

Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

LXVII. THERMAL EFFECTS OF VARIOUS TEMPERATURE-
HUMIDITY COMBINATIONS ON HOLSTEIN CATTLE
AS MEASURED BY EIGHT PHYSIOLOGICAL
RESPONSES

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LXVII. THERMAL EFFECTS OF VARIOUS TEMPERATURE-HUMIDITY COMBINATIONS ON HOLSTEIN CATTLE AS MEASURED BY EIGHT PHYSIOLOGICAL RESPONSES

INTRODUCTION

Temperature and humidity are two important factors which influence the economy of the dairy industry in various sections of the United States and in other countries. High productivity requires a high level of feed consumption and causes cattle to produce great amounts of heat which must be dissipated to the environment. High temperature limits animal heat dissipation by radiation, convection, and conduction. High humidity limits animal heat dissipation by evaporation from the outer surface and respiratory tract. Limitation of heat production (and consequently depression of milk production) therefore is influenced by the relative levels of high temperature and humidity.

Not a great deal of quantitative work has been done on the effects of combinations of temperature and humidity on lactating cattle. Earlier work¹ at the Missouri Climatic Laboratory showed that at environmental temperatures above 85° F, high humidity depressed evaporative cooling from the respiratory tract and outer surface. It also increased respiratory frequency and volume. Heat production (standing energy metabolism) was decreased in some animals and increased in others. In all instances, however, heat dissipation decreased more than heat production decreased, and all animals showed a rise in body temperature. As a consequence of these various effects, milk production and feed consumption were also depressed.² Whereas the earlier experiment usually included only one low and one high humidity condition at progressively increasing temperature, the experiment reported here covered a wide spectrum of hot-dry and hot-wet conditions as shown in Figure 1. Also, it featured scheduled switch-backs to a standard base condition to provide greater control over lactation persistency and acclimation factors. Bianca³ has pointed out that gradual progressive changes allow time for adaptive changes, as in hair coat. The switch-back design was employed to prevent or limit such adaptive changes.

The extreme variations in the temperature-humidity combinations that occur in different parts of this country are illustrated in the climograph shown in Figure 1. These data were plotted from monthly means published by the United States Weather Bureau.⁴⁻⁷ Not only do the four climates shown differ in their position on the chart, they also differ in their range of variation during the 12 months of the year. Other sections of the United States would, of course, appear in many intermediate positions on the climograph.

It would be convenient to express combinations of temperature and humidity as single index values. These index values could then be related to physiological comfort. An index called "effective temperature" was developed many years ago which established the limits

of the human comfort zone.^{8,9} The effective temperature for any air condition was set equal to the temperature of slowly moving (15 to 25 feet per minute) saturated air which induced a similar sensation of warmth or cold. "Sentient temperature," the temperature of the air at 30 percent humidity which provides the same feeling of comfort as the current air, has also been suggested as a human comfort index.¹⁰ Thom¹¹ has reviewed Bosen's development of a simple linear equation which gives a close approximation to effective temperature values.

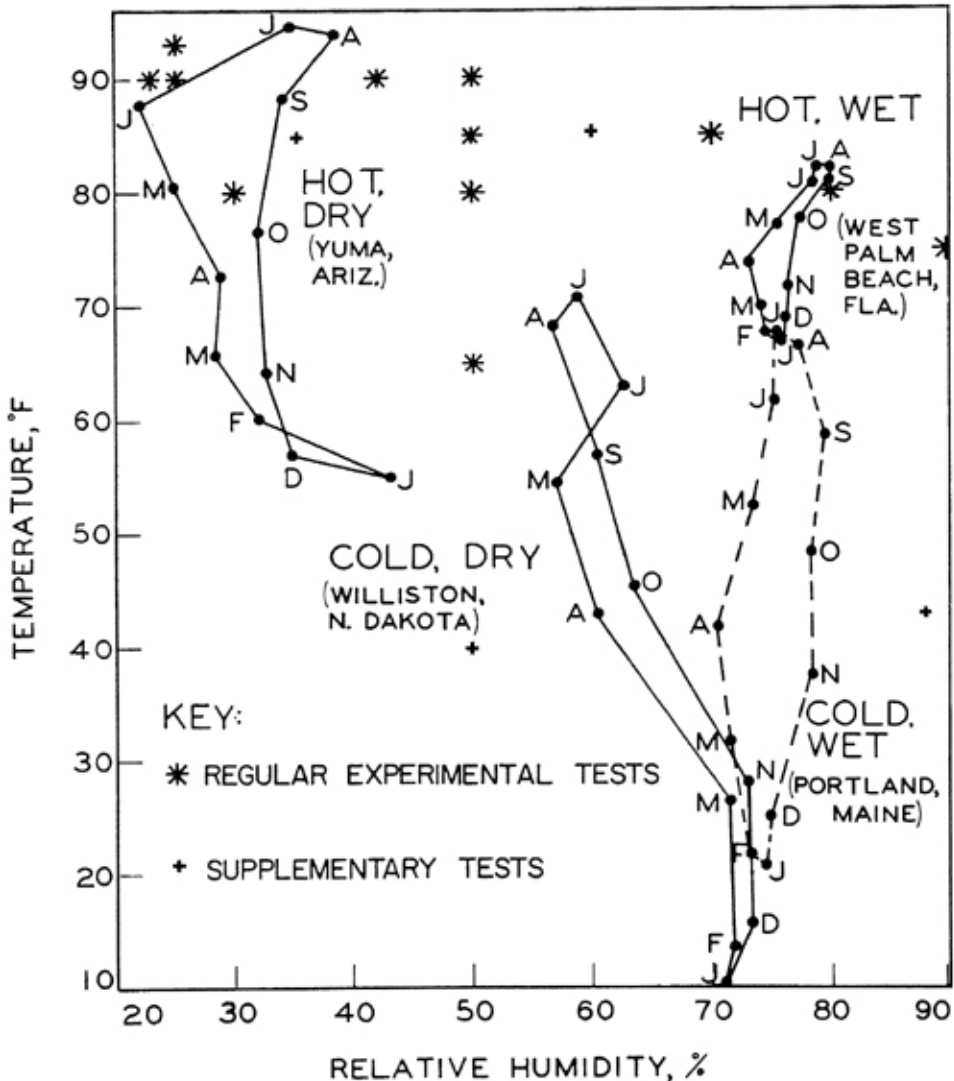


Fig. 1—Climograph showing four extreme conditions of temperature and humidity in the United States. Twelve normal monthly means identified by the first letter of month are shown for each of four cities. The large asterisks and crosses show the experimental conditions of tests reported in this bulletin.

This equation can be used to compute values known as temperature-humidity index (THI) values.

$$\text{THI} = 0.4 (T_d + T_w) + 15$$

where T_d = dry-bulb temperature, °F.

and T_w = wet-bulb temperature, °F.

The severity of climatic factors in determining comfort in cattle cannot, of course, be measured by the subjective feelings of the cattle. One objective of this experiment, therefore, was to determine the order of severity of different temperature-humidity (T-H) combinations on lactating Holstein cows by measuring and classifying the physiological responses of the animals to the different conditions. This was done for eight physiological measures during the exposure of 40 cows to 11 experimental and base conditions. Four supplementary tests were made on 12 cows under somewhat different conditions.

This bulletin (1) reports original data from experiments which were conducted between October, 1958, and March, 1962; (2) evaluates the eight physiological reactions (respiration rate, pulse rate, rectal temperature, oxygen consumption, carbon dioxide production, methane production, expired air volume, and heat production or standing metabolic rate with respect to various temperature-humidity combinations; (3) examines some of the interactions among these responses; and (4) classifies the severity (mild, moderate, or severe) of the various temperature-humidity combinations on the basis of the physiological reactions of the cattle.

As increasing U. S. Weather Bureau temperature-humidity index (THI) values have been found to be correlated with increasing milk depression, 12, 13 comparisons were made between THI values and the physiological reactions of the cattle.

METHODS

Experimental Animals

Twelve lactating Holstein cows were used during each phase of the experiment and a total of 40 different cows were included during a two year period. The milk production of these animals when they were taken into the Climatic Laboratory ranged between 25 and 75 pounds per day, depending in part on the stage of lactation.

Grain or concentrate was fed in proportion to milk production in the ratio by weight of 1 to 4. Beet pulp was fed twice daily, two pounds on a dry basis each morning and afternoon, and salt was available *ad libitum*. Finely ground alfalfa pellets were fed *ad libitum*. The pellets were obtained from different suppliers but the analyses of the different shipments were about the same. For additional information concerning the history of the cows and the composition of their feed see references 12 and 14.

Twelve cows were used in supplementary tests during the following two years. This was done to evaluate a broader psychrometric spectrum extending into lower ranges of temperature. However, as these animals were fed hay instead of pellets, and as only six were used at one time instead of 12, their data were treated separately.

Statistical Design

In planning an experimental design for this study several troublesome problems were confronted. It seemed probable that if cattle were exposed to successive temperature-humidity combinations, their current responses would be influenced by their preceding exposures. Consideration had to be given also to the persistency of lactation in a long experiment. Changes in productive level would be reflected in feed consumption, heat production, and related measures.

To overcome the foregoing problems, a switch-back or reversal design was chosen which provided a recovery period at 65° F temperature, and 50% relative humidity between exposures to all other temperature-humidity conditions. Two groups of animals were used. The A group consisting of six animals was exposed for two weeks to an experimental temperature-humidity (T-H) condition. At the same time a B group of the same number was exposed to a base condition of 65° F, 50% R.H. During the third and fourth weeks the environmental conditions were reversed for the two groups. During the fifth and sixth weeks the conditions were again reversed. An example of a reversal schedule for a 12-week period and a complete listing of all experimental conditions are shown in Table 1. The same base condition of 65° F, 50% R.H., was repeated for all experimental conditions throughout the experiment. The air velocity at cow-level in the two climatic rooms was 40 to 50 feet/minute throughout the experiment.

Six animals in each room were selected to provide two cows in early, two in middle, and two in late lactation. This balance was maintained

for long periods by adding two cows in early lactation and removing two cows in late lactation from each six-cow group every 12 weeks. Thus the same 12 cows were used for a 12-week period, but one-third were changed from one 12-week period to the next. All cows were usually changed from one year to the next.

TABLE 1. ENVIRONMENTAL SCHEDULE FOR TEMPERATURE-HUMIDITY (T-H) THREE PERIOD SWITCH-BACK STUDIES

(Cows were divided into 2 groups, A and B, of 6 cows each; Identification numbers are listed for individual cows)

FIRST 12 WEEKS OF EXPERIMENT
October 20, 1958 to January 11, 1959.

T ° F	H %	Week ⁺					
		1a	2m	3a	4m	5a	6m
65	50	A	A	B	B	A	A
80	50	B	B	A	A	B	B
		7a	8m	9a	10m	11a	12m
65	50	B	B	A	A	B	B
90	42	A	A	B	B	A	A

Group A: 793, 523, 440, 474, 473, 484

Group B: 856, 713, 804, 807, 487, 499

⁺ Measurements were made in the weeks marked "m". The weeks marked "a" were used for adjustment to the new T-H condition. In the remaining 54 weeks of the experiment during a 2-year period, the environmental conditions were maintained as shown below with 2-week switchbacks to 65° F, 50% R.H. as was done during the first 12 weeks.

(a) Jan. 12, 1959 to June 28, 1959 and (b) October 26, 1959-May 22, 1960

Weeks	Temp. ° F.	R.H., %	Cows
13-18 (a)	80	30	(A: 820, 823, 793, 523, 440, 474; B: 814, 818, 856, 713, 804, 807)
19-24 (a)	90	23	(A: 855, 852, 820, 823, 793, 523; B: 858, 849, 814, 818, 856, 713)
25-30 (a)	80	80	(A: 794, 830, 450, C818, 842, 852; B: 623, C829, U829, 880, 853, 895)
31-36 (a)	90	50	(A: 809, 864, 794, 830, 450, C818; B: 847, 813, 623, C829, U829, 880)
37-42 (b)	85	50	(A: 844, 473, 809, 864, 794, 830; B: 820, U818, 847, 813, 623, C829)
43-48 (b)	85	70	
49-54 (b)	93	25	
55-60 (b)	90	25	
61-66 (b)	75	90	

Other switchback tests were made in subsequent years for the conditions shown below. In these later tests, however, the cows were fed hay instead of fine-grind pelleted alfalfa, and only six cows were used. Also, the 65° F, 50% R.H. periods were for three weeks instead of two. These data are not included in the summary tables 4 and 5. They are shown in Figs. 2, 3, and 4.

Temp., ° F.	R.H. %	Cows
85 (c)	35	(871, 822, 842, 855, 821, 875)
85 (c)	60	
43 (d)	88	(46, 895, 851, 910, 921, 867)
40 (d)	50	

(c) March 2, 1961 to June 5, 1961

(d) November 20, 1961 to February 19, 1962

It was thought that cows in different stages of lactation would respond differently to a given experimental condition. A preliminary analysis of the data, however, showed no significant difference in the responses of the reported measures. Therefore, the classification for stage of lactation was dropped, and the data were pooled in subsequent computations.

The stability of the stage of lactation and fixed composition of the animal groups during each six-week period suggested that statistical comparisons be confined to the differences between the T-H condition and base condition within each six-week period. Similar comparisons of differences have been made by Brandt¹⁵ for reversal feeding trials.

An example of the computation of differences in physiological response between experimental T-H and base condition for 12 individual cows is given in Table 2. The differences in the right hand column show the deviation in response in the middle period as measured from the linear regression for the other two periods. These differences were then pooled and tested for significance by analyses of variance as described by Snedecor.¹⁶

Animal Measurements

Indirect calorimetry measurements of standing metabolic rate were made with a mobile, open-circuit apparatus on individual animals twice during the second week of each two-week period. The measurements were made on Tuesday and Wednesday in the experimental room (experimental T-H condition) and on Monday and Thursday in the control room (65° F., 50% R.H. base condition). These open circuit measurements also included O₂ consumption, CO₂ production, CH₄ production and psychrometric measurements necessary for determination of temperature, humidity, and pressure factors. Respiratory Vaporization Rate was also measured and will be reported with total vaporization in another bulletin. The open-circuit apparatus and accessory gas analyzers are described in detail in reference 17.

Rectal Temperature, Respiration Rate, and Pulse Rate were measured five days a week on all animals. The equipment used for these measurements were veterinary thermometer, stopwatch, and stethoscope.

All these measurements were made at the same time of day between 1:00 p.m. and 3:15 p.m. on animals which were standing quietly.

TABLE 2. RESPIRATIONS PER MINUTE AT 90° F TEMPERATURE AND 50% RELATIVE HUMIDITY (X), AND AT 65° TEMPERATURE AND 50% RELATIVE HUMIDITY (Y)

Cow No.	Period 1	Period 2	Period 3	Differences
	X_1	Y_2	X_3	$X_1 - 2Y_2 + X_3$
820	75	26	74	97
823	62	27	64	72
855	88	21	91	137
852	97	25	92	139
793	96	30	95	131
523	84	26	77	109
			Sum	685

Group B				
	Y_1	X_2	Y_3	$Y_1 - 2X_2 + Y_3$
814	30	77	34	- 90
818	28	73	22	- 96
849	30	73	25	- 91
858	26	86	26	-120
713	33	84	34	-101
856	29	82	26	-109
			Sum	-607

	A	B
Sum of differences = Sd	685	- 607
Sum of (differences) ² = Sd ²	81725.0	62079.0
(Sum of differences) ² /N = $\frac{(Sd)^2}{N}$	<u>78204.1</u>	<u>61408.2</u>
Sd ² - (Sd) ² /N	3520.9	670.8
Pooled variance	$\frac{3520.9 + 670.8}{5 + 5} = 419.17$	

Sum of squares for temperature = $[685 - (-607)]^2 / 2(6) = 139105$

ANALYSIS OF VARIANCE			
Source of variation	Degrees of Freedom	Mean square	F-ratio
Temperature	1	139105.3	331.8**
Error Variance	10	419.2	

**Indicates significance at the 0.01 level

RESULTS

The results for the major tests are shown in summary Tables 3 to 5 and Figures 2 to 5 in the text, and in Tables 6 to 21 on individual animals in the Appendix. The results for the supplementary tests are also shown in Figures 2, 3, and 4, and are recorded for individual cows in Tables 22 and 23 in the Appendix.

Variability at 65°F., 50% R.H. Base Conditions

Since the measured responses at the different temperature-humidity (T-H) conditions were all compared to the responses at the base conditions, it is important to examine the base-level responses. Table 3 shows that there was considerable variability in the mean body weights, O₂, CO₂, CH₄, and energy metabolism. Respiration rate, pulse rate, exhaled air, and rectal temperature were moderately variable. Great variability at the base condition occurred only when the individual animals had been changed in the 12-cow groups. For the two

TABLE 3. STATISTICAL CONSTANTS FOR SECOND-WEEK PERIOD AVERAGES AT 65° F TEMPERATURE AND 50% RELATIVE HUMIDITY

Measurement	Number of Weekly Averages ^a	Mean	Standard Deviation	Standard Error
Respirations per minute	240	33.7	9.1	0.6
Pulse rate (minute)	240	66.2	8.1	0.5
Rectal temperature °F	240	101.45	0.25	0.016
°C	240	38.58	0.14	0.009
Metabolic rate, k cal/hr.	234	761	158	10.3
Exhaled air, liters/minute	234	90.6	19.2	1.3
O ₂ consumption, l/hr.	234	155	33.0	2.2
CO ₂ production, l/hr.	234	141	29.7	1.9
CH ₄ production, l/hr.	234	7.8	5.3	0.35
Respiratory Vaporization ^b , g/hr.	234	140	47.1	3.1
Body weight lb.	234	1220	107.6	7.0
kg.	234	553	48.8	3.2

^a Averages for each second-week period at 65°F, 50% R.H. for individual cows. Two measurements were made on each cow during each second-week period for O₂, CO₂, CH₄, metabolic rate, and respiratory vaporization. Five such measurements were made on each cow for respiration rate, pulse rate, and rectal temperature.

^b Respiratory vaporization will be discussed in a later report.

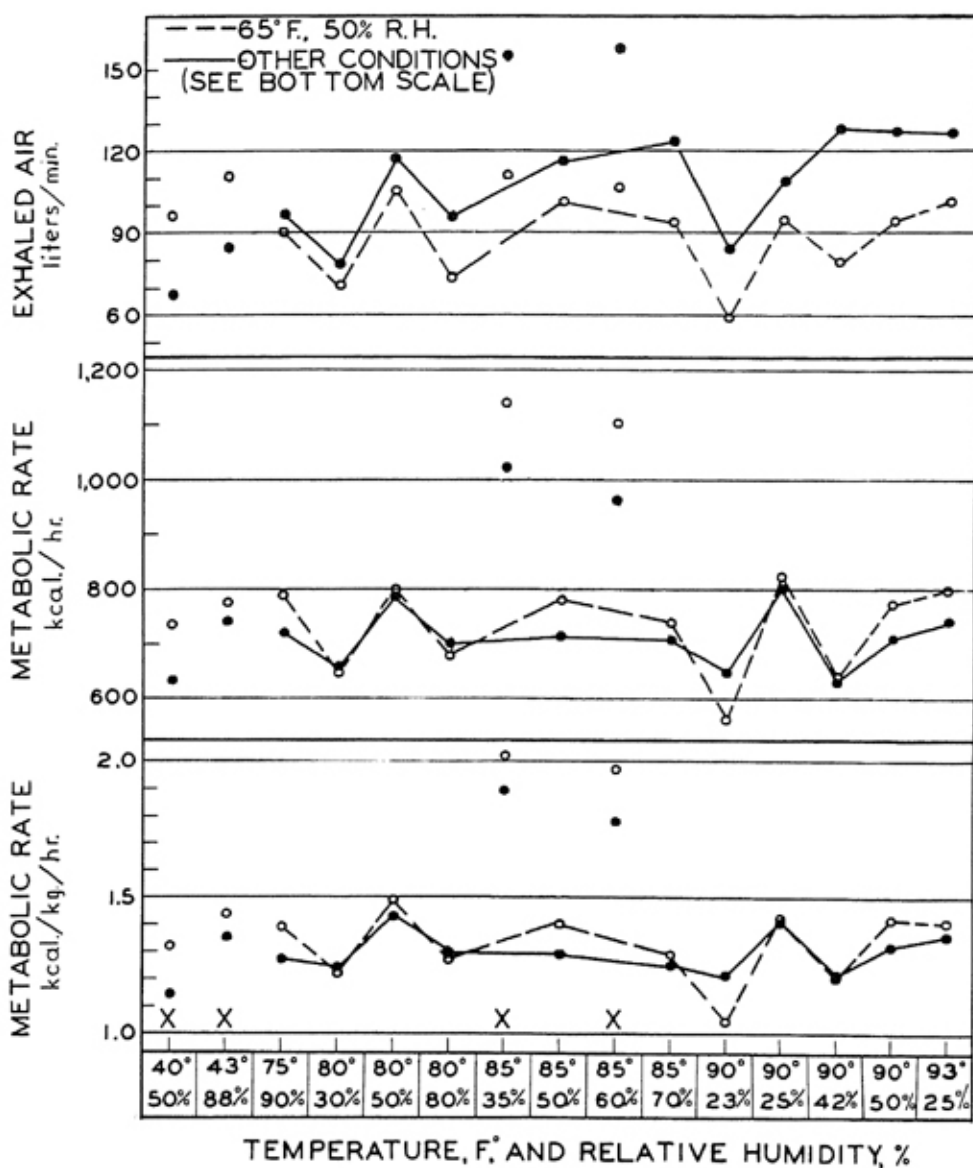


Fig. 2—Changes in the volume of air expired per minute and in energy metabolism in all cows at base condition (65° F, 50% R.H.) and at other values of temperature and humidity. The four supplementary tests marked X were not conducted under the same conditions as the regular tests (see text) and are not comparable to the regular tests on an absolute basis. However, they do show the relative effects of 35% and 85% R.H. at 85° F temperature.

six-week tests within each 12-week period, the cows were unchanged (Table 1) and the base levels were similar. For example, the base level values of exhaled air during reversals from 80° F, 80% R.H., and 90° F, 50% R.H., were measured in the same 12-week period and were similar (Fig. 2). However, the values obtained during the reversals from 80° F, 80% R.H. and 80° F., 50% R.H., were measured on different

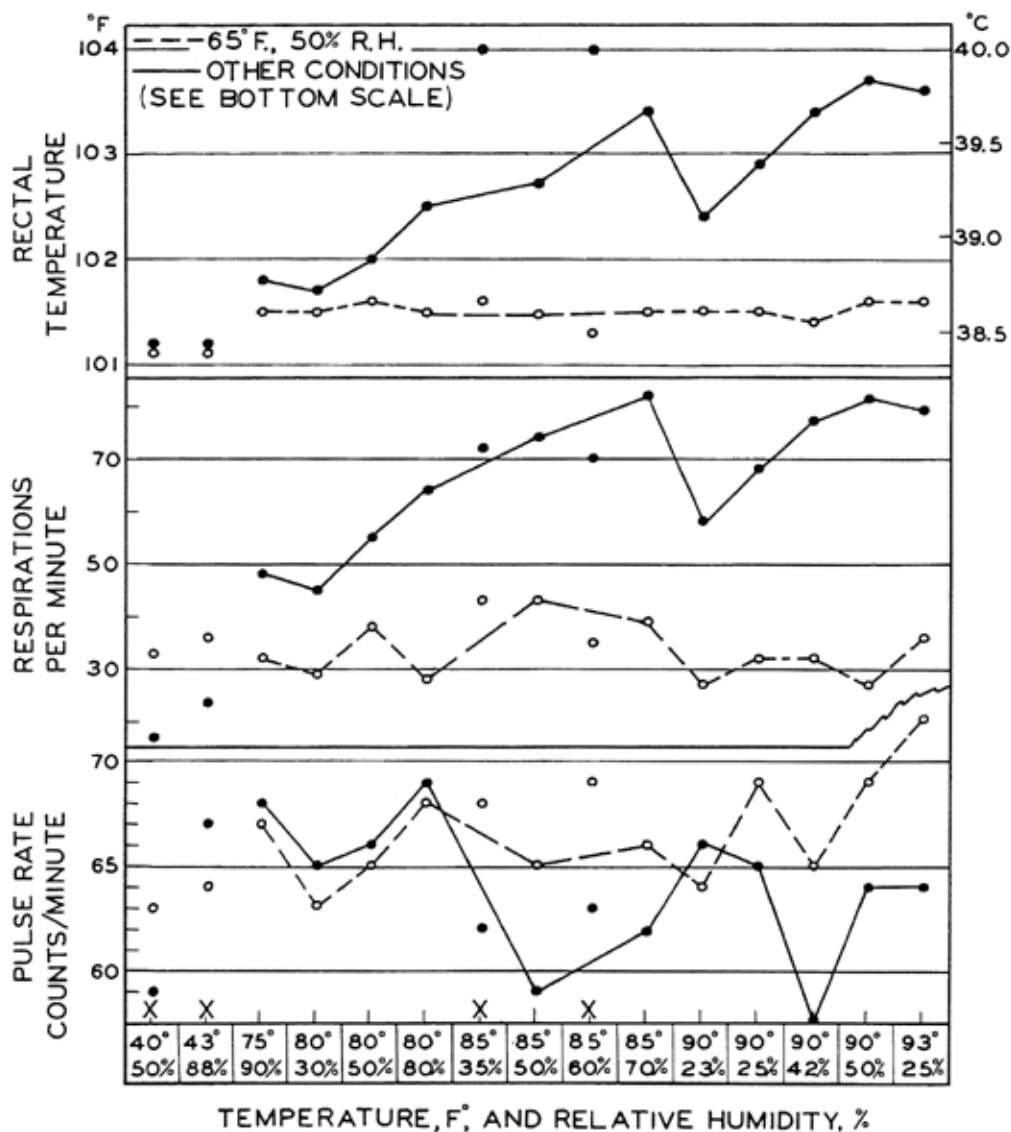


Fig. 3—Changes in rectal temperature, respirations per minute, and pulse rate in all cows at base condition (65° F., 50% R.H.) and at other values of temperature and humidity. The four supplementary tests at the condition marked X were not conducted under the same conditions as the regular tests (see text) and are not comparable with the regular tests on an absolute basis. However, they do show the relative effects of 35% and 85% relative humidity at 85° F. temperature.

cows, and were quite different. It is noteworthy that the rectal temperature and respiration rate were fairly stable at the 65° F., 50% R.H., base condition for all animals (Fig. 3).

Because of the shifts in base-level that occurred in most of the measurements; all tests of significance were made on differences be-

tween base and experimental levels within each six-week period. No change in animals occurred during these six-week periods.

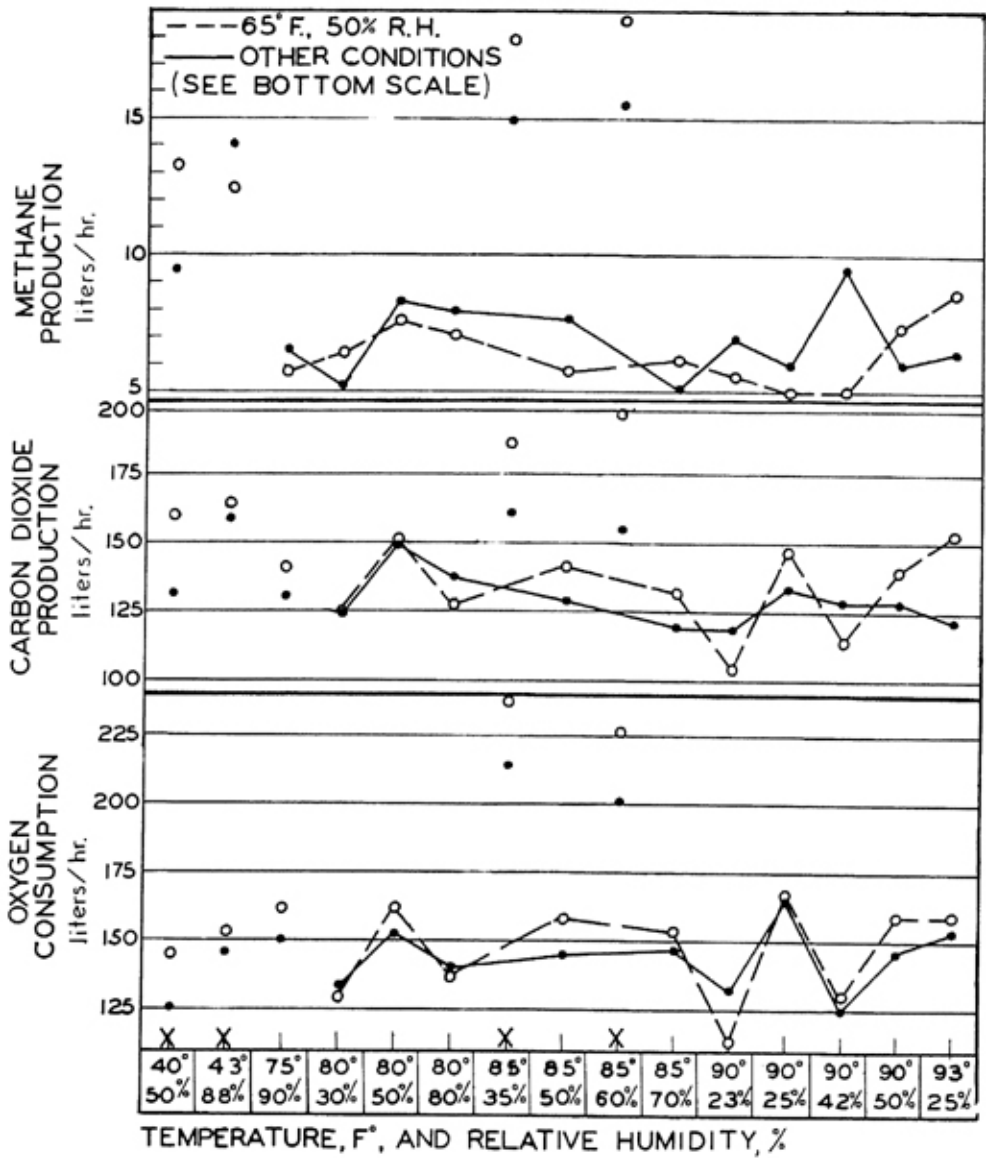


Fig. 4—Changes in methane production, carbon dioxide production, and oxygen consumption in all cows at base conditions (65° F., 50% R.H.) and at other values of temperature and humidity. The four supplementary tests at the conditions marked X were not conducted under the same conditions as the regular tests on an absolute basis. However, they do show the relative effects of 35% and 85% relative humidities at 85° F temperature.

TABLE 4. RESPONSES^a OF LACTATING HOLSTEIN COWS TO VARIOUS TEMPERATURES AND HUMIDITIES

(Averages for groups of 12 cows--4 early, 4 middle, and 4 late lactation--during second week at each condition.)

Environmental Temperature °F	Environmental Temperature °C	Relative Humidity %	Body Weight kg	Rectal Temperature °C	R. P. M. ^b	Pulse Rate (minute)	Standing Metabolic Rate k cal/hr	Exhaled air ^c l/min	O ₂ Consumption ^c l/hr	CO ₂ Production ^c l/hr	CH ₄ Production ^c l/hr
65	18.3	50	568	38.6	32	67	789	90	161	141	5.7
75	23.9	90	569	38.8*	48**	68	719**	97**	150	130*	6.5
65	18.3	50	531	38.6	29	63	645	71	129	125	6.4
80	26.7	30	528	38.7**	45**	65	653	79**	134	125	5.2
65	18.3	50	538	38.7	38	65	797	105	162	151	7.6
80	26.7	50	533**	38.9*	55**	66	785	118**	153	149	8.3
65	18.3	50	535	38.6	28	68	676	74	137	127	7.1
80	26.7	80	539	39.2**	64**	69	699	96**	140	137**	8.0
65	18.3	50	560	38.6	43	65	778	101	158	142	5.8
85	29.4	50	555	39.3**	74**	59**	711**	117**	145**	128**	7.7
65	18.3	50	577	38.6	39	66	738	94	154	127	6.2
85	29.4	70	569	39.7**	82**	62*	707	124**	147	120	5.1
65	18.3	50	539	38.6	27	64	560	59	113	104	5.6
90	32.2	23	538	39.1**	58**	66	648**	85**	132**	119*	7.0
65	18.3	50	576	38.6	32	69	823	95	168	147	5.0
90	32.2	25	570*	39.4**	68**	65**	800	110**	166	134**	6.0
65	18.3	50	530	38.6	32	65	634	80	130	114	5.0
90	32.2	42	525**	39.7**	77**	57**	632	129**	126	128*	9.5*
65	18.3	50	551	38.7	27	69	774	95	159	140	7.4
90	32.2	50	543*	39.8**	81**	64**	710**	128**	146*	129*	6.0
65	18.3	50	569	38.7	36	72	798	102	160	153	8.6
93	33.9	25	544**	39.8**	79**	64**	741	127**	154	122**	6.4

^a A significant difference from the base level at 65°F, 50% R.H. is indicated by ** for the .01 and by * for the .05 level of significance. Measurements were made between 1:00 and 3:15 p.m. on standing animals. Pelleted alfalfa hay was fed ad libitum. Grain and pelleted hay were given before the a. m. and p. m. milkings.

^b Respirations per minute.

^c All volumes have been adjusted to standard temperature, 0°C, and pressure, 760 mm Hg, for dry air.

Experimental Conditions

The results of the tests of significance are given in Table 4 for the 11 experimental conditions scheduled during the two years in which the cattle were fed pelleted hay.

The responses at the experimental conditions were all significantly different from the responses at the base conditions for rectal temperature, respiration rate, pulse rate and volume of air exhaled per minute.

Pulse rate was not significantly altered by the milder experimental conditions, Table 4, but it was significantly depressed by many of the more severe conditions. In all but one instance in which heat production was depressed, the pulse rate was also depressed. Body weight was more variable but was significantly depressed by temperatures of 90° F or above, except at the lowest humidity conditions (23%).

Standing metabolic rate and oxygen consumption were depressed by the most severe conditions, but the differences were not generally statistically significant. The greater variability in these two measurements may be attributed to several causes. Among these are:

1. Compensating reactions to increased thermal load. Heat production tends to decrease with decreasing feed intake but tends to increase with increasing respiratory effort. Rising body temperature also tends to increase heat production through the van't Hoff effect.
2. Temporary effects caused by changes in the palatability of different shipments of pelleted hay
3. Incomplete adjustments to the experimental conditions in some individual animals at the time measurements were made.

Additional variability in CO₂ and CH₄ production may have occurred as a result of changes in rumen function with changes in thermal load since all of the CH₄ and part of the CO₂ were produced in the rumen.

Supplementary Tests

The four temperature-humidity conditions for these tests are shown at the bottom of Table 1. The results are included in Figures 2, 3, and 4. Significant changes from the base conditions occurred at the two highest temperatures for all measurements except heat production at 85° F., 35% R.H., and CH₄ at both conditions. At the two lower temperatures only respiratory frequency and volume of air exhaled per minute were significantly affected by both conditions. CO₂, O₂, and pulse rate differed significantly from the base level at the 40° F, 50% R.H. condition. No significant changes occurred in the other measurements at the low temperatures.

In general, respiratory activity was increased by the two hot conditions and depressed by the two cool conditions. Energy metabolism was depressed by 85° F., 60% R.H., but it was not altered significantly by the cool conditions.

Comparative Effects of Temperature-Humidity Conditions

Figure 5 shows how much the 11 combinations of temperature and humidity of the comparable tests increased or decreased the eight measurements from their base levels at 65° F., 50% R.H. Since the differences from base levels were less affected by changes of the animals than the measurements themselves it is possible to estimate the relative effects of the different experimental conditions. It is evident that all 11 experimental conditions increased respiration rate, rectal temperature, and expired air above their 65° F., 50% R.H. levels. Table 5 shows which T-H combinations caused similar reactions and which combinations caused different reactions. It was found that the 11 conditions separated on the basis of THI values into three distinct groups designated as mild, moderate, and severe. Analyses of variance showed that the differences in reactions to the mild, moderate, and severe conditions were all significantly greater than the differences in reactions within the three conditions. The four respiratory exchange measurements did not show as consistent changes with increased temperature and humidity (see Table 4) for the reasons discussed in a preceding section. However, there was a tendency for heat production, carbon dioxide production, and oxygen consumption to be depressed by combinations of high temperature and high humidity.

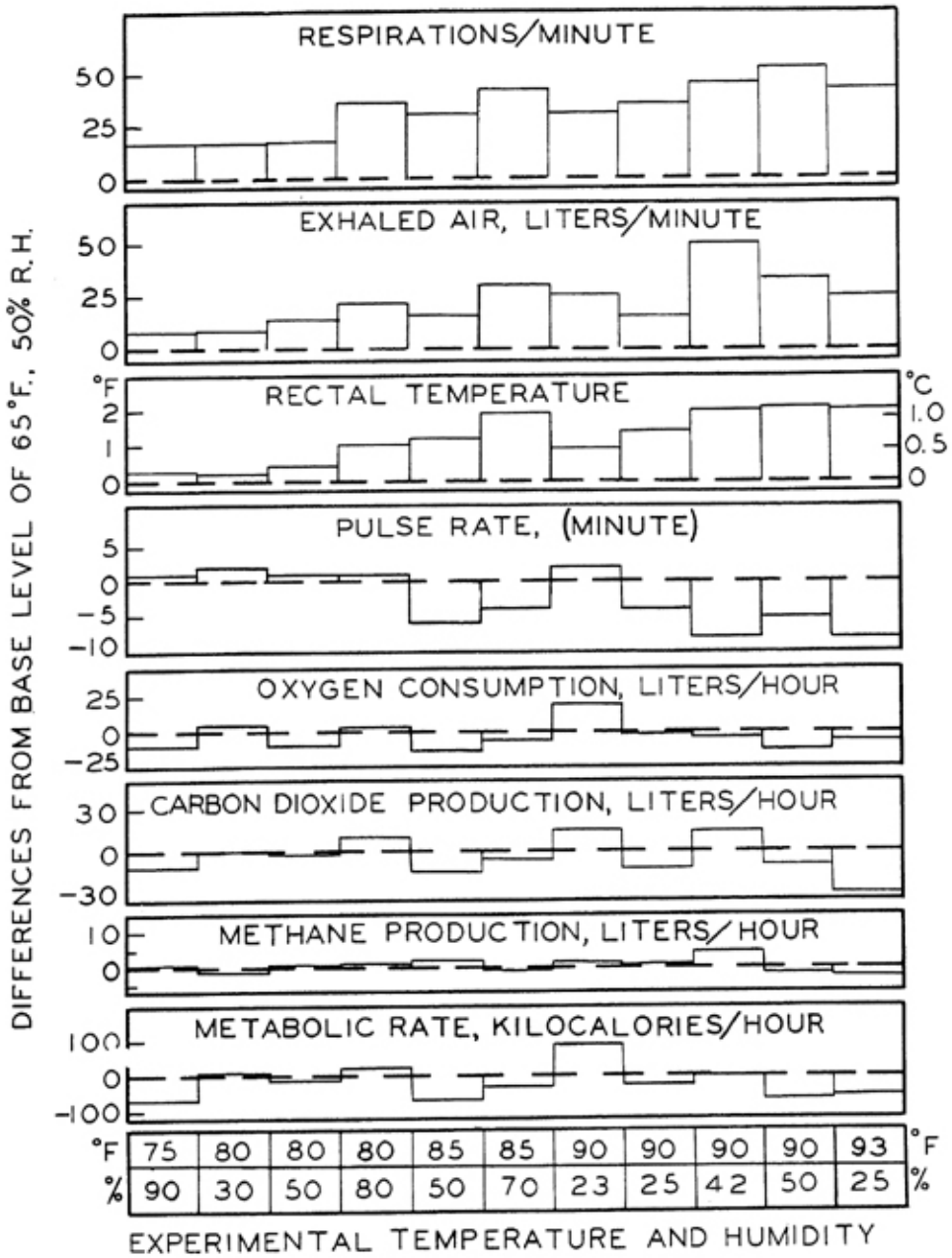


Fig. 5—Comparative effects of different combinations of temperature and humidity in altering eight physiological measures from their base levels at 65°F, 50% R.H. This chart summarizes the 11 regular tests conducted between October, 1958, and May, 1960. The supplementary tests of 1961 and 1962 were omitted as they were conducted under somewhat different conditions and with fewer animals.

TABLE 5. INCREASES IN RESPIRATION RATE, PULSE RATE, RECTAL TEMPERATURE, AND VOLUME OF EXPIRED AIR WITH INCREASING ENVIRONMENTAL TEMPERATURE AND HUMIDITY ABOVE BASE LEVELS OF 65° F., 50% R.H.

Condition	Temperature ° F	Relative Humidity %	THI ^a	Increases (Experimental level less base level)			
				R. P. M. ^e	Pulse Beats Min.	Rectal Temp. ° F	Expired air (STP) liters minute
Mild ^b	75	90	74.1	16	+1	0.3	7
	80	30	71.1	16	+2	0.2	8
	80	50	73.7	17	+1	0.4	13
Moderate ^c	85	50	77.3	31	-6	1.2	16
	90	23	76.8	31	+2	0.9	26
	90	25	77.1	36	-4	1.4	15
	80	80	77.1	36	+1	1.0	22
Severe ^d	93	25	79.0	43	-8	2.0	25
	85	70	79.8	43	-4	1.9	30
	90	42	79.8	45	-8	2.0	49
	90	50	81.0	54	-5	2.1	33

^a The differences in reactions between the mild, moderate, and severe conditions were all significant ($P < .05$ for pulse rate and $< .01$ for the other measures) with respect to the differences within the three conditions. The classifications were made on the basis of THI values computed for average daily conditions. See text for discussion of THI.

^b THI values in the mild range occur during June in Missouri.

^c THI values in the moderate range occur during June in several southern coastal states of the United States.

^d THI values in the severe range occur for a month in hot and arid sections (July in Yuma, Arizona) and in humid southern coastal areas (August in Brownsville, Texas). Other areas of the United States experience moderate or severe conditions for shorter periods of time.

^e Respirations per minute.

SUMMARY

Lactating Holstein cows were exposed to various combinations of temperature and humidity in a switchback or reversal experiment. Forty animals were used during 11 tests and 12 animals were used in four supplementary tests in which the environmental conditions were slightly different. The objective of the experiment was to measure the gradations in the physiological reactions of the cattle to the various conditions and thereby classify the various temperature-humidity combinations with respect to their thermal effects.

Data are reported in this bulletin for respiration and pulse rates, rectal temperature, heat production or energy metabolism, expired air volume, oxygen consumption, carbon dioxide production, and methane production. Statistical analyses showed that exposure to 11 temperature-humidity conditions at temperatures of 75° F. or higher caused significant increases from base levels (65° F, 50% R.H.) in rectal temperature, respiration rate, and volume of expired air. Pulse rate was significantly depressed by six out of seven temperature-humidity combinations for temperatures of 85° F or higher. Changes from base level were less consistent in heat production, oxygen consumption, and carbon dioxide and methane production because of compensating reactions (decreased feed consumption versus increased respiratory exertion).

The 11 experimentally comparable temperature-humidity combinations separated into three statistically significant levels of severity based on U. S. Weather Bureau temperature-humidity index (THI) values for man. The physiological responses of the cattle for respiration rate, rectal temperature, pulse rate, and expired air volume also separated into three statistically significant levels of response ($P < .05$ for pulse rate; $P < .01$ for the other three measures) when they were classified with respect to increasing values of THI. The close relationship of the magnitude of the responses of these measures to increasing THI values indicates that the THI values may be applicable to cattle as well as to man.

The three T-H conditions which caused the least change from base levels at 65° F, 50% R.H., in the four measures were 75° F, 90% R.H.; 80° F, 30% R.H.; and 80° F, 50% R.H. The THI values for these mild conditions are included within the range 71.1 to 74.1.

The four conditions which caused moderate responses in the four measures were 85° F, 50% R.H.; 90° F, 23% R.H.; 90° F, 25% R.H.; and 80° F, 80% R.H. For these conditions the THI values were within the range 76.8 to 77.3.

The four conditions which caused the greatest responses in the four measures were 95° F, 25% R.H.; 85° F, 70% R.H.; 90° F, 42% R.H.; and 90° F, 50% R.H. For these severe conditions the THI values were within the range 79.0 to 81.0.

The mild condition occurs in June in Missouri for periods lasting up to one month. At this time some of the southern coastal states are experiencing the moderate condition. The severe condition lasts for as

much as a month in some hot arid areas (July in Yuma, Arizona) and in humid coastal areas (August in Brownsville, Texas). Other areas of the United States experience either intermediate or severe temperature-humidity conditions for shorter periods.

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APPENDIX

The following tables (6 to 23) summarize the data on individual animals.

TABLE 6. RECTAL TEMPERATURE, °F. AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		101.6	101.4	101.3	101.5	101.4	101.4	80	50	102.2	102.0	102.0	101.8	103.2	101.6
80	50		102.0	102.4	101.6	101.7	101.9	101.5	65	50	101.6	102.3	101.5	101.7	101.7	101.5
65	50		101.6	101.5	101.2	101.6	101.4	101.5	80	50	102.4	101.7	101.9	101.8	102.6	102.0
90	42		105.4	104.8	105.0	105.3	103.3	102.6	65	50	101.9	101.6	101.7	101.6	101.6	101.9
65	50		101.4	100.9	100.8	101.3	100.8	101.5	90	42	103.0	102.5	103.0	102.4	104.6	103.1
90	42		103.4	102.8	103.9	102.7	101.8	102.1	65	50	101.3	101.6	101.5	101.3	101.3	101.9
°F.	% R.H.	Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		101.5	101.4	101.5	101.2	101.0	101.3	80	30	102.3	102.0	102.0	101.8	101.6	101.7
80	30		101.5	101.8	101.6	101.6	101.5	101.9	65	50	101.4	101.8	101.7	101.6	101.7	101.4
65	50		101.5	101.4	101.6	101.3	101.3	101.2	80	30	101.7	101.8	101.9	101.8	101.5	101.5
90	23		101.7	102.3	102.4	102.2	102.5	102.0	65	50	101.3	101.4	101.7	101.7	101.5	101.5
65	50		101.4	101.3	101.8	101.2	101.2	101.2	90	23	102.6	104.2	102.4	101.9	101.9	102.0
90	23		101.8	102.3	101.8	102.2	103.9	102.2	65	50	101.5	101.3	101.7	101.8	101.5	101.6
°F.	% R.H.	Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		101.5	101.3	101.2	101.4	101.5	101.3	80	80	102.5	102.5	103.9	104.5	101.9	102.4
80	80		101.8	102.1	102.0	103.6	101.9	101.9	65	50	101.2	101.6	101.4	101.6	101.9	101.7
65	50		101.5	101.3	101.5	101.3	101.6	101.4	80	80	102.7	102.1	102.3	103.4	101.9	102.4
90	50		102.6	102.9	102.8	104.8	103.7	104.1	65	50	101.5	101.6	101.3	101.5	102.0	101.8
65	50		101.9	101.4	101.6	101.4	101.7	101.3	90	50	104.8	103.1	103.2	105.2	101.9	103.3
90	50		102.6	103.3	103.8	104.1	104.1	104.2	65	50	101.3	101.6	101.2	101.2	101.9	101.6

TABLE 7. RECTAL TEMPERATURE, °F. AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		101.5	101.3	101.4	101.5	101.5	101.4	85	50	102.9	101.5	101.9	103.4	102.6	102.6
85	50		102.5	104.4	103.3	102.2	101.7	102.9	65	50	101.5	101.6	101.3	101.7	101.6	101.5
65	50		101.5	101.5	101.7	102.6	101.5	101.4	85	50	103.3	101.3	101.8	102.6	103.2	102.5
85	70		104.1	105.0	104.8	102.6	102.2	103.3	65	50	101.4	101.6	101.3	101.5	101.6	101.6
65	50		101.1	101.3	101.4	102.1	101.7	101.2	85	70	103.6	102.0	103.9	104.3	104.1	102.3
85	70		103.7	104.8	104.4	102.5	101.8	103.1	65	50	101.5	101.4	101.4	101.4	101.6	101.5
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		101.7	101.6	101.5	101.3	101.7	102.0	93	25	101.9	102.5	104.9	102.1	102.5	104.3
93	25		103.1	105.0	101.3	105.2	105.2	102.4	65	50	101.7	101.4	101.6	101.7	101.5	101.8
65	50		101.4	101.3	101.5	101.1	101.3	102.0	93	25	105.0	104.5	105.2	102.1	102.7	103.9
90	25		102.7	102.9	102.5	105.0	104.2	102.2	65	50	101.2	101.5	101.4	101.7	101.6	101.6
65	50		101.4	101.9	101.5	101.3	101.3	101.9	90	25	102.8	103.5	103.9	102.1	101.9	102.0
90	25		102.3	102.5	102.4	104.8	103.5	101.8	65	50	101.3	101.5	101.4	101.6	101.6	101.6
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		101.6	101.2	101.7	101.3	101.3	101.1	75	90	101.5	101.6	101.5	102.0	102.1	101.6
75	90		101.6	101.6	101.5	102.8	101.5	101.8	65	50	101.7	101.5	101.5	101.6	101.5	101.9
65	50		101.1	101.4	101.6	101.8	101.3	101.4	75	90	101.7	101.6	101.7	102.1	102.0	101.6

TABLE 8. RESPIRATIONS PER MINUTE WITHOUT MASK. AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R. H.	Cow No.	793	523	440	474	473	484	°F.	% R. H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		38	24	35	29	38	24	80	50	64	78	40	51	79	56
80	50		57	47	54	54	54	32	65	50	34	56	40	36	50	40
65	50		45	32	33	32	43	31	80	50	51	67	49	51	72	51
90	42		82	77	80	80	79	67	65	50	37	53	35	34	44	29
65	50		34	32	28	26	29	23	90	42	76	95	67	91	80	65
90	42		82	72	81	65	71	69	65	50	28	39	23	29	29	32
		Group A								Group B						
°F.	% R. H.	Cow No.	820	823	793	523	440	474	°F.	% R. H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		37	36	38	22	30	22	80	30	64	63	36	42	42	52
80	30		51	53	43	30	34	43	65	50	45	33	26	24	23	28
65	50		32	30	20	27	22	23	80	30	38	56	32	47	46	46
90	23		53	59	76	50	64	54	65	50	21	31	23	26	22	22
65	50		28	33	37	22	26	21	90	23	54	71	49	58	56	66
90	23		42	51	54	54	82	51	65	50	28	22	31	33	22	23
		Group A								Group B						
°F.	% R. H.	Cow No.	820	823	855	852	793	523	°F.	% R. H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		27	27	24	36	30	18	80	80	55	57	84	83	60	63
80	80		50	54	62	94	57	45	65	50	28	22	34	33	23	29
65	50		26	24	28	30	32	23	80	80	58	61	72	78	64	63
90	50		75	62	88	97	96	84	65	50	30	28	30	26	33	29
65	50		26	27	21	25	30	26	90	50	77	73	73	86	84	82
90	50		74	64	91	92	95	77	65	50	34	22	25	26	34	26

TABLE 9. RESPIRATIONS PER MINUTE WITHOUT MASK. AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R. H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R. H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		49	58	52	38	36	31	85	50	87	54	78	69	92	75
85	50		70	79	88	70	59	82	65	50	45	33	50	26	59	46
65	50		39	40	58	31	40	34	85	50	83	48	60	59	111	72
85	70		79	73	105	62	70	74	65	50	44	28	50	32	43	36
65	50		29	36	64	32	30	32	85	70	115	60	93	82	98	68
85	70		74	78	102	71	68	85	65	50	53	30	42	29	54	38
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R. H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		34	48	31	32	54	25	93	24	64	60	118	62	75	84
93	25		78	82	78	74	107	64	65	50	36	34	50	29	37	26
65	50		36	43	28	33	50	22	93	25	69	70	111	64	61	82
90	25		71	70	71	75	91	63	65	50	31	24	49	31	30	27
65	50		30	31	25	31	45	26	90	25	57	62	94	61	66	56
90	25		58	64	74	66	84	62	65	50	31	28	49	32	35	26
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R. H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		50	47	36	32	22	29	75	90	46	50	34	38	74	45
75	90		47	68	41	47	36	53	65	50	32	25	28	23	41	31
65	50		34	42	25	27	24	32	75	90	42	42	35	49	66	45

* 4 measurements (New Year's Day)

TABLE 10. PULSE RATE (PER MINUTE). AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R. H.	Cow No.	793	523	440	474	473	484	°F.	% R. H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		69	62	63	58	65	66	80	50	65	70	73	62	71	70
80	50		74	60	64	55	63	66	65	50	65	69	72	65	74	63
65	50		74	59	61	56	60	60	80	50	73	71	71	64	68	68
90	42		62	62	60	57	56	61	65	50	74	74	73	66	72	74
65	50		68	57	60	60	56	65	90	42	60	61	60	53	49	64
90	42		61	54	54	49	52	57	65	50	62	59	62	58	72	77
°F.	% R. H.	Cow No.	820	823	793	523	440	474	°F.	% R. H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		69	69	70	57	66	61	80	30	70	69	76	70	64	68
80	30		69	66	71	57	65	53	65	50	69	67	66	60	60	64
65	50		62	60	62	58	59	55	80	30	57	64	71	58	69	60
90	23		66	63	67	59	60	53	65	50	58	63	66	66	62	57
65	50		68	64	63	62	66	56	90	23	60	64	76	66	70	67
90	23		71	66	73	62	70	61	65	50	65	68	74	70	66	58
°F.	% R. H.	Cow No.	820	823	855	852	793	523	°F.	% R. H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		70	70	70	72	70	66	80	80	77	69	69	74	61	80
80	80		66	66	67	67	71	69	65	50	67	62	71	66	65	78
65	50		71	66	66	67	68	67	80	80	70	63	70	65	64	68
90	50		66	58	58	65	67	65	65	50	68	62	70	69	62	68
65	50		71	63	61	68	71	72	90	50	69	59	64	62	60	68
90	50		64	62	61	65	67	64	65	50	77	68	72	79	67	74

TABLE 11. PULSE RATE (PER MINUTE). AVERAGES OF 5 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		66	74	62	58	60	75	85	50	62	61	65	60	68	56
85	50		55	51	67	54	50	63	65	50	72	55	72	66	76	56
65	50		65	66	68	59	52	66	85	50	58	57	70	62	66	52
85	70		61	58	62	59	55	67	65	50	72	60	74	71	73	66
65	50		66	69	65	58	54	65	85	70	60	65	67	59	62	55
85	70		59	60	65	64	66	69	65	50	78	63	74	66	83	59
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		70	63	70	75	81	60	93	25	72	59	66	66	75	64
93	25		56	59	60	58	72	63	65	50	70	65	85	64	81	75
65	50		67	61	76	76	76	69	93	25	56	56	77	69	75	64
90	25		65	59	65	60	65	63	65	50	60	72	79	65	71	69
65	50		69	59	73	66	70	66	90	25	62	66	67	67	76	66
90	25		64	60	67	64	64	63	65	50	62	78	83	68	80	73
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		66	67	70	54	62	71	75	90	64	62	64	70	79	68
75	90		60	64	70	67	66	74	65	50	68	64	63	73	79	68
65	50		48	62	66	63	71	72	75	90	63	66	70	70	73	69

TABLE 12. EXHALED AIR VOLUME, STP, LITERS/MINUTE. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		118	78	94	109	101	109	80	50	109	139	121	119	156	123
80	50		125	114	87	121	101	98	65	50	99	143	108	104	120	99
65	50		115	89	89	101	89	91	80	50	121	160	121	107	151	107
90	42		187	137	157	172	155	129	65	50	101	114	121	103	105	82
65	50		69	57	63	70	64	72	90	42	122	136	125	124	136	110
90	42		114	107	119	113	103	89	65	50	67	80	66	70	75	72
°F.	% R.H.	Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		77	77	72	57	65	69	80	30	105	88	85	111	85	74
80	30		85	84	64	67	63	76	65	50	82	92	68	87	67	80
65	50		69	61	56	50	42	52	80	30	80	82	68	92	63	74
90	23		71	86	78	75	75	80	65	50	52	63	55	60	50	56
65	50		58	63	57	51	51	55	90	23	88	111	83	118	85	77
90	23		76	78	82	70	48	85	65	50	70	71	69	88	50	66
°F.	% R.H.	Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		84	85	50	68	74	62	80	80	99	101	94	109	102	95
80	80		85	103	75	113	89	76	65	50	83	85	71	70	86	77
65	50		80	76	62	64	70	54	80	80	106	106	102	106	104	93
90	50		112	105	114	139	137	136	65	50	120	98	96	88	93	98
65	50		98	101	77	89	99	103	90	50	136	139	136	138	137	141
90	50		94	108	103	126	122	123	65	50	113	90	86	77	84	96

TABLE 13. EXHALED AIR VOLUME, STP, LITERS/MINUTE. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A						Group B								
°F.	%R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	%R.H.	C-623	U-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		95	112	113	92	97	84	85	50	108	109	128	114	112	121
85	50		108	145	124	112	90	121	65	50	101	100	113	101	98	105
65	50		100	100	110	89	97	96	85	50	133	105	122	116	126	116
85	70		131	132	135	117	105	124	65	50	96	94	109	103	100	100
65	50		84	90	103	87	85	79	85	70	134	124	146	127	121	92
85	70		116	130	135	123	114	124	65	50	98	103	107	82	118	95
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	%R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		108	96	110	111	119	101	93	25		110	146	120	154	150
93	25		108	135	115	134	132	116	65	50	112	82	96	104	111	101
65	50		94	90	98	100	109	92	93	25	129	110	139	115	138	129
90	25								65	50	93	82	90	113	111	93
65	50		92	86	92	97	95	91	90	25	102	94	123	111	111	104
90	25		106	111	111	129	114	102	65	50	98	76	93	113	112	99
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	%R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		109	98	95	88	82	101	75	90	93	70	92	92	101	108
75	90		91	97	100	98	97	110	65	50	94	85	86	82	91	104
65	50		77	86	82	90	78	94	75	90	95	92	96	101	87	106

TABLE 14. STANDING METABOLIC RATE, kcal/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		869	736	883	768	685	796	80	50	620	829	851	896	824	759
80	50		880	677	777	676	579	653	65	50	736	727	794	730	1019	798
65	50		859	687	865	808	713	805	80	50	831	876	821	744	922	720
90	42		654	634	863	596	658	640	65	50	740	778	849	795	856	740
65	50		598	486	625	603	539	598	90	42	687	618	680	629	600	577
90	42		638	534	627	643	575	515	65	50	545	573	605	622	624	584
°F.	% R.H.	Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		705	730	684	513	677	642	80	30	779	679	717	744	698	673
80	30		734	643	630	516	684	671	65	50	759	799	636	742	581	699
65	50		575	550	541	452	466	518	80	30	587	708	611	615	536	577
90	23		590	665	615	497	516	555	65	50	460	663	547	557	453	539
65	50		509	619	588	440	576	520	90	23	664	751	664	733	642	615
90	23		648	635	678	534	853	639	65	50	628	732	655	667	473	557
°F.	% R.H.	Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		744	723	546	662	628	499	80	80	763	774	690	608	667	686
80	80		711	780	586	760	741	565	65	50	774	781	633	602	724	690
65	50		749	754	634	729	690	458	80	80	781	786	730	661	645	712
90	50		742	860	581	731	699	654	65	50	942	699	859	744	690	810
65	50		766	806	677	802	779	719	90	50	755	733	698	648	599	673
90	50		775	875	781	803	666	674	65	50	902	755	776	730	813	851

TABLE 15. STANDING METABOLIC RATE, kcal/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		702	920	888	796	688	803	85	50	602	689	745	625	767	773
85	50		761	675	749	625	600	720	65	50	784	777	887	731	839	663
65	50		805	759	770	747	641	798	85	50	731	801	851	810	693	711
85	70		666	746	788	737	656	777	65	50	731	797	861	777	818	607
65	50		659	762	795	763	609	703	85	70	753	891	754	638	606	515
85	70		663	604	704	791	782	749	65	50	761	956	786	606	830	607
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		834	617	737	802	791	733	93	25		490	723	941	897	742
93	25		654	667	800	709	721	770	65	50	882	740	818	805	900	873
65	50		723	739	727	887	774	748	93	25	678	625	782	947	956	681
90	25								65	50	676	685	674	986	947	803
65	50		832	708	795	852	859	807	90	25	861	745	852	963	966	781
90	25		774	713	698	799	735	718	65	50	773	690	819	1029	958	882
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		1009	904	910	885	820	943	75	90	861	614	796	770	780	965
75	90		530	676	744	588	575	762	65	50	764	742	692	705	706	902
65	50		520	826	827	679	710	885	75	90	913	764	722	826	596	911

TABLE 16. OXYGEN CONSUMPTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A						Group B								
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		176	153	176	164	136	163	80	50	127	166	175	182	165	152
80	50		174	134	158	134	115	134	65	50	153	160	158	145	202	161
65	50		170	140	180	161	146	166	80	50	170	184	166	149	194	148
90	42		130	130	176	119	135	128	65	50	153	163	170	163	175	150
65	50		122	100	129	121	109	124	90	42	136	125	135	124	121	115
90	42		129	107	126	128	115	102	65	50	113	118	124	129	126	118
		Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		144	147	136	104	136	129	80	30	155	134	143	148	143	137
80	30		148	130	127	103	142	152	65	50	154	160	131	151	116	126
65	50		115	110	109	91	94	103	80	30	118	142	125	123	110	126
90	23		119	135	124	100	104	111	65	50	94	134	110	113	92	110
65	50		103	126	117	88	116	103	90	23	135	156	139	146	127	125
90	23		131	128	137	109	178	132	65	50	129	149	135	134	96	111
		Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		148	143	110	134	124	101	80	80	154	154	140	126	135	136
80	80		141	155	116	152	147	116	65	50	157	157	130	124	147	139
65	50		152	151	131	148	140	91	80	80	156	157	148	134	130	147
90	50		180	170	118	146	144	133	65	50	187	138	173	154	140	162
65	50		160	165	141	164	160	146	90	50	152	148	147	130	121	136
90	50		160	187	165	168	136	140	65	50	181	155	160	150	171	175

TABLE 17. OXYGEN CONSUMPTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		147	187	179	165	139	163	85	50	126	144	152	125	159	163
85	50		160	137	150	124	121	146	65	50	165	158	178	147	168	135
65	50		160	153	155	150	130	163	85	50	151	159	172	167	142	148
85	70		140	159	165	152	134	160	65	50	153	167	178	158	164	125
65	50		140	155	164	158	125	142	85	70	156	182	159	135	123	109
85	70		135	127	144	165	157	155	65	50	155	198	158	122	165	176
		Group A								Group B						
°F.	% R.H.	Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		170	124	150	160	160	145	93	25		104	154	197	190	148
93	25		139	140	164	149	153	154	65	50	178	160	164	163	156	173
65	50		148	154	146	182	158	149	93	25	137	128	161	192	196	138
90	25								65	50	136	140	136	202	191	166
65	50		173	145	167	175	177	166	90	25	184	159	182	199	201	156
90	25		157	143	142	164	154	146	65	50	159	137	169	209	192	179
		Group A								Group B						
°F.	% R.H.	Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		211	184	189	184	171	195	75	90	175	123	161	157	161	194
75	90		110	138	150	119	166	153	65	50	153	152	138	140	144	184
65	50		107	168	167	135	148	185	75	90	188	152	141	169	118	187

TABLE 18. CARBON DIOXIDE PRODUCTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		161	124	178	160	149	142	80	50	111	160	148	167	159	152
80	50		182	146	142	141	165	113	65	50	122	144	155	143	208	154
65	50		181	124	141	156	127	138	80	50	146	143	165	144	182	127
90	42		135	112	154	116	122	144	65	50	128	128	169	142	153	136
65	50		110	85	107	113	101	103	90	42	164	128	143	137	114	111
90	42		118	109	118	126	113	117	65	50	92	98	106	105	118	132
°F.	% R.H.	Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		117	150	136	107	131	125	80	30	154	154	138	157	125	123
80	30		140	124	119	102	117	122	65	50	139	154	116	135	118	135
65	50		113	104	104	136	85	103	80	30	111	134	110	127	93	118
90	23		110	119	118	99	96	116	65	50	82	124	103	102	84	95
65	50		95	112	115	85	107	115	90	23	122	126	92	147	147	111
90	23		118	122	126	96	128	110	65	50	118	133	88	125	87	109
°F.	% R.H.	Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		152	158	102	120	128	91	80	80	142	152	125	105	123	150
80	80		151	164	137	149	147	100	65	50	141	147	111	105	132	132
65	50		139	169	107	134	129	94	80	80	151	152	134	120	126	122
90	50		136	185	112	168	122	120	65	50	193	148	190	127	125	158
65	50		127	143	114	142	136	139	90	50	142	138	108	123	119	124
90	50		129	128	119	118	148	105	65	50	172	126	109	129	129	148

TABLE 19. CARBON DIOXIDE PRODUCTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		115	167	165	110	137	146	85	50	99	114	134	106	128	98
85	50		123	133	145	143	112	130	65	50	125	141	167	139	162	118
65	50		162	142	144	148	118	143	85	50	126	165	162	137	117	114
85	70		106	101	121	128	117	135	65	50	119	130	132	141	159	106
65	50		101	139	186	131	107	131	85	70	129	158	119	97	110	78
85	70		120	83	168	131	154	128	65	50	140	164	170	115	170	101
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		156	118	162	157	147	164	93	25		128	98	145	140	150
93	25		102	88	122	104	110	127	65	50	165	121	167	156	155	201
65	50		128	123	137	167	138	148	93	25	127	112	135	173	168	124
90	25								65	50	129	123	126	173	176	139
65	50		140	131	120	149	149	141	90	25	124	104	106	167	165	157
90	25		142	136	125	136	110	133	65	50	164	147	142	193	184	176
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		164	166	163	167	126	167	75	90	153	110	142	139	113	187
75	90		90	121	140	108	107	145	65	50	148	130	137	140	127	161
65	50		79	149	154	144	98	121	75	90	145	151	140	147	122	160

TABLE 20. METHANE PRODUCTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	793	523	440	474	473	484	°F.	% R.H.	856	713	804	807	487	499
		Weight, kg	527	505	547	507	519	543			515	598	471	518	520	618
65	50		7.6	6.3	10.8	9.3	9.3	7.8	80	50	5.4	9.9	12.0	9.3	13.8	11.7
80	50		6.3	7.8	4.8	8.1	7.5	9.3	65	50	6.0	6.6	9.9	6.3	12.3	7.5
65	50		8.1	7.5	4.2	10.2	2.4	2.1	80	50	4.5	2.4	11.1	12.0	13.2	5.7
90	42		6.3	4.8	4.2	4.6	14.7	11.1	65	50	2.1	2.4	11.5	6.3	6.3	9.3
65	50		6.6	3.6	1.2	3.3	5.1	6.9	90	42	21.3	8.7	9.9	7.2	8.4	12.3
90	42		5.1	13.8	3.0	9.9	3.9	11.7	65	50	2.4	2.1	3.0	2.1	7.2	12.3
		Group A								Group B						
°F.	% R.H.	Cow No.	820	823	793	523	440	474	°F.	% R.H.	814	818	856	713	804	807
		Weight, kg	495	528	536	486	579	525			562	536	560	589	467	549
65	50		3.9	13.8	8.4	4.5	3.6	10.2	80	30	10.8	17.1	1.8	6.3	2.1	5.7
80	30		1.5	5.7	2.7	5.1	2.1	5.1	65	50	6.9	8.1	1.5	1.8	8.4	9.6
65	30		8.7	8.7	6.3	3.9	3.0	6.6	80	30	6.9	10.8	1.5	11.1	1.5	5.1
90	23		1.5	7.2	7.5	9.3	1.8	7.5	65	50	2.4	4.5	4.5	2.1	2.7	1.5
65	50		3.6	6.0	8.1	6.6	5.1	14.1	90	23	12.3	2.1	6.0	17.1	10.5	2.7
90	23		5.1	9.9	4.2	4.5	3.9	3.6	65	50	7.2	3.4	8.4	3.0	1.2	6.0
		Group A								Group B						
°F.	% R.H.	Cow No.	820	823	855	852	793	523	°F.	% R.H.	814	818	849	858	713	856
		Weight, kg	522	543	457	524	575	512			607	533	512	501	607	622
65	50		12.9	15.3	4.2	3.3	7.5	11.7	80	80	10.5	5.4	2.1	4.2	2.4	9.3
80	80		10.8	13.5	11.5	11.7	8.7	6.3	65	50	4.8	8.1	3.6	3.6	5.4	3.5
65	50		7.2	22.5	4.5	6.9	8.4	7.8	80	80	9.9	7.8	5.4	4.5	1.8	3.3
90	50		4.8	19.2	6.3	7.5	5.1	12.3	65	50	10.8	4.8	5.7	2.4	3.3	6.3
65	50		3.9	31.8	7.8	3.3	3.3	10.2	90	50	6.9	10.8	3.3	3.0	2.4	5.7
90	50		2.4	3.3	3.3	3.0	5.1	7.8	65	50	3.0	2.4	2.1	1.5	1.8	13.2

TABLE 21. METHANE PRODUCTION, STP, LITERS/HOUR. AVERAGES OF 2 MEASUREMENTS DURING 2ND WEEK OF 2-WEEK PERIODS.

		Group A								Group B						
°F.	% R.H.	Cow No.	C-794	U-830	U-450	C-818	C-842	U-852	°F.	% R.H.	C-623	C-829	U-829	C-880	U-853	C-895
		Weight, kg	520	629	556	535	622	547			513	579	592	580	530	589
65	50		2.4	13.5	3.6	5.4	10.2	3.0	85	50	2.7	2.1	9.6	2.1	3.9	14.4
85	50		6.6	6.6	10.8	12.6	9.6	4.5	65	50	2.7	3.9	5.7	6.0	6.0	2.7
65	50		16.2	3.9	5.4	12.6	4.8	3.9	85	50	4.8	5.4	12.6	5.7	10.8	8.7
85	70		6.9	3.3	3.6	7.5	8.4	3.0	65	50	3.0	3.0	11.1	2.4	11.4	2.4
65	50		2.4	6.9	3.0	6.6	2.7	9.9	85	70	4.5	4.2	4.5	4.8	3.0	2.1
85	70		11.7	3.3	4.2	3.3	15.6	6.4	65	50	9.9	4.5	17.1	5.7	11.4	2.7
		Cow No.	U-809	U-864	C-794	U-830	U-450	C-818	°F.	% R.H.	U-847	U-813	C-623	C-829	U-829	C-880
		Weight, kg	553	502	532	643	570	564			504	486	534	617	667	616
65	50		8.7	9.0	16.8	5.4	9.6	6.3	93	25		2.7	6.3	13.8	5.1	10.5
93	25		2.4	5.7	4.5	6.0	3.6	8.4	65	50	10.8	6.0	13.8	7.2	4.2	14.4
65	50		5.1	4.8	5.4	9.0	5.7	8.7	93	25	9.9	14.7	7.2	4.8	3.9	4.8
90	25								65	50	12.6	4.2	4.2	3.6	7.8	3.6
65	50		5.7	4.5	3.0	2.7	3.9	3.9	90	25	3.6	3.3	7.2	15.3	11.1	3.6
90	25		3.9	3.6	2.4	8.4	6.3	3.3	65	50	6.6	3.9	4.2	6.9	4.8	10.2
		Cow No.	U-844	U-473	U-809	U-864	C-794	U-830	°F.	% R.H.	U-820	U-818	U-847	U-813	C-623	C-829
		Weight, kg	510	583	560	526	532	684			544	629	523	524	553	664
65	50		12.0	3.0	2.4	3.6	4.2	3.6	75	90	4.8	11.4	4.2	2.4	3.0	13.8
75	90		12.3	3.0	4.8	9.3	6.0	5.1	65	50	4.8	8.1	5.7	2.7	4.8	8.4
65	50		7.5	4.5	4.8	9.0	9.3	4.2	75	90	5.7	8.1	8.4	3.9	3.0	7.2

TABLE 22. AVERAGE MEASUREMENTS DURING SPECIAL TESTS^a
ON SIX LACTATING HOLSTEIN COWS

Temp. °F.	R. H. %	Week at Condition	R. B. M. ^b	P. R. ^c	R. T. ^d	H. P. ^e	P. V. R. ^f
			<u>Cow 871</u>		(Av. body weight 571 kg)		
65	50	3rd	50	63	101.5	1261	125
85	35	2nd	76	59	105.4	895	157
65	50	3rd	40	64	101.4	1157	98
85	60	2nd	86	60	104.9	922	158
65	50	3rd	36	71	101.4	1060	109
			<u>Cow 822</u>		(Av. body weight 581 kg)		
65	50		42	63	101.1	1213	129
85	35		58	60	101.9	1170	148
65	50		35	64	101.4	1240	118
85	60		61	58	102.4	1054	156
65	50		23	62	101.2	1112	109
			<u>Cow 842</u>		(Av. body weight 587 kg)		
65	50		59	67	101.6	1183	132
85	35		75	63	105.2	1162	166
65	50		42	69	101.5	1242	118
85	60		79	67	105.3	1047	178
65	50		36	74	101.3	1255	129
			<u>Cow 855</u>		(Av. body weight 523 kg)		
65	50		40	65	101.2	1052	107
85	35		84	60	104.7	1053	155
65	50		42	64	101.4	1054	96
85	60		75	63	104.4	1087	161
65	50		30	73	101.1	1081	105
			<u>Cow 821</u>		(Av. body weight 542 kg)		
65	50		50	78	101.6	1134	120
85	35		71	68	104.5	868	162
65	50		50	72	101.4	999	98
85	60		66	66	104.7	822	159
65	50		38	78	101.1	1088	118
			<u>Cow 875</u>		(Av. body weight 513 kg)		
65	50		38	70	101.0	1074	106
85	35		68	64	102.1	979	136
65	50		26	69	101.2	1053	89
85	60		54	64	101.9	854	132
			<u>Averages for 6 Cows</u>				
65	50		46	63	101.3	1153	113
85	35		72	62	104.0	1021	149
65	50		39	67	101.4	1124	103
85	60		70	63	103.3	964	157
65	50		31	71	101.2	1083	111

^a The conditions for these special tests were different from the conditions for the regular tests as discussed in the text.

^b Respiration per minute.

^c Pulse rate, beats per minute.

^d Rectal temperature, °F.

^e Heat production, k cal/hr. (Computed from O₂, CO₂, CH₄, and P.V.R.)

^f Pulmonary ventilation rate or liters of air exhaled per minute.

TABLE 23. AVERAGE MEASUREMENTS DURING SPECIAL TESTS^a
ON SIX LACTATING HOLSTEIN COWS

Temp. °F.	R.H. %	Week at Condition	R.P.M. ^b	P.R. ^c	R.T. ^d	H.P. ^e	P.V.R. ^f	
			<u>Cow 867</u>		(Av. body weight 523 kg)			
65	50	3rd	27	61	101.2	846	137	
43	88	2nd	12	60	101.2	729	76	
65	50	3rd	20	59	101.3	802	100	
40	50	2nd	12	54	101.1	646	63	
65	50	3rd	19	57	101.1	824	98	
			<u>Cow 921</u>		(Av. body weight 513 kg)			
65	50	3rd	40	59	101.1	680	102	
43	88	2nd	19	70	101.2	722	77	
65	50	3rd	32	62	101.2	671	98	
40	50	2nd	17	59	101.1	589	67	
65	50	3rd	36	61	101.0	702	96	
			<u>Cow 910</u>		(Av. body weight 572 kg)			
65	50	3rd	36	62	101.3	695	101	
43	88	2nd	22	60	101.2	580	70	
65	50	3rd	42	62	101.3	644	101	
40	50	2nd	19	57	101.2	530	62	
65	50	3rd	34	59	101.1	634	86	
			<u>Cow 851</u>		(Av. body weight 616 kg)			
65	50	3rd	45	60	101.3	854	124	
43	88	2nd	24	64	100.9	892	108	
65	50	3rd	42	61	101.1	896	125	
40	50	2nd	20	54	101.4	672	69	
65	50	3rd	37	59	101.2	793	88	
			<u>Cow 895</u>		(Av. body weight 555 kg)			
65	50	3rd	38	66	101.1	791	116	
43	88	2nd	29	69	100.8	787	91	
65	50	3rd	31	66	100.9	766	97	
40	50	2nd	21	65	101.0	663	72	
65	50	3rd	32	65	100.9	620	82	
			<u>Cow 46</u>		(Av. body weight 512 kg)			
65	50	3rd	42	74	101.1	864	126	
43	88	2nd	21	78	100.8	718	84	
65	50	3rd	33	74	101.1	789	100	
40	50	2nd	15	64	101.1	691	71	
65	50	3rd	35	73	101.0	663	87	
			<u>Averages for 6 Cows</u>					
65	50	3rd	38	64	101.2	788	118	
43	88	2nd	21	67	101.0	738	84	
65	50	3rd	33	64	101.2	761	104	
40	50	2nd	17	59	101.2	632	68	
65	50	3rd	32	62	101.0	706	89	

^a The conditions for these special tests were different from the conditions for the regular tests as discussed in the text.

^b Respirations per minute.

^c Pulse rate, beats per minute.

^d Rectal temperature, °F.

^e Heat production, k cal/hr. (computed from O₂, CO₂, CH₄, and P.V.R.)

^f Pulmonary ventilation rate, or liters of air exhaled per minute.