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With Special Reference to Domestic Animals

XLI. Influence of Humidity and Wind on Heat Loads Within Dairy Barns

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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XLI. Influence of Humidity and Wind on Heat Loads Within Dairy Barns

H. J. THOMPSON

INTRODUCTION

The effects of humidity and air movement upon vaporization and heat dissipation within the closed type dairy structure are the major considerations in this progress report.

Two insulated, climatic test rooms of the Psychroenergetic Laboratory at Columbia were each fitted with 6 stalls 4 feet wide, complete with stanchions, gutters, and mangers (1). The animals were confined to the Laboratory throughout each test. Cows were machine milked, fed standard grain rations of the University of Missouri dairy herds, fed all the alfalfa hay they could consume, and weighed daily. Automatic waterers were heated for tests below 32° F.

Schedules were similar to those of previous tests, with the exception that no control groups were used. Two weeks was the usual time allocated for all except the 95° F climatic conditions discussed in this report.

HUMIDITY STUDIES

Facilities, Animals and Procedure

Modifications of air conditioning equipment used in previous studies (1) are shown in Figure 1. To maintain relative humidities above 80% (high humidity) for the 10° F to 40° F tests, it was necessary to meter steam directly into the test room. It would have been possible to raise the relative humidity within the test rooms by increasing the amount of near-saturated supply air. However, this was impractical because of limited blower capacity and the necessity of keeping air movement within the test room similar to air movements used in previous studies.

At temperatures above 50° F, high humidity was obtained by adding steam to the supply duct air ahead of the measuring instruments. This simplified the calculation procedures. Low humidities were obtained by

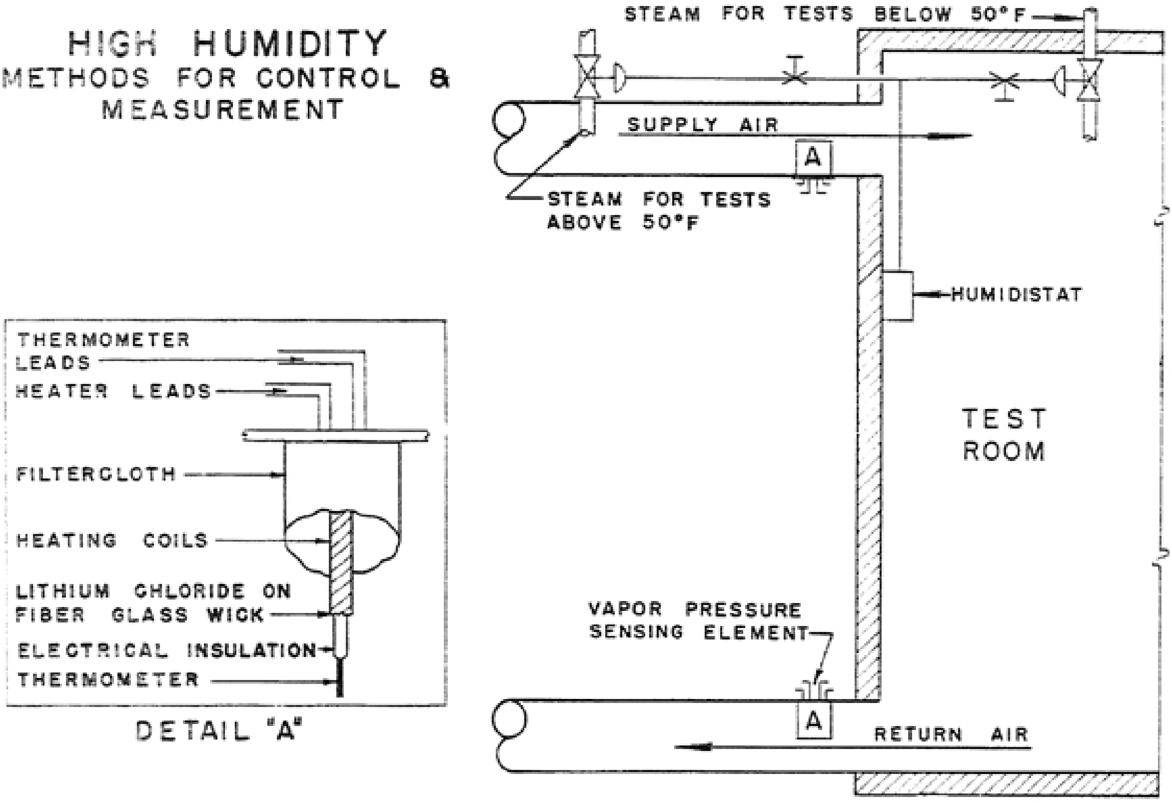

Fig. 1. Methods Used to Measure and Control Humidity.

lowering the temperature of the condensing surfaces in the main air conditioners. The relatively greater amount of cooling available for the smaller animals, as compared to the Holstein-Brown Swiss, resulted in lower minimum air temperatures for the Jersey-Brahman tests.

Dew point temperatures and air volume measurements were used to estimate vaporization. Electrolytic dew point type hygrometers mentioned in a previous report (1), and also reported by Baxter (2) and Muehling (3), are shown in Figure 1. The membrane type humidistat shown on the test room wall near a return air opening (Figure 1) was used to control either condensation on cooling coils or the amount of steam added. Steam was measured once or twice daily by use of sight gages on a calibrated supply boiler.

Due to entrainment of test room air in the relatively high velocity inlet air streams, psychrometric conditions within each test room were quite uniform. Air and wall temperatures (4) indicated that with steady control, the maximum difference between ceiling and floor surface temperatures was from 3 to 6 degrees during the 7° to 20° F tests. At 100° F there was practically no difference between floor and ceiling temperatures.

Vapor pressure differences between ambient air and test room surfaces were greatest near the wetted or moist stall areas. Muehling (3) showed that stall air dew point temperatures 12 inches above the floor were about 4° F lower than the dew point temperatures of air near the moist stall surface in tests at dry bulb temperatures below 20° F.

The schedule of tests is listed in chronological sequence and is summarized in Tables 1 and 2. The general scheme of testing was to measure high, medium, and low humidity effects at test room air temperatures of 7° to 20°, 40° and 75° F. At 85° and 95° F test room air temperatures, only high and low humidities were used. Periods at 65° and 50° F with 60 to 70% relative humidity were used to train animals or to provide rest

TABLE 1 -- THE EFFECT OF HUMIDITY ON TOTAL HEAT LOADS AND TOTAL TEST ROOM VAPORIZATION AT SEVERAL TEMPERATURES WITH JERSEY AND BRAHMAN COWS, 1950-51

Days	Mean by Weeks				Total Heat		Total Vapor	
per wk. N	Temp. °F.	Rel. Hum.%	Body Wt.#	FCM*	Btu/Hr. Mean	± S.E.**	Lbs./Hr. Mean	± S.E.**
			Oct. 1950 to Feb. 1951, 6 Jerseys					
3	50	60	902	28	3770	120	1.18	.03
5	50	60	902	28	3630	30	1.20	.03
7	40	55	900	24	3660	40	.91	.01
7	40	58	890	24	3690	30	.90	.02
6	40	48	894	21	3670	30	.96	.02
7	40	47	893	21	3400	60	.88	.01
7	40	88	907	19	3280	50	.83	.02
7	40	83	906	19	3340	20	.88	.02
7	50	74	902	18	3060	40	1.09	.02
7	50	68	903	18	3130	30	1.15	.02
6	10	70	913	15	3470	50	.52	.02
6	12	64	921	15	3580	60	.61	.02
6	13	77	924	10	3450	70	.49	.04
6	11	91	922	10	3470	80	.54	.02
7	11	65	928	9	3950	70	.55	.03
3	10	59	925	9	3750	60	.48	.07
4	50	61	927	8	4360	80	1.10	.06
7	50	61	923	8	3140	40	.92	.02
			Feb. to June 1951, 4 Jerseys & 2 Brahmans					
7	65	68	837	11	2460	20	.86	.01
7	65	66	837	11	2390	40	.80	.03
1	74	43	838	10	2100	---	1.12	--
2	75	36	841	10	2450	250	1.34	.01
3	76	83	843	9	2710	70	1.17	.05
7	65	70	846	9	2740	50	.95	.05
7	84	42	850	12	2260	100	1.52	.06
7	85	39	857	12	2170	40	1.47	.03
4	85	87	848	7	2660	70	1.51	.05
6	86	88	844	7	2870	70	1.74	.07
4	65	67	865	8	2760	10	1.05	.01
7	65	67	879	8	3000	40	1.04	.02
6	65	65	896	6	2880	50	.96	.04

*Pounds per day at 4% fat corrected milk

**S.E. Standard Error of the mean

TABLE 2 -- THE EFFECT OF HUMIDITY ON TOTAL HEAT LOADS AND TOTAL TEST ROOM VAPORIZATION AT SEVERAL TEMPERATURES WITH HOLSTEIN AND BROWN SWISS COWS, 1950-51.

Days per wk.	Mean by Weeks				Total Heat Btu/Hr.		Total Vapor Lbs./Hr.	
N	Temp. °F	Rel. Hum.%	Body Wt.#	FCM*	Mean	± S.E.**	Mean	± S.E.**
			Oct. 1950 to Feb. 1951, 6 Holsteins					
3	53	61	1339	48	4470	160	1.63	.04
5	51	67	1330	48	4290	80	1.45	.08
7	40	64	1335	46	4230	40	1.01	.01
7	40	65	1333	46	4350	80	.98	.02
6	40	70	1323	44	4430	100	.93	.05
7	41	80	1328	44	4190	100	.82	.09
7	40	47	1318	40	4710	90	1.09	.02
7	40	50	1327	40	4940	60	1.24	.03
6	50	61	1322	41	4960	60	1.49	.03
7	50	66	1306	41	4710	70	1.39	.04
6	14	64	1316	38	4950	40	.72	.02
6	13	75	1317	38	5280	70	.80	.02
6	14	66	1325	38	5150	20	.77	.02
7	12	64	1330	38	5060	60	.73	.03
1	20	69	1338	34	5350	---	.77	---
5	15	83	1332	34	5200	130	.66	.04
6	52	68	1324	30	3990	80	1.38	.04
7	51	65	1335	30	3990	60	1.21	.03
			Feb. to June 1951, 3 Holsteins & 3 Brown Swiss					
7	65	69	1116	27	3280	50	1.40	.03
7	65	68	1111	27	3290	50	1.40	.04
5	74	40	1108	25	2960	40	1.74	.07
3	75	36	1105	25	3080	30	1.82	.00
4	78	71	1112	25	3160	240	1.94	.12
2	76	84	1124	25	3700	0	2.09	.00
7	66	71	1117	24	3790	70	1.69	.07
7	85	47	1114	24	3210	110	2.21	.05
7	86	41	1105	24	3070	50	2.24	.04
5	86	90	1114	20	3040	130	1.77	.10
6	85	90	1094	20	3150	60	1.88	.03
5	65	72	1106	22	3320	30	1.35	.02
7	65	70	1092	22	3490	40	1.39	.03
6	66	68	1048	20	3650	110	1.60	.07

* Pounds per day of 4% fat corrected milk

** S.E. Standard Error of the mean

periods during the 85° and 95° F tests.

Equipment capacities and psychrometric combinations made it difficult to follow rigid test schedules. Tables 1 and 2 indicate that the average temperatures for 24-hour periods which were scheduled for 10° F, varied from 10° to 20° F. High and low humidities were difficult to maintain. On the other hand, it was impossible for animals to withstand laboratory temperatures near 100° F and 90 percent relative humidity for 2 weeks. Therefore, it was both impractical and impossible to hold a humidity range of 40 to 90 percent at all temperatures between 10° and 100° F.

All 12 cows for the 7° to 20° F and 40° F tests were lactating. Feed and water records, milk production, and animal history have been reported (5). For the 75°, 85°, and 95° F test there were 3 lactating Holsteins and 3 lactating Brown Swiss in one group, and 2 dry Brahman, 2 dry Jerseys, and 2 lactating Jerseys in the second group.

Total heat load as used in this report may be defined as the heat dissipated within the stable. It is the heat that was picked up by the ventilation system with deductions made for the heat added by the lamps, equipment, and personnel and with deductions or additions for the heat gained and lost from the building. These adjustments or corrections were made because these factors are variable from structure to structure and can be calculated for any particular structure under given conditions.

Total test room vaporization as used in this report may be defined as the total vapor released within the stable. It includes vaporization both from the animals and from the moist surfaces within the test room. Adjustments were made for vaporization from personnel at temperatures above 65° F.

Results—Humidity Studies

The basic values used in the analyses were weekly averages of test room air temperature, air relative humidity, animal total heat dissipation, and animal plus stall surface moisture vaporization. Adjustments for body weight and milk production were needed to estimate the effects of humidity within, as well as between, the breed groups. Other factors being equal, it may be assumed that Holstein, Brown Swiss, and Jersey cows of the same size and production level have similar reactions to variation in humidity.

All total heat load adjustments due to FCM (4 percent fat corrected milk) were made using 20 Btu per hour per pound of FCM per day. The 20 Btu per hour value is estimated from observations at several temperatures and from some considerations of the feed energies customarily associated with milk production. Weekly averages in Tables 1 and 2 were used in simultaneous equations for computing combined effect of body weight (to the .75 power) and FCM upon total heat loads.

It is generally assumed that basal energy metabolism varies according to some power (x) of body weight (BW) where x has different values for different species. In this work $(BW)^{.75}$ is used.* An expression for total

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*Extensive discussion by Brody (6) and Kleiber (7) would indicate that the body weight exponent to be used when a production factor is also involved should be on the order of .75. Although this factor may also be open to question, it will be used in this report as a basis for necessary comparisons and not to substantiate or refute claims by various other investigators. The primary purpose for applying these adjustments is to make better estimates of the effects of humidity and wind from the limited information on hand.

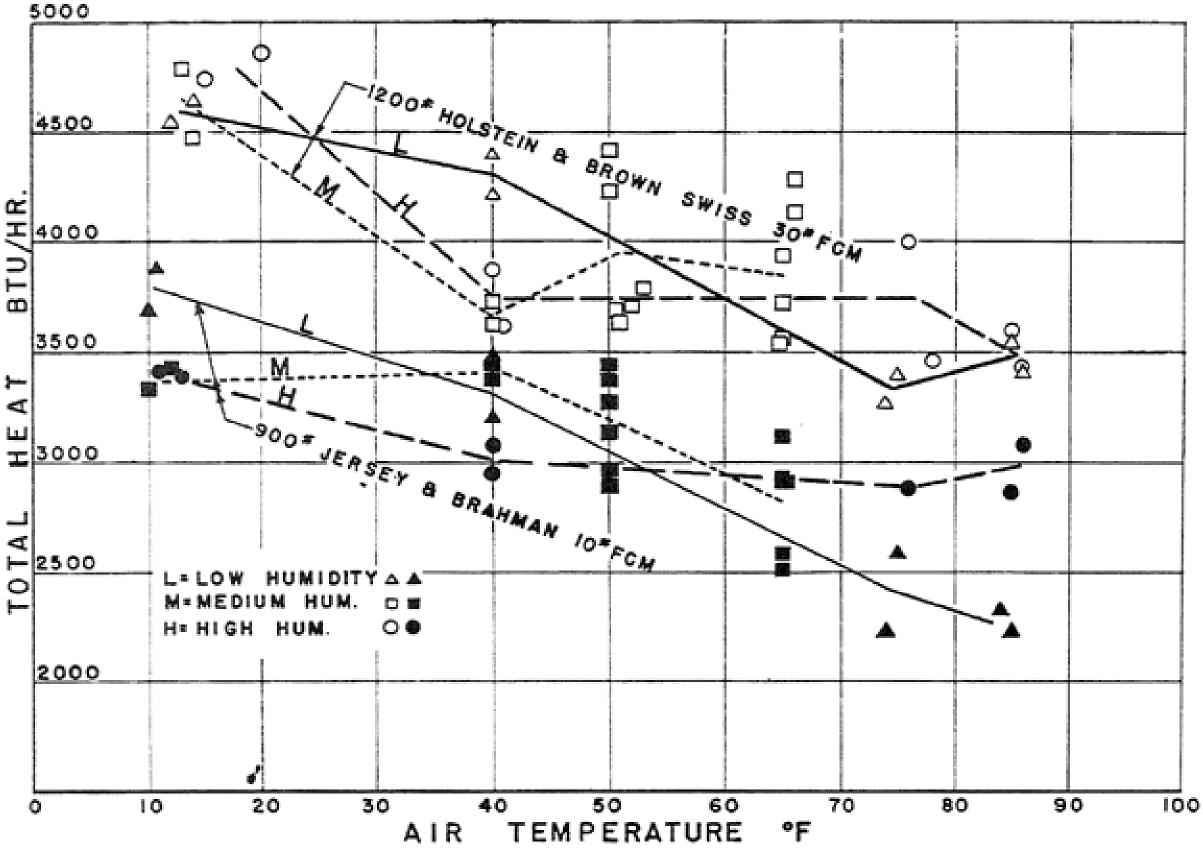

Fig. 2. Effect of Humidity on Total Heat Load at Various Temperatures, 1950-51 Data. All values were adjusted to common body weight and milk production bases near the average weight and production level of each of the two test groups. The base values are shown with the curves for their respective groups. Milk production adjustments were made at 20 Btu/hr. per pound of 4 percent FCM/day above or below respective base points. Weight adjustments were made according to the 0.75 power of the ratio of base weight to actual weight. For example, the first total heat load value of Table 1 was adjusted as follows:

$$[3770 - 20(28-10)]\,[900/902]^{0.75} = 3400 \text{ Btu/hr.}$$

Relative humidity ranges were: 35 to 55 percent; medium, 55 to 75 percent; and high, 75 to 95 percent. There seems to be no consistent difference due to humidity, especially below 65° F.

heat load can be written as $(BW)^{.75}(b_1) + FCM\,(b_2) =$ Total heat load, Btu/hr., where coefficient b_1 is in units of Btu/lb/hr. and b_2 is in units of Btu/hr. per lb. FCM/day.

To illustrate determination of b_1 and b_2 for a given temperature and humidity, 6 weekly averages of body weight and FCM were taken from Table 1 for the Jersey-Brahman group at 65° F. These averages were totaled and are shown as Equation 2. Likewise, 6 weekly averages of body weight and FCM were taken from Table 2 for the Holstein-Brown Swiss group at 65°-66° F, and summed to form Equation 1. Simultaneous solution of (1) and (2) yielded the required coefficient values.

$(BW)^{.75}\, b_1 + (FCM)\, b_2 =$ Total heat load, Btu/hr.

$1141\, b_1 + 142\, b_2 = 20820$ Equation (1)

$954\, b_1 + 53\, b_2 = 16230$ Equation (2)

$b_1 = 16 \qquad b_2 = 18$

Using similar calculation procedures at 10° to 20° F, $b_2 = 20$; at 40° F, $b_2 =$ minus 15; at 50° F, $b_2 =$ minus 3; at 75° F, $b_2 = 13$; and at 85° F, $b_2 = 9$.

It is evident that such small and variable differences make further study necessary.

Figure 2 shows that at 40° F, group differences are not as consistent as at other temperatures; therefore, the unreasonable b_2 of minus 15 should be disregarded. For data that will lead to a detailed study of "within cow" effects of FCM, the reader is referred to the "control" group metabolism information (8) for the temperature tests in this series. These metabolism data can also be used to demonstrate that the choice of a body weight exponent will materially change the FCM adjustment. Feed energy is used primarily for maintenance, milk production, and body weight gain. For instance, the b_1's above decreased from about 20 to 15 in the same temperature range. Our data are not extensive enough to make estimates of the weight gain factor on mature lactating cows.

Using the FCM coefficient proposed by Brody (6) to estimate nutrients required (TDN), a coefficient of 1814 calories per pound of TDN and the assumption that 15% of the TDN is lost in urine and methane, the heat released after accounting for milk energy would be on the order of 22 Btu/hr. per lb. FCM/day.

For this report, an FCM coefficient of 20 Btu or 5 Kilocalories per hour per pound of FCM per day was used.

Data plotted in Figures 2 through 6 were taken from Tables 1 and 2 after adjustment had been made for size and milk production. The data were first adjusted for milk production using 1 pound of milk per day as the equivalent of 20 Btu per hour, then size adjustments were made in proportion to the .75 power of body weight. Body weight and milk production adjustments when made according to a base near the average weight and production levels of each of the test groups, rather than to some arbitrary base such as 1000 lb. body weight and 20 lb. FCM, would minimize the effect of errors in the weight and production adjustment factors. The fact that the low, medium, and high humidity curves tended to cross each other at some points is partly due to the humidity variation within each range. In fact, the humidity ranges overlapped in some cases.

At temperatures below 65° F, humidity apparently had no effect upon total heat load. (Figure 2). At 75° F and 85° F there is some evidence

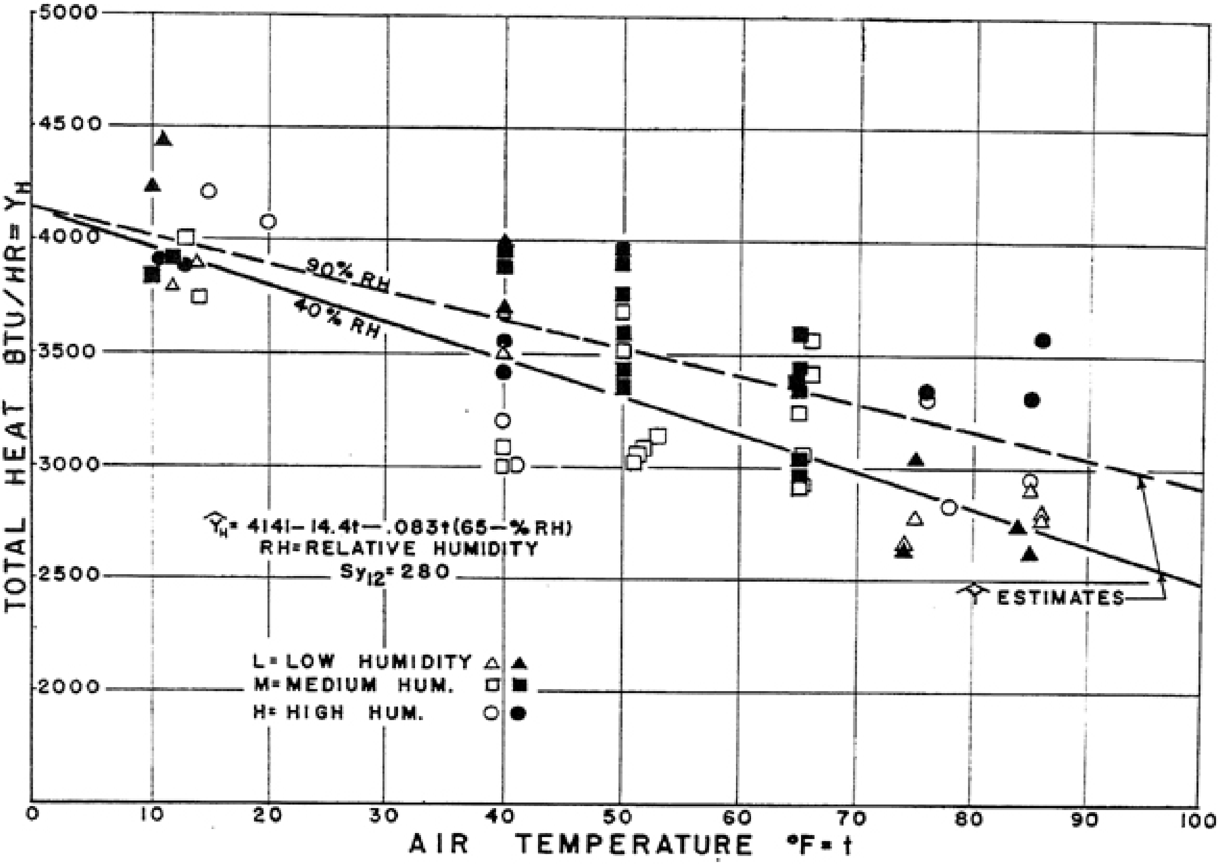

Fig. 3. Estimated Effects of Humidity on Total Heat Load at Various Temperatures, 1950-51 Data. All values were adjusted to common body weight and milk production bases as described in Figure 2. However, since both groups are together the bases of 1000-pound body weight and 20 pounds FCM were used. Solid points represent Jersey and Brahman cows. The open points represent Brown Swiss and Holstein cows. Although the multiple correlation coefficient of 0.78 for 60 degrees of freedom is significant, the humidity coefficient is significant at only the 5 percent level. Note the wide range of data at 40° and 50° F. Time effects for the intermittent periods of 50° F do not seem to be consistent (see Tables 1 and 2).

that at high humidity there is a higher total heat load. This is contrary to observations made by others on animal reactions. At the same time it should be noted that the range of total heat load at any given temperature has little relation to the relative humidities used.

As in all previous tests, the dominant influence is air temperature. The more linear characteristics of these curves as compared to previous total heat load vs. temperature curves may be due in part to the adjustments for FCM. In other words, if milk production, body weight and relative humidity remain constant, the total heat vs. temperature should be more nearly linear than in prior tests where FCM declined with time and temperatures either above or below 50° F.

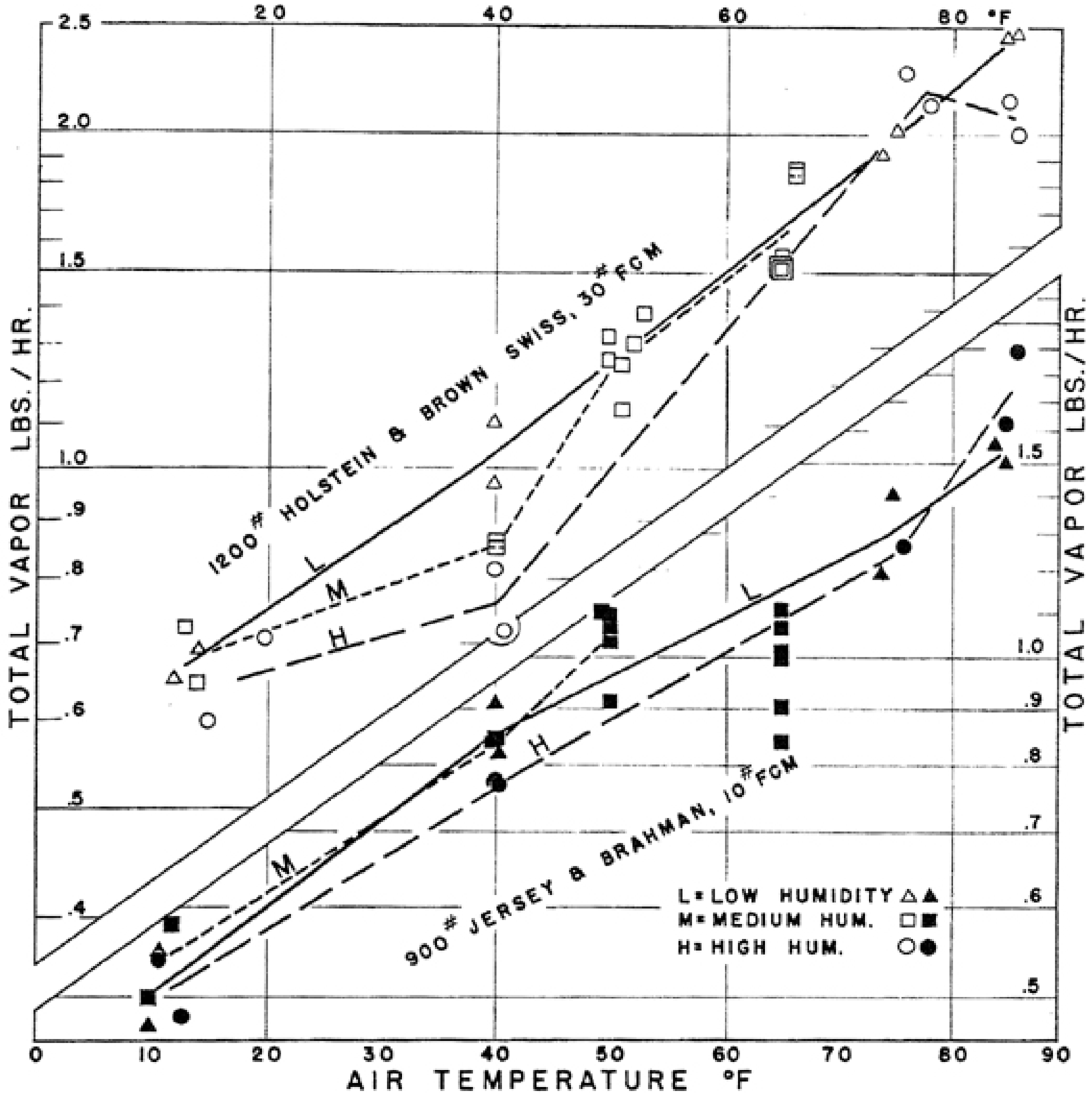

Fig. 4. The Effect of Humidity on Total Test Room Vaporization at Various Temperatures. These values were adjusted by ratios of measured to adjusted total heat loads. For example, the first total vapor value in Table 1 equals $1.18 \frac{(3400)}{3700} = 1.06$ pounds per hour.

Total heat load data from both test rooms were pooled to represent all breeds on a 1000-lb. body weight and 20-lb. FCM basis. Figure 3 indicates that the breed classifications were in good agreement except possibly at 40° and 50° F. As mentioned for Figure 2, there seems to be little effect of humidity below 65° F on total heat load.

The ranges of total heat and moisture measurements shown on Tables 1 and 2 indicate that within any week the values may change as much as 10%. Aside from measurement errors involved, such variation also may be partly due to animal reactions. A preliminary analysis of day-of-week effects indicates very little variation due to within-week test schedules.

On the semilog plot of Figure 4 there seems to be very little effect of humidity on vaporization at any temperature. A definite breakdown of the sources of vapor throughout the temperature range would assist materially in this analysis. As it is, one would suppose that increasing humidity at temperatures below 65° F would decrease both stall surface evaporation and animal metabolic heat production. However, for these particular data, total heat load seemed to increase slightly with increasing humidity, thereby making it difficult to find any significant relation between humidity and total vaporization. If, on the other hand, one were to reason that increasing relative humidity at any given temperature above 65° F raised the rectal temperatures of the animals, then animal vaporization should increase within the limits of the animals' capacity to vaporize. Kibler (9) reports considerable variability for these animals. Near 75° F metabolic heat production increased with humidity and at 85° F rectal temperatures and respiration rates increased with humidity.

Except for the 40° F medium and high humidity tests on the Holstein-Brown Swiss group, a linear relationship of temperature vs logarithm of total test room vaporization is shown in Figure 4. Figure 5 shows the results of a multiple regression analysis of data adjusted to a 20-pound FCM and 1000-pound body weight basis. The second term in the equation fitted to the semilog plot is the humidity term and should reflect only differences due to humidity deviations from 65 percent. If saturated vapor pressure at dry bulb temperature were substituted for t, then the term should represent effects of vapor pressure deviation from 65 percent relative humidity. Preliminary observations of the data indicated that such a term attributed too much difference to humidity at the higher temperatures. Therefore, the more simple term, $t\ (65\text{-}\%RH)$ was retained. Only small differences in total vaporization from animals and test room surfaces can be attributed to humidity. For instance, at 85° F increasing relative humidity about 50 percent decreased total test room vaporization only about 8 percent. The data for non-evaporative heat shown in Figure 6 are differences between adjusted total heat load in Figure 2 and adjusted latent heat load corresponding to the vaporization in Figure 4. Latent heat or heat required to vaporize water at 68° F, i.e., 1054 Btu/lb., was used at all temperatures instead of theoretical requirements varying from 1070 Btu/lb. at 20° F to 1037 at 100°F. The maximum non-evaporative heat load error involved in making such an assumption will occur at the higher temperatures, but at 85° F it amounts to only about ± 2 percent. Differences due to humidity below 65° F are small and inconsistent. At each relative humidity level the non-evaporative heat load curves seem to have more linear characteristics than the total heat load curves. This is as it should be if it is assumed that evaporative heat load, on an arithmetic

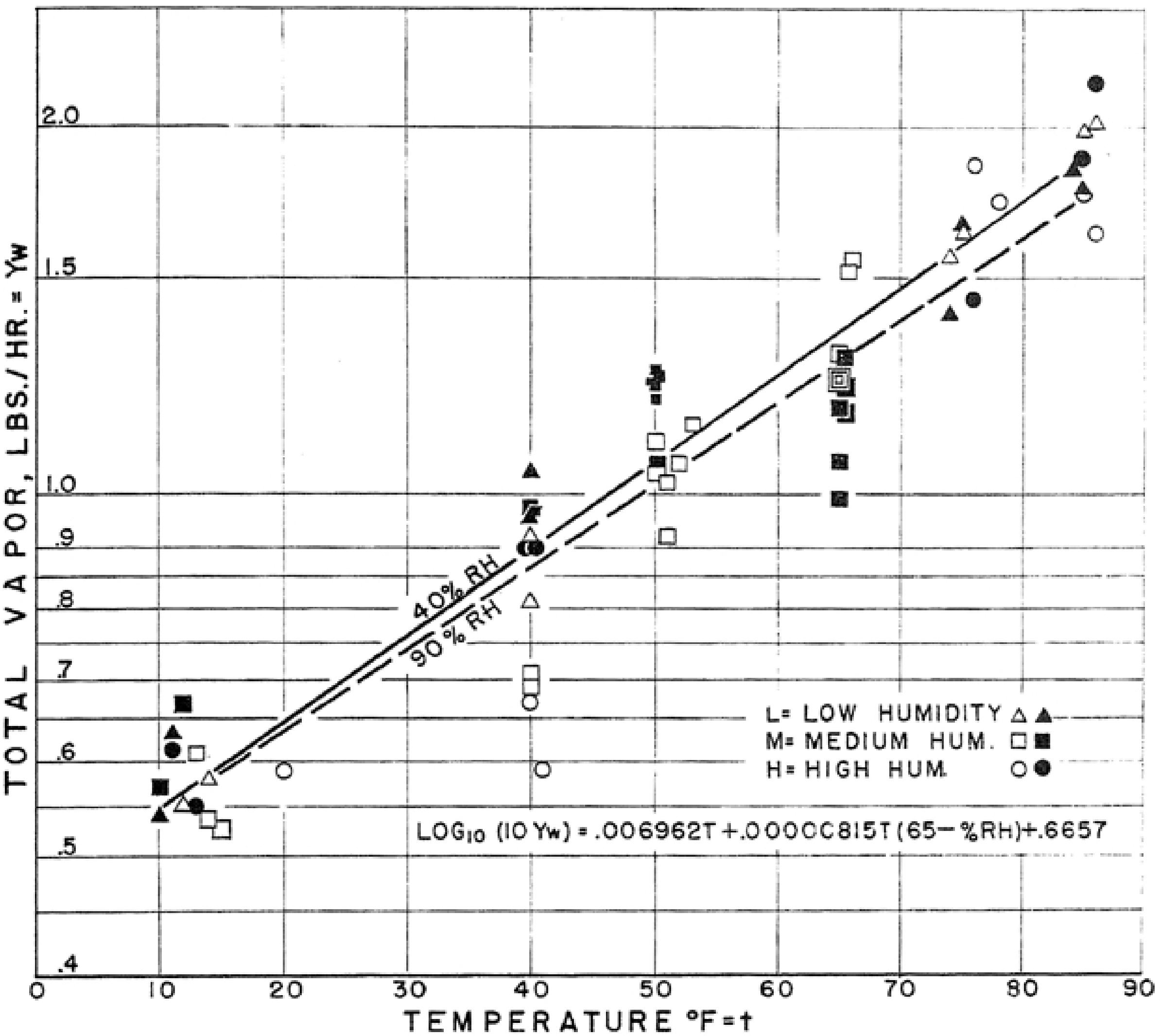

Fig. 5. Estimated Effects of Humidity on Total Test Room Vaporization at Various Temperatures. All values were adjusted to a common body weight of 1000 pounds and 4 percent FCM milk production of 20 pounds by the method used for Figure 4. The multiple regression which was used assumes that at 0° F there is no difference due to humidity. Even at 85° F there apparently are only small differences due to humidity. As with Figure 3, the plotted points are not regression estimates. The solid points represent Jersey and Brahman cows. The open points represent Brown Swiss and Holstein cows.

basis, is non-linear. Immediately, on such a basis, one might conclude that most of the errors involved in total heat estimates might come from the latent or evaporative components. Such may be the case at medium and high humidities for the Holstein-Brown Swiss group near 40° F.

Evaporation from non-animal sources may be quite variable due to management practices. Some of the factors involved are: methods of handling moist bedding, the initial moisture content of bedding and feed, and the amount of time animals spend on their feed.

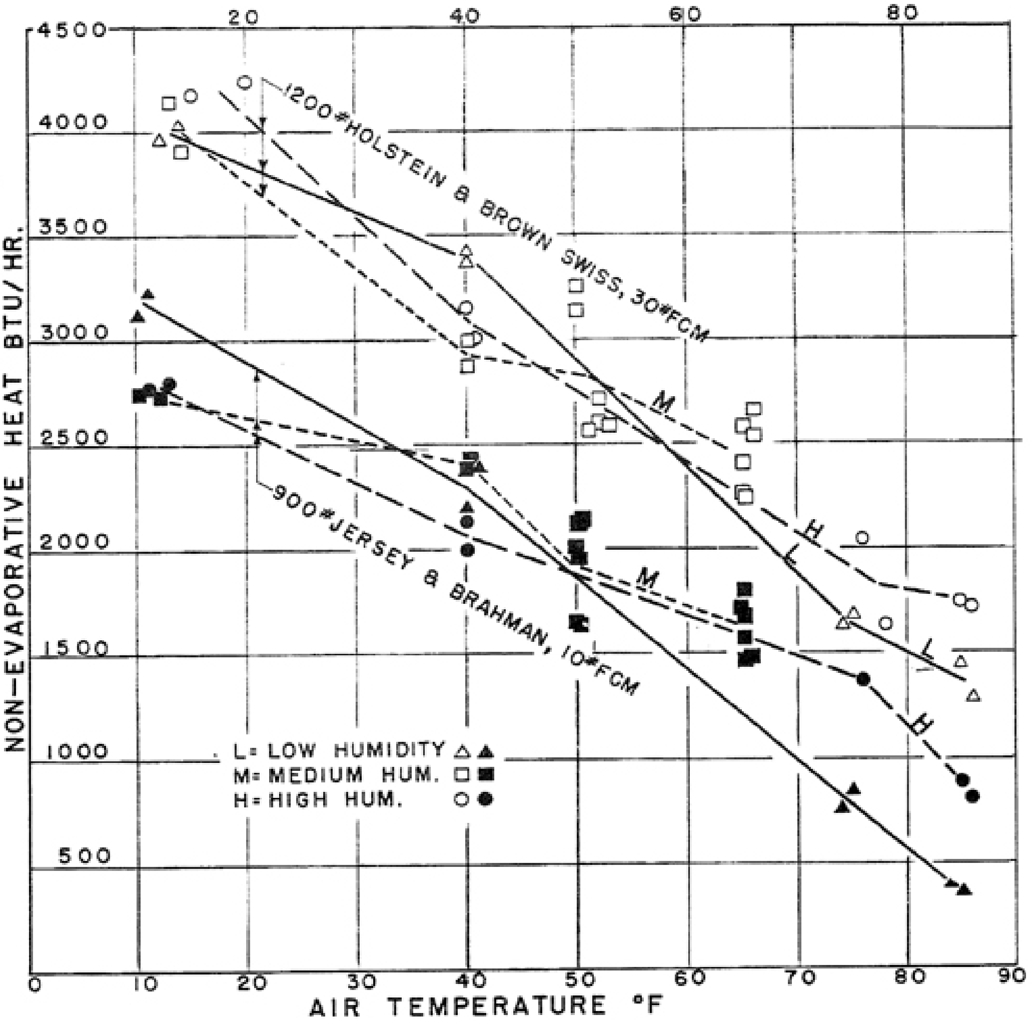

Fig. 6. The Effect of Humidity on Adjusted Non-evaporative Heat Loads at Various Temperatures, 1950-51 Data. All values were adjusted to the approximate mean body weight and milk production of their respective test groups. Evidently increases in total heat load due to high humidity at 85° F may be attributed to non-evaporative sources. Note the uniform range of measurements for both groups at all temperatures. The heat of vaporization was assumed to be 1054 Btu per pound.

Estimates of stall surface vaporization made by Baxter (2) and Muehling (3) are given in Table 3. Measurements were made at 3 temperatures—around 15° F, 40° F and 50° F. The small amount of information given indicates: first, that vaporization from barn surfaces decreases with increasing relative humidity at any given temperature; second, that even though the air in the barn may approach saturation as it is exhausted, there probably is some vaporization from the non-animal surfaces; and third, that the methods used may have practical significance in measuring barn surface vaporization.

TABLE 3 -- STALL SURFACE VAPORIZATION, HUMIDITY STUDIES 10-50°F.

				Vaporization, lbs/hr.*		
					Stall Surface	
Date Surface Meas. Col. #1	Cow No. #2	Temp. °F #3	Humidity RH % #4	Cow IWL #5	Weekly Average #6	Estimate #7
1-8-51	H154	14	65	.49	.24	.34
1-9-51	H129	13	66	.49	.24	.36
1-9-51	H109	14	66	.49	.24	.32
1-11-51	J994	11	82	.29	.25	.24
1-11-51	J508	10	87	.29	.25	.22
1-12-51	J970	14	97	.29	.25	.26
1-20-51	J508	10	66	.52	.24	.23
1-20-51	J526	10	66	.52	.24	.31
1-23-51	H154	18	94	.54	.12	.22
1-26-51	H159	18	78	.54	.12	.30
1-26-51	H109	18	94	.54	.12	.23
11-30-50	J970	40	82	.36	.52	.43
11-30-50	J526	40	83	.36	.52	.36
12-1-50	J510	40	83	.36	.52	.35
11-28-50	H109	40	48	.47	.77	.73
11-28-50	H129	40	46	.47	.77	.56
12-1-50	H141	40	50	.47	.77	.45
2-6-51	J526	50	60	.51	.41	.40
2-6-51	J508	50	62	.51	.41	.54
2-8-51	J970	51	60	.51	.41	.36
2-8-51	H129	51	62	.60	.61	.56
2-8-51	H154	51	62	.60	.61	.56

*Cow Insensible Water Loss (IWL) measurements were obtained from *Mo. Agr. Exp. Stat. Res. Bull.* 531, Reference (4). Weekly average values for stall surface vaporization were calculated by subtracting the Cow IWL from the weekly average test room vaporization rates. "Estimates" were made by Baxter (Table III) (2) and Muehling (Table V) (3) using Fitzgerald's formula: Evaporation, inches/day equals (.40 + .2V) (Pw-Pa) where V equals mphr wind, and P equals vapor pressure mm Hg at surface and air respectively.

In reference to the second finding, there could be no vaporization in a saturated atmosphere if the vaporizing surfaces were at the same temperature as the air dry bulb temperature. However, some of the vaporizing surfaces are at temperatures somewhat higher than air temperatures. Heat conduction from animals to the floor while they are lying down, radiation from animals, and possibly litter fermentation may contribute to this temperature difference between stall surfaces and air. If it is assumed that animal vaporization is not affected by humidity at 10° F, then changes in stall surface vaporization at 10° F due to, for example, a 25% drop in relative humidity should be equal to a corresponding change in test room total vaporization. It should be noted that the terms chosen for the vaporization regression cause no apparent differences in vaporization at 0° F (Figure 5).

The last 3 columns in Table 3 give a rough overall check on the total

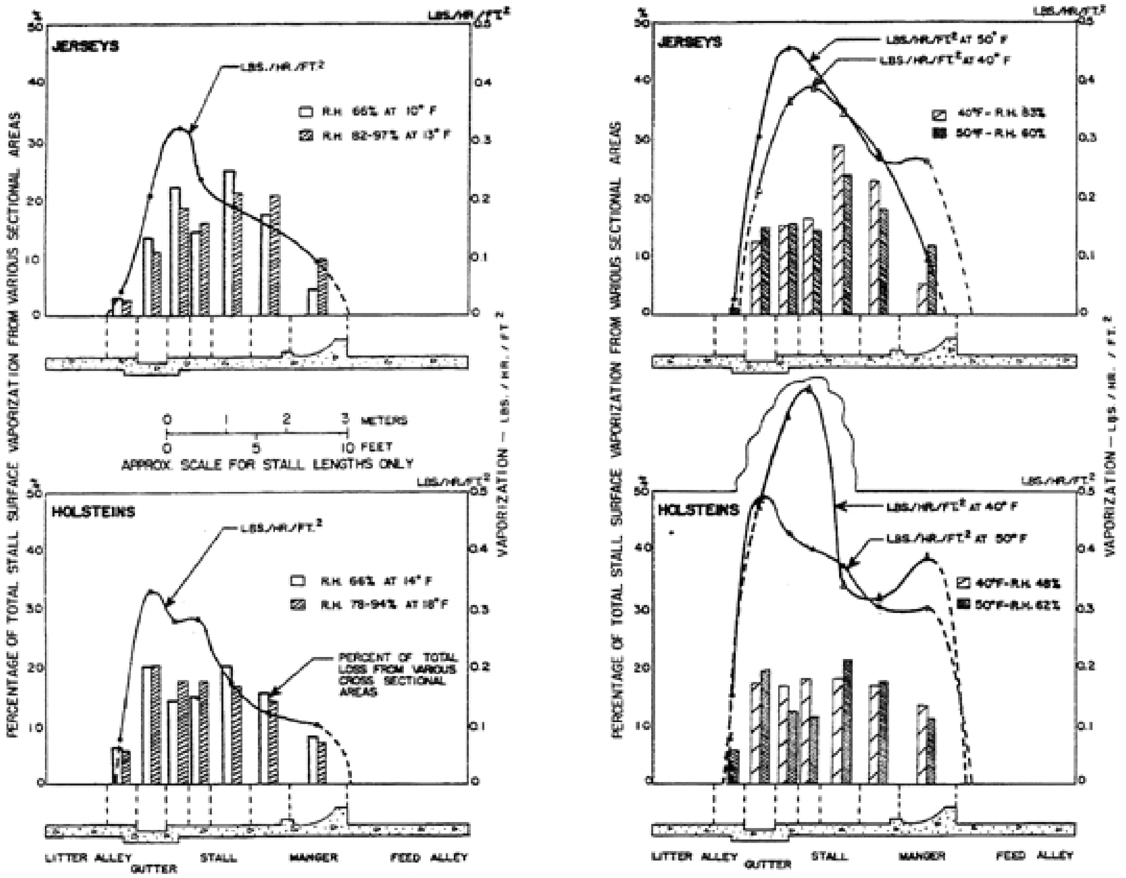

Fig. 7. Percent of Test Room Surface Evaporation From Various Segments of the Stall. See references (2) and (3).

test room vaporization measurements. In most instances the "weekly average" estimates (column 6) made from ventilation and animal measurements are within .1 lb./cow/hr. of estimates made by Baxter and Muehling (column 7).

A breakdown of the sources of water vaporized from stall surfaces is shown in Figure 7. The highest vaporization rates per unit of surface area are evidently near the rear edge of the stall platform and are not in all cases from the liquid surfaces in the gutter. About one-half of the stall platform vaporization comes from the rear one-third of the stall area.

WIND STUDIES

Facilities and Procedures

Ventilating fans having diameters up to 44 inches were placed over the animals as shown in Figure 8 to obtain air movements equivalent to outside winds up to 10 miles per hour. Low air movements could be ob-

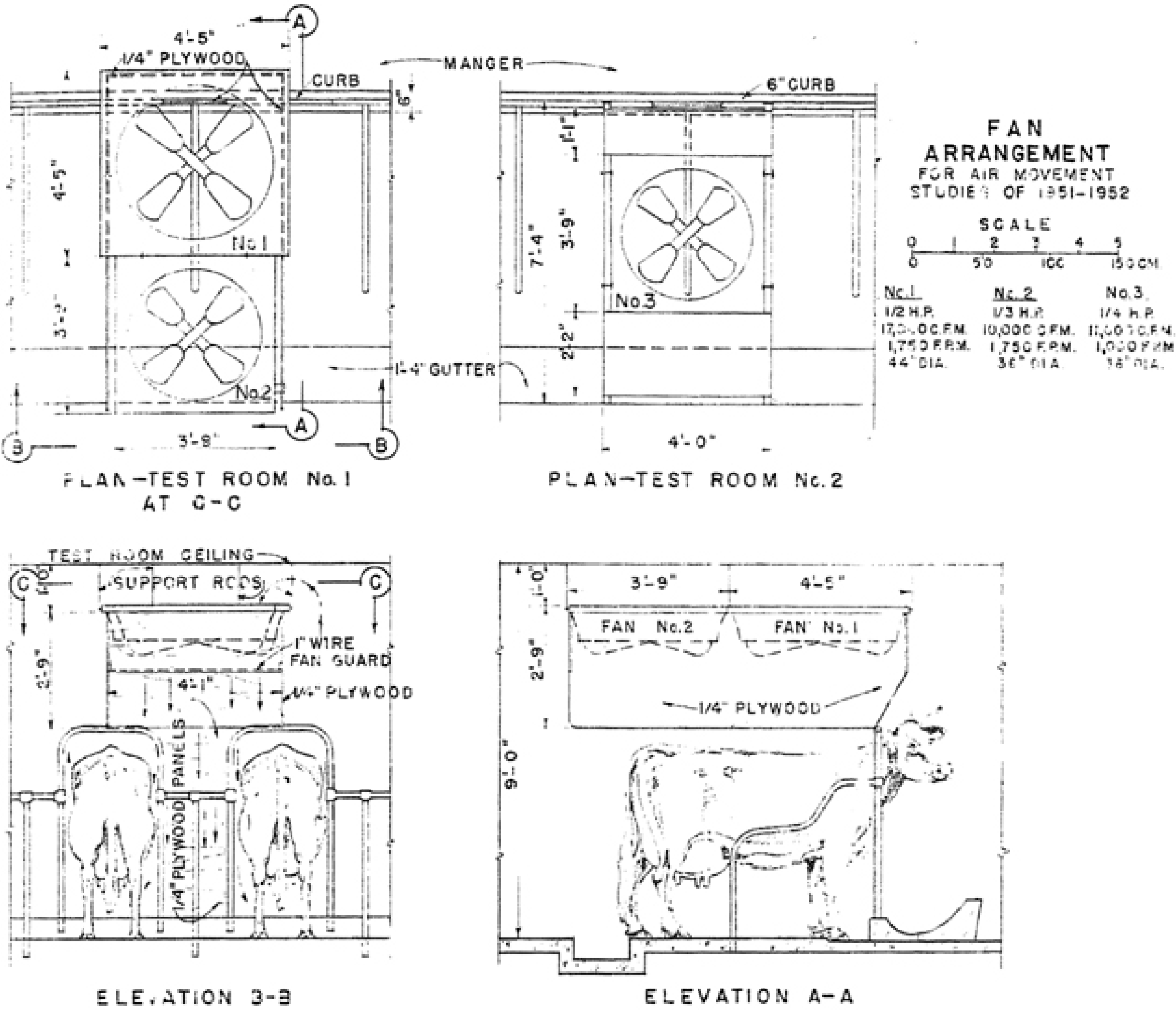

Fig. 8. Fans Used to Provide Air Movement Around Animals.

tained in either test room without using these fans. Low winds reported in the ½ mph range are comparable to air movements used in all previous temperature and humidity effect studies. Fans for the 5 mph tests were installed in Test Room II. Test Room I was equipped for the higher winds. Otherwise, test rooms were identical.

Return duct air temperatures were again used as the environmental dry bulb temperatures. Air movements, however, could not be measured easily with mechanical anemometers. Commercial hot wire anemometers were used for most of the measurements. Calibrations of these instruments were frequently checked in a duct air stream of known velocity. Temperature and relative humidities were measured and recorded during the low temperature wind studies by the same methods used for the humidity studies. Beginning with the high temperature wind studies, resistance thermometer recordings were used for all air temperatures used in heat transfer calculations. At the same time, the experimental lithium

TABLE 4 -- THE EFFECT OF WIND ON TOTAL HEAT LOADS AND TOTAL TEST ROOM VAPORIZATION AT SEVERAL TEMPERATURES WITH JERSEY AND BRAHMAN COWS, 1951-52

Days per wk. N	Mean by Weeks				Total Heat Btu/Hr.		Total Vapor Lbs./Hr.	
	Temp. °F	Wind mph.	Body Wt.#	FCM*	Mean	± S.E.**	Mean	± S.E.**
	Oct. 1951 to Feb. 1952, 4 Jersey & 2 Brahman							
6	51	4.2	906	8	2630	80	.84	.03
7	51	4.2	908	6	3180	70	1.05	.04
7	51	6.0	911	6	3360	150	1.22	.03
5	50	6.0	919	5	3200	80	1.13	.05
7	50	.4	919	5	2850	40	.83	.04
7	50	.4	926	4	2730	50	.75	.02
5	16	3.8	942	3	4170	40	.69	.05
3	20	3.8	905	2	4320	160	.83	.08
7	19	7.6	918	2	4350	90	.98	.01
7	18	.5	913	2	3880	170	.81	.05
6	18	.5	933	1	3620	60	.75	.01
	Feb. to May 1952, 4 Jerseys and 2 Brahman							
5	65	.5	938	12	3080	240	1.36	.05
6	66	6.2	938	11	3130	80	1.25	.06
6	66	6.2	936	11	3010	20	1.15	.03
6	64	.4	943	10	2870	50	1.09	.04
6	66	8.5	945	10	3010	90	.94	.02
7	66	8.5	947	9	2660	110	.99	.07
5	80	7.7	948	10	2270	60	1.17	.02
2	80	4.7	925	7	2550	150	1.37	.04
7	80	4.7	922	8	2970	70	1.68	.04
7	80	.4	949	8	3060	60	1.91	.04

* Pounds per day of 4% fat corrected milk

** S.E. Standard Error of the mean

chloride hygrometer sensing units were replaced by similar lithium chloride units of a commercial make. Temperatures of resistance thermometers within these units were recorded by a 6-point electronic impedance bridge instrument. By use of calibration tables, these temperatures were converted to dew point temperatures. These revisions of the system made it easier to integrate air exchange measurements for each day. Frequency of dry bulb and dew point recordings were increased to minimize variability of hourly averages.

Air movement around the animals was very turbulent during all medium and high winds. There was no fixed direction to the winds. Head winds and tail winds might be expected to cause slightly lower convection losses than side winds. For instance, total heat losses by forced convection from long bare heated pipes in an airstream are less with end winds than with side winds. Air movements reported are averages of 20 measurements representing equal areas in plan 36 inches above each stall platform. Individual animals were removed from the stalls before measurements were made. The sets of 20 measurements for empty stalls were found to be about equal to sets of measurements made within about 6

TABLE 5 -- THE EFFECT OF WIND ON TOTAL HEAT LOADS AND TOTAL TEST ROOM VAPORIZATION AT SEVERAL TEMPERATURES WITH HOLSTEIN AND BROWN SWISS COWS, 1951-52.

Days	Mean by Weeks				Total Heat		Total Vapor	
per wk.	Temp.	Wind	Body		Btu/H.		Lbs./Hr.	
N	°F.	mph.	Wt.#.	FCM*	Mean	± S.E.**	Mean	± S.E.**
Oct. 1951 to Feb. 1952, 3 Holstein & 3 Brown Swiss								
6	52	4.5	1152	33	3790	50	1.19	.02
7	50	4.5	1148	33	4120	70	1.45	.04
7	50	.4	1141	33	4140	50	1.47	.03
7	50	.4	1140	32	3860	70	1.25	.03
2	50	8.1	1140	30	4280	230	1.47	.04
4	18	.4	1140	27	4040	100	.78	.06
6	17	3.4	1122	26	5150	100	.71	.02
7	18	.5	1141	25	3770	140	.82	.03
3	19	10.0	1141	24	5350	60	1.12	.01
6	21	10.0	1128	24	5140	100	1.26	.01
Feb. to May 1952, 3 Holstein & 3 Brown Swiss								
6	64	.4	1260	46	3890	80	1.52	.02
4	65	8.8	1241	44	4760	190	1.83	.12
7	66	8.8	1230	43	4700	40	1.71	.06
6	65	6.4	1231	40	3980	50	1.24	.02
7	67	4.8	1217	42	4180	80	1.54	.05
6	64	.4	1230	38	4290	190	1.99	.05
6	80	4.5	1226	38	4210	60	2.15	.07
2	80	8.7	1214	35	3800	50	2.04	.07
7	81	8.7	1220	34	4020	80	2.15	.05
7	80	.4	1218	32	4080	40	2.47	.03

* Pounds per day of 4% fat corrected milk

** S.E. Standard Error of the mean

inches of the cows when they were in the stall. Due to shifting of animals when they were in the stall, empty stall measurements were more consistent. This procedure also minimized the chances of animals damaging the fine wires of the hot wire anemometer probes.

Several measurements of heat loss from animal surfaces under field conditions and in the laboratory indicated that the test room wind values had slightly higher heat dissipating characteristics than outside winds having similar speeds. Temperature differences between air and dry structural surfaces did not exceed about 2° F at the 10 mph winds (10). Some difficulty was experienced with the high winds blowing feed out of the mangers. For that reason, high-wind fans were turned off about 4 hours a day during feeding periods (11).

The test schedules used were similar to those used for the humidity studies. The three winds, low, medium, and high, were used at temperatures near 18°, 50°, 66° and 80° F. Test periods are listed in chronological sequence in Tables 4 and 5. In general, a 2-week period was used for each wind-temperature combination. The extra heat generated in the test rooms by fan motors sometimes caused low humidities during high winds. Variations in fan deliveries with temperature and difficulties in adjusting fan speeds caused some irregularities in the ranges of medium and high wind speed classifications.

Four groups of 6 animals each were used for the wind studies. The Fall or low-temperature studies included 2 dry Jerseys, 2 dry Brahmans, and 2 lactating Jerseys as one group and 3 lactating Holsteins and 3 lactating Brown Swiss as the other. Similar groups were used for the high temperature wind tests in the Spring of 1952. For practical purposes, the Brahman-Jersey six-cow groups may be considered non-lactating since milk production ranged from about 1 to 12 pounds per day. Production records, age, stage of lactation, and feed and water consumption have been reported previously (11).

Results—Wind Studies

Data were processed in much the same manner used for the humidity studies. FCM or b_2 coefficients calculated in a manner similar to those for the humidity studies were: minus 1 near 19° F, 30 at 50° F, 23 at 65° F, and 36 at 80° F, giving an average of 22 Btu/hr. per lb. FCM/day. Therefore 20 Btu/hr. per lb. FCM/day was also used for adjusting the wind data.

Near 18° F there is a definite increase in sensible heat load due to wind. Although winds of 10 mph would never be experienced in closed barns, some open shelters may easily be expected to expose animals to occasional winds up to 3 or 4 mph. The more simple type of windbreak may cause exposures equivalent to the 10 mph wind tests.

Figure 9 presents total heat loads adjusted for body weight and milk production. Approximations of average weight and milk production (FCM) of the Holstein-Brown Swiss and Jersey-Brahman classifications were used as bases. Resultant adjustments were small in comparison with the adjustments that would have been required had all values been converted to 1000-pound body weight and zero FCM.

Near 20° F we find the only crossing of the Holstein-Brown Swiss and the Jersey-Brahman total heat curves. Previous measurements during temperature studies (1) on a mixed group of large and small cows indicate that near 18° F these Jersey-Brahman total heat load measurements may be somewhat high and the Holstein-Brown Swiss slightly low. Some shivering of Brahmans at temperatures below 20° F would indicate that high values might be expected.

Figure 10 gives total heat loads, on a common body weight and pro-

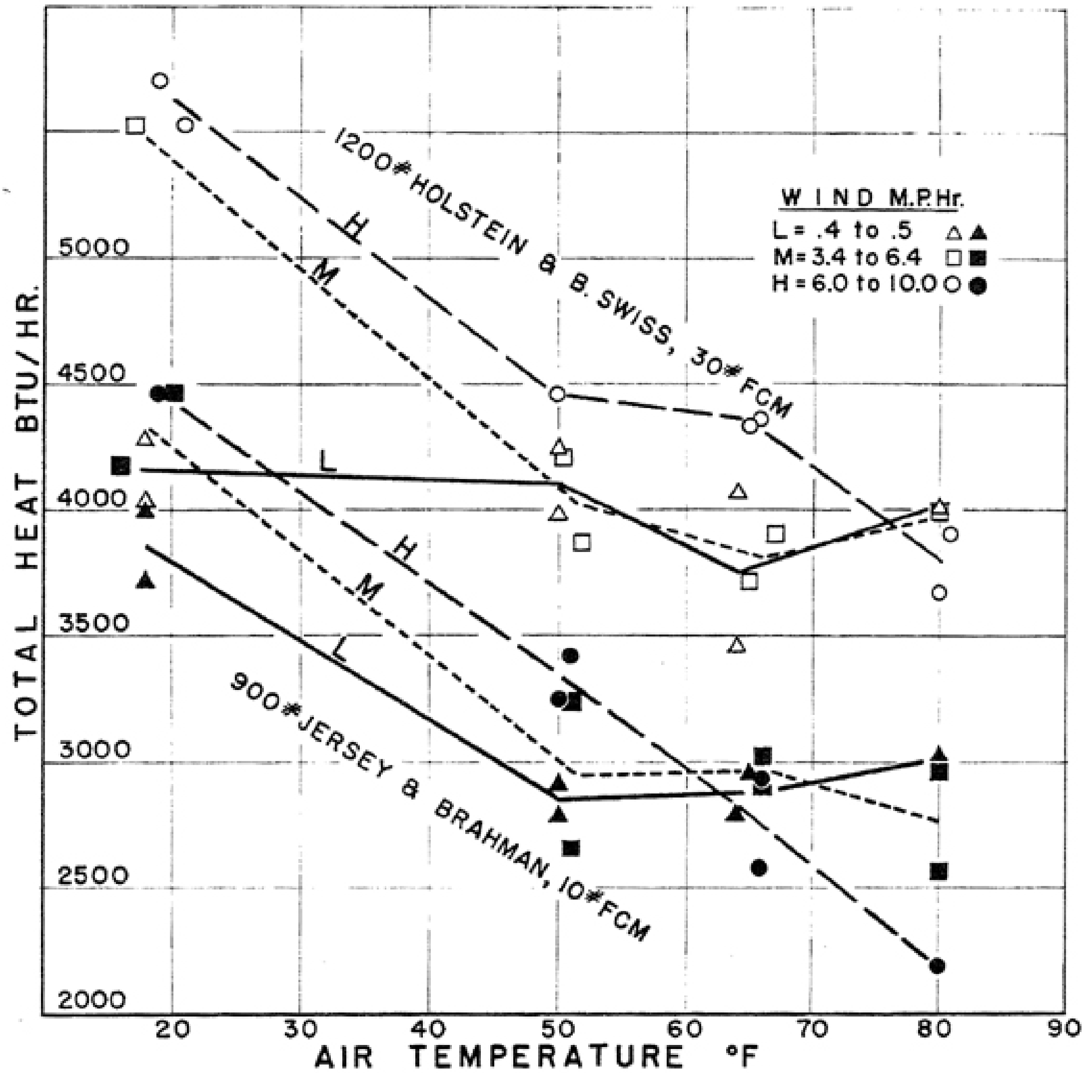

Fig. 9. The Effect of Wind on Total Heat Loads at Various Temperatures, 1951-52 Data. All values were adjusted to the approximate mean body weights and milk production of their respective test room. (See Figure 2). High winds ranged from 8 to 10 miles per hour, medium from 4 to 6 miles per hour, and low from 0.4 to 0.5 miles per hour. The 1200-pound curves, when compared to the 900-pound curves, have similar characteristics except for low winds at 18° F. The variation due to wind is quite irregular at 75° F.

duction basis, as affected by wind speeds at different air temperatures. Here again there seems to be a definite effect of both temperature and wind on total heat load at 20° F. The crossing point near 75° F was arbitrarily selected after visual inspection of the total heat, evaporative, and non-evaporative heat load curves, Figures 9, 11, and 13. Thus it is assumed that wind has no effect upon heat load and vaporization at 75° F. The evaporative heat load curves (Figure 11) cross somewhere below 75° F and the non-evaporative (Figure 13) somewhere above 75° F. The

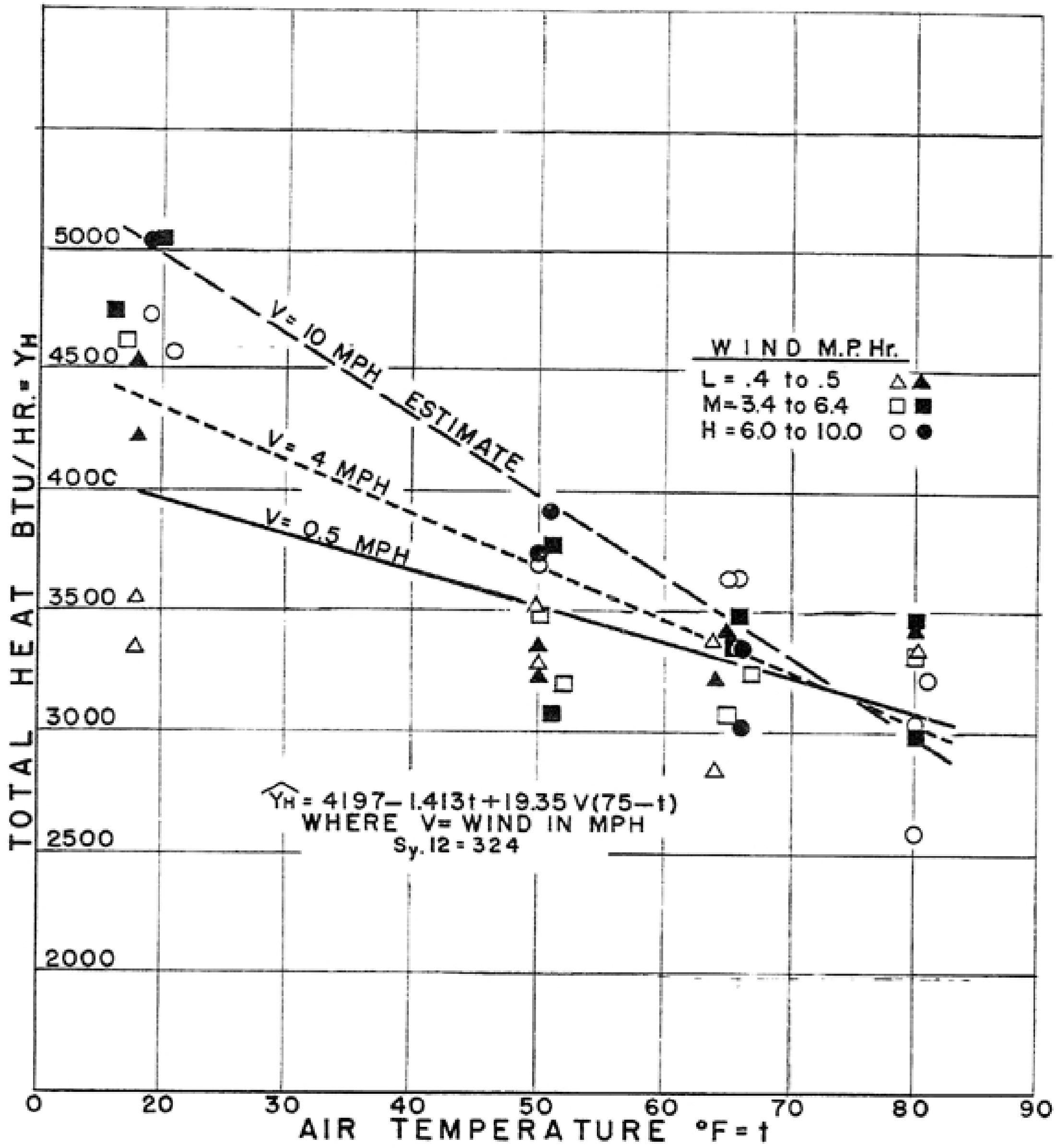

Figure 10. The Effect of Wind on Estimated Total Heat Loads at Various Temperatures. All values were adjusted to common 1000-pound body weight and 20 pounds 4 percent FCM bases as in Figure 3. Open points represent Holstein and Brown Swiss cows. Solid points represent Jersey and Brahman Cows.

½ mph estimate of total heat load (v = 0.5 MPH in Fig. 13) is comparable to estimates made from adjusted data for previous temperature studies (1).

High winds increased total test room vaporization at 20° F and decreased it at 80° F, (Figure 11). Consider separately the two sources of this vaporization: stall surfaces and animals. Stall surface vaporization will increase with increasing wind at both temperatures. At 20° F wind increases animal metabolic heat; therefore, it is quite likely that animal vaporization must increase. At 80° F, wind decreases animal vaporization more than the same wind can increase stall surface varporization, therefore the net decrease. We may assume that in the 50-65° F range, wind had

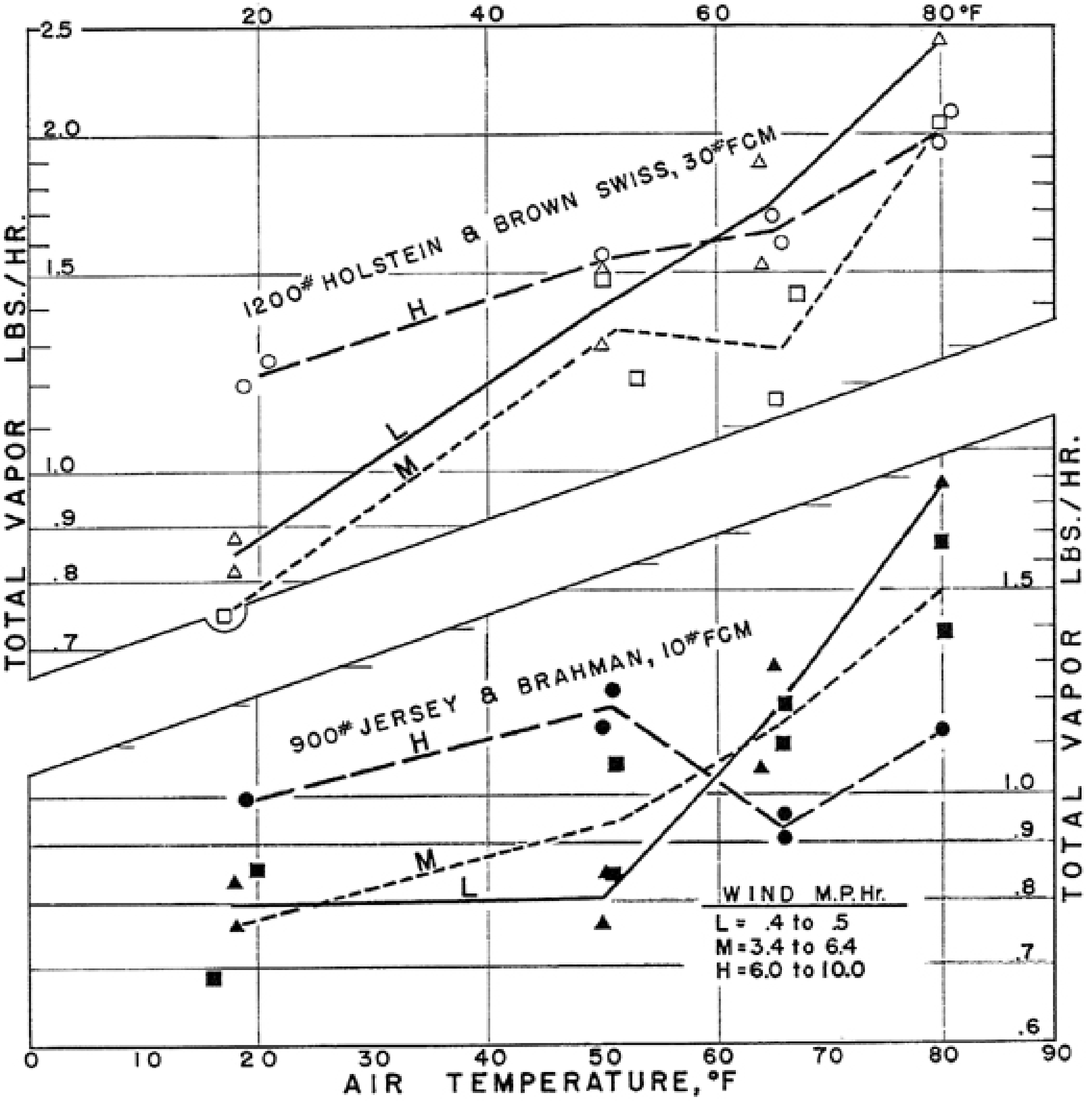

Fig. 11. The Effect of Wind on Adjusted Total Test Room Vaporization at Various Temperatures, 1951-52. All values were adjusted to an approximate mean body weight and milk production for their respective test groups as per method described in Figure 4. The respective base points for each group are shown in the Figure. Wind increased the total test room vaporization within a 16-21° F temperature range and decreased total test room vaporization at 80° F. The effect of wind probably reaches a minimum somewhere between 50° and 65° F.

little effect upon total test room vaporization.

Discrepancies from combining data for two 6-cow groups (such as lower section Figure 11) were not significant. In this instance four of the animals were used throughout the tests at all four temperatures. Differences between the average FCM and body weights for the 20° to 50° F group versus the 65° to 80° F group were also very small.

Figure 12 represents a regression estimate based upon the assump-

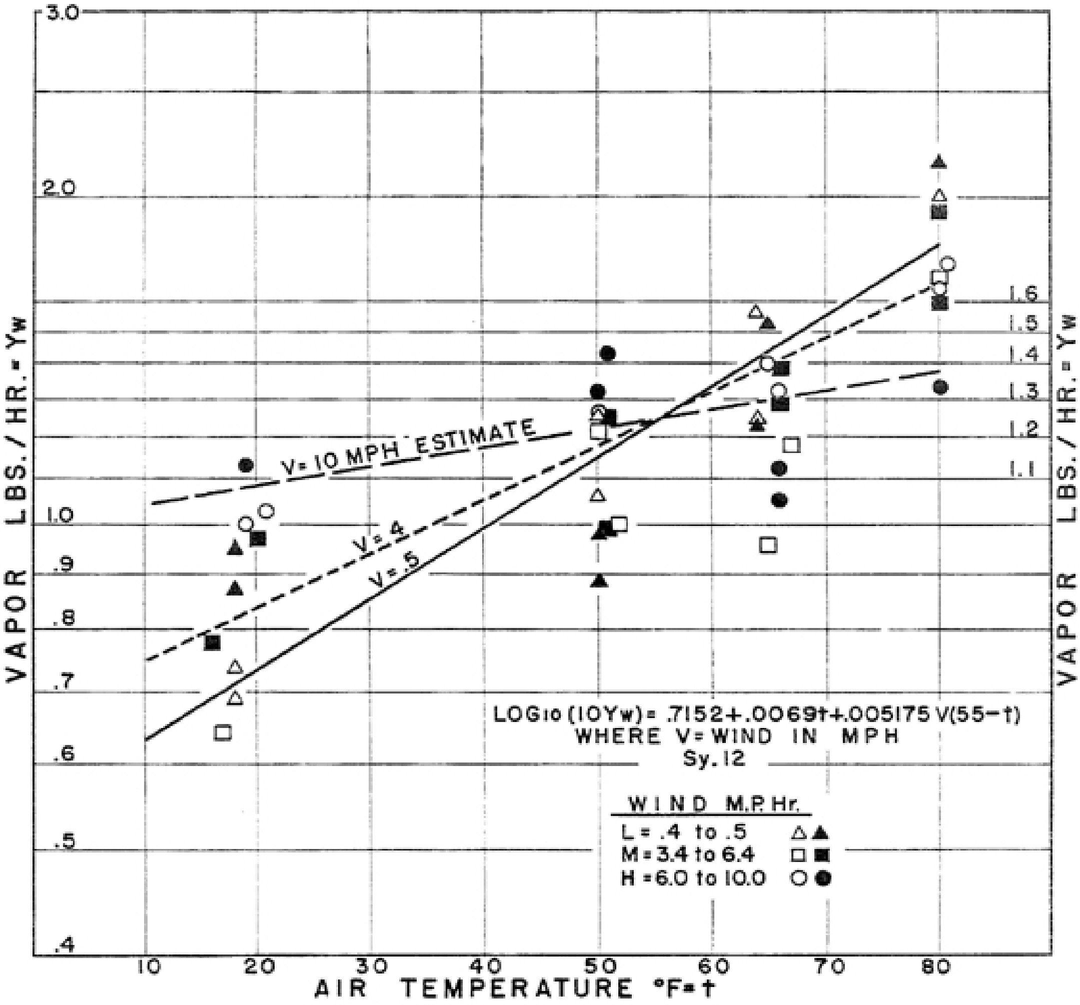

Fig. 12. The Effect of Wind on Total Test Room Vaporization at Various Temperatures, 1951-52 Data. Data are the same as in Figure 11 except that adjustments were made to a 1000-pound body weight base and a 20-pound FCM base. Solid points represent Jersey and Brahman cows, open points represent Holstein and Brown Swiss cows. The crossing point of the curves at 55° F was arbitrarily selected after inspection of Figure 11. Wind apparently affects the sum of animal and stall vaporization at 20° and 80° F. The differences between the ½ and 10 mph curves are about equal but opposite in sign at 20° and 75° F.

tion that wind has no effect upon total test room vaporization at 55° F. The semilog plot of Figure 12 at first glance may appear to show a greater spread between high and low wind curves at 20° than at 80° F. Closer observation, however, reveals that the spread is arithmetically greater at 80° F. As with the humidity-vaporization data, extrapolations below 15° or above about 85° F should not be made. On a vapor pressure basis it is difficult to visualize that all the spread at 18° F could be attributed to wind, since the vapor pressure of water at 50° F is about 3-½ times that at 20° F. Although there is no general agreement on the non-linear relationship of vaporization to wind, it is sometimes assumed that vaporization is a function of about the 0.75 power of wind speed. (12). The regression lines in Figure 12 are in fair agreement with this assumption.

Of interest is a brief survey of the differences between 1st and 2nd weeks of selected 2-week periods, for total heat load test room vaporization and rates as shown in Tables 4 and 5. Five pairs of weeks were selected: The first 4 weeks at 50° F; the last 2 weeks near 20° F; the 2nd and 3rd weeks at 65° F; and the 2nd and 3rd weeks at 80° F. Except for wind speed and stage of lactation, the 2nd week was a replication of the 1st week.

It was observed that in each 2-week test period, with one exception, whenever the total heat load increased from the first to the second week the latent heat also increased. Similarly, when the total heat load decreased so did the latent heat. This would be expected if we assume that the ratio of latent to total heat load is constant at any given climatic condition for any given group of animals. It was noted also that whenever the total and latent heat for the Jersey-Brahman group increased from the first to the second week, similar increases can also be found for the Holstein-Swiss group. It is evident that whatever influenced one group, simultaneously influenced the other in the same way. Variations in bedding and management practices and test schedules for various physiological measurements and errors in measuring heat flow, heat storage, vapor pressure or air volume may all have contributed to the differences between successive weekly periods. Barometric pressure, wind, temperature and stage of lactation during or immediately preceding the paired week periods seem to have little in common with such differences.

Non-evaporative heat loads calculated from data adjusted for approximate mean body weight and milk production are shown in Figure 13. The temperature versus heat relationships appear to have definite linear characteristics with very small differences due to wind above 65° F. The general slope of all curves indicates that non-evaporative heat loads might reach zero somewhere above 100° F. Measurements at 95° F (not reported in Tables) for 1 day at high wind averaged 3000 Btu/hr./cow and 3.09 lbs. water vapor/hr./cow for the Holstein and Brown Swiss group. Similar measurements for 2 days on the Jersey and Brahman group at low wind and 95° F averaged 2700 Btu/hr./cow vs. 2.19 lbs. water vapor/hr./cow on the first day and 2450 Btu/hr./cow vs. 2.56 lbs. water vapor/hr./cow on the second day. Thus we might say that for any given wind or air movement, non-evaporative heat dissipation is proportional to the difference between animal surface temperature and air and surrounding surface temperatures. Similar conclusions may be drawn from

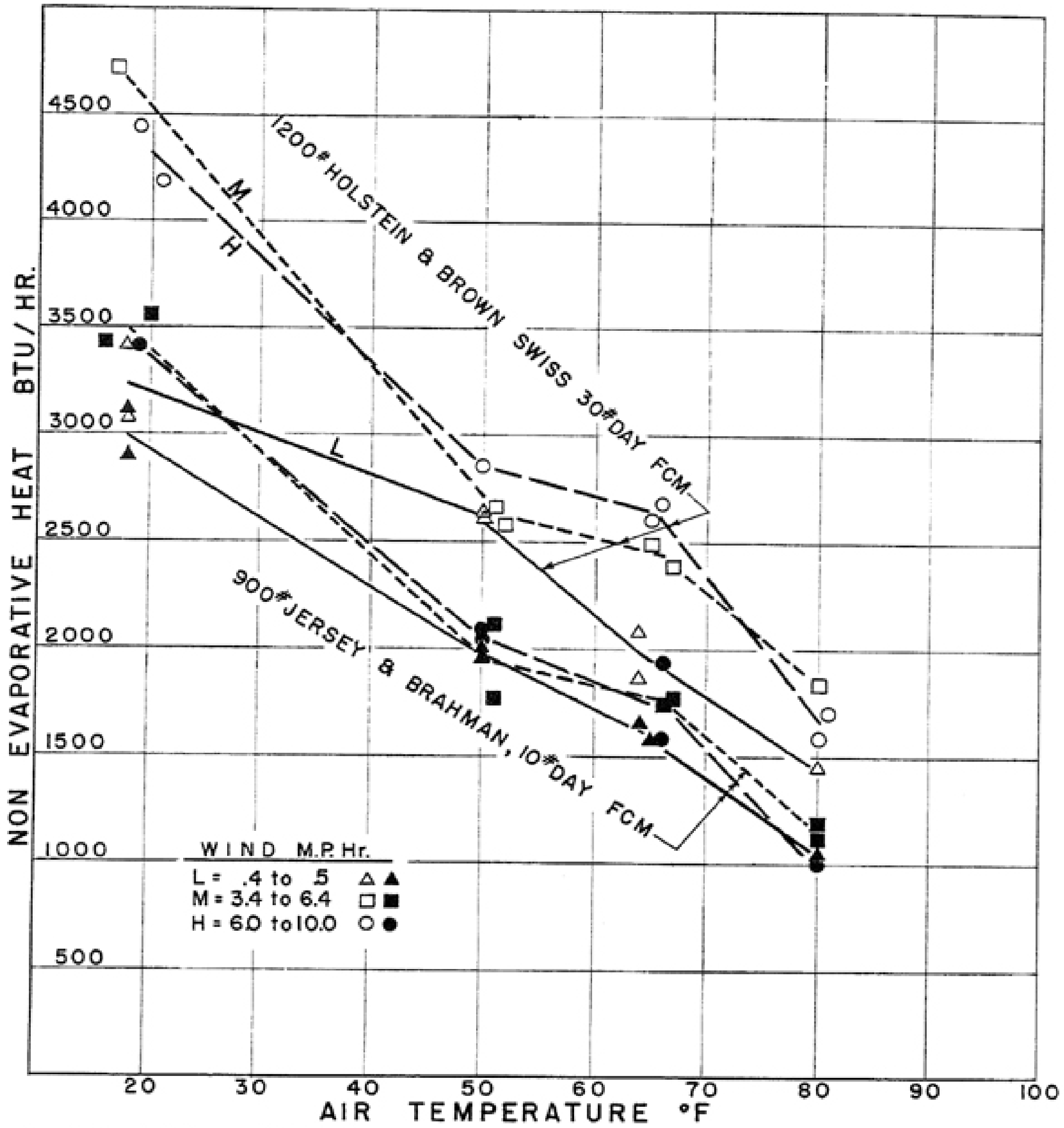

Fig. 13. The Effect of Wind on Non-evaporative Heat Loads at Various Temperatures, 1951-52 Data. These data were derived by subtracting adjusted latent heat (1054 Btu per pound total test room vapor) from adjusted total heat. At constant wind, sensible heat is directly proportional to differences between animal body temperature (near 100° F) and air temperatures.

animal surface temperature data (10). Fanning of animals in barns near 100° F will do little to increase non-evaporative heat dissipation. With low relative humidity at 100° F wind will cause a considerable increase in stall surface vaporization under moist bedding conditions.

Actual evaporation from the more open type of structure under natural wind conditions may be lower than estimates based on these test results. Wind energies dissipated as frictional heat (i.e., sensible) within the open structure may be lower than the frictional heat and electrical energies dissipated as sensible heat in our tests. The non-evaporative heat loads reported do not include the electrical energy supplied to the motors driving the "wind" fans. It is possible that this sensible heat when added to the animals' sensible or non-evaporative heat dissispation, may have caused more heat to leave the structure in the form of water vapor. In other words, even though it is known how much energy was supplied the fan motors, it is difficult to partition the vaporizing influences of animal heat and the resultant heat energy from the fans.

SUMMARY

The effects of barn humidity upon barn moisture vaporization and heat loads are given in the first section of this report. Similar effects for wind or air movement within the barn are given in the second section.

Measurements were made under laboratory conditions that approximated housing and handling practices in stanchion barns. In all, 8 groups of 6 cows each were studied. Barn total heat load and animal heat production were assumed to be the same in this report, whereas moisture vaporization was the sum of animal vaporization and stall surface vaporization. Methods are given to estimate the effects of body size and milk production on heat and moisture dissipation.

Below about 50° F, humidity had little effect upon either the total heat or the water vapor that was removed by ventilation. Generally speaking, vaporization decreased when humidity increased. At temperatures below 55° F, increasing winds increased vaporization, and at temperatures above 55° F, increasing winds decreased vaporization.

Near 20° F, increasing winds from ½ to 10 mph increased total heat loads as much as 25%. Above about 65° F, wind made little difference in total heat loads. Non-evaporative heat dissipation was practically nil when barn air temperatures approximated animal surface and body temperatures.

Total heat and vaporization measurements made during these humidity and wind studies and previous temperature studies (at ½ mph and 60 to 70 percent relative humidity) are comparable when adjustments are made for animal size and production.

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