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Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

XXXV. HEAT AND MOISTURE REMOVED BY A DAIRY STABLE VENTILATION SYSTEM DURING DIURNAL TEMPERATURE RHYTHMS

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This bulletin reports on Department of Agricultural Engineering Research Project 66, "Influence of Climatic Factors on Shelter Requirements of Cattle"

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INTRODUCTION

Past work in the Psychroenergetic Laboratory dealt primarily with the reaction of dairy animals to constant temperatures within and between days for weekly periods. The diurnal temperature rhythm studies were made to determine comparable reactions of the animals to a variable temperature, more like the daily variation experienced outdoors. Such conditions are also similar to those which would occur in open barns and to a somewhat lesser degree to those which would occur in poorly insulated, totally enclosed barns.

This bulletin has a threefold purpose: (1) to present data on the heat and moisture exchange that can be expected in a dairy barn under variable temperature conditions; (2) to present data on the diurnal change in stable heat and moisture dissipation which in turn can be correlated with diurnal heat and moisture production of the animals; and (3) to present detailed data on the test room environmental condition as a companion to other research bulletins in the Environmental Physiology and Shelter Engineering series reporting results of work in the Psychroenergetic Laboratory. All bulletins of this series report on the broad objective of determining the effect of environment on cattle in order to establish building design and animal selection criteria.

EXPERIMENTAL DESIGN

The test program was designed to represent some normal daily temperature rhythms as they exist during various seasons and in various areas of the United States. The diurnal temperature ranges were: a "Midwest Cold," 10 to 40° F (10° F was the lower limit of the laboratory cooling equipment); a "Midwest Normal," 40 to 70° F; a "Midwest Hot," 70 to 100° F; and an extreme range diurnal with a maximum day temperature of

*A Report on ventilation studies and environmental conditions in the Psychroenergetic Laboratory during the Diurnal Temperature Rhythm Investigations.

110° F and minimum night temperatures of 40, 50, or 60° F, somewhat simulating a desert or mountain rhythm. Tables 1 through 5 show the sequence of the tests.

These four diurnal rhythms were used with two groups of cows. The first or fall of 1953 group consisted of six cows, all in early stages of lactation and subjected to very limited physiological measurements. The second or spring of 1954 group also consisted of six cows but they were in more advanced stages of lactation and subjected to additional measurements which might exert slight depressing effects on milk production.

These additional measurements consisted primarily of those involving hypodermic injections and the drawing of blood for such studies as blood composition, blood volume, body water and thyroid activity. Measurements of feed and water consumption, milk production, metabolism, rectal and surface temperatures and respiration and pulse rates were made on both groups of cattle. Standard management and feeding schedules were followed. The cows were machine milked at 5 a.m. and again at 3 p.m. Water was available at all times in individual drinking cups. The grain concentrate mixture was fed according to milk production. Two pounds of dry beet pulp per cow, wetted prior to feeding, was fed daily. Alfalfa hay was fed in quantities slightly greater than consumed, with the uneaten hay being removed and weighed daily. The gutters and back edges of the stall platform were cleaned at 6:30 a.m. and 4:30 p.m. Wheat straw was used most of the time for bedding. Early in the first test period some wood shavings were used.

LABORATORY DESCRIPTION

A detailed description of the laboratory has been presented in a previous report.[1] The test rooms were patterned after a stable having a single row of stalls, 5 ft. 8 in. long and each 4 ft. wide. The feed alleys were 4 ft. 10 in. wide and the litter alleys were 4 ft. wide. The mangers had high fronts and gutters were 16 in. wide by about 8 in. deep. The test room inside dimensions were 18 ft. x 26 ft. by 9 ft. high. The inside walls were lined with a varnished cement asbestos board. The ceiling was of the same material with the exception of an 8 x 24-foot strip above the stalls that contained insulated glass and galvanized iron panels used during a previous radiation experiment. The entire ceiling however had a fairly uniform coefficient of heat transfer. Floors were concrete and the stalls were well-bedded with wheat straw.

The stable environments were provided by conditioning the ventilating air with Freon 12 refrigerant coils (having a continual defrost CaCl spray system) and ethylene- glycol-filled heating coils heated by a gas fired boiler. A pneumatic system of controls was provided for metering the flow of glycols and refrigerants. During the two low temperature tests (10 to 40°

F diurnal) and the fall highest temperature diurnal (40 and 50 to 110° F) it was necessary to supplement the ventilation system with 436 feet of 1¼-inch iron wall coils, ethylene glycol filled, located along the upper third of the side and rear walls. Heat transfer through the walls and ceilings was minimal as the corridors around and the crawl space above the test rooms were conditioned so as to maintain temperatures about the same as in the test rooms.

DESCRIPTION OF THE CATTLE

Each group of cattle consisted of three Jerseys and three Holsteins. At the beginning of the experiment the Jerseys of the fall group ranged from 3½ to 5 years of age, 800 to 850 pounds in weight and produced between 24 and 35 pounds milk daily with a butterfat content of 5 to 6 percent. The Holsteins initially ranged from 5 to 7 years of age, 1250 to 1300 pounds in weight and produced 51 to 56 pounds of milk daily with butterfat content between 2.8 and 3.0 percent.

With the exception of one Holstein and one Jersey, the same group of cows was used for the spring tests. Except that the replacement Jersey was about one year younger and the replacement Holstein was about 3 years older, the replacement cows were comparable to those they replaced. Milk production, feed and water consumption, and body weights during the test periods are shown in Table 6. Three cows were removed from the laboratory during the spring tests: one Jersey on March 9, 1954, for removal of hardware from the rumen; one Holstein on May 1 due to heat stroke; and another Jersey on May 24 after having aborted on May 7 and failing to recover. The latter two losses were attributed to heat stress. Both Jerseys were replaced by non-lactating Jerseys of similar size, one on April 13, the other on May 24th. The Holstein was not replaced. A detailed description of the cattle has been presented in a previous report.[2]

INSTRUMENTATION

Instrumentation was provided by a combination of manual and recording measuring systems. Most temperature data for ventilation exchange calculations were recorded by resistance recording bridges, working through small and very sensitive resistance bulbs. For a short time during the failure of one of the recorders, the record from the temperature control instrument, with its large gas-filled bulb, had to be used.

Temperature variation within the test rooms was measured with a 30-gauge lap welded thermocouple, remotely connected to a manually operated potentiometer. Surface temperature gradients through the walls and ceilings were recorded by a 16-point mechanical balance potentiometer having 10-junction thermopiles as its detecting elements. This instrument also served to record the temperature difference between the test room exhaust air and the temperature inside a 6-inch globe thermometer. The globe thermometer was placed between the fourth and fifth stalls about 4.5 feet above the floor. It was painted with a mixture of lamp black and varnish and had a slightly glossy finish.

The difference between the moisture content of the test room intake and exhaust air was determined with a lithium chloride dew point measuring apparatus. This determined the dew point in terms of the temperature near which lithium chloride changed from a moist to a dry salt and lost its electrical conductivity. Base points for use with these differential moisture content measurements were obtained with a hygrothermograph mounted near the exhaust air grill. Frequent calibration checks were made with a sling psychrometer.

Ventilation duct air velocities were recorded by a recording manometer actuated by a combined reverse pitot tube in the intake duct. These measurements were checked and average duct velocity traverses were made with a carefully calibrated deflecting vane type anemometer, having a probe similar to that of the combined reverse pitot tube. Air velocities within the test room were measured with a portable hot wire anemometer oriented to record maximum velocity. Light intensities were measured with a General Electric photo-cell type light meter oriented with the measuring surface of the light cell horizontal.

TEST ROOM CONDITIONS

The pattern of temperature change within each diurnal range was regulated by an index cam on the temperature controllers. This cam was cut according to Washington, D. C., Weather Station records, which are discussed in a companion publication.[2] The maximum temperatures occurred between 3 and 4:00 p.m. and the minimum between 5 and 7:00 a.m. Figures 1 and 2 show the pattern of temperature and relative humidity variation during each week of the eight test periods. These curves were based on hourly averages. Table 1 shows the highest and lowest temperatures reached during each week. In general, these curves were representative of each day within the indicated week. The midwest cold diurnal patterns varied the greatest as the cooling equipment was being taxed to the limit. At times changes in outdoor conditions were reflected in the test room conditions.

Room surface temperatures, although not measured directly, were estimated as being within 3° F of the corresponding air temperatures. Estimates were based on measured temperature differences between the outer corridors and the test rooms as well as the recorded surface temperature gradient through the test room walls.

The globe thermometer indicated that it was receiving some radiant heat, as its inside temperature was as much as 5° F above ambient air. However, the average difference for the entire test was about 2° F above ambient air with no one diurnal cycle having a daily average much different from the other. The air velocity around the globe was about 25 fpm. Since the globe was located between two cows, just above a point level with their backs, much of the radiant heat was assumed to be gained from them. The use of the wall coils for cooling during the 10 to 40° F diurnal and for heating during the 40 and 50 to 110° F diurnal had very little effect on the globe thermometer.

Temperatures for each stall were measured along the stall partitions at midpoints of the feed alley, the stall platform and the litter alley, and at heights above the floor of 1.5, 4.5, and 7.5 feet. The points of measurement as well as an example of the variation that occurred during the medium temperature period within the 40 and 70° F diurnal are shown in Figure 3. Results during maximum, mean, and minimal temperature periods for each of the 4 diurnal cycles are presented in Table 7. Temperatures, 1.5 and 4.5 feet above the floor, along the stall platforms were important as they more truly represented the animal exposure temperatures than any others. A comparison of these stall temperatures with the exhaust air temperature (the exhaust air record was used to represent the test room environment) showed fair agreement between the two.

In general, the stall temperatures were below the exhaust air temperatures at the lowest temperature within each diurnal rhythm. They averaged about the same as the exhaust air during the mean temperature period and they were above the exhaust air at the highest temperature period within each diurnal rhythm. This would tend to increase the effective range or spread of temperatures within each rhythm. The difference between maximum and minimum values shown in Figures 1 and 2 and Table 1 would be increased by about 3.5° F in the 10 to 40 diurnal, about 3.5° F in the 40 to 70 diurnal, about 2° F in the 70 to 100 diurnal, and about 3° F in the 60 to 110 diurnal. These differences would be important only in the high temperature diurnals and then primarily as they increased the effective maximum temperature to which the cows were exposed. At the 4.5 ft. height, the stall temperatures were 2 to 3° F above exhaust air temperatures during the maximum temperature period of the 70 to 100° F and 60 to 110° F diurnals. However, at the 1.5 ft. height, they were as much as 3° F below exhaust air which would counteract this difference and make the exhaust air temperature a true record of the maximum effective temperature to which the cow was exposed.

An interesting point would be, "Did the cows take advantage of the cooler temperatures (abut 6° F in some cases with 110°F) at the 1.5 than at the 4.5 foot levels by lying down at temperatures of 110?" They did lie down but whether from exhaustion brought on by stress, by the cooler environment, or just normal habit remains a question.

Air velocities within the test room are shown in Figure 4. Velocities at the stall partitions are shown to range from 20 to 45 feet per minute. This is representative of all test conditions.

Illumination was provided by six 200-W incandescent lamps spaced three above the feed alley and three above the litter alley. These lights were on from 4 a.m. to 6 p.m. After October 21, 1953, switching was automatic. An additional 40-W light was centered above the litter alley and was on at all times. The light intensities in terms of foot candles are shown in Figure 5. The illumination would be considered bright for a stable and was sufficient to read fine scale divisions on instruments.

Other test room conditions were considered satisfactory for dairy barns. Stables were cleaned twice daily. Odors were present but were not acrid nor did they impart off-flavor to the milk. Fresh air brought into the air conditioning system was estimated at between 20 and 50 cfm per cow. The average carbon dioxide concentration was below 5000 ppm, the maximum allowable concentration for daily exposure for humans.[3] It was always below 6,700 ppm.

TOTAL HEAT AND MOISTURE REMOVED DAILY BY VENTILATION

The heat and moisture dissipated by the cows and their litter during each day were calculated by measuring the difference between the psychrometric properties of the test room exhaust and intake ventilating air and multiplying the difference in heat and moisture content of the air by the volume of test room intake air. This volume represented the entire air exchange as the test rooms were slightly pressurized by the intake air blower. Heat and moisture were determined from reference points of temperature and dew point. A more detailed presentation of these calculations is given in a previous bulletin.[1]

The ventilation exchange calculations were adjusted for the supplemental heat removed by the wall coils during the 10 to 40° F rhythms and for the heat added during the 40 and 50 to 110° F rhythms. The temperature difference between the intake and outlet of the wall coils, as determined by a thermopile, along with the volume of flow as determined with a rotameter, was used to calculate this adjustment. The moisture removed by the wall coils was measured through weekly measurements of frost accumulation. Adjustments were made for the heat and moisture added or removed by personnel, feed, water, milk, equipment, lights, and the daily average structural heat storage and transfer. Vapor losses to surfaces were insignificant in the daily ventilation exchange calculations.

Tables 1 through 5 present results of the daily heat and moisture exchange calculations for all diurnal tests.

The average daily test room heat dissipation decreased and the moisture dissipation increased with increasing stable temperatures. The average rate of heat dissipation decreased from 4,720 Btu/hr./1000 lb. cow during the spring 10 to 40° F tests to 2,820 Btu/hr./1000 lb. cow during the spring 70 to 100° F tests. The rate of moisture dissipation increased from .77 lb./hr./1000 lb. cow during the fall 10 to 40° F tests to 2.41 lb./hr./1000 lb. cow during the fall 70 to 100° F tests.

Generally, the heat and moisture dissipation was higher during the fall than during the spring tests. A major contributing factor for this difference was the higher total milk production of the fall group. The 10 to 40° F and 50 to 110° F diurnal results were subject to the greatest errors. This was due to instrumentation difficulties, encountered when measuring the wall-coil heat transfer during these two diurnal cycles.

Past heat and moisture dissipation data from the psychroenergetic laboratory were concerned primarily with stables at constant temperatures over prolonged periods of time. *What happens to stable heat and moisture dissipation when stable temperatures vary during the day? Are average stable temperatures satisfactory for ventilation design calculations under such conditions?* These questions were answered in the diurnal rhythm studies in the laboratory during the 1953-54 season. The 30° F or greater daily range of temperatures was recognized as extreme for any dairy stable. However, extreme conditions would certainly emphasize any ventilation exchange data differences between constant and variable conditions.

Figure 6 shows a comparison of the fall diurnal, spring diurnal and previous constant temperature stable heat dissipation. All are based on 1000-pound animal units. Theoretically, the heat dissipation should be lower under diurnal tests (with the average temperature used for comparison) than during previous constant temperature tests. This is because heat production drops at an increasing rate with rising temperatures. The depressing effect of temperatures above the average temperature would therefore overbalance the elevating effect of those temperatures below the average.

Figure 6 shows this to be true only during the spring 40 to 70° F and spring 70 to 100° F diurnals. However, except for the 10 to 40° F diurnal where considerable instrument error was involved, the differences were small. The expected overbalance was also small. Using the constant temperature data as a base, the expected overbalance would be under 7 percent of the total heat dissipation during the 70 to 100° F diurnal and under 2 percent for the 40 to 70° F diurnal. Milk production could easily account for any differences in all except the 10 to 40° F diurnal.

The total milk production of each group of cows in the diurnal tests was well above that of each of the constant temperature groups of cows at all times except during the spring 70 to 100° F diurnal (two non-lactating Jerseys replaced lactating Jerseys in the spring 70 to 100° F diurnal). In the previous constant temperature experiments two of the six cows in each group were non-lactating Brahmans. At the beginning of test periods, the production of the constant temperature group was about 24 lb. per day whereas the initial total production of the fall diurnal group averaged 41 lb. per day and the spring group 28 lb. per day. The possible importance of milk production was pointed out previously in the comparison of spring and fall data.

The individual animal metabolic heat production before and after each of the two feeding periods[4] shows relationships between diurnals and between diurnal and previous constant temperature tests that compare favorably with Figure 6. It is therefore concluded that under conditions of varying stable temperatures and within practical limits (say where the daily temperature cycle is 30° F or less), the average stable temperature for the day may be used with previous constant temperature heat dissipation data for estimating daily heat and moisture dissipation rates. Even with a 50° F daily temperature cycle wherein the maximum temperatures were 110° F, previous constant temperature daily heat dissipation data, when based on the daily average stable temperatures, would only need to be reduced 10 percent in order to be applicable to such a wide-range diurnal cycle.

Figure 7 shows a comparison of fall diurnal, spring diurnal and previous constant temperature *stable moisture dissipation.* The data are in terms of 1000-pound animal units. The same analysis was made as for the previous heat dissipation data except that moisture dissipation increases at an increasing rate with rising temperature and, theoretically, the diurnal values based on average stable temperature should be higher than constant temperature values. Figure 7 definitely shows this to be true. The differences were least in the 10 to 40° F diurnals and greatest in the 50 to 110° F diurnal. Insofar as 70° F is probably the maximum winter stable temperature and since part of the difference between diurnal and constant temperature values is due to differences in milk production, it is concluded that for winter ventilation calculations, moisture production based on constant temperature would be satisfactory for stables with variable temperatures. For stables with temperatures that exceed 70° F, perhaps to be encountered if summer air conditioning is provided, some allowance will need to be made for variable stable temperatures. The magnitude of this difference will vary with the level of herd milk production and the maximum temperatures reached.

In order to further explain the differences between stable moisture dissipation rates, correlations were made with cattle water consumption. Results showed that much of the difference between companion bars of Figure 7 could be correlated with water consumption. Therefore, much of the differences could be attributed to changing animal reactions. The rate of dissipation decreased with decreasing water consumption. For instance, with the three bars representing the 40 to 70° F diurnal, the respective consumption rates for the fall, spring, and previous constant temperature tests were 5.7, 5.4, and 4.7 lb./hr./cow. The corresponding stable moisture dissipation rates were 1.3, 1.1, and 1.0 lb./hr./cow.

The foregoing correlation suggests that perhaps stable moisture dissipation rates could be determined by multiplying cattle drinking water consumption by some constant based on stable temperature. Figure 8 provides this constant as the ratio of stable moisture dissipation to water consumption relative to stable temperature. This ratio is shown to increase from about 0.1 to 0.4 with a 5 to 90° F temperature increase. However, the scatter of points indicates that this system would involve errors as great as 50 percent. Stable moisture dissipation rates can be determined much more accurately by the correlation of stable temperatures with animal body weights.

DIURNAL CHANGES IN STABLE HEAT AND MOISTURE DISSIPATION

The heat and moisture dissipation rates during consecutive two-hour periods were calculated for several days within each diurnal. The method of calculation was the same as for the daily heat and moisture dissipation calculations. However, unlike the daily calculations where the temperatures were nearly the same at the beginning of one day as at the beginning of the next, the temperatures differed from the beginning of one two-hour test period to the beginning of the next two-hour period. This presented a problem in heat and moisture storage. Calibration tests showed that the moisture storage factor was small and could be neglected. However, heat storage proved very indeterminate for the two-hour periods.

Figure 9 shows the diurnal heat dissipation neglecting storage. The storage error can readily be recognized when one considers that minus values are impossible and that metabolic heat production never dropped below 2700 BTU/hr./cow even during the hottest part of the day. As a matter of fact, the metabolic heat production data[4] show little difference between the low temperature morning and the high temperature afternoon periods. The metabolic heat production was lower before feeding than after feeding in both. Of course, other sources of heat account for an appreciable part of the total stable heat dissipation. These other sources such as litter and rumen fermentation may have a diurnal variation.

The diurnal changes in stable moisture dissipation shown in Figure 9 agree very well with single animal vaporization rates as measured with a plastic vaporization tent.[7] In all diurnal ranges the stable moisture dissipation increased with rising temperatures and decreased with falling temperatures. However, there was a two to four-hour lag in the maximum and minimum moisture dissipation rates when compared respectively with maximum and minimum temperatures. This was also true when compared with the vapor pressure changes as they changed directly with air temperature. These results show that stable moisture dissipation responds very rapidly to changes in stable conditions.

The magnitude of the diurnal change in moisture dissipation is also shown in Figure 9. It varied with the diurnal temperature range, being least (about 0.4 lb./hr./cow) for the 10 to 40° F range and greatest (about 1.5 lb./hr./cow) for the 60 to 110° F range. This means that when designing ventilation systems for stables with less than 60° F air temperatures, diurnal changes in moisture dissipation need not be considered. However, with higher stable temperatures, varying stable temperatures will necessitate the consideration of diurnal moisture dissipation in ventilation system design. The 3.05 lb./hr./cow water dissipation rate following the 100° F temperatures of the 70 to 100° F diurnal is about 35 percent above the 2.25 lb./hr./cow average dissipation rate for the day.

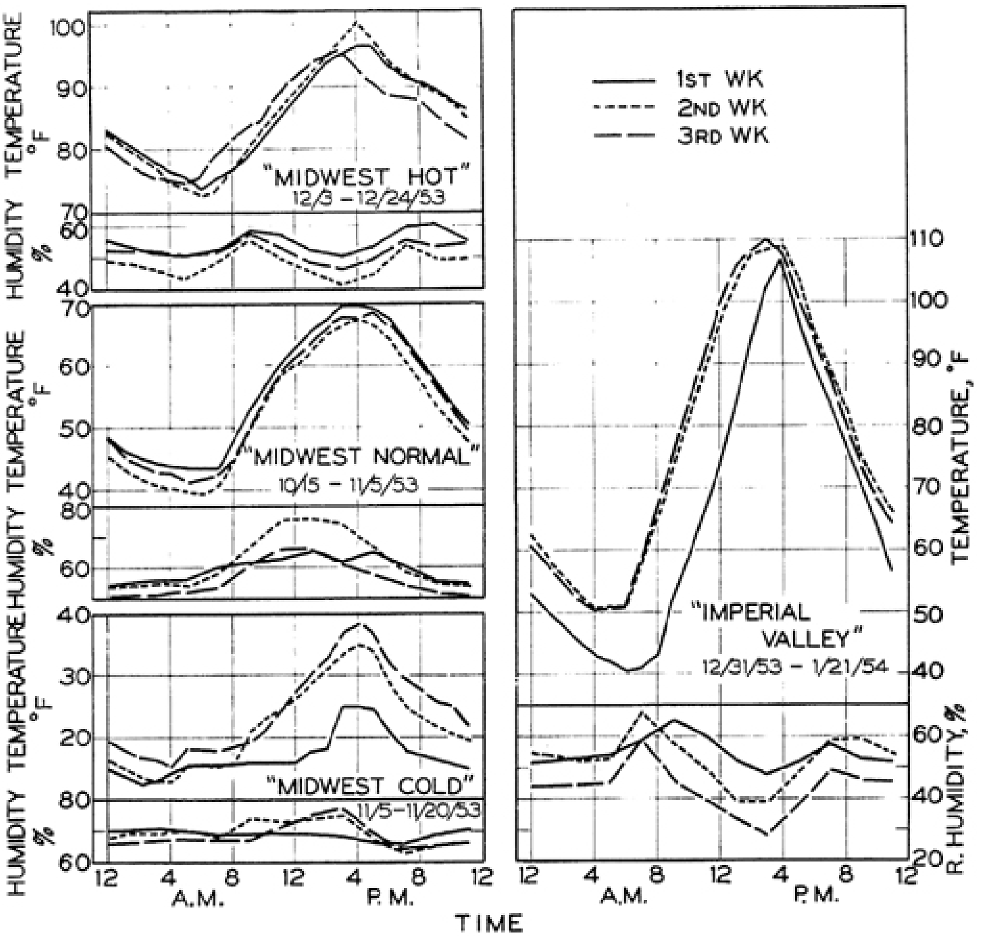


Fig. 1—The schedule of temperature and relative humidity for each week of the fall, 1953, tests. Each diurnal curve was plotted from average temperatures of one-hour periods.

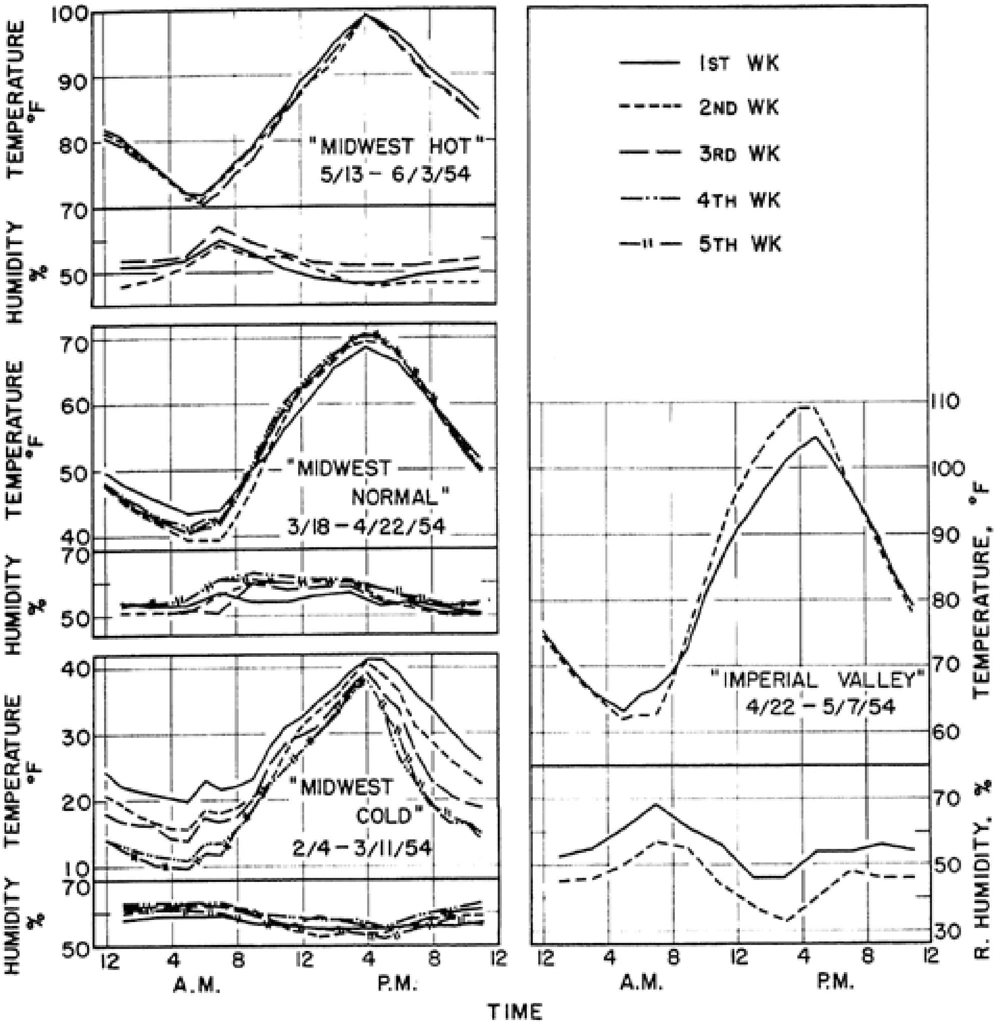


Fig. 2.—The schedule of temperature and relative humidity for each week of the spring, 1954, tests. Each diurnal curve was plotted from average temperatures of one-hour periods.

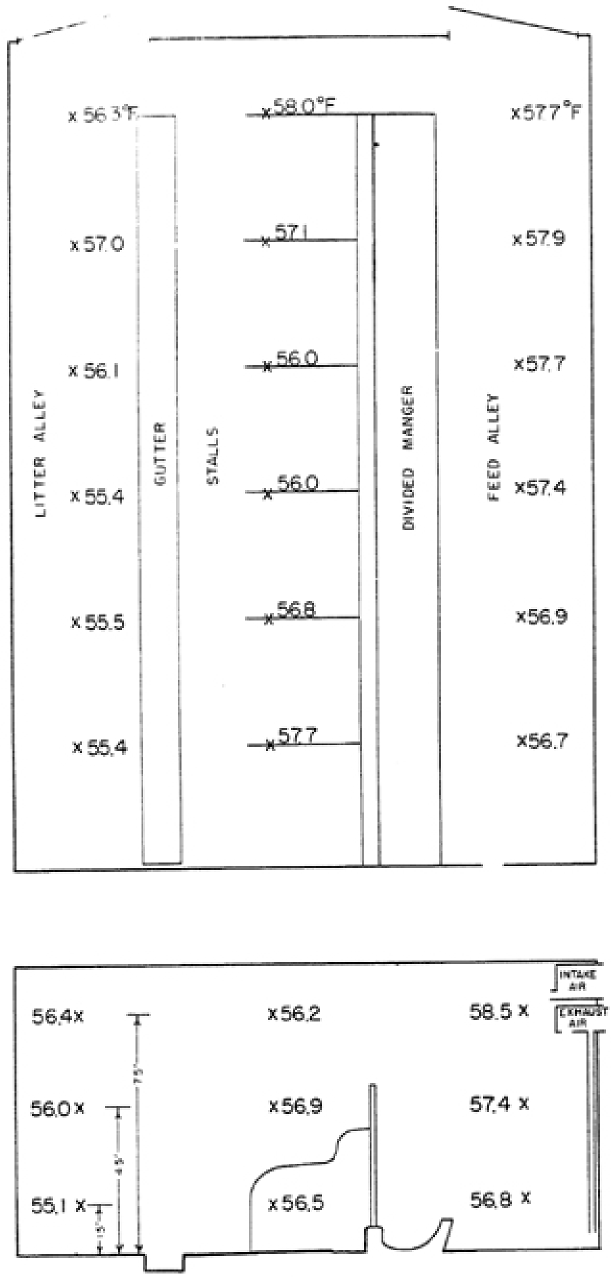
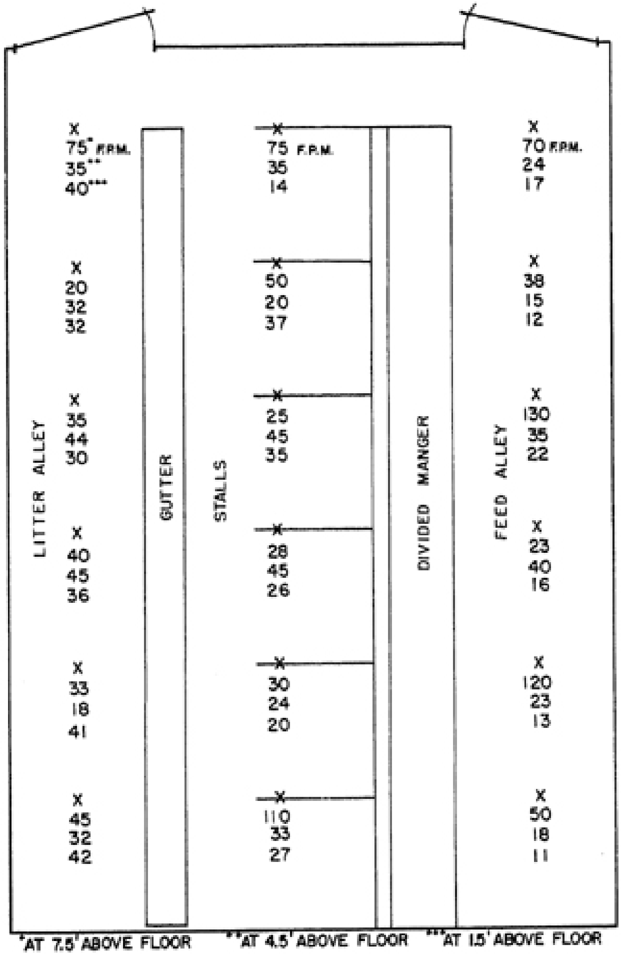


Fig. 3—An example of the air temperature variation within the test room during the mean temperature period of the 40 to 70° F diurnal temperature cycle. The values in the upper section are those measured 4.5 ft. above the floor. Those in the lower section represent average values for the six stalls. The stalls are numbered beginning with 1 at the top of the page. The exhaust air temperature during these measurements increased from 55.3° to 57.1° F. Intake temperatures ranged from 50.6° to 54.9° F.



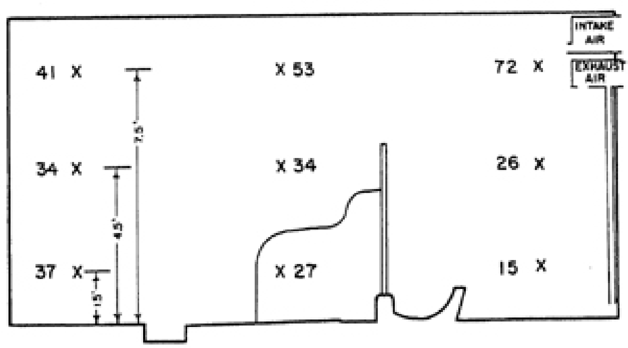


Fig. 4—Air velocities within the test room during the diurnal temperature cycles. The upper section shows the velocities at each position indicated by an "X". The three values of a set are given according to height above the floor, the upper one representing a height of 7.5 ft., the next 4.5 ft., and the lowest 1.5 ft. The lower section of the figure shows average values for the six stalls. The velocity around the cows averaged about 30 feet per minute.

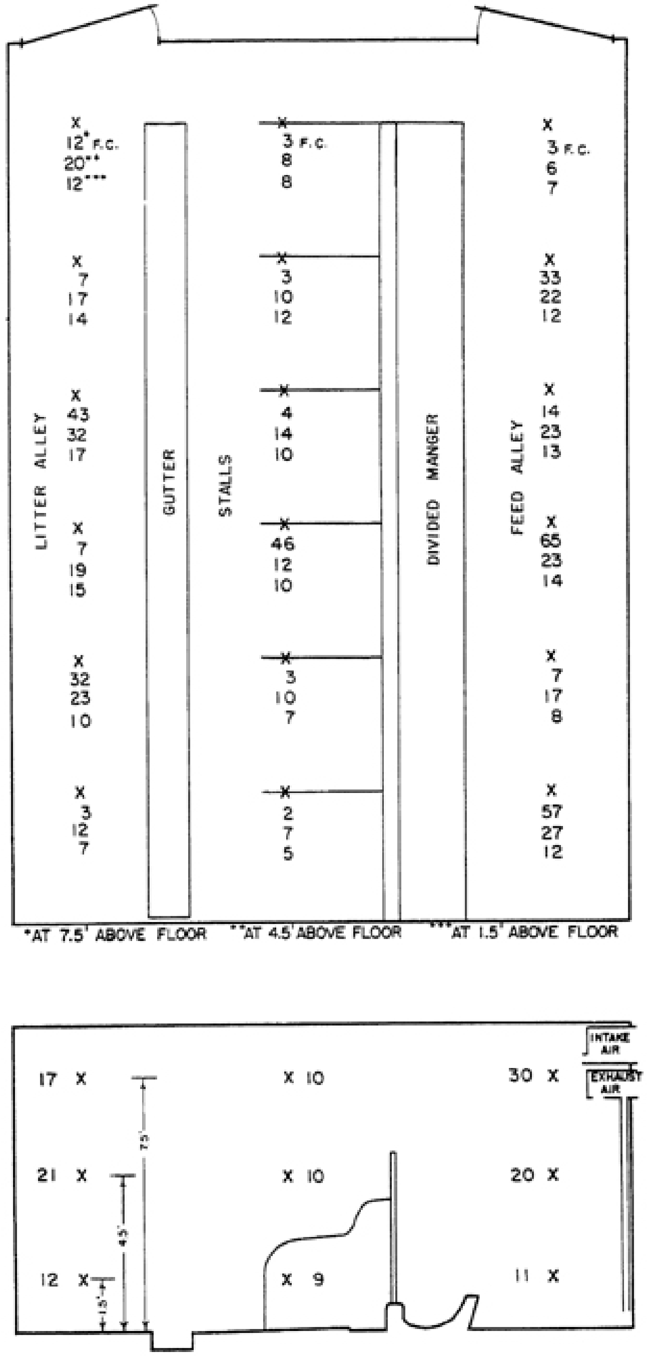


Fig. 5—Light intensities (in foot candles) in the test room during the diurnal temperature cycle. The measuring stations are designated by an "X". There was sufficient light near the floor to read the fine graduations on instruments.

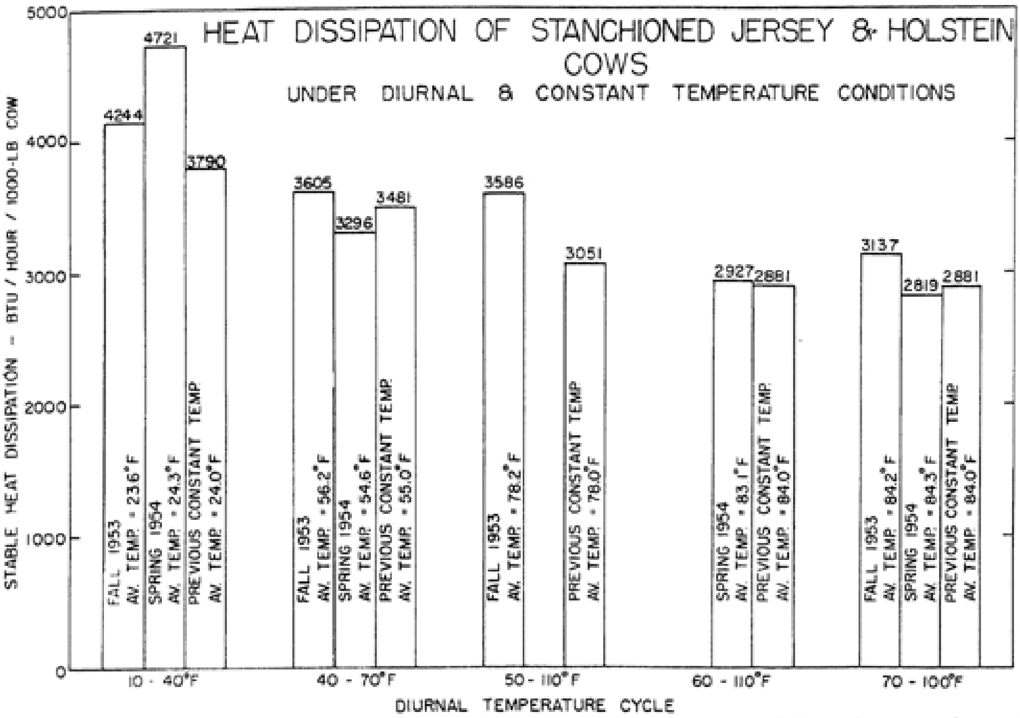


Fig. 6—Average daily rate of stable heat dissipation during the fall and spring diurnal test experiments as compared with previous constant temperature tests. The average air temperature of each diurnal was used as a basis for comparison. The values above each bar are their respective rates in terms of BTU/hr./1000 lb. cow.

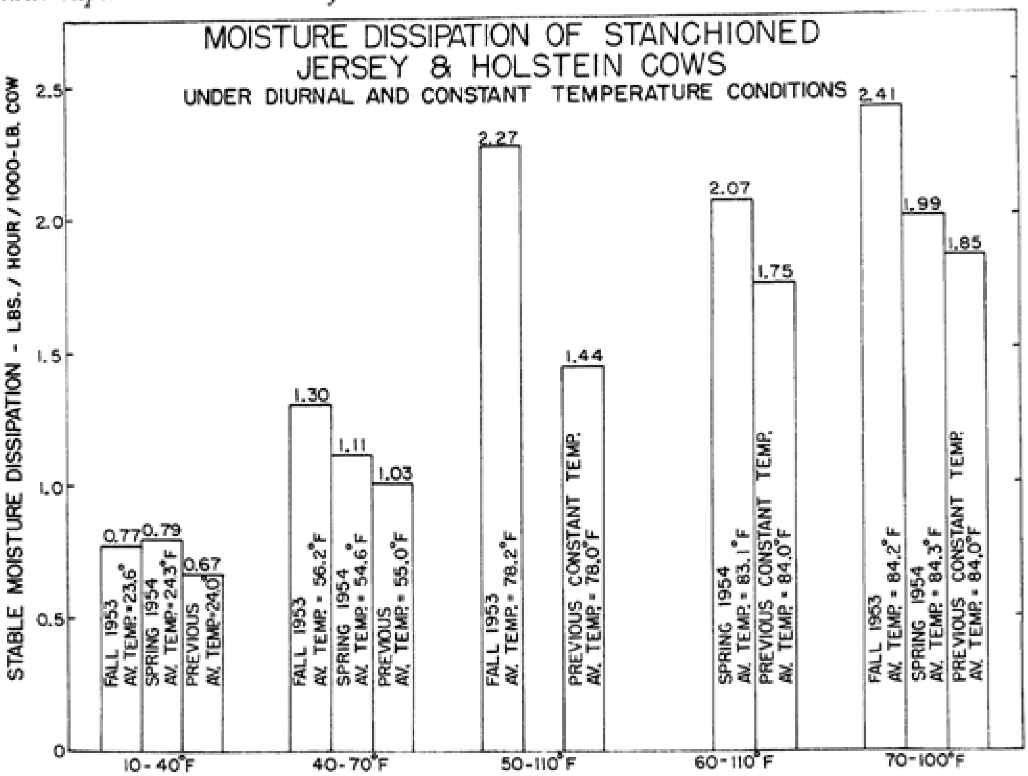


Fig. 7—Average daily rate of stable moisture dissipation during the fall and spring diurnal test experiments compared with previous constant temperature tests. The average air temperature of each diurnal was used as a basis for comparison. The values above each bar are the respective rates in terms of lb./hr./1000 lb. cow.

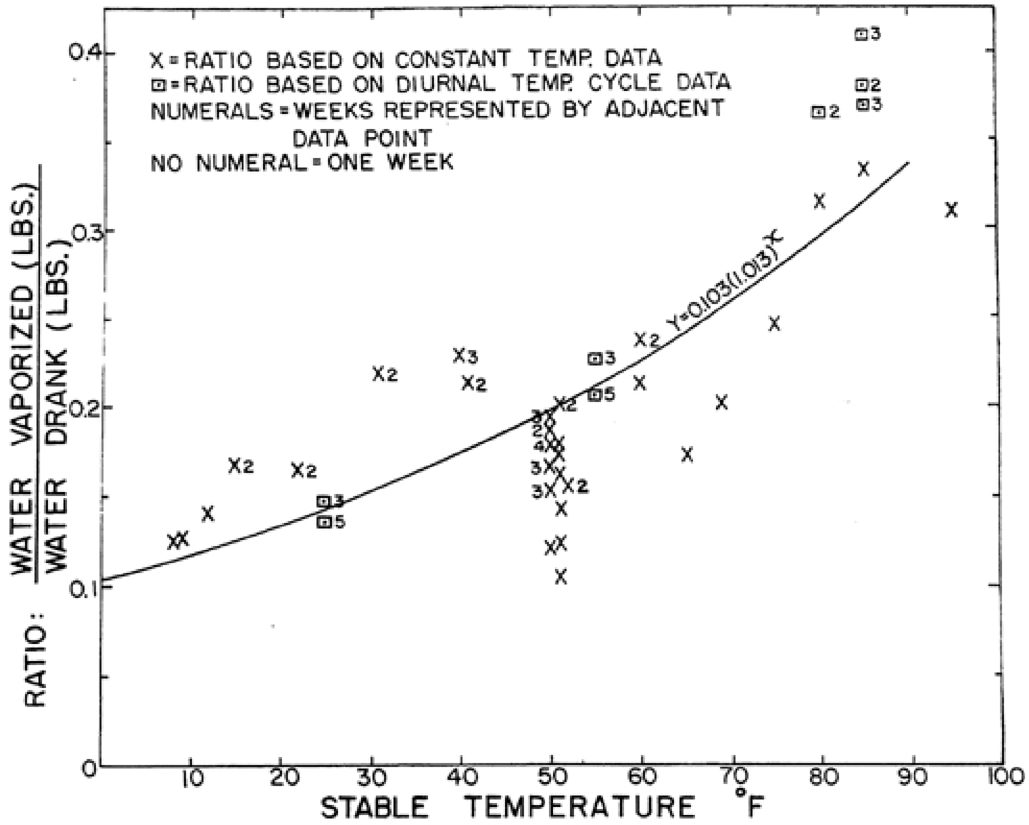


Fig. 8—The ratio of water vaporized in the test rooms to water the cows drank, relative to test temperature. This chart represents a means of estimating ventilation moisture loads where stable temperatures and water consumption are known. The curve was fitted by means of least squares with weighted value given to each point according to time represented. Constant temperature data were taken from previous reports. [1, 5, 6]

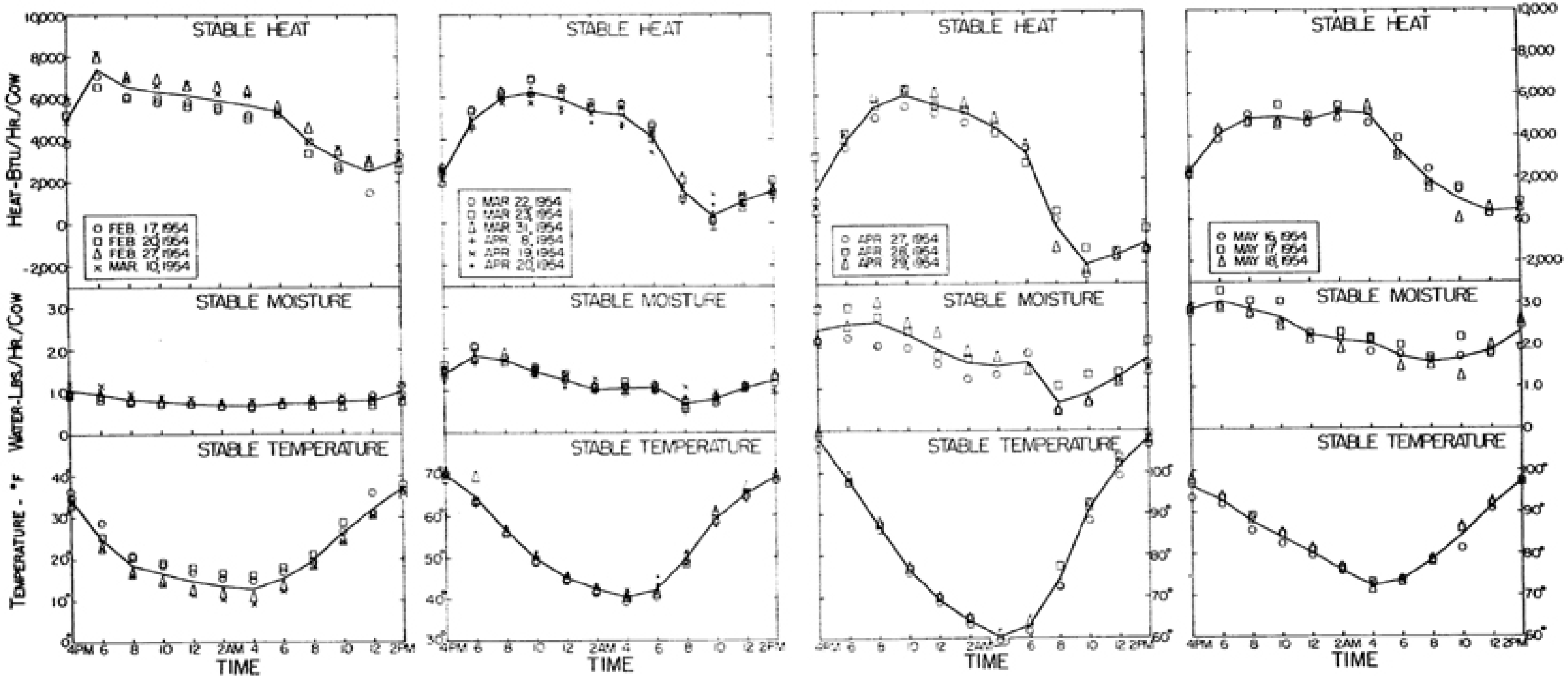


Fig. 9—Variation in the rate of stable heat and moisture dissipation within each diurnal. Each point represents the average rate over a two-hour period. The time represents the mid-point of each two-hour period. The data on stable heat dissipation do not allow for structural heat storage, an indeterminate factor in the two-hour by two-hour calculations.

TABLE 1 -- DAILY STABLE HEAT & MOISTURE DISSIPATION RATES WITH CORRESPONDING ENVIRONMENTAL CONDITIONS

Date	Heat Btu/cow/hr.	Water Lbs./cow/hr.	Av.Temp. °F	Max.Temp. °F	Min.Temp. °F	Rel.Hum. %
		Fall, 1953, 40-70°F Diurnal Rhythm				
Oct. 15	5081*	1.37	62.4	70.6	42.4	56
16	5277*	1.42	62.2	70.0	41.1	61
17	3867	1.44	58.0	71.3	43.0	59
18	3811	1.43	57.4	71.4	42.4	58
19	3749	1.32	56.6	69.4	42.4	55
20	3996	1.32	56.8	68.7	43.5	58
21	3877	1.28	55.0	69.4	40.1	60
22	3840	1.39	54.6	71.2	40.0	62
23	3942	1.36	54.5	70.4	38.1	64
24	3823	1.30	54.0	67.6	38.7	64
25	3986	1.45	54.2	69.5	38.1	61
26	3597	1.24	53.6	67.8	37.7	60
27	3626	1.25	53.6	67.9	37.6	63
28	3641	1.29	54.2	68.0	39.3	61
29	3517	1.27	55.0	70.1	38.5	59
30	3490	1.48	58.0	71.1	41.9	55
31	3686	1.34	56.0	68.5	39.9	55
Nov. 1	3577	1.34	56.2	69.5	39.5	55
2	3673	1.41	56.2	70.1	42.1	54
3	3912	1.43	55.6	69.0	41.1	58
4	3934	1.53	56.2	69.5	43.3	59
Av. (3 wk.)	3774	1.37	56.2	69.6	40.5	59
		Fall, 1953, 10-40°F Diurnal Rhythm				
Nov. 5	5132*	.90	31.2*	68.8*	19.1*	61
6	4604	.77	23.4	25.8	17.1	67
7	3935	.71	20.1	25.7	15.6	67
8	3654	.68	16.4	28.8	9.8	70
9	3895	.66	11.0	13.0	6.0	72
10	4301	.76	14.4	16.1	9.4	74
11	4637	.82	17.0	31.6	8.7	79
12	4754	.77	20.0	34.8	10.0	77
13	4322	.74	24.8	39.1	11.6	71
14	4220	.70	23.4	35.0	12.3	68
15	4100	.80	25.6	37.9	12.6	67
16	4063	.79	26.8	37.8	13.8	69
17	4588	.76	24.4	37.9	12.5	70
18	4763	.86	27.2	37.9	16.6	70
19	4651	.84	30.6	39.3	19.9	70
20	4145	.83	26.0	39.4	12.5	70
21	4051	.78	23.9	38.0	11.9	69
22	4206	.81	27.4	38.0	18.0	67
23	4291	.83	25.4	38.1	14.5	67
24	4758	1.00	24.6	38.9	12.1	68
25	4512	.92	24.8	38.0	11.4	68
Av. (3 wk.)	4315	.80	22.6	33.1	13.1	69

*Data not included in average values.

TABLE 2 -- DAILY STABLE HEAT & MOISTURE DISSIPATION RATES WITH CORRESPONDING ENVIRONMENTAL CONDITIONS

Date	Heat Btu/cow/hr.	Water Lbs./cow/hr.	Av.Temp. °F	Max.Temp. °F	Min.Temp. °F	Rel.Hum. %
		Fall, 1953, 70-100°F Diurnal Rhythm				
Dec. 3	3222	1.18*	90.0	95.5	77.2	56
4	----	----	83.4	97.6	70.3	59
5	2275*	1.02*	83.5	100.0	70.2	56
6	----	----	83.4	98.9	70.0	55
7	1871*	2.19	86.2	99.4	75.2	52
8	3359	2.40	83.2	100.0	68.6	51
9	3539	2.48	84.2	98.0	76.1	54
10	2648	2.30	82.0	100.6	65.6	52
11	2365	2.48	86.0	101.0	74.6	47
12	2443	2.31	83.5	101.2	70.4	49
13	2864	2.44	83.6	100.9	70.6	50
14	2694	2.51	84.4	101.2	70.0	46
15	3159	2.53	85.6	99.4	78.3	54
16	3300	2.43	83.6	101.1	70.6	46
17	3251	2.33	83.6	98.3	71.4	48
18	----	----	82.6	100.1	72.6	50
19	----	2.53	84.4	101.0	74.3	53
20	3372	2.47	87.6	98.6	79.6	56
21	3110	2.25	82.0	99.1	69.5	52
22	3036	2.22	82.6	94.5	75.1	54
23	3050	2.40	83.4	95.0	78.3	56
Av. (3 wk.)	3106	2.38	84.2	99.1	72.8	52
		Fall, 1953-54, 40-110°F Diurnal Rhythm				
Dec.31	----	1.92*	68.6	108.5	40.7	53
Jan. 1, '54	----	1.61*	63.0	110.3	39.5	54
2	----	1.81*	64.6	107.8	39.3	53
3	1019*	1.88*	66.2	107.9	39.2	52
4	1659	1.92	65.2	107.7	39.4	54
5	2135	2.00	66.4	108.2	40.7	55
6	2042	2.38	68.8	108.5	41.9	59
Av. (1 wk.)	1945	2.10	66.1	108.4	40.1	54
		Fall, 1953-54, 50-110°F Diurnal Rhythm				
Jan. 7	1231*	2.73	79.0	111.9	50.0	57
8	2857	2.83	77.8	111.0	51.4	55
9	3534	2.52	76.2	110.0	48.9	55
10	4161	2.54	77.4	110.4	48.6	53
11	3866	2.46	76.6	110.6	48.7	52
12	4119	2.66	79.0	110.5	50.0	51
13	3951	2.22	76.1	110.9	49.5	45
14	3193	2.13	76.8	110.0	50.5	44
15	3566	2.22	80.2	109.9	48.2	43
16	3378	2.10	78.4	109.5	47.6	41
17	3637	2.20	79.2	111.5	48.0	42
18	3301	2.24	80.6	111.4	51.6	43
19	3525	2.31	79.6	110.6	51.4	44
20	4095	2.39	79.0	110.4	49.4	45
Av. (2 wk.)	3638	2.40	78.3	110.7	49.6	48

*Data not included in average values.

TABLE 3 -- DAILY STABLE HEAT & MOISTURE DISSIPATION RATES WITH CORRESPONDING ENVIRONMENTAL CONDITIONS

Date	Heat Btu/cow/hr.	Water Lbs./cow/hr.	Av.Temp. ^{o}F	Max.Temp. ^{o}F	Min.Temp. ^{o}F	Rel.Hum. %
		Spring, 1954, 10-40^{o}F Diurnal Rhythm				
Feb. 4	5795*	.78	30.0	38.6	20.5	58
5	5169*	.88	30.8	40.0	15.3	55
6	5371	.81	31.1	40.8	16.9	57
7	4807	.78	30.0	38.9	14.8	58
8	4838	.73	27.5	38.6	11.0	61
9	4857	.87	29.2	41.4	14.7	56
10	4278	.78	28.0	38.6	11.5	59
11	3923	.80	27.8	39.5	10.2	58
12	4519	.65	25.7	43.0	12.1	56
13	4038	.82	26.8	43.9	17.1	57
14	4244	.82	27.8	43.9	20.7	57
15	4599	.80	26.2	43.5	15.7	60
16	4666	.79	25.0	45.0	13.2	61
17	4713	.82	24.0	41.8	12.4	63
18	4564	.81	24.0	40.0	13.6	59
19	----	----	25.8	40.0	15.2	58
20	4772	.78	23.8	39.7	13.9	60
21	4868	.74	23.2	40.4	12.4	61
22	4623	.78	24.2	39.6	13.3	60
23	4989	.76	23.4	40.0	10.8	59
24	4746	.86	25.2	41.0	15.1	60
25	5440	.84	20.8	39.5	9.6	62
26	----	----	21.0	39.5	10.2	61
27	5527	.82	20.3	38.9	9.1	63
28	5498	.81	23.0	39.6	14.5	61
Mar. 1	5546	.83	20.2	39.6	10.9	60
2	4954	.81	19.3	40.2	7.3	59
3	5157	.81	21.4	41.6	11.6	60
4	5328	.86	22.6	40.5	13.6	57
5	----	----	19.9	39.4	8.2	57
6	5167	.82	20.2	39.0	8.4	57
7	5054	.81	20.8	39.1	8.7	57
8	6348*	1.13	20.8	43.1	8.4	57
9	5383	.93	20.3	38.5	8.4	58
10	5608	.95	19.9	38.6	8.4	62
Av. (5 wk.)	4901	.82	24.3	40.5	12.5	59

*Data not included in average values.

TABLE 4 -- DAILY STABLE HEAT & MOISTURE DISSIPATION RATES WITH CORRESPONDING ENVIRONMENTAL CONDITIONS

Date	Heat Btu/cow/hr.	Water Lbs./cow/hr.	Av. Temp. °F	Max. Temp. °F	Min. Temp. °F	Rel. Hum. %
		Spring, 1954, 40-70°F Diurnal Rhythm				
Mar. 18	4413	1.50	54.1	72.0	41.3	56
19	----	----	63.1	70.5	54.5	56
20	4265	1.33	51.6	67.0	38.2	51
21	4070	1.23	52.2	69.4	38.1	56
22	3904	1.30	53.5	70.0	38.3	54
23	3722	1.28	53.7	71.2	38.8	55
24	3898	1.47	56.4	70.0	46.3	55
25	3924	1.49	53.8	70.3	38.7	56
26	----	----	54.8	70.5	38.6	54
27	4045	1.48	54.1	69.9	39.3	55
28	4180	1.58	54.0	70.0	38.7	54
29	3622	1.29	53.6	69.8	38.2	55
30	3548	1.30	53.8	70.7	38.3	54
31	3566	1.34	54.8	71.4	39.6	55
Apr. 1	3564	1.38	55.9	70.8	41.5	54
2	----	----	55.1	70.5	39.8	51
3	3719	1.30	54.9	70.5	39.6	53
4	3590	1.22	54.7	71.0	40.0	53
5	3708	1.19	54.2	70.0	40.4	55
6	3279	1.02	55.0	70.1	41.2	56
7	3463	1.09	54.7	70.5	39.7	56
8	3512	1.26	54.6	70.5	39.5	55
9	----	----	55.1	70.6	40.0	55
10	----	----	55.1	70.5	40.4	57
11	----	----	54.5	70.4	40.0	59
12	3278	1.18	57.4	70.5	46.3	56
13	3741	1.19	55.4	70.9	40.0	57
14	2954	.93	55.4	70.5	41.4	59
15	3539	.94	54.8	70.5	39.8	58
16	----	----	55.0	70.6	39.9	56
17	----	----	55.3	70.7	40.2	56
18	----	----	56.0	70.5	41.9	56
19	3726	1.27	55.1	70.6	40.5	57
20	3862	1.26	55.0	70.5	40.3	57
21	----	----	54.6	75.8	40.3	58
Av. (5 wk.)	3699	1.25	54.6	70.4	40.3	56

TABLE 5 -- DAILY STABLE HEAT & MOISTURE DISSIPATION RATES WITH CORRESPONDING ENVIRONMENTAL CONDITIONS

Date	Heat Btu/cow/hr.	Water Lbs./cow/hr.	Av.Temp. °F	Max.Temp. °F	Min.Temp. °F	Rel.Hum. %
		Spring, 1954, 60-110°F Diurnal Rhythm				
Apr. 22	3120	1.73	75.7	102.0	60.0	69
23	3832	2.89	85.0	105.1	66.4	53
24	3624	2.20	77.3	104.1	60.6	60
25	2885	1.91	80.6	105.6	65.0	56
26	2904	2.06	82.6	108.2	61.7	53
27	2700	1.83	82.2	109.6	58.9	47
28	3444	2.37	85.4	111.5	63.7	49
29	2743	2.01	84.0	109.5	61.4	52
30	3069	2.17	84.5	109.9	61.3	47
May 1	3138	2.21	82.8	109.8	63.0	49
2	3176	2.31	86.2	109.5	63.8	47
3	3121	2.21	82.9	107.7	62.4	39
4	3232	2.42	84.0	109.6	60.4	43
5	3441	2.57	83.7	109.7	60.5	47
6	3139	2.47	85.8	110.9	60.6	43
7	----	1.95	74.4	109.6	58.0	46
Av. (2 wk.)	3169	2.24	82.7	108.6	61.9	49
		Spring, 1954, 60°F Diurnal Rhythm				
May 8	3648	1.43	61.5	66.6	59.4	55
9	3598	1.38	61.0	63.7	59.2	58
10	3519	1.42	60.8	63.7	59.2	60
11	3504	1.23	58.9	59.4	58.1	61
12	3817	1.59	59.1	60.8	58.4	60
Av. (1 wk.)	3617	1.41	60.3	62.8	58.9	59
		Spring, 1954, 70-100°F Diurnal Rhythm				
May 13	----	1.82	77.5	101.0	64.0	56
14	3240	2.57	84.7	101.1	71.7	47
15	3395	2.46	84.4	100.9	71.7	52
16	3228	2.17	83.6	101.6	72.1	56
17	3322	2.40	85.1	101.3	72.1	51
18	3223	2.31	85.2	100.5	70.4	49
19	2995	2.19	84.5	100.4	70.0	44
20	2798	2.08	84.1	100.2	70.0	43
21	2469	1.91	83.7	100.1	70.1	45
22	2829	1.87	83.6	98.6	70.4	52
23	2747	1.89	84.8	100.5	70.4	54
24	2619	1.86	84.5	100.1	69.9	50
25	3050	2.21	84.5	99.1	76.3	52
26	2811	2.09	84.3	100.0	69.8	54
27	3157	2.11	84.6	100.5	69.9	57
28	2841	1.96	84.1	100.1	69.4	55
29	2707	1.71	85.2	100.0	72.7	54
30	3038	1.97	84.7	99.8	70.5	58
31	2883	1.97	84.3	100.2	69.8	54
June 1	2923	1.91	82.9	100.0	68.4	52
2	2648	1.91	82.8	100.0	69.4	54
Av. (3 wk.)	2960	2.09	84.3	100.3	70.8	52

TABLE 6 -- MILK PRODUCTION, FEED AND WATER CONSUMPTION, AND BODY WEIGHTS OF CATTLE DURING EACH TEST PERIOD*

Temperature Condition	Milk Production Lbs./Day/Cow	TDN Consumption Lbs./Day/Cow	Water Consumption Gals./Day/Cow	Body Weight Lbs./Cow
		Fall 1953		
Adjustment (60°)	41.1	17.5	----	1052
"Midwest Normal" (40° to 70°)	40.8	19.7	16.4	1047
"Midwest Cold" (10° to 40°)	35.6	18.4	16.3	1032
Adjustment (60°)	36.7	18.3	18.9	1028
"Midwest Hot" (70° to 100°)	30.6	16.1	16.9	990
Adjustment (60°)	33.2	17.9	17.1	996
"Imperial Valley" (40° or 50° to 110°)	32.0	18.7	17.8	1010
Adjustment (60°)	31.7	18.8	16.6	1020
		Spring 1954		
Adjustment (60°)	30.1	18.8	16.9	1031
"Midwest Cold" (10° to 40°)	26.3	20.3	15.4	1037
Adjustment (10° to 70°)	24.1**	21.7**	16.8**	1131
"Midwest Normal" (40° to 70°)	23.9**	21.0**	15.4**	1121
"Imperial Valley" (60° to 110°)	17.5**	15.6**	15.6**	1084
Adjustment (60°)	18.4**	16.7**	13.9**	1059
"Midwest Hot" (70° to 100°)	18.1**	16.3**	15.4**	1049

*Condensed from Brody, Samuel, et al, "Milk Production, Feed and Water Consumption, and Body Weight of Jersey and Holstein Cows in Relation to Several Diurnal Temperature Rhythms," University of Missouri Agricultural Experiment Station Research Bulletin 578, 1955.

**Averages are based on lactating cows only.

TABLE 7 -- TEMPERATURE VARIATION WITHIN THE TEST ROOM*

Station	Feet Above Floor	Diurnal Rhythm 10-40	40-70	70-100	60-110
	Low Temperature Period of Rhythm				
Feed Alley	1.5	11.9	43.8	72.3	58.4
	4.5	12.2	42.0	71.8	58.5
	7.5	10.2	39.4	69.3	56.0
Cow Stall	1.5	9.7	40.8	70.1	57.0
	4.5	10.3	40.1	69.5	56.9
	7.5	9.6	39.0	68.6	55.8
Litter Alley	1.5	9.3	38.8	69.8	56.3
	4.5	9.4	39.1	68.9	56.7
	7.5	10.0	39.8	68.8	57.1
Exhaust Air		13°F	42-42.3°F	71-72°F	59-60°F
	Medium Temperature Period of Rhythm				
Feed Alley	1.5	23.0	56.8	83.7	89.2
	4.5	24.2	57.4	84.9	91.4
	7.5	23.6	58.5	85.5	94.2
Cow Stall	1.5	22.4	56.5	83.5	88.5
	4.5	23.3	56.9	83.0	90.4
	7.5	23.2	56.2	83.5	91.7
Litter Alley	1.5	21.2	55.1	84.1	90.2
	4.5	22.4	56.0	84.9	91.4
	7.5	23.5	56.4	84.9	92.2
Exhaust Air		25°F	55.3-57.1°F	83.4-84.2°F	87.2-89.4°F
	High Temperature Period of Rhythm				
Feed Alley	1.5	38.5	69.3	97.3	108.6
	4.5	39.2	69.6	98.6	111.7
	7.5	39.7	68.3	100.5	114.9
Cow Stall	1.5	39.3	69.6	97.9	107.7
	4.5	39.8	71.0	99.6	113.6
	7.5	38.9	70.9	100.2	115.9
Litter Alley	1.5	35.0	68.7	99.8	110.4
	4.5	35.5	68.8	100.0	114.0
	7.5	36.3	69.1	100.1	115.2
Exhaust Air		37-39°F	68-68.6°F	98.3°F	110.2-110.5°F

*Each temperature shown represents the average of seven measurements, one for each stall.

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SUMMARY

Ventilation requirements with variable stable temperatures such as encountered during diurnal temperature cycles of 10 to 40, 40 to 70, 70 to 100 and 50 or 60 to 110° F were determined. The rate of stable heat dissipation dropped and the rate of stable moisture dissipation increased with increasing stable temperatures. This concurs with previous constant temperature results.

The average temperature of the diurnal cycle was satisfactory for use with previous constant temperature ventilation exchange data in order to predict most of the daily heat and moisture dissipation rates. The diurnal values were generally above the constant temperature values. Only during the extreme range, 50 to 110° F cycle, did the daily rate of moisture dissipation differ notably from that of previous constant temperature data. The differences between the rates of heat dissipation for the diurnal and for the constant temperature test were greatest for the 10 to 40° F cycle. However, instrument errors during the 10 to 40° F cycle may have produced this result.

Air-conditioning requirements from one two-hour period to the next within a day were found to change. Moisture dissipation rates changed greatest within the high temperature diurnals and least within the low temperature diurnals. The moisture load increased about 35 percent over the daily average moisture dissipation rate during the two-hour period following the 100° F temperatures of the 70 to 100° F cycle and even more during the 60 to 110° F cycle. This would mean that added ventilation or dehumidifying equipment would be necessary at certain times of the day in stables having temperature cycles such as these two high temperature diurnal rhythms if a low stable relative humidity was to be maintained.

Structural heat storage was found to be of major importance in determining ventilation requirements in stables with varying temperatures. It made hour-to-hour heat dissipation calculations impractical.