7	87.8	88.6	73	4	33.7	81.6	37.0	67.4	59	4
69.9	93.9	71.2	90.5	91.4	89.0	76	4	25.8	81.7	29.3	62.8	60	4
74.7	95.0	77.0	93.0			71	2	17.2	82.5	22.8	58.8	62	4
79.8	96.0	80.6	94.3	93.7	91.0	65	2	11.0	79.9	18.6	54.5	65	2
84.4	97.0	86.4	95.0	94.8	94.5	65	2	4.0	74.2	11.8	48.8	66	2
89.1	98.4	90.4	96.7	96.9	96.0	68	2	50.4	89.0	53.0	75.6	65	6
94.7	99.6	94.4	98.4	98.4	97.3	56	2						
100.3	102.6	98.6	100.9	99.8	99.9	60	2						
105.2	103.7	105.0	102.7	102.7	102.9	59	2						
50.8#	83.8	53.6	79.1	68.5	64.2	67	2						

*Each observation consists of an average of six spot measurements; back, belly, right and left sides of body, neck and rump.

At end of experiment.

TABLE 2. AIR, SURFACE, AND SKIN TEMPERATURES, °F, OF BROWN SWISS AND BRAHMAN COWS AND HEIFERS. (February 6 to June 9, 1950)

COWS								HEIFERS							
Thermocouple		Radiometer				Humidity	No.	Thermocouple		Radiometer				Humidity	No.
Chamber Air	Cow Skin*	Chamber Surface	Cow Surface*	Jaw	Leg	%	of Obs.	Chamber Air	Cow Skin*	Chamber Surface	Cow Surface*	Jaw	Leg	%	of Obs.
BROWN SWISS															
42.0	86.6	45.2	74.5			57	6	39.6	86.5	43.0	69.1			64	6
50.7	85.5	52.8	79.7			56	6	49.9	90.3	51.8	76.2			64	6
60.3	88.3	59.9	84.4	83.5	80.9	69	6	59.5	93.0	60.8	83.7	83.2	82.2	79	6
70.8	92.4	70.9	89.4	89.2	85.4	72	6	70.4	93.7	71.6	89.9	88.7	84.5	70	6
79.8	95.5	80.3	93.9	93.6	91.2	67	6	80.3	96.5	80.3	94.1	94.2	91.3	68	6
85.0	97.1	85.3	95.9	95.5	94.4	68	9**	84.3	97.3	84.6	96.3	97.1	95.7	70	6**
90.1	98.7	89.8	97.1	96.6	96.1	66	6	90.3	98.6	90.0	97.3	97.5	96.0	60	6
95.6	99.2	94.6	99.0	98.0	97.3	59	3	95.2	99.8	94.7	99.4	99.5	98.6	49	3
100.0	100.8	98.9	100.8	100.7	101.5	54	3	100.4	102.2	99.1	101.6	101.8	101.7	56	3
105.6	102.3	103.9	103.6	102.3	104.0	55	3	105.4	103.3	103.4	103.3	102.8	103.4	51	3
42.5#	80.5	44.4	76.8	81.2	60.3	64	6**	40.9#	83.2	43.0	76.8	83.4	54.4	66	6
BRAHMAN															
42.0	86.1	44.8	73.7			57	6	39.4	83.4	42.9	74.1			64	6
50.6	86.2	52.8	77.7			56	6	50.3	86.0	51.6	79.7			64	6
60.2	87.8	59.8	82.4	86.3	74.6	69	6	59.3	89.5	60.4	84.7	87.8	81.2	79	6
70.8	91.6	70.7	89.3	91.6	85.1	72	6	70.5	92.5	71.0	90.7	92.5	86.1	70	6
80.0	95.0	80.4	94.3	95.0	91.0	67	6	80.0	96.7	80.0	95.0	95.1	92.6	68	6
85.2	96.2	85.3	96.9	97.5	94.5	68	9**	84.3	97.4	84.3	97.1	98.8	95.2	70	6**
90.2	98.2	89.5	97.9	98.4	94.9	66	6	90.2	98.5	89.8	97.6	98.0	95.6	60	6
95.5	98.5	94.5	99.1	99.4	96.4	59	3	95.1	99.5	94.8	99.1	99.7	98.2	49	3
98.9	100.1	98.9	100.7	100.9	100.0	54	3	100.2	101.5	99.2	101.1	101.2	100.8	56	3
105.4	102.0	103.5	102.8	102.9	102.7	55	3	105.1	103.0	103.5	102.8	102.5	103.2	51	3
43.0#	76.9	44.6	73.6	80.2	51.1	64	6**	40.6#	78.1	42.6	74.8	82.4	48.4	66	6

*Each observation consists of an average of six spot measurements; back, belly, right and left sides of body, neck and rump.

At end of experiment.

**Number of observations given is for the radiometer readings; at 85°F the observations for the thermocouple is three less than the radiometer and at 40° (end) three more.

TABLE 3. EQUATIONS RELATING SURFACE TEMPERATURE (Y) TO CHAMBER AIR TEMPERATURE (X)
(Curves for 1949 shown in lower section of Fig. 3; 1950 curves shown in Fig. 4)

Y	Breed	No. of Obs.	Equation Y = surface temp., °F X = air temp., °F	Coefficient of Correlation	Standard Error of Estimate
			0° to 65°F		
Skin Temperature (touch thermocouple) 1949	Jersey	28	Y = 78.9 + .193X	.818	2.59
	Holstein	28	Y = 73.9 + .269X	.860	3.02
	Brahman	28	Y = 76.3 + .208X	.812	2.78
Hair Temperature (Radiometer) 1949	Jersey	28	Y = 46.6 + .682X	.987	2.15
	Holstein	28	Y = 50.0 + .611X	.985	2.04
	Brahman	28	Y = 46.6 + .644X	.977	1.85
			65° to 105°F		
Skin Temperature (touch thermocouple) 1949	Jersey	22	Y = 79.6 + .226X	.936	1.22
	Holstein	19	Y = 78.7 + .234X	.950	1.02
	Brahman	22	Y = 74.1 + .278X	.978	0.84
1950	Brown Swiss Cows	33	Y = 72.9 + .281X	.978	0.65
	Brown Swiss Heifers	30	Y = 74.7 + .269X	.975	0.71
	Brahman Cows	33	Y = 71.1 + .294X	.975	0.72
	Brahman Heifers	30	Y = 74.9 + .264X	.903	1.45
Hair Temperature (Radiometer) 1949	Jersey	22	Y = 67.3 + .332X	.987	0.77
	Holstein	21	Y = 70.7 + .292X	.986	0.66
	Brahman	22	Y = 66.7 + .341X	.984	0.88
1950	Brown Swiss Cows	33	Y = 62.8 + .383X	.968	1.10
	Brown Swiss Heifers	30	Y = 63.6 + .377X	.988	0.68
	Brahman Cows	33	Y = 63.2 + .382X	.976	0.92
	Brahman Heifers	30	Y = 68.1 + .332X	.973	0.86

TABLE 4. EQUATIONS RELATING THE DIFFERENCE BETWEEN SURFACE TEMPERATURE AND AIR TEMPERATURE (Y) TO CHAMBER AIR TEMPERATURE (X)
(Curves for 1949 shown in upper section of Fig. 3;
1950 curves shown in Fig. 4)

Y	Breed	No. of Obs.	Equation Y = temp. diff. °F X = air temp., °F	Coefficient of Correlation	Standard Error of Estimate
			0° to 65° F		
Skin T. less Air T. (touch thermocouple) 1949	Jersey	28	Y = 78.9 - .808X	.987	2.55
	Holstein	28	Y = 73.9 - .731X	.977	3.02
	Brahman	28	Y = 76.3 - .792X	.983	2.78
Hair T. less Chamber Surface T. (Radiometer)	Jersey	28	Y = 38.7 - .206X	.881	2.11
	Holstein	28	Y = 42.0 - .273X	.942	1.85
	Brahman	28	Y = 39.4 - .260X	.932	1.88
Skin T. less Hair T. (Radiometer) 1949	Jersey	28	Y = 32.3 - .489X	.928	3.76
	Holstein	28	Y = 23.9 - .343X	.886	3.76
	Brahman	28	Y = 29.7 - .436X	.964	2.25
			65° to 105° F		
Skin T. less Air T. (touch thermocouple) 1949	Jersey	22	Y = 79.6 - .774X	.994	1.22
	Holstein	19	Y = 78.7 - .766X	.995	1.02
	Brahman	22	Y = 74.1 - .722X	.997	0.84
1950	Brown Swiss Cows	33	Y = 72.9 - .719X	.997	0.65
	Brown Swiss Heifers	30	Y = 74.7 - .731X	.997	0.71
	Brahman Cows	33	Y = 69.4 - .686X	.969	0.60
	Brahman Heifers	30	Y = 72.7 - .715X	.996	0.78
Hair T. less Chamber Surface T. (Radiometer) 1949	Jersey	22	Y = 61.5 - .610X	.991	1.17
	Holstein	21	Y = 62.4 - .622X	.992	1.01
	Brahman	22	Y = 57.5 - .563X	.986	1.34
1950	Brown Swiss Cows	33	Y = 57.5 - .553X	.988	0.95
	Brown Swiss Heifers	30	Y = 56.5 - .539X	.989	0.93
	Brahman Cows	33	Y = 59.3 - .570X	.987	1.00
	Brahman Heifers	30	Y = 63.2 - .613X	.992	0.88
Skin T. less Hair T. (Radiometer) 1949	Jersey	22	Y = 12.3 - .106X	.875	0.85
	Holstein	19	Y = 8.22 - .060X	.696	0.82
	Brahman	22	Y = 7.43 - .063X	.828	0.60
1950	Brown Swiss Cows	33	Y = 9.21 - .106X	.825	0.80
	Brown Swiss Heifers	30	Y = 10.8 - .106X	.818	0.87
	Brahman Cows	33	Y = 7.95 - .088X	.774	0.78
	Brahman Heifers	30	Y = 5.02 - .047X	.626	0.68

TABLE 5. EFFECT OF AIR TEMPERATURE CHANGES WITH TIME ON THE DIFFERENCES BETWEEN HAIR AND SKIN TEMPERATURE.

Schedule of Tests	Beginning of Experiment at 50° F (or 40° F)	End of Experiment at 50°F (or 40°F)	Difference
A. Skin Temperature less Hair Temperature Before and After Increasing Temperature, 50° F (or 40° F) to 105° F.			
Summer 1949 (June 7 to Aug. 15)	Ambient Temperature, 50° F.		
Jersey	4.8	3.2	-1.6
Holstein	4.8	4.1	-0.7
Brahman	6.4	4.6	-1.8
Spring 1950 (Feb. 27 to June 6)	Ambient Temperature, 40° F.		
Brown Swiss Cows	12.1	4.0	-8.1
Brahman Cows	12.4	3.2	-9.2
Brown Swiss Heifers	17.4	6.4	-11.0
Brahman Heifers	9.3	3.3	-6.0
B. Skin Temperature less Hair Temperature Before and After Decreasing Temperature, 50° F to 0° F.			
Winter 1949 (Oct. 11, '49 to Jan. 31, '50)	Ambient Temperature, 50° F.		
Jersey	8.6	15.6	+7.0
Holstein	4.0	13.0	+9.0
Brahman	4.1	13.3	+9.1
C. Skin Temperature less Air Temperature Before and After Increasing Temperature, 50° F (or 40° F) to 105° F.			
Summer 1949 (June 7 to Aug. 15)	Ambient Temperature, 50° F.		
Jersey	36.8	31.0	-5.8
Holstein	35.8	29.3	-6.5
Brahman	35.0	32.9	-2.1
Spring 1950 (Feb. 27 to June 6)	Ambient Temperature, 40° F.		
Brown Swiss Cows	44.6	38.7	-5.9
Brahman Cows	44.1	34.3	-9.8
Brown Swiss Heifers	46.8	42.3	-4.5
Brahman Heifers	44.0	37.5	-6.5
D. Skin Temperature less Air Temperature Before and After Decreasing Temperature, 50° F to 0° F.			
Winter 1949 (Oct. 11, '49 to Jan. 31, '50)	Ambient Temperature, 50° F.		
Jersey	36.2	42.1	+5.9
Holstein	30.4	41.0	+10.6
Brahman	31.7	38.6	+6.9