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Environmental Physiology And Shelter Engineering

With Special Reference to Domestic Animals

XXIV. Effect of Temperature Upon Heat Exchanges In Dairy Barns

H. J. Thompson

Missouri Agricultural Experiment Station and the United States Department of Agriculture Cooperating
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SUMMARY

This report summarizes heat and moisture exchange data relative to ventilation for the initial "temperature-effect" studies. A fairly detailed description is given of the animal shelter laboratory, its instrumentation, and method of use.

Test room total heat values reported were calculated by adjusting for extraneous sources. Extraneous heat sources are lights, structural conduction, and temperature differences between water, feed, and bedding added, and milk and litter removed from the test rooms. Therefore, total heat values reported come primarily from the sum of animal sensible and latent heats. Such values are from 10 to 20 percent higher than metabolic total heat measurements on these same animals. Vaporized moisture values reported include vaporization from test room surfaces as well as vaporization from animals.

With temperature declining from 80°F to 10°F total heat production increases about 20 percent. Moisture production decreases with decreasing temperatures in this same temperature range. These facts suggest that from a winter ventilation standpoint there is an advantage in a relatively low stable air temperature.

At a constant barn temperature of 50° for the 24-hour day, the maximum heat production (which occurs after the evening feeding) is about 18 percent higher than the minimum heat production (during the morning hours).

Acknowledgments

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H. J. Thompson is Resident Agricultural Engineer, BPISAE

Report on Department of Agricultural Engineering research project number 6 entitled "Climatic Factors."

XXIV. Effect of Temperature Upon Heat Exchanges In Dairy Barns

(A Report on Ventilation Studies in the Psychroenergetic Laboratory)

H. J. THOMPSON

Better dairy building designs are the objective of this research. The rise in productivity of dairy cows, demands for disease-free herds and high quality milk, and need to lower costs all contribute to the urgency of this problem. Manufacturers of improved construction materials and barn equipment are anxious to obtain scientific data to help adapt their products to farm needs.

Improvement of dairy barns requires detailed knowledge of the environments in which cows are healthiest and can convert feed into milk most efficiently. Agricultural engineers recognize also that for scientific design of a dairy barn ventilation system, it is necessary to know overall rates at which heat and moisture are released inside the building. [1,2]

In barn design as early as 1920 there were attempts to use data on heat and moisture exchange obtained in basal metabolism studies performed under laboratory conditions, usually at temperatures of 70 to 80°F.[3] However, the data were not in accord with those obtained under actual conditions in the dairy stable. [4,5,6] Forbes, *et al.,* [7] (1926) discussed the theoretical effects of environmental temperature on heat production of cattle. In 1940, Brody[8] discussed before the American Society of Agricultural Engineers, a generalized diagram representing heat production as a function of ambient temperature with special reference to the effect of species, body size, age, productive

[1]King, F. H., Ventilation for Dwellings, Rural Schools, and Stables, 1908.

[2]Clarkson, W. B. ; Smith, L. J.; and Strahan, J. L.; "Report of Committee on Barn Ventilation," transactions of the American Society of Agricultural Engineers, 13:176, 1919.

[3]Armsby, H. P., and Kriss, M., "Some Fundamentals of Stable Ventilation," Journal of Agr. Research, Vol. 21, No. 5, June 1, 1921. Reprinted in Agricultural Engineering 2:151-155 and 2:174-177, July and August, 1921.

[4]Kelley, M. A. R., "Test of a Fan System of Ventilation for Dairy Barns," Agricultural Engineering, 2:203-206, October 1921.

[5]Strahan, J. L., "The Design of Outtake Flues for Stable Ventilation," Agricultural Engineering, 2:207-209, October 1921.

[6]Clyde, A. W., "Barn Ventilation with Electric Fans,' Agricultural Engineering, 12:9-14, January 1931.

[7]Forbes, E. B., Braman, W. W., Kriss, M., et al., "The Influence of the Environmental Temperature on the Heat Production of Cattle," Journal of Agr. Research, 33: 579-589, 1926.

[8]Brody, S., "Reactions of Animals to Environmental Temperature, Humidity, and Air Movement," Agricultural Engineering, 21:265-268, July 1940.

level, acclimatization, wind, humidity, and related factors. This diagram is discussed in detail in relation to the present research in the first bulletin of this series.[9] However, prior to 1947 no research data had been made available on heat and moisture exchanges under typical dairy stable conditions.

In 1947, the present Psychroenergetic Laboratory at Columbia, Mo., was constructed and equipped to provide means of measuring under controlled conditions the effects of temperature, humidity, air movement, light, and other factors upon heat exchange, moisture vaporization, feed and water consumption, and the production and growth of dairy cattle or other farm animals. In this laboratory the animals are housed, fed, and cared for about as they are on the ordinary farm, with comparatively little interference from laboratory procedures.

FACILITIES AND INSTRUMENTATION

The outer shell of the laboratory is a rigid frame galvanized steel building. It includes two identical test rooms (18′ x 26′), a small work room adjoining each test room, an equipment room for climatic control machinery and a combination office and instrument room. Both test room and outer walls are insulated so work room spaces as well as test rooms can be conditioned. Figure 1 is a cutaway view showing the general layout. Figure 2 is a plan view, Figure 3 is a cross section of test room II and Figure 4 shows the interior of test room II.

Basic air-conditioning equipment consists of three cooling systems and two heating systems. All systems are interconnected for maximum flexibility in servicing the two test rooms. Each cooling system has two 5-ton Freon 12 compressors and each heating system a gas fired boiler with a capacity of about 100,000 Btu per hr. As the installation grew, the equipment room proved much too small, making it necessary to install new equipment in other parts of the laboratory.

Initially psychrometric conditions within the work rooms were maintained by iron pipe coils on the outer walls. Later a direct expansion, Freon 12, forced air, finned, copper tube unit equipped with a cacium chloride ($CaCl_2$) defrosting spray functioned as the cooler for the fresh air preconditioner (Figure 5). In addition this unit furnished cooling for work room II. A prime surface (i.e., without fins), copper tube heating coil, equipped with a water spray, furnished vaporized moisture and(or) additional heat for preconditioning in work room II.

Figure 5 also indicates the method used to condition air supplied directly to the test rooms. This supply-air furnished the primary means for removing heat and moisture from the test rooms as the wall coils inside the test room (Figure 3) were not used. The basic functions of the supply-air conditioners

[9]Brody, S., "Physiological Backgrounds," Univ. Missouri Agr. Expt. Sta. Res. Bul. 423, 1948.

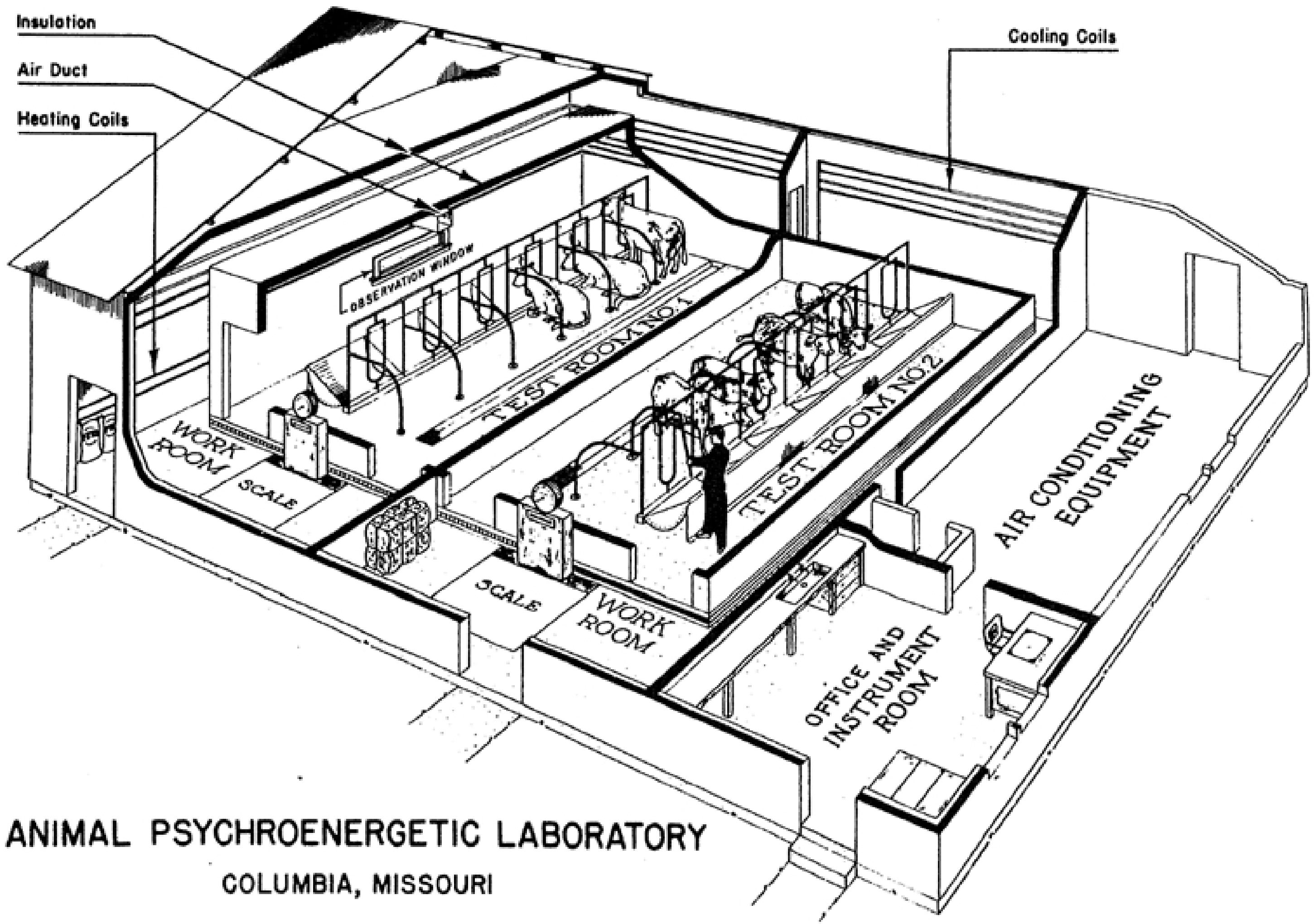

Fig. 1—This structure is also referred to as a climatic laboratory. The basic arrangement shown was used for all temperature studies reported in this bulletin.

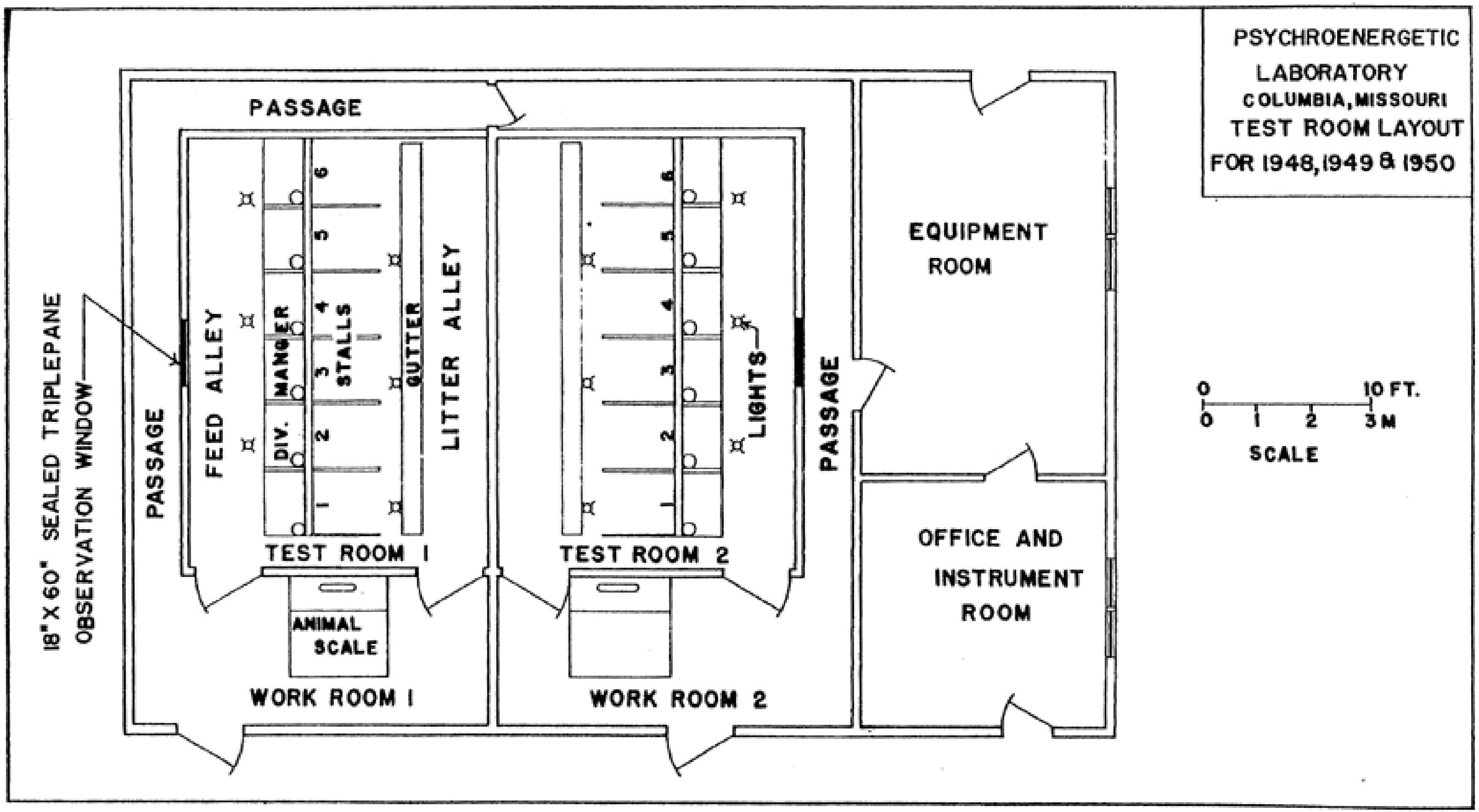

Fig. 2—Floor plan of laboratory.

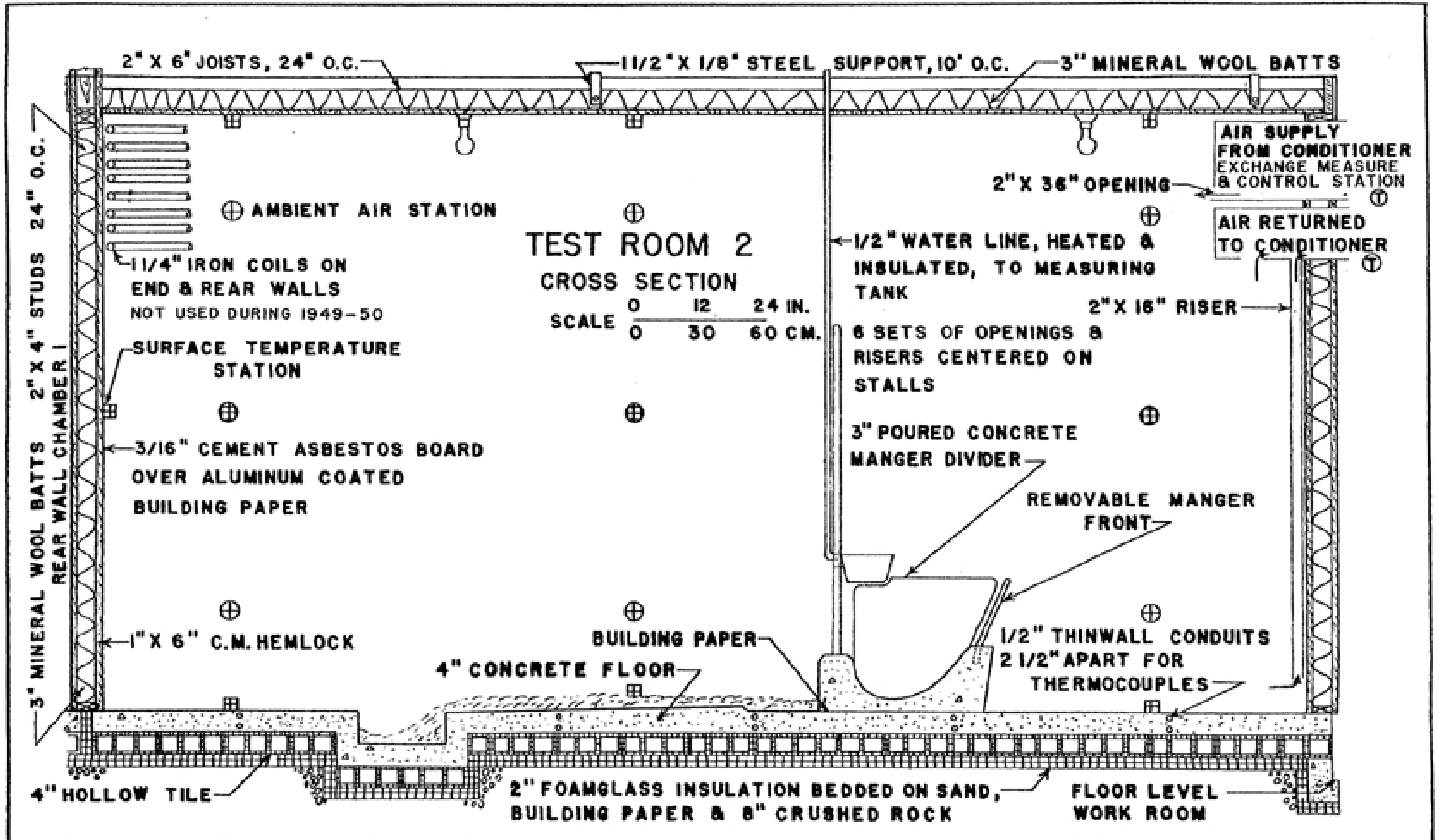

Fig. 3—Arrangement and construction details of the test chambers. Outer walls and upper ceiling of work room are not shown. Animals remained inside these chambers throughout test periods, except while being weighed.

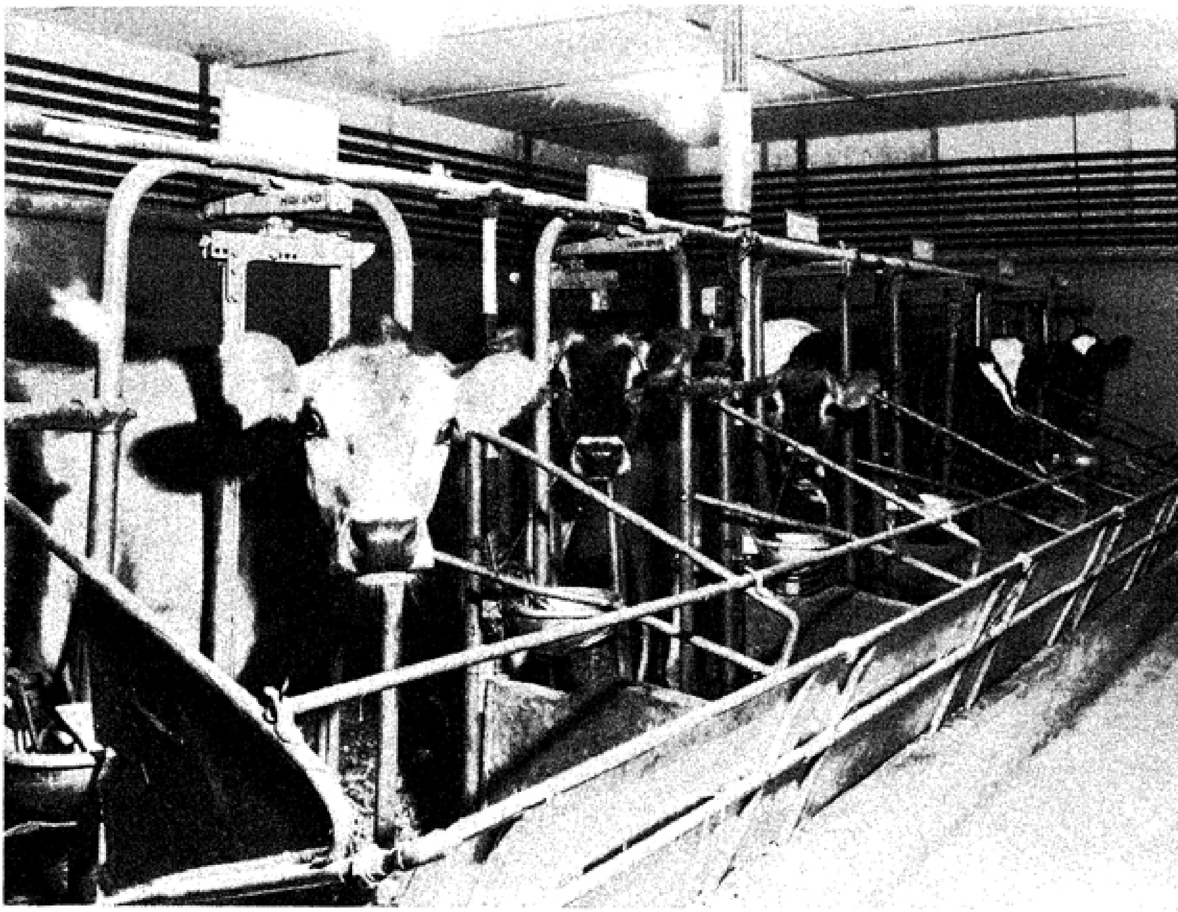

Fig. 4—Control group pictured in Chamber II at 50°F during summer 1948. One-half inch pipe unions on individual manger fronts were kept hand tight to facilitate removal of the metal front when using masks on animals for metabolism measurements. Lead covered heating cable is shown, suspended on underside of water bowls before being covered with mineral wool insulation and protected by sheet metal. Heating cable also was placed on each pipe before insulating. Only one thermostat was used for control by placing its sensing element within the insulated part of the six risers to overhead measuring tanks.

were (1) to lower the dew point and(or) dry-bulb temperature by cooling and (2) to raise the dry-bulb temperature with the reheating coils as required by variations in weather and test room conditions. With extreme or unfavorable air-conditioning loads due to peculiarities of weather or test conditions, it was sometimes necessary to use on-off control of the supply-air heating and(or) cooling units, rather than the usual throttling or gradual control devices. This on-off control at times would give perceptible changes in wet-bulb and dew point temperatures. Data from days having such changes that were considered too wide or erratic were not used in ventilation studies.

Due to the large amount of moisture removed from the recirculated portion of the test room air and the frequent below-freezing surface temperatures of the F12 coolers, defrosting was a major problem. A $CaCl_2$ and water solution containing a corrosion inhibitor of potassium dichromate (500 parts per million) was used as a defrosting spray. As this solution was being diluted continually, use of a brine concentrator was neccesary to remove excess moisture and thus maintain the required freezing point. Replacement

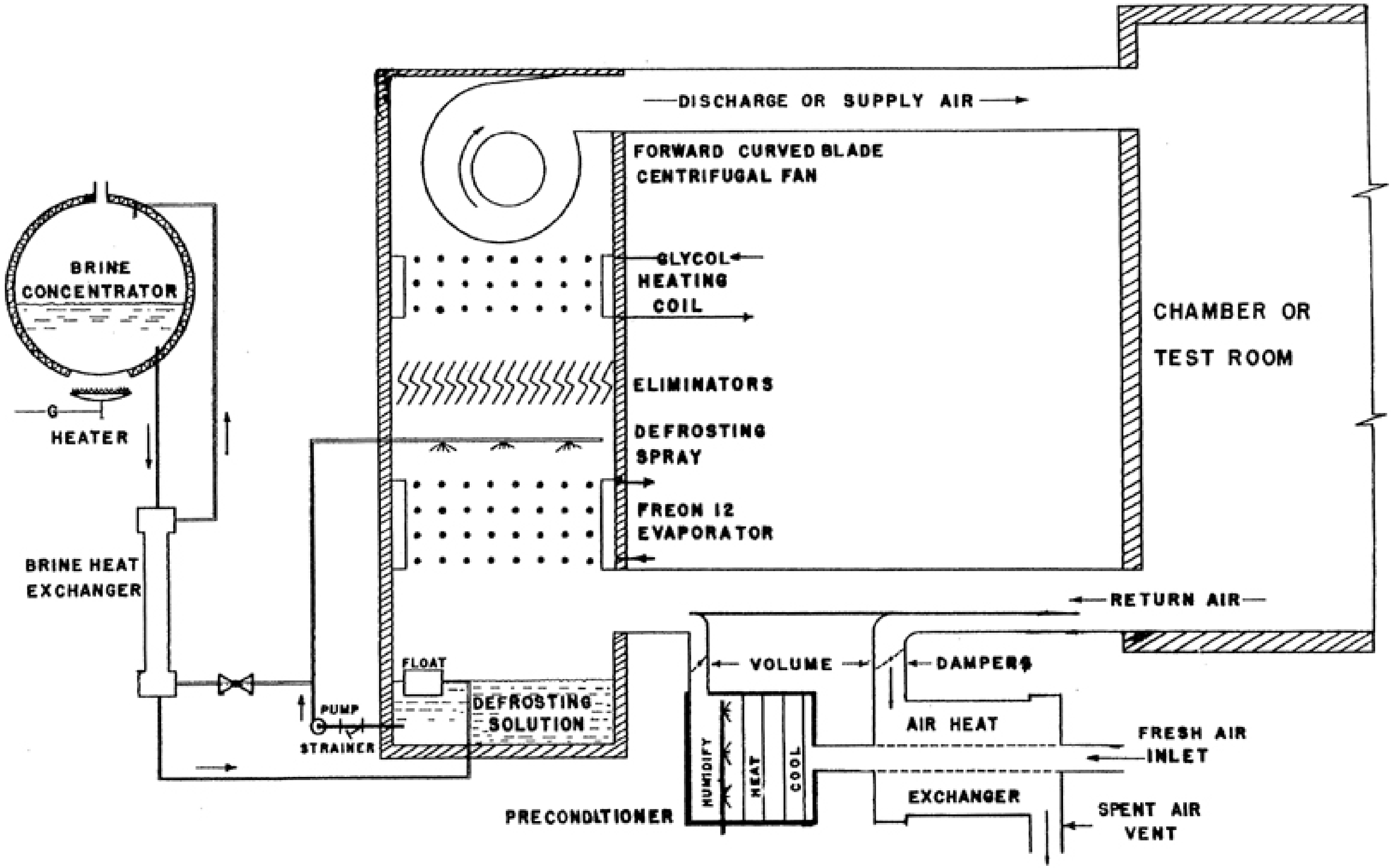

Fig. 5—Schematic diagram of arrangement of air conditioning equipment. The air-to-air heat exchanger was constructed in work room II over the north half of chamber ceiling, using corrugated aluminum roofing for a heat transfer surface. Various combinations of this equipment were used in the tests. In general, the temperature tests below 50° F were run in the winter months. Equipment not shown includes 6 reciprocating F12 compressors, 3-finned bare-copper-coil evaporative condensers, 2 hot water boilers, 3 hot-water-to-glycol heat exchangers and 2 F12-to-glycol heat exchangers.

of the solution was frequently necessary due to contamination with feed dust in the recirculated air stream. Removal of lime deposits in the brine-to-brine heat exchanger with cleaning acids, required additional wasting and replacement of $CaCl_2$ solutions.

Duct air temperatures and humidities were measured and recorded for two reasons. First, it was necessary to have a continuous record of the average dry-bulb temperature of the air around the animals. It was found that the return air temperature gave a representative reading of the average temperature of the test room air. Figure 6 gives a comparison of the average of

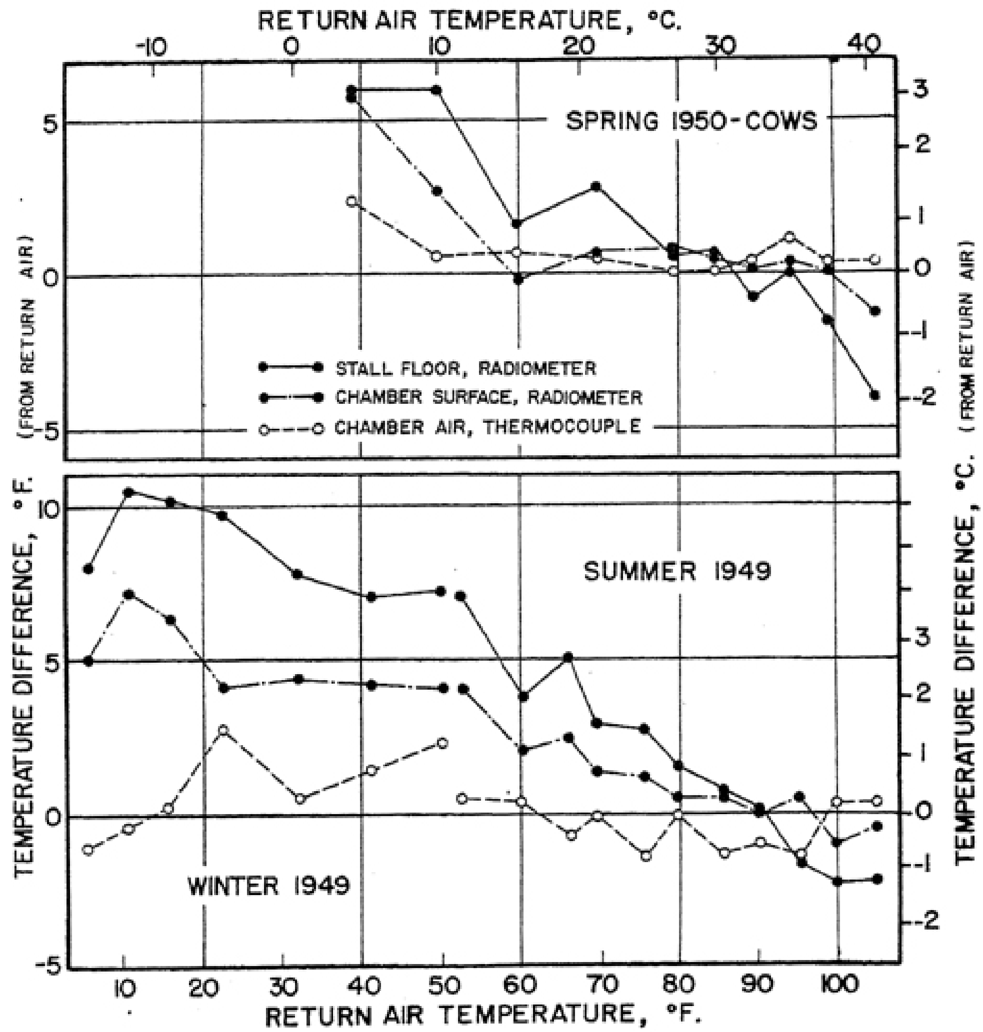

Fig. 6—Relationship of the test room (or chamber) return air temperature and surface and air temperatures taken at the various locations indicated in Figure 2. The stall-floor minus return air difference rises with declining temperatures due to increased radiation and convection heat loss by animals. Likewise the chamber-surface minus return air difference increases due to increasing radiant heat losses from animals with declining temperature. Uninsulated barns in cold climates having barn air temperatures comparable to above air temperatures would be expected to have a slightly lower effective temperature index. However, since no effective temperature index is available for dairy cattle, the magnitude of such changes are not estimated.

54 ambient air temperatures (stations shown in Figure 3) and the return air temperature. Ambient temperatures were measured with exposed copper-constantan, 30-gage thermocouples. The return air temperature was measured and recorded by an instrument having a gas-filled sensing element located directly in the air stream.

The second objective of measurements on duct air was to find out how much heat and moisture was removed by ventilation. The dry-bulb temperature difference between the return air and the supply-air was measured with thermopiles (Figure 7). This difference was subtracted from the return air dry-bulb temperature to give the supply-air temperature. The supply-air temperature was recorded by the instrument having the gas-filled sensing element. A similar method was used for wet-bulb measurements. All wet-bulb, dry-bulb, and relative humidity readings were recorded continuously. Thermocouple and thermopile readings were recorded continuously by a 16-point potentiometer.

Due to breakage and the slow response of the dry-bulb thermopiles encased in glass tubing, their use was abandoned in 1940. New thermopiles were made, using 24-gage copper-constantan wires having each junction and at least 1 inch of each junction wire exposed directly to the air stream. Where wet-bulb temperatures were below freezing, relative humidity measurements were taken with recording hair hygrometers or were estimated from sling psychrometer readings taken at frequent intervals. Due to this situation and problems in keeping the wet-bulb clean and in operation, wet-

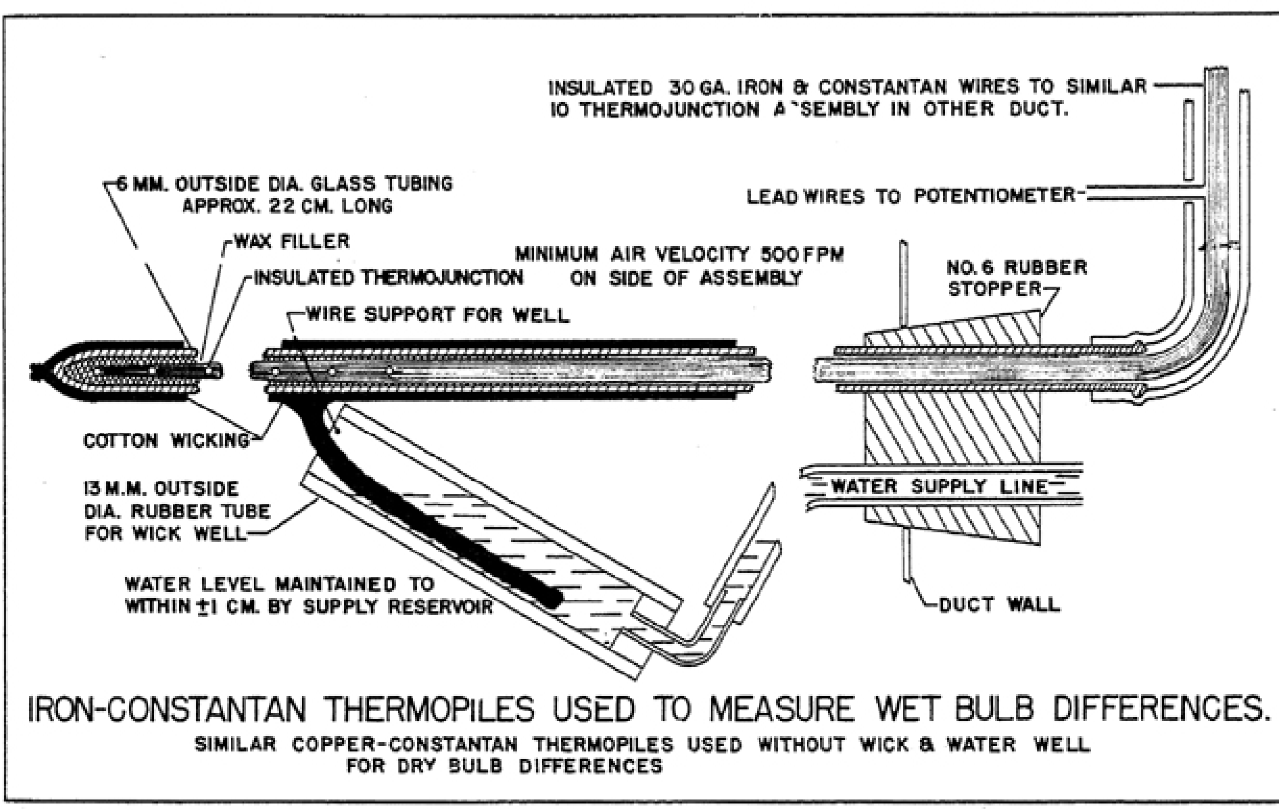

Fig. 7—Thermopile construction used in wet and dry-bulb temperature difference measurements. The wet-bulbs, especially in the return air, would often require cleaning twice daily and could not be used at temperatures below 32°F.

bulb thermopiles were replaced in the fall of 1950 by electrical dew point measuring equipment.

The flow of the air mass through the test room was computed to make air heat exchange calculations. The basic instrument used for this purpose was a slack-diaphragm type recording draft gage having a range of 0.00 to 0.20 inches of water column differential pressure. Sensing elements were industrial type, combined-reverse Pitot tubes, located in the center of the 16-inch diameter supply ducts. This center flow reading was converted to an average flow reading for the entire cross-sectional area of the duct according to a standard cross-sectioning procedure described by ASHVE.[10] A deflecting vane type anemometer having a duct probe was utilized for this cross-sectioning work. A standard Pitot tube connected to a micrometer hook gage was used for calibration and checking purposes. The air measuring equipment was recalibrated for each changed test condition.

Supply-air psychrometric and draft gage readings were converted to pounds of dry air per animal per hour. The relationship used was

$$A = C\sqrt{\frac{D}{v\,(1+w)}} \qquad \text{.....................(1)}$$

where:

A is the pounds of dry air exchanged per animal per hour.

C is a constant whose value depends upon the following factors.

1. Duct cross-sectional area and center factor values.
2. Station barometric pressure.
3. Combined reverse Pitot tube constant.
4. Number of animals in test room.

D is the recorded differential pressure on the combined reverse Pitot tube in the center of the supply duct.

v is the volume of moist air per pound dry air in the supply duct as taken from moist air tables or charts using standard atmospheric pressure.

w is the pounds of water per pound of dry air in the supply duct (sometimes called specific humidity or moisture-ratio).

C was recalculated whenever calibration was necessary due to wide changes in test conditions. Values of *D, v* and *w* were averages for each 24-hour test day.

Air heat exchange was computed by multiplying *A* by the difference between the enthalpy (total heat of moist air mixture per pound of dry air) of the return air and the enthalpy of the supply air. The air moisture exchange was computed by multiplying *A* by the difference in humidity of the return air and the supply air, the humidity being expressed in pounds of water vapor per pound of dry air. For example, assume that, in addition to

[10]American Society of Heating and Ventilating Engineers Guide, 1951, pp. 1028-1029, (hereafter referred to as ASHVE Guide, 1951).

water vapor, the air conditioner were circulating 1,000 lbs. of dry air per cow per hour (approximately 210 c.f.m.) through test room II. Furthermore, assume this moist air mixture was supplied at 40°F. and 85 percent relative humidity and removed at 50°F and 70 percent relative humidity. Using psychrometric tables and charts giving enthalpies in Btu and absolute humidity in pounds of water per pound of dry air, results in the following:

Total air heat exchange = A (enthalpy return—enthalpy supply)
= 1000 (17.8—14.4) = 3,400 Btu per cow per hr.

and Total vaporization from
cow and stall surfaces = A (absolute humidity return—absolute humidity supply)
= 1000 (.0053—.0044) = .9 lbs. per cow per hr.

Although air heat exchange was the major factor in all heat balances, other items were considered as, shown in Figure 8. Adjusting the air-exchange for the extraneous sources of heat and water shown (lights, structural transfer, water, manure, feed, bedding, milk, equipment and personnel), gave the values of total heat and moisture reported in Tables 3 through 7 in the appendix. Similar extraneous factors must be considered in making up the heat balance for a dairy barn.

Floor heat losses were estimated by measuring the temperature difference between the ½-inch conduits with thermopiles (Fig. 3) and using a coefficient of conductance of 12.5 Btu per square foot per hour per inch thickness per degree Fahrenheit temperature difference.

Wall and ceiling losses were estimated by measuring the temperature difference between the inner and outer wall surfaces with 10 pairs of copper-

HEAT AND MOISTURE EXCHANGES AFFECTING THE LABORATORY

Exchange Item	Heat	Water
Air brought in by ventilation	adds	adds
Air removed by ventilation	removes	removes
Bedding	adds	adds
Drinking water	adds	adds
Equipment, electrical such as lights and motors	adds	
Feed	adds	adds
Litter	removes	removes
Milk	removes	removes
Personnel	adds	adds
Storage in animals, feed, litter and structure	adds or removes	adds or removes
Structural transfer	adds or removes	adds or removes
Net exchange from above factors is equal to the sum of the following:		
Fermentation, animal rumen	adds	adds
Fermentation, litter	adds	adds
Metabolism, animal	adds	adds

Fig. 8—Factors in heat and moisture exchanges affecting the laboratory. Of the factors shown, estimates were made from measurements on all except fermentation energies.

constantan thermocouples, each pair representing an equal area on the wall or ceiling. The *U* value or conductance coefficient for wall and ceiling sections was estimated to be 0.08 Btu per square foot per hour.

Heat from lights and laboratory equipment was estimated by spot-checking with a watt-hour meter. Heat added or removed from the test rooms by milk, bedding and manure was estimated from periodic measurements of quantities and temperatures involved. For example, if an animal exposed to 90°F test room temperature drank 80 pounds of 70°F water per day, and the manure was removed at a temperature of 90°F, then the heat removed by water in the manure would be about 67 Btu per animal per hour.

Heat storage effects occurred when changing the test room temperature. The heat storage within the walls, floor, and test room contents was calculated to be about 30 Btu per hour per animal per degree Fahrenheit difference between the first and last hour of each test day. No attempt was made to estimate this heat storage factor due to temperature changes for each hour of the day, beause heat transfer characteristics of the structure could not be estimated with the required accuracy. Effects of laboratory personnel upon

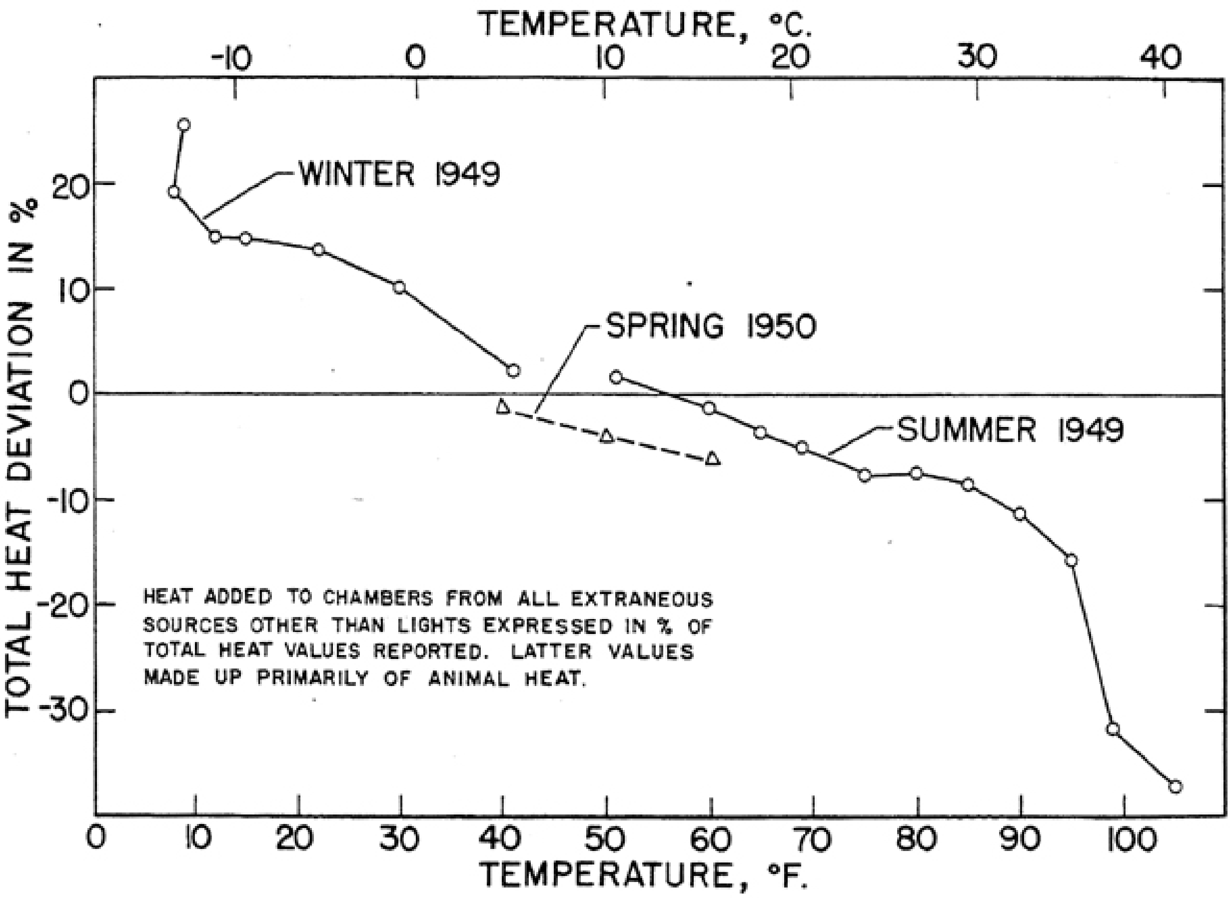

Fig. 9—Estimates of heat exchanges due to sum of milk, drinking water, personnel, equipment, structural storage and transfer, feed, bedding, and litter, expressed in percent of the total heat values reported. All total animal heat values are calculated by subtracting (with proper regard to the algebraic sign) the sum of the above extraneous factors and the heat due to lights from the heat removed by the ventilation air. Disregarding experimental errors, this total heat value corresponds to the sum of fermentation energies and animal metabolism. These percent deviations are based on the average total heat at each temperature.

chamber heat production were estimated by using 760 Btu per man hour[11] for all temperatures with evaporative heat losses ranging from 12 percent of this total at 50°F up to about 110 percent of the total at 95°F.

Secondary sources of heat, other than lights, are briefly summarized in Figure 9. The values are totaled and expressed as a percentage of the total heat values reported. Values at either extreme are more variable because of the short time available to stabilize chamber conditions.

Estimates on gutter litter vaporization were made twice each day by measuring the weight loss of litter samples exposed to test room atmospheres.

ENVIRONMENTAL DETAILS AND TEST SCHEDULE

As variability due to lights, air movement, and humidity were to be minimized in these tests, attempts were made to keep such factors constant throughout the temperature ranges. Table 1 indicates the order of variability

TABLE 1 -- AIR MOVEMENT AND LIGHT WITHIN TEST CHAMBERS

Date Measured	°F.	Ventilation[1] Rate	Group	Near Animal[2]	Near Chamber Surface[3]	Chamber Ambient[4]
					Air Movement ft. per min.	
June 17, 1949	60	980	Experimental		37	68
June 21, 1949	50	980	Control	49	58	46
June 24, 1949	65	920	Experimental	39	44	40
Aug. 1, 1949	95	830	Experimental	27	32	38
Aug. 5, 1949	50	920	Control	34	43	43
Aug. 9, 1949	100	830	Experimental	38	51	41
Dec. 5, 1949	5	1030	Experimental			46
Jan. 6, 1950	5	1310	Experimental			50
Jan. 27, 1950	50	770	Control	34	26	34
May 10, 1950	90	720	Heifers	27		37
May 10, 1950	90	820	Cows	27		39
June 7, 1950	40	830	Heifers	37		38
June 7, 1950	40	870	Cows	42		38
					Light foot candles[6]	
June 24, 1949	65		Experimental	7	12	16
June 24, 1949	50		Control	6	9	13
Aug. 4, 1949	95		Experimental	9	13	17
Aug. 5, 1949	50		Control	8	12	16
Jan. 6, 1950	5		Experimental			18
May 11, 1950	90		Heifers	8	15	20

[1]Amount of chamber ventilation air exchange in pounds dry air per cow per hour. Values are representative for any given test period.
[2]Average of 54 measurements taken within six inches of animals.
[3]Average for points within six inches of 54 chamber surface temperature stations. See Figure 2.
[4]Average of 54 points in room where air temperatures were measured. See Figure 2.
[5]Measured with an Alnor type 8,500 hot wire anemometer.
[6]Measured with a General Electric model 8DW48Y6 exposure meter oriented to give the maximum reading at any one point with six 200-watt bulbs on in each chamber.

[11]ASHVE Guide, 1948, p. 209, Table 4, estimate for an average man walking 2 miles per hour and curve E, Fig. 7

of light and air movement. The air movements of about ½ mile per hour were only slightly related to the ventilation rate of amount of air moved through the test rooms. Relative humidity values ranged from about 60 percent to 70 percent.

All data given in this report were taken on the six groups of animals shown in Table 2. Prior to 1950, only the experimental groups of animals

TABLE 2 -- BREEDS, BODY WEIGHTS, AND MILK PRODUCTION OF ANIMALS IN EACH TEST GROUP

Milk production and body weights are the averages for the first month of tests, or a month immediately preceding the tests.[12]

Animal Number	Stall Number	Milk, lbs.	Body Weight, lbs.	Animal Number	Stall Number	Milk lbs.	Body Weight, lbs.
SUMMER 1949 (May 23 to August 15, 1949)							
EXPERIMENTAL - Increasing temperature, 50°F. to 105°F.				CONTROL - Temperature held approx. 50°F.			
Jersey 994	1	32	770	Jersey 504	1	30	840
Jersey 212	2	34	990	Jersey 205	2	38	950
Brahman 190	3	6	750	Brahman 196	3	7	880
Brahman 209	4	10	710	Brahman 189	4	dry	710
Holstein 109	5	36	1250	Holstein 147	5	37	1180
Holstein 7	6	48	1270	Holstein 146	6	48	1010
Average		28	957			27	928
WINTER 1949 (October 4, 1949 to February 1, 1950)							
EXPERIMENTAL - Decreasing temperature, 50°F. to 8°F.				CONTROL - Temperature held approx. 50°F.			
Jersey 957	1	24	840	Jersey 979	1	20	870
Jersey 977	2	20	920	Jersey 508	2	22	890
Brahman 190	3	dry	850	Brahman 196	3	dry	940
Brahman 209	4	dry	820	Brahman 189	4	dry	800
Holstein 118	5	39	1200	Holstein 132	5	41	1190
Holstein 154	6	39	1200	Holstein 149	6	39	1130
Average		20	972			20	970
SPRING 1950 (February 6 to June 9, 1950)							
COWS - Increasing temperature, 40°F. to 105°F.				HEIFERS - Increasing temperature, 40°F. to 105°F.			
Brahman 209	1	dry	930	Brahman 2	1		410
Brown Swiss 20	2	50	1270	Brown Swiss 2	2		340
Brahman 189	3	dry	940	Brahman 3	3		410
Brown Swiss 16	4	49	1350	Brown Swiss 3	4		370
Brahman 190	5	dry	980	Brahman 1	5		500
Brown Swiss 24	6	43	1410	Brown Swiss 1	6		410
Average		24	1147				407

[12]Ragsdale, A. C.; Thompson, H. J.; Worstell, D. M.; and Brody, S.; "Milk Production and Feed and Water Consumption Responses of Brahman, Jersey, and Holstein Cows to Changes in Temperature, 50° to 105°F and 50° to 8°F," University of Missouri Agricultural Experiment Station Research Bulletin 460, 1950, and "Influence of Increasing of Temperature, 40° to 105°F on Milk Production on Brown Swiss Cows, and on Feed and Water Consumption and Body Weight in Brown Swiss and Brahman Cows and Heifers," University of Missouri Agricultural Experiment Station Research Bulletin 471, 1951; give detailed records on these animals during testing.

were studied at temperatures other than 50°F. The control groups were composed of individuals that were matched according to size, age, breed, body weight, and production with individuals in the experimental groups. These controls were exposed to a constant temperature of 50°F throughout the tests. This was done to provide a means of measuring the effect of stage of lactation, growth and age upon the variables under study. Beginning in 1950 this practice was discontinued because of the limited number of matched

[12]See Table 2.

pairs of animals available and the necessity for more test data at the experimental temperatures.

Each animal retained the same stall number when moved from one test room to the next. Water and hay were kept before each animal at all times. The animals were weighed once each day and fed grain and milked twice daily.

RESULTS

Effect of Various Temperatures Upon Total Heat and Moisture Vaporization Exchanges

The total heat production per animal and the total moisture vaporization per stall (including animal vaporization) is given in Tables 3, 4, 5, and 6 in the appendix. These data do not include any of the extraneous sources of heat and moisture mentioned previously. The data for the two experimental groups (upper sections, Tables 3 and 4) in 1949 and the "cow" group of 1950 (right-hand section of Table 5) were converted to a per 1,000-pound body weight basis for use in Figure 10. With the exception of points below 20°F and those above 95°F, each point represents an average of at least one week's data on a group of six animals.

It was found that decreasing temperature from 90°F to 10°F increased heat production and decreased moisture vaporization. The regression lines of Figure 10 indicate the magnitude of such changes. The vaporization regression line is not fitted to points above 90°F. The heat exchange at 10°F is plotted but not included in the heat regression because of the short time periods involved. At temperatures above 90°F most of the heat is dissipated in the latent form.

Data (in Fig. 10 and Table 2) at the 40°F, 50°F, and 60°F temperatures indicate that variability may arise from the use of groups of animals having different average body weights and milk production. Theoretically, other factors being equal, increasing milk production should increase heat production and increasing body weight should decrease heat production per unit body weight.

In comparing the vaporization data for the test room with that taken on animals [13] it is found that the test room vaporization is higher. This is because bedding, gutter surfaces, and manger surfaces receive sensible heat from both animals and lights; and this energy is then dissipated in the latent form. Chief avenues of animal heat dissipation to these surfaces are conduction while lying down, radiation while standing, and body heat loss through urine and feces.

In comparing test room gutter surface vaporization (Table 9), total animal vaporization from insensible loss measurements ([13]), and total test

[13]Thompson, H. J., McCroskey, R. M., and Brody, S., "Influence of temperature on insensible weight loss and moisture vaporization in Braham, Brown Swiss, Holstein, and Jersey cattle," Univ. Missouri Agric. Exp. Sta. Res. Bul. 479, 1951.

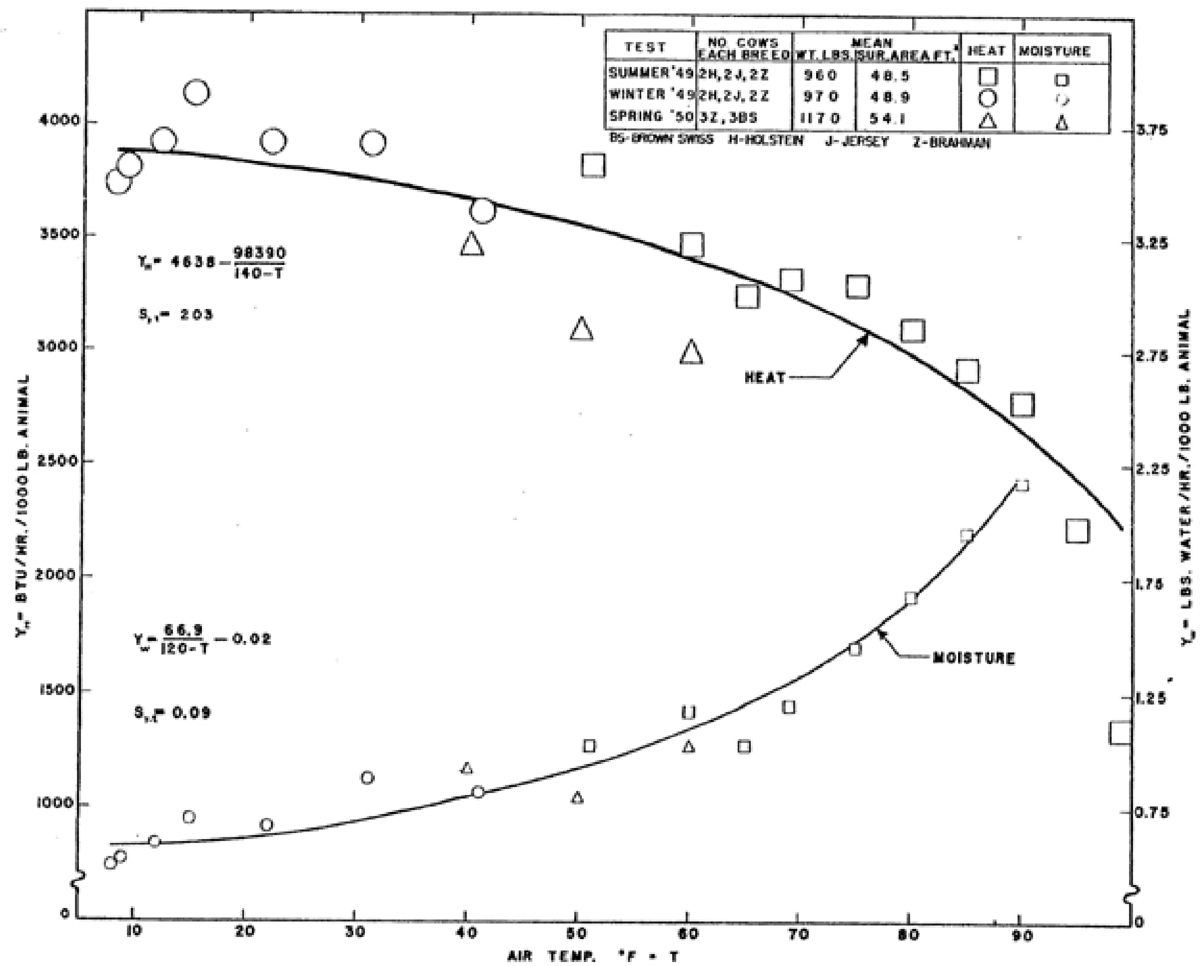

Fig. 10—Effect of air temperature upon heat and moisture exchange. Exchanges per 1000-lb. animal were calculated by using the ratio of the surface area of a 1000-lb. dairy cow to the surface area of the average animal in the test group. Surface areas were computed by the use of a formula proposed by Brody for dairy cattle, i.e., surface area in sq. meters equal .15(body wt. in Kg.)^{56}. Univ. of Mo. Agric. Exp. Sta. Res. Bul. 89.

room vaporization, it is evident that only a small part of the chamber surface vaporization comes from the moist gutter surfaces. Evidently vaporization from all hygroscopic surfaces in the stall must be considered.

The relationship between total heat and latent heat is of particular significance to stable ventilation. It should be noted that at 55°F latent heat of water vapor accounts for 30 percent of total heat while at 35°F it accounts for only about 21 percent. In this respect there is an advantage in a relatively low stable temperature. Other factors involved in ventilation design, include heat losses through stable walls and ceiling, and the relative amounts of heat lost by the ventilation air in vaporizing moisture. Health, milk production, and feed consumption of the cows and comfort of the workers must be considered. Other reports in this series indicated the effects of temperatures near freezing did not affect milk production and feed consumption unfavorably.

In comparing the heat production values with heat measured by metabolism experiments, [14], [15] it is evident that the test room values are higher. Such differences are due principally to the following: heat of rumen fermentation is not measured by mask metabolism methods;[16] metabolism measurements were taken during a short period between 1:00 and 3:00 p.m. about three times a week, whereas ventilation measurements were taken continuously (ventilation data show higher heat production at night than during the day); and possible cumulative experimental errors which may have increased the overall heat values.

The experimental group data in Tables 3 and 4 frequently show variability between successive days. For instance, in Table 4, 90°F column, total heat increases from 2,430 to 3,140 Btu per hour. This may be due to a carry-over of animal response, to management procedures (time of milking, feeding, watering, etc.), or to a carry-over unaccounted for in heat and moisture storage of the structure and its contents.

Data for the control groups in Tables 4 and 6 indicate variability between periods with some indication that with advancing lactation there is a decline in total heat production. Vaporization values do not show such a decline. In fact, the average vaporization of the first four periods in each control group (columns 1 through 4 in Tables 4 and 6) gives values that are less than the averages for all test periods during the respective season.

Ratios of latent heat to total heat for these control groups at 50°F remain relatively constant. Where this ratio is not constant, the variability

[14]Kibler, H. H., and Brody, S., "Effects of Temperature, 50° to 105°F and 50° to 9°F on Heat Production and Cardiorespiratory Activities in Braham, Jersey and Holstein Cows," Univ. Missouri Agric. Exp. Sta. Res. Bul. 464, 1950.

[15]Kibler, H. H., and Brody, S., "Influence of Increasing Temperature, 40° to 105°F, on Heat Production and Cardiorespiratory Activities in Brown Swiss and Braham Cows and Heifers," Univ. Missouri Agric. Expt. Sta. Res. Bul. 473, 1951.

[16]Washburn, L. E., and Brody, S., "Methane, Hydrogen, and Carbon Dioxide Production in the Digestive Tract of Ruminants," Univ. Missouri Agric. Exp. Sta. Res. Bul. 263, 1937, and 295, 1939.

in the latent heat determinations seems to account for much of the variability in the total heat.

Diurnal Variations of Test Room Total Heat and Vaporized Moisture Exchanges at 50°F

Variation of test room heat and moisture exchange within the day, for three selected days, is given in Table 7. The values given were calculated in the same manner that daily values were calculated for previous tables. The days selected were those having a minimum variation in the hour-to-hour test room conditions, i.e., heat storage effects were minimized. In addition to the diurnal changes in animal heat production, there were other hour-to-hour effects on test room heat exchange, such as local temperature rise of the floor beneath the animals while lying down, heat gained from urine and feces, and effects of practices followed in cleaning out manure and bedding down stalls.

The sine curve relationship of heat vs. time used in Figure 11 summarizes heat data given in Table 7. The sine curve relationship (calculated by

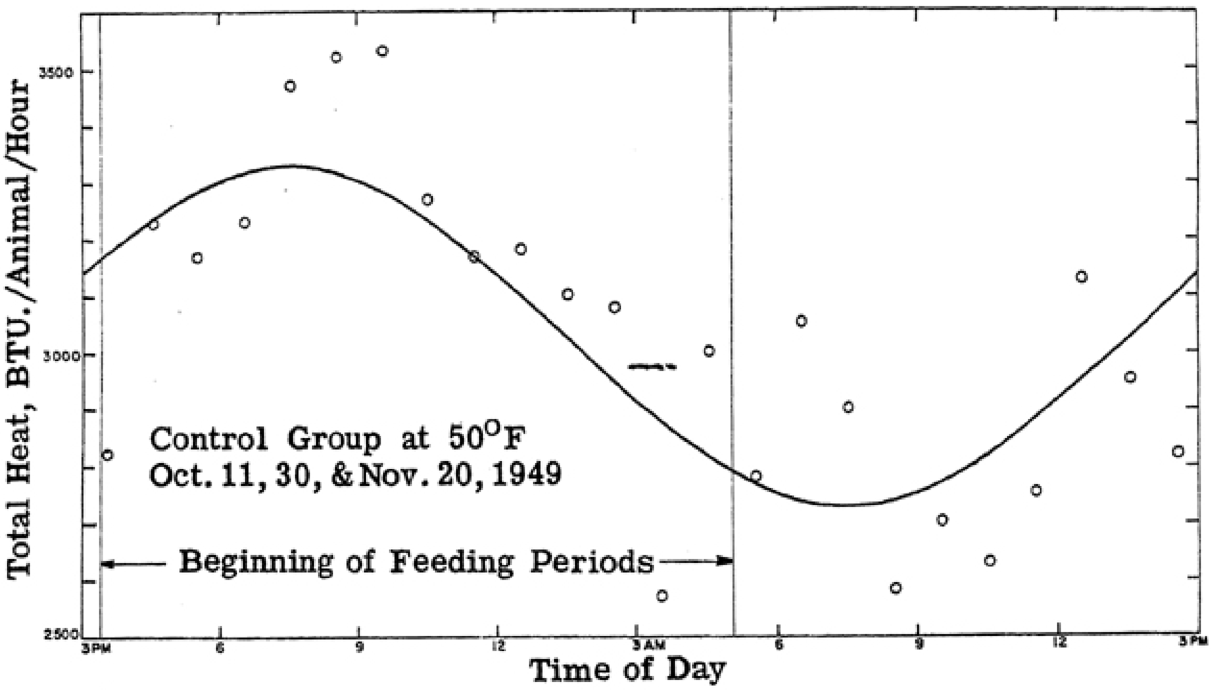

Fig. 11—Effect of time of day upon total heat exchange. Two Jersey, two Holstein, and two Brahman cow group tests of Oct. 11, 30, and Nov. 20, 1949, plotted points being averages of values for 3 days whereas regression is calculated from all values for the 3 days (Table 7). Approximate beginnings of feeding and milking periods are 3 p.m. and 5 a.m. Air temperature 50°F. The sine curve is fitted with the following regression formula.

Y =3026+299X where

X =sin [(elapsed time in hours after 2 p.m.) $\left(\frac{360}{24}\text{ degrees}\right)$]

giving

r =.764** which is statistically highly significant

Sy.x = ±186 Btu/hr.

the method of least squares) was used because of the need for a simple periodic function in the statistical analysis of the limited amount of data available. Evidently heat production is higher after the evening feeding than after the morning feeding. There is little difference between moisture vaporization durng night and day. Hour-to-hour vaporization values in Table 7 indicate variability of such a nature that it is difficult to establish any definite diurnal pattern.

The effect of the test room lamp energy upon heat removed by the ventilation air (Fig. 12) is quite apparent. Conversion of part of the sensible heat from the lamps into the latent form during the day may help explain why there is such a small difference between day and night vaporization rates, compared to the relatively larger differences between day and night heat production. After adjusting the air heat exchange for the effect of the lights (lower section Fig. 12), the diurnal curve is somewhat similar to that of the total heat sine curve in Figure 11.

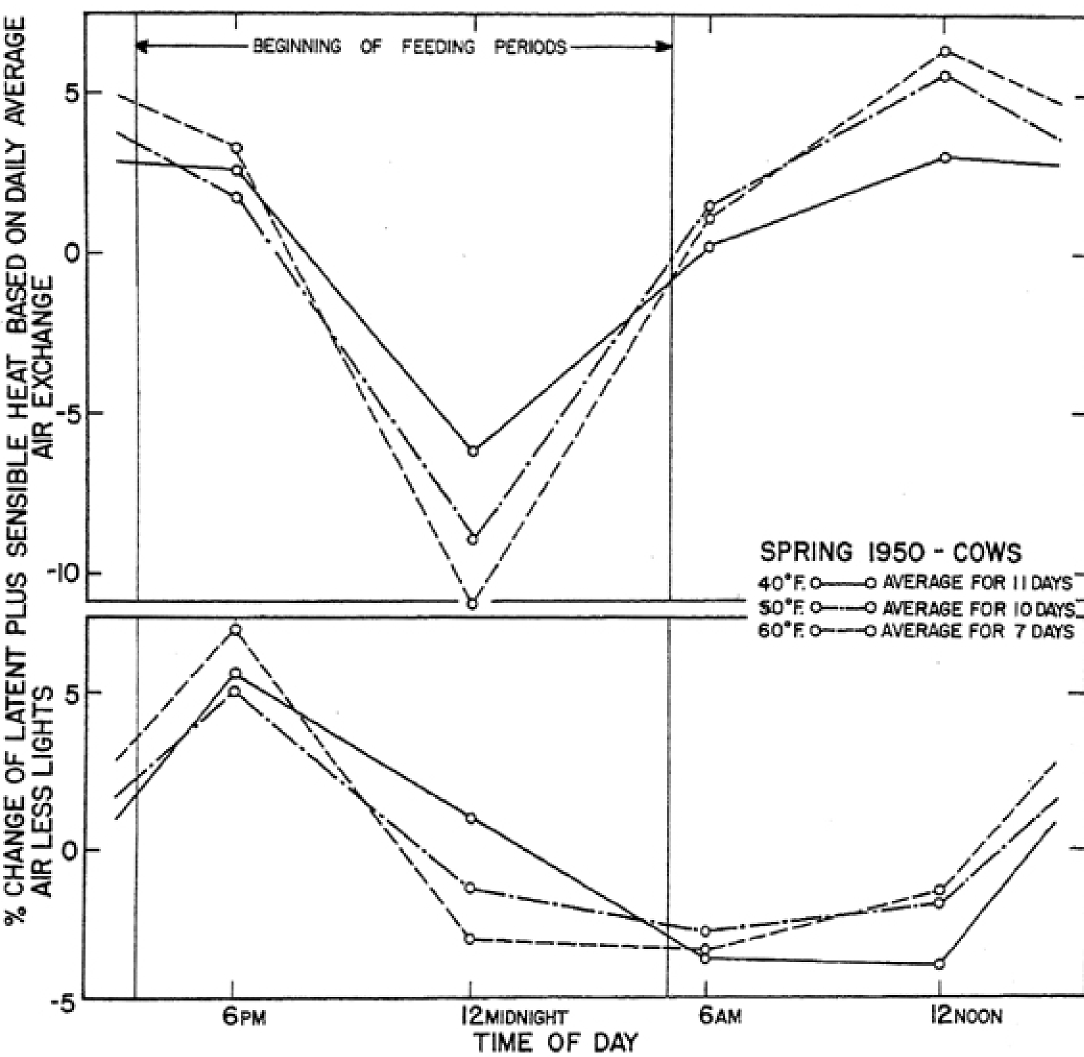

Fig. 12—Effect of time of day and heat from lights upon the diurnal variation of air heat exchange averaged by six-hour periods. Air less light values are quite representative of total heat values reported for 50°F because at this temperature heat added or removed by walls, floors, drinking water, manure, etc., tend to balance out as shown in Figure 9.

APPENDIX

TABLE 3 -- HEAT AND MOISTURE EXCHANGE, OCTOBER 1949--FEBRUARY 1950, EXPERIMENTAL GROUP
Average Btu. or Lbs. Per Animal Per Hour for Chamber

Date of Temp Period, 1949-1950			Oct. 15 to 28	Oct. 29 Nov. 11	Nov. 12 to 25	Nov. 26 Dec. 9	Dec. 10 11 & 12	Dec. 13 to 19	Dec. 20 21 & 22	Dec. 23 to 30	Dec. 31 Jan. 6
Average Temp. °F & %RH of Experimental Chamber			41° 57%	31° 60%	22° 60%	15° 63%	21 - 16° 66%	12° 68%	12 - 16° 63%	8° 66%	9° 66%
1st	Heat,	Btu.	3540	3850	3710	4000	3430	4010	4180	3890	3600
day	Water,	lbs.	0.96	0.94	0.90	0.86	0.62	0.72	0.72	0.45	0.57
2nd	Heat,	Btu.	3600	3670	4170	3970	3540	3880	3720	3700	3470
day	Water,	lbs.	0.89	0.77	0.74	0.69	0.69	0.61	0.55	0.45	0.53
3rd	Heat,	Btu.	3340	3780	3760	3920	3770	3930	3790	3640	4080
day	Water,	lbs.	0.79	0.80	0.64	0.64	0.72	0.51	0.49	0.45	0.57
4th	Heat,	Btu.	3440	3930	3900	3980		3670		3530	3600
day	Water,	lbs.	0.66	0.88	0.63	0.68		0.52		0.43	0.57
5th	Heat,	Btu.	3510	3880	3840	4130		4030		3810	3820
day	Water,	lbs.	0.70	0.80	0.63	0.72		0.57		0.45	0.46
6th	Heat,	Btu.	3650	3820	3870	4020		3720		3670	3880
day	Water,	lbs.	0.81	0.89	0.64	0.64		0.58		0.46	0.43
7th	Heat,	Btu.	3720	3880	3940	4100		3760		3900	3820
day	Water,	lbs.	0.79	0.95	0.62	0.67		0.58		0.54	0.43
8th	Heat,	Btu.	3240	3920	3800	4050				3310*	
day	Water,	lbs.	0.62	0.93	0.61	0.67				0.57	
9th	Heat,	Btu.	3430	3930	3800	4130					
day	Water,	lbs.	0.74	0.91	0.62	0.68					
10th	Heat,	Btu.	3660	3950	3670	4100					
day	Water,	lbs.	0.86	0.88	0.60	0.64					
11th	Heat,	Btu.	3560	3930	3910	4070					
day	Water,	lbs.	0.80	0.82	0.70	0.59					
12th	Heat,	Btu.	3700	3820	3890	4100					
day	Water,	lbs.	0.88	0.84	0.65	0.73					
13th	Heat,	Btu.	3650	3840	3790	4240					
day	Water,	lbs.	0.82	0.87	0.62	0.80					
14th	Heat,	Btu.	3760	3740	4040	(Omitted)					
day	Water,	lbs.	0.93	0.89	0.66						
Aver-	Heat,	Btu.	3560	3850	3860	4060	3580	3860	3900	3680	3750
age	Water,	lbs.	0.80	0.87	0.66	0.69	0.68	0.58	0.59	0.48	0.51

These values are averages for the 24-hour periods of heat and moisture due primarily to the animals, litter, and bedding. Extraneous heat sources such as lights, laboratory equipment, personnel; and wall, floor, and ceiling transfer are not included in these net values.

*Average temperature December 30, 18°F.

TABLE 4 -- HEAT AND MOISTURE EXCHANGE, SUMMER 1949, EXPERIMENTAL GROUP

Dates of Temp. Period, 1949			June 5 to 11	June 12 to 18	June 19 to 25	June 26 July 2	July 3 to 9	July 10 to 16	July 17 to 23	July 24 to 30	July 31 Aug. 6	Aug. 7 to 10	Aug. 11	Aug. 14 & 15
Average Temp. °F & %R. H. of Experimental Chamber			51° 67%	60° 71%	65° 73%	69° 76%	75° 70%	80° 65%	85° 64%	90° 66%	95° 57%	99° 62%	105° 59%	51° 66%
1st	Heat,	Btu.	3110	3440	2950	2980	3250	3020	2850	3020	1960	2500	1310	2720
day	Water,	lbs.	0.52	1.10	0.94	0.96	1.23	1.70	1.80	2.19	2.10	2.05	1.78	0.64
2nd	Heat,	Btu.	3480	3570	3110	3180	3340	3170	2710	2740	1980	2400		2580
day	Water,	lbs.	1.07	1.29	1.03	1.14	1.38	1.85	1.79	2.13	2.09	2.13		0.60
3rd	Heat,	Btu.	3580	3440	3280	3250	3340	3250	2890	2550	2470	1810		
day	Water,	lbs.	1.08	1.26	0.99	1.24	1.61	1.84	1.89	1.99	2.52	1.85		
4th	Heat,	Btu.	4070	3440	3280	3430	3380	2820	2920	2560	2560	1960		
day	Water,	lbs.	1.10	1.28	0.99	1.34	1.40	1.53	1.92	2.12	2.00	1.92		
5th	Heat,	Btu.	4460	3460	3260	3340	3360	3000	3020	2430	2450			
day	Water,	lbs.	0.99	1.13	0.98	1.17	1.60	1.61	2.04	1.84	1.73			
6th	Heat,	Btu.	3790	3250	3260	3200	2920	3080	3010	3140	1990			
day	Water,	lbs.	1.04	0.98	1.18	1.22	1.36	1.47	1.97	2.59	1.62			
7th	Heat,	Btu.	3720	3040	3090	3310	2970	2890	2690	2530	2230			
day	Water,	lbs.	1.17	0.98	0.99	1.20	1.33	1.54	1.82	2.03	1.52			
Aver-	Heat,	Btu.	3740	3380	3180	3240	3220	3030	2870	2710	2240	2170	1310	2650
age	Water,	lbs.	1.00	1.15	1.01	1.18	1.42	1.65	1.89	2.13	1.94	1.99	1.78	0.62

HEAT AND MOISTURE EXCHANGE, SUMMER 1949, CONTROL GROUP

Average Temp. °F & %R. H. of Control Chamber			50° 70%	50° 69%	51° 67%	51° 67%	52° 68%	51° 64%	51° 64%	51° 64%	51° 66%	53° 62%	51° 63%	49° 66%
1st	Heat,	Btu.	3560	3720	3370	3350	3610	3690	3640	3520	3320	3400	3450	3280
day	Water,	lbs.	0.67	0.83	0.72	0.48	0.76	0.90	1.02	0.98	0.55	1.28	0.73	0.74
2nd	Heat,	Btu.	3690	3510	3150	3420	3690	3630	3700	3730	3310	3360		3280
day	Water,	lbs.	0.84	0.64	0.50	0.52	0.87	0.80	1.11	1.03	0.70	0.70		0.76
3rd	Heat,	Btu.	3480	3450	3300	3260	3560	3240	3490	3490	3360	2720		
day	Water,	lbs.	0.78	0.61	0.45	0.40	0.66	0.54	0.93	0.93	0.68	0.71		
4th	Heat,	Btu.	4030	3580	3280	3420	3890	3550	3710	3320	3480	3450		
day	Water,	lbs.	0.94	0.68	0.52	0.60	0.79	0.86	0.93	0.71	0.71	0.62		
5th	Heat,	Btu.	3620	3320	3190	3830	3670	3660	3630	3250	3460			
day	Water,	lbs.	0.76	0.56	0.42	0.84	1.10	1.03	0.98	0.71	0.73			
6th	Heat,	Btu.	3580	3230	3260	3550	3400	3510	3650	3310	3360			
day	Water,	lbs.	0.64	0.50	0.77	0.73	0.72	0.93	0.94	0.77	0.74			
7th	Heat,	Btu.	3590	3170	3180	3850	3350	3700	3460	3210	3540			
day	Water,	lbs.	0.68	0.39	0.43	0.84	0.64	0.98	1.03	0.67	0.80			
Aver-	Heat,	Btu.	3650	3420	3250	3530	3600	3570	3610	3400	3400	3230	3450	3280
age	Water,	lbs.	0.76	0.60	0.54	0.63	0.79	0.86	0.99	0.83	0.70	0.83	0.73	0.75

These values are averages per animal per hour for the 24-hour periods of heat and moisture due primarily to animals, litter, and bedding. Extraneous heat sources such as lights, laboratory equipment, personnel; and wall, floor, and ceiling transfer are not included in these net values.

Eight hours at 105° F, 12 hours at about 100°F, and 4 hours between 100 and 105° F.

TABLE 5 -- HEAT AND MOISTURE EXCHANGE, FEBRUARY 1950--APRIL 1950

Date of Temp. Period, 1950			Chamber I, Heifers				Chamber II, Cows		
			Feb. 8 to Mar. 3	Mar. 4 to 17	Mar. 18 to 31	Apr. 1 to 14	Feb. 8 to Mar. 3	Mar. 4 to 17	Mar. 18 to 31
Av. °F & %R. H.			40° 64%	50° 65%	60° 76%	70° 72%	40° 61%	50° 58%	60° 70%
1st	Heat,	Btu.	1940	1830	1900	1350	4290	3140	2790
day	Water,	lbs.	0.64	0.48	0.28	0.37	1.42	0.87	0.99
2nd	Heat,	Btu.	1650	1630	1600	1880	3980	3420	3100
day	Water,	lbs.	0.40	0.44	0.46	0.93	1.37	1.00	1.03
3rd	Heat,	Btu.	1580	1760	1600	1760	4410	3450	3190
day	Water,	lbs.	0.36	0.50	0.36	0.77	1.34	0.91	1.02
4th	Heat,	Btu.	1560	1940	1580	1520	3480	3450	2980
day	Water,	lbs.	0.39	0.53	0.43	0.52	0.65	0.87	0.96
5th	Heat,	Btu.	1820	1780	1630	1560	4010	3360	3130
day	Water,	lbs.	0.44	0.43	0.48	0.61	1.13	0.87	0.96
6th	Heat,	Btu.	1600	1670	1610	1570	3980	3260	3120
day	Water,	lbs.	0.33	0.46	0.46	0.61	1.15	0.79	1.00
7th	Heat,	Btu.	1780	1700	1660	1620	3340	3430	3480
day	Water,	lbs.	0.47	0.45	0.48	0.63	0.61	0.89	1.14
8th	Heat,	Btu.	1750	1740	1620	1480	3630	3420	3400
day	Water,	lbs.	0.36	0.48	0.41	0.55	0.96	0.85	1.18
9th	Heat,	Btu.	1760	1820	1650	1590	3830	3360	3480
day	Water,	lbs.	0.37	0.55	0.42	0.66	1.09	0.85	1.32
10th	Heat,	Btu.	1900	1890	1760	1400	3880	3460	3530
day	Water,	lbs.	0.37	0.51	0.47	0.45	1.14	0.86	1.23
11th	Heat,	Btu.	1770	1850	1630	1420	3840	3520	3490
day	Water,	lbs.	0.37	0.55	0.39	0.47	1.04	0.84	1.23
12th	Heat,	Btu.	1740	1760	1820	1560	3720	3400	3420
day	Water,	lbs.	0.38	0.47	0.52	0.63	1.05	0.84	1.28
13th	Heat,	Btu.	1830	1760	1650	1400	3610	3230	3360
day	Water,	lbs.	0.37	0.59	0.42	0.51	1.04	0.83	1.12
14th	Heat,	Btu.	1800	1740	1770	1420	3510	3440	3260
day	Water,	lbs.	0.34	0.46	0.46	0.52	0.84	0.86	1.14
15th	Heat,	Btu.	1640				3560		
day	Water,	lbs.	0.29				0.82		
16th	Heat,	Btu.	1640				3800		
day	Water,	lbs.	0.32				1.02		
17th	Heat,	Btu.	1670				3970		
day	Water,	lbs.	0.34				1.14		
18th	Heat,	Btu.	1840				3830		
day	Water,	lbs.	0.50				1.06		
19th	Heat,	Btu.	1580				3820		
day	Water,	lbs.	0.25				0.99		
20th	Heat,	Btu.	1810				3700		
day	Water,	lbs.	0.36				0.82		
21st	Heat,	Btu.	1820				3720		
day	Water,	lbs.	0.35				0.81		
22nd	Heat,	Btu.	1870				3440		
day	Water,	lbs.	0.41				0.87		
23rd	Heat,	Btu.	1820				3400		
day	Water,	lbs.	0.40				0.90		
24th	Heat,	Btu.	1790				3700		
day	Water,	lbs.	0.38				0.87		
Aver-	Heat,	Btu.	1750	1780	1680	1540	3770	3380	3270
age	Water,	lbs.	0.38	0.49	0.43	0.59	1.01	0.87	1.11

These values are averages per animal per hour for the 24-hour periods of heat and moisture due primarily to animals, litter, and bedding. Extraneous heat sources such as lights, laboratory equipment, personnel; and wall, floor, and ceiling transfer are not included in these net values.

TABLE 6 -- HEAT AND MOISTURE EXCHANGE, OCTOBER 1949--FEBRUARY 1950, CONTROL GROUP

Date of Temp. Period, 1949-1950			Oct. 8 to 14	Oct. 15 to 28	Oct. 29 Nov. 11	Nov. 12 to 25	Nov. 26 Dec. 9	Dec. 10, 11 & 12	Dec. 13 to 19	Dec. 20, 21 & 22	Dec. 23 to 30	Dec. 31 Jan. 6	Jan. 7 to 13	Jan. 14 to 27
Average °F & % R. H. of Control Chamber			52° 64%	50° 65%	50° 69%	50° 70%	50° 69%	51° 72%	50° 71%	51° 68%	51° 60%	50° 68%	51° 62%	50° 68%
1st	Heat,	Btu.	2770	2700	2900	2870	3020	3210	3230	3130	2960	2810	2840	1920
day	Water,	lbs.	0.51	0.47	0.69	0.71	0.76	0.81	0.81	0.90	0.88	0.72	0.79	0.73
2nd	Heat,	Btu.	2760	2700	2930	3020	3050	3160	3200	2830	3070	2710	2830	2790
day	Water,	lbs.	0.61	0.47	0.67	0.64	0.75	0.95	0.84	0.80	0.93	0.66	0.82	0.77
3rd	Heat,	Btu.	2970	2730	3060	3080	3070	3320	3270	2780	2720	2650	2600	2830
day	Water,	lbs.	0.57	0.43	0.68	0.73	0.74	0.88	0.82	0.68	0.72	0.60	0.83	0.85
4th	Heat,	Btu.	3140	2760	3330	3080	3020		3300		2920	2620	2990	2660
day	Water,	lbs.	0.84	0.46	0.70	0.64	0.71		0.82		0.85	0.61	0.77	0.63
5th	Heat,	Btu.	2750	2890	3010	3000	3040		3110		2880	2740	2820	2830
day	Water,	lbs.	0.45	0.62	0.77	0.70	0.75		0.83		0.64	0.61	0.78	0.53
6th	Heat,	Btu.	2740	2940	3080	2920	3160		3060		2920	2730	2960	2830
day	Water,	lbs.	0.56	0.58	0.75	0.74	0.78		0.78		0.86	0.74	0.89	0.63
7th	Heat,	Btu.	2810	2890	2970	3250	3060		2860		2990	2920	2970	3010
day	Water,	lbs.	0.50	0.61	0.68	0.78	0.74		0.67		1.23	0.77	0.73	0.83
8th	Heat	Btu.		2930	3070	2960	2960				2630			2780
day	Water,	lbs.		0.63	0.71	0.67	0.72				0.65			0.75
9th	Heat,	Btu.		2860	3200	2990	3100							2950
day	Water,	lbs.		0.59	0.67	0.66	0.78							0.74
10th	Heat,	Btu.		2850	3190	3090	3160							3030
day	Water,	lbs.		0.61	0.77	0.71	0.82							0.80
11th	Heat,	Btu.		2930	3020	3000	3280							3280
day	Water,	lbs.		0.67	0.71	0.75	0.79							0.80
12th	Heat,	Btu.		2680	3060	2920	3310							3130
day	Water,	lbs.		0.62	0.74	0.70	0.89							0.81
13th	Heat,	Btu.		2810	2990	3080	3330							3220
day	Water,	lbs.		0.62	0.75	0.70	0.84							0.75
14th	Heat,	Btu.		2960	3080	3300	3200							3090
day	Water,	lbs.		0.70	0.75	0.85	0.82							0.71
Aver-	Heat,	Btu.	2850	2830	3060	3040	3130	3230	3150	2910	2890	2740	2860	2880
age	Water,	lbs.	0.58	0.58	0.72	0.71	0.78	0.88	0.80	0.79	0.84	0.67	0.80	0.74

These values are averages per animal per hour for the 24-hour periods of heat and moisture due primarily to animals, litter, and bedding. Extraneous heat sources such as lights, laboratory equipment, personnel; and wall, floor, and ceiling transfer are not included in these net values.

TABLE 7 -- DIURNAL VARIATION OF HEAT & MOISTURE EXCHANGES FOR HOLSTEIN, JERSEY, & BRAHMAN CONTROL COWS AT 50° F, 1949

	Oct. 11		Oct. 30		Nov. 20	
(Av. temp. °F & R.H. %)	50°	62%	50°	68%	50°	69%
Period	Btu.	lbs.	Btu.	lbs.	Btu.	lbs.
3 p.m. to 4 p.m.	3250	1.05	2550	.65	2650	.70
4 p.m. to 5 p.m.	3050	.90	2600	.65	2800	.65
5 p.m. to 6 p.m.	3550	.95	3250	.75	2900	.60
6 p.m. to 7 p.m.	3250	.85	3250	.80	3000	.60
7 p.m. to 8 p.m.	3200	.80	3250	.75	3250	.70
8 p.m. to 9 p.m.	4100	.90	2900	.60	3400	.70
9 p.m. to 10 p.m.	4050	.85	3150	.70	3350	.75
10 p.m. to 11 p.m.	4200	.95	3200	.70	3200	.75
11 p.m. to 12 p.m.	3350	.80	3150	.65	3300	.75
12 p.m. to 1 a.m.	3450	.85	2950	.60	3100	.65
1 a.m. to 2 a.m.	3550	.90	2950	.55	3050	.55
2 a.m. to 3 a.m.	3300	.60	3000	.60	3000	.70
3 a.m. to 4 a.m.	3400	.60	2700	.50	3150	.55
4 a.m. to 5 a.m.	2350	.70	2550	.75	2800	.75
5 a.m. to 6 a.m.	2800	.90	3100	.85	3100	.85
6 a.m. to 7 a.m.	2750	.85	2700	.65	2900	.75
7 a.m. to 8 a.m.	3200	1.00	3000	.75	2950	.65
8 a.m. to 9 a.m.	2600	.75	3000	.80	3100	.80
9 a.m. to 10 a.m.	2650	.80	2550	.45	2550	.65
10 a.m. to 11 a.m.	2450	.65	2850	.75	2800	.60
11 a.m. to 12 a.m.	2500	.80	2750	.65	2650	.55
12 a.m. to 1 p.m.	2650	.80	2800	.60	2800	.65
1 p.m. to 2 p.m.	3100	.90	3150	.85	3150	.75
2 p.m. to 3 p.m.	2950	.70	2900	.60	3000	.60
Average	3154	.83	2927	.68	2998	.68

These values are averages per animal per hour for the 24-hour periods of heat and moisture due primarily to animal, litter, and bedding. Extraneous heat sources such as lights, laboratory equipment, personnel; and wall, floor and ceiling transfer are not included in these net values. Approximate feeding time 3 p.m. and 5 a.m. Av. body wt. 970 lbs.

TABLE 8 -- DIURNAL VARIATION IN TEST ROOM HEAT AND MOISTURE EXCHANGE FOR BROWN SWISS AND BRAHMAN COWS ON A PERCENT DEVIATION FROM THE DAILY AVERAGE BASIS

Date	3 p.m. to 9 p.m.		9 p.m. to 3 a.m.		3 a.m. to 9 a.m.		9 a.m. to 3 p.m.	
1950	Sensible[1]	Latent[2]	Sensible	Latent	Sensible	Latent	Sensible	Latent
40°F, average total[3] heat, 4009 Btu/cow/hr. Approximately 84% sensible, 16% latent[4].								
February 13	1.3	1.7	- 6.3	- 8.9	-0.4	-0.1	5.5	7.2
February 16	1.6	1.1	- 5.6	- 3.8	-1.1	-1.6	5.2	4.4
February 17	0.7	1.5	- 6.5	- 6.4	0.7	0.5	5.1	4.3
February 18	5.5	2.7	- 7.3	- 8.4	-1.8	-1.2	3.7	7.0
February 19	2.8	-1.8	- 5.6	- 6.2	-1.9	1.6	4.6	6.3
February 20	1.1	3.6	- 5.2	- 4.5	-0.7	-1.8	4.7	2.7
February 23	4.4	4.9	- 5.3	- 1.7	0.9	-1.8	0.0	- 1.3
February 24	2.9	3.4	- 4.2	- 4.0	1.1	4.8	0.2	- 4.2
February 26	5.2	5.5	- 6.6	- 4.4	1.6	1.3	- 0.2	- 2.4
March 1	-0.5	8.3	- 4.1	-13.8	0.5	0.1	4.1	5.4
March 3	1.8	7.2	- 8.2	-11.2	3.6	3.6	2.7	0.4
Average	2.436%	3.456%	- 5.900%	- 6.651%	0.227%	0.487%	3.236%	2.697%
Average total heat[5]	2.599%		-6.020%		0.269%		3.150%	
Average total heat without lights at 533 Btu/hour when on between 4:20 a.m. and 5 p.m. daily.								
	5.565%		1.05%		-3.29%		-3.37%	
50°F, average total[3] heat, 3570 Btu/cow/hr. Approximately 81% sensible, 19% latent[4].								
March 6	0.2	2.3	- 9.2	- 8.6	5.0	2.6	4.0	3.7
March 7	4.5	7.8	- 8.8	- 7.6	1.7	-0.1	2.6	- 0.1
March 10	-0.5	0.5	- 8.1	- 5.3	3.3	1.5	5.2	3.2
March 11	1.4	3.2	- 8.9	- 7.8	0.5	1.9	7.0	2.6
March 12	0.5	6.6	-10.0	-10.8	2.4	2.4	7.2	1.6
March 13	2.8	3.1	-10.4	-10.1	0.0	-1.2	7.5	8.1
March 14	0.5	7.6	-10.0	- 6.1	2.4	-2.5	7.1	1.6
March 15	3.5	2.9	- 4.0	- 8.5	-3.1	4.0	3.5	1.6
March 16	0.2	3.8	-11.0	- 9.5	1.2	-0.3	9.6	5.9
March 17	-0.7	-0.5	- 9.1	-12.0	2.1	4.8	7.7	7.6
Average	1.240%	3.739%	- 8.950%	- 8.633%	1.560%	1.311%	6.140%	3.589%
Average total heat[5]	1.715%		-8.890%		1.505%		5.655%	
Average total heat without lights at 533 Btu/hour when on between 4:20 a.m. and 5 p.m. daily.								
	5.02%		-1.09%		-2.43%		-1.52%	
60°F, average total[3] heat, 3353 Btu/cow/hr. Approximately 2/3 sensible, 1/3 latent[4].								
March 20	3.2	6.2	- 9.5	- 4.8	3.2	-3.6	3.2	2.2
March 21	2.4	0.1	-11.5	-12.0	-1.9	0.6	11.0	11.1
March 22	2.5	2.0	-13.1	- 6.4	2.5	0.7	8.1	3.8
March 23	3.5	1.5	-12.8	-12.6	-0.8	0.2	10.1	10.9
March 24	6.4	-0.9	- 9.0	-13.6	3.3	7.0	- 0.8	7.5
March 25	6.2	3.6	-11.0	-12.2	-1.3	3.6	6.2	5.0
March 26	1.3	6.2	-10.5	-12.0	1.3	2.7	7.8	3.1
Average	3.643%	2.678%	-11.057%	-10.521%	0.900%	1.610%	6.514%	6.237%
Average total heat[5]	3.321%		-10.878%		1.137%		6.422%	
Average total heat without lights at 533 Btu/hour when on between 4:20 a.m. and 5 p.m. daily.								
	6.99%		-2.73%		-3.11%		-1.19%	

[1] Sensible heat variation from measurements on temperature rise of ventilation air. Days selected were those not affected by power failure or scheduled temperature changes.

[2] Latent heat variation from measurements on dewpoint rise of ventilation air.

[3] Total heat added to ventilating air.

[4] Ratios approximated from heat and water values, table no. 5.

[5] Using weighted averages of sensible and latent heat.

TABLE 9 -- ESTIMATED AMOUNTS OF MOISTURE VAPORIZED FROM STALL GUTTER LBS./STALL/HR.
EXPERIMENTAL GROUPS

	Winter 1949								Summer 1949									
Approx. Air Temp. °F	4	11	15	21	31	41	50		60	65	69	75	80	85	90	95	99
Lbs./stall/da.[a]	.08	.08	.08	.09	.06	.09	.10		.08	.08	.09	.10	.14	.18	.16	.22	.24
Litter Temp.[b] ±2° F.	30	32	35	34	46	52	63	(± 1° F.)	---	---	---	80	79	85	90	93	94

a. From wt. loss of sample gutter contents.
b. As measured in litter cart when removed twice daily.