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Environmental Physiology

With Special Reference to Domestic Animals

XI. Effects of Temperature, 50° to 105° F and 50° to 9° F on
Heat Production and Cardiorespiratory Activities
in Brahman, Jersey and Holstein Cows.

H. H. KIBLER AND SAMUEL BRODY



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TABLE OF CONTENTS

	Page
Introduction	3
Animals and Methods	3
Data	4
Effects of Increasing Temperature, 50° to 105°F.	7
Effects of Decreasing Temperature, 50° to 9°F.	10
Discussion	11
Summary and Abstract	15
References	15
Appendix	16

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INTRODUCTION

Indian-evolved cattle, *Bos Indicus*, are generally believed to withstand oppressively hot weather much better than European-evolved cattle, *Bos Taurus*. The usual explanation for this difference—for which there is no scientific evidence—is that Indian, but not European, cattle sweat. It seemed desirable to make a laboratory study of the comparative reactions of these two sub-species of cattle to various environmental temperatures and attempt to gain an insight into the mechanisms responsible for this difference in heat tolerance.

A preceding bulletin¹* reported data on the effect of various temperatures on milk production, feed and water consumption, and body weight on Brahman (Indian-evolved), and Holstein and Jersey (European-evolved) cows; this bulletin reports data on respiration rate, pulse rate, rectal temperature, heat production computed from oxygen consumption and carbon dioxide production, methane production, and pulmonary ventilation rate in the same cows. These and other measurements to be reported in future bulletins will, it is hoped, clarify the mechanisms contributing to the superior heat tolerance of the Brahman over the Holstein and Jersey cows.

ANIMALS AND METHODS

This report includes two separate periods: first, the summer of 1949 when the Experimental group consisting of two each of Brahman, Jersey, and Holstein cows were exposed to gradually increasing temperatures from 50° up to 105°F; second, the winter of 1949-50 when the Experimental cows were exposed to gradually decreasing temperatures from 50° down to 9°F. The similar groups of matched Control cows were maintained at 50° during both periods.

The same Brahman cows were used during both periods but the Holsteins and Jerseys were different in the two periods. With the exception of Control Brahman 189, all cows were lactating during the summer, the period of rising temperature. The Brahman cows were dry during the winter period of declining temperature. Details of the management, feeding, birth and breeding dates of these cows are given in the preceding report¹.

*See numbered list of references on page 15.

The two methods^{2, 3} of measuring heat production, closed- and open-circuit, were used as checks for detecting gross errors and thus preventing continued improper operation of apparatus. The open-circuit method is undoubtedly more reliable because it is physiologically more normal for animals to breathe normal room air by the open-circuit method than to rebreathe the humid (80 to 90% relative humidity) oxygen-rich mixture by the closed-circuit method. The high humidity of the closed-circuit air must depress evaporative cooling from the respiratory tract, a serious matter at high temperatures, as it was shown⁴ by the open-circuit method, that up to 30 per cent of the total heat produced by the animal may be dissipated by respiratory vaporization at high temperature and moderate relative humidity.

DATA

The data for the different temperature levels are given in Tables 1 to 9. The more important data relating to the period of rising temperature, 50° to 105°F, are shown in Figs. 1 and 2; the corresponding data for the period of declining temperature, 50° to 9°F, are brought together in Fig. 3. Control data

TABLE 1.--TEST SCHEDULE AND NUMBER OF OBSERVATIONS

Chamber Temperature Level, °F		Relative Humidity %		Date 1949-50		Number of Tests			
						Closed-circuit		Open-circuit	
Exp.	Contr.	Exp.	Contr.	From	To and Including	Exp.	Contr.	Exp.	Contr.
Summer 1949									
51	50	67	69	May 23	June 11	8	8	2	2
60	50	71	69	June 12	June 18	4	4	2	1
65	51	73	67	June 19	June 25	5	5	2	1
69	51	76	67	June 26	July 2	5	5	2	1
75	52	70	68	July 3	July 9	4	4	2	1
80	51	65	64	July 10	July 16	5	6	2	1
85	51	64	64	July 17	July 23	5	5	2	1
90	51	66	64	July 24	July 30	5	5	2	1
95	51	57	66	July 31	Aug. 6	5	5	2	1
99	53	62	62	Aug. 7	Aug. 11	3	3	1	1
105	51	59	63	Aug. 11		1	1	1	
to 50	50	63	62	Aug. 12	Aug. 13	2	2		1
51	49	66	66	Aug. 14	Aug. 15	2	1	1	
All temperature changes up to August 11 were made about 4:30 p.m. of the last day of each experimental period. The August 11 change to 105° F was made at 4:00 a.m. and lasted until 4:00 p.m.									
Winter 1949-50									
50	50	66	64	Oct. 6	Oct. 14	7	7	2	2
41	50	57	65	Oct. 15	Oct. 28	10	10	3	2
31	50	60	69	Oct. 29	Nov. 11	10	10	2	2
22	50	60	70	Nov. 12	Nov. 25	9	9	3	2
15	50	63	69	Nov. 26	Dec. 9	10	10	2	2
12	50	67	70	Dec. 13	Dec. 22	6	6	2	1
9	50	66	64	Dec. 23	Jan. 6	6	6	2	1
to 50	51	68	62	Jan. 7	Jan. 13	5	5	1	1
50	50	67	68	Jan. 14	Feb. 1	12	10	4	1

Because of power failures, the chamber temperature was not controlled on Dec. 10, 11, 12, 20, 21, and 30; and observations for these days were not included in the data. For more detailed chamber temperature information see Fig. 1 Ref. 1.

TABLE 2.--AVERAGE* HEAT PRODUCTION FOR THE DIFFERENT TEMPERATURE LEVELS AS MEASURED BY THE OPEN- AND CLOSED-CIRCUIT METHODS
SUMMER 1949

Temperature Level, °F	Exper. J-994	Contr. J-504	Exper. J-212	Contr. J-205	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-109	Contr. H-147	Exper. H-7	Contr. H-146
Exper. Contr.	Open-Circuit Data, Calories per hour											
51 50	711	615	699	531	516	558	477	582	996	987	939	927
60 50	657	570	663	618	498	630	489	501	867	1014	960	936
65 51	717	588	675		402	510	435	456	888	936	951	834
69 51	672	714	636	708	456	558	504		909	1014	984	978
75 52	654	624	648	666	441	534	459	462	888	948	936	888
80 51	579	624	621	684	438	516	441	480	894	900	912	870
85 51	615	660	636	690	456	534	477	516	810	870	756	990
90 51	480	630	525	654	456	576	414	486	597	966	618	948
95 51	465	684	498	684	471	522	438	444	636	894	567	900
99 53	372	654	402	666	372	534	426	468	636	912	†	888
105 51	408		439		372		402		618			
to 50 50		690		594		546		432		1014		1110
51 49	462		528		480		468		624			
Closed-Circuit Data, Calories per hour												
51 50	661	574	624	588	495	577	477	536	842	816	840	731
60 50	658	507	658	549	498	602	422	522	808	733	849	697
65 51	503	515	597	564	445	533	430	480	803	751	847	702
69 51	530	566	638	579	454	551	465	532	747	785	868	736
75 52	451	536	563	563	450	524	350	441	771	753	771	689
80 51	461	612	612	622	454	525	453	455	782	756	750	744
85 51	528	565	556	597	403	545	367	496	763	767	722	813
90 51	427	563	531	608	452	498	392	440	592	791	679	793
95 51	466	584	488	651	410	551	410	448	681	804	622	784
99 53	453	557	521	607	323	538	356	435	563	807	†	778
105 51	533	675	522	469	314	454		426	587	819		773
to 50 50	361	545	438	524	405	471	409	440	517	774		742
51 49	482	563	534	643	459	547	430	461	456	934		859

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

† H-7 was removed from chamber at 6:00 p.m. August 8.

(50°F temperature level) are included for both periods. A further analysis of the changes in heat production at both increasing and decreasing temperature in relation to surface area, milk production* (FCM) and feed consumption* (TDN) is made in Figs. 4 and 5. Tables 6, 7, 8, and 9, which report valuable data but are not discussed in the text, are included in the appendix.

In preceding experiments to study the effects of increasing and decreasing temperatures on Jersey and Holstein cows^{2, 3}, it was found that the responses to increasing temperatures became critical for heat production and pulse rate above 80°F, and for rectal temperature above 70°F. The respiration rate increased most rapidly between 70° and 90°F. Decreasing temperature, 50° to 5°F, increased the heat production up to 30 per cent in Holsteins and up to 35 per cent in Jerseys, and caused somewhat parallel but lesser changes in pulse rate. Rectal temperature, however, remained at the usual level.

The results of the present experiments are summarized below:

*The data on milk production, feed consumption, and body weight were taken from the preceding bulletin¹.

TABLE 3.--AVERAGE* PULSE RATE, RESPIRATION RATE, AND RECTAL TEMPERATURE
AT EACH TEMPERATURE LEVEL
SUMMER 1949

SUMMER 1945													
Temperature Level, °F	Exper. J-994	Contr. J-504	Exper. J-212	Contr. J-205	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-109	Contr. H-147	Exper. H-7	Contr. H-146	
Exper.	Contr.	Pulse Rate Per Minute											
51	50	64	65	62	65	69	62	69	67	67	61	69	70
60	50	60	60	60	57	66	62	66	66	63	60	64	67
65	51	60	60	59	56	67	62	65	67	63	59	64	63
69	51	62	66	55	61	63	66	63	66	60	58	61	72
75	52	62	66	60	60	64	62	62	62	61	55	62	66
80	51	60	64	59	60	64	58	60	62	62	54	62	66
85	51	58	65	56	58	63	57	62	60	60	54	60	69
90	51	52	62	47	60	62	57	61	59	51	52	56	65
95	51	51	59	44	56	65	58	65	56	49	53	51	67
99	53	47	63	41	55	55	59	59	60	51	56	46†	68
105	51	55	66	46	57	73	58	66	61	85	56		74
to 50	50	48	64	46	56	55	59	61	57	60	57		68
51	49	55	66	53	56	64	60	66	60	64	60		70
Respiration Rate Per Minute													
51	50	24	30	22	19	20	19	18	18	26	36	28	30
60	50	28	22	27	20	17	13	18	12	29	26	30	28
65	51	31	22	33	19	20	10	20	8	33	28	35	29
69	51	40	23	40	21	20	11	20	9	34	30	44	28
75	52	63	24	56	21	21	10	24	8	52	27	60	28
80	51	76	26	69	22	24	11	29	10	72	32	68	29
85	51	104	26	88	22	45	11	48	11	85	31	79	29
90	51	117	28	93	24	44	12	62	11	96	30	81	29
95	51	123	28	102	21	74	12	94	10	109	32	94	30
99	53	117	29	107	20	96	12	96	10	114	37	98†	31
105	51	119	29	120	24	130	13	146	10	104	37		29
to 50	50	28	30	35	21	20	12	21	11	24	40		31
51	49	24	27	28	23	16	13	17	12	19	39		29
Rectal Temperature													
51	50	100.3	100.6	100.5	101.2	100.5	100.1	100.4	100.7	100.4	100.6	100.7	100.2
60	50	100.4	100.4	100.6	100.2	101.2	99.8	100.5	100.6	100.7	100.9	100.5	100.6
65	51	100.0	100.7	100.5	100.6	100.7	100.3	100.6	101.1	100.4	101.1	100.5	100.8
69	51	100.4	100.7	100.7	100.5	100.6	100.7	100.2	101.1	100.2	101.0	100.4	100.7
75	52	100.7	100.8	100.8	100.6	101.0	100.8	100.9	101.3	100.7	100.9	101.1	100.7
80	51	101.0	100.6	101.2	100.2	101.1	100.5	100.9	101.5	101.4	100.4	101.7	100.7
85	51	102.5	100.5	102.1	100.3	102.0	100.7	100.8	101.2	102.4	100.6	103.2	100.8
90	51	103.5	100.5	103.0	100.5	101.7	100.7	101.1	101.2	103.4	100.8	104.5	100.8
95	51	104.7	100.7	103.7	100.3	102.0	100.9	101.8	101.2	105.1	100.9	105.4	100.8
99	53	106.2	100.7	104.5	100.4	103.9	100.9	105.2	101.0	106.7	100.8	107.0†	101.1
105	51	108.6	100.4	106.4	100.0	106.5	100.4	106.4	101.4	108.5	100.8		101.1
to 50	50	99.6	100.5	99.8	100.2	99.2	100.5	99.3	101.3	97.9	100.7		100.8
51	49	98.2	100.6	98.7	100.8	99.4	100.9	99.4	101.4	96.6	100.2		100.7

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

† H-7 was removed from chamber about 6:00 p.m., August 8.

TABLE 4.--AVERAGE* HEAT PRODUCTION PER COW FOR THE DIFFERENT TEMPERATURE LEVELS,
AS MEASURED BY THE OPEN- AND CLOSED-CIRCUIT METHODS
WINTER 1949-50

WHLER 1949-50													
Temperature Level, °F		Exper. J-957	Contr. J-979	Exper. J-977	Contr. J-508	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-118	Contr. H-132	Exper. H-154	Contr. H-149
Exper.	Contr.	Open-Circuit Data,						Calories per hour					
50	50	579	582	540	609	483	519	459	486	843	846	837	753
41	50	606	603	638	612	453	495	548	462	852	852	812	777
31	50	612	537	660	654	519	486	507	465	780	789	921	852
22	50	628	582	602	594	572	477	684	486	818	900	974	906
15	50	714	543	678	603	609	525	627	387	852	819	984	765
12	50	720	681	675	651	666	588	783	372	903	894	984	873
9	50	681	654	621	630	741	552	735	450	840	876	951	
to 50	51	606	582	474	660	552	522	456	432	774	900	846	678
50	50	600	636	572	600	580	522	501	420	729	792	948	756
		Closed-Circuit Data,						Calories per hour					
50	50	614	598	567	563	535	492	449	442	788	785	780	643
41	50	688	573	525	662	711	643	535	507	801	864	720	779
31	50	630	573	594	704	614	532	535	502	693	908	774	773
22	50	705	571	629	568	661	486	613	470	764	827	859	772
15	50	673	549	646	604	682	545	622	478	743	847	820	806
12	50	741	616	683	686	736	568	727	457	784	860	868	740
9	50	743	572	604	638	740	545	835	490	799	777	892	769
to 50	51	592	671	558	650	533	546	498	462	630	844	671	729
50	50	607	630	545	602	576	608	473	446	649	792	693	659

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

TABLE 5.--AVERAGE* PULSE RATE, RESPIRATION RATE, AND RECTAL TEMPERATURE
AT EACH TEMPERATURE LEVEL
WINTER 1949-50

WINTER 1949-50													
Temperature Level, °F	Exper. J-957	Contr. J-979	Exper. J-977	Contr. J-508	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-118	Contr. H-132	Exper. H-154	Contr. H-149	
Pulse Rate Per Minute													
Exper.	Contr.	58.0	60.1	59.4	58.3	67.4	60.6	64.6	60.6	66.9	61.7	61.6	61.4
50	50	58.4	56.8	60.7	55.8	62.5	59.8	62.3	60.4	63.9	60.8	58.7	59.4
41	50	59.0	60.0	63.4	55.4	63.7	60.8	61.8	60.8	63.3	61.4	63.2	60.4
31	50	61.0	62.4	64.1	58.0	67.1	59.6	61.4	61.8	68.2	60.5	65.8	61.6
22	50	62.4	62.2	66.5	57.5	67.4	60.2	61.3	60.4	64.9	60.5	64.8	62.8
15	50	64.5	64.3	66.0	57.3	68.7	62.0	61.5	58.2	68.5	60.7	63.5	63.3
12	50	64.8	64.0	65.7	58.0	71.0	62.0	66.5	61.3	68.2	56.8	64.3	54.0
9	50	58.2	64.4	61.8	55.6	67.2	60.0	61.6	56.8	62.8	56.8	57.2	57.6
to 50	51	59.4	68.2	64.2	56.0	68.5	63.2	61.5	59.0	61.6	54.3	58.8	58.9
50	50												
Respiration Rate Per Minute													
50	50	19.7	23.0	19.9	28.6	14.3	18.6	14.7	18.3	25.4	25.6	29.9	29.4
41	50	15.9	23.2	16.3	24.8	13.9	17.6	13.4	19.8	21.3	25.5	23.8	24.4
31	50	14.9	22.6	14.6	24.6	12.7	16.2	12.7	14.6	17.9	25.4	22.6	26.2
22	50	14.2	23.3	13.2	23.3	11.9	14.4	12.4	14.0	17.2	26.4	20.1	27.3
15	50	13.4	22.8	14.2	23.2	12.2	16.2	12.5	14.2	15.4	27.1	17.7	27.8
12	50	14.8	23.7	14.5	24.3	12.0	14.7	12.5	15.0	15.7	27.0	17.3	30.3
9	50	14.5	23.8	14.3	24.7	12.5	15.3	12.7	13.5	14.8	24.0	15.7	30.8
to 50	51	16.4	23.6	17.8	23.2	14.2	15.6	15.0	12.8	23.4	23.2	24.2	31.6
50	50	20.5	23.3	22.9	24.6	16.4	15.6	16.8	12.4	26.8	22.4	31.8	30.8
Rectal Temperature													
50	50	100.9	101.1	100.2	101.2	101.0	101.2	101.0	101.0	100.4	101.1	101.0	100.8
41	50	101.0	99.7	100.5	100.6	101.0	100.5	101.2	101.2	100.0	101.9	101.2	100.5
31	50	101.0	100.2	100.5	100.4	101.5	100.8	101.2	101.0	100.2	100.9	101.3	100.4
22	50	100.9	100.6	100.7	100.8	101.1	101.1	101.2	101.2	100.0	100.9	101.3	100.9
15	50	100.8	100.8	100.7	100.9	101.3	101.0	101.1	101.2	99.8	101.0	101.5	100.9
12	50	100.8	101.1	100.7	100.9	101.2	101.0	101.1	101.2	99.8	100.9	101.3	101.0
9	50	100.8	101.1	100.8	101.1	101.3	101.1	101.1	101.4	100.2	100.9	101.5	101.1
to 50	51	100.9	100.8	100.4	101.1	101.4	101.1	101.3	101.4	100.0	100.9	101.0	101.0
50	50	100.8	101.0	100.6	101.0	101.3	101.1	101.3	101.5	100.8	101.0	101.0	101.2

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

EFFECTS OF INCREASING TEMPERATURE, 50° TO 105°F

Heat production (Fig. 1) at the 50°F Control temperature varied between 800 and 1000 Cal/hr. in the Holsteins, 600 to 700 Cal/hr. in the Jerseys, and 450 to 500 Cal/hr. in the Brahms. The lower heat production in the Brahms than in Jerseys of approximately the same body weight was unexpected and will be referred to again.

Elevating the environmental temperature from 70° to 100°F decreased the heat production about 35 per cent in the Jerseys and Holsteins but only about 10 per cent in the Brahms.

Pulse rates varied considerably between the individual Control cows at 50°F (Fig. 2, upper right) but were closely grouped about an average value of 61 beats per minute in the Experimental cows (Fig. 2, upper left) at temperatures between 69° and 80°F. The pulse rate *decreased* slightly in the Brahms at 99°F, and sharply in the Jerseys and Holsteins between 80° and 99°F. The pulse rate *increased* in all cows at 105°F.

Rectal temperature began to rise in the Jerseys and Holsteins at about 75°F, and in the Brahms at about 90°F; at 105° environmental temperature, the rectal temperature exceeded 108°F in the Holsteins and in one of the Jerseys; and exceeded 106°F in the Brahms.

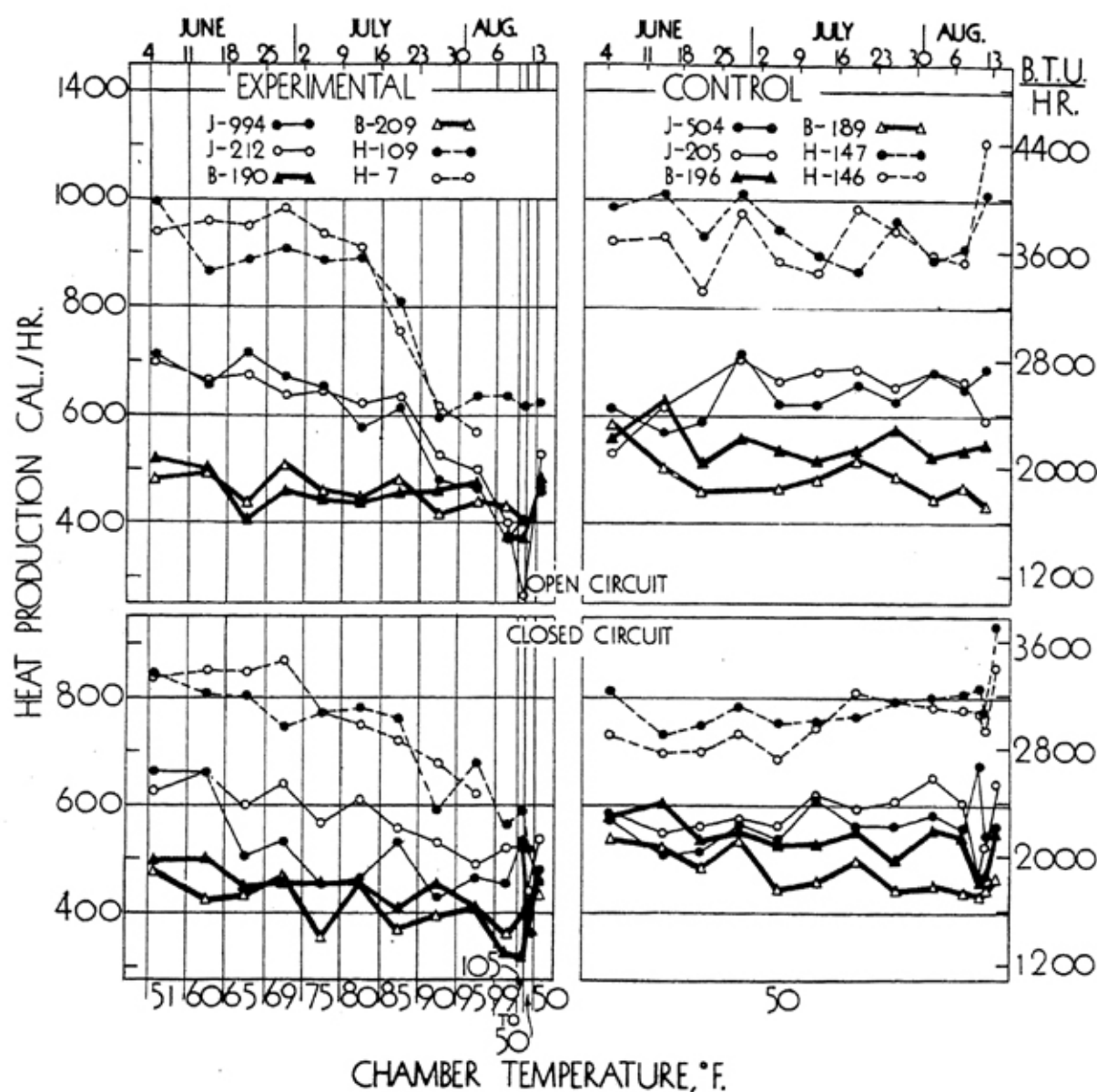


Fig. 1.—Heat production per animal in Brahman, Jersey, and Holstein cows as a function of rising temperature, 51° to 105°F for the Experimental cows, and of constant 50°F temperature for the Control cows. Both the open-circuit curves (top) and the closed-circuit curves (bottom) show noticeable differences in heat production levels in Brahman and Jersey cows of approximately the same body weight at temperatures below 95°F.

Respiration rates (Fig. 2) rose in S-shaped curves in the Jerseys and Holsteins, rising most rapidly between 69° and 90°F, and flattening out at about 95°F. Little rise occurred in the curves for the Brahmans at temperatures below 80°F, but above 80°F and up to 105°F they rose rapidly without flattening out, exceeding the highest levels reached in the Jerseys and Holsteins.

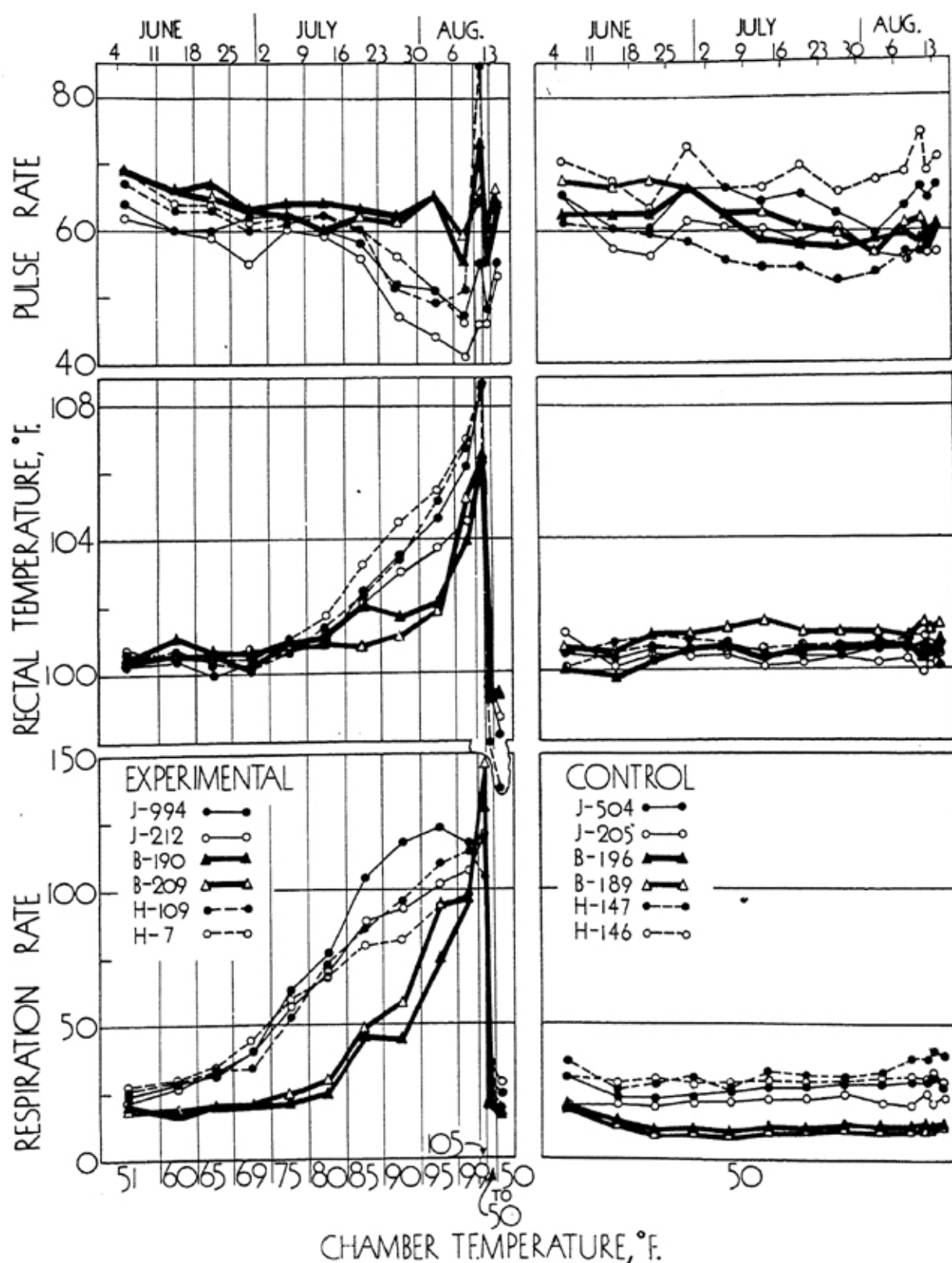


Fig. 2.—Pulse rate, rectal temperature, and respiration rate as functions of rising temperature, 51° to 105°F, for the Experimental cows, and of constant 50°F temperature for the Control cows. These curves illustrate the greater heat tolerance of the Indian than the European-evolved cows to environmental temperatures above 75°F.

EFFECTS OF DECREASING TEMPERATURE, 50° TO 9°F

Heat production (Fig. 3) increased on the average 15 per cent in the Holsteins, 20 per cent in the Jerseys, and 50 per cent in the Brahmins as the temperature was decreased from 50° down to 12° or 9°F.

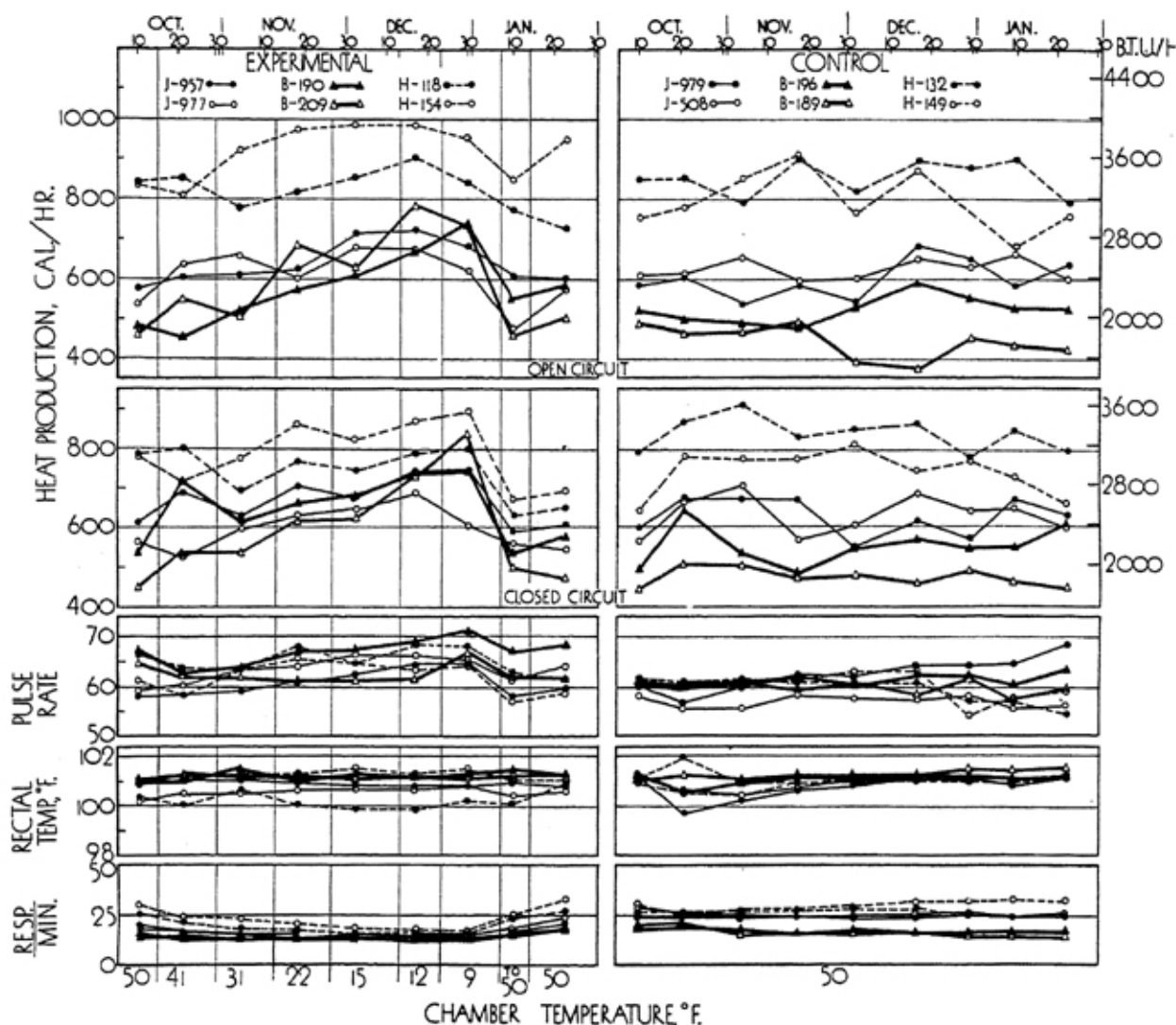


Fig. 3.—Heat production, pulse rate, rectal temperature, and respiration rate as functions of decreasing temperature, 50° to 9°F in the Experimental cows, and of constant 50°F temperature in the matched Control cows.

Pulse rates similarly increased slightly in all cows, increasing most in one Brahman cow from 63 beats per minute at 40°F to 71 beats per minute at 9°F.

Rectal temperature remained at the normal level (within the usual limits of diurnal variations).

Respiration rates per minute decreased from about 25 to 15 in the Holsteins, from 20 to 14 in the Jerseys, and from 14 to 12 in the Brahmins as the temperature decreased from 50° to 9°F.

DISCUSSION

This report confirms the preceding ones in showing that increasing environmental temperature above 70° to 80°F increases the rectal temperature and respiration rate, and decreases the heat production and pulse rate in European-evolved cows*; and it extends the observations to Indian-evolved cattle, demonstrating for the first time that these cows undergo similar changes beginning, however, not at 70° to 80°F but at about 90° to 95°F. These observations would not be expected on the basis of investigations on man, because man shows no such changes at these environmental temperatures; and when man's rectal temperature increases as a result of fever, naturally or artificially induced, his heat production increases approximately in accordance with the rule of van't Hoff and Arrhenius^{5, 6}.

A possible explanation of the decreasing heat production with increasing temperature, 50° up to 100°F, may be found in the decrease in feed consumption and milk production; and this relation of heat production with feed intake and milk production may provide also an explanation of the low heat production of the Brahman cows at 50° to 85°F in comparison to Jersey cows of about the same weight. At the 51°F temperature level, Jersey 994—weight 758 pounds, production 37.5 pounds FCM, feed consumption 19.6 pounds TDN per day—had a heat production rate of 711 Cal/hr. The two Brahman—weights 710 and 743 pounds, production 11.5 and 7.4 pounds FCM, feed consumption, 11.8 and 11.2 pounds TDN per day—had heat production rates of 477 and 516 Cal/hr. respectively. It is, of course, also possible that Indian cows have an inherently lower basal metabolic rate than European cows.

The rate of blood circulation in the various regions of the skin—especially dewlap, navel flap, and ears—may be differently affected in the two categories of cattle by the changing environmental temperature and thus affect the rates of heat loss.

The decline in heat production with increasing temperature may also be partly due to declining thyroid activity with increasing temperature as has been demonstrated on rats⁷ or to changes in other endocrines, especially the adrenals.

In view of the considerably lower heat production in the Brahmans than in Jerseys of the same weight in the optimal temperature zone (Fig. 1), it may be suggested that the Brahmans relatively (in comparison to the high milking Jerseys) have lower thyroid activity. Unpublished data by others on this project, however, indicate that the protein-bound iodine was slightly higher in the Brahmans than in the high milking Jerseys. Further investigation of this question is needed.

*At 105°F chamber temperature, the cows were very weak and their rectal temperatures ranged between 106° and 109°F. Under these conditions it was very difficult to obtain representative heat production measurements, as the use of the mask, even with the open-circuit apparatus, tended to depress their respiration rate. Following such tests they panted very heavily, especially with the closed-circuit method. The pulse rates did rise in all cows at 105°F chamber temperature, and as the changes in pulse rate tend in general to parallel the changes in heat production, it is possible that a rise in heat production, not shown by the data, did occur at these extremely high rectal temperatures.

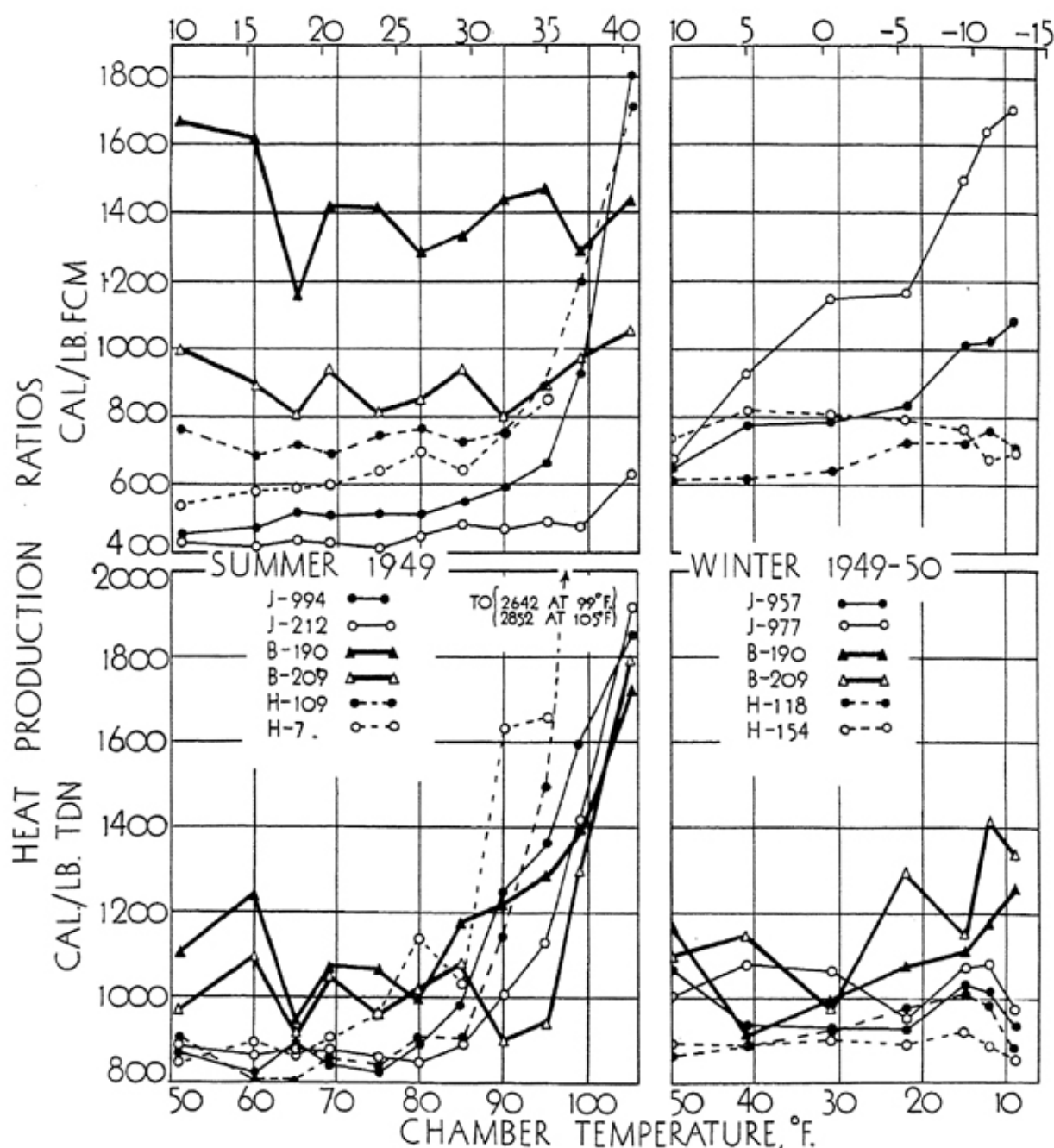


Fig. 4.—Ratio of heat production to milk production (top) and to total digestible nutrient consumption (bottom) for both increasing and decreasing temperatures.

Fig. 4 shows curves relating Cal/lb. TDN and Cal/lb. FCM with changes in chamber temperature. Since the ratio Cal/lb. TDN rises with increasing temperature, the pounds of TDN must decrease at a faster rate than heat production; apparently the heat production at high temperature is associated, in part, with loss in body weight. Holstein 109, which lost the most weight, did indeed show the greatest rise in Cal/lb. TDN. The curves for Cal/lb. FCM (Fig. 4) show considerable variation between cows.

It seems unbelievable, in the light of the large literature^{5, 6} demonstrating the applicability of the van't Hoff Arrhenius rule to physiologic rate processes,

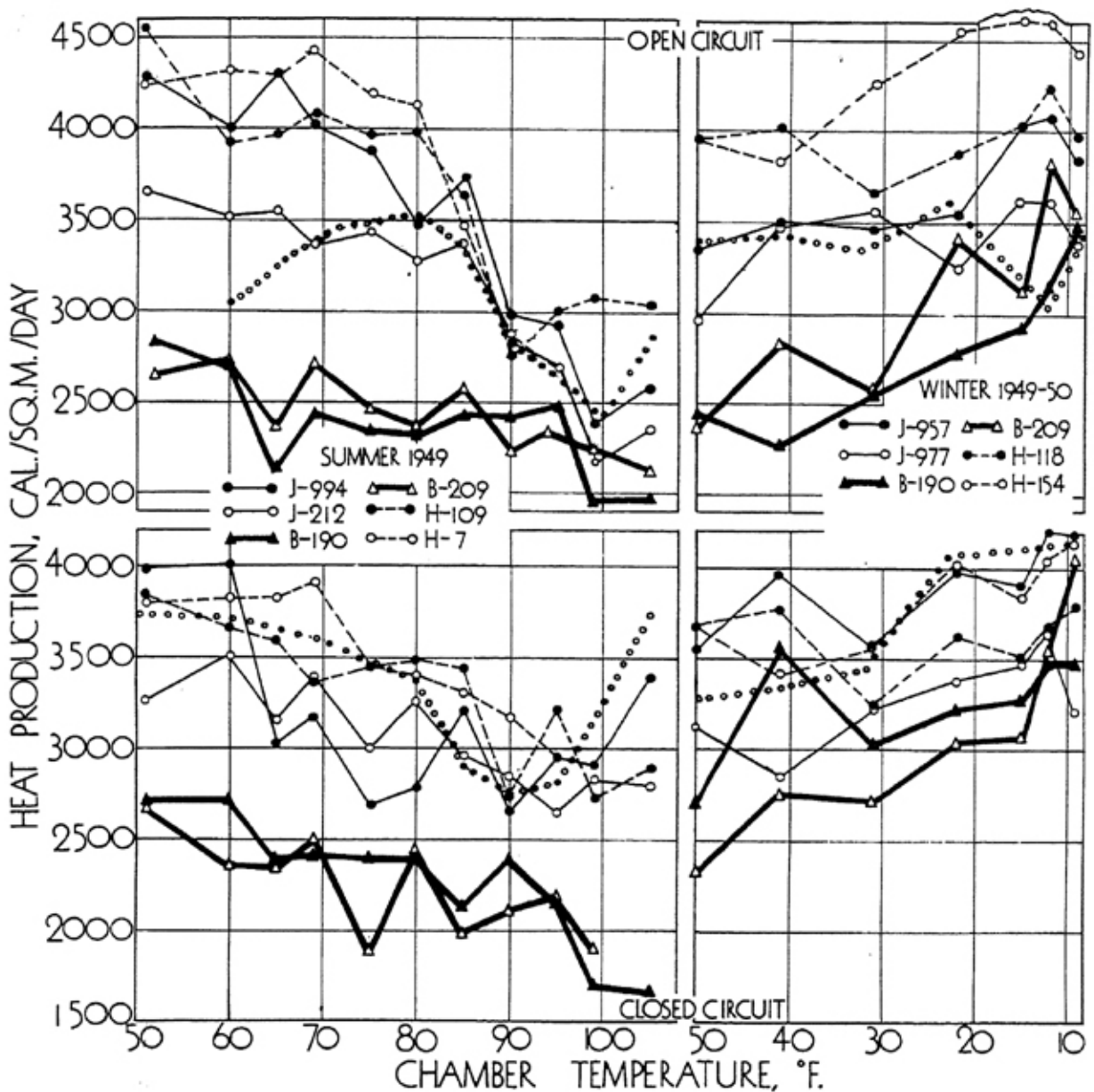


Fig. 5.—Heat production per unit surface area in Brahman, Jersey, and Holstein cows as a function of increasing temperature (left) and decreasing temperature (right). The curves made up of open circles without connecting lines represent earlier tests on dry Holstein cows.

that rising body temperature should not increase the rate of tissue metabolism. The total metabolism may be the algebraic sum of the raised metabolism (in accordance with the van't Hoff Arrhenius rule) and the lowered metabolism due to lowered endocrine activity, feed consumption, and milk production.

Another striking result is the rise at about 90° to 95°F in rectal temperature and related changes in Brahmans in contrast to the rise at about 70° to 80°F in the Jerseys and Holsteins. This evidence of greater heat tolerance in the Brahmans is apparently not entirely due to greater sweating rates as their rectal temperature was only slightly below that in the Jerseys at 105°F environmental temperature. The difference seems more probably due to the 12 per

cent* greater surface area in the Brahmans than in Jerseys of the same weight, which enables the Brahmans to dissipate heat faster. This greater surface area per unit weight and consequent greater rate of heat dissipation by convection, radiation, and vaporization from the larger surface area may suffice to maintain body temperature and related processes approximately normal up to 90°F, but not up to 100° or 105°F. If this reasoning represents the facts, increased surface area rather than increased sweat gland activity per unit surface area may be the explanation for the greater heat tolerance of the Brahman cattle.

Fig. 5 shows the changes in heat production per unit surface area with increasing and decreasing temperatures. It is interesting to note that the heat production of the dry Holstein cows (data from previous experiments represented by open circles without connecting lines) like that of lactating cows, was depressed by increasing temperature up to about 100°F. It appears from these few data that the thermoneutrality zone in the Brahmans (the zone of minimal heat production at normal rectal temperature) lies between 50° and 80°F, while the preceding report on Jerseys and Holsteins³ located their thermoneutrality zone between 40° and 60°F.

*Measurements made on these cattle by means of a surface integrator and also by direct linear measurements indicate that because of their large dewlap, ears, navel flap, and hump, the Brahmans have about 12 per cent more area than Jerseys of the same weight.

SUMMARY AND ABSTRACT

Data are presented on the influence of increasing temperature, 50° up to 105°F, and of decreasing temperature, 50° down to 9°F, on heat production and cardiorespiratory activities in Brahman, Jersey, and Holstein cows. The results confirm previous reports on European-evolved Jersey and Holstein cows that increasing environmental temperature above the critical level, 70° to 80°F, increases rectal temperature and respiration rate, and decreases heat production and pulse rate*; and demonstrate for the first time that the critical level in Indian-evolved Brahman cows is not 70° to 80°F, but 90° to 95°F. The greater heat tolerance of the Brahman cows above 70° to 80°F does not appear to be associated so much with greater sweating rate per unit surface area, since they developed almost as high rectal temperatures at 105°F environmental temperature as Jersey cows of similar body weight, as with their greater surface area per unit weight with resulting greater heat dissipation below 95°F by convection, radiation and vaporization from their larger surface. The lower heat production of these Brahman cows—associated perhaps with their lower milk production and feed consumption, and possibly with an inherently lower basal metabolism—may also be a factor in their greater heat tolerance.

Decreasing the temperature from 50° to 9°F did not affect the rectal temperature; decreased the respiration rate more in the Holstein and Jersey than in the Brahman cows; and increased the heat production more in the Brahman than in the Jersey and Holstein cows.

Numerical details are given in the text and tables.

*The pulse rate increased in all cows at 105°F as the rectal temperature reached high levels, 106.4° to 108.6°F.

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APPENDIX

Tables 6, 7, and 9 include data on the rates of oxygen consumption, carbon dioxide production, methane production, and pulmonary ventilation. Table 8 records the rate of metabolic weight loss, computed as the difference in the rates of weight lost in the carbon dioxide and methane exhaled and the weight gained in the oxygen consumed, and to be used together with the rate of insensible weight loss in a subsequent report to estimate total evaporative weight loss.

TABLE 6.--AVERAGE* OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION, AND METHANE PRODUCTION FOR THE DIFFERENT TEMPERATURE LEVELS (OPEN-CIRCUIT METHOD)
SUMMER 1949

Temperature Level, °F		Exper. J-994	Contr. J-504	Exper. J-212	Contr. J-205	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-109	Contr. H-147	Exper. H-7	Contr. H-146
Exper.	Contr.	Oxygen Consumption, liters per hour											
51	50	142	122	138	106	102	112	95	118	198	196	186	184
60	50	130	113	132	124	98	128	98	101	173	201	190	186
65	51	142	117	134		81	101	86	92	178	186	192	166
69	51	133	142	127	141	90	111	100		182	201	196	194
75	52	130	124	129	133	88	106	91	92	177	188	186	176
80	51	115	124	124	136	86	102	88	96	179	178	182	172
85	51	122	132	126	136	89	106	95	103	160	177	150	196
90	51	98	129	105	130	90	115	84	99	121	197	126	190
95	51	98	136	100	136	94	103	88	91	128	178	115	179
99	53	76	129	84	132	74	106	85	93	134	181	†	176
105	51	87		94		77		85		132			
to 50	50		137		118		108		86		206		222
51	49	91		106		96		93		125			
Carbon Dioxide Production, liters per hour													
51	50	136	122	146	116	108	112	96	105	208	192	192	192
60	50	138	114	139	119	105	116	98	94	168	214	195	206
65	51	156	127	132		80	99	90	84	170	183	177	163
69	51	140	147	127	138	92	112	108		186	201	200	189
75	52	136	126	127	127	98	109	92	87	173	185	183	180
80	51	120	134	163	143	88	108	86	92	172	176	177	192
85	51	128	137	134	152	92	106	92	105	172	161	152	195
90	51	88	114	103	129	93	111	76	87	108	171	110	181
95	51	74	135	96	147	104	105	85	77	121	175	103	180
99	53	63	141	69	150	82	115	79	95	105	204	†	204
105	51	63		65		64		62		83			
to 50	50		137		130		121		85		186		215
51	49	104		103		103		100		119			
Methane Production, liters per hour													
51	50	11.8	8.8	11.4	11.4	9.2	7.8	16.6	4.8	15.2	16.5	13.5	16.6
60	50	13.0	26.5	12.2	5.6	7.2	6.1	8.4	4.2	11.2	20.4	16.7	25.7
65	51	12.8	11.5	13.4		8.6	10.2	8.8	7.3	12.8	16.5	11.9	18.5
69	51	12.9	12.1	11.6	12.1	7.0	10.6	9.8		15.4	25.1	22.2	17.2
75	52	10.0	9.4	10.7	9.2	7.0	9.4	6.6	7.1	13.6	19.0	15.0	16.8
80	51	8.6	16.3	12.0	10.9	5.8	8.2	7.7	8.8	14.0	17.0	18.5	18.0
85	51	11.0	16.5	13.4	14.3	5.7	12.7	10.1	9.7	21.4	12.6	17.8	17.2
90	51	9.2	8.2	9.7	12.4	7.8	8.0	8.6	5.9	10.7	16.7	6.6	21.1
95	51	4.0	8.8	8.2	13.1	9.9	11.4	7.6	4.1	12.7	17.0	7.5	15.8
99	53	3.7	10.7	6.5	16.0	5.6	13.6	5.6	9.4	20.4	18.2	†	23.1
105	51	1.4		4.8		6.5		3.4		12.4			
to 50	50		7.6		12.7		11.2		7.8		13.6		17.6
51	49	9.7		8.5		7.0		7.8		7.6			

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

† H-7 was removed from chamber about 6:00 p.m., August 8.

TABLE 7.--AVERAGE* OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION, AND METHANE PRODUCTION FOR THE DIFFERENT TEMPERATURE LEVELS (OPEN-CIRCUIT METHOD)

WINTER 1949-50

Temperature Level, °F		Exper. J-957	Contr. J-979	Exper. J-977	Contr. J-508	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-118	Contr. H-132	Exper. H-154	Contr. H-149
Exper.	Contr.	Oxygen Consumption, liters per hour											
50	50	115	154	108	124	96	104	91	101	167	169	167	152
41	50	121	120	127	124	90	98	109	92	169	169	161	153
31	50	121	106	133	130	103	96	101	93	158	157	183	169
22	50	125	116	120	118	114	95	135	98	162	197	193	180
15	50	142	107	136	120	121	104	124	77	170	162	198	152
12	50	143	135	136	129	134	118	155	75	178	177	195	206
9	50	135	130	124	124	149	110	181	90	167	174	188	124
to 50	51	121	116	95	131	109	104	91	85	154	179	168	181
50	50	119	125	109	120	115	107	100	83	145	157	188	151
Carbon Dioxide Production, liters per hour													
50	50	113	154	102	110	96	99	99	81	178	168	164	142
41	50	121	119	128	113	106	100	117	90	171	170	179	167
31	50	121	105	129	130	110	104	105	90	150	168	194	185
22	50	128	120	118	126	119	97	142	94	174	197	206	183
15	50	138	112	133	130	129	104	126	74	166	181	198	159
12	50	142	135	128	136	124	116	157	70	181	184	201	176
9	50	133	134	118	140	139	110	160	85	178	178	206	124
to 50	51	118	110	90	141	118	107	88	83	163	193	172	181
50	50	120	130	113	117	122	92	102	83	156	156	191	157
Methane Production, liters per hour													
50	50	8.4	14.4	8.7	6.9	8.7	11.0	10.8	5.1	17.1	16.5	11.7	14.7
41	50	12.1	12.0	11.6	9.6	10.8	10.8	10.8	8.4	15.6	18.3	21.6	17.1
31	50	11.4	8.4	16.2	9.9	11.1	12.0	9.9	7.5	10.5	20.1	22.2	18.6
22	50	13.0	11.7	13.0	11.4	10.2	12.6	14.8	8.4	14.6	24.6	20.0	13.2
15	50	12.3	10.2	12.6	13.5	12.9	10.2	11.1	6.0	14.7	21.6	17.4	14.4
12	50	13.2	11.1	12.6	12.6	12.3	13.8	11.1	7.2	15.0	21.3	21.3	19.8
9	50	13.5	14.4	12.6	16.8	8.4	9.0	8.4	5.4	22.8	18.6	30.0	11.4
to 50	51	11.4	9.6	5.4	10.2	11.4	8.4	7.2	6.0	16.8	25.2	18.0	16.5
50	50	11.1	10.8	11.8	9.0	10.4	4.8	7.6	9.0	15.0	15.6	19.5	25.2

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

TABLE 8.--AVERAGE* METABOLIC WEIGHT LOSS FOR THE DIFFERENT TEMPERATURE LEVELS, GRAMS PER HOUR (OPEN-CIRCUIT DATA)

Temperature Level, °F		Exper. J-994	Contr. J-504	Exper. J-212	Contr. J-205	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-109	Contr. H-147	Exper. H-7	Contr. H-146
Exper.	Contr.					Summer 1949							
51	50	75	73	100	86	74	67	65	43	139	39	124	129
60	50	96	83	95	62	73	50	60	45	193	150	125	160
65	51	114	93	79		48	59	61	40	91	107	85	98
69	51	96	97	79	81	58	70	78		119	28	131	109
75	52	90	79	75	67	73	71	57	46	99	111	107	116
80	51	79	99	154	97	55	74	49	51	94	106	103	147
85	51	87	93	94	116	59	68	53	58	126	74	99	117
90	51	40	47	61	78	61	61	36	35	49	68	42	101
95	51	9	79	53	106	79	69	47	25	65	104	45	111
99	53	19	103	21	119	60	86	39	62	31	157	†	167
105	51	2		-2		22		4		-16			
to 50	50		80		97		93		51		84		121
51	49	83		59		72		71		61			

† H-7 was removed from chamber 6:00 p.m., August 8.

Temperature Level, °F		Exper. J-957	Contr. J-979	Exper. J-977	Contr. J-508	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-118	Contr. H-132	Exper. H-154	Contr. H-149
Exper.	Contr.					Winter 1949-50							
50	50	65	94	54	45	59	55	74	20	125	101	94	75
41	50	75	73	81	53	89	66	83	53	107	107	140	123
31	50	74	63	76	78	78	78	71	50	78	122	138	138
22	50	83	80	71	88	79	65	99	52	123	125	145	114
15	50	79	75	78	96	91	64	80	40	96	142	120	107
12	50	86	82	68	94	63	70	96	36	115	126	133	68
9	50	80	89	65	112	68	66	63	43	129	117	160	76
to 50	51	68	58	46	99	85	69	49	47	114	144	113	110
50	50	75	86	76	66	84	33	64	51	112	95	123	112

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

TABLE 9.--AVERAGE* PULMONARY VENTILATION RATE FOR THE DIFFERENT TEMPERATURE LEVELS, LITERS PER MINUTE (OPEN-CIRCUIT DATA)

Temperature Level, °F		Exper. J-994	Contr. J-504	Exper. J-212	Contr. J-205	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-109	Contr. H-147	Exper. H-7	Contr. H-146
Exper.	Contr.	Summer 1949											
51	50	96	95	98	78	69	71	70	73	121	137	144	129
60	50	88	88	91	78	62	68	72	58	116	154	156	133
65	51	106	92	91		62	60	63	52	125	145	142	119
69	51	102	101	95	80	63	65	76		117	140	170	130
75	52	106	97	102	89	67	65	65	55	134	144	208	122
80	51	137	101	127	90	63	64	64	51	150	129	247	136
85	51	204	102	178	99	76	59	75	54	205	130	264	124
90	51	193	86	179	74	79	61	65	52	178	132	242	131
95	51	174	104	182	78	114	60	90	49	212	142	242†	132
99	53	157	98	182	83	135	63	151	53	179	169		137
105	51	227		193		136		140		206			
to 50	50		98		88		65		49		134		148
51	49	65		78		61		60		79			

† H-7 was removed from chamber about 6:00 p.m., August 8.

Temperature Level, °F		Exper. J-957	Contr. J-979	Exper. J-977	Contr. J-508	Exper. B-190	Contr. B-196	Exper. B-209	Contr. B-189	Exper. H-118	Contr. H-132	Exper. H-154	Contr. H-149
Exper.	Contr.	Winter 1949-50											
50	50	84	94	64	80	59	61	66	54	118	100	104	96
41	50	83	73	89	86	70	72	89	62	105	103	102	108
31	50	72	62	68	81	55	63	68	49	84	102	103	112
22	50	71	74	60	92	54	56	81	48	96	124	92	116
15	50	82	74	71	87	54	63	68	48	87	102	93	102
12	50	82	88	72	110	61	72	89	58	97	116	100	125
9	50	76	87	63	94	70	72	94	57	94	106	92	94
to 50	51	73	68	68	106	59	65	65	47	104	104	92	118
50	50	80	91	87	84	75	55	77	46	110	103	131	110

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