RESEARCH BULLETIN 578 FEBRUARY, 1955

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XXXIII. Milk Production, Feed and Water Consumption, and Body Weight of Jersey and Holstein Cows in Relation to Several Diurnal Temperature Rhythms

SAMUEL BRODY, A. C. RAGSDALE, R. G. YECK, AND DOROTHY WORSTELL

Missouri Agricultural Experiment Station and the United States Department of Agriculture Cooperating

(Publication authorized February 21, 1955)

COLUMBIA, MISSOURI

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ACKNOWLEDGEMENTS

This is part of a broad cooperative investigation between the Departments of Dairy Husbandry and Agricultural Engineering of the Missouri Agricultural Experiment Station, University of Missouri, and Agricultural Engineering Branch, Agricultural Research Service, U. S. Department of Agriculture.

Acknowledgements are made to Harry Ball for care and feeding of animals, to H. J. Thompson, Agricultural Engineer, U.S.D.A., for his assistance in setting up the program, and to Samuel Barrett for maintenance work on the Psychroenergetic Laboratory.

This bulletin reports on the Department of Dairy Husbandry research project num-125, Climatic Factors.

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ORIENTATION

Previous data in the Psychroenergetic Laboratory were obtained while holding the climatic conditions virtually constant 24 hours a day. Results from these constant-temperature experiments may not be applicable to animals kept under outdoor conditions which tend to vary in a diurnal rhythm. The daily variations in sunlight always follow a diurnal rhythm; temperature usually follows sunlight, and relative humidity tends to vary inversely with temperature. The situation is further complicated by the presence of endogenous or inherent diurnal body temperature rhythms.[1]

The preceding reports demonstrated that exposure to *constant* temperatures above 80° F. is definitely stressful to European-evolved cows with consequent depression of feed consumption and milk production. The higher the temperature the greater the stress, attaining the upper constant-temperature limit of endurance at about 105° F. when the surface and environmental temperatures meet, that is, when the thermal gradient is abolished. How do temperatures, diurnally imposed, affect the maximal tolerable temperature of cows? Would cool temperatures at night increase their maximal heat tolerance during the day? One would expect it to be so from the large size and consequently large heat capacity of cows: It would take some time for the deep body temperature to attain a fever temperature and by that time the air temperature would begin to decline, thus halting the rise in body temperature and later reducing it. Moreover, it is conceivable that the diurnal *change* in outdoor temperature would be stimulating rather than deteriorating to the cows, depending, however, on the relative length of exposure above the heating 80° F. and below the cooling 70° F. temperatures.

Attempts, therefore, were made to throw some light on this problem by simulating average outdoor diurnal-temperature rhythms in the climatic chambers. While the average outdoor hour-to-hour temperature changes were simulated successfully, no attempt was made to simulate the other out-

[1]See References, page 20.

door variables, such as light, humidity, air movement, and rain. These were maintained roughly constant for the three-and five-week test periods.

EXPERIMENTS

Data from the U. S. Weather Bureau were used as guides in simulating the outdoor diurnal temperature rhythms. Fig. 1 shows a frequency distribution curve of the daily temperature range in Columbia, Mo. The average daily temperature range is of the order of 20° F. The greatest variation occurred during the fall, and the least during the winter. The ranges varied from less than 5° to more than 40° F., with a maximum of 58° F. A daily temperature range of 30° occurs quite frequently (Fig. 1), so this range was chosen for most of these experiments.

It was desired to study the relative effects of diurnal temperature ranges for cold, hot, and "optimal" weather. This program has been designated, respectively, as: "Midwest Cold", 10° to 40° F. (10° F. was the lower limit for the laboratory cooling equipment); "Midwest Hot", 70° to 100° F.; and "Midwest Normal", 40° to 70° F. In addition, there was included a diurnal rhythm of an especially wide range with a maximum day temperature of 110° F. and a relatively low night temperature of 40°, 50°, or 60° F., simulating somewhat the Imperial Valley or mountain rhythm.

The temperatures were controlled so that the troughs occurred at 5 to 7 a.m. and the peaks at 3 to 4 p.m.; they roughly simulated the diurnal temperature rhythms obtained by the Washington, D. C., Weather Station between 1890 and 1942. The diurnal patterns of temperature and humidity in the climatic chambers are given in Figs. 2 and 3.

In the preceding, constant-temperature experiments, the walls, ceiling, and air had approximately the same temperature. In the present diurnal-rhythm experiments the temperatures of the chamber surfaces differed somewhat from the air temperature (not more than 2° F.), depending on whether or not the outer alley temperatures were leading or lagging the test room diurnal temperature.

Illumination was provided by one 40-watt bulb which was on at all times and, in addition, six 200-watt incandescent bulbs which were on between 4 a.m. and 6 p.m. in each chamber. Air movement was about ½ m.p.h.

Two separate series of diurnal-temperature experiments were conducted; one in the fall of 1953 and one in the spring of 1954. The experimental subjects in each experiment were three Holsteins and three Jerseys, all lactating. There were three important differences between the fall and spring groups of cows: The fall group consisted of much higher producing cows; they were in earlier stages of lactation and gestation (by 4 months); and the experimental measurements on the fall cows were limited to avoid inter-

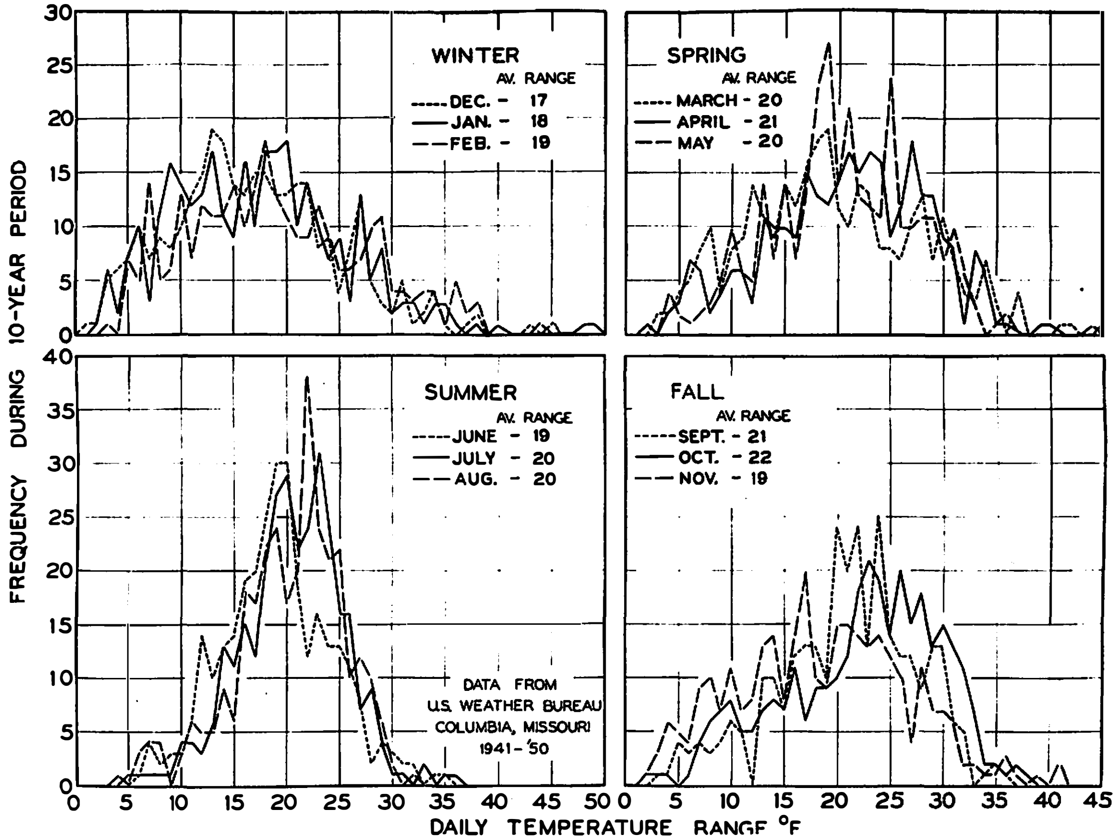

Fig. 1—Frequency distribution curve for the daily temperature range during a 10 year period at Columbia, Mo.

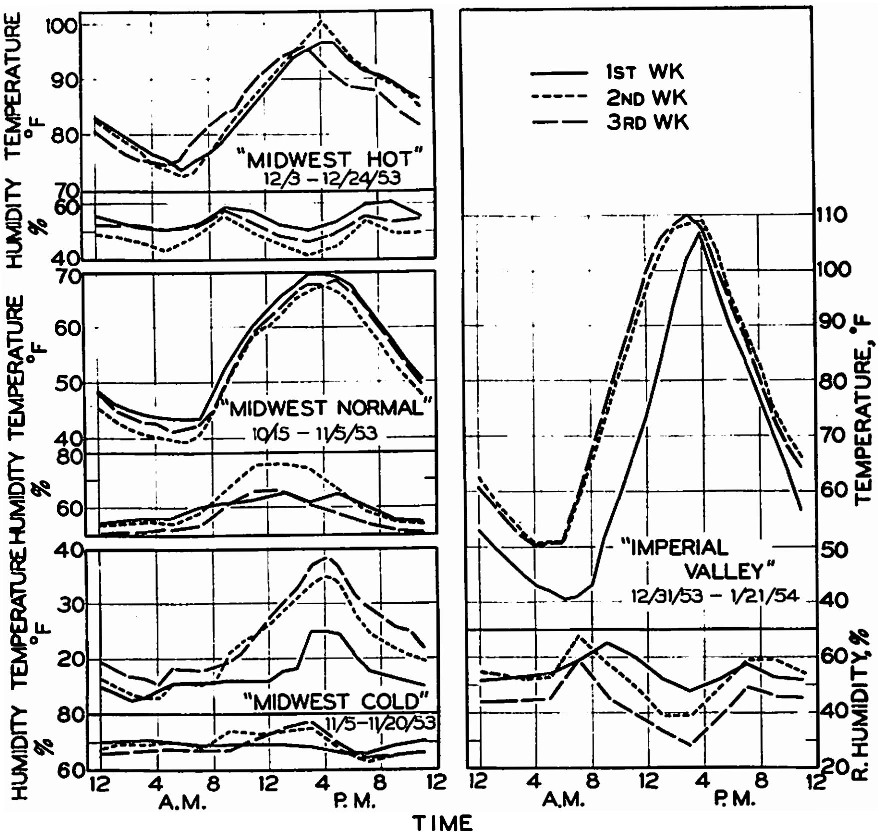

Fig. 2—The diurnal rhythms in the Psychroenergetic Laboratory of temperature and relative humidity, *fall,* 1953. Each curve is an average for the given week, plotted from average data of one-hour intervals for temperature and two-hour intervals for humidity. Each test condition was of three weeks' duation.

ference with maximal milk production. The spring, 1954, group of cows was used for additional measurements, including determination of blood composition, blood volume, body water, and thyroid activity, which may have exerted slight depressing effects on the milk production and feed consumption.

During the fall, 1953, experiment each diurnal range was of three weeks' duration; during the spring, 1954, experiment each diurnal range was of five weeks' duration to allow for the additional measurements. Between most diurnal rhythm patterns an adjustment period was allowed of one week at about 60° F. Table 1 presents average weekly chamber temperatures and humidities. Figs. 2 and 3 present the hour-to-hour diurnal temperature patterns in the climatic chambers.

TABLE 1 -- CALENDAR, OCT. 1953-JUNE 1954

Temperature Condition	Diurnal Temperature Range*, °F.	Week (1953-54) 3 p.m. to 3 p.m.	Average Weekly: Air Temp. °F.	Average Weekly: Relative Humidity*, %	Average Weekly: Vapor Pressure mm Hg
		FALL 1953			
Adjustment	**	Oct. 8 to 15	60	58	7.7
"Midwest Normal"	40 to 71	Oct. 15 to 22	58	59	7.3
	38 to 71	Oct. 22 to 29	54	62	6.6
	38 to 71	Oct. 29 to Nov. 5	56	56	6.4
"Midwest Cold"	6 to 32	Nov. 5 to 12	20	69	1.8
	10 to 39	Nov. 12 to 19	25	69	2.3
	12 to 39	Nov. 19 to 26	26	68	2.4
Adjustment	**	Nov. 26 to Dec. 3	64	65	9.9
"Midwest Hot"	70 to 100	Dec. 3 to 10	85	56	17.3
	70 to 101	Dec. 10 to 17	84	48	14.3
	73 to 101	Dec. 17 to 24	84	53	15.8
Adjustment	**	Dec. 24 to 31	65	53	8.4
"Imperial Valley"	39 to 110	Dec. 31 to Jan. 7	66	55	9.0
	49 to 110	Jan. 7 to 14	77	53	12.6
	48 to 112	Jan. 14 to 21	79	43	10.9
Adjustment	**	Jan. 21 to 28	64	53	8.1
		SPRING 1954			
Adjustment	**	Jan. 28 to Feb. 4	60	57	7.6
"Midwest Cold"	11 to 40	Feb. 4 to 11	30	58	2.4
	10 to 44	Feb. 11 to 18	26	59	2.0
	11 to 41	Feb. 18 to 25	24	60	1.9
	7 to 42	Feb. 25 to Mar. 4	21	61	1.7
	8 to 43	Mar. 4 to 11	21	58	1.6
Adjustment	+	Mar. 11 to 18	37	57	3.2
"Midwest Normal"	38 to 72	Mar. 18 to 25	55	55	6.1
	38 to 71	Mar. 25 to Apr. 1	54	55	5.9
	40 to 71	Apr. 1 to 8	55	54	6.0
	40 to 71	Apr. 8 to 15	55	57	6.3
	40 to 71	Apr. 15 to 22	55	57	6.3
"Imperial Valley"	59 to 112	Apr. 22 to 29	81	55	14.9
	60 to 111	Apr. 29 to May 7	84	46	13.7
Adjustment	**	May 7 to 13	63	57	8.4
"Midwest Hot"	70 to 102	May 13 to 20	84	51	15.2
	70 to 100	May 20 to 27	84	50	14.9
	68 to 100	May 27 to June 3	84	55	16.4

*See Figs. 2 and 3 for the hour-to-hour temperature and humidity changes. Range given here represents the minimum and maximum temperature.
**Constant temperature of about 60° F.
+The 10° to 40° diurnal temperature range was gradually increased during the week to a range of 40° to 70° F.

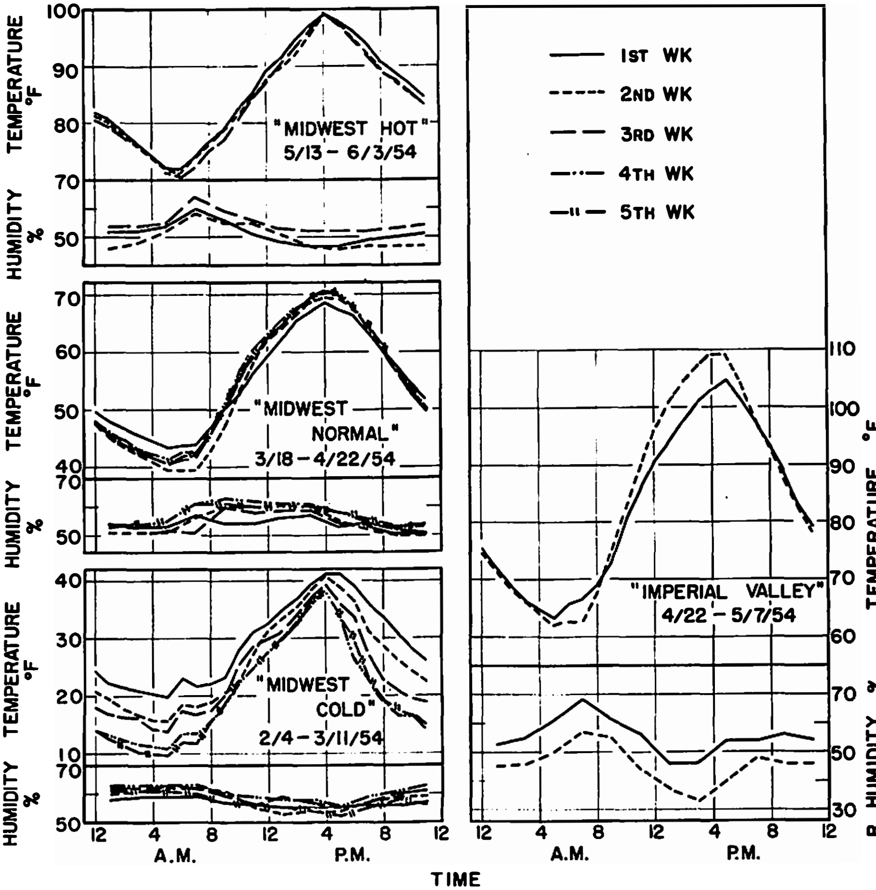

Fig. 3—Same as Fig. 2 but for the *spring*, 1954, period. Each curve represents the average for a week and was plotted from average data of one-hour intervials for temperature and two-hour intervals for humidity. "Midwest Cold" and "Midwest Normal" were of five weeks' duration, "Midwest Hot", three weeks', and "Imperial Valley" two weeks' duration.

Information on the experimental animals is given in Table 2. The cows were machine-milked twice daily at 5 a.m. and 3 p.m. Water was available in individual drinking cups and the total amount supplied to the water cups was recorded automatically. Alfalfa hay chopped in approximately ¾ to 1-inch lengths was fed *ad libitum;* the left-over hay was air dried before weighing back and deducted from the amount fed. The cows received 2 lb. dry beet-pulp daily. The grain mix, including cod liver oil supplement, was the same as in previous studies (Table 3, page 10, Res. Bul. 425). The amount fed was based on the previous week's milk production (Jerseys received 1

TABLE 2 -- HISTORY OF THE COWS

					At Beginning of Expt.		Average During October 1953	
Cow No.	Birth Date	Date of Last Calving	Number of Previous Lactations	Date of Last Breeding	Approx. Age Years	Approx. Body Weight Lbs.	Milk Lbs./Day	Butterfat %
FALL 1953								
Jersey								
274	Oct. 25, 1948	Aug. 19, 1953	2	Apr. 19, 1954	5	850	27.8	6.0
277	Nov. 21, 1948	July 5, 1953	2	Oct. 1, 1953	5	850	24.3	5.1
295	Apr. 11, 1950	Oct. 4, 1953	1	Apr. 18, 1954	3 1/2	800	35.0	5.0
Holstein								
184	Feb. 13, 1947	Sept. 27, 1953	4	-----	7	1300	56.1	3.0
144	June 11, 1945	Sept. 3, 1953	5	June 14, 1954	8	1300	45.6	2.8
337	May 7, 1949	Sept. 21, 1953	2	Feb. 14, 1954	5	1250	51.6	3.0
SPRING 1954 -- Cows as above except for Holstein 337 and Jersey 277 which were removed from Laboratory and replaced by:							Average During Jan. 1954	
Jersey								
564	Jan. 16, 1950	Sept. 20, 1953	1	Nov. 30, 1953	4	870	15.4	6.0
Holstein								
178	Dec. 12, 1946	Apr. 1, 1953	3	-----	8	1300	30.7	4.0

Additional Remarks:

J-295 -- Removed from experiment March 9, 1954; taken to Veterinary Clinic. Hardware was removed from rumen. Although cow recovered she was not returned to Laboratory.

H-184 -- Had heat stroke May 1 during the 60° to 110° F. Diurnal Range and was removed from Laboratory. Her left hind leg became paralyzed and she was euthanized May 11. The postmortem report by the Veterinary Department was: The left hind leg was swollen due to an occluding blood clot in the femoral artery. About 3/4 of the muscle in the hind leg had undergone necrosis. She also had acute, diffuse mastitis caused by a streptococcus. Microscopic sections of the brain and spinal cord showed no morphological changes except for microscopic hemorrhages. The cow would probably have recovered from the heat prostration had she not developed the femoral clot.

J-564 -- Aborted 5-month fetus May 7. To avoid possible loss she was removed from the Laboratory on May 24; her pulse very weak; rectal temperature 108° F. She was slaughtered June 5. The postmortem Veterinary report was as follows: A septic thrombus almost filled the right ventricle. The right ventricle, considerably dilated, was lined with 2 cm. of connective tissue in some areas. This would indicate that the lesion had been present possibly two weeks or longer. The lesion was caused by a streptococcus. No lesions were observed that are commonly associated with heat stroke.

pound of grain per 3 pounds of milk and Holsteins 1 pound of grain per 4 pounds of milk). Butterfat determinations were made three times weekly from a composite sample of the morning and evening milkings.

Data for the Fall 1953 Experiments

Fig. 4 is a summary of the effects of the several diurnal rhythms during the fall, 1953, experiments, averaged by *weeks* and plotted on semi-log paper. It is recalled that on semi-log paper equal slopes represent equal *relative* or *percentage* changes and that in Fig. 4 the relative changes are represented directly with respect to time and indirectly with respect to temperature. Figs. 5 and 6 present *daily* values of milk production and feed consumption on arithmetic paper.

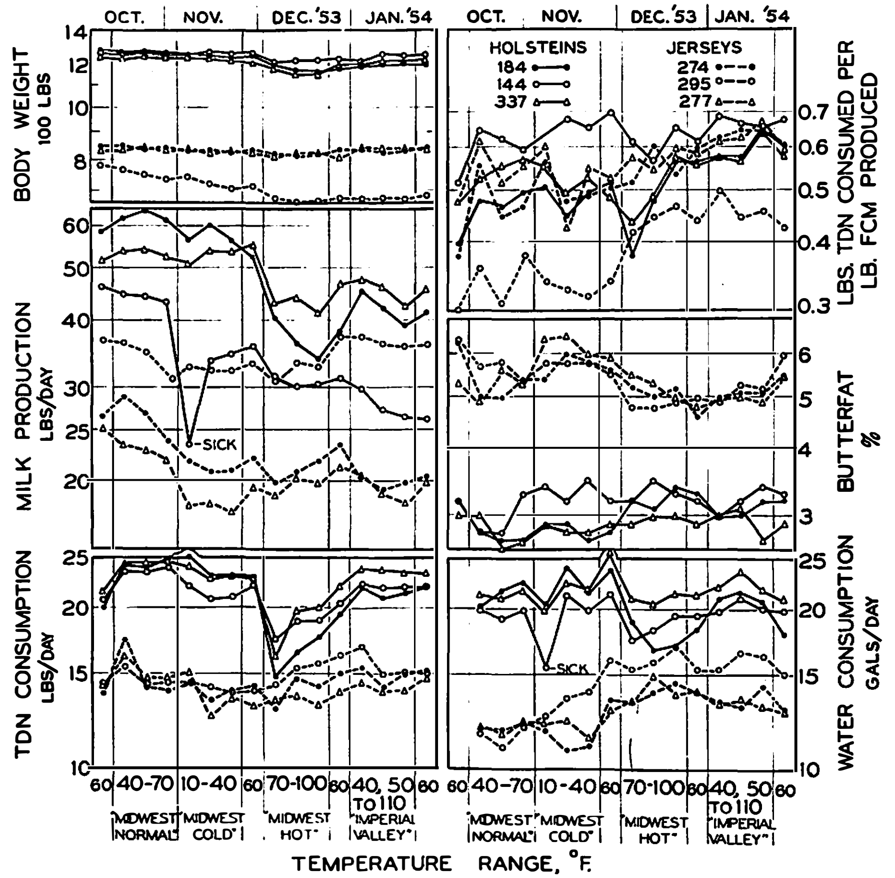

Fig. 4—Average *weekly* data obtained during the *fall,* 1953 period, and plotted on semi-logarithmic grids on which equal slopes represent equal percentage changes with respect to time. Note the greater effects on the Holstein than on the Jersey and the greater effects of the 70° to 100° than 40° to 110° F.

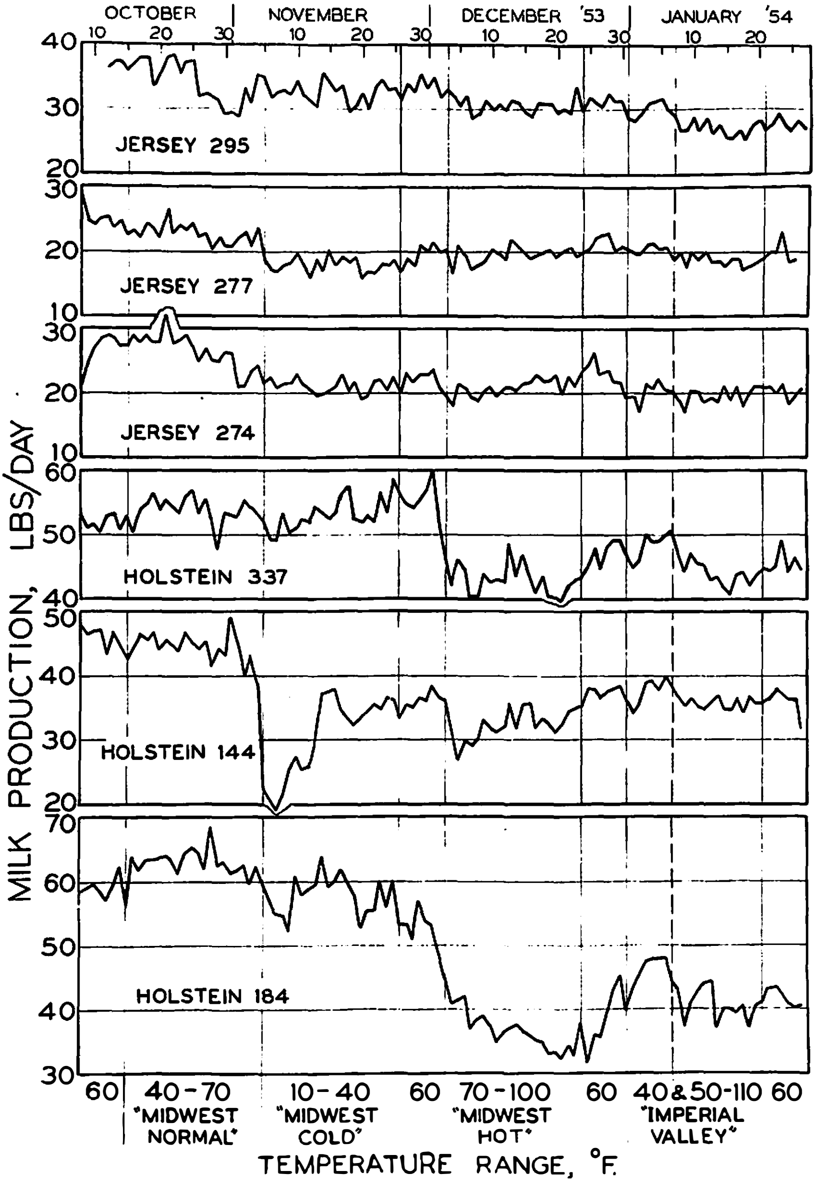

Fig. 5—Individual *daily* milk production during *fall*, 1953, period. H-144 was sick during the first part of the "Midwest Cold" period, which accounts for the decline in milk production. The Holsteins were more affected than the Jerseys and the effect was greater at the 70° to 100° than at the 40° to 110° F. ranges.

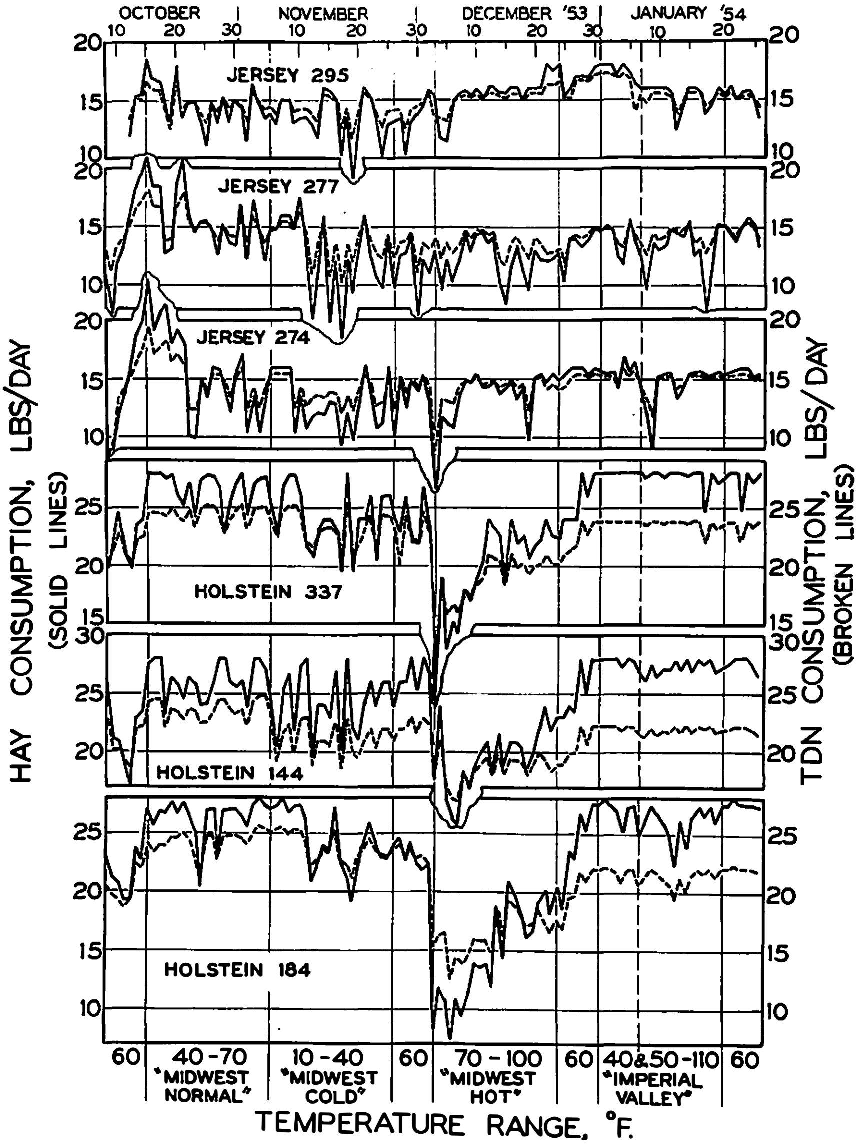

Fig. 6—Individual *daily* feed consumption during the *fall*, 1953, period. Hay consumption is represented by solid lines and TDN (total digestible nutrients) by broken lines. Again, the Holsteins were much more affected than the Jerseys and more by the 70° to 100° F. than by either the 40° to 110° F. or 50° to 110° F. ranges.

The *milk production* data show no changes during the 40° to 70° F. rhythm other than those normally associated with advancing stage of lactation. The 10° to 40° F. range appears to have had no effect on the milk production of the (larger) Holsteins but it lowered production somewhat in two of the (smaller) Jerseys. With the beginning of the 70° to 100° F. range, milk production dropped appreciably in the (larger) Holsteins. During the 60° F. adjustment week immediately following the 3-week period of 70° to 100° F., there was a partial recovery in the milk yield. This level was maintained during the 40° to 110° F. range and declined somewhat on changing to the 50° to 110° F. period.

The *butterfat* percentage remained fairly constant except for a slight increase in the Jerseys during the (cold) 10° to 40° F. range. It is generally known that butterfat percentage tends to be higher during the cold season of the year.[2]

The *feed consumption* level roughly paralleled the milk production. It was lowered abruptly in the Holsteins at the beginning of the 70° to 100° F. period, and recovered somewhat after the first week. The recovery continued throughout the 60° F. adjustment period and apparently during the 40° (or 50°) to 110° F. range. Little, if any, change occurred in the Jerseys. The feed consumption dropped during the first 2 or 3 days after the change to the 70° to 100° F. period but it recovered its normal level thereafter. The amount of grain fed was based on milk production and the cows ate all grain put before them. However, the TDN consumption curves (including both grain and hay) paralleled the hay curves (Fig. 6), except for sharper declines in the hay than in TDN consumption on increasing the temperature.

More TDN was required to produce a pound of FCM (4 percent fat-corrected milk) at the end than at the beginning of the period (upper-right section of Fig. 4), presumably because of decline in milk yield with advancing periods of lactation and gestation.

With the exception of a slight dip in the Holstein curve (Fig. 4) during the 70° to 100° F. period, *body weights* did not change appreciably during the experiment. The decline in body weight of J-295 does not coincide with the heat-stress period.

Water consumption increased during the higher temperature ranges (70° to 100° and 40° or 50° to 110° F.) in the *Jersey* cows; the *Holstein* cows showed an opposite trend, a slight decrease in water consumption during the 70° to 100° F. range. This could possibly be a breed difference and needs to be investigated in more detail. The water consumption records are difficult to interpret because of individual differences in spillage at the higher temperatures and because of decreased milk production and feed consumption with increasing temperatures, with consequent reduced need for water in the digestive, excretory, and milk-producing processes.

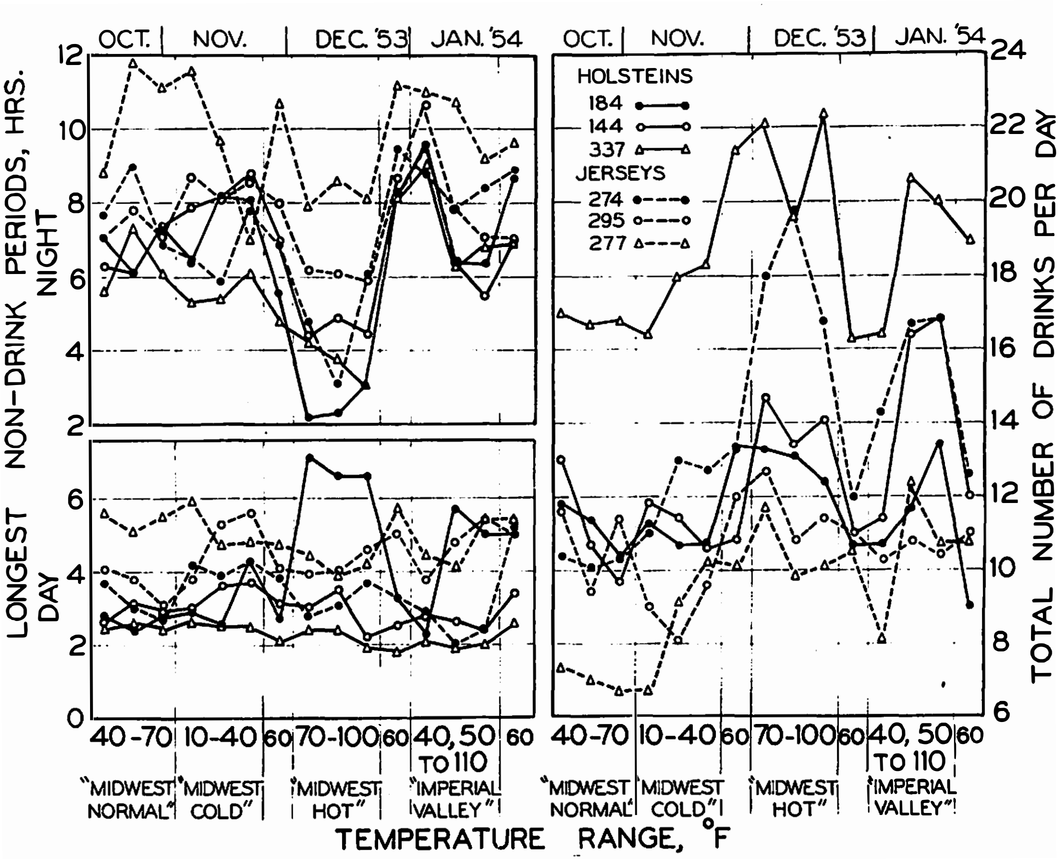

Fig. 7—Total number of drinks per day (right-hand section) and length of "rest" periods (represented by the non-drink periods, left-hand sections) for the *fall,* 1953, period. The greater number of drinks per day on the part of H-337 is, no doubt, an individual characteristic.

The right half of Fig. 7. shows that the total number of drinks is higher during "Midwest Hot" and "Imperial Valley." The left side of Fig. 7. shows the "resting" or "non-drink" periods separated into day and night. The *day* periods show no significant difference in rest periods with exception of H-184. She increased her non-drink period from 3 to about 7 hours during the "Midwest Hot" period. The "rest" periods during the night are shorter during the "Midwest Hot" periods for all cows. The explanations for these differences are not clear because of the many confusing factors that seem to be involved. These include, breed differences in discomfort of animals (Holsteins had higher rectal temperatures than Jerseys), reduced productivity, and water temperature in relation to environmental and body temperature.

The increase in number of drinks, but not in total amount, during the latter part of the 10° to 40° F. range in the *Jerseys* was puzzling as there was no increase in hay consumed or in milk produced in spite of the low temperature. Could this be attributed to playing with the water which was warmer than the cold air, just as cows like to play with water in hot weather if the water is cooler than the air?

Data for the Spring 1954 Experiments

As previously stated, the data on milk production and feed consumption during the spring, 1954, diurnal-temperature rhythm experiments may have been influenced by subjecting the cows to additional experimental measurements. Furthermore, the stage of lactation in this spring group of cows was advanced by 4 months, with consequently lower milk yields, so these data have a different order of significance than those obtained during the fall period. With the exception of Jersey 564 and Holstein 178 (Table 2), the same cows were used during the fall and spring experiments. The removal of Jersey 295 during the early part of the spring experiment (due to illness and not resulting from excessive heat stress) decreased the number of animals, thereby reducing the significance of the data.

As the 50° to 110° F. range seemed to be less stressful than the 70° to 100° F. range during the fall, 1953, period, it was thought desirable to use a diurnal period of wider range than the 70° to 100° F., yet have the *same average* daily temperature (85° F.). Hence, the shift to the 60° to 110° F. range in place of 50° to 110° F. range as in the fall, 1953, period.

Fig. 8 summarizes the data obtained during the spring experiments. While there are a few minor exceptions, these results are, in general, similar to those presented in Fig. 4 for the fall experiments. Milk production in the Jersey declined and feed (TDN) consumption increased somewhat during the 10° to 40° range. Both the Jerseys and the Holsteins declined in milk production and feed consumption during the 60° to 110° and the 70° to 100° periods. The decline was greater during the 60° to 110° period although the average temperature was the same. Acclimatization may have been a factor.

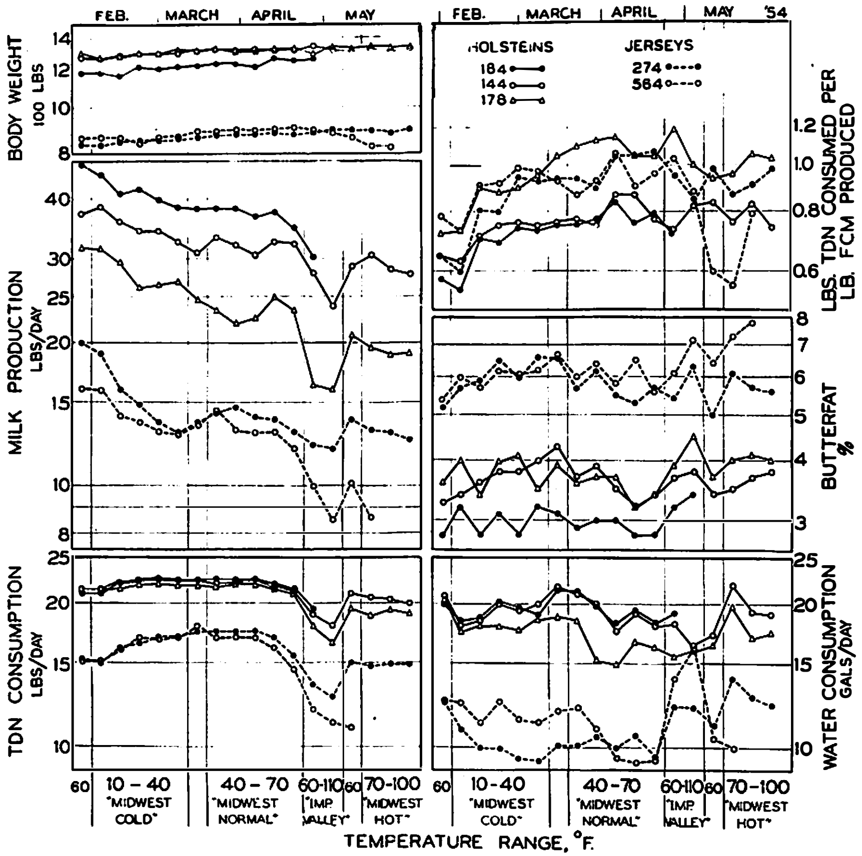

Fig. 8—A summary of the data obtained during the *spring*, 1954, period, averaged by *weeks* and plotted on a semi-logarithmic grid.

Note that the values in the ratio of TDN consumed to FCM produced are higher during this second, spring, period than in the first, fall period, undoubtedly because of decline in milk production with the advances (by 4 months) in the periods of lactation and gestation.

DISCUSSION

The preceding reports on the effects of different *constant* environmental temperatures on European-evolved lactating dairy cows indicate that the climatic "comfort zone" is between about 40° and 60° (at a relative humidity of 50 to 70 percent), that 70° F. is the critical temperature for rise in rectal temperature, that 80° F. is a critical temperature[3] for decline in feed consumption and milk production, and that the upper temperature limit of endurance is 105° F. when the body surface and environmental temperatures meet, that is, when the thermal gradient is abolished.

How do these results obtained under constant temperatures compare with the stresses imposed by diurnal rhythms?

The stressful effects of high diurnal temperatures are the resultants of several factors: the average temperature; time exposed to the definitely stressful temperatures above 80° F.; time exposed to the unstressful temperatures below 70° F.; the maximal and minimal temperatures in each diurnal cycle; and the rates of the rise and decline in the daily temperature rhythms. The following figures indicate some of the conditions for the diurnal rhythms employed in these experiments:

Diurnal Rhythm	Average Daily Temp. °F.	Hours per day exposed to temperatures		
		Above 80°F.	Above 85°F.	Below 70°F.
40° to 110°F.	75	7	6	14
50° to 110°F.	80	11	9	11
60° to 110°F.	85	13	11	7
70° to 100°F.	85	15	12	0

The 60° to 110°F. period was used during the Spring 1954 group; the 40° (or 50°) to 110°F., during the Fall 1953 group; and the 70° to 100°F. was used for both groups.

The higher the environmental temperature the greater the importance of the number of hours below 70° if the cow is to maintain her normal body temperature and milk production. As previously stated, above 70° F. the rectal temperature of cows (particularly in the Holsteins) increases. If during the day the temperature had been as high as 100° or 110° F., the rectal temperature would have increased from 3° to 6° F. above normal. If the environmental temperature does not go below 70° during the night, then it is unlikely that the rectal temperature will return to its normal level before the high day-time temperature, as the rise in rectal temperature lags behind the rise in environmental temperature. Thus, appetite and feed consumption would be reduced by abnormal rectal temperature, and milk production consequently would decline. The detailed effects of ambient temperature on rectal temperature will be reported in a later research bulletin.

During the variable diurnal rhythms, as previously reported for the constant temperature experiments, the (larger) Holsteins suffered more from the high temperatures than the (smaller) Jerseys. Other conditions being equal, the heavier animal with its smaller surface area per unit weight, and therefore slower rate of heat dissipation, would take more time to get cooled to normal during the declining (evening) phase of the diurnal rhythm than the smaller animal with the larger heat-dissipating surface per unit weight. The larger animals would probably also build up temperatures at a higher rate during the rising segment of the diurnal environmental temperature curve. Experiments evidently are needed for tracing the relative rates of increase and decrease in body temperature in large and small cows with increasing and decreasing phases of the diurnal environmental temperature rhythms.

How do the effects of a diurnal rhythm of 70° to 100° F. compare to the effects of an 85° F. constant temperature? Attempts were made to make such a comparison in regard to the effect on milk production and feed consumption but because of the great individual differences in the small number of animals used and in the difference in the length of exposure, the results were difficult to interpret. In general, changing the "optimal" diurnal temperature rhythm 40° to 70° F. to the "hot-weather" rhythm of 70° to 100° F. has approximately the same depressing effect on milk production and feed consumption as changing from the "optimal" *constant* temperature of 50° to the "high temperature" of 85° F. With continuous exposure at constant temperatures of 85° F. and above, a deterioration effect took place, whereas during the 70° to 100° F. diurnal rhythm, an acclimatization effect apparently was noted after the first week.

As noted in Table 2, Jersey 564 was removed from the laboratory after aborting a five-month fetus. A Jersey cow on special experiment in the other chamber maintained under the same conditions also aborted a six-month fetus a few days earlier. Heat stress appears to be aggravated by pregnancy. Previously, we observed[4] that two pregnant *Brucellosis*-free Holsteins aborted simultaneously two days following 27 hours exposure to 100° F. Dr. Erdheim[5] recently observed five abortions in show cows when their rectal temperatures reached 105° to 106° F. during a heat wave. Macfarlane[6] and associates reported that exposure to a temperature of 87° F. wet bulb predisposed to resorption of the fetuses in sheep; the ewes either failed to lamb or produced weak, undersized young. These investigators and also Thrift and M. K. Shah[7] reported a 60 percent fetal resorption in rats subjected to 95° F. Rabbits reacted more or less similarly to high temperatures or gave birth to very small litters.[7] They cited somewhat similar results by Steinach and Kammerer (1920) and by Sundstroem (1927) on rats, by Ogle (1934) on mice and by the U. S. Department of Agriculture (1950 report) on goats (autumn-born kids were 1.5 lb. lighter than spring-born).

Why did Holstein 184 (not bred) develop symptoms of "heat stroke" during the 60° to 110° (spring, 1954) period (see Table 2) when during the fall, 1953, experiment she withstood three weeks of 70° to 100° and three weeks of 50° to 110° F. without serious consequences? One possible contributing factor is that she suffered from chronic mastitis. Could the injections and blood sampling be additional factors in lowering her resistance to high temperartures? Holstein 184 did not drink as frequently during the 70° to 100° (Fig. 7). In a previous experiment,[8] the greater tolerance of Jersey 212 to high temperature was attributed, in part, to her frequent drinking and relatively great consumption of water. Could the intolerance of Holstein 184 be analogously attributed to her not drinking under conditions of high temperature? Extra water consumption at high temperatures may be an important homeothermic mechanisms in the individuals that drink more during hot weather.

SUMMARY

Two groups of six lactating (3 Jersey and 3 Holstein) cows were exposed to diurnally-varying temperature rhythms similar in pattern to the outdoor temperature rhythms in Midwestern U. S. A.: 10° to 40° F. ("Midwest Cold"); 40° to 70° F. ("Midwest Optimal"); 70° to 100° F. ("Midwest Hot"); 40°, 50°, or 60° to 110° F. ("Imperial Valley"). The physiological effects were analyzed from various view-points. The present bulletin reports the effects on milk production, and feed and water consumption.

Exposure to the 40° to 70° F. diurnal rhythm had no effect on milk production or feed consumption. Therefore, this is assumed to be within the zone of optimal temperature. The milk yield during the 10° to 40° F. diurnal rhythm was the same as during the 40° to 70° F. in the Holsteins but it was somewhat less in the Jerseys. During the first week of 70° F. to 100° diurnal rhythm, milk production declined by about 20 percent in the Holsteins and by about 8 percent in the Jerseys (decline associated with advanced stage of lactation would have been about 6 percent); feed consumption (TDN) declined 20 or 30 percent in the Holsteins but very little in the Jerseys. After about a week of 70° to 100° F. diurnal temperatures, there was some acclimatization with regard to feed consumption and milk production. The 40° to 110° F. appeared to have little effect; the 50° to 110° F. depressed the milk yield and feed intake but not to the extent it did during the 70° to 100° diurnal rhythm.

The effects of the 40° to 70° F. *diurnal rhythm* appear to be approximately the same on milk production and feed consumption as on *constant temperature* between 40° and 60° F.; the 70° to 100° F. *diurnal rhythm* appeared to be very roughly equivalent to 85° F. *constant temperature.* The small number of the animals and the individual variabilities make it difficult at this time to make more precise comparisons.

It is believed that the stressful effects of high diurnal temperatures are not only the result of the average and maximal and minimal temperatures, but also of the number of hours exposed to heating temperatures above 80° F. and cooling temperatures below 70° F.

REFERENCES

[1]For review of the literature on diurnal body-temperature rhythms, see Brody, S., *Bioenergetics and Growth*, pp. 232-42, New York, 1945; also Hutchinson, H. G., and Mabon, R. M., J. Agr. Sc. 44:121, 1954. Unpublished observations by H. J. Thompson in the Psychroenergetic Laboratory indicate that cows have a diurnal temperature rhythm even if housed at a constant temperature of about 65° F.

[2]For review of literature on seasonal variations in milk composition, see Brody, S., *Bioenergetics and Growth*, pp. 221-4, Reinhold, New York, 1945.

[3]Critical temperature refers to the approximate environmental temperature after which marked changes occur in the slopes of the physiological reactions of animals subjected to rising environmental temperature, Univ. Mo. Agr. Exp. Sta. Res. Bul. 515 (pages 21 and 22) gives a table of critical temperatures for various physiological reactions in cattle; p. 9, Res. Bul. 471 is a graph of critical temperatures for milk production and feed consumption; p. 15, Res. Bul. 435, p. 9, Res. Bul. 464 and p. 10 Res Bul. 473 indicate graphically the critical environmental temperatures for rectal temperature.

[4]Univ. Mo. Agr.. Expt. Sta. Res. Bul. 423, Sept. 1948, p. 24.

[5]Erdheim, M., personal communication, July 29, 1954.

[6]Macfarlane, W. V., Yeates, N.T.N., Moule, G. R., Robinson, K., and Klem, G., Pan Indian Ocean Science Congress Conference, Perth, W. A., 1954. See also: Yeates, J. Agr. Sc. 43:199, 1953. Moule, G. R., Austr. Vet. J. 30:153, 1954.

[7]Personal communication, Oct., 1954.

[8]Univ. Mo Agr. Expt. Sta. Res. Bul. 436, 1949, and 460, 1950.

APPENDIX

TABLE 3 -- WEEKLY AVERAGES FOR MILK PRODUCTION, LBS/DAY

Temperature Condition	Average Weekly Temp. °F.	Fall 1953					
		Holstein Cows			Jersey Cows		
		184	144	337	274	277	295
Adjustment (60°)	60	59.2	46.5	52.1	26.7	25.3	37.1
"Midwest Normal"	58	62.4	45.2	54.2	28.8	23.6	36.6
(40° to 70°)	54	64.4	44.7	54.7	27.1	23.0	35.0
	56	61.9	43.5	53.0	23.9	22.0	31.3
"Midwest Cold"	20	56.9	23.6*	51.3	21.9	18.2	33.0
(10° to 40°)	25	60.4	33.8	54.3	20.8	18.3	32.6
	26	56.9	34.8	54.1	21.1	17.7	32.5
Adjustment (60°)	64	53.1	36.0	55.8	22.3	19.5	33.5
"Midwest Hot"	85	40.5	31.0	43.5	19.9	18.9	31.1
(70° to 100°)	84	36.7	33.6	44.4	20.9	20.3	30.3
	84	33.9	33.1	41.5	21.9	20.0	30.7
Adjustment (60°)	65	38.4	37.5	47.0	23.5	21.4	31.4
"Imperial Valley"	66	45.7	37.4	48.1	20.4	20.6	30.1
(40° or 50° to 110°)	77	42.5	36.3	46.4	19.4	19.2	27.6
	79	39.4	35.8	43.0	20.0	18.3	26.7
Adjustment (60°)	64	41.7	36.2	45.8	20.5	20.0	26.3
		Spring 1954					
		Holstein Cows			Jersey Cows		
		184	144	178	274	564	295
Adjustment (60°)	60	47.2	37.3	31.7	20.2	16.1	28.1
"Midwest Cold"	30	45.0	38.6	31.5	19.1	15.8	27.9
(10° to 40°)	26	41.0	35.8	29.4	15.9	14.0	25.2
	24	42.0	34.3	26.2	14.8	13.7	23.6
	21	39.9	34.3	26.6	13.7	13.0	20.5
	21	38.4	32.7	26.8	13.0	12.8	**
Adjustment (10° to 70°)	37	38.3	30.8	24.7	13.6	13.5	
"Midwest Normal"	55	38.6	33.3	23.4	14.3	14.4	
(40° to 70°)	54	38.3	32.2	22.2	14.7	13.2	
	55	36.9	30.6	22.6	14.0	12.9	
	55	38.2	32.6	25.0	13.8	13.1	
	55	35.1	32.3	23.4	13.0	12.0	
"Imperial Valley"	81	30.4	28.0	16.3	12.3	10.1	
(60° to 110°)	84	**	23.9	16.1	12.0	8.5	
Adjustment (60°)	63		28.9	20.8	13.8	10.2	
"Midwest Hot"	84		30.6	19.6	13.2	8.6	
(70° to 100°)	84		28.5	18.9	13.0	6.7	
	84		27.8	19.1	12.6	**	

*Sick
**Removed from chamber.

TABLE 4 -- WEEKLY AVERAGES FOR BUTTERFAT, %

Temperature Condition	Average Weekly Temp. °F.	Fall 1953 Holstein Cows 184	Holstein Cows 144	Holstein Cows 337	Jersey Cows 274	Jersey Cows 277	Jersey Cows 295
Adjustment (60°)	60	3.2	3.2	3.0	6.3	5.3	6.4
"Midwest Normal"	58	2.8	2.8	3.0	5.0	4.9	5.7
(40° to 70°)	54	2.7	2.8	2.6	5.0	5.6	5.8
	56	2.7	3.3	2.7	5.4	5.3	5.4
"Midwest Cold"	20	2.9	3.4	2.9	5.4	6.4	5.8
(10° to 40°)	25	2.9	3.2	2.8	6.0	6.5	5.8
	26	2.7	3.5	2.8	5.8	6.0	5.8
Adjustment (60°)	64	2.8	3.2	2.9	5.6	5.9	5.5
"Midwest Hot"	85	3.2	3.2	2.9	5.2	5.5	4.8
(70° to 100°)	84	3.1	3.5	3.0	5.0	5.3	4.8
	84	3.4	3.3	3.0	5.2	5.0	4.9
Adjustment (60°)	65	3.3	3.2	2.9	4.6	4.8	5.0
"Imperial Valley"	66	3.0	3.0	3.0	5.0	4.9	4.9
(40° or 50° to 110°)	77	3.0	3.2	3.1	5.1	5.0	5.3
	79	3.2	3.4	2.7	5.1	4.9	5.2
Adjustment (60°)	64	3.2	3.3	2.9	5.5	5.5	6.0

Temperature Condition	Average Weekly Temp. °F.	Spring 1954 Holstein Cows 184	Holstein Cows 144	Holstein Cows 178	Jersey Cows 274	Jersey Cows 564	Jersey Cows 295
Adjustment (60°)	60	2.8	3.3	3.6	5.2	5.4	5.2
"Midwest Cold"	30	3.2	3.4	4.0	5.7	6.0	6.0
(10° to 40°)	26	2.8	3.6	3.4	5.9	5.7	5.8
	24	3.1	3.8	4.0	6.5	6.2	5.9
	21	2.8	3.8	4.1	6.0	6.1	7.6
	21	3.2	4.0	3.5	6.6	6.2	*
Adjustment (10° to 70°)	37	3.1	4.3	3.9	6.6	6.7	
"Midwest Normal"	55	2.9	3.7	3.6	5.7	6.0	
(40° to 70°)	54	3.0	3.9	3.7	6.2	6.4	
	55	3.0	3.5	3.7	5.5	5.8	
	55	2.8	3.2	3.2	5.3	6.5	
	55	2.8	3.4	3.4	5.7	5.6	
"Imperial Valley"	81	3.2	3.7	3.9	5.4	6.1	
(60° to 110°)	84	+	3.8	4.5	6.3	7.2	
Adjustment (60°)	63		3.4	3.7	5.0	6.4	
"Midwest Hot"	84		3.5	4.0	6.1	7.3	
(70° to 100°)	84		3.7	4.1	5.7	7.8	
	84		3.8	4.0	5.6		

*Jersey 295 was removed from chamber March 9.
+Holstein 184 was removed from chamber May 1, 9:30 a.m.

TABLE 5 -- WEEKLY AVERAGES FOR TDN CONSUMPTION, LBS/DAY
(Computed with the aid of F. B. Morrison's "Feeds and Feeding," 21st Ed., 1948)

Temperature Condition	Average Weekly Temp. °F.	Fall 1953 Holstein Cows 184	144	337	Jersey Cows 274	277	295
Adjustment (60°)	60	20.2	20.8	21.6	13.8	14.3	14.5
"Midwest Normal"	58	24.3	23.6	24.4	17.5	16.3	15.5
(40° to 70°)	54	23.9	23.5	24.4	14.3	14.9	14.4
	56	24.8	23.9	24.7	14.1	14.7	14.5
"Midwest Cold"	20	25.2	22.2	24.0	14.5	15.2	14.4
(10° to 40°)	25	23.2	20.8	22.8	13.4	12.6	14.3
	26	23.2	21.0	23.1	14.0	13.6	13.9
Adjustment (60°)	64	23.2	22.2	22.8	14.3	13.2	14.1
"Midwest Hot"	85	14.8	17.6	16.3	13.1	13.5	14.4
(70° to 100°)	84	16.6	18.9	19.8	14.7	13.7	15.4
	84	17.7	19.1	20.2	14.3	13.3	15.7
Adjustment (60°)	65	19.6	20.5	22.1	15.0	13.9	16.3
"Imperial Valley"	66	21.9	22.2	23.8	15.4	14.5	17.0
(40° or 50° to 110°)	77	21.0	21.8	23.7	14.2	14.1	15.0
	79	21.4	22.0	23.5	15.1	14.0	15.1
Adjustment (60°)	64	22.1	22.1	23.5	15.3	14.9	15.1

Temperature Condition	Average Weekly Temp. °F.	Spring 1954 Holstein Cows 184	144	178	Jersey Cows 274	564	295
Adjustment (60°)	60	22.2	22.0	22.8	15.3	15.2	15.4
"Midwest Cold"	30	22.2	22.2	22.9	14.9	15.2	15.3
(10° to 40°)	26	23.8	23.8	23.2	16.2	16.0	16.3
	24	24.8	25.0	23.9	16.5	16.9	16.8
	21	24.9	25.0	24.0	17.1	16.8	16.4
	21	24.9	24.9	23.7	17.1	16.9	*
Adjustment (10° to 70°)	37	24.9	24.8	23.8	17.4	17.8	
"Midwest Normal"	55	25.0	24.2	23.5	17.4	16.8	
(40° to 70°)	54	24.9	24.7	24.1	17.4	16.9	
	55	25.0	24.8	24.0	17.4	16.8	
	55	23.9	23.9	23.0	16.9	16.2	
	55	23.0	22.8	22.0	15.6	14.5	
"Imperial Valley"	81	19.5	18.9	17.8	13.7	12.0	
(60° to 110°)	84	+	17.8	16.6	12.8	11.3	
Adjustment (60°)	63		20.9	19.6	15.1	11.0	
"Midwest Hot"	84		21.3	18.8	14.8	7.6	
(70° to 100°)	84		20.8	19.4	14.9	8.0	
	84		20.2	19.1	14.9		

*Jersey 295 was removed from chamber March 9.
+Holstein 184 was removed from chamber May 1, 9:30 a.m.

TABLE 6 -- WEEKLY AVERAGES FOR BODY WEIGHT, LBS.

Temperature Condition	Average Weekly Temp. °F.	Fall 1953 Holstein Cows 184	144	337	Jersey Cows 274	277	295
Adjustment (60°)	60	1289	1277	1262	856	839	787
"Midwest Normal" (40° to 70°)	58	1287	1274	1258	855	842	771
	54	1293	1294	1268	843	847	756
	56	1285	1276	1260	853	840	741
"Midwest Cold" (10° to 40°)	20	1273	1271	1261	839	843	748
	25	1264	1280	1259	840	830	726
	26	1252	1275	1242	832	837	709
Adjustment (60°)	64	1260	1279	1236	840	836	718
"Midwest Hot" (70° to 100°)	85	1219	1229	1190	828	820	683
	84	1178	1241	1170	822	830	676
	84	1174	1240	1172	825	831	676
Adjustment (60°)	65	1192	1245	1204	844	812	682
"Imperial Valley" (40° or 50° to 110°)	66	1202	1235	1216	839	841	681
	77	1217	1275	1236	829	846	684
	79	1221	1263	1238	834	846	682
Adjustment (60°)	64	1214	1271	1251	848	847	689

Temperature Condition	Average Weekly Temp. °F.	Spring 1954 Holstein Cows 184	144	178	Jersey Cows 274	564	295
Adjustment (60°)	60	1191	1280	1311	840	867	698
"Midwest Cold" (10° to 40°)	30	1191	1275	1278	834	867	698
	26	1177	1287	1294	848	867	695
	24	1224	1302	1311	850	838	717
	21	1220	1304	1306	858	869	717
	21	1225	1321	1326	864	877	689
Adjustment (10° to 70°)	37	1233	1330	1330	868	893	*
"Midwest Normal" (40° to 70°)	55	1244	1330	1334	881	888	
	54	1246	1330	1323	879	901	
	55	1226	1331	1324	877	898	
	55	1273	1336	1340	887	907	
	55	1259	1330	1336	879	911	
"Imperial Valley" (60° to 110°)	81	1270	1349	1311	888	894	
	84	+	1328	1347	897	882	
Adjustment (60°)	63		1314	1330	895	866	
"Midwest Hot" (70° to 100°)	84		1334	1339	895	831	
	84		1321	1335	884	827	
	84		1338	1345	898		

*Jersey 295 was removed from chamber March 9.
+Holstein 184 was removed from chamber May 1, 9:30 a.m.

TABLE 7 -- WEEKLY AVERAGES FOR WATER CONSUMPTION, GALS/DAY

Temperature Condition	Average Weekly Temp. °F.	Fall 1953 Holstein Cows 184	144	337	Jersey Cows 274	277	295
"Midwest Normal"	58	20.3	19.9	21.3	12.0	12.1	11.7
(40° to 70°)	54	21.7	19.3	21.0	11.8	11.7	11.0
	56	22.5	20.0	21.7	12.3	12.3	12.2
"Midwest Cold"	20	20.5	15.5	19.9	11.8	12.3	12.7
(10° to 40°)	25	23.9	21.3	22.5	10.8	12.4	13.7
	26	21.6	19.9	21.8	11.1	11.4	11.4
Adjustment (60°)	64	23.8	21.4	25.5	13.6	12.9	16.1
"Midwest Hot"	85	19.0	17.6	20.9	13.4	13.4	15.5
(70° to 100°)	84	16.8	18.3	20.6	14.0	15.0	15.9
	84	17.2	19.5	21.4	14.6	13.8	17.2
Adjustment (60°)	65	18.4	19.5	21.3	13.9	14.0	15.4
"Imperial Valley"	66	20.9	19.8	22.1	13.4	13.3	15.4
(40° or 50° to 110°)	77	21.6	21.0	23.6	13.2	13.6	16.6
	79	20.7	20.2	21.7	14.4	13.2	16.4
Adjustment (60°)	64	18.2	19.8	20.8	13.0	12.8	15.2
		Spring 1954 Holstein Cows 184	144	178	Jersey Cows 274	564	295
Adjustment (60°)	60	20.1	20.8	20.5	12.5	12.6	14.6
"Midwest Cold"	30	18.4	18.2	17.6	10.9	12.4	14.0
(10° to 40°)	26	18.7	18.6	18.0	10.1	11.3	13.7
	24	20.3	20.2	18.0	10.0	12.5	14.3
	21	19.7	19.4	17.7	9.5	11.5	12.6
	21	19.0	20.0	18.6	9.4	11.3	*
Adjustment (10° to 70°)	37	21.4	21.8	18.8	10.2	11.9	
"Midwest Normal"	55	21.3	21.2	18.6	10.2	12.2	
(40° to 70°)	54	19.9	20.1	15.3	10.6	11.0	
	55	18.3	17.6	15.0	10.0	9.5	
	55	19.4	19.1	16.7	10.7	9.3	
	55	18.3	18.2	16.3	9.6	9.4	
"Imperial Valley"	81	19.2	18.3	15.6	12.3	13.9	
(60° to 110°)	84	+	16.4	15.9	12.2	16.5	
Adjustment (60°)	63		17.3	16.4	11.2	10.5	
"Midwest Hot"	84		22.0	19.8	14.0	10.0	
(70° to 100°)	84		19.3	16.9	12.8	5.9	
	84		19.1	17.4	12.4		

*Jersey 295 was removed from chamber March 9.
+Holstein 184 was removed from chamber May 1, 9:30 a.m.

TABLE 8 -- WEEKLY AVERAGES FOR TOTAL NUMBER OF DRINKS PER DAY

Temperature Condition	Average Weekly Temp. °F.	Fall 1953 Holstein Cows 184	144	337	Jersey Cows 274	277	295
"Midwest Normal"	58	11.8	13.0	17.0	10.4	7.3	11.6
(40° to 70°)	54	11.4	10.7	16.7	10.1	7.0	9.4
	56	10.4	9.7	16.8	10.3	6.7	11.4
"Midwest Cold"	20	11.3	11.8	16.4	11.0	6.7	9.0
(10° to 40°)	25	10.7	11.4	18.0	13.0	9.1	8.1
	26	10.7	10.6	18.3	12.7	10.2	9.6
Adjustment (60°)	64	13.4	10.8	21.4	13.3	10.1	12.0
"Midwest Hot"	85	13.3	14.7	22.1	18.0	11.7	12.7
(70° to 100°)	84	13.1	13.4	19.6	19.8	9.8	10.8
	84	12.4	14.1	22.4	16.8	10.1	11.4
Adjustment (60°)	65	10.7	11.0	16.3	12.0	10.5	11.0
"Imperial Valley"	66	10.7	11.4	16.4	14.3	8.1	10.3
(40° or 50° to 110°)	77	11.7	16.4	20.6	16.7	12.4	10.8
	79	13.4	16.8	20.0	16.8	10.7	10.4
Adjustment (60°)	64	9.0	12.0	19.0	12.6	10.7	11.0

Temperature Condition	Average Weekly Temp. °F.	Spring 1954 Holstein Cows 184	144	178	Jersey Cows 274	564	295
Adjustment (60°)	60	11.8	11.3	11.8	12.0	12.8	10.4
"Midwest Cold"	30	10.1	12.7	10.3	15.6	15.0	10.7
(10° to 40°)	26	10.0	12.8	11.3	14.1	13.6	9.0
	24	12.1	13.0	14.7	17.0	15.1	11.1
	21	13.7	16.3	12.3	15.1	15.1	8.8
	21	11.6	15.7	14.6	15.1	13.8	*
Adjustment (10° to 70°)	37	14.0	14.3	12.6	14.7	13.6	
"Midwest Normal"	55	11.6	13.7	13.0	11.6	13.1	
(40° to 70°)	54	11.1	13.3	9.6	10.8	11.3	
	55	11.3	12.4	7.0	11.0	9.8	
	55	10.8	12.3	8.6	10.8	10.7	
	55	10.1	10.4	7.3	9.0	9.4	
"Imperial Valley"	81	13.6	14.3	14.0	12.3	11.7	
(60° to 110°)	84	+	16.0	17.5	16.5	7.8	
Adjustment (60°)	63		12.3	10.2	11.3	12.5	
"Midwest Hot"	84		18.8	18.0	17.4	14.4	
(70° to 100°)	84		14.7	14.6	12.7	9.8	
	84		16.1	14.7	13.7		

*Jersey 295 was removed from chamber March 9.
+Holstein 184 was removed from chamber May 1, 9:30 a.m.