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HEAT AND MOISTURE PRODUCTION IN A CLOSED ENVIRONMENT BEEF BUILDING DURING WARM WEATHER

BY

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in partial fulfillment of the requirements for the
degree Master of Science, Major in Agricultural
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1972

HEAT AND MOISTURE PRODUCTION IN A CLOSED ENVIRONMENT BEEF BUILDING DURING WARM WEATHER

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

The design of livestock confinement facilities requires a thorough understanding of environmental parameters and their effects on the animals. Economic considerations require that the design provide conditions necessary for optimum animal growth and gain which will allow the highest possible economic returns for the producer. Heat and moisture production are environmental parameters that must be evaluated to provide a scientific basis for design. Reliable data on the total heat and moisture production of beef cattle in a closed confinement system under actual production conditions are not available. However, these data are available for livestock under controlled laboratory conditions.

The need for improved production facilities is emphasized by the fact that beef consumption is at record levels in the United States with continued growth predicted. The annual per capita consumption of beef and veal in the United States was nearly 73 pounds in 1949 and increased 56 per cent to approximately 114 pounds per person by 1969 (15)[1]. During the same twenty years the population of the United States increased 53 million (7, 8) which represents a significant increase in the demand for beef. Predictions are that the total United States consumption of beef and veal will continue to rise and will be one third greater than present by the

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[1] Numbers in parenthesis refer to literature cited.

end of the decade (15). The demand for beef is also increasing in developed areas throughout the rest of the world.

Increases in demands for beef have stimulated the beef industry to make significant gains in production. The production of beef in the United States has increased by 224 per cent during the last twenty years from 9,439,000,000 pounds to 21,125,000,000 pounds. Beef production in South Dakota paralleled national trends and is the dominant agricultural industry in the state. Livestock and livestock products accounted for over 80 per cent of South Dakota's 1.1 billion dollar income from farm produce marketed in 1970 (15). More than half of this income came from cattle and calf sales which economically makes beef South Dakota's most important agricultural product. South Dakota had 1.7 million head of beef cows and marketed 552,000 head finished to slaughter weight in 1970 which ranked the state sixth in the nation in number of beef cows and tenth in fed cattle marketed (14). South Dakota annually produces nearly twice as many feeder cattle and approximately two million tons more feed grains than are utilized within the state (15). This represents a significant loss of potential income for beef producers and related industries in the state each year.

Significant changes in beef production methods and efficiencies have made increases in output possible. Current national trends are toward greater specialization and increased size of production facilities. Due to severe climatic conditions, availability of space, pollution control regulations, labor costs and other factors, trends in the upper Midwest are toward livestock confinement structures. Available design criteria for confinement housing often prove inadequate in meeting the needs of the producer and the livestock. Since beef is the major agricultural product in South Dakota and climatic conditions are severe, it is vital that a study be initiated which will ultimately provide a solution to environmental control problems. Therefore, this study was conceived to answer the following objectives:

1. Determine the total heat and moisture production in a closed confinement beef building under actual production conditions.
2. Determine sensible and latent heat production inside a closed confinement beef building.
3. Determine the effect of ventilation rates on latent heat production.

REVIEW OF LITERATURE

The production of heat and moisture by livestock influences the environmental conditions in a structure and, therefore, the design of environmental controls for that structure. Many investigators have cited the importance of heat and moisture production data to solve environmental design problems; Bond, Kelly and Heitman (5), Longhouse, Ota and Ashby (21), Walton and Dale (32), Jansen, et al. (19), Reece and Deaton (25) and Stewart (28).

Calorimetric Studies

Individual Livestock. Researchers have studied livestock on an individual basis to gain information about their physiological responses to environmental factors. The effect of ambient temperature, relative humidity, temperature of surrounding surfaces and other factors on heat and moisture production has been investigated. Factors such as age, weight, sex and breed have also been considered. Brody (9) studied the resting metabolism of farm animals by employing indirect calorimetric methods. These studies found the level of metabolism of beef calves to be higher than that of dairy calves. Walton and Dale (32) employed a four pi radiometer-gradient layer calorimeter and drying columns to measure convective, radiant and latent heat losses from individual White Leghorn chickens in a temperature range from 55 to 70 F. Over this temperature range the average radiant and latent heat productions were 13.65 and 3.49 BTU per hour, respectively, for birds weighing from 3.5 to 4.8 pounds.

Jordon and Dale (20) emphasized the effect surroundings have on radient heat transfer from White Leghorn laying hens in a four pi radiometer-gradient layer calorimeter. Conclusions from this study carried out at ambient temperatures of 67.3, 53.5 and 53.4 F were that a 15 per cent change in radiation transfer would occur if wall temperatures were changed 5 degrees. Studies of individual Leghorn laying hens by Roller and Dale (26) revealed that increasing dew point temperatures depressed feed consumption independent of dry bulb temperature. Butchbaker and Shanklin (11) employed a partitional calorimeter to study heat losses of newborn pigs in ambient temperatures of 55, 75, 90 and 105 F and found that sensible heat losses were approximately two thirds by radiation and one third by convection. Latent heat losses comprised approximately 8 per cent of total heat losses at 55 F and nearly 100 per cent at 100 F. Blaxter and Wainman (3) studied the fasting metabolism of seventeen cattle with reference to the effects of age, weight and breed. Results showed that Ayrshire steers produced 100 Kcal/kg $W^{0.73}$/24 hr while Black steers produced 81 Kcal/kg $W^{0.73}$/24 hr and that metabolism increased an average of 16.6 Kcal/24 hr kg weight gain. Morrison, Bond and Heitman (22) found as ambient temperature was increased from 60 to 85 F at a constant 50 F dew point, 198 pound Duroc gilts were able to offset the decrease in sensible heat loss associated with increasing temperature by doubling skin heat loss and tripling lung evaporative heat loss. Studies conducted in a two compartment respiration calorimeter by Roper, Esmay and

Ringer (27) determined that all latent and 40 per cent of the sensible heat loss of 15 month old White Leghorn hens comes from the head area.

Small Groups of Livestock. The need to increase prediction accuracies by minimizing the effect of individual variation has led researchers to investigate small groups of livestock in controlled environmental chambers. A diurnal rhythm in the metabolic rate of chickens was noted by Barott and Pringle (2). The maximum value occurred at 8 a.m. and was followed by a gradual decline to a minimum value at 8 p.m. This respiration calorimeter study also indicated that moisture production from respiration was nearly constant at the point of minimum metabolism. Above this point, rapid increases in moisture production were noted as large amounts of moisture were exhaled to increase body cooling. Ota as cited by Longhouse, Ota and Ashby (21) found that latent heat production per pound live weight of White Leghorn and Rhode Island Red laying hens was nearly 15 per cent of total heat production at 20 F and approximately 60 per cent of the total heat produced at 90 F. Variation in the total heat production of the same species with respect to different breeds and weights held at the same environmental temperature (60 F) was noted when White Leghorn hens produced 9.0 BTU/hr/lb and Rhode Island Red hens, which averaged nearly two pounds heavier, produced 7.4 BTU/hr/lb. Ota, Garver and Ashby (24) found total heat production of five pound Rhode Island Red hens decreased from approximately 54 BTU/hr/hen at 42 F to nearly 34 BTU/hr/hen at 86 F.

Over the same temperature range, sensible heat decreased from nearly 33 BTU/hr/hen to 5 BTU/hr/hen as the latent heat production increased from 21 BTU/hr/hen to 29 BTU/hr/hen. Heitman and Hughes (17) studied the effects of air temperature and relative humidity on body temperature, respiration rates and pulse rates of swine. Results of this study showed increased respiration rates and decreased pulse rates as air temperature increased. Air temperatures of 95 F caused the respiration rates of heavier hogs to double that of small ones subjected to the same environment. Studies by Bond, Kelly and Heitman (5) on the total heat loss of swine concluded that total heat loss from pigs weighing from 75 to 125 pounds was approximately 600 BTU/hr/100 lb at 47 F and nearly 380 BTU/hr/100 lb at 97 F. For the same range of conditions, latent heat loss increased from approximately 18 per cent to nearly 90 per cent of total heat loss. Bond, Kelly and Heitman (6) measured heat and moisture losses of groups of four and five pigs in the California Psychrometric Chamber and found that evaporation became increasingly more important as temperature was increased. At 100 F approximately 90 per cent of animal heat loss was released by vaporization of moisture. Further studies of swine by Bond, Kelly and Heitman (4) found there were no significant differences between total daily heat losses and daily animal evaporative heat losses under diurnally varying temperature as compared to constant temperature losses. Thompson and Stewart (30) found that the total heat production of six dairy cows housed in a psychrometric chamber was much higher than that found by metabolism measurements only. Findings also showed a 20 per cent increase in total heat production as ambient temperatures were lowered from 80 to 10 F. Latent heat production was found to be nearly equal to total heat production at 100 F. Results of ventilation exchange measurements by Thompson (29) showed total heat production of dairy cows decreased from 3800 BTU/hr/1000 lb at 10 F to 2600 BTU/hr/1000 lb at 90 F. The latent heat portion of total heat increased from nearly 600 BTU/hr/1000 lb at 10 F to approximately 2400 BTU/hr/1000 lb at 90 F. Cargill and Stewart (12) studied groups of six lactating Holstein cows and found that increasing the relative humidity from 20 to 80 per cent at a given ambient temperature caused decreases in total heat and latent heat dissipation. Cartwright (13) concluded that Hereford cattle have lower rates of gain at high ambient temperatures than Brahman or Brahman-Hereford cross cattle. Yeck (33) concluded that total heat dissipation estimates of Shorthorn, Brahman and Santa Gertrudis beef calves 10 to 20 weeks old were 5100, 3800, and 4400 BTU/hr/1000 lb, respectively, for both 50 and 80 F ambient temperatures. McDowell as cited by Nelson (23) found that Shorthorn heifers had higher evaporation rates than either Santa Gertrudis or Brahman heifers at air temperatures of 50 and 80 F.

Production Studies

The final step in obtaining data for environmental design is to study livestock in shelters under actual production conditions. Only through studies of this type can accurate assessments be made of all the factors that simultaneously influence total heat and moisture production. Reece and Deaton (25) studied the sensible and latent heat in ventilation air exhausted from a windowless poultry house during summer and winter. Summer total heat production was approximately 16 BTU/hr/lb for 7.5 week old broilers with latent heat being nearly 11 BTU/hr/lb and sensible heat approximately 5 BTU/hr/lb for an average weekly temperature of 81 F. Winter total heat production was approximately 13 BTU/hr/lb with latent heat nearly 6 BTU/hr/lb and sensible heat approximately 7 BTU/hr/lb for an average weekly temperature of 48 F. The amounts of moisture produced by swine in finishing houses with solid, partially slotted and fully slotted floors was studied by Harmon, Dale and Jones (16). Conclusions from this study were that vapor production from a fully slotted floor finishing house was 0.42 as much as that on solid flooring. Noticeably lacking, however, are data from studies of the heat and moisture production of beef cattle under actual production conditions which are essential for proper environmental design.

DESCRIPTION OF RESEARCH FACILITIES

The Farmer's Union Grain Terminal Association's beef research facility located approximately four miles west of Sioux Falls, South Dakota, was used to evaluate heat and moisture production in a beef confinement building under actual production conditions.

The closed confinement portion of this structure measures 40 feet wide by 48 feet long and is divided into pens 16 feet by 14 1/2 feet. The building is oriented such that the long axis runs east and west. Figure 1 illustrates the floor plan, arrangement of environmental control equipment, location of temperature measuring points and recording apparatus. The end walls were constructed of 2-inch by 4-inch studs, 8 feet long, spaced 24 inches on center. A four-mil polyethylene vapor barrier was placed beneath the interior wall sheathing with 3 5/8-inch fiberglass insulation located between the studs. Interior and exterior walls were covered with 1/2-inch and 3/8-inch exterior plywood, respectively. The 8-foot end wall sections were placed on an 8-inch core filled concrete block foundation extending 28 inches above the concrete slotted floor. The side walls were constructed of 2-inch by 6-inch studs, 10 feet long, spaced 24 inches on center. The remainder of the side wall construction was similar to the end walls. The side walls were placed on an 8-inch core filled concrete block foundation extending 2 inches above the slotted floor. Access to the unit was through two 5-foot by 7 1/2-foot insulated sliding doors.

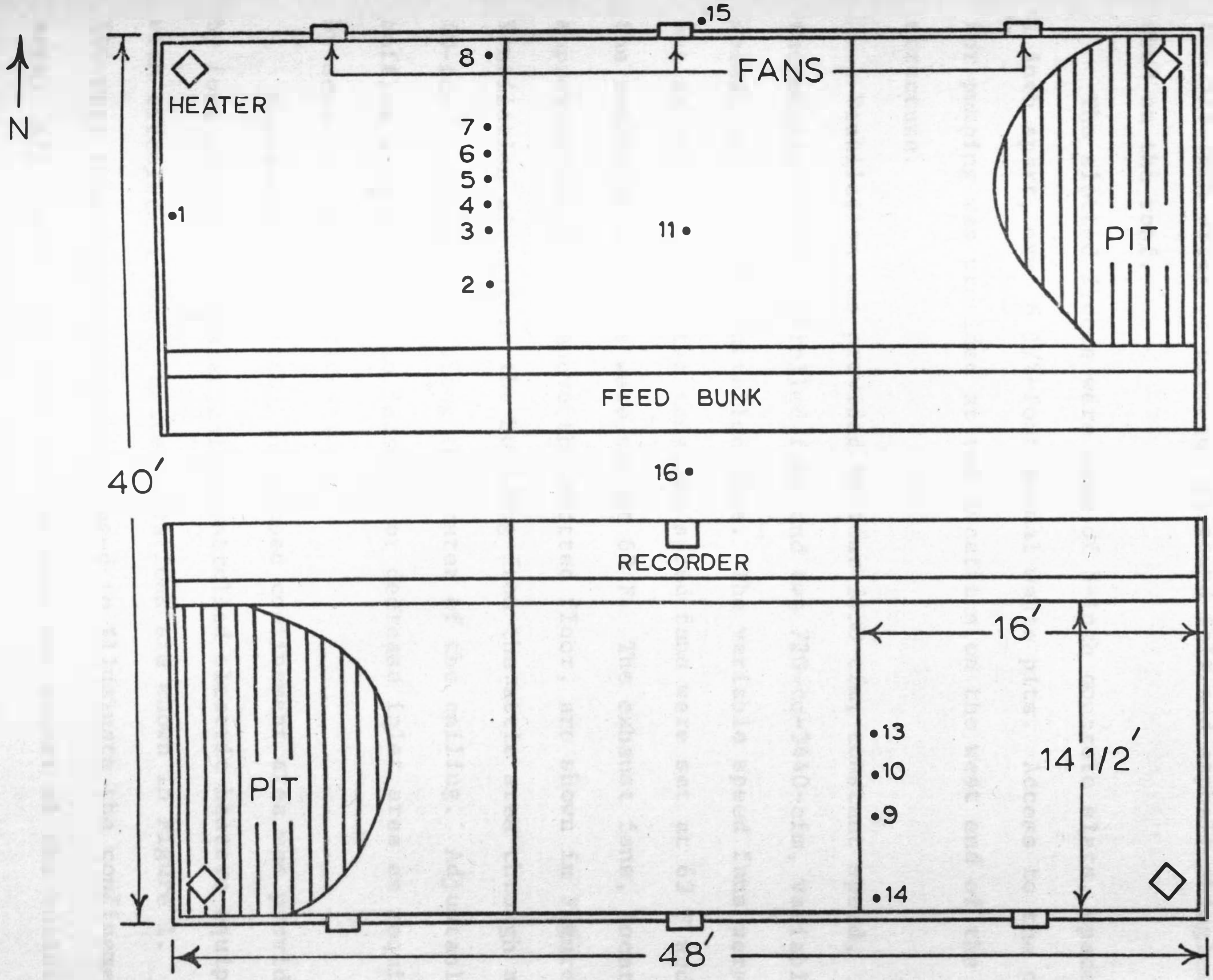

Figure 1. Floor Plan of the Closed Confinement Building; Numbers Refer to Temperature Measurement Locations

The ceiling was constructed of 1/2-inch exterior plywood, a four mil polyethylene vapor barrier and 6 inches of fiberglass insulation. Forty-foot trusses, spaced four feet on center, were used to support the 5/8-inch exterior plywood, 15-pound felt and asphalt shingles used on the roof.

The slotted floors were made of 5-inch concrete slats, spaced 1 inch apart, over 6 1/2-foot animal waste pits. Access to the pits for pumping was provided at two locations on the west end of the structure.

Ventilation was provided by four 3430-cfm, constant speed, thermostatically-controlled fans and two 720-to-3440-cfm, variable speed, solid state controlled fans. The variable speed fans were set at 55 F. Two of the constant speed fans were set at 63 F and the remaining two fans were set at 68 F. The exhaust fans, located approximately 6 feet above the slotted floor, are shown in Figure 1. Ventilation air enters the building from the attic area through a 40-foot baffled inlet along the center of the ceiling. Adjustable baffles were provided to increase or decrease inlet area as required by seasonal and climatic changes.

Supplemental heat for the closed confinement area was provided by four 15-kw, thermostatically-controlled electric heaters equipped with circulation fans. Heater locations are shown in Figure 1. Nine 100-watt incandescent lamps were used to illuminate the confinement area. All thermostats were located near the center of the building approximately 7 feet above the slotted floor.

A four-foot wide concrete feed and cattle handling alleyway, located 24 inches above the slotted floor was constructed full length of the research facility. A pole barn measuring 96 feet by 40 feet, open exposure to the south, was connected directly to the east end of the closed confinement area. Further description of this portion of the research facility was presented by Hellickson, Witmer and Barringer (18).

Temperatures at selected locations in the confinement area were measured with 26-gage copper-constantan thermocouples and recorded by a multi-point, strip-chart, recording potentiometer. Location of the temperature measuring points shown in Figure 1 are as follows:

Point	Location
1	west wall skin temperature
2	beneath the slotted floor
3	1 1/2 feet above slotted floor
4	ceiling skin temperature
5	1 1/2 feet from ceiling
6	5 feet above slotted floor
7	5 feet above slotted floor, wet bulb
8	north wall skin temperature
9	beneath the slotted floor
10	1 1/2 feet above slotted floor
11	attic temperature

Point	Location
13	ceiling skin temperature
14	south wall skin temperature
15	outside temperature
16	inlet temperature

PROCEDURE

Heat and moisture production in a closed environment structure housing 47 head of Angus-Hereford crossbred heifers averaging from 700 to 990 pounds on full ration was studied from June 17, 1971, to October 25, 1971. Care and feeding of the animals were provided by G. T. A. personnel. The animals were fed twice daily and weighed every 28 days. Water was continuously available.

Measurements of the dry bulb and dew point temperatures of inlet and exhaust ventilation air were made at selected intervals throughout the study using a Singer, Vap-Air Moisture Analyst. This apparatus consisted of dry bulb-dew point sensors, a strip chart recorder and a switching mechanism to alternate recording of the sensors.

Careful calibration was performed on each sensor prior to and after each measurement period in the research facility. Calibration was accomplished by placing each sensor in an ice bath apparatus and adjusting the dew point temperature to 32 F. A further check of calibration was made by comparing the readings of the dew point-dry bulb sensors to those of a sling psychrometer.

Inlet air conditions were measured by placing a sensor in the inlet duct. Exhaust air conditions were measured by locating sensors approximately 1 1/2 feet from the inlet side of the exhaust fans. Measurements by each sensor were recorded continuously over 5-minute intervals by the strip chart recorded before switching to another sensor. Continuous measurement of temperatures at locations

1 through 16 (Figure 1) was recorded simultaneously to further monitor the psychrometric properties of the ventilation air.

Air flow quantities were determined by using an inclined manometer to measure the static head against which the fans were exhausting. Ventilation rates were determined from performance curves for the fans provided by the Lau Blower Company, Dayton, Ohio.

Heat and moisture production in the structure was calculated from the psychrometric relationships of the inlet and exhaust air using Ideal Gas Law relationships. Total heat was computed using the relationship presented by Thompson (29):

$$QT = (HE - HI) \times 60 \times cfm/VA$$

QT = total heat production, BTU/hr
HE = enthalpy of exhaust air, BTU/lb
HI = enthalpy of inlet air, BTU/lb
cfm = avg. volume flow rate of air, ft^3/min
VA = specific volume exhaust air, ft^3/lb

Latent heat production was computed using the relationship presented by Roper, Esmay and Ringer (27):

$$QL = (HRE - HRI) \times HFG \times 60 \times cfm/VA$$

QL = latent heat production, BTU/hr
HRE = humidity ratio exhaust air, lb H_2O/lb air
HRI = humidity ratio inlet air, lb H_2O/lb air
HFG = latent heat of vaporation, BTU/lb H_2O

cfm = avg. volume flow rate of air, ft^3/min

VA = specific volume exhaust air, ft^3/lb

A computer program was written adapting Brooker's (10) mathematical solution of the psychrometric chart to solve the total and latent heat production equations. Sensible heat production was calculated by subtracting latent heat production from total heat production.

Data collected were adjusted for sensible and latent heat gains due to lights and human influences and conductive heat losses or gains by the structure. Average weight of the animals was calculated by projecting the average daily gain for that 28 day growth period to the day data were recorded. Adjustments in animal weight and density were also made for two animals removed from the building during the course of the study. Appendix B illustrates calculation of the overall conductance value for the structure. Appendix C lists the values used to correct for sensible and latent heat production by lights and people in the building during data collection. Heat and moisture production data recorded were averaged over 30 minute intervals for each recording period.

Adjusted data were analyzed using step-wise multiple regression techniques in which total heat production, latent heat production and sensible heat production were the dependent variables. The independent variables included dry bulb temperature, dew point temperature, cfm, animal weight and animal density (ratio of building volume to total animal weight). Only linear relationships were studied as preliminary analysis of the data did not indicate curvilinear trends.

RESULTS AND DISCUSSION

Heat Production

Total Heat. Studies to determine the total heat and moisture production in the closed confinement beef building under actual production conditions were made during periods requiring maximum ventilation rate. Total heat production ranged from 500 BTU/hr/head on July 8, 1971, to 5720 BTU/hr/head on July 13, 1971, and averaged 3020 BTU/hr/head for the study. Temperatures ranged from 67 F at 11:15 a.m. on July 13, 1971, to 97 F at 4:30 p.m. on August 13, 1971, with an average value of 80 F. Figure 2 illustrates the variation in total heat production as affected by dry bulb temperature. No significant relationships between total heat production and dry bulb temperature, dew point temperature, ventilation rate, animal weight or animal density were obtained.

Latent Heat. Latent heat production ranged from 1110 BTU/hr/head on August 24, 1971, to 4950 BTU/hr/head on August 17, 1971, with an average value of 2900 BTU/hr/head. The following significant prediction equation relating latent heat production to dew point temperature was determined:

$$Y = -293.4 + 57.0\ X$$

Y = latent heat production, BTU/hr/head

X = dew point temperature, °F

However, even though significance was indicated, dew point temperature predicted only 17.9 per cent of the total variation in latent heat production. Figure 3 illustrates the variation in

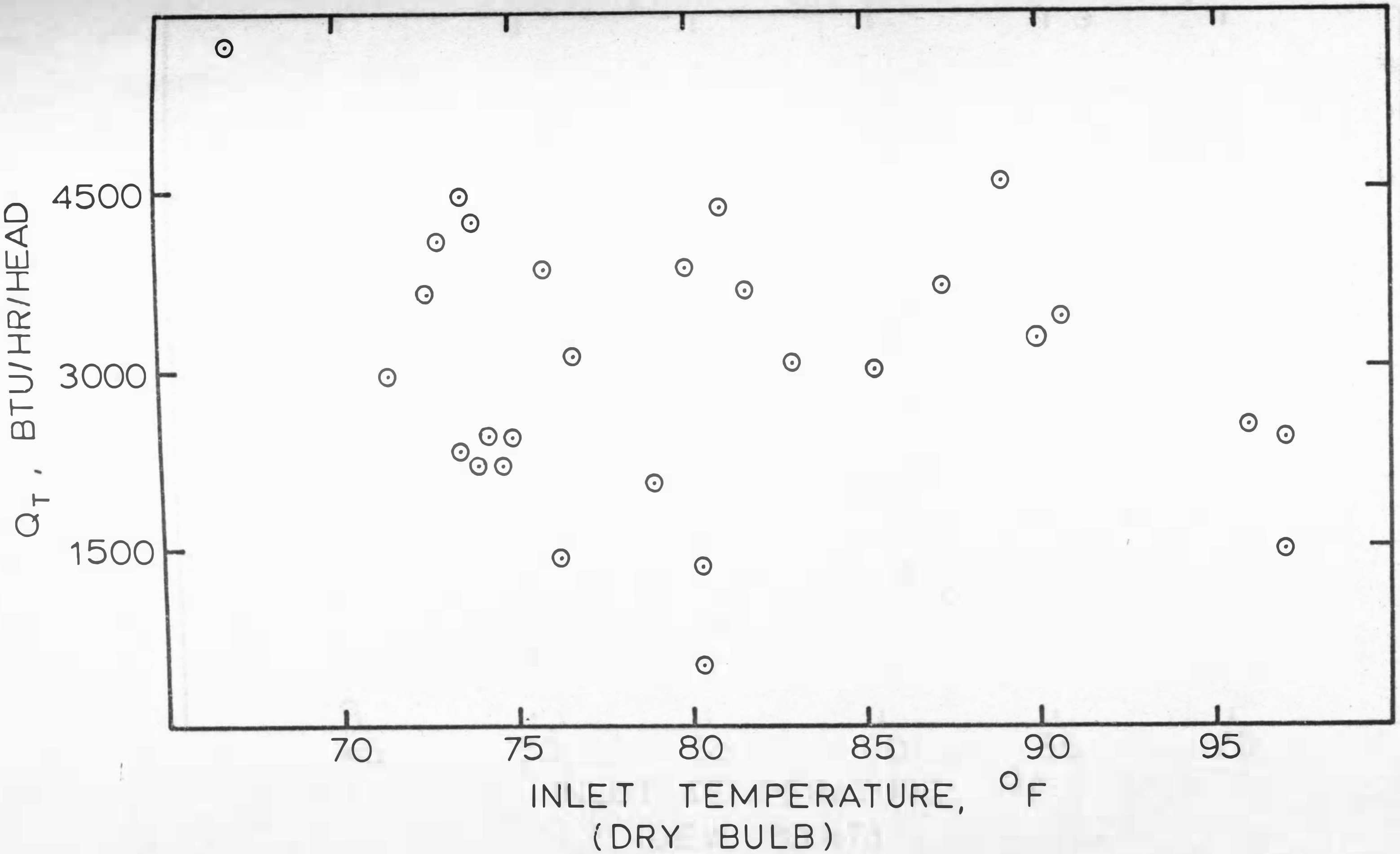

Figure 2. Total Heat Production as Affected by Inlet Dry Bulb Temperature

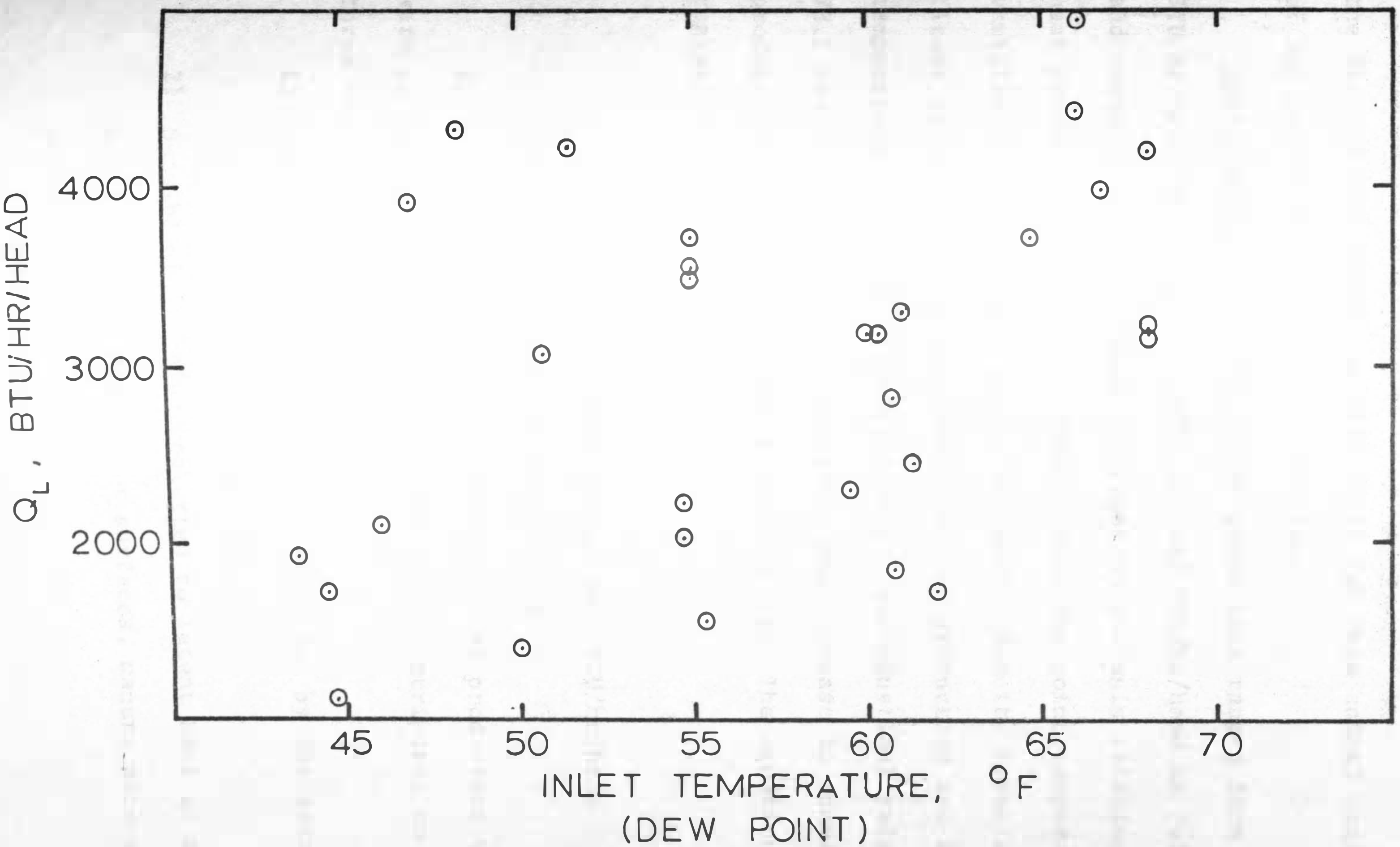

Figure 3. Latent Heat Production as Affected by Inlet Dew Point Temperature

latent heat production related to dew point temperature. Some of the factors attributing to this variation were animal activity, time of day and depth of manure in the pits.

Sensible Heat. Sensible heat production ranged from -1170 BTU/hr/head on August 17, 1971, to 1480 BTU/hr/head on July 13, 1971, and averaged 60 BTU/hr/head. Regression analysis relating sensible heat production to dry bulb temperature, dew point temperature, ventilation rate, animal weight and animal density revealed a significant relationship between sensible heat production and dry bulb temperature with an R^2 (coefficient of determination) value of 73.1 per cent. Figure 4 illustrates the decrease in sensible heat production with increased inlet temperature. The equation for the regression line is:

$$Y = 4982.5 - 60 X$$

Y = sensible heat production, BTU/hr/head

X = dry bulb temperature, °F

At temperatures above 80 F sensible heat production values were generally negative. This trend may be attributed to at least three factors:

1) Reduction of sensible heat production by the animals as ambient temperature increased.
2) Sensible heat being converted to latent heat as moisture was evaporated from floor surfaces, manure pits and surfaces of the waterers.

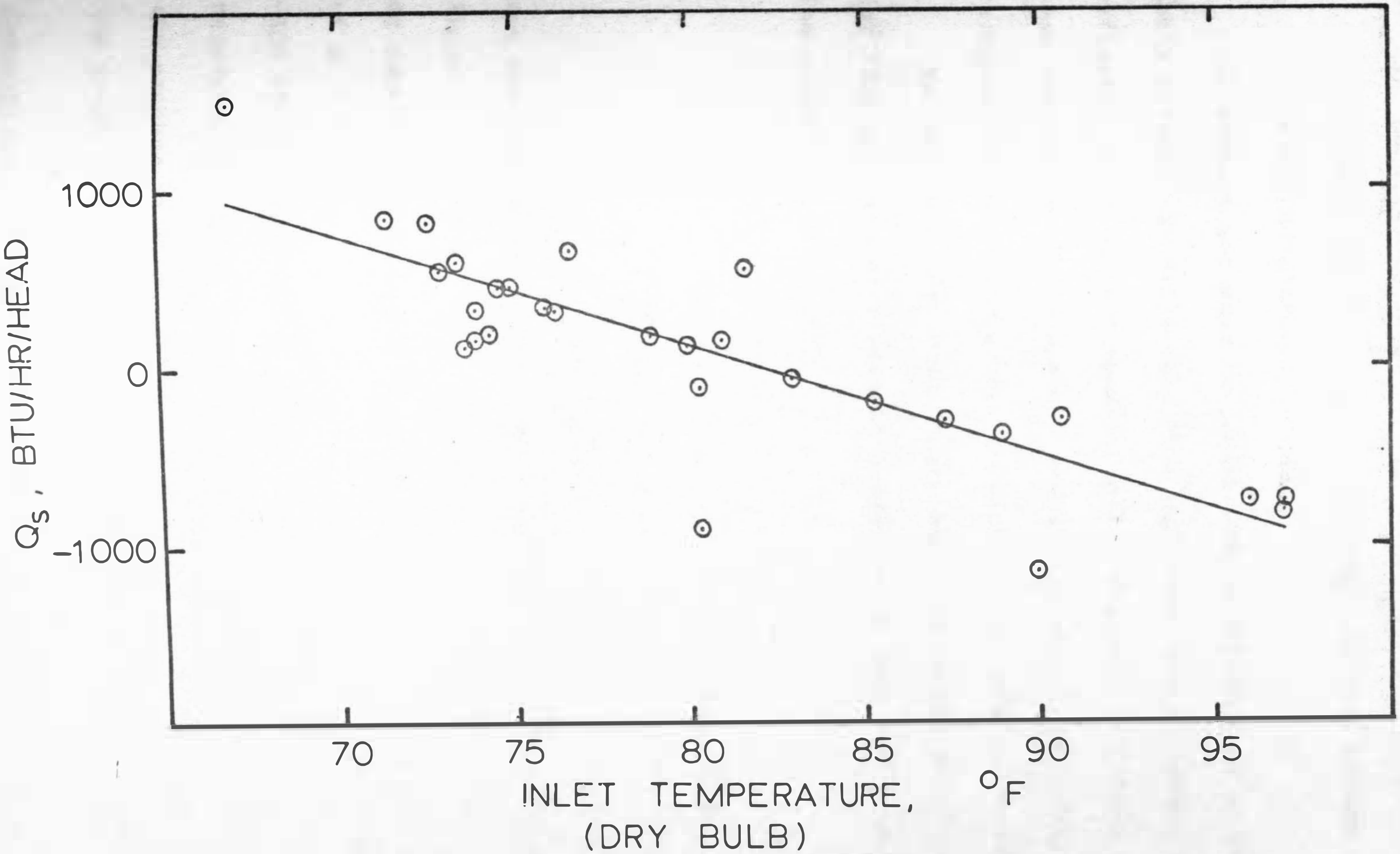

Figure 4. Sensible Heat Production as Affected by Inlet Dry Bulb Temperature

3) Capacitance effect of the floors and manure pits acting as a heat sink for temporary storage of heat during periods of high temperature.

No attempt was made to isolate these factors and to determine their effect. Sensible heat that was converted to latent heat was reflected in total heat measurements. However, variation in sensible heat production of the animals and the amounts of sensible heat being absorbed by the floors and manure pits were not measured.

Variations in dry bulb temperature and animal density accounted for 78.1 per cent of the total variation in sensible heat production. The prediction equation

$$Y = 8238.6 - 69.9\ X_1 - 103.6\ X_2$$

Y = sensible heat production, BTU/hr/head

X_1 = dry bulb temperature, °F

X_2 = animal density, ft^3/lb

was used to construct the sensible heat production lines shown in Figure 5. This equation illustrates the effect animal weight has on sensible heat production. For example, at a constant temperature of 80 F sensible heat production at 27 ft^3/lb is approximately -150 BTU/hr/head. At 25 ft^3/lb sensible heat production rises to nearly 56 BTU/hr/head and at 23 ft^3/lb approximately 260 BTU/hr/head are produced. These data demonstrate a significant improvement in the prediction of sensible heat production of beef cattle.

Comparisons With Previous Studies

Average total, latent and sensible heat production values

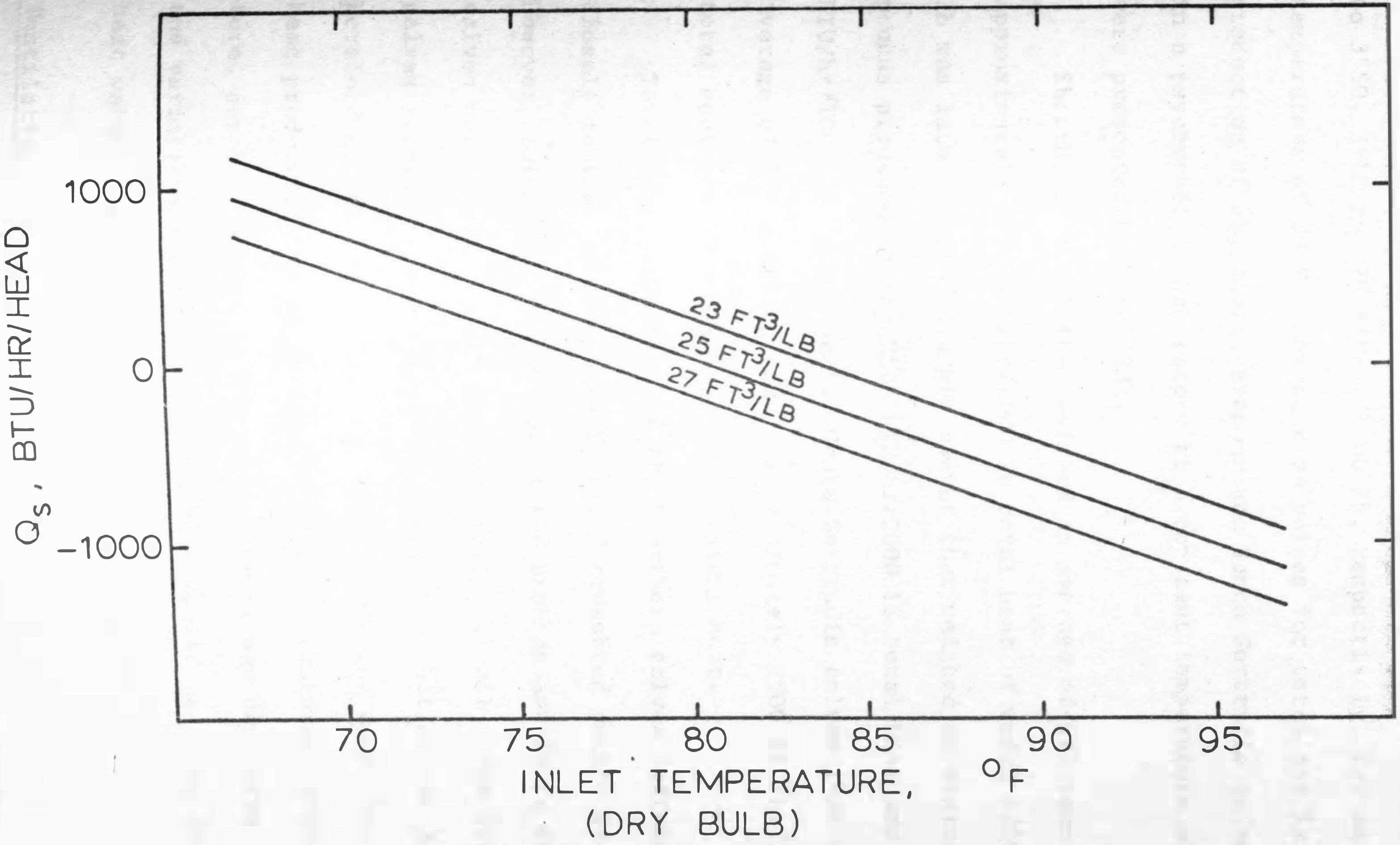

Figure 5. Sensible Heat Production as Affected by Inlet Dry Bulb Temperature and Animal Density

previously presented in this report as BTU/hr/head are equivalent to 3550, 3410 and 70 BTU/hr/1000 lb, respectively, for an average temperature of 80 F. Comparative values for total and latent heat production of Shorthorn, Brahman and Santa Gertrudis calves reared in a psychrometric laboratory at a constant temperature of 80 F were presented by Yeck (33).

Shorthorn calves that weighed an average of 623 pounds produced approximately 3000 BTU/hr/1000 lb total heat of which 2200 BTU/hr/1000 lb was latent heat. Brahman calves that weighed an average of 772 pounds produced nearly 2500 BTU/hr/1000 lb total heat and 1400 BTU/hr/1000 lb latent heat. Santa Gertrudis calves that weighed an average of 815 pounds produced approximately 2500 BTU/hr/1000 lb total heat and 1800 BTU/hr/1000 lb latent heat.

Total heat production of the Shorthorn calves corresponds closely to that of the Angus-Hereford crossbred cattle studied. However, total heat production of the Brahman and Santa Gertrudis calves was lower. Latent heat production of all three breeds of calves reported was considerably lower than that of the Angus-Hereford crossbred cattle. Sensible heat being converted to latent heat production during periods of high temperatures, sol-air temperature, depth of manure in the pits, time of day data were recorded, and variations due to breed would be expected to cause the higher heat values received in this study.

Ventilation Effects

Ventilation Rates. An auxiliary study to determine the effect ventilation rate had on latent heat production involved data obtained when ventilation rates were manually adjusted to 7240, 14200 and 19680 cfm. Regression analysis of these data showed no significant relationships. Note, however, that manually adjusting ventilation rates to volumes other than that required by environmental conditions at that specific time created unrealistic situations in the structure. This study did not indicate that changing air flow rates significantly affect heat and moisture production in the structure.

CONCLUSIONS

The following conclusions were reached during this investigation:

1. No significant relationships were found between total heat production and dry bulb temperature, dew point temperature, ventilation rate, animal weight or animal density.
2. A significant relationship between latent heat production and dew point temperature was found. However, dew point temperature accounted for only 17.9 per cent of the total variation in latent heat production.
3. Dry bulb temperature significantly accounted for 73.1 per cent of the total variation in sensible heat production.
4. Dry bulb temperature and animal density significantly accounted for 78.1 per cent of the variation in sensible heat production.
5. Sensible heat production values were generally negative above 80 F.
6. Sensible heat production increased as animal weight increased.
7. Average total and latent heat production values were higher than that of Shorthorn, Brahman and Santa Gertrudis calves.
8. No significant relationships between ventilation rate and heat and moisture production were found.

SUMMARY

An investigation was performed to determine the total heat and moisture production in a closed confinement beef building housing 47 head of Angus-Hereford crossbred heifers for the 130-day period from June 17, 1971, to October 25, 1971. Sufficient reliable data of this type are presently unavailable for the design of beef confinement structures.

Results of this study allowed several significant relationships to be formulated. Variation in dew point temperature significantly accounted for 17.9 per cent of the variation in latent heat production. Sensible heat production was found to be significantly related to dry bulb temperature and animal density. Dry bulb temperature accounted for 73.1 per cent of the variation in sensible heat production and dry bulb temperature plus animal density accounted for 78.1 per cent of the variation. Sensible heat production was generally negative at temperatures above 80 F. Total and latent heat production values were higher than those previously reported for Shorthorn, Brahman and Santa Gertrudis calves of approximately the same weight.

No significant relationship was shown between total heat production and dry bulb temperature, dew point temperature, ventilation rate, animal weight or animal density. An auxiliary study to determine the effect ventilation rate had on latent heat production did not indicate that changing air flow rates significantly affected heat and moisture production.

The significant prediction of increased sensible heat production as animal density increased illustrates the need to increase ventilation in the building as animals became heavier or numbers were increased. Negative sensible heat values above 80 F indicate the need for increased ventilation as this heat is either being absorbed or changed to latent heat which must be removed from the structure. Further improvements in confinement housing design may be realized as future studies define more of the parameters that affect heat and moisture production.

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APPENDIX

APPENDIX A. Heat and Moisture Production Data

Table 1. Psychrometric Conditions and Heat and Moisture Production in the Beef Confinement Unit

Date	Temperature, °F				Ventilation	Heat Production			Avg.
	Dry Bulb		Dew Point		Rate	BTU/Hr/Head			Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
070871									
1000	73	73	48	56	19680	4870	4730	140	706
1015	73	73	48	55	19680	4170	4070	100	
1030	74	74	49	56	19680	4320	4190	130	
1100	74	75	46	54	19680	4990	4410	580	
1115	74	74	48	54	19680	3500	3410	90	
1230	80	78	51	53	19680	240	1140	-900	
1245	80	78	50	52	19680	210	1100	-890	
1300	81	78	48	53	14200	1060	1980	-920	
071371									
1100	67	70	52	58	19680	5410	3940	1470	721
1115	67	70	51	58	19680	6020	4530	1490	
1330	74	74	55	58	19680	2060	2050	10	
1345	74	74	55	58	19680	2060	2050	10	
1400	74	75	54	57	19680	2450	1980	470	
071571									
1000	73	74	55	60	19680	4080	3530	550	727
1015	73	74	55	60	19680	4080	3530	550	
1030	74	74	55	58	19680	2070	2040	30	
1045	74	75	55	58	19680	2510	2040	470	
1100	75	75	54	58	19680	2730	2660	70	
1115	76	76	55	60	19680	3610	3500	110	
1130	76	77	55	60	19680	4050	3490	560	
1300	80	80	55	60	19680	3590	3470	120	
1315	80	80	55	61	19680	4400	4240	160	
1330	80	80	55	60	19680	3590	3470	120	
1345	80	80	55	59	19680	2810	2720	90	
1400	81	80	56	57	19680	190	640	-450	

Table 1. Continued

	Temperature, °F				Ventilation	Heat Production			Avg.
Date	Dry Bulb		Dew Point		Rate	BTU/Hr/Head			Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
071571									
1415	80	80	55	57	19680	1320	1300	20	727
072271									
1000	76	78	62	65	19680	3490	2520	970	735
1010	77	78	61	64	19680	2950	2440	510	
1020	77	78	61	64	19680	2950	2440	510	
1030	78	79	61	63	19680	2060	1580	480	
1045	79	79	61	63	19680	1620	1600	20	
1100	80	80	60	63	19680	2430	2360	70	
072971									
1000	62	67	45	55	7240	2950	2030	920	769
1030	62	67	45	54	7240	2700	1790	910	
1045	63	67	45	55	7240	2780	2030	750	
1100	62	68	45	55	7240	3120	2030	1090	
1115	62	67	45	55	7240	2980	2090	890	
1130	63	67	46	55	7240	2630	1910	720	
080571									
1000	69	71	52	59	14200	4190	3430	760	780
1015	70	71	53	58	14200	2830	2440	390	
1030	70	71	52	58	14200	3290	2880	410	
1045	71	72	53	58	14200	2820	2430	390	
081071									
1445	82	83	52	57	19680	3790	3200	590	795
1500	81	82	50	55	19680	3560	3000	560	
1515	81	82	50	55	19680	3560	3000	560	
081771									
1000	80	80	68	72	19680	4360	4210	150	809
1015	81	81	68	72	19680	4350	4200	150	

Table 1. Continued

Date	Temperature, °F				Ventilation	Heat Production			Avg.
	Dry Bulb		Dew Point		Rate	BTU/Hr/Head			Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
081771									
1030	82	82	68	72	19680	4350	4190	160	809
1045	82	82	68	71	19680	3210	3120	90	
1100	83	83	68	71	19680	3200	3110	90	
1115	84	83	68	71	19680	2750	3110	-360	
1130	85	84	68	71	19680	2750	3100	-350	
1145	85	85	68	71	19680	3190	3090	100	
1200	86	85	68	71	19680	2740	3090	-350	
1215	86	85	67	70	19680	2650	3000	-350	
1230	88	87	67	71	19680	3730	4030	-300	
1245	88	87	66	71	19680	4730	4960	-230	
1300	89	88	66	71	19680	4710	4950	-240	
1315	89	87	66	71	19680	4270	4960	-690	
1330	89	88	66	71	19680	4710	4950	-240	
1345	90	87	66	70	19680	2710	3900	-1190	
1400	90	87	66	71	19680	3820	4960	-1140	
1415	90	89	65	69	19680	3480	3770	-290	
1430	91	90	65	69	19680	3470	3760	-290	
1445	91	90	64	68	19680	3350	3640	-290	
082071									
1000	72	74	60	64	19680	4340	3360	980	815
1010	73	74	61	64	19680	3050	2560	490	
1020	73	75	61	64	19680	3500	2550	950	
1030	74	75	62	64	19680	2190	1730	460	
1040	75	76	62	64	19680	2190	1720	470	
1050	75	76	62	64	19680	2190	1720	470	
082371									
1415	95	93	61	66	19680	3480	4180	-700	821

Table 1. Continued

	Temperature, °F				Ventilation	Heat Production			Avg.
Date	Dry Bulb		Dew Point		Rate	BTU/Hr/Head			Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
082371									
1430	96	94	61	65	19680	2530	3290	-760	821
1445	97	95	61	64	19680	1620	2420	-800	
1500	97	95	60	64	19680	2430	3180	-750	
1515	97	95	60	64	19680	2430	3180	-750	
1530	97	95	60	64	19680	2430	3180	-750	
1545	97	95	60	64	19680	2430	3180	-750	
1600	97	95	60	64	19680	2430	3180	-750	
1615	97	95	60	63	19680	1530	2340	-810	
082471									
1100	71	73	46	50	19680	3050	2090	960	823
1110	71	73	46	50	19680	3050	2090	960	
1120	72	73	46	50	19680	2590	2090	500	
1130	72	74	46	50	19680	3050	2090	960	
1140	73	74	45	48	19680	1960	1480	480	
1150	73	74	44	48	19680	2450	1950	500	
1200	74	75	45	48	19680	1940	1470	470	
1210	74	76	44	48	19680	2900	1940	960	
1220	75	76	44	48	19680	2440	1940	500	
1230	75	76	43	48	19680	2910	2390	520	
1240	75	76	44	47	19680	1900	1420	480	
1250	76	76	44	46	19680	920	920	0	
1300	76	77	45	47	19680	1400	950	450	
1310	77	78	45	48	19680	1950	1460	490	
091071									
0940	61	65	50	61	7240	3510	2800	710	857
0950	62	67	50	63	7240	4320	3410	910	
1000	64	66	50	61	7240	3160	2790	370	

Table 1. Continued

Date	Temperature, °F Dry Bulb		Dew Point		Ventilation Rate	Heat Production BTU/Hr/Head			Avg. Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
091071									
1010	66	68	50	63	7240	3790	3400	390	857
1020	67	69	50	58	19680	6280	5230	1050	
1030	68	70	50	58	19680	6270	5220	1050	
1040	71	71	50	58	19680	5340	5210	130	
1050	72	72	50	57	19680	4570	4470	100	
1100	72	72	50	58	19680	5330	5190	140	
1130	74	74	50	57	19680	4560	4440	120	
1150	74	74	50	57	19680	4560	4440	120	
1210	75	75	50	58	19680	5300	5160	140	
1230	75	75	50	58	19680	5300	5160	140	
1250	76	76	50	57	19680	4540	4420	120	
1310	76	76	50	57	19680	4540	4420	120	
1330	77	77	50	56	19680	3810	3710	100	
1350	78	78	50	56	19680	3810	3710	100	
1410	79	79	49	54	19680	3000	2930	70	
091471									
1430	65	70	35	46	10725	3790	2490	1300	869
1445	65	70	35	46	10725	3790	2490	1300	
1500	66	70	35	46	10725	3540	2490	1050	
1530	66	70	35	44	14200	3990	2600	1390	
1545	67	70	36	44	14200	3390	2350	1040	
1615	66	69	38	41	19680	2580	1200	1380	
1630	66	69	38	41	19680	2580	1200	1380	
100171									
1300	70	71	62	66	19680	4120	3580	540	921
1310	70	71	62	68	19680	6160	5550	610	
1320	70	71	62	67	19680	5120	4550	570	

Table 1. Continued

Date	Temperature, °F				Ventilation	Heat Production			Avg.
	Dry Bulb		Dew Point		Rate	BTU/Hr/Head			Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
100171									
1330	70	71	62	68	19680	6160	5550	610	921
1340	70	71	62	67	14200	3680	3280	400	
1400	70	71	62	68	14200	4420	4000	420	
1410	71	72	63	69	14200	4550	4120	430	
1420	71	73	63	69	14200	4870	4110	760	
1430	70	72	62	68	14200	4740	3990	750	
1440	70	73	62	69	14200	5830	4720	1110	
1450	70	73	63	70	7240	3010	2480	530	
1500	71	74	63	70	7240	3010	2470	540	
1510	72	74	64	70	7240	2500	2150	350	
1520	72	74	64	71	7240	2920	2550	370	
100471									
1350	69	69	42	49	19680	3530	3460	70	932
1430	70	70	41	46	19680	2330	2290	40	
1500	70	72	41	47	14200	2710	2020	690	
101171									
1040	52	58	27	44	7240	3460	2360	1100	951
1100	53	58	27	43	7240	3100	2180	920	
1120	54	58	27	43	7240	2930	2180	750	
1200	54	58	26	42	7240	2840	2120	720	
1230	55	59	26	42	7240	2840	2110	730	
1300	56	60	25	41	7240	2770	2040	730	
1330	57	60	25	40	7240	2430	1880	550	
1400	58	60	25	33	14200	2490	1790	700	
1410	59	60	25	33	14200	2130	1790	340	
1430	60	61	27	31	19680	1740	1790	-50	

Table 1. Continued

Date	Temperature, °F Dry Bulb		Temperature, °F Dew Point		Ventilation Rate	Heat Production BTU/Hr/Head			Avg. Weight
Time	Inlet	Exhaust	Inlet	Exhaust	cfm	Total	Latent	Sensible	lb.
101971									
1050	53	59	39	51	7240	3320	2220	1100	974
1100	53	60	39	51	7240	3490	2230	1260	
1120	53	60	39	52	7240	3730	2460	1270	
1130	54	60	39	52	7240	3550	2460	1090	
1200	54	60	38	50	7240	3260	2180	1080	
1220	55	61	38	50	14200	6400	4220	2180	
1230	56	60	38	46	14200	4060	2630	1430	
1240	56	60	39	46	14200	3770	2360	1410	
1250	56	60	38	46	14200	4070	2650	1420	
1300	58	60	40	43	19680	2310	1350	960	
1320	59	60	38	44	19680	3170	2660	510	
1330	59	60	38	43	19680	2680	2180	500	
102571									
1130	59	65	54	62	7240	3360	2260	1100	990
1200	60	66	54	63	7240	3700	2570	1130	
1210	60	64	54	60	14200	4680	3230	1450	
1220	60	63	54	58	14200	3160	2080	1080	
1230	60	63	54	59	14200	3740	2650	1090	
1245	61	63	54	56	19680	2360	1400	960	
1255	61	63	54	58	19680	3890	2890	1000	
1305	62	63	54	57	19680	2630	2130	500	
1310	62	63	54	58	19680	3400	2890	510	
1320	62	64	54	59	19680	4680	3670	1010	
1330	62	65	54	58	14200	3120	2070	1050	
1340	63	65	55	59	14200	2840	2140	700	
1400	64	67	55	59	7240	1600	1080	520	

Table 1. Continued

Date Time	Temperature, °F Dry Bulb Inlet	 Exhaust	 Dew Point Inlet	 Exhaust	Ventilation Rate cfm	Heat Production BTU/Hr/Head Total	 Latent	 Sensible	Avg. Weight lb.
102571									
1410	64	68	55	63	7240	3050	2320	730	990
1420	65	68	55	60	7240	1900	1370	530	
1430	65	68	55	63	7240	2870	2320	550	

APPENDIX B. Heat Transmission Components of the Beef Confinement Building

Table 2. Heat Transmission Components of the Beef Confinement Building (1)

Material	Resistance	Conductance Coefficient	Conductance Heat Loss
Side Walls:	R = 15.57	U = .0642	61.66 BTU/hr/°F
End Walls:	R = 14.67	U = .0682	54.53 BTU/hr/°F
Doors:	R = 7.49	U = .1335	8.54 BTU/hr/°F
Ceiling:	R = 22.91		
Roof:	R = 2.00		
(Roof and Ceiling Combined):		U = .0406	77.92 BTU/hr/°F
Foundation:			
8-in. Blocks:	R = 3.03	U = .3300	
12-in. Blocks:	R = 6.13	U = .1631	
			95.87 BTU/hr/°F
Primeter Loss:	.55 BTU/hr/linear foot/°F		96.80 BTU/hr/°F
		Total Conductance Heat Loss:	395.35 BTU/hr/°F

APPENDIX C. Correction Factors for Sensible and Latent Heat Production

Table 3. Correction Factors for Sensible and Latent Heat Production

Sensible Heat:

9 - 100 watt incandescent lights = 3072 BTU/hr

1 person (moderately heavy work) = 375 BTU/hr (30)

Latent Heat:

1 person (moderately heavy work) = 625 BTU/hr (30)