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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XXXVIII. INFLUENCE OF DIURNAL TEMPERATURE CYCLES ON HEAT PRODUCTION AND CARDIORESPIRATORY ACTIVITIES IN HOLSTEIN AND JERSEY COWS

H. H. KIBLER AND SAMUEL BRODY

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INTRODUCTION

The physiological adjustments of cattle to changes in weather reflect seasonal, diurnal, and variable changes in temperature, humidity, wind, and sunshine. Because of the interactions of these weather components it is impossible under field conditions to interpret the effects of change in any one component.

In early experiments* at the Psychroenergetic Laboratory, the attempt was made to isolate the effects of temperature from the other weather factors. Relative humidity, wind, and radiation were maintained at uniform levels, while temperature was varied from 0° to 105° F in steps of 5° to 10° F at 1 or 2-week intervals. Day and night temperatures were always the same. Under these artificially simplified conditions it was possible to avoid acclimatization effects due to sudden changes in temperature such as occur in nature. The resulting data were valuable for relating physiological response to different constant temperature levels.

In the present experiment attention was shifted to the effects of diurnal changes in temperature. Temperature was varied continuously in repetitive 24-hour cycles about a given mean daily value. During periods of 3 to 5 weeks the mean daily temperatures were controlled at about 25°, 55°, and 85° F with a diurnal range of 30° F at each condition. Maximal temperatures occurred between 3 and 4 p.m. and minimal temperatures occurred between 3 and 7 a.m. Such temperature diurnals occur in the midwest during the different seasons of the year. In other periods, the mean temperatures were maintained at 80° and 85° F and the diurnal ranges were increased to 50° and 60° F to simulate extreme day-to-night differences such as occur in some localities in the southwest of the United States.

The reactions of the experimental animals to the different diurnal temperature conditions are reported in this and other bulletins of this series.

*For bibliography of early bulletins in this series see p. 21 of Ref. 1.

This bulletin is concerned with indices of heat stress, with heat production, and with one component of heat loss. Data are presented on rectal temperature, respiration rate, pulmonary ventilation rate, pulse rate, heat production (by oxygen consumption), and heat loss by respiratory vaporization. The preceding experiments on the effects of constant temperature have demonstrated that these activities are related in varying degree to the heat and cold tolerance and productive level of cattle. It is hoped that these data will give further insight into the effects of diurnal temperature rhythms on the thermal response of Jersey and Holstein cattle.

METHODS

Animals: Two groups of lactating cows were used. Each group consisted of three Jerseys and three Holsteins ranging in age from 3½ to 8½ years. The A-group used in the Winter of 1953-54 was made up of high producing cows in early lactation which were subjected only to relatively infrequent external measurements. During the Spring of 1954, a second or B-group was formed by retaining two Jerseys and two Holsteins from the A-group and bringing in one of each breed from the Station herd. These animals in advanced stages of lactation were measured frequently and were subjected to radioiodine and dye injections and blood sampling. More complete data on the animals of both groups are given in a preceding bulletin.[2]

Environment: The diurnal temperature ranges employed in this experiment were outlined briefly in the introductory section and are summarized in Table 1. Further comments may be made, however, in regard to other environmental factors.

Air velocity over the animals was relatively constant at about ½ mile per hour. Grain and hay were fed twice a day. Electric lamps were turned on 12 hours a day. Relative humidity tended to decrease with increasing temperature and increase with decreasing temperature. As shown in Figures 1 and 3, the variations in range were rather small, 40 to 60 percent in six periods and 50 to 70 percent in two periods. Changes in vapor pressure, however, tended to vary in phase with temperature and were quite pronounced during the 50° to 110° F and 60° to 110° F diurnal temperature ranges. The effects of high temperatures were reinforced by the effects of high vapor pressure. Figure 2 shows that a similar relationship between vapor pressure and air temperature existed during preceding constant temperature experiments, making the diurnal and constant temperature data comparable for corresponding temperature ranges.

Apparatus and Procedures: Heat production rate was measured with an open-circuit respiratory exchange apparatus, employing laboratory chemical and electronic gas analyzers. The open-circuit apparatus was used also to measure respiratory vaporization by psychrometric and gravimetric meth-

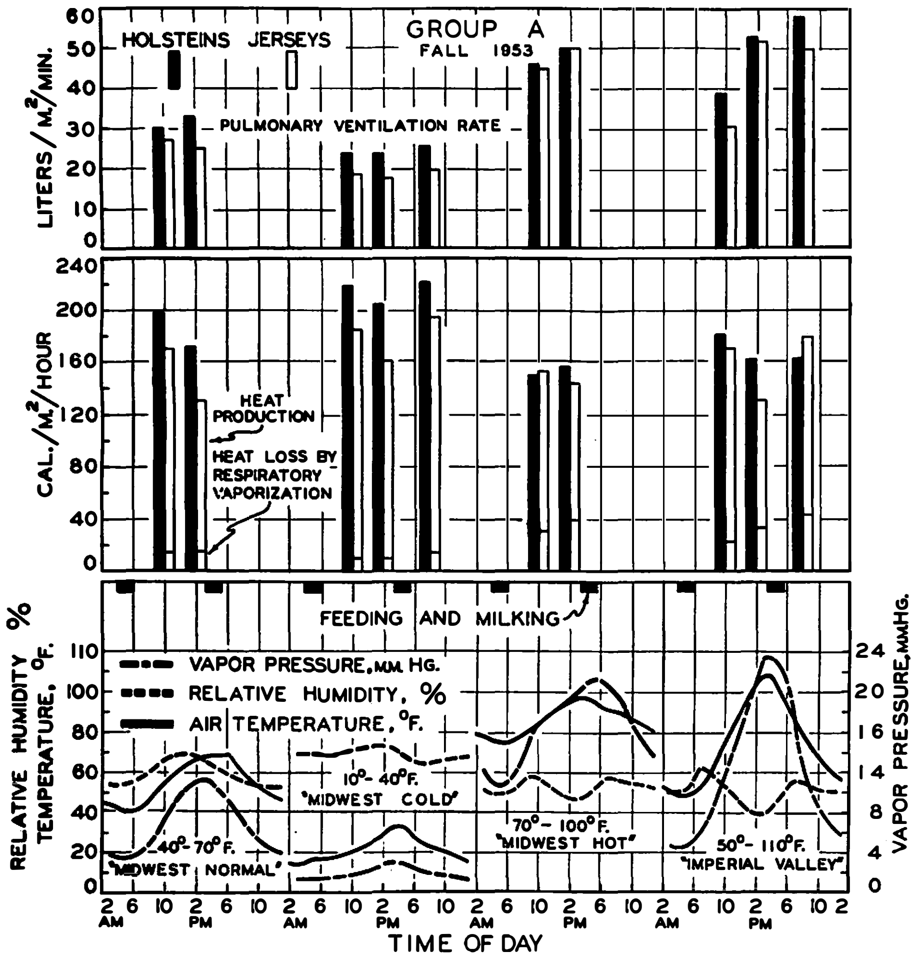

Fig. 1—Effects of diurnal changes in temperature and other environmental factors on heat production, pulmonary ventilation rate, and heat loss by respiratory vaporization in the cows of Group A, all related to time. The heights of the bars in the upper sections show the responses in these measures to the four diurnal changes shown in the bottom section. Each pair of black and white bars is centered over the time of measurement.

ods. In the psychrometric method, the exhaled air (warmed to about 100° F to prevent condensation) was blown over wet- and dry-bulb thermometers to determine its dewpoint temperature and moisture content. Simultaneous passage of metered, exhaled air through anhydrous calcium sulfate drying units gave a comparable gravimetric determination. Total vaporization was measured by a new method, reported in another bulletin.[3]

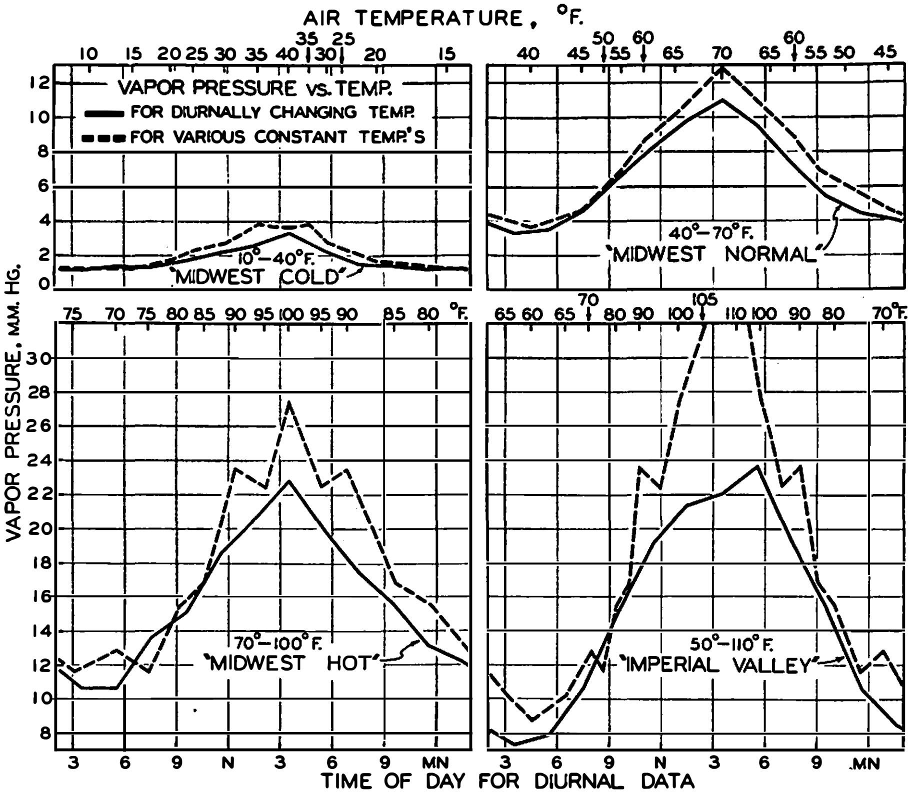

Fig. 2—Comparisons of vapor pressures during the present diurnal temperature experiments with vapor pressures duing preceding constant temperature experiments. As the relative humidity was nearly constant in all experiments, the vapor pressure tended to vary with temperature in all experiments. The physiological effects of high temperatures were, therefore, accentuated by accompanying high vapor pressures.

Respiration rate was determined by counting flank movements, pulse rate by the use of a stethoscope, rectal temperature by veterinary thermometer.

The methods used in controlling environmental factors during this experiment are described in another bulletin[4] of this series.

DATA AND DISCUSSION

While these experiments were primarily concerned with the effects of diurnal changes in temperature, other diurnal environmental factors were present as previously explained. The bottom sections of Figures 1 and 3 summarize the major environmental changes that occurred.

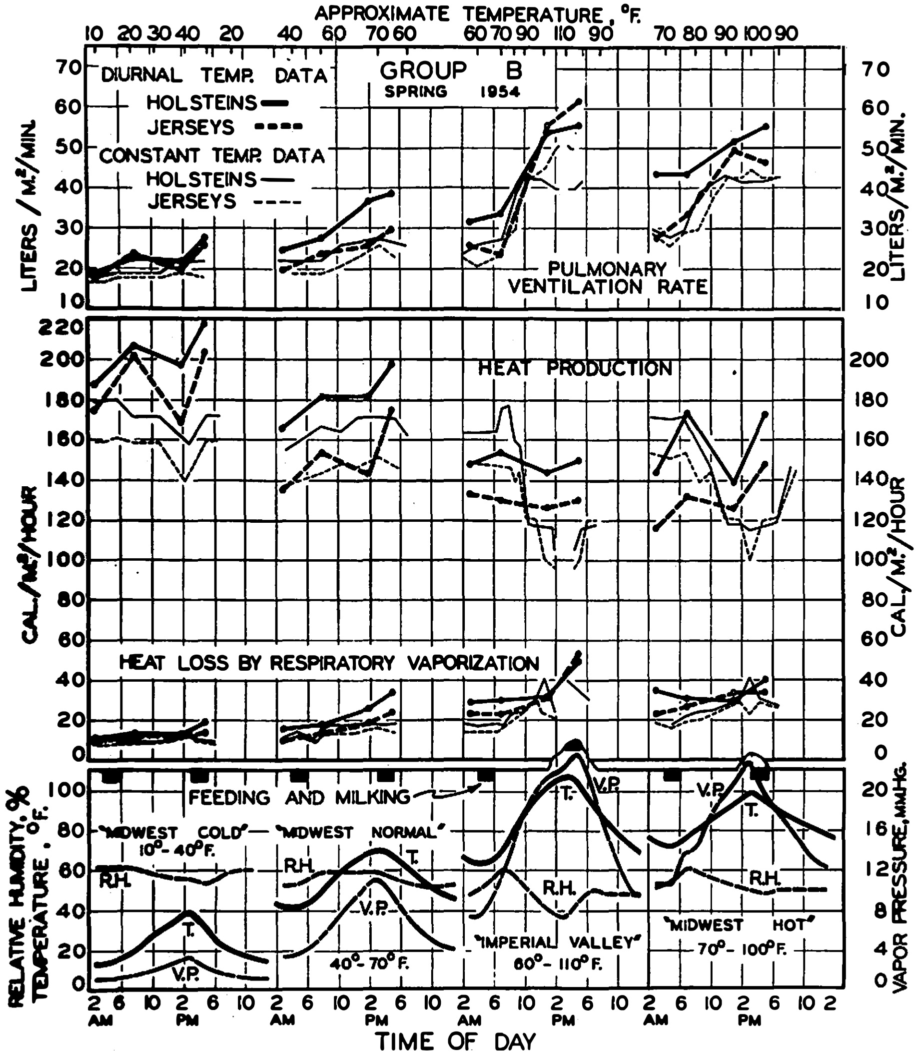

Fig. 3—Relative effects of diurnally cycling temperature and gradually progressing constant temperature on pulmonary ventilation, heat production, and heat loss by respiratory vaporization in the cows of group B. Data for the diurnal temperature experiments (heavy lines) are compared with data from preceding constant temperature experiments (light lines). The outstanding difference between the two sets of data appears in the heat production values for the 60° to 110° F temperature range. Heat Production was less depressed at 60° to 70° F and more depressed at 100° to 105° F when the ambient temperature was constant than when it was cycling through both these extremes every 24 hours. It appears that exposure to the 60° to 110° F diurnal temperature cycles affected these functions as though the animals were exposed to some intermediate constant temperature near 90° F.

The physiological data are summarized in Figures 1 and 3 to 11 and in Tables 2 to 5. They are closely interrelated but it is more convenient to discuss them in separate sections.

Heat Production, Pulmonary Ventilation Rate and Respiratory Vaporization: In the 10° to 40° F, 50° to 110° F, and 60° to 110° F periods, measurements were made before and after the afternoon feeding. At these two times, the air temperatures were nearly alike and were below the maximum temperature for the day.

Within the 10° to 40° F period, increases in the heat production, pulmonary ventilation rate, and respiratory vaporization after feeding presumably reflected feeding effects; the maximum air temperature, which occurred between measurements, was too low to cause heat stress.

During the 50° to 110° F and 60° to 110° F temperature cycles, the maximal air temperature occurred at the time of the afternoon feeding, increasing body temperature and depressing appetite. The differences that occurred in physiological response were probably more closely identified with increased body temperature than with feeding effects. Only irregular differences appeared in the heat production and pulmonary ventilation rate before and after feeding but respiratory vaporization was higher after feeding as shown in Figures 1 and 3.

Comparisons of measurements made after the morning feeding with those made before the afternoon feeding show that heat production usually was high after the morning feeding and decreased with rising ambient temperature and length of time after feeding. Pulmonary ventilation rate and respiratory vaporization rate increased during this period of decreasing heat production.

The cows reacted not only to the changes in temperature during each day but also to the different levels of mean daily temperature. Heat production was generally highest and pulmonary ventilation lowest during the 10° to 40° F periods. Pulmonary ventilation rate and respiratory vaporization rate were highest during the 50° to 110° F and 60° to 110° F periods.

The upper sections of Fig. 3 display two types of data. The heavy lines show the changes for the environmental conditions given in the bottom section. The light lines show the changes observed during previous constant temperature experiments in which temperature was varied from 0° to 105° F and measurements were made only between 1 and 3 p.m. The most striking contrast in the effects of the diurnally changing and gradually changing temperatures appears in the heat production data. When the temperature was increased from 60° to 110° F by increments of 5° to 10° F at 1 or 2-week intervals, heat production was depressed by 40 to 45 percent. When the temperature was changed rapidly (diurnally) from 60° to 110° F in 24 hours, the change in heat production was only about 5 percent.

The differences in response may be due to acclimatization. In preceding experiments, when the temperature was constant for long periods and the increases were in small steps, the animals became acclimatized to the new conditions. As the temperature increased above 80° F, feed consumption and milk production decreased, lowering the heat production. Studies by the radioiodine method[5] indicate a similar depression in thyroid activity with slowly increasing temperature at about 80° F. In the present experiment, however, when the temperature dropped to 60° F at night and rose to 110° F in the afternoon, the changes in temperature were too rapid for acclimatization except at some constant intermediate level corresponding to a temperature near 85° or 90° F.

During the 40° to 70° F temperature cycles, which were mostly in the thermoneutrality zone for lactating cattle, the heat production rate did not change appreciably whether the changes in temperature were gradual or diurnal in nature. Milk production and feed consumption were likewise relatively constant.[2].

Rectal Temperature: Figures 4 and 5 show the differences in the amplitude of the diurnal rectal temperature cycles at environmental temperatures above and below 70° F.

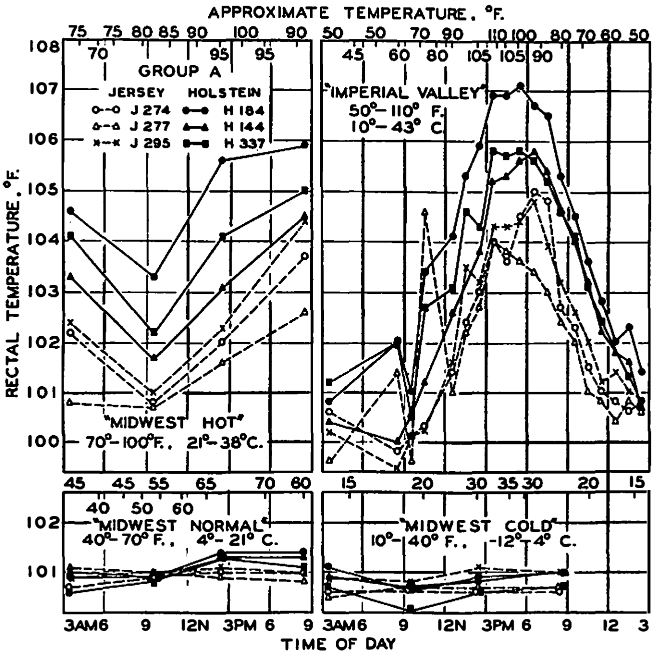

Fig. 4—Rectal temperatures in the individual cows of group A at different times during diurnal cycles in ambient temperature. When daytime temperatures did not exceed 70° F only minor changes occurred in rectal temperature. During the 70° to 100° F diurnal cycles, however, pronounced cycles in rectal temperature did occur, and breed differences in the amplitude of these cycles were quite evident.

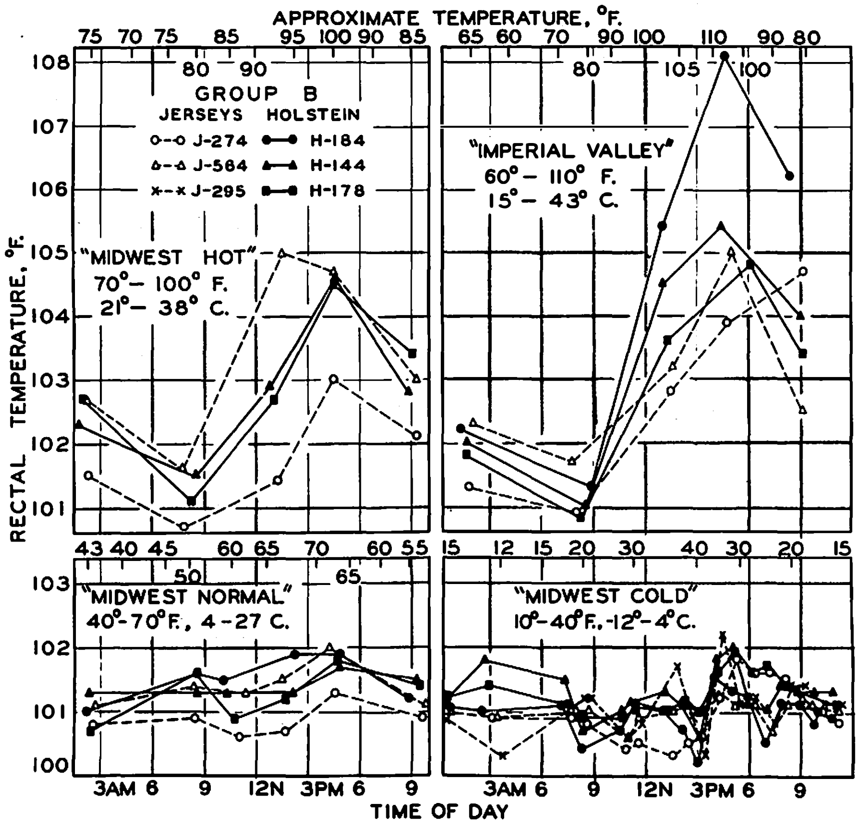

Fig. 5—Rectal temperatures in the individual cows of Group B at different times during diurnal cycles in ambient temperature. The more numerous measurements made on the Group B cows at low temperatures confirmed the results obtained on the high milking Group A cows. Below 70° F only minor changes occurred in rectal temperature. Above 70° F, increases in rectal temperature were general. Greater heat strain was experienced by the cows of this group during the 60° to 110° F diurnal condition than by the cows of the A-Group during the 50° to 110° F. condition. The distress of the B-group cows at 110° F is evident in Fig. 6. Low night-time temperatures are essential for the dissipation of body heat stored during hot days.

During the 10° to 40° F temperature periods, rectal temperatures were relatively constant, averaging about 101° F in the B-group and slightly lower in the A-group. There was a very slight rise between 3 and 6 p.m. and a slight fall between 8 a.m. and noon. A more definite cycle in rectal temperature occurred during the 40° to 70° F diurnal temperature periods. Values were highest between 2 and 5 p.m. and lowest during the morning. In neither diurnal period was the amplitude of the rectal temperature cycle greater than 2° F.

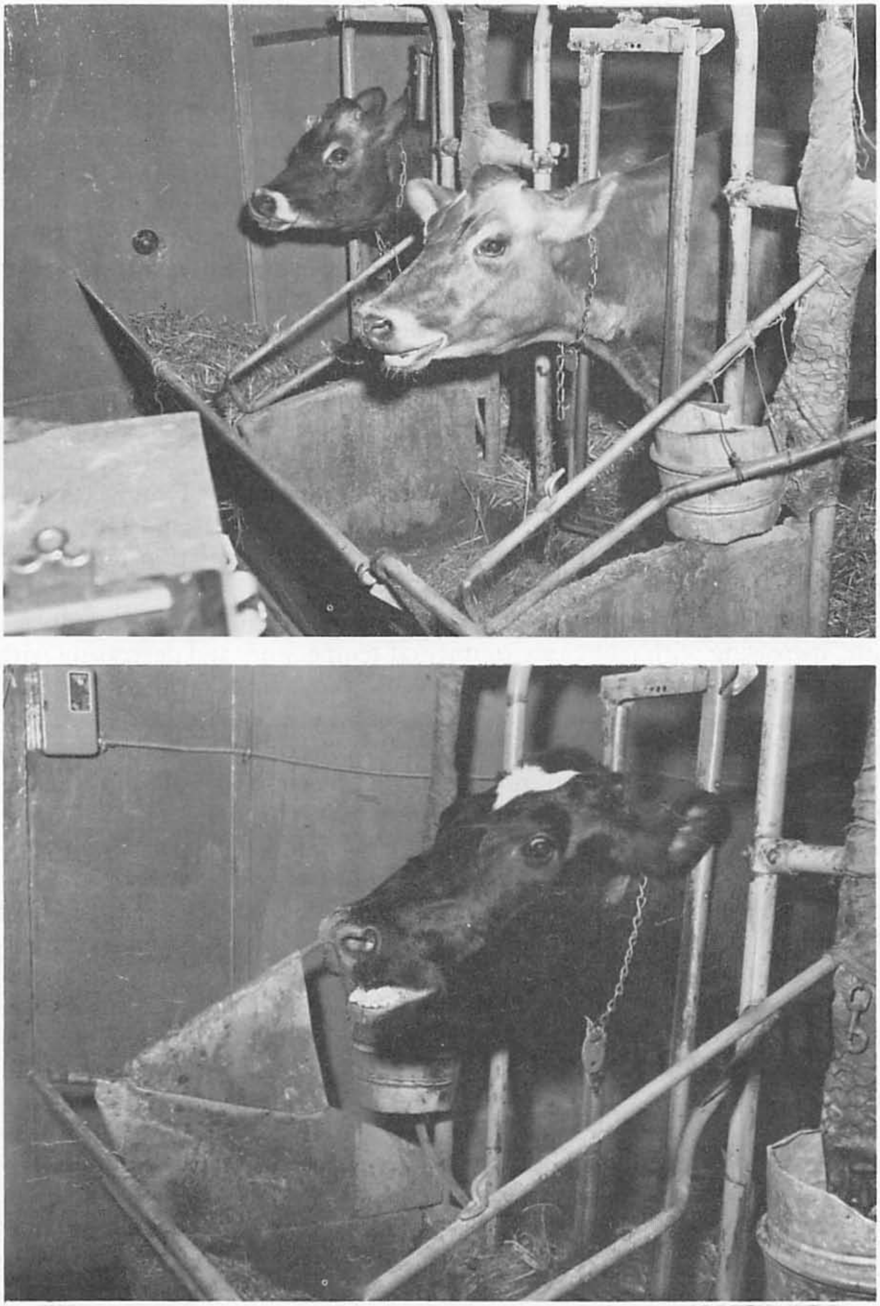

Fig. 6—Group B cows showing distress at 110° F during a 60° to 110° F temperature cycle.

The amplitudes of the rectal temperature cycles were much increased when the air temperature cycled from 70° F or lower to 100° or 110° F. Maximal increases above normal rectal temperature ranged from 2° to 4° F in the Jerseys and 3.5° to 7° F in the Holsteins. Decreases of 1° to 1.5° F below normal levels occurred in three Jerseys and one Holstein during the colder part of the 50° to 110° F period. During the 70° to 100° F temperature period, rectal temperatures fell no lower than 101.7° F to 103.3° F in the A-group Holsteins. Since this experimental period followed the 10° to 40° F temperature period, the change in average environmental temperature from 25° to 85° F may have been too great for rapid acclimatization. However, rectal temperatures below 101° F were observed in some of the Jerseys.

Respiration Rate: Figures 7 and 8 show that the sensitivity of respiration rate within diurnal temperature cycles varied with changes in ambient temperature level, with the diurnal range, and with breed or size. Although respiration rate was insensitive to temperature reductions between 10° to 40° F, it became moderately sensitive between 40° and 70° F, and extremely sensitive between 70° and 100° F, 60° and 110° F, and 50° and 110° F. For the 50° to 110° F diurnal temperature period, the respiration rate cycled from 35 to 155 in the Jerseys and from 50 to 125 in the Holsteins.

Pulse Rate: Figures 9 and 10 show that pulse rate followed temperature, increasing with rising environmental temperature and decreasing with falling temperature. The sensitivity of pulse rate to diurnal change did not appear to be dependent on temperature level or breed. Pulse rate also showed a tendency to rise after feeding and fall between feedings. Large differences in pulse rates between individual animals, and random fluctuations blurred the sharpness of the diurnal pattern.

Heat Storage and Body Size: Figure 11 shows that rectal temperature lagged behind ambient temperature but was otherwise closely correlated. This time-lag was obviously related to the heat storage capacity of the animal body. During the 50° to 110° F diurnal change in ambient temperature shown in Figure 11, the maximal daily excursions in rectal temperature were 5.4° F in the Holsteins and 4.3° F in the Jerseys. The greater change in rectal temperature in the 1300-pound Holsteins than in the 850-pound Jerseys does not necessarily discredit the heat storage concept. Heat storage is proportional to average body temperature rather than rectal temperature, and it is possible that the greater change in average body temperature occurred in the smaller animals. Skin temperatures were found to vary as much as 26° F in the Jerseys but only 14° F in the Holsteins.**

The advantage of great heat storage capacity of the large animal may be offset by other factors. Heat dissipation is a function of surface area.

**Unpublished data by R. E. Stewart. Details will be published in a research bulletin of this series.

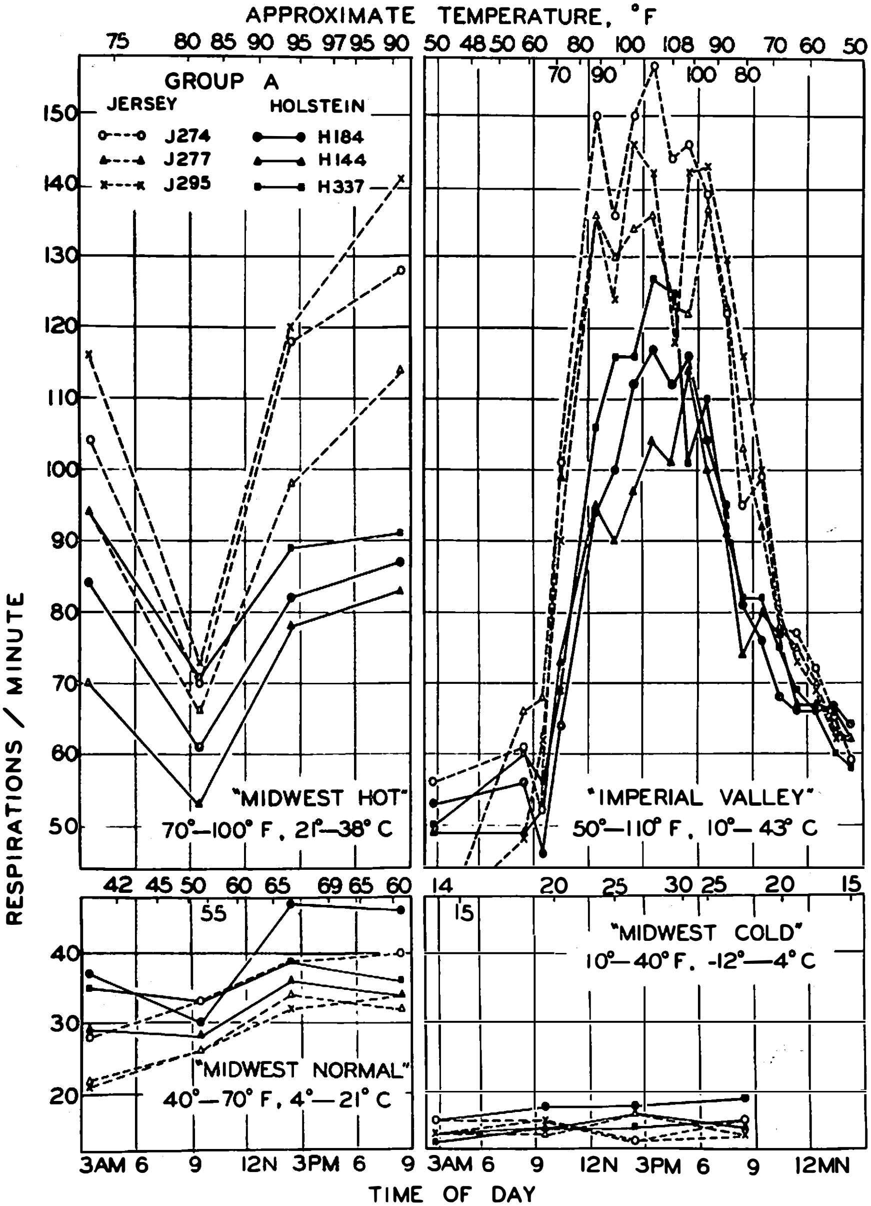

Fig. 7—Respiration rates in the individual cows of Group A were affected by all except the 10° to 40° F diurnal temperature cycles. Maximum rates were attained during the 50° to 110° F cycles. It is perhaps significant in regard to body temperature regulation, that the rise in respiration rate was greater in the small Jerseys than in the large Holsteins, whereas the rise in rectal temperature (Fig. 3 and 4) was greater in Holsteins than in Jerseys. This inverse relationship between respiration rate and rectal temperature does not seem to hold for the animals of different size within breeds.

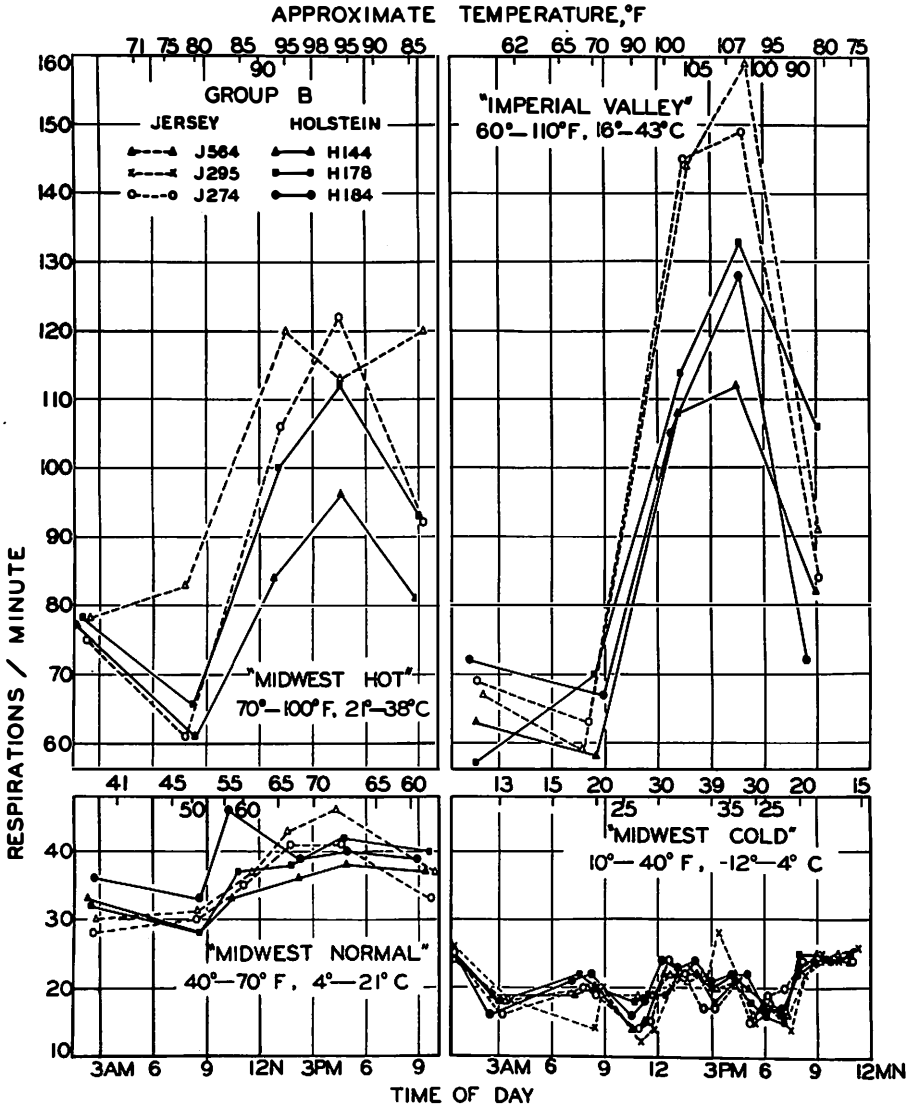

Fig. 8—Respiration rates in the individual cows of Group B during diurnal cycles in ambient temperature. It is interesting that the respiration rates reached much higher levels in the Jerseys during the 60° to 110° F cycles than during the 70° to 100° F cycles although the rectal temperatures were about the same.

Therefore, an animal that produces a great amount of heat per unit area is at a disadvantage in maintaining heat balance. During the 50° to 110° F cycles, the average heat production in Cal/m^2/hr was 170 in the Holsteins compared to 162 in the Jerseys. The greater productivity of the Holsteins may have accounted for this difference. Milk production in kg/m^2/day was

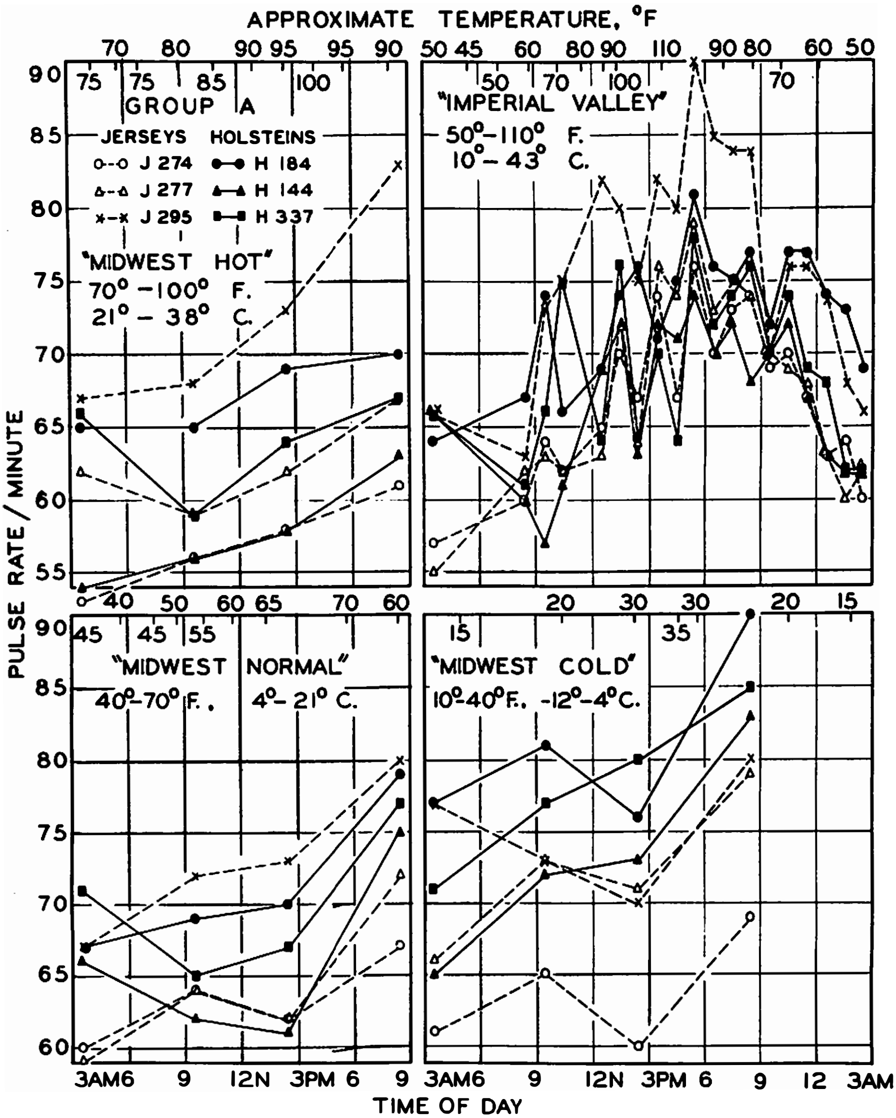

Fig. 9—Pulse rates in the individual cows of Group A during diurnal cycles in ambient temperature. This chart summarizes more than 600 observations omitted from the tables because of space limitations. The hourly data for the 50° to 110° F diurnal cycle show a definite cycle in pulse rate. More complete data for the low temperature cycles were obtained on the Group B animals shown in Fig. 10.

3.6 in the Holsteins, 2.5 in the Jerseys. Feed consumption in kg/m²/day TDN was 1.95 in the Holsteins, 1.68 in the Jerseys.†

†The data on milk production and feed consumption were computed from Tables 3 and 5 of Ref. 2. On a fat-corrected basis, the milk production per unit surface area was the same in both breeds during the 60° to 110° F diurnal cycles.

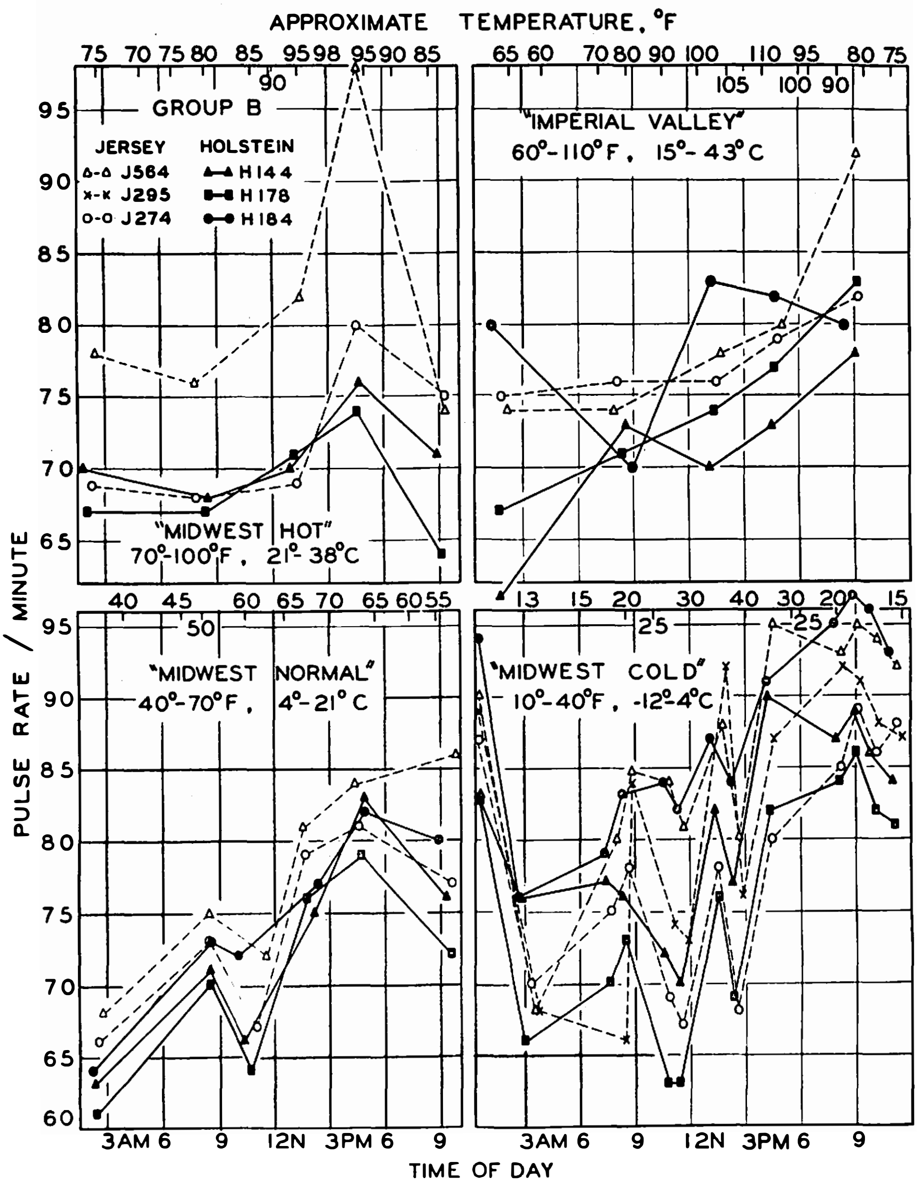

Fig. 10—Pulse rates in the individual cows of Group B during diurnal cycles in ambient temperature. Like Fig. 9, this chart summarizes a large body of data omitted from the tables. Figs. 9 and 10 show that pulse rates were generally lowest from 2 a.m. to 9 a.m. and were highest from 3 p.m. to 9 p.m.

High respiration rates in the Jerseys, as shown in the bottom section of Figure 10, may have aided in increasing evaporative cooling from the respiratory tract and oral surfaces. Figure 1 does not show greater respiratory vaporization per unit surface area in the Jerseys than Holsteins but the

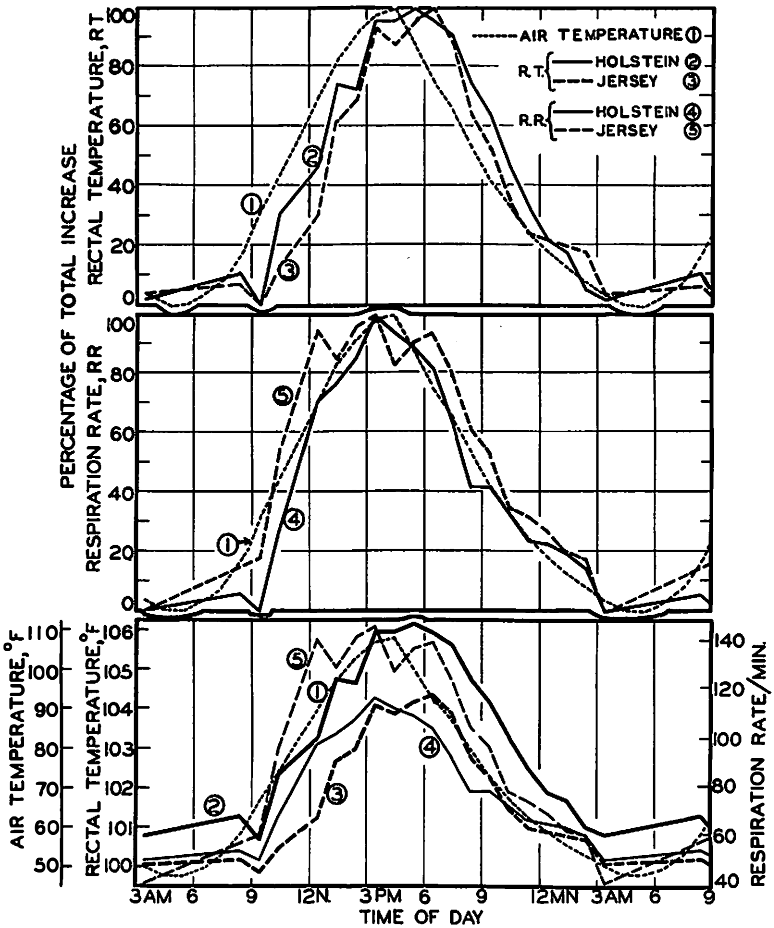

Fig. 11—Rectal temperature and respiration rate by breed averages relative to 50° to 100° F diurnal cycles in ambient temperature for the cows of Group A. The bottom section shows the absolute changes in these functions. The two upper sections compare their phase relations. The top section, for example, shows that ambient temperature reached 40 percent of its 60° F rise by 10:20 a.m. but that rectal temperature did not make a comparable 40 percent rise until 11:35 a.m. in the Holsteins and 12:45 p.m. in the Jerseys. Rectal temperature, therefore, lagged behind rising ambient temperature by 1 hour and 15 minutes in the Holsteins and by 2 hours and 25 minutes in the Jerseys at the 40 percent level. During falling ambient temperature, however, the lag was greater in the Holsteins than Jerseys. Respiration rate, on the other hand, rose more rapidly in the Jerseys than Holsteins with increasing ambient temperature but fell more slowly in the Jerseys than Holsteins with decreasing ambient temperature. It appears that the high respiration rates in the Jerseys may have increased their respiratory evaporative cooling and so have aided them in holding their rectal temperatures below those of the Holsteins.

measurements were probably affected by the use of a mask. Free respiration rates were higher in the Jerseys than Holsteins at high temperatures by about 30 respirations per minute. During the respiratory vaporization measurements with a mask, however, this margin was decreased to 15. It, therefore, seems probable that respiratory vaporization per unit of surface area was greater in the Jerseys than Holsteins at high ambient temperatures except during the brief periods of measurements using a mask. The middle section of Figure 11 shows that respiration rates not only rose to higher levels in the Jerseys than Holsteins but also more rapidly with increasing ambient temperature and fell more slowly with decreasing ambient temperature.

In brief, it appears that the smaller change in rectal temperature in Jerseys than in Holsteins exposed to the same 50° to 110° F diurnal ambient temperatures can be explained as follows: (1) heat production per unit surface area was slightly lower in the Jerseys than in the Holsteins; (2) the apparent heat storage capacity of the smaller Jerseys was increased by greater peripheral cooling during cool periods in the temperature cycles; and (3) higher respiration rates probably increased respiratory evaporative cooling more in the Jerseys than Holsteins.

SUMMARY

Two groups of six Jerseys and six Holstein cows, all lactating, were exposed to diurnal temperature cycles of the following amplitudes; 10° to 40°, 40° to 70°, 70° to 100°, 50° to 110°, and 60° to 110° F; and to vapor pressures ranging from 1 to 25 mm Hg. Data were obtained for corresponding diurnal changes in heat production, respiration rate, pulmonary ventilation rate, pulse rate, rectal temperature, and respiratory vaporization.

Heat production appeared to be adjusted to the mean temperature within a given diurnal cycle, but it also was influenced by acclimatization effects. Heat production was highest during the 10° to 40° diurnal cycle and was depressed during the higher temperature cycles. Peak values were reached twice a day after the morning and afternoon feedings. Flattening of the afternoon peaks occurred during the 50° to 110° F and 60° to 110° F cycles because of reduced afternoon feed consumption and a tendency on the part of the cows to defer much of their feeding until the cool early morning hours.

Respiratory vaporization proved to be an important means of heat dissipation at high temperatures. At the low point of the 10° to 40° F temperature cycle, only about 6 percent of the heat produced was dissipated by this method, but at the high points of the 50° to 110° and 60° to 110° F cycles, as much as 35 percent of the heat produced was dissipated by respiratory vaporization. Generally speaking, the ratio of the heat loss by respiratory vaporization to heat production tended to increase with temperature and with feeding.

Pulmonary ventilation rate and respiration rate, which are related to the respiratory evaporative heat dissipation function, likewise cycled with the ambient temperature rhythm. Within diurnal cycles, pulmonary ventilation rate increased with temperature and feeding but never more than two-fold in the Holsteins or three-fold in the Jerseys. Respiration rate per minute was not affected by the 10° to 40° cycles but increased with rising temperature from 35 to 155 in the Jerseys and from 50 to 125 in the Holsteins during the 50° to 110° F cycles.

Pulse rate tended to increase with rising temperature and feeding and to decrease with falling temperature and between feeding. Diurnal patterns were confused because of random fluctuations and individual differences.

Rectal temperatures varied less than 2° F during the 10° to 40° and 40° to 70° F diurnal temperature cycles. Increases in rectal temperature of 2° to 4° F in the Jerseys and 3.5 to 7° F in the Holsteins occurred during the 70° to 100°, 50° to 110°, and 60° to 110° F diurnal cycles. Decreases of 1° to 1.5° F below normal occurred in two Jerseys and one Holstein during the coldest part of the 50° to 110° F diurnal cycle.

Although rectal temperature and respiration rate generally followed the cyclic pattern of the diurnally changing ambient temperature, varying time-lags appeared in their responses. During the 50° to 110° F diurnal cycles, the rise in rectal temperature lagged behind that in ambient temperature by 1 to 2 hours in the Holsteins and by 2 to 3 hours in the Jerseys. The fall in rectal temperature to normal levels with decreasing ambient temperature required about 9 hours in the Holsteins but only 5 hours in the Jerseys. Respiration rate, on the other hand, rose more rapidly and fell more slowly in the Jerseys than in the Holsteins.

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APPENDIX TABLES

TABLE 1 -- SCHEDULE OF TESTS AND EXPERIMENTAL CONDITIONS

Daily Temperature Range °F	Average Relative Humidity %	Period Dates	Measurements Made on Each Cow: Heat Production Time	No. of Obs.	Cardio-respiratory Time	No. of Obs.
		Group A: Oct. 15, 1953-Jan. 21, 1954 (3 Jerseys & 3 Holsteins, all lactating)				
40°-70°	59	Oct. 15-Nov. 5	9-11 A.M.	3	3 A.M.	3
			1-3 P.M.	3	9 A.M.	8
					2 P.M.	8
					8 P.M.	6
10°-40°	69	Nov. 5-Nov. 26	9-11 A.M.	2	3 A.M.	3
			1-3 P.M.	2	9 A.M.	6
			7-9 P.M.	1	2 P.M.	4
					8 P.M.	6
70°-100°	52	Dec. 3-Dec. 24	9-11 A.M.	3	3 A.M.	2
			1-3 P.M.	3	9 A.M.	6
					2 P.M.	6
					8 P.M.	5
50°-110°*	48	Dec. 31-Jan. 21	9-11 A.M.	2	Spaced	
			1-3 P.M.	3	Over 24	55
			7-9 P.M.	1	Hours	
		Group B: Feb. 5, 1954-May 12, 1954 (3 Jerseys & 3 Holsteins, all lactating)				
10°-40°	59	Feb. 5-Mar. 11	2-4 A.M.	2	Several	
			7-9 A.M.	2	each	52
			1-3 P.M.	3	24 Hours	
			4-6 P.M.	3		
40°-70°	56	Mar. 18-Apr. 22**	2-4 A.M.	2	Several	
			7-9 A.M.	2	each	38
			1-3 P.M.	3	24 Hours	
			4-6 P.M.	3		
60°-110°	50	Apr. 22-May 13†	2-4 A.M.	1	Several	
			7-9 A.M.	1	each	22
			12-2 P.M.	2	24 Hours	
			5-6 P.M.	2		
70°-100°	52	May 13-June 3	2-4 A.M.	2	Several	
			7-9 A.M.	2	each	23
			1-2 P.M.	2	24 Hours	
			5-6 P.M.	2		

*40°-105°F during first week, 50°-110°F during second and third weeks.

**From March 11 to 18, room temperature was brought up to 70°F.

†Room temperature was held at 60°F from May 7 to 12 because of the poor condition of the animals.

TABLE 2 -- EFFECTS OF DIURNAL TEMPERATURE CHANGES ON RESPIRATORY EXCHANGE MEASUREMENTS IN HOLSTEIN AND JERSEY COWS
(Oct. 5, 1953--Jan. 21, 1954)

Diurnal Temperature Range °F	Time of Day	Dry Bulb Temperature °F	Vapor Pressure mm Hg	Holstein			Jersey			Holstein			Jersey		
				184	144	337	274	277	295	184	144	337	274	277	295
				Heat Production, Cal/hr.						Heat Production, Cal/m^2/hr.					
40°-70°	9-11 A.M.	53-58	6-7	1132	990	972	764	718	646	213	187	185	181	171	164
	1-3 P.M.	64-67	10-11	988	850	938	704	630	598	186	160	179	167	150	152
10°-40°	9-11 A.M.	18-19	1-2	1155	1137	1167	720	843	708	220	215	223	172	202	183
	1-3 P.M.	32-33	3-4	1095	1116	1080	663	744	657	208	211	206	159	178	170
	7-9 P.M.	28-32	2-3	1260	1188	1176	768	870	744	240	225	225	184	208	193
70°-100°	9-11 A.M.	82-84	15-17	764	762	786	596	606	632	150	147	156	144	146	170
	1-3 P.M.	92-95	17-19	862	750	800	628	488	600	170	144	158	152	118	162
50°-110°	9-11 A.M.	63-68	8-10	975	933	927	678	681	705	190	178	179	163	162	189
	1-3 P.M.	99-102	19-20	866	836	834	552	496	576	169	159	161	132	118	155
	7-9 P.M.	78-85	11-15	840	834	876	588	798	786	163	159	169	141	190	211
				Oxygen Consumption. lit/hr.*						Carbon Dioxide Production, lit/hr.*					
40°-70°	9-11 A.M.	53-58	6-7	227	199	193	151	143	129	226	223	194	161	140	162
	1-3 P.M.	64-67	10-11	197	169	187	140	125	119	214	175	193	140	125	122
10°-40°	9-11 A.M.	18-19	1-2	229	226	232	142	168	140	257	241	260	157	179	149
	1-3 P.M.	32-33	3-4	218	222	214	132	149	131	211	216	238	131	149	142
	7-9 P.M.	28-32	2-3	250	235	233	152	174	147	291	240	260	165	169	154
70°-100°	9-11 A.M.	82-84	15-17	153	151	156	119	121	127	147	155	167	119	130	127
	1-3 P.M.	92-95	17-19	176	149	158	127	98	120	152	164	173	118	102	119
50°-110°	9-11 A.M.	63-68	8-10	193	185	184	136	137	139	202	190	234	154	130	149
	1-3 P.M.	99-102	19-20	173	166	167	110	100	115	168	168	176	112	97	115
	7-9 P.M.	78-85	11-15	167	166	173	118	158	156	200	193	212	112	164	185
				Methane Production, lit/hr.*						Pulmonary Ventilation Rate, lit/min.*					
40°-70°	9-11 A.M.	53-58	6-7	15	21	17	16	8	8	170	159	151	115	110	107
	1-3 P.M.	64-67	10-11	28	14	11	11	14	7	194	161	168	108	100	93
10°-40°	9-11 A.M.	18-19	1-2	23	24	25	14	14	17	136	112	136	81	88	66
	1-3 P.M.	32-33	3-4	14	22	28	11	12	16	131	117	134	76	74	68
	7-9 P.M.	28-32	2-3	35	9	26	16	11	13	142	116	144	80	94	73
70°-100°	9-11 A.M.	82-84	15-17	10	10	16	7	12	12	230	239	243	172	183	178
	1-3 P.M.	92-95	17-19	10	19	22	9	7	8	230	268	268	203	194	205
50°-110°	9-11 A.M.	63-68	8-10	13	12	33	15	4	17	183	204	216	126	142	112
	1-3 P.M.	99-102	19-20	12	12	17	8	5	8	261	279	286	208	202	214
	7-9 P.M.	78-85	11-15	27	8	37	6	23	29	303	287	311	207	159	226

*Gas values were corrected to dry STP (0°C, 760 mm Hg) conditions.

TABLE 3 -- INFLUENCE OF DIURNAL TEMPERATURE CYCLES ON EVAPORATIVE COOLING FROM THE RESPIRATORY TRACT IN JERSEY AND HOLSTEIN COWS
(Oct. 1953--Jan. 1954)

Diurnal Temperature Range °F	Time of Day	Before or After Feeding	Dry Bulb Temperature °F	Relative Humidity %	Vapor Pressure mm Hg	Body Weight Lb.	Evaporative Rate From the Respiratory Tract: Weight Loss/Hour gm/cow	gm/m²	Heat Dissipation/Hour Cal/cow	Cal/m²	Relative to heat Production %
					Holstein 184						
40°-70°	9-11 A.M.	A	53	62	6.33	1288	195	37	113	21	10
	1-3 P.M.	B	64	65	9.82		237	45	137	26	14
10°-30°	9-11 A.M.	A	18	73	1.73	1263	126	24	73	14	6
	1-3 P.M.	B	32	76	3.47		146	28	85	16	8
	7-9 P.M.	A	32	60	2.74		188	36	109	21	9
70°-100°	9-11 A.M.	A	82	56	15.5	1190	280	55	162	32	21
	1-3 P.M.	B	92	46	17.5		331	65	192	38	22
50°-110°	9-11 A.M.	A	63	59	8.62	1213	238	46	138	27	14
	1-3 P.M.	B	99	40	18.9		349	68	202	39	23
	7-9 P.M.	A	85	48	14.6		483	94	280	55	33
					Holstein 144						
40°-70°	9-11 A.M.	A	55	60	6.03	1281	191	36	111	21	11
	1-3 P.M.	B	65	69	10.2		173	33	100	19	12
10°-30°	9-11 A.M.	A	18	72	1.71	1275	104	20	60	12	5
	1-3 P.M.	B	32	74	3.38		132	25	77	14	7
	7-9 P.M.	A	31	60	2.62		117	22	68	13	6
70°-100°	9-11 A.M.	A	82	57	15.8	1237	314	60	182	35	24
	1-3 P.M.	B	92	45	17.1		387	75	224	44	30
50°-110°	9-11 A.M.	A	64	58	8.96	1258	290	55	168	32	18
	1-3 P.M.	B	100	40	19.5		335	64	194	37	23
	7-9 P.M.	A	83	47	13.5		464	88	269	51	32
					Holstein 337						
40°-70°	9-11 A.M.	A	57	60	7.09	1262	159	30	92	17	9
	1-3 P.M.	B	66	66	10.7		204	39	118	23	13
10°-30°	9-11 A.M.	A	19	71	1.77	1254	126	24	73	14	6
	1-3 P.M.	B	32	71	3.25		159	30	92	17	9
	7-9 P.M.	A	31	60	2.62		148	28	86	16	7
70°-100°	9-11 A.M.	A	83	59	16.9	1177	283	56	164	32	21
	1-3 P.M.	B	93	44	17.3		392	78	227	45	28
50°-110°	9-11 A.M.	A	65	58	9.07	1230	286	55	166	32	18
	1-3 P.M.	B	100	40	19.5		310	60	180	35	22
	7-9 P.M.	A	82	48	13.3		490	95	284	55	32

					Jersey 274						
40°-70°	9-11 A.M.	A	58	58	7.10	850	118	28	68	16	9
	1-3 P.M.	B	66	67	10.7		118	28	68	16	10
10°-30°	9-11 A.M.	A	18	68	1.61	837	73	17	42	10	6
	1-3 P.M.	B	32	71	3.25		78	19	45	11	7
	7-9 P.M.	A	30	60	2.50		78	19	45	11	6
70°-100°	9-11 A.M.	A	84	59	17.4	825	198	48	115	28	19
	1-3 P.M.	B	94	45	18.2		278	67	161	39	26
50°-110°	9-11 A.M.	A	66	58	9.40	834	160	38	93	22	14
	1-3 P.M.	B	101	38	19.1		233	56	135	32	24
	7-9 P.M.	A	80	45	11.7		318	76	184	44	31
					Jersey 277						
40°-70°	9-11 A.M.	A	57	59	6.97	843	106	25	61	14	8
	1-3 P.M.	B	66	68	11.0		104	25	60	14	10
10°-30°	9-11 A.M.	A	19	68	1.69	837	76	18	44	10	5
	1-3 P.M.	B	32	71	3.25		70	17	41	10	6
	7-9 P.M.	A	29	57	2.27		90	22	52	13	6
70°-100°	9-11 A.M.	A	84	57	16.8	827	212	51	123	30	20
	1-3 P.M.	B	95	45	18.8		251	61	146	35	30
50°-110°	9-11 A.M.	A	67	57	9.57	844	170	41	99	24	15
	1-3 P.M.	B	102	38	19.6		196	47	114	27	23
	7-9 P.M.	A	78	46	11.2		246	59	143	34	18
					Jersey 295						
40°-70°	9-11 A.M.	A	58	59	7.23	756	100	25	58	14	9
	1-3 P.M.	B	67	65	10.9		98	25	57	14	10
10°-30°	9-11 A.M.	A	19	68	1.69	728	58	15	34	9	5
	1-3 P.M.	B	33	70	3.32		71	18	41	10	6
	7-9 P.M.	A	28	56	2.13		73	19	42	11	6
70°-100°	9-11 A.M.	A	84	58	17.1	678	225	61	130	35	21
	1-3 P.M.	B	95	45	18.8		291	78	169	45	28
50°-110°	9-11 A.M.	A	68	57	9.90	682	144	39	84	23	12
	1-3 P.M.	B	102	38	19.6		227	61	132	35	23
	7-9 P.M.	A	78	46	11.2		350	94	203	54	26

TABLE 4 -- EFFECTS OF DIURNAL TEMPERATURE CHANGES ON RESPIRATORY EXCHANGE MEASUREMENTS IN HOLSTEIN AND JERSEY COWS
(Feb. 5, 1954--May 12, 1954)

Diurnal Temperature Range °F	Time of Day	Dry Bulb Temperature °F	Vapor Pressure mm Hg	Holstein			Jersey			Holstein			Jersey		
				184*	144	178	274	564	295	184	144	178	274	564	295**
				Heat Production, Cal/ r.						Heat Production, Cal/m2/ r.					
10°-40°	2-4 A.M.	10-12	1-2	1014	1014	948	688	624	810	198	190	177	164	147	214
	7-9 A.M.	15-20	1-2	1112	1104	1060	704	821	925	217	207	198	168	193	244
	1-3 P.M.	36-39	3-4	1068	1038	1019	727	662	670	208	194	191	173	156	177
	4-6 P.M.	38-39	3-4	1166	1167	1119	829	809	849	227	219	209	198	190	224
40°-70°	2-4 A.M.	42-43	3-4	893	896	870	574	594	---	171	165	161	134	136	---
	7-9 A.M.	45-48	4-6	997	966	966	722	609	---	191	178	178	168	140	---
	1-3 P.M.	66-67	9-10	1061	933	922	658	577	---	203	172	170	153	133	---
	4-6 P.M.	67-69	8-10	1052	1024	1108	748	768	---	201	189	205	174	176	---
60°-110°	2-4 A.M.	61-63	5-7	---	738	864	636	516	---	---	136	161	147	119	---
	7-9 A.M.	67-70	9-11	---	858	804	582	540	---	---	158	150	135	125	---
	12-2 P.M.	92-101	22-26	870	747	690	597	492	---	165	138	129	138	114	---
	5-7 P.M.	100-103	21-23	786	768	866	645	483	---	149	141	161	149	112	---
70°-100°	2-4 A.M.	72-73	10-11	---	813	753	528	456	---	---	150	139	122	110	---
	7-9 A.M.	75-76	14-15	---	969	921	651	468	---	---	179	170	150	113	---
	1-3 P.M.	92-94	21-22	---	759	750	564	510	---	---	140	138	130	123	---
	5-7 P.M.	92-94	20-21	---	900	978	639	---	---	---	166	180	148	---	---
				Oxygen Consumption, lit/hr.†						Carbon Dioxide Production, lit/ r.†					
10°-40°	2-4 A.M.	10-12	1-2	204	201	192	138	125	165	191	205	175	139	121	150
	7-9 A.M.	15-20	1-2	220	218	210	139	163	184	298	252	250	168	185	251
	1-3 P.M.	36-39	3-4	212	206	203	145	132	133	218	201	203	145	131	137
	4-6 P.M.	38-39	3-4	231	232	221	164	160	168	323	292	301	185	199	199
40°-70°	2-4 A.M.	42-43	3-4	182	181	176	115	121	---	160	168	160	109	107	---
	7-9 A.M.	45-48	4-6	198	192	191	143	121	---	212	250	228	162	131	---
	1-3 P.M.	66-67	9-10	212	188	183	131	115	---	221	188	189	127	119	---
	4-6 P.M.	67-69	8-10	209	203	220	148	152	---	241	224	254	199	175	---
60°-110°	2-4 A.M.	61-63	5-7	---	148	171	130	104	---	---	141	177	115	97	---
	7-9 A.M.	67-70	9-11	---	170	160	116	107	---	---	171	166	158	118	---
	12-2 P.M.	92-101	22-26	178	149	139	119	101	---	157	164	132	120	88	---
	5-7 P.M.	100-103	21-23	161	155	173	127	97	---	142	142	167	144	95	---
70°-100°	2-4 A.M.	72-73	10-11	---	164	152	104	94	---	---	152	142	113	80	---
	7-9 A.M.	75-76	14-15	---	193	183	144	94	---	---	236	196	154	87	---
	1-3 P.M.	92-94	21-22	---	152	150	112	108	---	---	142	142	109	80	---
	5-7 P.M.	92-94	20-21	---	182	199	128	---	---	---	164	190	124	---	---

					Methane Production, lit/hr.†						Pulmonary Ventilation Rate, lit/min.†				
10°-40°	2-4 A.M.	10-12	1-2	12	20	8	10	5	8	102	100	100	76	74	74
	7-9 A.M.	15-20	1-2	28	16	15	14	17	29	130	120	116	86	93	105
	1-3 P.M.	36-39	3-4	22	9	14	11	6	11	115	110	121	76	91	77
	4-6 P.M.	38-39	3-4	38	22	26	13	14	16	147	143	151	102	111	101
40°-70°	2-4 A.M.	42-43	3-4	8	8	13	7	5	---	124	136	136	90	88	---
	7-9 A.M.	45-48	4-6	24	38	24	12	14	---	146	154	156	104	102	---
	1-3 P.M.	66-67	9-10	17	14	20	4	11	---	221	203	174	109	121	---
	4-6 P.M.	67-69	8-10	7	10	20	23	20	---	176	211	231	133	132	---
60°-110°	2-4 A.M.	61-63	5-7	---	3	35	3	5	---	---	172	171	125	98	---
	7-9 A.M.	67-70	9-11	---	8	14	26	15	---	---	185	177	112	94	---
	12-2 P.M.	92-101	22-26	14	20	6	7	2	---	285	282	300	226	262	---
	5-7 P.M.	100-103	21-23	4	5	16	22	11	---	315	292	296	260	282	---
70°-100°	2-4 A.M.	72-73	10-11	---	6	7	8	2	---	---	239	234	116	124	---
	7-9 A.M.	75-76	14-15	---	29	11	14	2	---	---	238	232	148	138	---
	1-3 P.M.	92-94	21-22	---	1	8	8	1	---	---	274	282	184	240	---
	5-7 P.M.	92-94	20-21	---	2	19	12	---	---	---	305	311	204	---	---

*Holstein 184 was removed from the laboratory, May 1.
**Jersey 295 was removed from the laboratory, March 9.
†Gas volumes were corrected to dry STP (0°C, 760 mm Hg) conditions.

TABLE 5 -- INFLUENCE OF DIURNAL TEMPERATURE CYCLES ON EVAPORATIVE COOLING FROM THE RESPIRATORY TRACT IN JERSEY AND HOLSTEIN COWS
(Feb. 1954--May 1954)

Diurnal Tempera- ture Range °F	Time of Day	Before or After Feeding	Dry Bulb Tempera- ture °F	Relative Humidity %	Vapor Pressure mm Hg	Body Weight Lb.	Evaporative Rate From The Respiratory Tract: Weight Loss/Hour		Heat Dissipation/Hour		
							gm/cow	gm/m^2	Cal/cow	Cal/m^2	Relative to Heat Production %
					Holstein 184						
10°-40°	2-4 A.M.	B	10	63	1.01	1208	97	19	56	11	6
	7-9 A.M.	A	15	62	1.28		109	21	63	12	6
	1-3 P.M.	B	36	56	3.00		120	23	70	13	7
	4-6 P.M.	A	39	58	3.49		163	32	95	19	8
40°-70°	2-4 A.M.	B	43	54	3.80	1250	134	26	78	15	9
	7-9 A.M.	A	45	64	4.84		156	30	90	17	9
	1-3 P.M.	B	66	61	9.88		218	42	126	24	12
	4-6 P.M.	A	69	52	9.34		312	60	181	35	17
60°-110°	12-2 P.M.	B	96	55	23.7	1270	348	66	202	38	23
	5-6 P.M.	A	100	46	22.4		478	91	277	53	35
					Holstein 144						
10°-40°	2-4 A.M.	A	10	64	1.03	1299	104	19	60	11	6
	7-9 A.M.	B	16	63	1.36		123	23	71	13	6
	1-3 P.M.	A	36	57	3.06		119	22	69	13	7
	4-6 P.M.	B	39	56	3.37		157	29	91	17	8
40°-70°	2-4 A.M.	A	43	55	3.87	1332	140	26	81	15	9
	7-9 A.M.	B	46	64	4.84		166	31	96	18	10
	1-3 P.M.	A	66	59	9.57		262	48	152	28	16
	4-6 P.M.	B	69	51	9.16		298	55	173	32	17
60°-110°	2-4 A.M.	A	63	45	6.57	1338	269	50	156	29	21
	7-8 A.M.	B	70	57	10.6		280	52	162	30	19
	12-2 P.M.	A	99	54	25.5		276	51	160	30	21
	5-6 P.M.	B	103	40	21.3		450	83	261	48	34
70°-100°	2-4 A.M.	A	73	58	11.9	1332	333	62	193	36	24
	7-8 A.M.	B	76	70	15.9		296	55	172	32	18
	12-2 P.M.	A	92	58	22.1		258	48	150	28	20
	5-6 P.M.	B	92	54	20.6		374	69	217	40	24

					Holstein 178						
10°-40°	2-4 A.M	B	10	64	1.03	1303	99	19	57	11	6
	7-9 A.M.	A	16	61	1.32		127	24	74	14	7
	1-3 P.M.	B	37	57	3.17		128	24	74	14	7
	4-6 P.M.	A	39	56	3.37		183	34	106	20	9
40°-70°	2-4 A.M.	B	43	54	3.80	1332	154	28	89	16	10
	7-9 A.M.	A	47	64	5.24		178	33	103	19	11
	1-3 P.M.	B	67	61	10.2		233	43	135	25	15
	4-6 P.M.	A	68	51	8.86		328	61	190	35	17
60°-110°	2-4 A.M.	B	62	44	6.20	1312	273	51	158	29	18
	7-8 A.M.	A	69	56	10.0		270	50	157	29	20
	12-2 P.M.	B	100	52	25.3		280	52	162	30	23
	5-6 P.M.	A	100	44	21.4		432	80	251	46	29
70°-110°	2-4 A.M.	B	73	56	11.5	1340	312	57	181	33	24
	7-8 A.M.	A	76	66	15.0		286	53	166	31	18
	12-2 P.M.	B	92	56	21.3		312	57	181	33	24
	5-6 P.M.	A	92	54	20.6		395	73	229	42	23
					Jersey 274						
10°-40°	2-4 A.M.	B	12	64	1.14	844	66	16	38	9	6
	7-9 A.M.	A	17	61	1.38		80	19	46	11	7
	1-3 P.M.	B	37	57	3.17		73	17	42	10	6
	4-6 P.M.	A	39	56	3.37		93	22	54	13	7
40°-70°	2-4 A.M.	B	42	54	3.65	882	74	17	43	10	7
	7-9 A.M.	A	48	65	5.51		99	23	57	13	8
	1-3 P.M.	B	67	58	9.74		132	31	77	18	12
	4-6 P.M.	A	67	50	8.40		181	42	105	24	14
60°-110°	2-4 A.M.	B	61	42	5.72	891	200	46	116	27	18
	7-8 A.M.	A	67	55	9.23		178	41	103	24	18
	12-2 P.M.	B	101	51	25.6		204	47	118	27	20
	5-6 P.M.	A	101	42	21.1		381	88	221	51	34
70°-100°	2-4 A.M.	B	72	54	10.7	893	158	36	92	21	17
	7-8 A.M.	A	76	66	15.0		199	46	115	27	18
	12-2 P.M.	B	93	56	22.0		205	47	119	27	21
	5-6 P.M.	A	93	54	21.2		252	58	146	34	23

TABLE 5 -- CONTINUED

Diurnal Temperature Range °F	Time of Day	Before or After Feeding	Dry Dulb Temperature °F	Relative Humidity %	Vapor Pressure mm Hg	Body Weight Lb.	Evaporative Rate From The Respiratory Tract: Weight Loss/Hour: gm/cow	gm/m^2	Heat Dissipation/Hour: Cal/cow	Cal/m^2	Relative to Heat Production %
					Jersey 564						
10°-40°	2-4 A.M.	B	12	63	1.12	864	66	16	38	9	6
	7-9 A.M.	A	18	62	1.47		83	20	48	12	6
	1-3 P.M.	B	38	56	3.24		89	21	52	12	8
	4-6 P.M.	A	38	55	3.18		103	24	60	14	7
40°-70°	2-4 A.M.	B	42	54	3.65	902	86	20	50	12	8
	7-9 A.M.	A	50	64	5.85		103	24	60	14	10
	1-3 P.M.	B	68	60	10.4		148	34	86	20	15
	4-6 P.M.	A	67	50	8.40		179	41	104	24	14
60°-110°	2-4 A.M.	B	60	42	5.52	891	147	34	85	20	16
	7-8 A.M.	A	65	55	8.61		170	39	99	23	18
	12-2 P.M.	B	102	49	25.3		254	59	147	34	30
	5-6 P.M.	A	104	40	21.9		410	95	238	55	49
70°-110°	2-4 A.M.	B	72	57	11.3	829	178	43	103	25	23
	7-8 A.M.	A	75	64	14.1		191	46	111	27	24
	12-2 P.M.	B	94	55	22.3		292	70	169	41	33
	5-6 P.M.	A	94	51	20.7		---	--	---	--	--
					Jersey 295						
10°-40°	2-4 A.M.	B	14	66	1.29	703	52	14	30	8	4
	7-9 A.M.	A	20	63	1.64		87	23	50	13	5
	1-3 P.M.	B	39	56	3.37		80	21	46	12	7
	4-6 P.M.	A	38	55	3.19		108	29	63	17	7