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J. H. LONGWELL, *Director*

Environmental Physiology

With Special Reference to Domestic Animals

VII. Influence of Temperature, 50° to 5° F and 50° to 95° F, on Heat Production and Cardiorespiratory Activities of Dairy Cattle

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Missouri Agricultural Experiment Station and the United States Department of Agriculture Cooperating, Assisted by the Office of Naval Research.

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H. H. Kibler and Samuel Brody

ABSTRACT

This report presents data on the effects of slowly and rapidly decreasing and increasing temperatures from 50° to 5°F and from 50° to 95°F on rectal temperature, pulse rate, respiration rate, heat production computed from oxygen consumption and carbon dioxide production, methane production, and pulmonary ventilation rate in lactating and non-lactating Jersey and Holstein cows. Rectal temperature was constant below 70°F and rose above 70°F. Respiration rates of 20 to 30 per minute at 50°F decreased to 10 to 15 at 5°F and increased to over 100 at 95°F. Heat production and pulse rate reached minimal levels between 40° and 60°F indicating that the zone of thermoneutrality lay in this range; below and immediately above the thermoneutrality zone these functional responses increased; and above 70° or 80°F they decreased. Rapid changes in temperature tended to accentuate these responses. Extreme changes in temperature produced acclimatization effects which lasted several weeks.

ORIENTATION

A preceding bulletin (1)* reported data on the influence of environmental temperature (both slowly rising, 50° to 105°F, and rapidly rising, 50° to 100°F) on rectal temperature, cardiorespiratory activities and heat production in Jersey and Holstein cows; the present bulletin is an extension of these observations to another group of similar cows for slowly decreasing temperature, 50° to 5°F, followed by increasing temperature, 50° to 95°F. Theoretical considerations and references to the literature may be found in the preceding bulletins (2, 1).

The effects of various changes in environmental temperature, and the relations of the involved factors in the heat balance of the dairy cow may be discussed more readily if these factors are listed and classified as shown in Table 1. Table 1 lists the components in heat production and heat dissipation under the laboratory conditions. Heat dissipation is largely, but not entirely, determined by environmental temperature. Radiation, convection, and conduction losses increase, of course, with increase in the gradient be-

*See list of numbered references to literature, on page 19.

TABLE 1.—COMPONENTS OF HEAT PRODUCTION AND AVENUES OF HEAT DISSIPATION

HEAT PRODUCTION	HEAT DISSIPATION
BASAL HEAT PRODUCTION	RADIATION
CALORIGENIC EFFECTS OF:	To Walls, Floors, Ceiling
Endocrine Stimulation	CONVECTION
Muscular Activity	To Air Passing Over Body
Tensing of muscles	To Air Passing Through Lungs
Exercise	CONDUCTION
Shivering	To Floors, Stanchions, Feed, and Water
Feed (SDA)	VAPORIZATION
Productive Processes	From Respiratory Tract
Gestation	From Skin
Lactation	Osmotic or diffusion moisture
	Sweat

tween body temperature and chamber temperature.† Evaporative cooling, however, increases with increasing ambient temperature, the extent of increase depending on the sweating ability of the animal. The animal also can make limited respiratory and circulatory adjustments, grow or shed hair as required, consume more or less feed, and employ other temperature regulating mechanisms. Heat production by the animal must of necessity be varied to balance heat dissipation if the animal is to maintain normal body temperature.

The results of the earlier tests (1) show that as the chamber temperature was increased from 50° to 105°F, the rectal temperature increased from the normal 101°F to 108°F in the Holstein and to 106°F in the Jersey cow. This condition was not caused by increases in basal heat production, muscular activity, calorigenic action of feed, or milk production. On the contrary, the heat production decreased by 25 to 35 per cent (1), and the milk production and feed consumption (12) decreased by still greater percentages. The rise in rectal temperature with increasing chamber temperature resulted, for the most part, from the decrease in temperature gradient between surface temperature and environment, which reduced the heat loss by radiation, convection, and conduction to such an extent that the cows were unable to compensate for this deficiency, by increased respiratory and surface vaporization.* Although the respiration rate at 100°F was 4 to 5 times as rapid as at 50°F and the pulmonary ventilation rate was up 2 to 3 times, the rectal temperature still continued to rise.

†At environmental temperatures slightly above 100°F, the heat losses by radiation, convection, and conduction are negative; the animal receives heat from the environment.

*In man, increased cooling by vaporization of sweat prevents a rise in rectal temperature at these environmental temperatures.

AIMS

This bulletin is mainly concerned with reporting the influence of decreasing temperature on the following processes:

1. Heat production; how much extra heat is produced to maintain the normal internal temperature of the cows at the lower environmental temperatures and, incidentally, how is this related to feed consumption and milk production?

2. Changes in the rates of activity of several heat dissipating mechanisms (respiration rate, ventilation rate, pulse rate, rectal temperature) and the critical temperatures at which these changes occur.

3. Relation of body size and lactational level to the rates of heat production and heat dissipation. In large size, which appears to be a liability at high temperature, an asset at low temperature?

4. Location of the lower limits of thermoneutrality for lactating dairy cows.

5. Quantitative respiratory-exchange data (carbon dioxide and methane production, and oxygen consumption) for animal shelter design, and for computing evaporative cooling from insensible weight loss data as explained in the appendix.

METHODS

Animals:—As in the previous tests (1) twelve dairy cows were divided into an Experimental group and a Control group. Each cow in the Experimental group was matched as closely as possible with respect to body weight, milk production, age, and previous history (3) with a cow in the Control group. Each group included three lactating Jerseys, two lactating Holsteins, and one non-lactating, non-pregnant Holstein. The milk yield level of this winter group was, however, considerably below that of the preceding summer group.

Temperature Control:—The two groups were housed separately in air conditioned chambers (4, 5) the control group being maintained at 50°F, except for a short period during which time the temperature was lowered to 4°F. The Experimental group was subjected to a gradual lowering of chamber temperature from 50° down to 5°F, followed by rapid increases from 50° to 95°F. The temperature schedule and related information are given in Table 2.

Measurements:—The following data were obtained at each chamber temperature level, as indicated in Table 2, with the cows standing quietly:

1. The rate of heat production was computed from the rate of oxygen consumption and carbon dioxide production as measured by an open-circuit mask method, involving analysis of room air and of metered exhaled air.* The rate of heat production was also computed from oxygen consumption data, obtained by the closed-circuit mask method. The two methods, open-circuit and closed-circuit, were previously described (1).

2. The pulmonary ventilation rate was measured by both open- and closed-circuit mask methods.

*The methane in the exhaled air was also determined.

TABLE 2.—TEMPERATURE CALENDAR AND TEST SCHEDULE

Chamber Temperature Level, °F		Relative Humidity %		Date 1948-49		Number of Tests			
						Closed-Circuit		Open-Circuit	
Exp.	Contr.	Exp.	Contr.	From	To and Including	Exp.	Contr.	Exp.	Contr.
52	53	71	69	Oct. 25	Nov. 7	10	10	2	2
41	50	65	60	Nov. 8	Nov. 21	10	10	2	2
32	50	70	63	Nov. 22	Dec. 5	10	9	2	1
23	50	79	66	Dec. 6	Dec. 19	11	10	2	3
12	49	85	61	Dec. 20	Jan. 2	8	3	2	1
# 8	49	88	55	Jan. 3	Jan. 10	5	6	1	1
5	50	83	53	Jan. 17	Jan. 23	5	5	1	1
20	35	81	41	Jan. 24	Jan. 25	2	2	1	1
34	20	75	40	Jan. 26	Jan. 28	3	3		2
50	4	58	77	Jan. 31	Feb. 13	9	8	2	3
50	*	65		Feb. 14	Feb. 20	5		2	
	12		78	Feb. 14			1		
	19		74	Feb. 15			1		
	28		70	Feb. 16			1		
	36		66	Feb. 17			1		
	35		63	Feb. 18			1		
50	50	60	69	Feb. 21	Feb. 27	5	4	2	
65	50	65	60	Feb. 28	Mar. 6	5	5	1	1
69	50	68	61	Mar. 7	Mar. 13	5	5	2	1
74	50	60	55	Mar. 14	Mar. 20	5	6	2	1
80	50	58	64	Mar. 21	Mar. 27	5	4	2	1
84	51	60	64	Mar. 28	Mar. 29	2	2	1	
90	51	60	65	Mar. 30	Mar. 31	2	2	1	
95	50	46	64	Apr. 1	Apr. 2	2		1	
	50		64	Apr. 1			1		
	56		65	Apr. 4			1		1

#No temperature control from Jan. 11 to 16 due to power failure.

*The temperature was increased from 4 to 50 °F during this period as shown by the following daily observations in the table.

TABLE 2A.--BODY WEIGHTS†, LBS., AT THE BEGINNING AND END OF EXPERIMENT

Experimental			Control		
Cow	Beginning	End	Cow	Beginning	End
J-502	797	849	J-957	864	986
J-508	854	947	J-979	844	1027
J-933	835	913	J-977	908	987
H-136	1221	1230	H-125	1207	1275
H-109	1200	1272	H-95	1180	1447
H-14	1441	1597	H-5	1400	1586

†For more complete body weight data see Ref. 3.

3. The respiration rate (without mask) was counted from flank movement counts.

4. The rectal temperature was determined with clinical mercury thermometers.

5. The pulse rate was counted manually by placing the index finger on the saphenous artery of the hind leg.

The reliability of the respiratory exchange data (ventilation rate, tidal air, oxygen consumption, carbon dioxide production, methane production, and heat production) suffered somewhat from mechanical difficulties associated with the extreme temperatures employed.

The closed-circuit metabolism apparatus apparently requires modification for use at both high and low temperatures. For these tests a thermostat and heating coil were used to prevent freezing of the water seal. At low temperatures, condensation from the exhaled air collected around the rubber inspiratory check valves and prevented their complete closure (drains have now been installed). The sudden change in inspired air from the relatively cold dry room air to the warm humid oxygen-rich spirometer air may have affected the animals physiologically. The efficiency of the soda lime used as a carbon dioxide absorbent may also have been unfavorably affected by excessive moisture condensation at low temperature.

The open-circuit respiratory exchange apparatus was not affected by chemical factors or changes in temperature of inspired air as no chemicals were used and the animal inspired room air at the existing temperature and humidity. Nor was moisture condensation a problem since the exhaled air after leaving the mask was heated to approximately 100°F and maintained at this temperature while it was passing through the apparatus. Unfortunately, however, difficulties of a mechanical nature developed during this winter experiment. The expiratory check valve became defective and was replaced by a new valve which had to be built while the experiment was in progress, and a leak in a pipe line was found (and repaired). These difficulties arose during the early part of the experiment while the temperature of the experimental chamber was being lowered from 50° to 5°F (Table 2). The new valve was installed in time to make one set of measurements at the 5° level. Earlier measurements, however, may have been affected by the defective action of the valve that was replaced.

DATA AND DISCUSSION

The data for the different temperature levels are given in Tables 3 to 11. Different aspects of the heat production data (Figs. 1 to 3) and of the

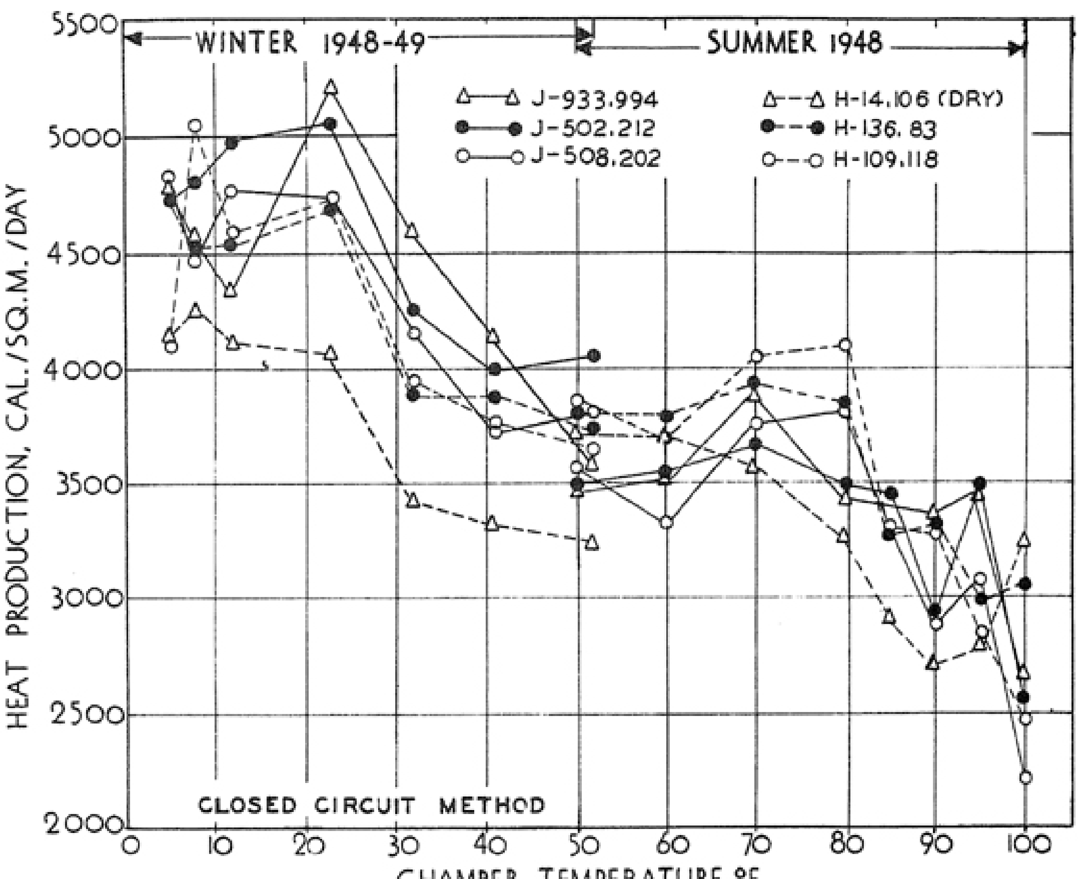

Fig. 1.—Heat production per square meter of surface area in Jersey and Holstein cows for decreasing temperatures from 50° to 5°F and for increasing temperatures from 50° to 100°F. Note the thermoneutrality zone from 40° to 60°F.

cardiorespiratory data (Figs. 4 to 8) are presented graphically. Figs. 1, 2, and 4 include supplementary data from the preceding bulletin (1). Tables 7 to 11 and Figs. 6 to 8 which report valuable data but do not contribute greatly to the discussion are presented in the appendix.

Heat Production:—One of the aims of this research, the location of the temperature range of "thermoneutrality" for lactating dairy cows, is realized in Fig. 1. The zone of minimal heat production (at normal rectal temperature) occurred at chamber temperatures from 40° to 60°F. Decreasing the chamber temperature increased the heat production (and heat dissipation, since rectal temperature remained constant) by about 25 per cent in Holstein cows and by about 35 per cent in Jersey cows. This breed difference in the rate of heat production and dissipation per square meter may be attributed to differences in body size; the temperature gradient between internal organs and external environment is steeper in the smaller cows, the Jerseys, than in the larger cows, the Holsteins. The increasing steepness in temperature gradient with decreasing body size may explain the reported (6) 275 per cent increase in heat production in guinea pigs on reduction in room temperature from 88° to 32°F. Increasing the chamber temperature (Fig. 1) from 60° to 80°F increased the heat production of our cows slightly;* increasing the chamber temperature above 80°F decreased the heat production as discussed in the preceding bulletin (1).

Comparison of the heat production data for the Experimental cows at different chamber temperatures with those for the Control cows at 50°F chamber temperature is made in Fig. 2 by plotting the ratios of Experimental to Control data. The mismatching within pairs caused by differences in advancing stages of lactation and gestation, as well as in heredity, is reduced by averaging the ratios computed for the individual pairs. Fig. 2 represents separate averages for three pairs of lactating Jersey cows, two pairs of lactating Holstein cows, and a single pair of dry Holstein cows.

The similarity of these ratio heat production curves (Fig. 2) with the absolute Experimental group heat production curves (Fig. 1) indicates that the changes in heat production levels are not caused by extraneous factors but are directly or indirectly associated with changes in environmental temperature.

The corresponding relative changes in body weight for the Experimental and Control cows (bottom section, Fig. 2) were very slight except at chamber temperatures above 85°F.

Fig. 3 presents the average values of heat production per animal (from Tables 3 and 4) for the 1948-49 winter data. During this winter experiment the temperature of the Experimental chamber was (1) gradually lowered from 50° to 5°F; (2) rapidly brought back up to 50°F; (3) maintained at 50°F for four weeks; (4) raised from 50° to 95°F. The temperature of the Control chamber was maintained at the 50°F level except for a four-week period, during which time it was lowered rapidly and held at 4°F for two weeks (to bring out the effect of low temperature on unac-

*This rise in heat production may have been caused, in part, by a change to better quality hay which increased milk production.

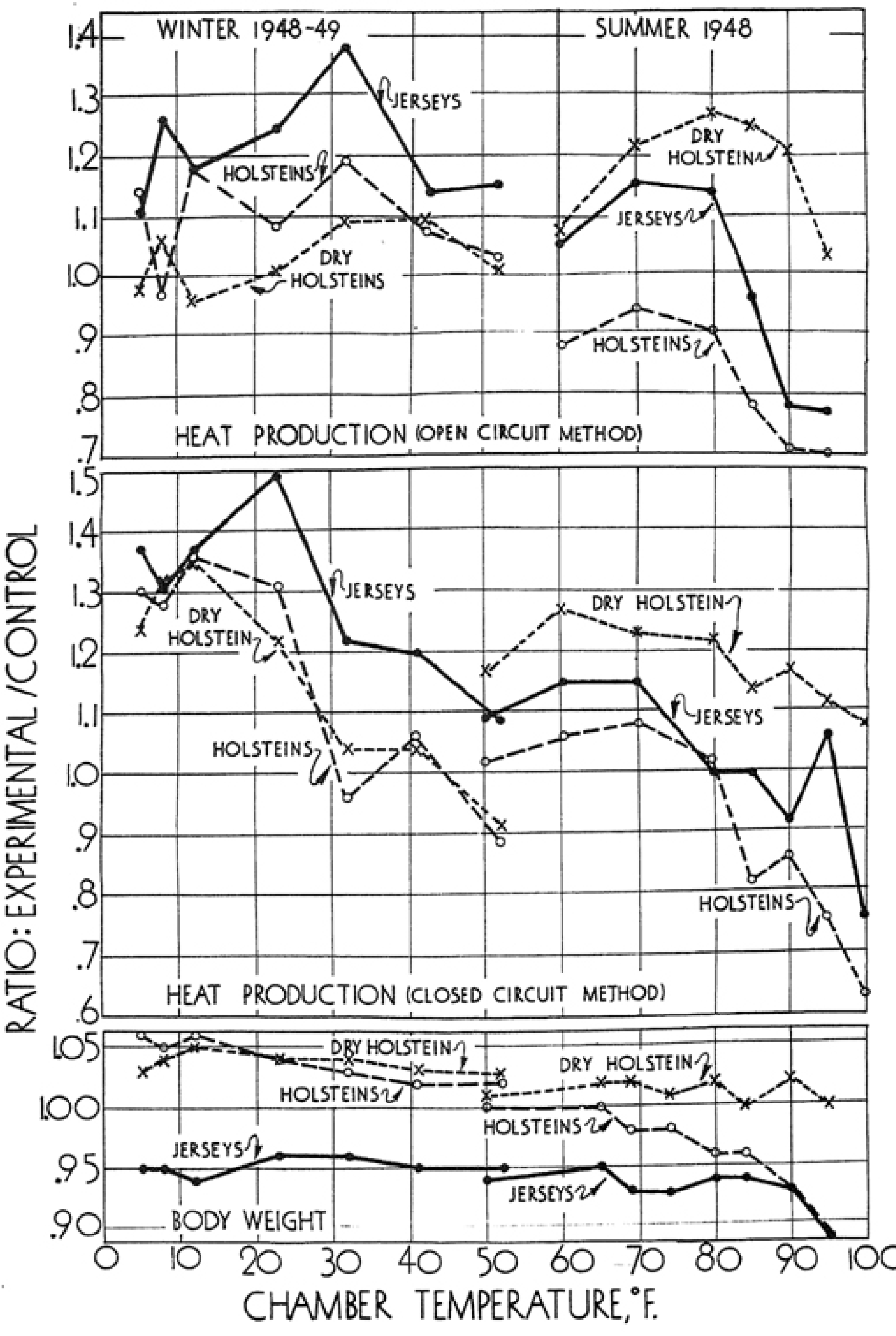

Fig. 2.—Comparison of heat production data (upper sections) and body weight data (lower section) for Experimental cows at various temperature levels with data for Control cows at 50°F, by means of computed ratios for corresponding time intervals. Different cows were used in the winter and summer tests. This chart summarizes data for 24 cows covering test periods at controlled laboratory conditions totaling approximately 11 months.

TABLE 3.— AVERAGE[1] HEAT PRODUCTION PER COW FOR EACH TEMPERATURE LEVEL, AS OBTAINED BY THE OPEN CIRCUIT METHOD

Temperature Level, °F.		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.	Heat Production, Cal/hr.											
52	53	654	508	669	552	597	624	858	846	876	834	796	792
41	50	582	534	528	531	549	423	762	789	798	693	807	741
32	50	726	384	684	546	663	444	921	786	909	750	801	738
23	50	750	576	702	638	771	578	951	874	915	848	873	868
12	49	732	546	660	666	627	516	924	798	990	834	741	774
8	49	762	564	672	558	642	528		864	894	840	840	792
5	50	780	612	582	672	678	564	954	810	948	864	870	888
20	35	732	618	600	618	636	600	984	678	906	786	858	738
34	20		660		699		546		825		816		828
50	4	717	896	600	778	606	702	993	1040	888	1020	828	1004
50	4 to 50	648		585		570		873		858		735	
50	50	693		579		582		882		831		747	
65	50	690	648	486	690	462	366	786	774	852	846	744	816
69	50	660	534	630	690	585	618	867	750	876	882	711	822
74	50	678	612	654	720	657	600	936	744	942	774	774	834
80	50	666	540	639	672	681	534	840	738	795	846	774	876
84	51	666		516		600		780		774		654	
90	51	558		558		756		648		750		846	
95	50	570		546		468		546		648		612	
	56		786		834		660		894		1044		948
		Heat Production, B.T.U./hr.											
52	53	2595	2016	2655	2190	2369	2476	3405	3357	3476	3309	3166	3143
41	50	2309	2119	2095	2107	2178	1678	3024	3131	3166	2750	3202	2940
32	50	2881	1524	2714	2167	2631	1762	3655	3119	3607	2976	3178	2928
23	50	2976	2286	2786	2532	3059	2294	3774	3468	3631	3365	3464	3444
12	49	2905	2167	2619	2643	2488	2047	3666	3166	3928	3309	2940	3071
8	49	3024	2238	2666	2214	2547	2095		3428	3547	3333	3333	3143
5	50	3095	2428	2309	2666	2690	2238	3785	3214	3762	3428	3452	3524
20	35	2905	2452	2381	2452	2524	2381	3905	2690	3595	3119	3405	2928
34	20		2619		2774		2167		3274		3238		3286
50	4	2845	3555	2381	3087	2405	2786	3940	4127	3524	4047	3286	3984
50	4 to 50	2571		2321		2262		3464		3405		2916	
50	50	2750		2297		2309		3500		3297		2964	
65	50	2738	2571	1928	2738	1833	1452	3119	3071	3381	3357	2952	3238
69	50	2619	2119	2500	2738	2321	2452	3440	2976	3476	3500	2821	3262
74	50	2690	2428	2595	2857	2607	2381	3714	2952	3738	3071	3071	3309
80	50	2643	2143	2536	2666	2702	2119	3333	2928	3155	3357	3071	3476
84	51	2643		2047		2381		3095		3071		2595	
90	51	2214		2214		3000		2571		2976		3357	
95	50	2262		2167		1857		2167		2571		2428	
	56		3119		3309		2619		3547		4143		3762

[1]See Table 1 for the number of observations in each average.

climatized cows), then brought back to 50°F. The curves of Fig. 3, consequently, exhibit temperature-reversal and acclimatization effects, and cannot be compared with the curves of Fig. 1 and 2, except for the period of gradually decreasing chamber temperature, 50° to 5°F, represented in all three curves. Some of the acclimatization effects, however, are worth noting.

The decrease in heat production for decreasing temperature, 50° to 40°F, was caused, apparently, by the change from the usual herd conditions and management to laboratory conditions, since a similar decrease occurred in both the Experimental and Control groups during the first weeks of the experiment. The greater rise in heat production with decreasing chamber temperature, 50° to 4°F, in the Control cows (right side of Fig. 3) in comparison with the Experimental cows (left side of Fig. 3) was due, apparently, to the relatively greater rapidity with which the Control chamber temperature was lowered.

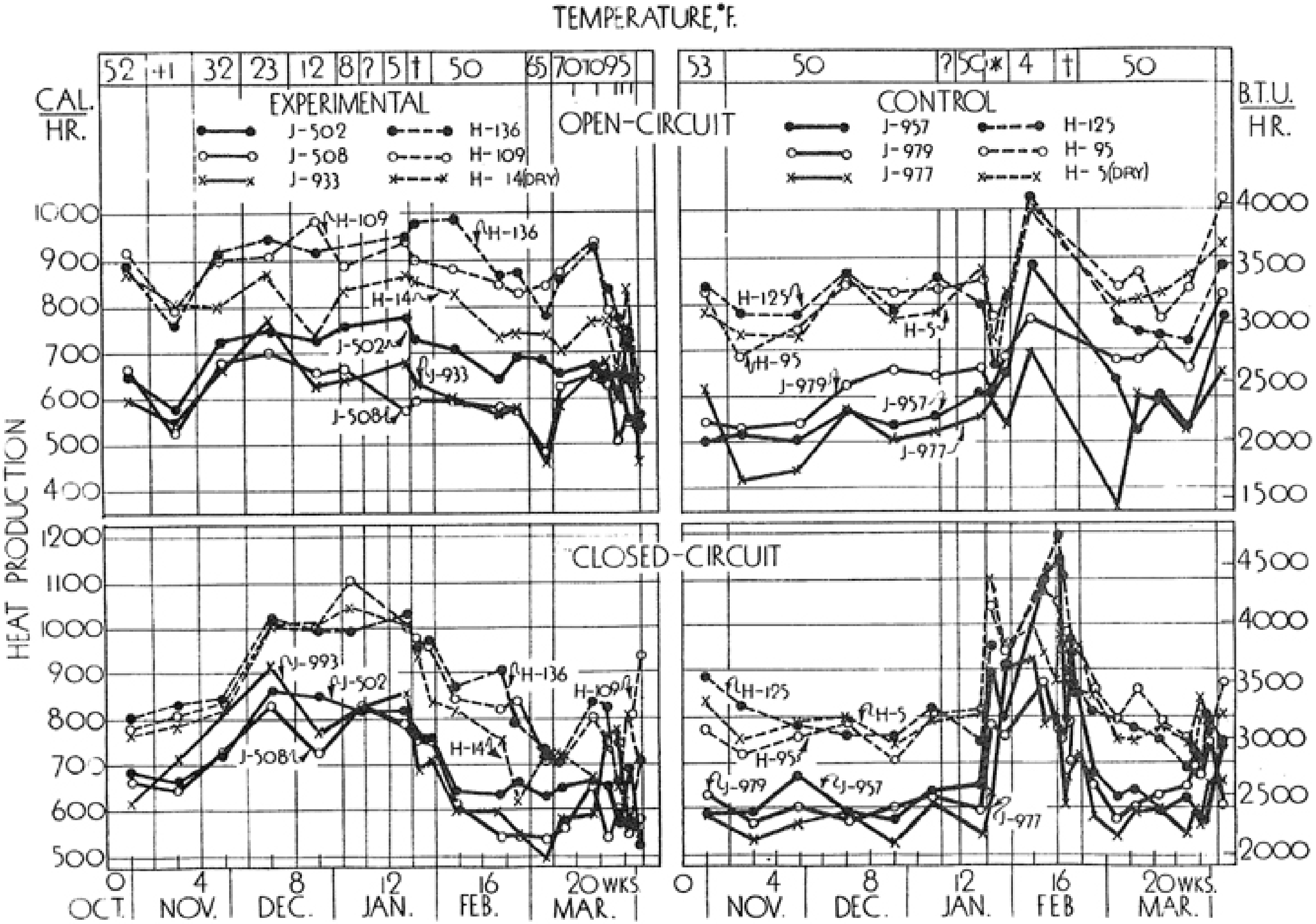

Fig. 3.—Comparison of heat production of Experimental cows (left-hand sections) and of Control cows (right-hand sections) as measured by the open-circuit and closed-circuit mask methods in relation to environmental temperature and time. The question marks on the temperature scales at the top of the chart indicate a period of variable temperature due to a power failure. The asterisk and daggers indicate transitional temperature periods (see Table 2).

TABLE 4.--AVERAGE[1] HEAT PRODUCTION PER COW FOR EACH TEMPERATURE LEVEL, CLOSED CIRCUIT METHOD

Temperature Level, °F.		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.	Heat Production, Cal/hr.											
52	53	686	587	665	632	617	585	801	892	777	774	766	836
41	50	668	598	644	570	714	528	833	833	803	721	786	757
32	50	723	677	727	607	805	572	846	791	844	762	821	792
23	50	868	595	832	576	923	589	1024	770	1021	784	981	806
12	49	854	582	727	606	766	527	1000	765	1004	710	1008	744
8	49	824	647	844	636	820	614	995	828	1105	814	1046	794
5	50	821	662	797	599	857	547	1038	755	1008	819	1013	817
20	35	768	902	756	788	690	632	962	966	980	1050	940	1108
34	20	765	802	768	762	708	912	973	921	969	949	839	966
50	4	646	1117	617	881	600	932	873	1117	848	1084	822	1011
50	*	637		543		600		909		826		756	
	12		1152		778		787		1206		1062		949
	19		1005		747		816		1118		957		885
	28		800		803		616		910		992		987
	36		947		706		669		974		888		878
	35		869		710		733		874		954		960
50	50	663	686	546	656	549	586	797	819	843	864	621	868
65	50	633	637	544	576	499	546	738	777	718	794	731	760
69	50	647	644	566	611	582	592	707	743	702	863	725	755
74	50	669	602	655	636	598	602	865	759	807	795	672	780
80	50	655	632	543	652	769	551	830	695	757	737	736	746
84	51	574	592	608	696	677	603	668	727	749	722	653	678
90	51	694	598	550	674	562	568	574	718	817	810	818	846
95	50	532		582		557		710		944		706	
	50		579		749		661		835		774		795
	56		754		608		667		739		880		810
		Heat Production, B.T.U./hr.											
52	53	2722	2329	2639	2508	2448	2321	3178	3539	3083	3071	3039	3317
41	50	2651	2373	2555	2262	2833	2095	3305	3305	3186	2861	3119	3004
32	50	2869	2686	2885	2409	3194	2270	3357	3139	3349	3024	3258	3143
23	50	3444	2361	3301	2286	3662	2337	4063	3055	4051	3111	3893	3198
12	49	3389	2309	2885	2405	3039	2091	3968	3036	3984	2817	4000	2952
8	49	3270	2567	3349	2524	3254	2436	3948	3286	4385	3230	4151	3151
5	50	3258	2627	3162	2377	3401	2170	4119	2996	4000	3250	4020	3242
20	35	3047	3579	3000	3127	2738	2508	3817	3833	3889	4166	3730	4397
34	20	3036	3182	3047	3024	2809	3619	3861	3655	3845	3766	3329	3833
50	4	2563	4432	2448	3496	2381	3698	3464	4432	3365	4301	3262	4012
50	*	2528		2155		2381		3607		3278		3000	
	12		4571		3087		3123		4785		4214		3766
	19		3988		2964		3238		4436		3797		3512
	28		3174		3186		2444		3611		3936		3916
	36		3758		2801		2655		3865		3524		3484
	35		3448		2817		2909		3468		3785		3809
50	50	2631	2722	2167	2603	2178	2325	3162	3250	3345	3428	2464	3444
65	50	2512	2528	2159	2286	1980	2167	2928	3083	2849	3151	2901	3016
69	50	2567	2555	2246	2424	2309	2349	2805	2948	2786	3424	2877	2996
74	50	2655	2389	2599	2524	2373	2389	3432	3012	3202	3155	2666	3095
80	50	2599	2508	2155	2587	3051	2186	3293	2758	3004	2924	2920	2960
84	51	2278	2349	2413	2762	2686	2393	2651	2885	2972	2865	2591	2690
90	51	2754	2373	2182	2674	2230	2254	2278	2849	3242	3214	3246	3357
95	50	2111		2309		2210		2817		3746		2801	
	50		2297		2972		2623		3313		3071		3155
	56		2992		2413		2647		2932		3492		3214

[1]See Table 1 for the number of observations in each average.

*The temperature was increased from 4 to 50°F during this period as shown by the following daily observations.

A striking feature of the curves for the Experimental group (Fig. 3) is the long continued (four-week) decrease in heat production at constant chamber temperature following the rapid increase in chamber temperature from 5° to 50°F. Acclimatization after a major change in environmental temperature, apparently, is a function both of the duration of the earlier conditioning temperature and of the rapidity and extent of change in temperature. The heat production might have continued its decline over a longer period if the temperature had not been raised at the end of the four-week period; the heat production in rats (7), for example, decreased in eight days from 650 to 540 calories per square meter per day, and continued to decrease for twenty days after a 25°F decrease in temperature.

Pulse Rate:—The pulse rate curves (upper sections of Figs. 4 and 5) have very similar trends to the corresponding heat production curves (comparing Fig. 2 with 4, and 3 with 5). This similarity is not surprising,* considering that the blood pumped by the heart supplies oxygen and nutrients for heat production, and also carries heat from the interior to the surface of the body for dissipation. Other factors which affect pulse rate,† likewise affect heat production (see Table 1)—though perhaps not to the same degree—and so contribute to the complexity yet also to the general parallelism of the curves.

The pulse ratio chart (Fig. 4, upper section) corresponds to the heat production ratio chart (Fig. 2) and was computed by the same method. Minimal pulse ratios (at normal rectal temperature) occurred from approximately 40° to 60°F chamber temperature. In view of the close correlation between pulse rate and the heat production, it seems probable that these limiting temperatures for minimal pulse rate marked the boundaries of the zone of thermoneutrality for these lactating Jersey and Holstein cows.

The slight rise in the pulse ratios (Fig. 4) from 60° to 70°F was followed by a rapid fall at chamber temperatures above 70°F. This fall in pulse ratios was associated with (1) increasing rectal temperature at chamber temperatures above 70°F (Fig. 4, center section); (2) decreasing heat production at chamber temperatures above 80°F (Fig. 2); (3) decreasing hay consumption at chamber temperatures above 85°F in Jersey cows and above 80°F in Holstein cows (12); (4) decreasing milk (FCM) production at variable critical temperatures for individual cows, but more pronounced in Holstein than Jersey cows (12). The rise in pulse ratios at 100°F chamber temperature was caused in part by a decrease in pulse rates in the Control group (the 100°F period was short and only two observations were made on each cow); the pulse rates in the Jersey cows actually decreased (see Table 3, Ref. 1). An earlier parallel increase in pulse rate and heat production occurred in the dry cow (Ref. 1, Fig. 5a) at chamber temperatures above 70°F.

The rise of approximately 8 per cent in pulse ratios (Fig. 4) at chamber temperatures below 40°F was associated with increased heat production (Fig. 2) and moderately increased hay and TDN consumption (3). That the percentage rise in pulse ratios was less than in heat production ratios (Fig. 2) at chamber temperatures below thermoneutrality may have resulted from increased heat production for maintenance of normal body temperatures and decreased peripheral circulation for conservation of body heat.

*The close correlation between pulse rate and heat production has been generally known for a long time (8).

†See for example references 9, 10, 11 for the effects of feed and other factors on pulse rate.

TABLE 5.--AVERAGE[1] PULSE AND RESPIRATION RATES PER COW AT EACH TEMPERATURE LEVEL

Temperature Level, °F		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.												
						Pulse Rate per Minute							
52	53	72.8	66.0	65.6	69.8	66.0	70.6	65.2	68.8	64.0	64.4	63.4	59.6
41	50	65.8	59.4	60.4	66.8	62.6	59.8	65.6	62.2	63.4	61.6	58.6	55.4
32	50	69.2	64.2	65.0	67.6	66.4	63.6	66.0	66.0	64.2	62.7	55.8	52.7
23	50	72.7	65.2	66.7	67.2	69.3	62.4	65.1	62.0	68.2	62.8	60.4	55.8
12	49	70.5	63.3	66.6	69.3	66.0	60.7	64.4	63.3	69.8	60.7	61.8	56.0
8	49	71.2	64.0	66.8	67.7	70.0	65.0	66.4	63.2	67.2	63.3	63.2	57.0
5	50	71.2	63.6	67.2	74.4	68.4	63.2	64.0	61.2	69.2	64.0	61.2	58.4
20	35	72.0	66.0	66.0	73.0	71.0	66.0	64.0	62.0	70.0	66.0	64.0	56.0
34	20	74.7	67.3	66.7	67.3	67.3	65.3	66.7	65.3	69.3	68.7	59.3	64.7
50	4	69.8	70.8	65.1	74.5	64.9	70.9	65.6	66.2	68.2	70.7	57.9	68.2
50	*	66.8		65.6		61.6		61.2		65.6		56.4	
	12		74.0		76.0		72.0		70.0		73.0		72.0
	19		72.0		78.0		73.0		68.0		70.0		66.0
	28		70.0		78.0		72.0		64.0		72.0		66.0
	36		70.0		70.0		72.0		68.0		72.0		72.0
	35		72.0		78.0		68.0		68.0		66.0		70.0
50	50	68.8	68.5	68.8	78.5	63.2	69.5	66.0	63.8	67.6	69.0	57.6	70.8
65	50	70.0	63.2	66.4	72.6	62.4	68.4	60.4	61.6	66.0	69.2	57.2	66.0
69	50	69.2	65.2	71.6	73.0	64.4	70.4	61.2	64.4	74.4	67.2	59.6	67.6
74	50	71.6	67.0	72.4	72.2	67.2	70.2	64.0	65.0	69.6	67.3	58.8	66.0
80	50	72.8	67.5	74.0	71.5	71.2	69.5	64.0	66.0	68.0	70.0	65.2	67.0
84	51	70.0	67.0	71.0	73.0	70.0	70.0	56.0	67.0	65.0	69.0	62.0	66.0
90	51	70.0	68.0	64.0	74.0	64.0	71.0	57.0	65.0	69.0	71.5	60.0	67.0
95	50	64.0		66.0		61.0		54.0		66.0		61.0	
	50		66.0		73.0		70.0		68.0		71.0		70.0
	56		70.0		74.0		72.0		66.0		72.0		64.0
						Respiration Rate per Minute							
52	53	43.6	21.6	30.0	24.0	28.7	29.7	30.3	29.3	28.0	27.6	30.3	22.0
41	50	29.4	19.6	24.4	23.8	20.8	23.0	27.4	25.4	25.6	25.0	27.0	20.6
32	50-	25.2	19.3	22.4	20.9	17.7	22.4	23.4	28.7	22.5	23.8	20.8	20.2
23	50	22.4	19.2	19.8	22.4	15.6	21.2	19.4	26.8	20.0	24.8	18.5	19.6
12	49	19.4	20.7	18.4	25.3	12.8	25.0	16.8	30.3	18.5	22.7	15.9	20.0
8	49	17.8	18.3	16.8	21.0	11.2	19.7	16.4	24.0	16.0	24.3	14.2	18.3
5	50	18.2	20.4	16.8	24.4	10.0	18.4	14.2	27.6	16.2	23.2	14.8	21.6
20	35	22.5	18.0	17.5	22.0	11.5	18.0	16.0	16.0	16.5	23.0	16.0	18.0
34	20	22.7	14.0	21.3	18.0	16.0	14.7	19.3	15.7	23.3	15.0	18.0	16.0
50	4	29.1	12.3	25.8	13.7	24.8	10.2	30.2	12.4	30.1	13.1	29.8	11.5
50	*	31.0		27.2		25.2		38.4		34.0		30.4	
	12		11.0		12.0		9.0		11.0		12.0		10.0
	19		12.0		16.0		11.0		14.0		12.0		13.0
	28		12.0		16.0		11.0		12.0		12.0		12.0
	36		14.0		17.0		12.0		14.0		15.0		15.0
	35		13.0		16.0		12.0		14.0		15.0		14.0
50	50	33.2	19.2	25.2	23.5	25.6	17.0	30.4	18.0	28.8	19.2	28.0	19.2
65	50	46.8	20.2	36.4	23.2	34.4	17.6	32.0	21.8	28.8	20.8	36.2	19.8
69	50	43.6	20.8	37.6	25.6	42.0	18.4	42.0	23.4	36.4	26.2	41.2	21.8
74	50	59.6	22.3	54.0	27.5	53.6	21.3	52.4	25.7	75.2	28.7	44.8	23.8
80	50	66.4	22.2	56.8	24.8	76.8	20.8	52.4	25.8	82.8	27.5	44.0	24.7
84	51	84.0	23.0	62.0	25.5	88.0	21.0	60.0	25.0	102.0	27.5	68.0	26.0
90	51	92.0	21.5	79.0	24.5	91.0	22.0	73.0	26.0	103.0	27.0	75.0	24.5
95	50	103.0		87.0		94.0		98.0		106.0		91.0	
	50		20.0		24.0		20.0		30.0		28.0		24.0
	56		23.0		27.0		20.0		24.0		26.0		24.0

[1]See Table 1 for the number of observations in each average.

*The temperature was increased from 4 to 50°F during this period as shown by the following daily observations.

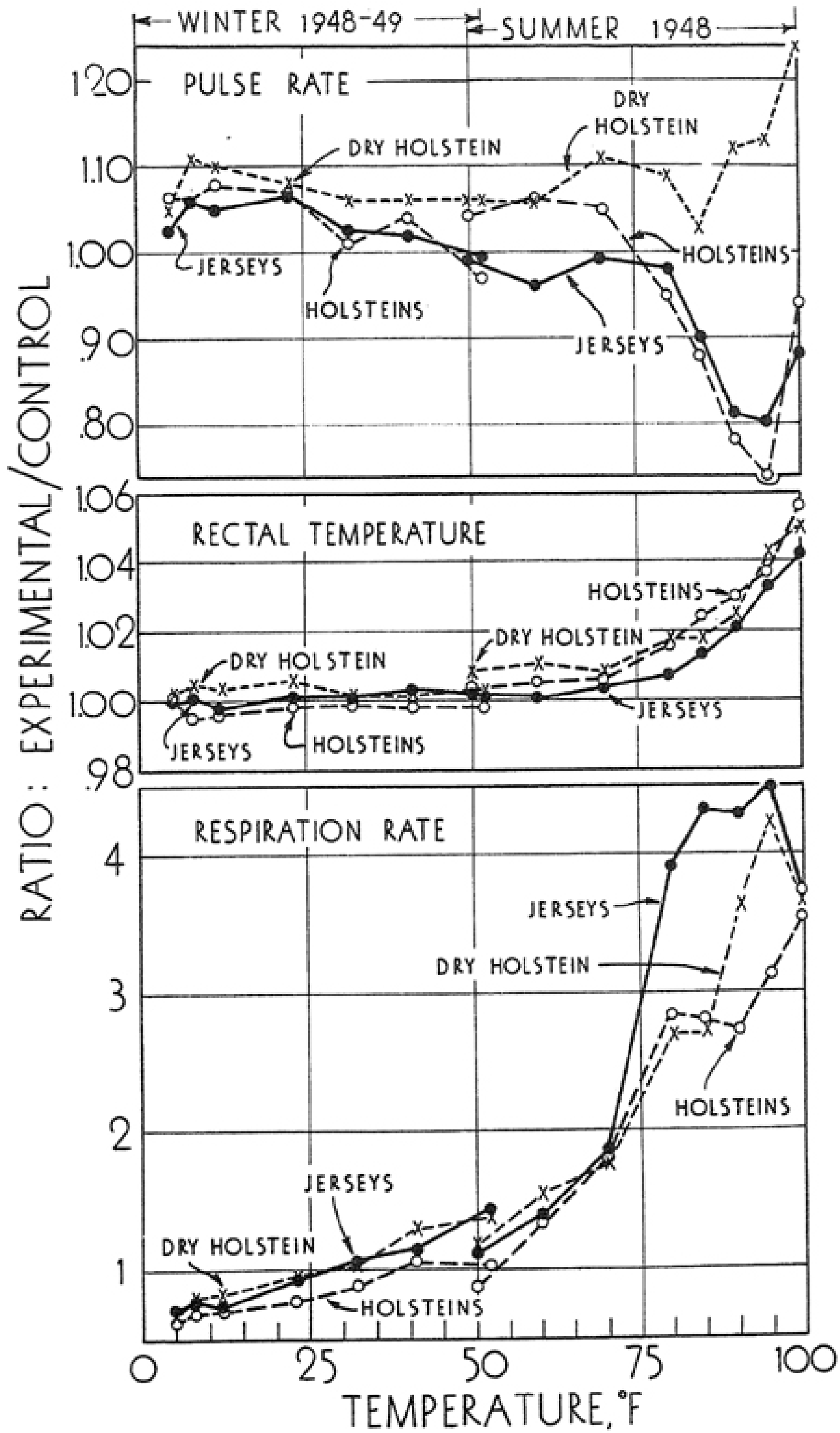

Fig. 4.—Ratios of pulse rate, rectal temperature, and respiration rate data in Experimental cows at environmental temperatures from 5° to 100°F to data for Control cows at 50°F. The method of computing the ratios for the different curves is explained in the legend to Fig. 2, and the curves are discussed in the text.

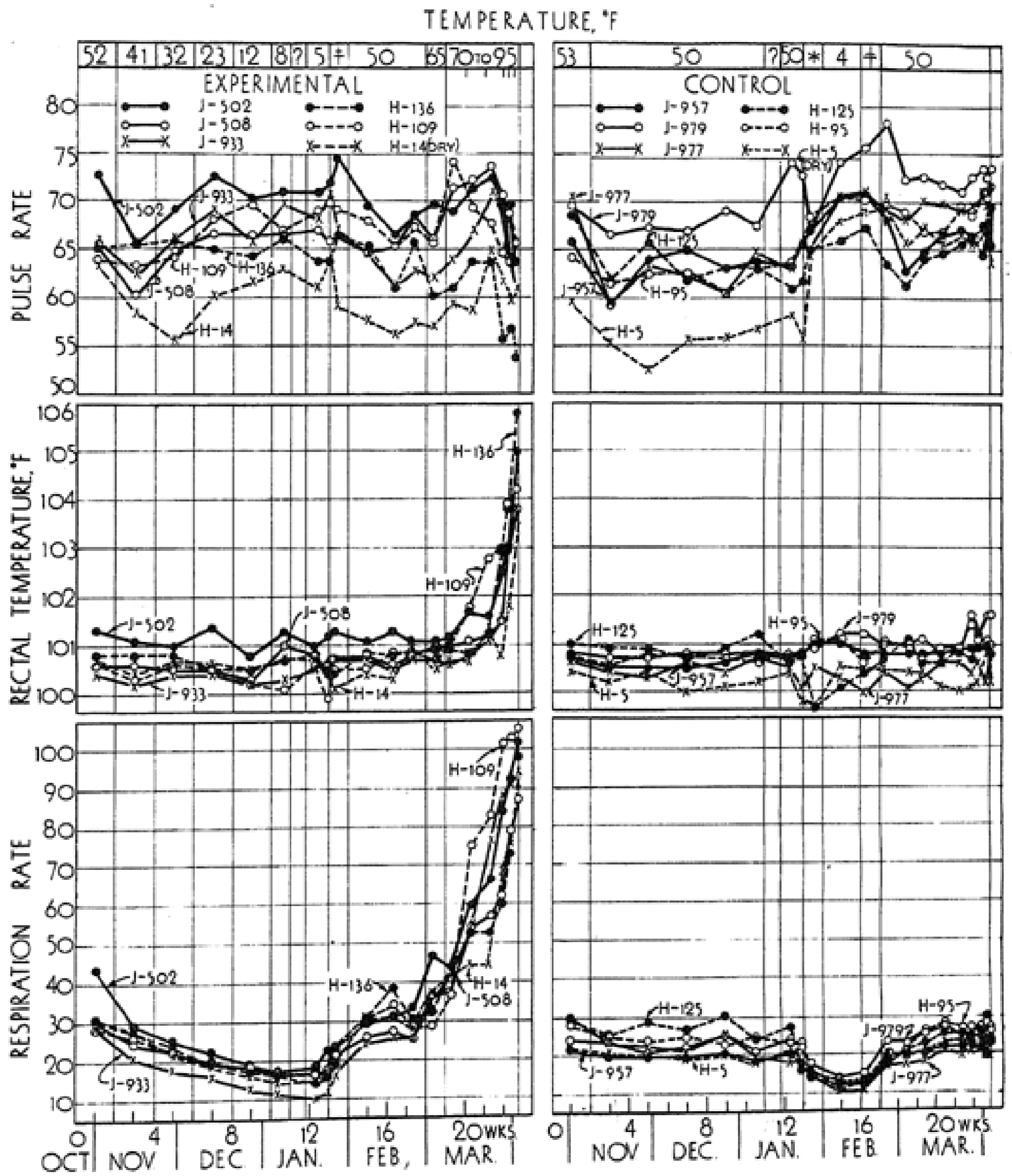

Fig. 5.—Pulse rate, rectal temperature, and respiration rate of Experimental cows (left-hand sections) and of Control cows (right-hand sections) in relation to environmental temperature shown at top of chart and to time at bottom of chart. The symbols in the temperaure scale are explained in the legend for Fig. 3.

The pulse rate curves (Fig. 5) which are strikingly similar to the heat production curves (Fig. 3) were plotted from the same 1948-49 winter data. The remarks concerning acclimatization effects noticeable in the heat production curves of Fig. 3 are equally applicable to the pulse rate curves of Fig. 5.

Rectal Temperature:—Fig. 4, center section, indicates that rectal temperature in the Jersey and Holstein cows was constant at chamber temperatures from 70° to 5°F and increased at chamber temperatures from

TABLE 6.--AVERAGE[1] RECTAL TEMPERATURE, °F, FOR THE DIFFERENT TEMPERATURE LEVELS

Temperature Level, °F. Exper.	Temperature Level, °F. Contr.	Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
52	53	101.3	100.7	100.6	100.8	100.4	100.6	100.8	101.0	100.6	100.7	100.7	100.4
41	50	101.1	100.5	100.6	100.7	100.2	100.4	100.8	100.9	100.3	100.5	100.4	100.2
32	50	101.0	100.5	100.5	100.7	100.4	100.3	100.8	100.9	100.6	100.7	100.6	100.4
23	50	101.4	100.5	100.5	100.8	100.4	100.6	100.5	100.7	100.5	100.7	100.6	100.0
12	49	100.8	100.6	100.3	100.8	100.2	100.4	100.5	100.9	100.2	100.5	100.5	100.1
8	49	101.3	100.8	101.0	100.8	100.3	100.7	100.7	101.2	100.1	100.6	100.7	100.2
5	50	101.0	100.7	100.8	100.7	100.5	100.5	100.8	100.6	100.6	100.8	100.6	100.4
20	35	101.2	100.8	100.4	100.8	100.7	100.1	100.4	100.8	99.9	100.8	100.5	99.8
34	20	101.5	101.0	100.8	100.9	100.7	100.5	100.4	99.7	100.5	101.1	100.1	99.7
50	4	101.1	101.0	100.8	101.2	100.7	100.3	100.8	100.1	100.5	101.1	100.4	100.5
50	*	101.3		100.6		100.5		100.8		100.8		100.3	
	12		101.1		100.8		99.2		100.2		100.5		100.6
	19		101.0		100.7		100.0		101.0		100.4		101.2
	28		101.0		101.8		100.8		101.3		100.8		100.0
	36		100.9		101.1		99.7		100.7		100.4		99.9
	35		101.2		101.4		99.7		99.0		100.9		100.4
50	50	101.1	100.8	100.8	101.0	100.7	100.4	100.8	100.7	100.8	101.0	100.8	100.4
65	50	101.1	100.8	101.0	101.0	100.7	100.1	100.9	101.1	100.7	100.9	100.5	100.4
69	50	101.2	100.8	101.0	101.1	100.6	100.3	100.9	100.6	100.9	100.7	100.6	100.4
74	50	101.7	100.8	101.1	100.8	100.8	100.6	100.8	100.6	101.8	100.9	100.7	100.1
80	50	101.6	100.9	101.2	100.8	101.1	100.6	101.4	100.8	102.8	100.9	101.2	100.0
84	51	102.5	100.9	101.5	101.6	101.6	100.4	102.9	100.7	102.9	101.4	100.8	100.1
90	51	103.0	100.9	102.9	101.2	103.0	100.6	103.8	101.2	103.9	101.1	101.8	100.2
95	50	105.0		103.8		103.8		105.8		104.2		103.6	
	50		101.0		101.6		100.2		101.0		101.0		101.0
	56		100.8		101.6		100.7		100.8		101.0		100.1

[1]See Table 1 for the number of observations in each average.

*The temperature was increased from 4 to 50°F during this period as shown by the following daily observations.

70° to 100°F. The rectal temperatures of the Jersey cows lagged behind those of the Holstein cows with rising chamber temperatures. Fig. 5, center section, shows similar trends for the 1948-49 winter data. In general, it appears that for the range of chamber temperatures shown, increased heat dissipation at temperatures below thermoneutrality was balanced by increased heat production; and that above 70°F, decreased heat dissipation was not balanced by decreased heat production.

Respiration Rate:—The respiration rate ratios (Fig. 4, lower section) responded consistently to changes in ambient temperatures. At a chamber temperature of 5°F, the respiration rate was approximately four-tenths that at 50°F, and at 95°F, the respiration rate was over four times that at 50°F. The greatest rise occurred above 70°F. At low temperatures there was no evidence of breed difference in respiratory response, but at high temperatures, especially in the 75° to 90°F range, the Jersey cows had much higher rates. These higher respiration rates in the Jersey cows probably explain, in part, their superiority over the Holstein cows in their ability to dissipate heat at high temperatures.

The trends for the 1948-49 winter respiration rate data are shown in Fig. 5, lower section. Minimal rates of 10 to 15 respirations per minute were observed at 4°F, and maximal rates of over 100 respirations per minute were observed at 90°F. Above 95° the respiration rate decreased.

CONCLUSIONS*

Gradually decreasing temperatures from 50° to 5°F caused:

1. No significant change in rectal temperature.

2. An increase in heat production of 30 to 35 per cent in lactating Jersey cows and of 20 to 30 per cent in lactating Holstein cows; this increased heat production was associated with decreased milk (FCM) production and some increase in feed consumption (Ref. 3, Tables 3, 5, 7), so that the extra heat was the result of increased muscular tone (there was little visible shivering) and/or increased specific dynamic action of feed.

3. A greater increase in heat production and dissipation in the Jersey than in the Holstein cows which was presumably associated with body size differences.

4. A greater decrease in milk (FCM) production in the Jersey than in the Holstein cows which was presumably associated with increasing diversion of feed for maintenance of normal body temperature.

5. A progressive decrease in respiration rate to minimal value of 10 to 15 per minute at 5°F.

6. An increase in pulse rate of approximately 8 per cent.

Gradually increasing temperatures from 50° to 100°F caused:

1. An increase in rectal temperature at environmental temperatures above 70°F.

2. A decrease in heat production of 20 to 30 per cent above 70° to 80°F, associated with decreasing feed consumption, milk production, and presumably thyroid activity.

3. A progressive increase in respiration rate to more than four times the rate at 50°F.

4. Changes in pulse rate tending to parallel changes in heat production.

Rapid changes in environmental temperature tended to accentuate functional response.

Acclimatization of heat production and pulse rate levels to extreme changes in environmental temperature required as much as four weeks under some conditions.

Under the conditions of our tests, the thermoneutrality zone was found to be from 40° to 60°F for lactating Jersey and Holstein cows.

*The discussion on the physiologic effects of changing temperature are restricted to the conditions of approximately constant relative humidity, air movement, and light. As this experiment included no data for gradually increasing temperature, a further analysis was made of such data from the preceding experiment (1, 12). In our opinion, that part of the present (1948-9) data for **rapidly** rising temperature, 5° to 50° and 50° to 95° F., is not comparable to the former (1948) data for **gradually** rising temperature, and is here discussed only with reference to acclimatization effects. The observed differences in heat production obtained by the open- and closed-circuit methods are shown on the charts and indicated here as ranges in percentage values. These are exploratory experiments with few animals and require further substantiation.

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APPENDIX

Data on oxygen consumption, carbon dioxide production, methane production, pulmonary ventilation rate and metabolic weight loss as measured by the open-circuit respiratory exchange apparatus, and heat production per unit surface area as computed from both the open-circuit and closed-circuit data are given in Tables 7 to 11.

Table 9 records the rate of "metabolic weight loss." Some explanation of these metabolic weight loss data and how they may be used in determining the rate of evaporative weight loss may be useful. Since metabolic processes involve the oxidation of body fuel, the weight of the oxygen so utilized would tend to increase body weight were it not for the exhalation of carbon dioxide (and methane in cows). The metabolic weight loss, then, is the difference between the weight of the carbon dioxide and methane exhaled* and the weight of oxygen consumed. The rate of metabolic weight loss decreased with increasing temperature. At 50°F chamber temperature the loss amounted to about 4 pounds per day for a Jersey cow and to about 5 pounds per day for a Holstein cow, decreasing to practically zero† at 100° to 105°F.

The rate at which the body loses weight, the rate of insensible loss, as measured on sensitive scales, comprises two factors: (1) the rate of metabolic weight loss and (2) the rate of evaporative weight loss from the skin and respiratory tract. This total evaporative weight loss can be estimated by subtracting the metabolic weight loss for a given period from the insensible weight loss for the same period. The data in Table 9 on metabolic weight loss will be used in a later report in conjunction with data on insensible loss to estimate total evaporative weight loss.

Figs. 6, 7, and 8 present daily records of pulse rate, rectal temperature, and respiration rate.

*There may be some anal loss of carbon dioxide and methane which the mask method does not measure. Actual weight losses may thus be somewhat greater than reported in Table 9.

†The few negative values of metabolic weight loss in Table 9 at 100° to 105°F apparently represent temporary effects produced by the restrictive action of mask-type apparatus on the freedom of respiration in panting animals.

TABLE 7.--AVERAGE[1] OXYGEN CONSUMPTION AND CARBON DIOXIDE PRODUCTION PER COW FOR EACH TEMPERATURE LEVEL (OPEN-CIRCUIT METHOD)

Temperature Level °F. Exper.	Temperature Level °F. Contr.	Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
		Oxygen Consumption, liters per hour											
52	53	131	102	134	111	122	126	178	170	182	169	174	158
41	50	116	107	105	106	110	86	154	156	161	139	160	148
32	50	144	102	138	110	133	89	183	156	180	150	159	146
23	50	150	115	141	128	154	116	189	176	182	169	174	175
12	49	146	110	132	132	126	104	184	159	198	165	148	153
8	49	154	113	136	111	127	104	153	173	178	167	168	157
5	50	154	125	116	133	134	112	189	160	188	171	176	180
20	35	148	123	119	123	126	119	195	134	180	156	172	147
34	20		132		138		110		164		163		165
50	4	142	179	119	155	120	139	198	208	176	202	164	199
50	4 to 50	129		117		114		173		170		146	
50	50	138		115		116		175		165		148	
65	50	137	130	97	137	91	75	155	156	173	168	148	162
69	50	130	105	126	140	116	123	172	149	174	175	142	162
74	50	134	125	131	144	131	121	186	148	188	153	155	166
80	50	132	109	128	133	134	109	167	148	159	168	154	174
84	51	134		103		119		156		154		130	
90	51	113		113		126		132		151		169	
95	50	116		109		92		111		131		122	
	56		156		166		131		177		209		188
		Carbon Dioxide, liters per hour											
52	53	126	96	127	107	109	114	176	160	184	154	180	155
41	50	114	102	105	104	104	78	142	160	153	134	167	146
32	50	148	100	131	103	126	85	186	156	186	145	158	147
23	50	145	111	135	124	154	108	195	166	180	166	170	162
12	49	149	103	134	133	124	98	184	158	193	165	142	153
8	49	143	108	124	115	135	106	147	165	181	174	164	157
5	50	159	111	113	144	133	110	201	161	183	170	163	165
20	35	134	123	126	127	128	117	213	147	198	165	166	160
34	20		135		144		100		164		166		166
50	4	147	171	129	157	128	139	198	204	192	208	168	212
50	4 to 50	133		121		128		192		176		151	
50	50	147		123		124		194		163		156	
65	50	152	123	105	146	92	71	156	146	156	172	150	170
69	50	132	105	122	129	120	121	170	164	174	190	146	169
74	50	142	110	135	137	136	112	188	142	193	155	154	163
80	50	142	100	125	138	146	98	177	142	153	175	158	176
84	51	126		119		130		151		156		136	
90	51	103		105		106		116		141		163	
95	50	104		113		99		99		118		124	
	56		166		162		129		180		202		194

[1]See Table 1 for the number of observations in each average.

TABLE 8.--AVERAGE[1] METHANE PRODUCTION PER COW FOR EACH TEMPERATURE LEVEL (OPEN-CIRCUIT METHOD)

Temperature Level, °F.		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.					liters per hour							
52	53	11.4	6.3	13.2	6.1	9.0	5.4	20.8	11.0	20.8	9.1	22.3	8.4
41	50	9.7	6.6	11.0	11.2	9.6	6.6	12.5	12.8	16.1	12.5	17.5	15.4
32	50	10.7	11.2	10.0	10.7	10.8	9.8	18.8	12.1	22.7	16.8	15.6	16.1
23	50	9.0	9.2	12.0	10.0	16.9	10.8	15.4	15.3	16.6	16.3	14.4	12.3
12	49	12.2	5.6	11.3	12.4	9.5	9.0	11.8	12.4	15.4	17.0	13.7	9.0
8	49	11.4	9.2	7.0	10.7	18.0	11.0	11.6	14.3	26.8	13.6	20.4	16.6
5	50	14.8	6.8	9.5	12.4	11.9	10.9	19.7	10.7	16.5	12.7	23.8	8.0
20	35	19.0	10.2	9.7	9.4	5.3	12.4	13.6	14.3	21.4	18.5	12.7	14.6
34	20		17.2		10.7		8.8		12.7		13.2		12.2
50	4	9.6	13.5	10.8	14.6	11.2	12.7	17.0	18.1	16.2	19.4	9.9	17.7
50	4 to 50	12.5		7.3		11.8		19.2		19.8		12.2	
50	50	13.2		10.0		11.9		24.0		16.0		14.5	
65	50	12.4	7.8	10.2	8.8	9.2	3.2	7.0	9.4	9.5	12.9	14.3	10.0
69	50	8.4	10.7	10.2	8.2	9.2	13.3	11.6	15.6	13.8	12.9	12.0	16.8
74	50	10.2	7.8	9.4	13.3	9.7	6.6	17.0	11.7	17.8	9.4	12.7	14.5
80	50	16.3	9.8	10.0	11.9	13.6	7.1	23.2	9.7	13.2	14.8	19.0	14.6
84	51	9.8		12.2		8.3		17.0		12.7		10.7	
90	51	8.5		5.5		8.5		13.1		4.6		20.4	
95	50	12.6		14.0		14.9		5.6		7.1		12.4	
	56		14.6		16.5		8.2		8.9		12.7		16.0

[1]See Table 1 for the number of observations in each average.

TABLE 9.--AVERAGE[1] METABOLIC WEIGHT LOSS PER COW FOR EACH TEMPERATURE LEVEL (OPEN-CIRCUIT METHOD)

Temperature Level, °F Exper.	Temperature Level, °F Contr.	Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
				WINTER 1948-49 DATA, grams per hour									
52	53	70	49	69	57	47	49	109	81	119	68	123	86
41	50	66	54	66	63	56	36	70	102	83	75	113	89
32	50	95	60	69	55	67	48	120	94	127	85	96	93
23	50	79	61	75	69	96	56	126	87	108	97	97	79
12	49	95	51	84	83	72	51	110	94	110	102	80	89
8	49	71	59	56	76	99	69	81	89	123	115	98	98
5	50	105	45	64	104	81	65	141	97	104	101	87	75
20	35	68	74	86	82	77	70	152	110	149	117	91	117
34	20		90		96		47		99		104		101
50	4	114	91	96	99	98	85	120	119	139	136	105	148
50	4 to 50	88		77		99		147		119		99	
50	50	103		86		88		151		97		107	
65	50	113	63	76	99	58	35	91	73	68	109	96	111
69	50	81	66	68	61	77	72	99	122	105	135	95	114
74	50	97	44	87	74	89	53	118	79	126	94	91	95
80	50	103	49	71	92	108	43	127	77	84	117	106	109
84	51	65		97		93		88		97		91	
90	51	49		51		36		49		66		94	
95	50	49		77		76		41		51		90	
	56		116		94		74		109		109		126

[1]See Table 2 for the number of observations in each average.

		J-212	J-205	J-202	J-204	J-994	J-504	H-83	H-100	H-118	H-132	H-106	H-90
				SUMMER 1948 DATA, grams per hour									
60						60		114					
70	50	67	52	84	59	51	57	106	99	106	97	88	75
80		59		96		96		97		123		96	
85	55	80	68	77	96	83	101	96	144	96	181	114	61
90	57	82	91	67	115	65	61	77	121	68	112	67	67
95	57	64	111	49	114	64	116	62	151	74	144	28	86
100		49		52		46		56		42		41	
105		49		5		12		-23		10		-6	
60		57		45		87		102		95		60	
	58		92		97		92		79		127		77
	66		81		77		90		39		121		54
	85				89		113		76		129		64
	95		111		82		83		50		76		56
	101		35		29				-36		10		58

[1]See Ref. 1, Table 4 for the number of observations in each average. The last five lines of data represent single observations.

TABLE 10.--AVERAGE[1] PULMONARY VENTILATION RATE PER COW FOR THE DIFFERENT TEMPERATURE LEVELS (OPEN-CIRCUIT METHOD)

Temperature Level, °F		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.	liters/minute											
52	53	81	48	78	65	65	65	96	99	104	92	105	78
41	50	61	55	53	60	55	45	80	97	83	81	90	74
32	50	90	69	78	56	77	55	97	91	104	78	87	75
23	50	80	68	80	77	83	64	96	103	97	96	83	98
12	49	79	63	77	79	64	66	93	108	98	95	73	88
8	49	58	72	68	81	60	73	68	108	83	94	74	90
5	50	96	72	66	98	76	70	93	112	107	106	99	110
20	35	106	89	73	78	79	83	114	119	124	110	93	94
34	20		81		85		73		96		93		94
50	4	109	88	88	82	94	70	166	100	133	94	119	93
50	4 to 50	106		94		103		153		120		~~111~~	
50	50	119		92		95		158		128		113	
65	50	122	93	84	98	90	76	165	92	106	127	140	104
69	50	121	81	95	97	130	83	154	104	128	127	138	103
74	50	154	87	137	105	169	69	207	88	199	103	152	96
80	50	186	71	128	86	188	63	217	96	208	117	166	105
84	51	148		169		199		203		214		163	
90	51	156		184		201		218		252		196	
95	50	191		179		226		232		235		230	
	56		98		95		90		115		125		134

[1]See Table 1 for the number of observations in each average.

TABLE 11.--AVERAGE[1] HEAT PRODUCTION PER UNIT SURFACE AREA FOR EACH TEMPERATURE LEVEL AS OBTAINED BY TWO METHODS

Temperature Level, °F		Exper. J-502	Contr. J-957	Exper. J-508	Contr. J-979	Exper. J-933	Contr. J-977	Exper. H-136	Contr. H-125	Exper. H-109	Contr. H-95	Exper. H-14	Contr. H-5
Exper.	Contr.	Cal/sq. meter/day (Open-Circuit Method)											
52	53	3865	2869	3804	3160	3436	3428	3996	3965	4118	3957	3387	3414
41	50	3467	3080	3037	3023	3158	2354	3549	3717	3732	3271	3419	3189
32	50	4255	2934	3895	3065	3767	2458	4260	3718	4221	3526	3354	3151
23	50	4356	3260	3968	3544	4344	3185	4378	4165	4213	3950	3613	3662
12	49	4266	3049	3724	3656	3537	2836	4198	3795	4508	3850	3034	3246
8	49	4429	3135	3779	3060	3597	2892	3476	4118	4078	3867	3426	3310
5	50	4478	3387	3245	3651	3760	3076	4352	3872	4316	3961	3554	3690
20	35	4168	3379	3342	3354	3531	3251	4459	3208	4125	3571	3494	3049
34	20		3608		3794		2958		3903		3708		3421
50	4	4087	4861	3331	4153	3364	3796	4521	4874	4059	4583	3377	4125
50	4 to 50	3701		3238		3155		3975		3922		2998	
50	50	3923		3161		3195		3997		3776		3030	
65	50	3900	3500	2653	3718	2549	1970	3603	3620	3861	3730	3013	3333
69	50	3699	2847	3418	3643	3214	3287	3982	3501	3970	3857	2875	3347
74	50	3811	3237	3524	3756	3570	3186	4270	3441	4243	3357	3124	3383
80	50	3728	2834	3422	3509	3672	2814	3851	3398	3603	3654	3108	3553
84	51	3722		2754		3229		3576		3531		2634	
90	51	3166		3003		4094		3030		3445		3383	
94	50	3285		2963		2584		2583		3003		2461	
	56		4123		4281		3460		4062		4423		3812
		Cal/sq. meter/day (Closed-Circuit Method)											
52	53	4054	3316	3781	3617	3551	3214	3731	4180	3653	3673	3251	3604
41	50	3979	3449	3705	3246	4107	2939	3880	3924	3755	3404	3330	3258
32	50	4237	3849	4140	3407	4574	3166	3913	3742	3920	3582	3438	3382
23	50	5042	3368	4703	3200	5200	3246	4714	3670	4701	3651	4060	3400
12	49	4977	3250	4746	3327	4322	2897	4544	3638	4571	3278	4128	3120
8	49	4790	3596	4444	3487	4594	3363	4539	3946	5041	3748	4266	3319
5	50	4714	3664	4818	3255	4752	2983	4735	3609	4590	3755	4138	3395
20	35	4373	4931	4211	4277	3831	3424	4360	4570	4462	4771	3828	4578
34	20	4356	4385	4278	4136	3931	4941	4409	4357	4412	4312	3416	3991
50	4	3683	6060	3425	4703	3331	5040	3975	5235	3877	4871	3353	4153
50	*	3638		3006		3321		4139		3776		3084	
	12		6196		4134		4244		5617		4712		3893
	19		5406		3969		4400		5207		4246		3630
	28		4303		4267		3322		4238		4402		4049
	36		5094		3751		3607		4536		3940		3601
	35		4674		3772		3952		4071		4233		3938
50	50	3753	3681	2981	3510	3014	3137	3612	3814	3830	3841	2519	3546
65	50	3578	3441	2970	3104	2753	2939	3383	3634	3254	3501	2961	3105
69	50	3626	3433	3071	3226	3197	3149	3247	3468	3181	3774	2931	3074
74	50	3760	3184	3529	3318	3249	3196	3946	3510	3635	3448	2712	3164
80	50	3667	3317	2908	3405	4146	2904	3805	3200	3430	3183	2400	3026
84	50	3207	3127	3246	3623	3644	3171	3062	3339	3417	3099	2630	2731
90	51	3938	3181	2960	3498	3043	2997	2684	3298	3753	3476	3271	3407
95	50	3066		3159		3075		3359		4375		2839	
	50		3055		3867		3468		3844		3296		3202
	56		3955		3121		3497		3358		3728		3257

[1] See Table 1 for the number of observations in each average.

*The temperature was increased from 4 to 50°F during this period as shown by the following daily observations.

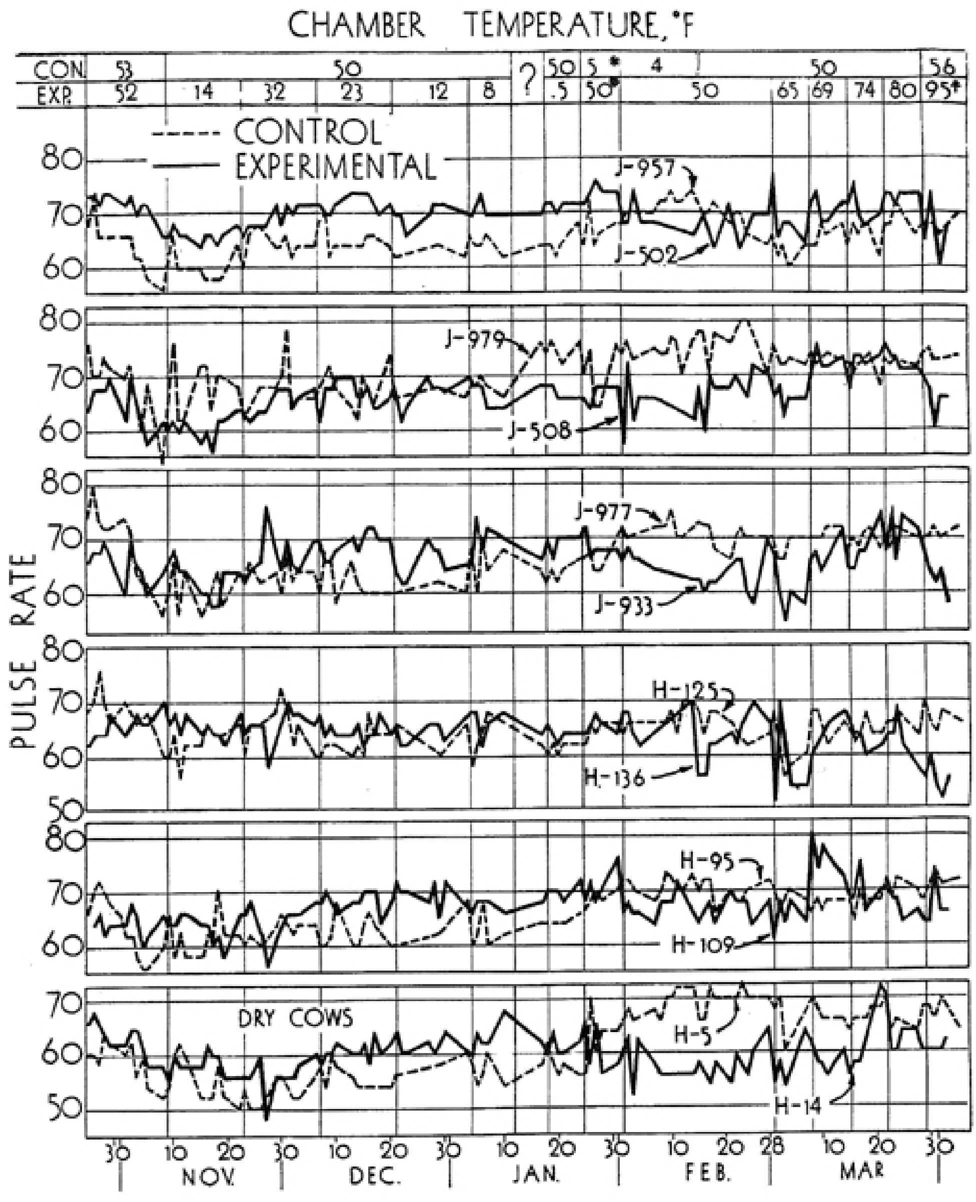

Fig. 6.—Comparison of the daily pulse rates of the Experimental cows (continuous curves) and of their matched Control cows (broken curves). The asterisk in the temperature scale indicates a transitional temperature period; the dagger indicates a lowering of room temperature at the end of the experiment (see Table 2).

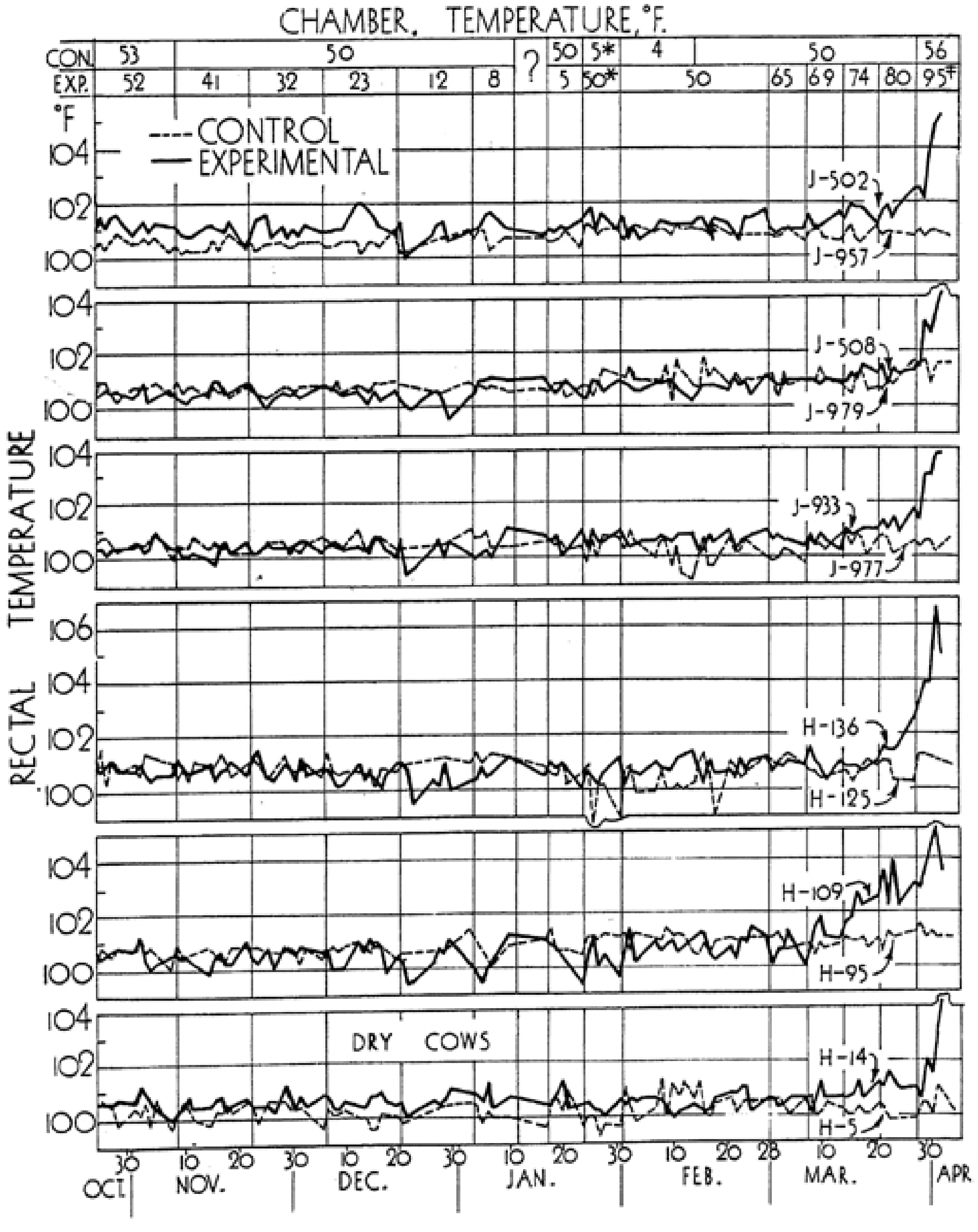

Fig. 7.—Similar curves as in Fig. 6 but for daily rectal temperature measurements. Note that rectal temperature is constant below a room temperature of approximately 70°F but rises rapidly for higher room temperatures.

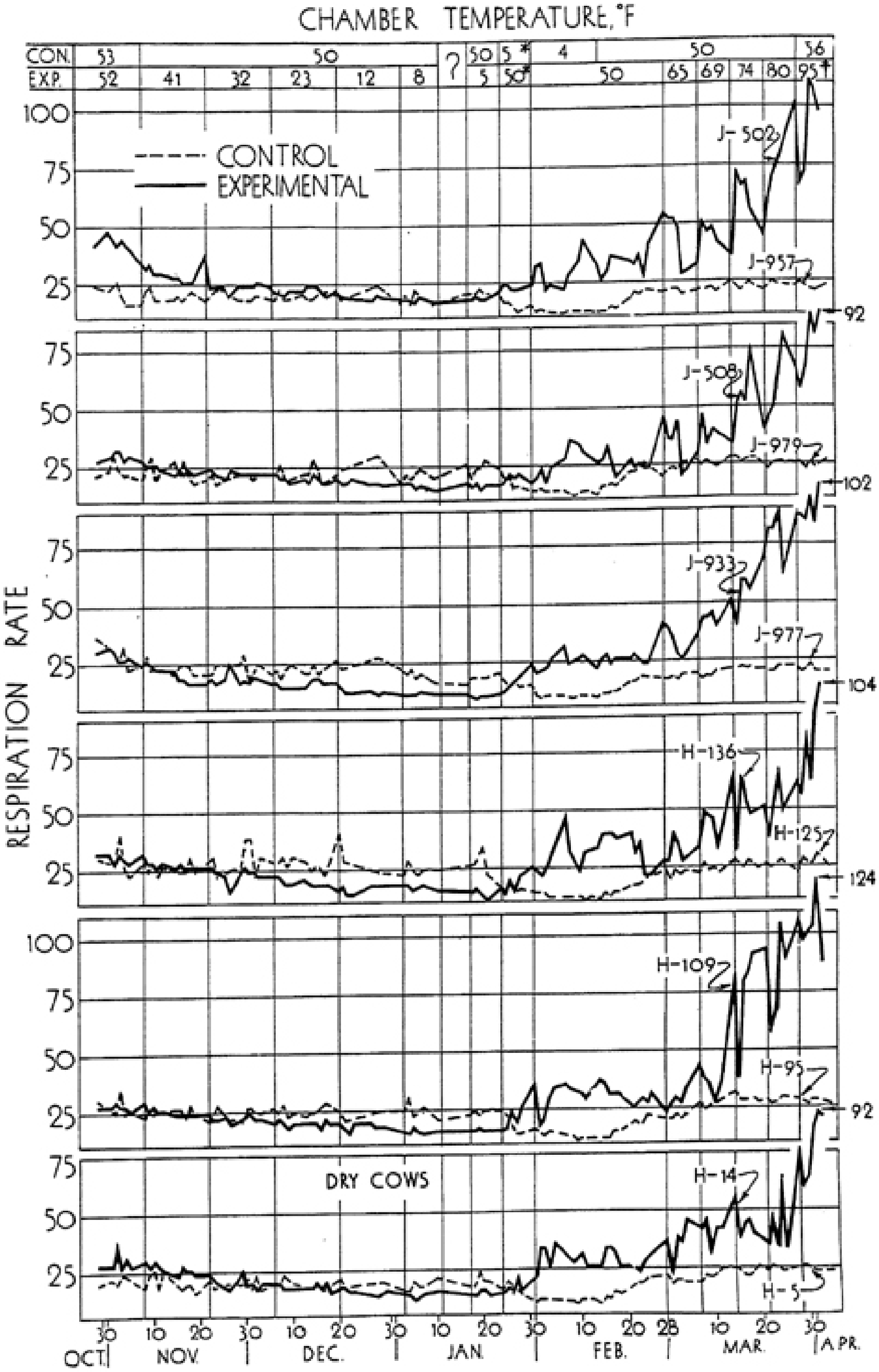

Fig. 8.—Similar curves as in Figs. 6 and 7 but for daily respiration rates. Note that respiration rate rises with rising chamber temperature over the entire temperature range from 5° to 95°F. Results of a preceding study (1) indicate that respiratory rate reaches a maximal value at about 95°F and decreases with further rise in chamber temperatures.