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J. H. LONGWELL, *Director*

Environmental Physiology

With Special Reference to Domestic Animals

X. Influence of Temperature, 5° to 95° F, on Evaporative Cooling From the Respiratory and Exterior Body Surfaces in Jersey and Holstein Cows

H. H. KIBLER AND SAMUEL BRODY

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INTRODUCTION

An environmental temperature of 105°F (40.5°C) at moderate humidity increased the rectal temperature to near lethal limits of 106.7°F (41.5°C) in Jersey and to over 108°F (42.2°C) in Holstein cows[1]*. Similar environmental conditions have little effect on the rectal temperature of man. This species difference in body-temperature regulation is presumably associated with differences in evaporative cooling capacity.

The two areas from which moisture vaporizes and cools the body are, of course, the external and respiratory surfaces. The respiratory surface in man has been estimated[2] to be 70 square meters, thirty times that of the outer body surface[3]; yet the vaporization rate from the respiratory passages is not thirty times but about half that of the outer surface[4].

The relatively greater evaporative cooling capacity of the smaller outer surface than of the larger respiratory surface is mainly associated with differences in the volume rates of air flow over the two surfaces. A unit volume of inspired air may take up more moisture from the respiratory surfaces than a unit volume of ambient air takes up from the outer body surface, yet the external ventilation rate is, normally, so much greater than the pulmonary ventilation rate† that the resultant moisture vaporization rate is correspondingly greater from the outer than from the respiratory surfaces.

The vaporization from the respiratory tract is directly affected by the temperature and humidity of the inspired air, and indirectly by the respiratory rate and volume response to the given environmental conditions. High water vapor content in the inspired air associated with high temperature and high humidity tends to decrease the vaporization from the respiratory tract. Increasing pulmonary ventilation rate with increasing environmental temperature increases the vapor pressure gradient between the respiratory surfaces and the air, and therefore increases the vaporization rate.

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*See numbered list of references on page 19.

†Ventilation rates of 40 to 60 cu. ft./min. per cow are recommended for dairy barns[5]; pulmonary ventilation rates in the Jersey and Holstein cows ranged from 2 to 9 cu. ft./min.[6]

The vaporization rate from the outer body surface is evidently dependent on the vaporizing effect of the environment (temperature, humidity, air movement) and on the moisture secretion rate of the body surface (by sweating and diffusion or osmotic processes). In profusely sweating man, after he breaks out in sweat (above 80° or 90°F), the evaporative cooling is mainly limited by the vaporizing effect of the environment; in sparsely-sweating cattle, evaporative cooling rate is mainly limited by the moisture secretion rate of the body surface.

At high environmental temperatures, when non-evaporative cooling is severely reduced, most of the heat dissipation is shifted to cooling by vaporization from the outer body surface, although increased pulmonary ventilation rate[1] also increases cooling by respiratory vaporization. At low environmental temperatures, on the contrary, when most of the heat is lost by radiation, conduction and convection, the surface vaporization is reduced to osmotic or diffusion levels[7, 8, 9] and the respiratory vaporization is likewise reduced in cows by decreased pulmonary ventilation[6] to levels incidental to the necessary metabolic exchange. Such respiratory compensation apparently does not occur in man[3, 10].

As previously reported[1, 6], unlike in man, the rectal temperature of the Jersey and Holstein cows began to rise at relatively low environmental temperature (70° to 75°F, 21° to 24°C). The usual explanation for this difference between man and cow is that while man breaks out in sweat at relatively low temperature[11], cows do not. There is no question that cows have sweat glands[12, 13]; the question relates rather to the functional capacity of the sweat glands. Our data on surface vaporization, while not separated into sweat and osmotic or diffusion components, may throw some light on this question.

METHODS

The vaporization from the *respiratory tract* was determined by direct gravimetric and psychrometric measurements as described below. The vaporization from the *external body surface* was determined by subtracting the *respiratory* evaporative weight loss from the previously reported[14] *total* evaporative weight loss (determined by the difference between insensible weight loss[14] and metabolic weight loss[6]).

All these interrelated data, with the exception of the insensible weight loss, were obtained from simultaneous measurements[6] with the *open-circuit* respiratory exchange apparatus[1] from 1:30 to 3:00 p. m. under the usual laboratory condition.

As discussed in the report on the respiratory exchange measurements for this experiment[6] mechanical difficulties with apparatus at temperatures between 50° and 5°F, may have affected some of the data on metabolic weight loss used in estimating total evaporative weight loss[14] and pulmonary ventilation rate[6] used in the present computation. The critical changes in vaporization rates occurred at temperatures above 50°F, however, and these difficulties had been corrected before these measurements above 50°F were made. The rapid change in temperature from 50° to 95°F with little time for acclimatization may, however, have affected the animals. Later reports will present data for gradually increasing temperature. A more disturbing factor arises in combining metabolic weight loss data obtained in the experimental chambers a short time before the afternoon feeding with insensible weight loss data obtained in an antechamber several hours earlier. The environmental conditions were nearly but not quite the same and the physiological conditions were also somewhat different since carbon dioxide and methane production vary with time after feeding.

We do not know of previous determination of vaporization from the respiratory tract in cows although it has been suggested[15, 16] that estimates may be made on the assumption that exhaled air is completely saturated. Considerable, though somewhat contradictory, data have been reported on man, and admirably reviewed by Burch[17], and by Newburgh and Johnston[18].

The methods used for man become inconveniently cumbersome when applied to large animals such as cows. We accordingly determined the moisture in the inspired and expired air psychrometrically, that is from wet- and dry-bulb thermometer readings and psychrometric tables[5, 19, 20]; and gravimetrically by passing a part of the expired air through a drying unit and meter. Fig. 1 shows the excellent agreement between the results obtained by the psychrometric and gravimetric methods.

Fig. 2 shows the positions of the drier, air meter, vacuum pump, and wet- and dry-bulb thermometers.

The drying unit contained anhydrous calcium sulfate with a cobalt chloride moisture indicator*. This material reduces the moisture content of the air to 0.005 mg. of water vapor per liter of air (-86°F dewpoint equivalent).

The small wet-type meter was filled with a silicone fluid† of low viscosity and volatility as a replacement for the water usually used in these meters; and was used to measure the dry air from the drying unit. Accurate volume rate measurements** were obtained by readjusting the liquid level in the meter to compensate for the silicone specific gravity of 1.037.

The vacuum pump was operated at approximately atmospheric pressure by adjusting by-pass openings to give a constant low rate of flow of about 4 liters per minute through the drying unit and meter. The test on each cow lasted 5 to 10 minutes after equilibrium conditions had been obtained. The volume and temperature of the dry air was read at the meter. The weight of the moisture absorbed by each drying unit (a separate unit was used for each cow) was obtained by weighing the unit to 0.001 gm. on a large precision balance before and after each test.

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*The 2.5-inch diameter by 11.5-inch high glass units containing "Indicator Drierite" were obtained from W. A. Hammond Drierite Co., Xenia, Ohio.

†The DC-701 silicone fluid was obtained from Dow Chemical Co.

**The meter, graduated to 0.01 liter, was calibrated by syphoning water from a large closed bottle and measuring the flow of air through the meter to replace the measured volume of water removed from the bottle.

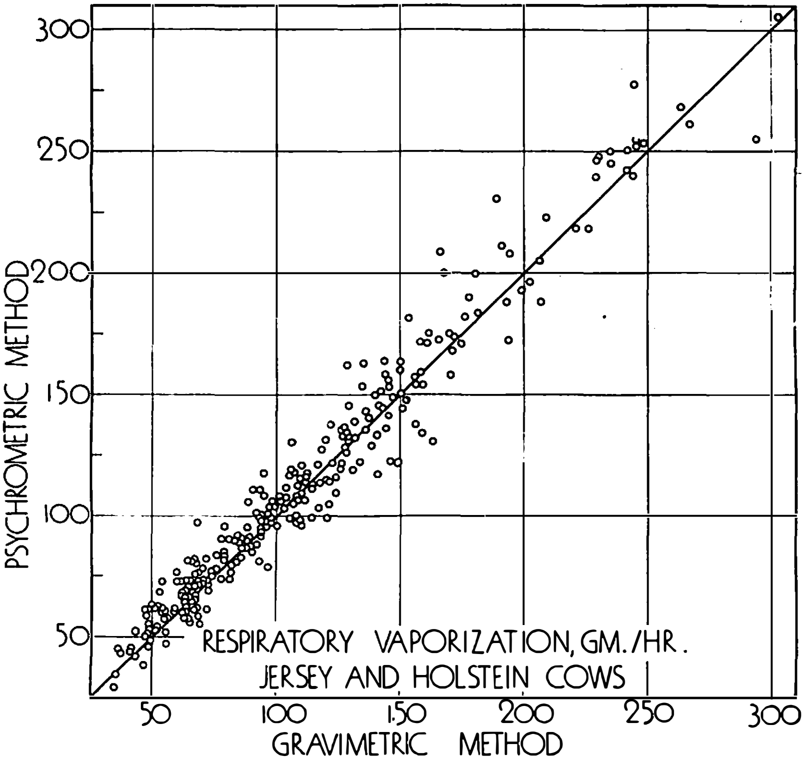

Fig. 1.—Comparison of the psychometric and gravimetric data obtained in determining moisture vaporization from the respiratory tract. The plotted data represent all the pairs of simultaneous measurements made by the two methods on six Jersey and six Holstein cows at environmental temperatures from 5° to 95°F. Perfect agreement between the two methods is represented by the diagonal line; the absence of systematic deviations of the data from this line indicates that the two methods give comparable results.

Measurements: The measurements (including those taken in connection with the respiratory exchange data[6] but used also for these respiratory vaporization calculations) included:

1. Chamber temperature (dry bulb temperature in outlet air duct from chamber)
2. Relative humidity in chamber (hair hygrometer†† readings)
3. Barometric pressure (spring-type barograph readings)
4. Volume of expired air passing through large displacement meter during each test (to 0.1 cubic foot).
5. Time intervals (precise to 0.01 minute)
6. Dry and wet bulb temperature of expired air at the outlet of the large displacement meter.

††The accuracy of the hair-hygrometer was checked periodically with a sling psychrometer.

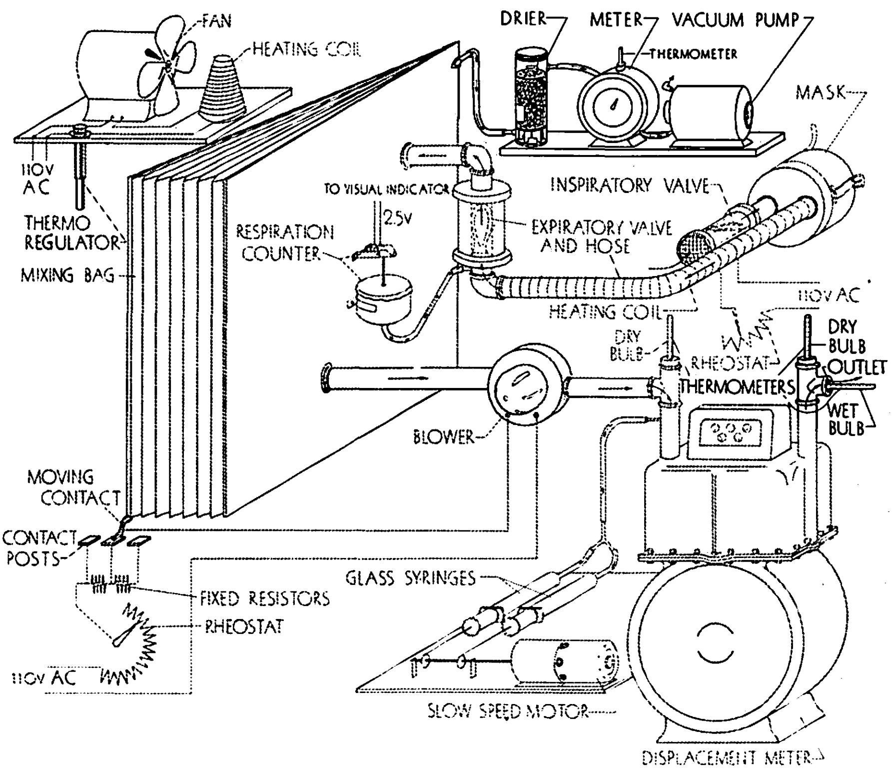

Fig. 2.—Diagram of open-circuit respiratory exchange apparatus (light dotted lines) including equipment (heavy solid lines) for the measurement of the water-content of expired air. A tightly fitting rubber sleeve provides a tight connection between the animal's muzzle and the metal walls of the mask. Room air is inspired through the inspiratory check valve and hose, and expired through the heated expiratory hose and check valve into a large rubber mixing bag. A blower removes the exhaled air from the mixing bag at the same average rate at which the animal exhales air into the bag, and expels it through a large dry-type displacement gas meter. A portion of the air passing through the mixing bag (about 4 per cent) is removed by the small vacuum pump shown in the upper right-hand corner. This small fraction of the moist expired air passes through a drying unit containing a water absorbent, and through a small meter located between the drier and vacuum pump.

All parts of the expiratory air circuit are maintained at approximately 100°F to prevent condensation of moisture and—excluding the mask and heated expiratory hose connection—are enclosed in a constant-temperature insulated metal case which is mounted on wheels.

The water content of the expired air during each test is determined by two types of measurements obtained (A) by reading the dry-bulb and wet-bulb thermometers in the outlet of the large displacement meter and referring to psychrometric tables, and (B) by weighing the drying units before and after each test and relating the weight of water absorbed to the corresponding temperature and volume of dry air passed through the small meter.

7. Volume and temperature of the dry air passing through the small wet-test meter.
8. Weight of water absorbed in the drying unit during the test.
9. Nitrogen-ratio of expired to inspired air as determined by laboratory analysis of expired and chamber air.

DATA AND DISCUSSION

The data, obtained between November 1948 and April 1949 on an Experimental group of three lactating Jerseys, two lactating Holsteins and one non-lactating, non-pregnant Holstein held successively at temperatures between 50° and 5°F and 5° to 95°F, and a similar Control group maintained at 50°F, except near the end of the experiment when the Control chamber temperature was increased rapidly to 95°F, correspond to data from other tests[6, 14, 21] reported for the same period. Complete information on the animals and their management and experimental schedules have been given in the cited reports.

In view of the excellent agreement between the gravimetric and psychrometric data (Fig. 1), the two sets of data were combined for simplicity of analysis and to give stability to the averages for the different temperature levels. These combined data are presented in Figs. 1, and 3 to 6, and Tables 1 to 4.

The specific humidity (gm moisture per kg dry air) of the expired air (Fig. 3) increased almost linearly from 9 to 30 gm as the environmental temperature was increased from 5° to 95°F. A corresponding increase from 1 to 16 gm occurred in the specific humidity of the inspired air although the relative humidity in the experimental chamber tended to be higher at the low than at the high temperatures. The differences between the two curves, of course, represents the moisture taken up in the respiratory tract per unit weight of dry air.

There was no significant breed difference in the specific humidity of the expired air, so that the respiratory vaporization rate at a given temperature tended to be proportional to the pulmonary ventilation rate of the animal.

Fig. 4, based on Tables 1 to 3, illustrates the relative respiratory and outer surface vaporization and evaporative cooling with increasing environmental temperature. The rate of respiratory vaporization increased slowly and uneventfully from about 50 gm/hr. at 5°F to about 240 gm/hr. at 95°F in Jerseys and 280 gm/hr. in Holsteins. The corresponding rise in respiratory evaporative cooling (assuming the latent heat of vaporization of water is 0.58 Cal/gm) was 30 to 140 Cal/hr. in the Jerseys and 30 to 160 Cal/hr. in the Holsteins.

The vaporization rate from the outer body surface between 50° and 5°F was nearly the same as from the respiratory tract. Between 50° and 90°F, however, there was a fourfold increase in surface evaporative cooling rate to maximal levels of 400 Cal/hr. in the Jerseys and 500 Cal/hr. in the Holsteins. The sudden rise in surface moisture vaporization rate above 65°F suggests active functioning of the sweat glands in these cows similar to the "breaking out in sweat" of man at about 80° to 90°F. Quantitatively, however, the difference in "sweating" rate between man and cow is great. In a 150-pound man, the sweating rate increases with rising temperature to about 1700 gm (3 1/3 lb, about 1000 Cal) per hour in dry air and to 3500 gm (7 lb, about 2000 Cal) per hour in moisture-saturated air [22, 23, 24, 25, 26]; in our 1200-pound cows, the vaporization rate attained a maximal level of 900 gm (about 522 Cal) per hour at 90°F.

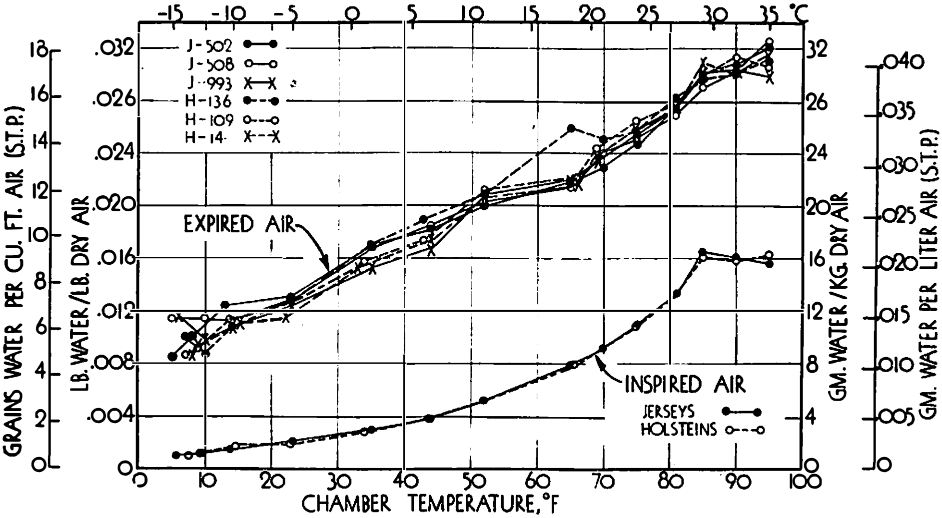

Fig. 3.—Moisture content of the inspired and expired air per unit volume (°C, 760 mm) or per unit weight of dry air.

When the respiratory and outer surface vaporization data are computed per square meter of outer body surface as illustrated in Fig. 5 (upper two sections), breed differences due to body size disappear; and average values may be computed for all cows (lower section).

As the chamber temperature decreased from 50° to 5°F, the heat dissipated by respiratory vaporization decreased from 20 to 10 Cal/sq.m/hr., and that from the outer surface similarly decreased from 20 to 10 Cal/sq.m/hr. For increasing temperature from 50° to 95°F, the respiratory vaporization increased moderately from 20 to 33 Cal/sq.m/hr. From 50° to 80°F, the surface vaporization increased from 20 to a maximal level of 78 Cal/sq.m/hr., but above 95°F it showed a tendency to decline slightly, for what reason we do not know, but possibly, in part, due to a decrease in the metabolic level. The proportion of total heat dissipated by respiratory vaporization thus ranged from about 4 per cent at 5°F chamber temperature to 15 to 30 per cent at 95°F chamber temperature (Tables 1 and 2). The corresponding proportion of heat dissipated by surface vaporization ranged from 5 to 10 per cent at 5°F chamber temperature to 40 to 70 per cent at 80° to 95°F chamber temperature.

Fig. 6 presents the partition of the data in the lower section of Fig. 5 but in terms of percentages of total heat production (or heat dissipation). Considering the limited sweating ability generally assumed for these cows, the increase in evaporative cooling from the outer body surface at chamber temperatures above 65°F was surprisingly large in comparison to that from the respiratory tract. The fact remains, however, that evaporative cooling from

TABLE 1.--PARTITION OF EVAPORATIVE WEIGHT LOSS AND EVAPORATIVE COOLING BETWEEN THE RESPIRATORY AND EXTERIOR BODY SURFACES IN JERSEY COWS

Dry Bulb Temper-ature °F	Relative Humidity %	No. of Obs.	Body Weight		Respiratory Vaporization per Hour			Surface Vaporization per Hour			Heat Dissipation by Evaporative Cooling Cal/hr				Percentage of Total Heat Produced Dissipated by	
											From Respi-ratory Tract		From Surface			
			lbs.	kg.	gm. per cow	gm. per sq.m.	% of total vapor-ization*	gm. per cow	gm. per sq.m.	% of total vapor-ization*	per cow	per sq.m.	per cow	per sq.m.	Respi-ratory Vapor-ization	Surface Vapor-ization
							Jersey 502									
5	77	1	839	381	60	14	57	46	11	43	35	8	27	6	4	3
8	85	1	821	372	40	10	34	79	19	66	23	6	46	11	3	6
13	84	2	817	371	66	16	55	53	13	45	38	9	31	8	5	4
23	77	3	822	373	73	18	35	137	33	65	42	10	79	19	6	11
35	70	2	809	367	96	23	54	81	20	46	56	14	47	11	8	6
44	64	2	786	357	68	17	31	154	38	69	39	10	89	22	7	15
52	64	8	797	362	120	29	53	107	26	47	70	17	62	15	10	9
65	62	1	863	391	132	31	37	227	53	63	77	18	132	31	11	19
70	58	2	876	397	130	30	29	324	76	71	75	18	188	44	11	28
75	64	2	872	396	170	40	23	558	131	77	99	23	324	76	15	48
81	59	2	878	398	202	47	26	580	135	74	117	27	336	78	18	50
85	66	1	881	400	157	37	19	678	158	81	91	21	393	92	14	59
90	53	1	857	389	186	44	24	595	141	76	108	26	345	82	19	62
95	43	1	833	378	250	60	32	525	126	68	145	35	304	73	25	53

								Jersey 508								
5	77	1	884	401	51	12	32	108	25	68	30	7	63	15	5	11
10	85	1	871	395	54	13	34	104	24	66	31	7	60	14	5	9
14	82	2	866	393	58	14	35	110	26	65	34	8	64	15	5	10
23	78	3	863	391	65	15	37	113	27	63	38	9	66	16	6	11
35	68	2	852	386	83	20	44	107	25	56	48	11	62	15	7	9
44	63	2	837	380	60	14	22	216	52	78	35	8	125	30	7	24
52	63	8	890	404	101	23	40	150	35	60	59	14	87	20	10	14
65	62	1	918	416	88	20	24	280	64	76	51	12	162	37	11	33
70	60	2	929	421	110	25	23	372	84	77	64	14	216	49	10	34
75	57	2	940	426	158	35	23	530	119	77	92	21	307	69	14	47
81	58	2	950	431	136	30	16	696	155	84	79	18	404	90	12	63
85	64	1	956	434	168	37	24	538	120	76	97	22	312	69	19	60
90	54	1	942	427	201	45	24	631	142	76	117	26	366	82	21	66
95	43	1	928	421	242	55	32	504	113	68	140	32	292	66	26	53
								Jersey 933								
6	77	1	893	405	62	14	45	75	17	55	36	8	44	9	5	6
10	84	1	877	398	42	10	25	124	29	75	24	6	72	17	4	11
14	90	2	866	393	47	11	28	119	28	72	27	6	69	16	4	11
23	76	3	868	394	65	15	39	100	23	61	38	9	58	13	5	8
35	68	2	855	388	78	18	40	116	27	60	45	10	67	16	7	10
44	63	2	836	379	65	16	23	213	51	77	38	9	124	30	7	23
52	63	8	883	401	107	25	39	168	39	61	62	14	97	23	11	16
65	61	1	901	409	100	23	23	334	77	77	58	13	194	45	13	42
69	60	2	908	412	148	34	29	356	81	71	86	20	206	47	15	35
75	57	2	926	420	194	44	29	480	109	71	113	26	278	63	17	42
81	58	2	939	426	200	45	26	559	126	74	116	26	324	73	17	48
85	64	1	942	427	210	47	30	497	111	70	122	27	288	64	20	48
90	54	1	932	423	221	50	30	520	117	70	128	29	302	68	17	40
95	44	1	900	408	239	55	31	520	120	69	139	32	302	70	30	65

* Total vaporization from Tables 1 and 2, Ref. 14.

TABLE 2.--PARTITION OF EVAPORATIVE WEIGHT LOSS AND EVAPORATIVE COOLING BETWEEN THE RESPIRATORY AND EXTERIOR BODY SURFACES IN HOLSTEIN COWS

Dry Bulb Temperature °F	Relative Humidity %	No. of Obs.	Body Weight		Respiratory Vaporization per Hour			Surface Vaporization per Hour			Heat Dissipation by Evaporative Cooling Cal/hr				Percentage of Total Heat Produced Dissipated by	
											From Respiratory Tract		From Surface			
			lbs.	kg.	gm. per cow	gm. per sq.m.	% of total vaporization*	gm. per cow	gm. per sq.m.	% of total vaporization*	per cow	per sq.m.	per cow	per sq.m.	Respiratory Vaporization	Surface Vaporization
							Holstein 136									
7	79	1	1266	574	67	13	49	69	13	51	39	8	40	8	4	4
10	85	1	1266	574	40	8	27	110	21	73	23	5	64	12	3	8
14	86	2	1275	578	66	12	38	108	20	62	38	7	63	12	4	7
24	75	2	1247	566	80	15	38	133	26	62	46	9	77	15	5	8
35	68	2	1236	561	102	20	39	161	31	61	59	12	93	18	6	10
43	63	2	1219	553	95	18	30	223	43	70	55	10	129	25	7	17
52	63	8	1259	571	178	34	57	135	26	43	103	20	78	15	11	9
65	61	1	1256	570	234	45	48	250	48	52	136	26	145	28	17	18
70	60	2	1251	567	193	37	26	549	105	74	112	21	318	61	13	37
75	57	2	1263	573	246	47	27	658	123	73	143	27	382	73	15	41
81	58	2	1254	569	255	49	27	689	132	73	148	28	400	77	18	48
85	62	1	1257	570	216	41					125				16	
90	54	1	1211	549	242	47	29	584	114	71	140	27	339	66	22	52
95	44	1	1187	538	266	52					154				28	

								Holstein 109								
7	77	1	1272	577	63	12	38	104	20	62	37	7	60	12	4	6
9	85	1	1263	573	52	10	30	123	23	70	30	6	71	13	3	8
14	85	2	1272	577	72	14	35	133	25	65	42	8	77	14	4	8
23	75	3	1244	564	86	16	34	164	31	66	50	9	95	18	5	10
34	67	2	1227	557	103	20					60	12			7	
43	63	2	1208	548	88	17	24	286	56	76	51	10	166	32	6	21
52	62	8	1249	567	150	29	45	181	35	55	87	17	105	20	10	12
66	61	1	1281	581	118	22	24	367	69	76	68	13	213	40	8	25
69	60	2	1282	582	154	29	21	586	110	79	89	17	340	64	10	39
75	56	2	1294	587	243	46	28	634	119	72	141	27	368	69	15	39
81	59	2	1279	580	246	46	27	682	129	73	143	27	396	75	18	50
85	63	1	1266	574	240	46	25	734	140	75	139	27	426	81	18	55
90	54	1	1252	568	304	58	28	767	147	72	176	34	445	85	23	59
95	44	1	1230	558	262	51	27	713	138	73	152	30	414	80	23	69
								Holstein 14								
8	76	1	1541	699	58	10	31	132	22	69	34	6	77	13	4	9
9	82	1	1544	700	47	8	24	147	25	76	27	5	85	14	3	10
15	83	2	1537	697	54	9	26	150	26	74	31	5	87	15	4	12
22	75	3	1507	684	64	11	26	178	31	74	37	6	103	18	4	12
33	65	2	1477	670	85	15	35	161	28	65	49	9	93	16	6	12
44	63	2	1443	655	94	17	25	276	49	75	55	10	160	28	7	20
52	61	8	1524	691	133	23	45	165	28	55	77	13	96	16	10	12
66	61	1	1563	709	158	27	33	324	55	67	92	16	188	32	12	25
69	60	2	1572	713	159	27	22	549	92	78	92	16	318	53	13	45
75	57	2	1574	714	172	29	19	718	121	81	100	17	416	70	13	54
81	57	2	1589	721	185	31	19	765	128	81	107	18	444	74	14	57
85	62	1	1582	718	165	28	18	769	129	82	96	16	446	75	15	68
90	54	1	1598	725	220	37	20	898	150	80	128	21	521	87	15	62
95	44	1	1583	718	274	46	28	713	119	72	159	27	414	69	26	68

* Total vaporization from Tables 1 and 2, Ref. 14.

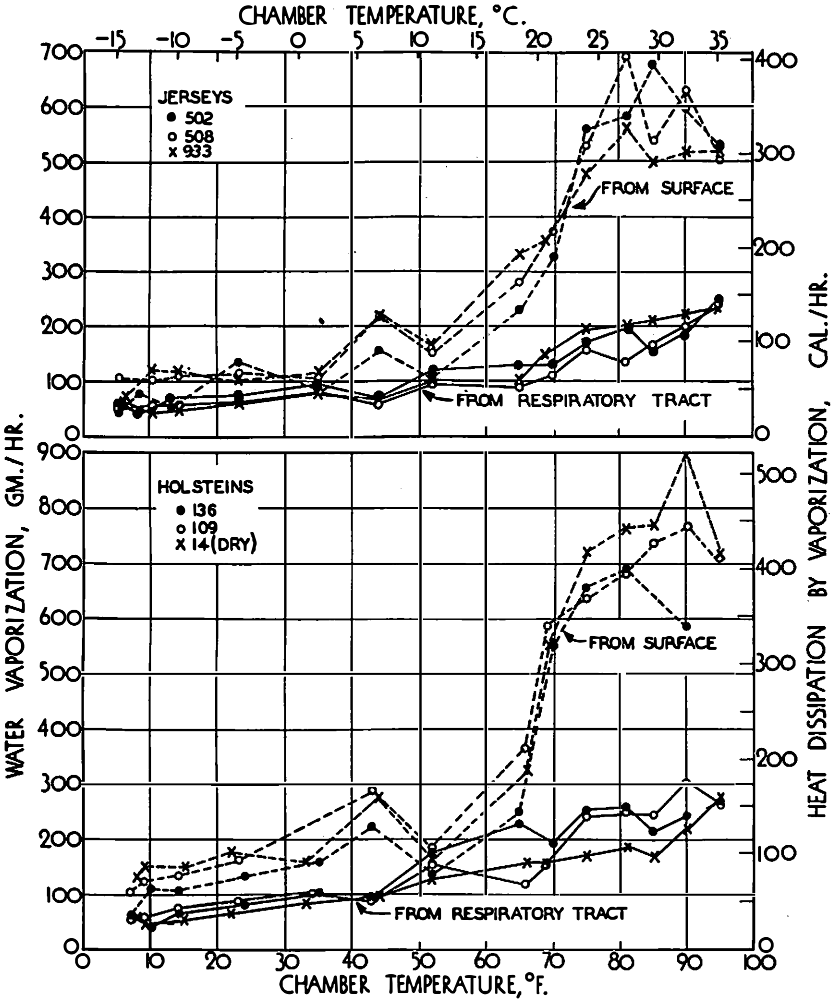

Fig. 4.—Water vaporization per cow from the respiratory tract and from the outer body surface. While the rise in vaporization from the respiratory tract with increasing chamber temperature was quite gradual, that from the outer surface was quite steep beginning at a critical temperature of about 65°F, apparently indicating initiation of sweat gland activity. The large Holstein cows, as might be expected, vaporized more water than the smaller Jersey cows.

both the outer body surface and the respiratory tract was not sufficient to prevent a rise in rectal temperature at chamber temperatures above 70° to 75°F[6].

The respiratory vaporization rates in man and cow were compared (Table 4) by relating the data to body surface area. The moisture vaporizing capacity of the respiratory tract is quite different in man and cow. A man sitting quietly at 68° to 70°F room temperature and 55 to 60 per cent relative humidity vaporizes about 5 gm/sq.m/hr., but the Jersey and Holstein cows under similar en-

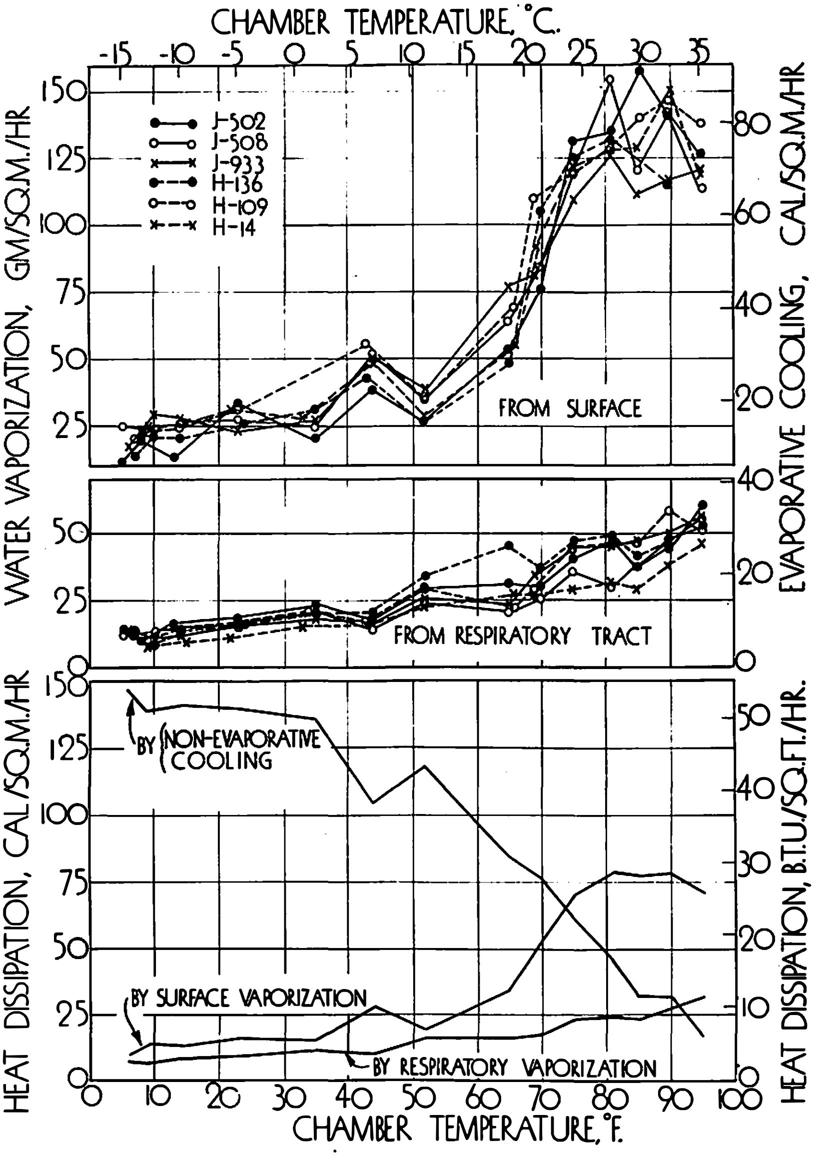

Fig. 5.—Water vaporization and evaporative cooling from the respiratory tract and from the skin per square meter of outer surface area. As the differences between the corresponding Jersey and Holstein vaporization curves (upper two sections) appeared to be no greater than the differences between the curves for cows of the same breed, the data for all cows were averaged and brought together in the lower section. It is significant that under the given conditions the curve for non-evaporative cooling crosses the curve for evaporative cooling from the respiratory tract at 90°F chamber temperature. Relative humidities at the various temperatures are given in Tables 1, 2, and 3.

vironmental conditions (and standing quietly) vaporized 30 gm/sq.m/hr., or 6 times that amount. The greater respiratory vaporizing capacity of the cow is even more pronounced at higher temperatures due to the rise in pulmonary ventilation rate in the cow and its relative stability in man, with rising temperature.

TABLE 3.--EVAPORATIVE WEIGHT LOSS AND EVAPORATIVE COOLING FROM THE RESPIRATORY TRACT IN JERSEY AND HOLSTEIN COWS (Control Group)

Dry Bulb Temperature °F	Relative Humidity %	No. of Obs.	Body Weight		Respiratory Vaporization per Hour		Heat Dissipation by Evaporative Cooling from the Respiratory Tract Cal/Hr		Percentage of Total Heat Produced Dissipated by Respiratory Vaporization
			lbs.	kg.	per cow	per sq.m.	per cow	per sq.m.	
					Jersey 957				
52	62	16	922	418	72	16	42	9	8
6	77	3	929	421	53	12	31	7	3
					Jersey 979				
52	60	15	944	428	94	21	55	12	9
6	77	3	956	434	56	12	32	7	4
					Jersey 977				
52	61	16	941	427	73	16	42	9	8
7	78	3	934	424	33	7	19	4	3
					Holstein 125				
53	60	15	1211	549	132	26	77	15	10
6	76	3	1205	547	72	14	42	8	4
					Holstein 95				
52	59	16	1313	596	130	24	75	14	9
6	74	2	1301	590	62	12	36	7	4
					Holstein 5				
52	59	16	1511	685	119	20	69	12	8
6	72	2	1526	692	64	11	37	6	4

TABLE 4.--COMPARISON OF EVAPORATIVE COOLING FROM THE RESPIRATORY TRACT IN MAN AND COW

	Jersey and Holstein cows			Man *
Temperature, °F	52	69.5	90	68 to 70
Relative Humidity, %	61	60	60	55 to 60
No. of Observations	142	12	6	56
Moisture Vaporization (gm/sq.m/hr.)	22.7	30.3	46.8	5.05
Evaporative Cooling Cal./sq.m/hr.	13.2	17.6	27.1	3.03
Pulmonary Ventilation Rate (S.T.P.) Lit/sq.m/hr.	1202	1565	2472	230

* Data on man are from Burch (3)

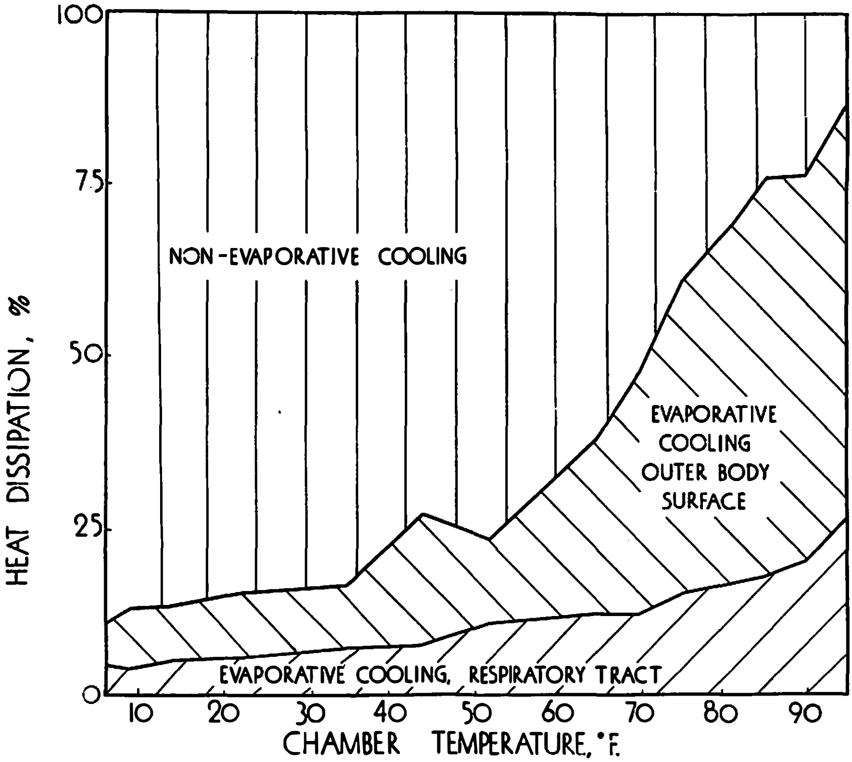

Fig. 6.—Partition of total heat loss (or heat production) in Holstein and Jersey cows into evaporative cooling from the respiratory tract, evaporative cooling from the outer body surface, and total non-evaporaitve cooling. The three shaded areas indicate the magnitudes of the three categories of heat losses at different environmental temperatures averaged for Jersey and Holstein cows. Relative humidities at the various temperatures are given in Tables 1, 2, and 3.

SUMMARY AND ABSTRACT

Methods are described for measuring moisture vaporization from the respiratory tract of cattle. Data obtained by these methods under controlled climatic conditions are presented for Jersey and Holstein cows for temperatures 5° to 95°F.

Corresponding data on outer body surface vaporization obtained by partitioning the previously reported total vaporization[14] into respiratory and surface vaporization components are also presented.

The resulting graphs show a slow, uneventful rise in respiratory vaporization with rising temperature, 5° to 95°F, amounting to a moisture vaporization range of 12 to 53 gm/sq.m/hr. and accounting for 4 to 30 per cent of the total heat dissipation. Between 5° and 60°F, the outer surface vaporization was about the same order as the respiratory vaporization but between 50° and 80°F the surface vaporization increased four fold to a maximal value of about 80 Cal/sq.m/hr. The sudden rise in outer surface vaporization between 65° and 80°F is analogous to "breaking out in sweat" in man at about 80° to 90°F. While in man, however, the rate of moisture secretion and vaporization continues to increase rapidly with rising environmental temperature, in cows it does not, and this is apparently the basic species difference in body temperature regulation—the greater functional development of sweat glands in man than in cow.

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