RESEARCH BULLETIN 893 SEPTEMBER, 1965

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Environmental Psysiology and Shelter Engineering

With Special Reference to Domestic Animals

LXIX. ACCLIMATION OF HOLSTEIN CATTLE TO 84°F (29°C) TEMPERATURE: CHANGES IN HEAT PRODUCING AND HEAT DISSIPATING FUNCTIONS

H. H. KIBLER, H. D. JOHNSON, M. D. SHANKLIN, AND LEROY HAHN

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ABSTRACT

Ten lactating and two non-lactating Holstein cows were placed in a 65°F (18.4°C) temperature, 50 percent relative humidity room for four to six weeks and then exposed for nine weeks to 84°F (29°C) temperature to study their physiological reactions and acclimation trends. They were then re-exposed to the 65°F, 50 percent R.H. condition for four weeks to permit calculation of changing 65°F base levels for the various measurements.

Exposure of the 10 lactating cows to the 84°F condition caused significant decreases from the 65°F levels in responses associated with heat production. These reductions were approximately 15 percent in energy metabolism, 10 to 15 percent in pulse rate and 2 percent in body weight. Feed consumption decreased by 10 to 25 percent and milk production decreased by about 15 percent.

At the same time responses associated with heat dissipation increased. The increases were as great as 85 percent in whole body vaporization, and 95 percent in respiratory rate, 80 percent in tissue conductance, 30 percent in expired air volume and respiratory vaporization.

Only the rectal temperature and pulse rate showed statistically significant trends toward normal levels during exposure to heat. The non-lactating cows were less affected by the 84°F temperature. Equilibrium levels of response to 84°F temperature were attained by measures such as respiration rate and surface temperature within one week. Others such as energy metabolism and milk production required two to four weeks. Pulse rate required eight weeks and body temperature and hair density were still decreasing after nine weeks.

CONTENTS

ACKNOWLEDGMENTS

This project 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 the Agricultural Engineering Research Division of the United States Department of Agriculture. This bulletin is a report on the Department of Dairy Husbandry research project No. 125, "Climatic Factors."

Acknowledgements are due for cooperation in this research to J. E. Edmondson for Dairy phases and to M. M. Jones and H. Walton for Engineering phases; to S. Barrett for assistance in environmental control; to E. Paschang for assistance with measurements; to D. Scott and R. Rumans for care of the animals; and to Donna Soos, Shirley Kidwell, D. Warner, and V. Qurollo for aid with gas analysis.

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INTRODUCTION

Although man by preference modifies his micro-climate to avoid the disforts of a hot environment, his concern for the comfort of domestic animals is tempered by economic considerations of cost versus productivity. Consequently, the ability of a dairy cow to acclimatize to a hot climate and thereby maintain productivity at an economic level is of considerable importance.

Acclimatization to heat involves mechanisms which affect or regulate heat dissipation and heat production. From a production viewpoint, increased loss of heat is the most desirable method of acclimatization in lactating cows since a decrease in heat production is correlated with a decrease in productive level.

This bulletin reports the departures of several physiological measures from their normal levels in a 65°F environment during exposure for nine weeks to an 84°F temperature. Special attention is given to initial displacements and subsequent acclimation trends during the nine weeks of heat exposure.

The specific objectives of this phase of the experiment were: (1) To cause displacements of many functions including energy metabolism, pulse rate, respiration rate, rectal temperature, vaporization, surface temperatures, hair density and minute volume of expired air from their normal levels at 65°F by exposure to 84°F heat; (2) to observe the direction and magnitude of the immediate displacements; (3) to observe the degree of recovery or acclimation toward normal 65°F levels during continued exposure to 84°F heat; and (4) to attempt to gain a better understanding of the interrelationships among the various displacements and acclimation trends. Another objective was to determine the time required for various functions to achieve equilibrium after they were displaced by changes in environmental conditions. This information is needed for use in planning switch-back or reversal experiments.

METHODS

Experimental Animals

Ten lactating and two non-lactating Holstein cows were used during the two years of this study. The cows were housed in one chamber of the Missouri Climatic Laboratory under controlled conditions of temperature, humidity, and air movement. They were placed there about two to three months after calving. The daily average milk production before entry into the laboratory was 53.6 pounds for the 1961-62 group and 48.6 pounds for the 1962-63 group. Most of the cows were three years of age or older. More complete information on the cattle and their management will be given in another bulletin by Johnson *et al.* (in press).[1]

Apparatus

The method of measuring energy metabolism from oxygen consumption, carbon dioxide, and methane production, and minute volume of expired air by the open-circuit mask method was described in a preceding bulletin.[2] The apparatus was modified to obtain pressurized samples of expired air as shown in Fig. 1a.[3]

The laboratory gas analyzer was also changed so that the pressurized samples could be used instead of a vacuum pump and mercury bulb to impel the sample gas through the three analyzers (Fig. 1b).[3] The analyzer system now consists of a paramagnetic oxygen analyzer, an infrared carbon dioxide analyzer, and an infrared methane analyzer in series.

Respiratory rate was obtained by counting flank movements and pulse rate by manual palpation. Rectal temperature was measured with a veterinary thermometer. Hair and skin temperatures were obtained with a touch thermocouple.[4] Hair density was determined by weighing the hair from a measured area.[5] Total vaporization was measured by placing each animal in a plastic enclosure and determining the increase in moisture content for a given rate of air flow through the enclosure.[6, 7]

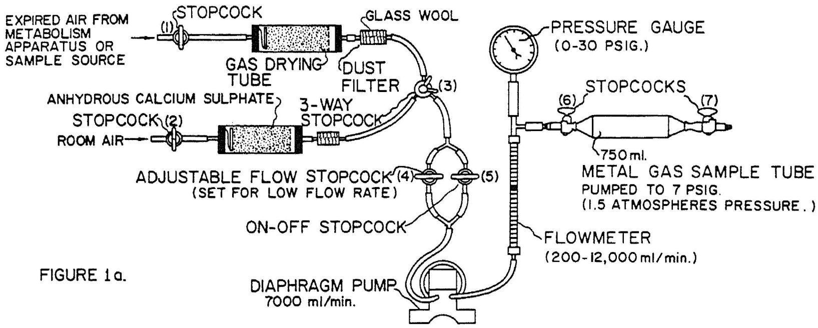

FIGURE 1a.

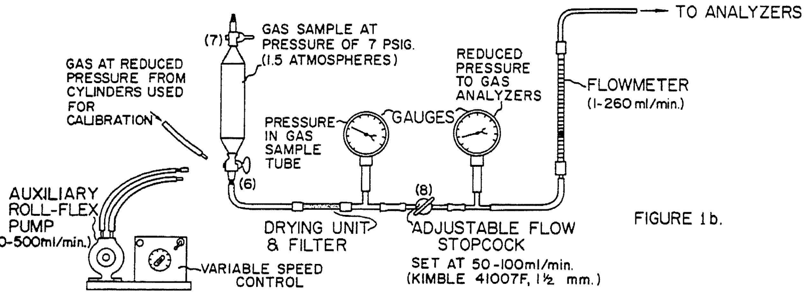

FIGURE 1b.

Fig. 1. Apparatus for collecting gas samples and for introducing them into gas analyzers without the use of mercury as a displacing agent. In collecting a gas sample, Fig. 1a, stopcocks 4, 5, 6, and 7 are opened; stopcocks 3 and 1 or 2, are set to connect system to desired sample source. The gas being collected is pumped through the collecting tube at about 3000 ml/min. to wash it out. Stopcocks 5 and 7 are then closed and stopcock 4 is adjusted to produce an increase to 1.5 atmosphere gas pressure in the desired time interval. The pump is then stopped, stopcock 6 is closed, and the collecting tube is disconnected. The collecting tube is then connected to the apparatus shown in Fig. 1b. The flow adjustment on stopcock 8 is set for the desired flow rate and stopcocks 6 and 8 are opened to establish flow of the gas through the analyzers. The auxiliary vacuum-pressure pump of the type which exerts a pumping flexure on plastic tubing is inserted into the system only if pressure in the collecting tube is lost by accident. A gas cylinder may be attached to the system for calibration of analyzers. *(Reprinted from Journal of Dairy Science*[3] *with the permission of the editors.)*

Experimental Design

All animals were exposed for six weeks to 65°F (18°C) temperature and 50 percent relative humidity; measurements were made during the last three or four weeks of this period to establish base levels for the various measurements. At this environmental temperature, cows can maintain normal body temperature and production. During the following nine weeks the temperature was increased to 84°F and 50 percent relative humidity (classified in a preceding bulletin as a moderately stressful condition for continuous exposure).[8] Following the heat exposure, the cattle were returned to the 65°F, 50 percent R.H. base condition for four weeks.

Because of the length of the experiment, the normal decline in lactation had to be considered. This was true because a decrease in production caused reductions in feed consumption, metabolic rate, and related functions. The changing 65°F base line for each measure was estimated for each cow by regressing a line through the weekly means of the last two weeks of the first 65°F condition and the third and fourth weeks of the final 65°F condition. It appeared that, except for hair density, essentially full recovery from the 84°F heat had occurred during the allotted recovery period of three to four weeks at 65°F temperature. The values computed from these regression equations are designated *expected 65°F values.*

Measurements were made five times per week on respiratory rate, pulse rate, and rectal temperature. Three to four values per week were obtained for minute volume of expired air, oxygen consumption, carbon dioxide production, and methane production, all of which were used in determining energy metabolism. Hair and skin temperatures were measured, and hair samples were collected for hair density determinations each week. Total vaporization was measured every two weeks. The internal conductance (shown in Fig. 9) is a computed value derived from the data for heat production, rectal temperature, and skin temperature shown in Tables 1 and 2.

To prevent diurnal variability in the day-to-day measurements each parameter was measured at approximately the same time of day. The majority of the measurements were made in the early afternoon or as close to then as possible.

TABLE 1 - WEEKLY MEANS OF SIX FUNCTIONS DURING EXPOSURE OF 10 LACTATING (L) AND 2 NON-LACTATING (NL) HOLSTEIN COWS TO ENVIRONMENTS OF 65°F, 50 PERCENT R.H. AND 84°F, 50 PERCENT R.H.

Temp. and Relative Hum.	Week	Energy Metabolism k cal/hr.		Expired Air Volume l/min.		Respirations per min.		Pulse Rate Beats per min.		Rectal Temp. °F		Respriatory Vaporization g/hr.	
		10 L	2 NL	10 L	2 NL	10 L	2 NL	10 L	2 NL	10 L	2 NL	10 L	2 NL
65°F 50% RH	1	-	-	-	122	48.8	43	76.9	66	101.5	101.2	-	242
	2	-	-	-	-	48.2	40	75.6	78	101.7	101.5	219	
	3	918	-	148	124	47.1	32	76.1	66	101.6	101.3		174
	4	979	853	139	114	43.0	32	73.5	70	101.6	101.5	206	168
	5	955	-	126	-	44.9	28	75.6	66	101.7	101.5	196	-
	6	985	875	139	118	44.4	29	75.6	71	101.7	101.4	185	140
84°F 50% RH	1	906	776	175	154	81.2	50	73.0	70	103.7	101.8	244	176
	2	794	707	131	148	77.7	50	63.7	64	103.7	102.0	196	208
	3					76.7	46	65.3	64	103.6	101.7		
	4	830	681	147	146	76.3	54	67.2	66	103.6	101.8	190	202
	5	-	-	-	-	76.9	50	67.7	68	103.3	101.4	-	-
	6	783	686	142	134	74.6	40	71.1	64	103.4	101.4	172	166
	7	-	-	-	-	74.3	38	73.8	66	103.3	101.6	-	-
	8	763	686	144	129	71.8	40	71.1	66	103.1	101.4	196	150
	9	762	682	135	138	75.0	43	71.5	67	103.2	101.4	176	167
65°F 50% RH	1	827	715	116	90	42.6	26	73.5	66	101.5	101.3	150	103
	2	815	724	106	92	38.6	24	78.7	68	101.6	101.3	140	106
	3	848	666	105	74	36.9	21	79.5	70	101.5	101.2	144	69
	4	891	680	104	78	34.9	20	77.7	70	101.5	101.2	140	78

TABLE 2 - WEEKLY MEANS OF FIVE FUNCTIONS DURING EXPOSURE OF 10 LACTATING (L) AND 2 NON-LACTATING (NL) HOLSTEIN COWS TO ENVIRONMENTS OF 65°F, 50 PERCENT R.H. AND 84°F, 50 PERCENT R.H.

Temp. and Relative Humidity	Week	Body Weight Kg.		Total Vaporization g/hr.		Skin Temp. °C		Hair Temp. °C		Hair Density g/cm^2	
		10 L	2 NL	10 L	2 NL	10 L	2 NL	10 L	2 NL	10 L	2 NL
65° F (18°C) 50% RH	4	-	-	846	680	27.3	27.6	26.1	25.7	.0288	.0374
	5	517	582	-	-	31.0	29.7	27.6	26.3	.0233	.0288
	6	510	596	975	915	31.5	31.0	28.3	27.4	.0222	.0272
84°F (29°C) 50% RH	1	497	590	1373	1415	35.7	34.3	34.1	33.1	.0243	.0262
	2	493	587	-	1292	35.6	35.6	33.8	34.1	.0226	.0260
	3	495	583	1232	1251	36.0	35.8	34.5	35.0	-	.0218
	4	508	603		-	36.0	35.4	34.5	34.3	.0197	.0241
	5	508	603	1220	1210	35.2	35.3	33.9	34.4	.0197	.0246
	6	507	603	-	-	35.4	35.1	34.0	33.2	.0174	.0256
	7	509	609	1370	1231	34.9	34.6	33.7	34.0	.0166	.0254
	8	510	609	-	-	36.0	37.2	34.7		.0155	.0228
	9	510	612	1297	1014	36.1	36.9	34.8		.0163	.0210
65°F (18°C) 50% RH	1	524	612	617	426	30.3	29.1	27.7	27.8	.0144	.0290
	2	526	617	673	483	30.3	29.8	27.8	28.1	.0147	.0245
	3	535	616	-	-	31.1	29.1	28.5	27.3	.0138	.0228
	4	538	620	704	378	-	-	-	-	-	-

Data Analyses

The effects of the 84°F, 50 percent R.H. condition in altering the various measures from the 65°F, 50 percent R.H. condition were determined with respect to magnitude and trend. The differences in magnitude were computed between the actual levels at 84°F, 50 percent R.H. and the expected values at 65°F, 50 percent R.H. This was done for the weekly means for each individual cow (see example in Fig. 2) so that differences in body size and persistency of lactation would not mask the effects of the heat exposure. The significance of the differences from expected levels during the nine weeks' exposure at 84°F, 50 percent R.H. was determined by means of t-tests.

The significance of the acclimation trends for the 10 lactating cows during the nine weeks exposure to heat was tested by comparing the regressions of the weekly 10-cow means for the 84°F and 65°F data by an analysis of covariance. This analysis tested the significance of the difference of the adjusted means and of the difference in the regression coefficients of the 65 and 84°F data.

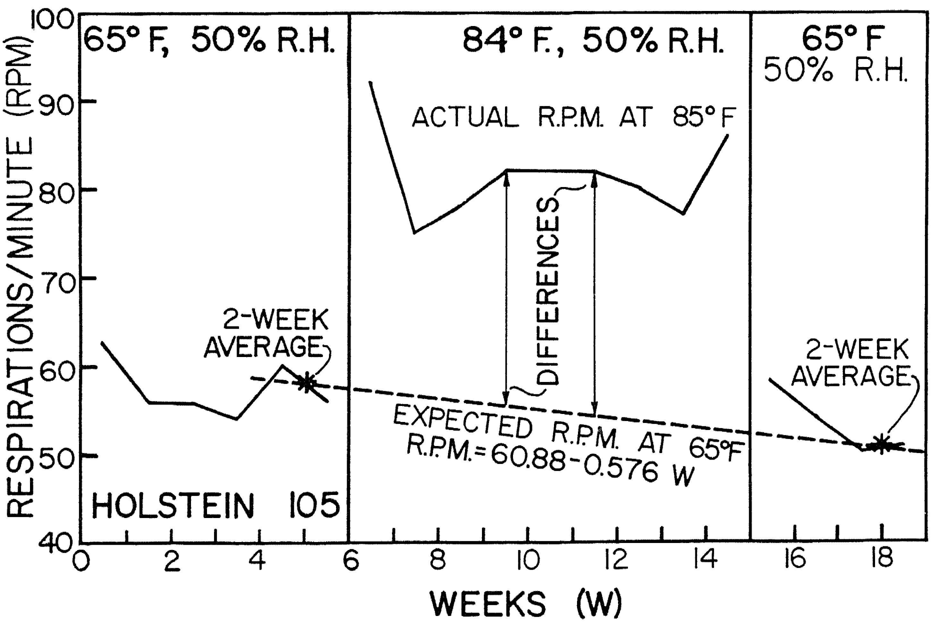

Fig. 2. Method of regressing an equation through the 65°F data during the two 65°F base periods to determine expected values. The equation was fitted to the weekly means of data for the last two weeks of the first 65°F period and the third and fourth weeks of the last 65°F period. Calculations of weekly differences were made for each cow and for all measures shown in this bulletin.

RESULTS

The responses of the cattle during the stabilization period at 65°F, the heat exposure period at 84°F, and the recovery period at 65°F are shown in Figs. 3 to 5. The weekly means for the 10 lactating, and for the two non-lactating cows are shown in Tables 1 and 2. Although the differences in body weight in the two groups could have affected such measures as metabolic rate and expired air volume, it seems probable that lactation caused the higher values of respiratory rate and rectal temperature in the lactating group during exposure to heat.

A few general observations will be made regarding the significance of the physiological displacements in the lactating cattle caused by the 84°F heat exposure and the subsequent recovery trends. A detailed discussion of the specific changes in each measure follows.

Differences in Responses at 65°F and 84°F Temperatures

The departures from expected values caused by the nine weeks of exposure to 84°F temperature and their significance are shown in Tables 3 and 4. The greatest reaction to the 84°F temperature occurred during the first or second week. However, all measurements were displaced from their 65°F levels by the 84°F heat. All differences between expected 65°F and measured 84°F values in the lactating cows were significant or highly significant except metabolic rate during the first week, respiratory vaporization during the second, fourth, and sixth weeks, pulse rate during the seventh week and body weight during the fourth week. Hair density decreased below the initial 65°F level during the nine weeks of heat exposure but for reasons explained later, the usual test of significance could not be calculated. The vaporization rate decreased in the non-lactating cows after the initial rise the first week of exposure to heat but remained close to the maximum level attained the first week in the lactating cows.

Acclimation Trends During Heat Exposure

One aspect of acclimation is the recovery trend in a function which has been displaced by heat exposure. However, if the stress is moderate to severe the recovery to usual physiological levels may not occur in all functions. Some heat dissipating functions will remain elevated and some heat producing functions will remain depressed.

To be meaningful, an examination for trends in the physiological data must separate the effects of thermal stress from the effects produced by the normal time changes in lactation at a thermoneutral temperature (65°F). This separation was made for each measure by comparing its trend during nine weeks at 84°F with its trend at 65°F. The results of the covariance tests are given in Tables 5 and 6. Graphical comparisons are made in Figures 6 and 7.

Tests of significance were not made on the limited data for the two non-lactating cows but their responses are shown in the Tables 1 to 4 and in Figures 3, 4, and 5. For the 10 lactating cows, the initial displacements and acclimation trends were as follows:

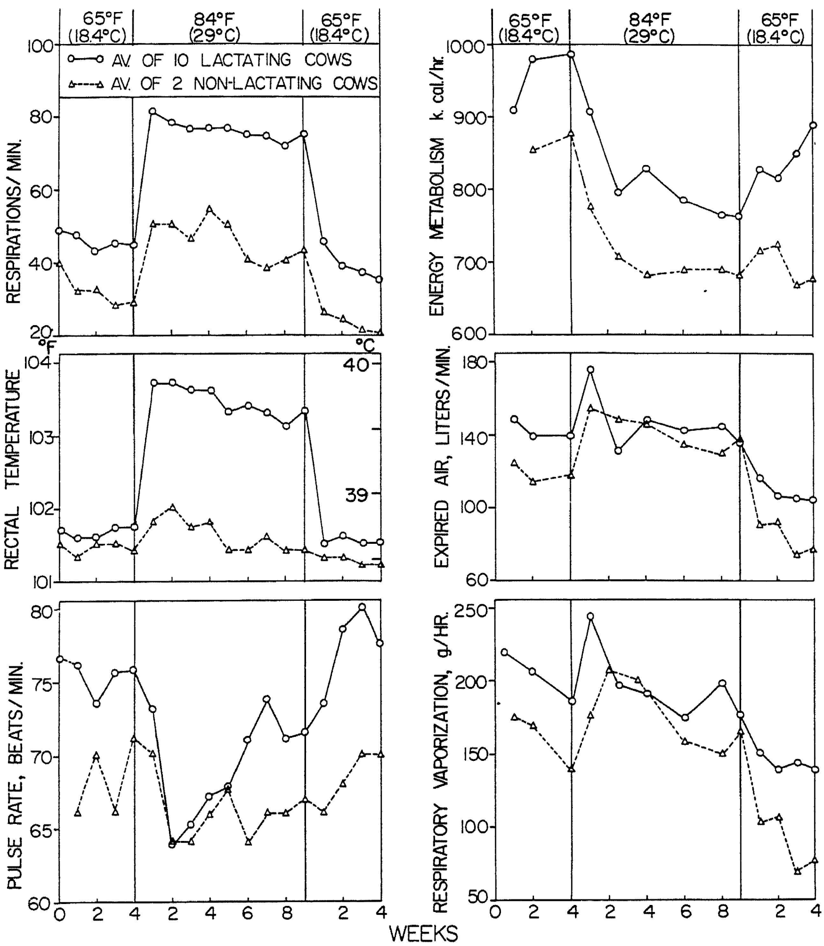

Fig. 3. Changes in several functions during nine weeks of exposure to 84°F temperature following prior conditioning at 65°F temperature. The greatest reaction to the 84°F temperature occurred during the first to second week. Thereafter there was a gradual readjustment or partial acclimation to the heat. By the end of the ninth week these functions appeared to have stabilized. The non-lactating cows generally respond less than the lactating cows to the 84°F temperature.

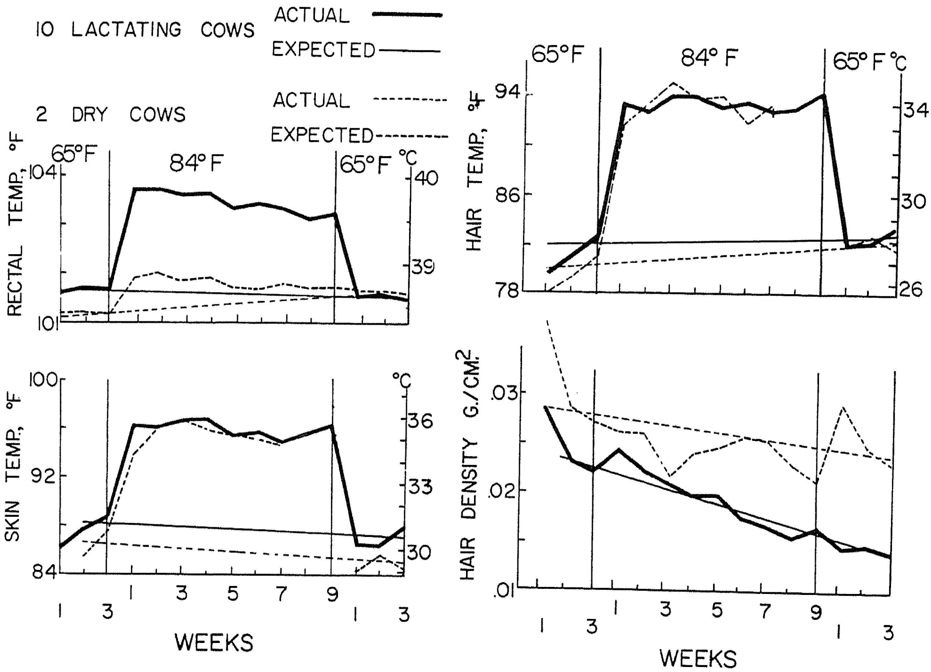

Fig. 4. Changes in skin and hair temperature, and hair density during nine weeks of exposure to 84°F temperature following prior conditioning at 65°F temperature. Hair density decreased steadily during the heat exposure.

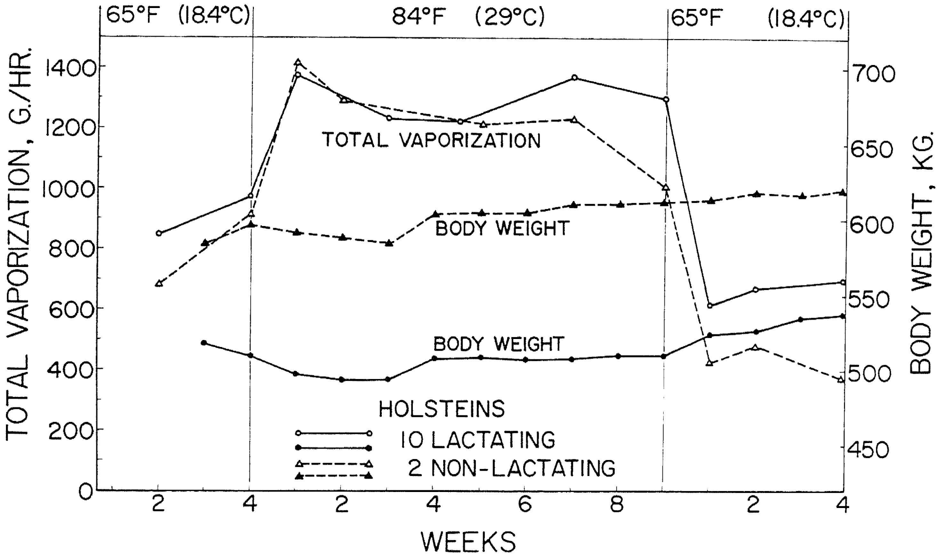

Fig. 5. Effects of nine weeks of exposure to 84°F temperature on total vaporization and body weight in 10 lactating and two non-lactating Holstein cows. The vaporization rate was as great in the lactating as in the non-lactating cows during the first five weeks at 84°F although the body weight was lower in the lactating cows.

Respiratory rate was significantly elevated about 35 respirations per minute in the lactating cows throughout the nine weeks at 84°F (Table 3) and did not exhibit a significant recovery trend (Figure 6 and Table 5). The respiratory rate was less affected by the 84°F heat in the non-lactating cows and tended to decrease irregularly after the fourth week (Figure 3 and Table 3).

Rectal temperature in the lactating cows increased significantly by 2°F during the initial exposure to 84°F (Table 3 and Figure 4) and although it displayed a significant recovery toward normal levels (Figure 6 and Table 5) it still remained significantly elevated during the nine weeks of exposure to 84°F heat. The non-lactating cows were affected less by the heat but displayed a similar decreasing trend in rectal temperature during 9 weeks at the 84°F temperature (Figure 3 and Table 3).

Pulse beats per minute in the lactating cows decreased by about 12 beats the first two weeks at 84°F temperature and then increased significantly to a new level which was only about 6 beats below expected 65°F levels during the remainder of the period (Tables 3, 5 and Fig. 6). The drop in pulse rate in the non-lactating cows during the first 2 weeks was only 4 beats per minute with no regular change thereafter (Figure 3 and Table 3). Repeated short exposures of calves to a hot environment likewise has been reported to cause progressive reductions in rectal temperature and heart rate.[9]

Energy metabolism, k cal/hr, in the lactating cows decreased about 150 k cal below expected levels during the first two to three weeks at 84°F and maintained this significant difference during the remainder of the heat exposure (Table 3). The downward trend in the metabolic rate paralleled the downward trend in the expected values so there was no significant recovery trend during the period (Figure 6 and Table 5). The changes in the metabolic rate in the non-lactating cows tended to parallel those in the lactating cows with all values at a lower level (Figure 3).

Expired air minute volume in the lactating cows increased about 45 liters during the first week at 84°F, decreased about 25 liters after two to three weeks, and thereafter continued at this significantly lower level to the end of the heat exposure (Table 3). There was no significant acclimation trend toward 65°F values. The increase was about the same in the non-lactating cows during the first week and there was no recovery thereafter (Figure 3 and Table 3).

Respiratory vaporization per hour in the lactating cows increased more than 60 grams during the first week at 84°F and then decreased about 35 grams by the second week (a value still significantly greater than the 65°F value). (Table 3) The subsequent decrease at 84°F was less than at 65°F so there was no significant recovery trend (Figure 6 and Table 5). In the non-lactating cows the respiratory vaporization rate did not drop much after the initial rise (Figure 3 and Table 3).

TABLE 3 - AVERAGE DIFFERENCES FROM EXPECTED VALUES (AT 65°F, 18.4°C) FOR 10 LACTATING (L) AND 2 NON-LACTATING (NL) HOLSTEIN COWS EXPOSED TO 84°F (29°C) TEMPERATURE AND 50 PERCENT RELATIVE HUMIDITY

Weeks at 84°F	Metabolic Rate, kcal/hr.		Expired Air 1/min.		Respirations minute		Pulse Rate Counts/Min.		Rectal Temp. °F.		Respiratory Vaporization g/hr.	
	L	NL	L	NL	L	NL	L	NL	L	NL	L	NL
1	-50	-58	44**	43	38**	23	-3.0*	1.8	2.0**	0.5	62.9**	34
2	-152**	-113	16**	40	34**	22	-12.5**	-4.8	2.1**	0.7	20.4	72
3					34**	19	-11.1**	-4.3	2.0**	0.4		
4	-104**	-111	22**	45	35**	28	-9.4**	-3.4	2.0**	0.5	19.0	78
5					36**	25	-8.8**	-1.6	1.7**	0.1		
6	-135**	-78	23**	39	34**	16	-5.0**	-4.6	1.7**	0.1	8.5	54
7			10		35**	14	-3.6	-2.8	1.7**	0.4		
8	-138**	-50	28**	40	33**	17	-6.5**	-3.4	1.6**	0.1	37.9**	50
9	-134**	-40	22*	52	37**	20	-6.3**	-2.4	1.6**	0.2	23.0*	73

*Significant by t-test at $P < .05$.

**Significant by t-test at $P < .01$.

TABLE 4 - AVERAGE DIFFERENCE FROM EXPECTED VALUES AT 65°F (18.4°C) FOR 10 LACTATING (L) AND 2 NON- LACTATING (NL) HOLSTEIN COWS EXPOSED TO 84°F (29°C) TEMPERATURE AND 50 PERCENT RELATIVE HUMIDITY

Weeks at 84°F (29°C)	Body Weight Changes kg		Total Vaporization Increases g/hr.		Skin Temperature °C		Hair Temperature Increases °C	
	L	NL	L	NL	L	NL	L	NL
1	-18.4**	-2.3	392**	+501	4.5**	4.0	6.1**	6.2
2	-23.9**	-6.8	---	+306	4.5**	5.4	5.8**	7.0
3	-23.4**	-13.6	307**	+374	4.9**	5.7	6.0**	7.9
4	-12.1	+4.5	---	---	4.9**	5.4	6.4**	7.2
5	-13.5*	+3.2	320	+370	4.2**	5.4	5.9**	7.2
6	-15.4**	-0.5	---	---	4.4**	5.3	6.0**	5.9
7	-15.0**	+3.6	459**	+427	4.0**	4.9	5.6**	6.6
8	-15.1**	+1.4	---	---	4.3*	7.6	6.0**	
9	-17.6**	+2.3	427**	+248	4.9**	7.3	6.6**	

*Significant by t-test at $P < .05$.

**Significant by t-test at $P < .01$.

TABLE 5 - COMPARISONS OF 84°F AND 65°F (28.9 AND 18.3°C) DATA BY ANALYSIS OF COVARIANCE; PARTIAL RECOVERY OR ACCLIMATION OF SIX MEASURES IN 10 LACTATING HOLSTEIN COWS DURING NINE WEEKS OF EXPOSURE TO 84°F TEMPERATURE

($\bar{x}$ = mean; r = coefficient of correlation; b = regression coefficient; Sy.x = standard error of estimate.)

Temp. F	Weeks[1] Showing Recovery at 84°F	$\bar{x}$	r	b	Sy.x	Level of Significance[2]: Differences of Adjusted Means	Level of Significance[2]: Differences in Regression Coefficients
		Rectal Temperature, °F					
65	-	101.6	.996	-.0153	.011	.01	.01
84	9	103.4	.939	-.0767	.026		
		Energy Metabolism, k cal/hr.					
65	-	919	.972	-8.14	8.7	.01	n.s.
84	5	786	.776	-8.01	20.3		
		Respirations/minute					
65	-	40.3	.974	-.676	.99	.01	n.s.
84	9	76.1	.855	-.817	.85		
		Pulse, beats/minute					
65	-	77.1	.897	0.22	1.02	.01	.01
84	8	68.9	.895	1.27	1.68		
		Expired Air Volume, liters/minute					
65	-	121.8	.998	-2.64	1.35	.05	n.s.
84	5	139.8	.146	0.36	7.55		
		Respiratory Vaporization, grams/hr.					
65	-	166	.975	-3.75	3.6	.05	n.s.
84	5	186	.433	-1.82	11.8		

[1]Indicates the number of weeks out of nine which show a recovery trend toward 65°F levels. The equations for the 84°F periods were derived from the data for these weeks. All equations for the 65°F periods were derived from data for four weeks.

[2]Significant = $P<.05$; highly significant = $P<.01$; not significant = n.s.

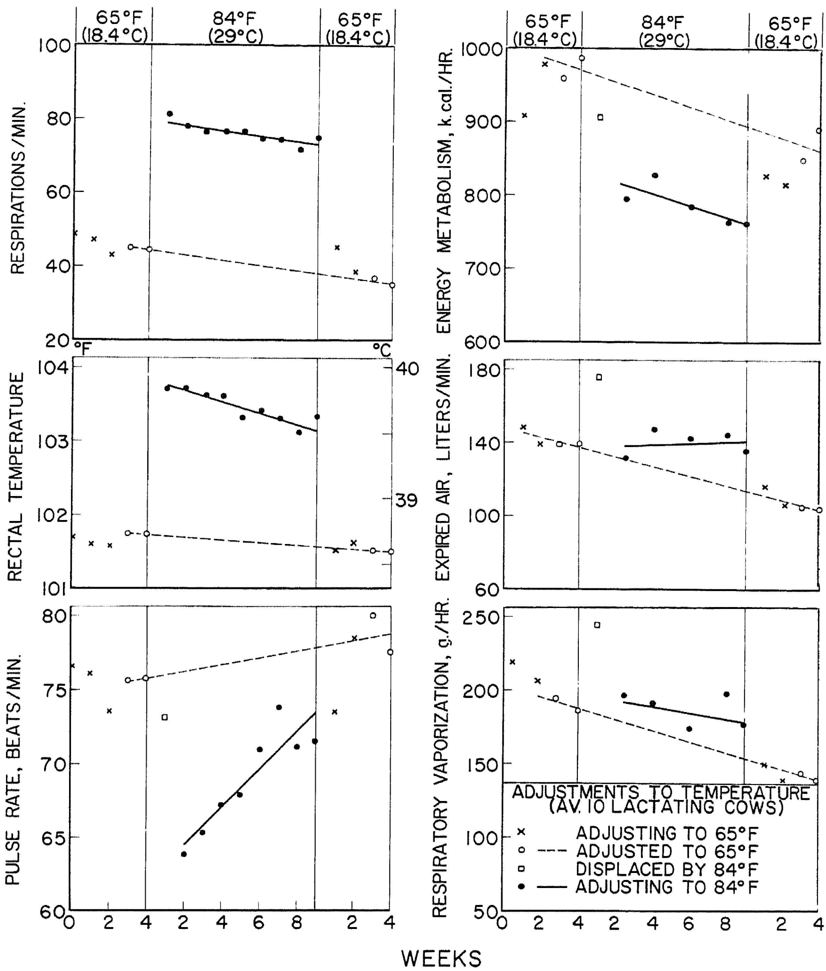

Fig. 6. Acclimation trends in six measures during nine weeks of exposure to 84°F temperature. The 84°F measurements are compared with the 65°F measurements to test the significance of the regression trends and the differences between adjusted means at the two conditions (Table 5). Although significant differences were obsered for the differences in adjusted means, only rectal temperature and pulse rate had significant acclimation trends (Table 5).

Total vaporization per hour (Fig. 5) in the lactating cows increased significantly (Table 4) by 300 to 400 grams above the 65°F level during the nine weeks at 84°F. The level fluctuated during the nine weeks period but there was no significant trend (Figure 7 and Table 6). The total vaporization in the non-lactating cows increased by 500 at the beginning of the 84°F period but was increased by less than 300 grams by the end of the period (Table 4). The total vaporization was nearly the same in the lactating and heavier non-lactating cows during the 84°F period (Figure 5). The water consumption of the lactating cows, however, was nearly twice as great as that of the non-lactating cows. Because of the need for water for milk production, the percent of consumed water vaporized (Fig. 8) was greater in the non-lactating than lactating cows. Vaporization as a percent of water consumed (Fig. 8) increased in the lactating cows from about 22 percent to 35 percent during the first week and maintained this level to the end of the nine week period of heat exposure. In the non-lactating cows there was a gradual decline in this ratio from 60 percent during the second week to 45 percent during the ninth week.

Skin temperature was almost the same in the lactating and non-lactating cows during the nine weeks of exposure to 84°F (29°C) temperature as shown in Figure 4. As has been indicated by others,[10] skin temperature in cattle is mainly a function of environmental temperature. However, the rise in skin temperature above expected 65°F (18°C) levels was only 4.4°C in the lactating cows compared to 5.7°C in the non-lactating cows (Table 4). Perhaps this difference in response to the heat was caused by the difference in hair density in the two groups. Figure 4 shows that the hair density was greater in the non-lactating than lactating cows at the beginning of the 84°F period, and that it appeared to decrease more slowly in the non-lactating cows during the heat exposure. There was no significant acclimation trend in the skin temperature data for the lactating cows. (Fig. 7 and Table 6).

Hair temperature, also, was nearly the same in the lactating and non-lactating cows during the exposure to 84°F temperature but was lower in the non-lactating cows during the initial exposure to 65°F (Figure 4). The rise in hair temperature of 6.0°C in the lactating cows was significant (Table 4) but was not as great as the 6.8°C rise in the non-lactating cows during exposure to 84°F temperature. The lower hair density of the lactating cows probably explains their higher hair temperature at the 65°F temperature. The greater rise in hair temperature than skin temperature shows that environmental temperature is more closely correlated with hair temperature than with skin temperature. There was no significant acclimation to heat in the hair temperature data (Table 6 and Figure 7).

TABLE 6 - COMPARISON OF 84°F AND 65°F (28.9 AND 18.3°C) DATA BY ANALYSIS OF COVARIANCE; PARTIAL RECOVERY OR ACCLIMATION OF FOUR MEASURES IN 10 LACTATING HOLSTEIN COWS DURING NINE WEEKS OF EXPOSURE TO 84°F TEMPERATURE

($\bar{x}$ = mean; r = coefficient of correlation; b = regression coefficient; Sy.x = standard error of estimate)

Temp. F	Weeks Included	$\bar{x}$ kg	r	b	Sy.x g/day	Level of Significance[2] Differences of Adjusted Means	Level of Significance[2] Differences in Regression Coefficients
		Body Weight, kg					
65	4	525	.964	1.75	3.13	P<.01	n.s.
84	9	504	.851	2.17	1.48		
		Total Vaporization, g/hr.					
65	4	800	.860	-15.8	87.0	P<.01	n.s.
84	5	1298	.012	0.28	84.1		
		Skin Temperature, °C					
65	4	31.0	.570	-0.04	0.50	P<.01	n.s.
84	9	35.7	.000	0.00	0.45		
		Hair Temperature, °C					
65	4	28.0	.635	0.021	0.40	P<.01	n.s.
84	9	34.2	.379	0.057	0.40		
		Hair Density, g/cm^2					
84	8	0.019	.970	-0.0011	0.00083		

[2]Highly significant (P<.01)

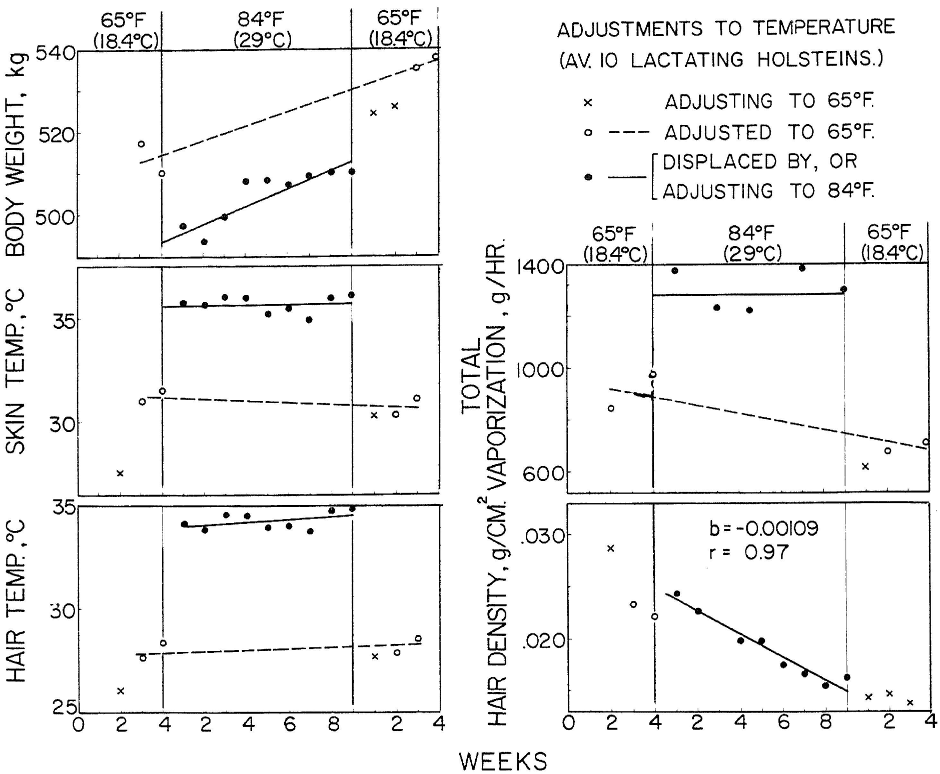

Fig. 7. Acclimation trends in five measures during nine weeks of exposure to 84°F temperature. See Table 6 and text for the tests of significance of the differences of adjusted means and regression coefficients for the 84°F and 65°F data.

Hair density decreased in both the lactating and non-lactating cows during the nine weeks exposure to 84°F temperature (Table 4). The statistically significant regression for the lactating cows at 84°F (Figure 7 and Table 6) indicated that there might be a definite acclimation trend. Since there was no recovery in hair density during the subsequent three weeks at 65°F, statistical tests comparable to those used for the other measures could not be made. Presumably, given sufficient recovery time at 65°F, the hair density would have regained its initial level. However, a precise statistical test of the acclimation trend in this measure would require a control group held at 65°F temperature for comparison with the experimental group exposed to 84°F temperature.

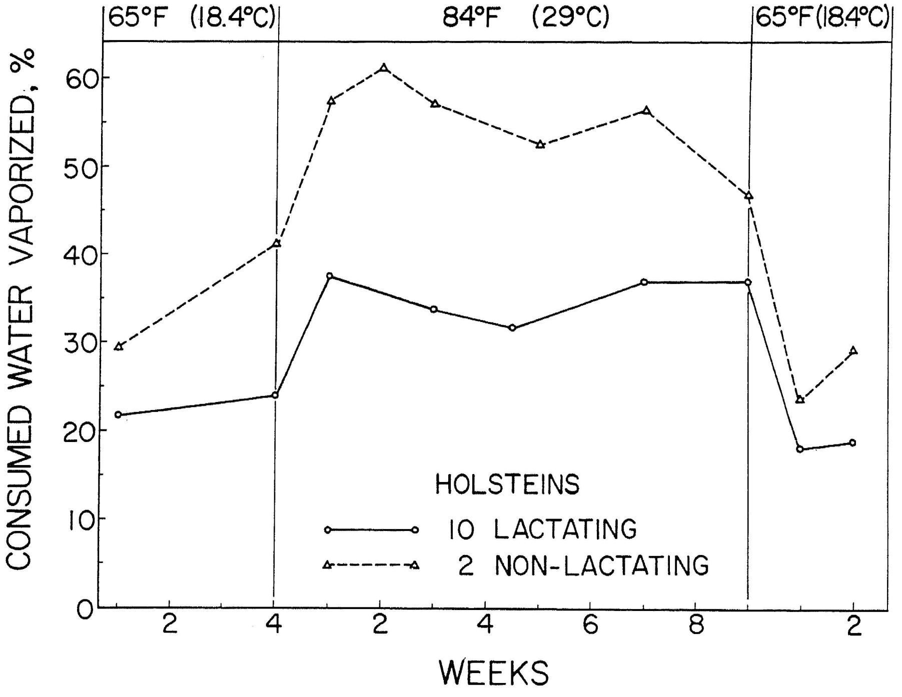

Fig. 8. Relation of water vaporized to water consumed in lactating and non-lactating cows at 65°F and 84°F temperatures.

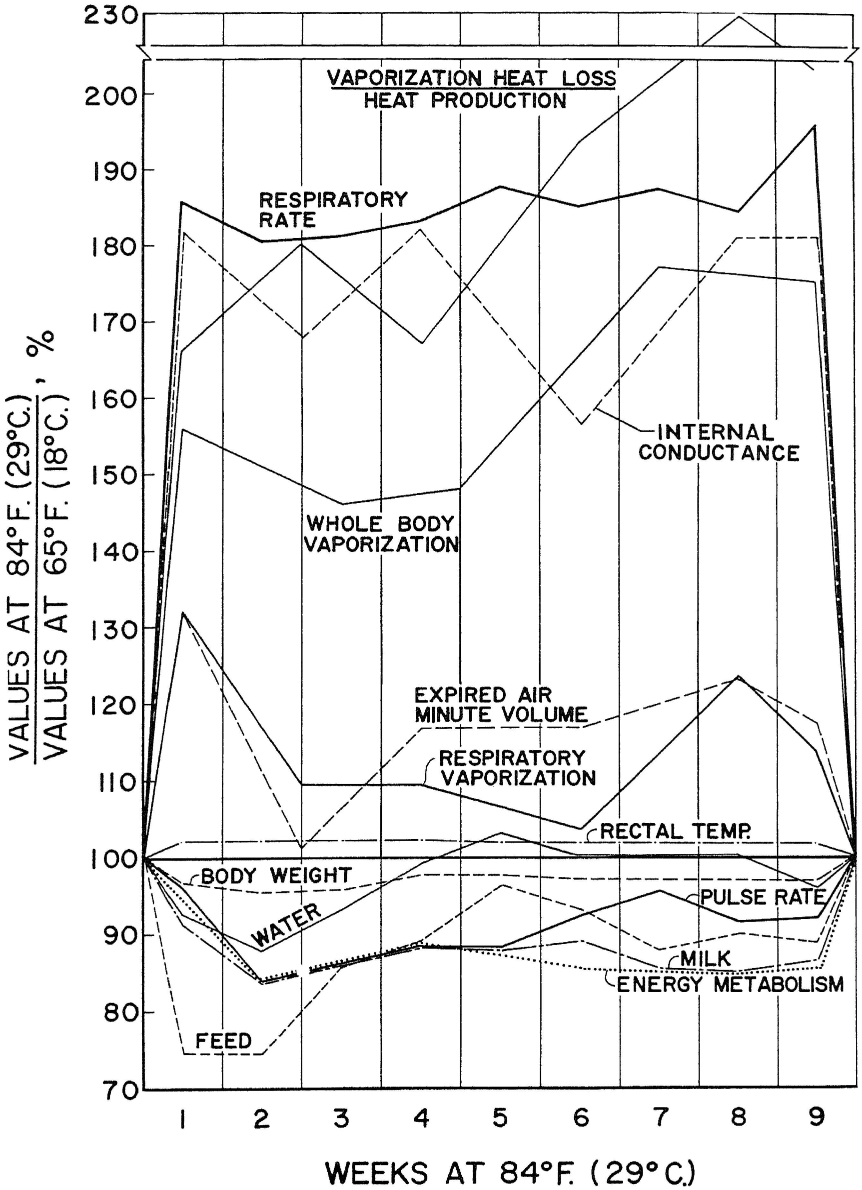

Fig. 9. Percentage changes in the heat producing and heat dissipating functions as factors in the acclimation of lactating Holstein cows to 84°F environmental temperature.

Body weight (Figure 5) decreased significantly in the lactating cows by about 20 kg during the initial exposure to 84°F temperature (Table 4). The initial decrease in weight tended to follow similar decreases in feed and water intake.[1] During continued exposure to 84°F temperature the rate of increase in body weight (Figure 7) was about the same as the rate of increase at 65°F and thus did not display an acclimation trend. Body weight recovered to a greater degree in the non-lactating than in the lactating cows.

Internal conductance, K_i was computed from the equation[11]:

$$K_i = \frac{M}{T_R - T_S}$$

where M represents metabolism expressed in k cal/m^2/24 hours. Temperatures, T are in Celsius degrees; R = rectal; S = Skin. The surface areas of the cattle were estimated from their body weights by the equation[12]

$$A = 0.15W^{.56}$$

where A is in square meters, weight in kilograms.

The great percentage rise in internal conductance from the 65°F to 84°F environmental temperature (Figure 9) indicates that the peripheral blood flow has increased either from vasodilation of blood vessels or from a decrease in vasoconstrictor tone.

DISCUSSION

The process of acclimatization to heat involves many interrelated structural and functional changes. In one view,[13] temporary acclimatization is brought about by greatly increased excitability of the thermoregulatory center and increased activities of endocrine glands. In the more permanent state of acclimatization, however, the excessive reactions are depressed by a habituation process in the higher brain center.[13] In this state, presumably, life processes are carried on with increased thermal economy. Structural changes, such as shedding of hair coat would be favored over methods of heat dissipation which require energy expenditure. Increased respiratory activity provides an example of the latter type; cooling by vaporization is increased but so is the exertion of the chest muscles. Vasodilation lowers the resistance to blood flow and thereby speeds up heat flow through the tissues (conductance) but it presumably increases the pumping requirements of the heart. Reduced activity and reduced feed consumption decrease heat production but at the cost of reduced production.

Figure 9 brings together many of the more important physiological adjustments to heat that occurred in the 10 lactating Holstein cows. Comparisons are made on a relative percentage-basis so that many physiological changes may be shown on one chart without the distraction of different absolute units.

The thermoregulatory functions were indeed stimulated during the first weeks of exposure to 84°F temperature. Compared to expected 65°F values, (100 percent) respiratory rate rose to 185 percent, internal conductance rose to 180 percent, and vaporization heat loss/heat production rose to 160 to 165 percent. Whole body vaporization rose to 155 percent of 65°F values. Minute volume of expired air and respiratory vaporization increased to 130 percent of 65°F levels. Meanwhile feed consumption, milk production, body weight, water consumption, pulse rate, and energy metabolism were all depressed below expected 65°F levels.

The changes that occurred in several of these functions during the succeeding weeks of heat exposure may explain the significant recovery trends toward 65°F levels observed in rectal temperature and pulse rate.

Milk production and feed consumption, after some fluctuations, eventually leveled off at 85 to 90 percent of expected values. Energy metabolism stabilized at 85 percent of expected value. Body weight remained three to four percent below expected value. Thus the heat stimulating functions were depressed below optimal levels for best production but did become stabilized during continued exposure to heat. A similar continued depression of metabolic levels during 30-40 days of exposure to diurnally varying temperatures, 75 to 95°F, was observed in yearling heifers.[14] This occurred even though dry matter intake and growth rate had returned to normal.

The heat dissipating functions, however, remained at elevated levels. Respiratory activity remained at about the level attained during the first weeks of exposure to heat. Water consumption, after the initial depression, returned to the expected 65°F level. Whole body vaporization and vaporization heat loss/heat production reached new high levels during the last three weeks of the 84°F period. The tissue conductance of body heat did not increase appreciably above the level attained during the first week of heat.

The increase in tissue conductance, and the functional displacements which decreased heat production were necessary to balance heat production with heat dissipation. However, the significant acclimation trend in rectal temperature and pulse rate appear to have been made possible by the progressive increase in evaporative cooling and the decrease in hair density.

Whether or not the initial rapid displacement of a function during heat exposure may be considered acclimation is open to question. A rise in body temperature may increase the rate of heat dissipation, and thus aid in establishing a new thermal equilibrium. Such a rise, however, may indicate inadequate capacity to make compensatory adjustments to maintain a desirable body temperature. The significant decrease in rectal temperature that occurred during the nine weeks of heat exposure appears to be a better indicator of acclimation than the initial rise that occurred during the first week. The continued elevation of the respiratory functions and tissue conductance, however, appears to be necessary to compensate for the decreased temperature gradient between body and environment. For these functions, it appears that a continued high displacement rather than a decreasing trend would be most effective in the acclimation complex. Shedding of the hair coat could decrease the load on the respiratory and cardiovascular systems.

In summary, the evidence indicates that the adjustments to heat resulted from a depression of productive, heat-stimulating functions coupled with an elevation of heat dissipating functions, especially vaporization. The hypothesis that acclimation to heat did occur rests mainly on the observation that significant progressive recovery trends occurred in rectal temperature and pulse rate during a nine week period. However, displacements of many functional activities from normal levels without progressive recovery seem essential to the acclimation process.

The time responses of the various measures to changes in temperature show that care must be used in planning a switch-back experiment. While equilibrium levels were reached by some functions in one to two weeks, other functions showed progressive changes for nine weeks. During the exposure to heat in this experiment, fairly stable levels of response were attained by respiration rate, skin temperature, and hair temperature in one week; by expired air minute volume, respiratory vaporization, milk production, and body weight in two to three weeks; by energy metabolism in two to four weeks; and by pulse rate in eight weeks. Body temperature and hair density were still decreasing after nine weeks.

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