RESEARCH BULLETIN 808 JULY, 1962

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

ELMER R. KIEHL, *Director*

Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

LXV. INFLUENCE OF RADIANT HEAT SINK ON THERMALLY-INDUCED STRESS IN DAIRY CATTLE

ROBERT L. BEDWELL AND MILTON D. SHANKLIN

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

(Publication Authorized July 20, 1962)

COLUMBIA, MISSOURI

ABSTRACT

Thermally-induced stress imposed by high temperatures, theoretically, could be relieved by radiant cooling. The purposes of this study were: (1) to determine the effects of radiant cooling panels on the relief of thermally-induced stress, and (2) to obtain design criteria for radiant cooling systems for livestock shelters.

Three control and three experimental non-lactating Guernsey cows were housed in one six-stanchion chamber of the Missouri Climatic Laboratory. Above each experimental cow a fluid-chilled panel was suspended vertically from the apex of a V-shaped aluminum-foil reflector. Dummy panel-radiation reflector units, physically similar to the experimental units, were suspended above each control cow.

During the five-week study, chamber temperature was held at 90°F and relative humidity at 50 percent. Refrigerated panel surface temperatures were varied weekly as follows: first week, 40°F; second week, 20°F; third week, 35°F; fourth week, 30°F; and fifth week, 40°F.

An analysis of variance involving rectal temperature, respiration rate, skin temperature, back-skin temperature, hair temperature, back-hair temperature, water consumption, ambient air temperature above the cow's back, and globe thermometer temperature was made between groups and within each group. Measurements that were associated with the heat-absorbing characteristics of the radiant cooling panels were: (1) total heat transferred to the refrigerating fluid from all sources, (2) mean panel surface temperature, and (3) the heat exchange to panel by radiation.

Conclusions drawn from the results of this study were:

1. There was a highly significant difference between Guernsey cows in their ability to withstand high temperature and humidity.
2. Responses of the experimental group to the discrete differences in panel surface temperature were significant at the 1 percent level.
3. Acclimation during the study period was a major factor contributing to the significant difference between "treatments" (panel surface temperatures) within the experimental group and "weeks" within the control group.
4. The refrigerated panels were effective in reducing respiration rate, skin temperature, hair temperature, water consumption, ambient air temperature above the animal's back, and globe thermometer temperatures of the experimental group, compared to the control group, but were not effective in reducing rectal temperatures.
5. The most effective panel surface temperature for maximum radiant heat transfer was the lowest temperature at which ice or frost was not present.

CONTENTS

ACKNOWLEDGMENTS

Acknowledgments are made to M. M. Jones for assistance and counsel; to Ivan L. Berry, AERD, ARS, USDA, for supplying equipment and instruments; to A. C. Ragsdale for furnishing the test animals; to Cecil L. Gregory for assisting with the analysis of variance; to Donald L. Braker, Loren A. Little and Samuel H. Barrett for helping construct experimental equipment and collecting data.

The information in this bulletin was condensed from a thesis submitted by the senior author to the Graduate Faculty of the University of Missouri in partial fullfillment of the requirements for the degree of Master of Science.

This bulletin reports on Department of Agricultural Engineering Research Project 136, Environmental Requirements for Farm Animal Shelters. Project 136 is a part of the North Central Regional Project NC-23 on Farm Structures Research and is partially financed by funds authorized by Section 9b3, Title I of the Research and Marketing Act of 1946.

Environmental Physiology and Shelter Engineering

With Special Reference to Domestic Animals

LXV. INFLUENCE OF RADIANT HEAT SINK ON THERMALLY-INDUCED STRESS IN DAIRY CATTLE

ROBERT L. BEDWELL AND MILTON D. SHANKLIN

INTRODUCTION

Thermally-induced stress imposed by high temperatures is accompanied by significant production losses in livestock. In considering the control of environment in livestock shelters, then, emphasis should be placed on the relief of thermally-induced stress.

While air-conditioned structures offer an immediate solution to this problem, they have not proven economical to date. Radiant cooling panels, to provide a heat-sink for surface dissipated heat, offer a possible economical solution.

A previous study, made by Shanklin and Stewart (10), investigated the relationship between the physiological effects of a refrigerated panel on thermally-stressed cows and (1) panel temperature, (2) panel position with respect to the animal, (3) panel surface conditions, and (4) the emissivity of the structural surround.

The purposes of this latest study were: (1) to determine the effects of radiant cooling panels on relieving thermally-induced stress[1] in dairy cattle, and (2) to obtain design criteria that could be used in the design of radiant cooling systems for livestock shelters.

REVIEW OF LITERATURE

Some of the factors affecting radiant energy transfer are: the temperature differential between the emitting and absorbing surfaces, the emissivities of these surfaces, the geometrical factor which is based on shape and relative position of the surfaces to one another, and the presence of materials in the flow path of the electromagnetic waves that would tend to absorb radiant energy.

The emissivity of a surface depends on the temperature of the surface, relative thickness of surface coating, and the degree of roughness of the surface. The emissivity of highly polished aluminum plate or foil to 100°F blackbody radiation is between 0.03 and 0.05. Accumulations of dust and oil can produce emissivities of 0.1 to 0.8 (8). A flat black lacquer surface, of a temperature 76° to 100°F, usually has an emissivity between 0.875 and 0.97, depending on lacquer thickness.

[1] An average animal is considered to be under stress when the rectal temperature and respiration rate deviate from established normals.

The presence of moisture or ice on a surface can alter the emissivity. Hoarfrost has one of the highest emissivities known in the infrared spectrum at 0.986 (11).

Hutchinson (6) studied the effects of infrared gaseous radiation and concluded that (in a room 15 feet by 15 feet by 9 feet covered with materials having a reflectivity of 90 percent or better) gaseous absorption of radiant energy will account for 50.3 percent of the total energy emitted from an occupant.

Bond and Kelly (2) determined mean radiant temperature with a blackened hollow sphere (globe thermometer) having a small physical size compared to its surroundings. In essence, the mean radiant temperature of a specific enclosed space is an index for predicting the thermal comfort of an "occupant" in that space due to the relative exchange of radiant energy between the "occupant" and the surroundings.

When the temperature of a refrigerated panel surface is below the dewpoint of the surrounding air, condensation of water vapor on the panel surface will occur. The formation of frost on the surface greatly influences the convective heat transfer from the surrounding air (13), and the transfer of the heat of fusion of water to the panel surface. The frost-air interface remains at 32°F regardless of frost depth or panel surface temperature.

Rectal temperature is considered a good indicator of thermally-induced stress, since the dairy animal regulates the temperature of its vital organs at an almost constant temperature. The rectal temperature is above the normal level of 101.1 ± 0.5°F when the environmental temperature is above 80°F (3).

As the temperature difference between the surface of the animal and the ambient decreases, the burden of heat dissipation is shifted to vaporization with a consequent increase in the respiration rate. The respiration rate has a limited use as an indicator of thermally-induced stress, since it reaches a maximum (about 150 respirations per minute in most breeds at about 100°F) above which an increase in environmental temperature is not reflected in an increased respiration rate (7).

Increasing hair and skin temperatures reflect rising environmental temperature and are not reliable indicators of deep-body temperatures (12). Around 105°F the surface temperature is equal to the environmental temperature (15).

Water consumption declines in lactating Jersey and Holstein cows above 80°F. Conversely, non-lactating cows and heifers increase their water intake at temperatures above 80°F (9).

Brooker (4) found that hair and skin at near ordinary body and environmental temperatures behave like blackbodies with an emissivity around 0.97. Skin emits predominantly in the infrared form 2 to beyond 40 microns.

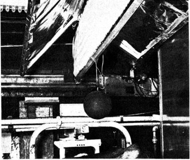


Figure 1—Heat sink suspended above experimental cow F-260 with a week's accumulation of hoarfrost on the 20°F surface of the refrigerated panels. The aluminum trough beneath the panel eliminated dripping of condensate on the cow. The partition between the experimental and control animals appears on the right.

METHODS AND MATERIALS

Radiation Chamber

The animals and experimental materials were housed in Chamber II of the Missouri Climatic Laboratory.[2] Two walls of the chamber were lined with aluminum plates to a height of 5 feet above the floor. The other two walls, the ceiling, and the space above the aluminum plates were lined with brown gypsum board.

The stanchion area was covered daily with 3 inches of dry wood shavings to absorb moisture and serve as bedding.

Refrigerated and Dummy Heat Sinks

Three refrigerated panels (14 inches by 86 inches) were constructed from 0.030-inch, specially manufactured copper sheets, which were inflated to form six tubes of ⅝ inch outside diameter spaced 1⅜ inches apart. Panel surfaces and headers were painted with one coat of flat black paint of emissivity 0.870 to

[2]A complete description of the facilities of the Missouri Climatic Laboratory is given in *Missouri Agricultural Experiment Station Research Bulletin No. 542*, March, 1954, entitled "Environmental Physiology and Shelter Engineering with Special Reference to Domestic Animals, XXIV. Effect of Temperature Upon Heat Exchanges in Dairy Barns."

0.925.[3] Panel influent and effluent openings were located diagonally opposite each other.

Each panel was suspended in a vertical position above each experimental animal with the lowest edge of the copper sheet 2.5 feet above the cow's back (Figure 1). Beneath each panel was suspended a small aluminum angle, which served as a trough for conveying liquid condensate to a gutter in the chamber floor.

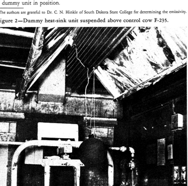
The three panels, parallel-connected across 1-inch diameter copper pipes, were connected to the refrigeration equipment located adjacent to the laboratory. This arrangement, producing parallel flow, theoretically resulted in the same flow rate through each panel.

A radiation-reflector, made of aluminum angles and aluminum foil in the shape of a "V", was positioned above each refrigerated panel, thus limiting the field of vision of each panel. The panel was attached to the radiation-reflector about three inches below the apex. Figure 1 shows an assembled heat-sink unit in operating position.

Three additional radiation-reflectors, identical to those over the experimental animals, were placed above the control animals. These radiation-reflectors contained a piece of 14-inch by 86-inch by 0.030-inch corrugated metal roofing painted with the same paint as that used on the refrigerated panels. Figure 2 indicates a dummy unit in position.

[3] The authors are grateful to Dr. C. N. Hinkle of South Dakota State College for determining the emissivity.

Figure 2—Dummy heat-sink unit suspended above control cow F-235.



The experimental and control cows were separated by a 95-inch by 86-inch polished aluminum partition. This partition prevented the refrigerated panels from affecting the control animals by minimizing radiant energy flow between the groups.

Control of Refrigerated Panels

The surface temperature of the refrigerated panels was regulated by controlling the temperature of the ethylene glycol-water refrigerating fluid circulating through the panels. The temperature of the refrigerating fluid was controlled by a gas-filled-bulb thermostat having an on-off temperature differential of ± 1.5°F. This caused moderate fluctuations of the refrigerated panel surface temperature.

The temperature differential across each panel was continuously measured by two 30-gage copper-constantan thermocouples (Figure 3), one at the influent header, the other at the effluent. The quantity of refrigerating fluid flowing was continuously recorded on a recording indicator mounted in the one-inch influent line. Thus, by determining the specific heat and knowing the temperature differential and the refrigerating-fluid flow rate, the heat transferred to the refrigerating fluid was calculated.

The surface temperature of each refrigerated panel was continuously measured with a 30-gage copper-constantan thermocouple soldered to the geometrical center of the panel. To check the use of the geometric center as the average panel temperature, one panel was equipped with nine thermocouples distributed symmetrically about the center of the panel (Figure 4). The two measuring techniques produced results within ± 1°F of each other; therefore, the geometrically centered thermocouple was considered acceptable.

The average radiant heat exchange between each panel and its surroundings was approximated with a non-selective, net-exchange radiometer of the Gier-Dunkle type (5). Six measurements, with the sensing element positioned 1 inch from the panel surface, were averaged to determine the average radiant-heat exchange.

Measuring Animal Responses

Measurements made to determine the animal responses to the refrigerated panels were: (1) rectal temperature, (2) respiration rate, (3) skin temperature, (4) hair temperature, (5) water consumption, and (6) the estimated radiant-heat exchange between each animal and its environment.

Other measurements concerned with the temperature of the environment near the animals were (1) ambient air temperature above the animal's back, (2) mean radiant temperature of the environment, (3) mean surface temperature of the chamber walls nearest the outside experimental and control animals, and (4) the temperature differential across the partition between the two groups of animals.

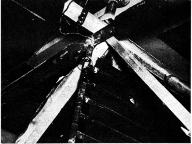
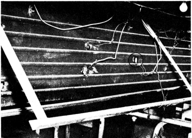


Figure 3—Thermocouples soldered to effluent header for determining temperature of refrigerating fluid. Insulation was removed to expose thermocouple-header junction (circled).

Figure 4—Refrigerated panel with nine thermocouples attached for measuring mean panel surface temperature. The geometrically centered thermocouple (circled) measured the surface temperature during the study. Average temperature, using all nine thermocouples, was compared with the temperature of the geometrically centered thermocouple. The aluminum foil has been removed from the radiation-reflector frame to display the panel.



Metabolic rates and feed consumption measurements would have added much to the significance of this study, but, due to the short length of the study and a shortage of labor, these measurements were not made. However, each cow received the same amount and type of feed throughout the study.

Rectal temperature was measured daily with a 24-gage copper-constantan thermocouple encased in an 8-inch length of ⅛-inch diameter brass tubing. The thermocouple lead wires were encased in ¼-inch diameter flexible plastic tubing for easy cleaning. The rectal thermocouple was inserted to a depth of 8 inches.

The respiration rate was taken once a day while the animals were standing in a relaxed position, usually during remastication, by counting flank movements for a 1-minute period. Additional checks for comparison with daily observations were made one day each week by observing the respiration rate every hour during the working portion of that day.

The mean skin and hair temperatures were considered to be the average skin and hair temperatures on the back, right side, left side, and belly. The touch thermocouple[4] (Figure 5) was inserted beneath the hair and moved slowly in contact with the skin until the potentiometer indicated a balanced condition; the touch thermocouple was then moved lightly over the hair surface to obtain the hair temperature.

Water was supplied to the water-cup fountain in each stanchion by gravity from individual tanks mounted above the cups. Automatic recorders (weekly Kymograph) (9) installed on the tanks permitted measurement of the total amount of water delivered to the cups per day.

The radiant-heat exchange between each cow and its environment was approximated once during each of the last four weeks of the study with the Gier-Dunkle type net-exchange radiometer. The sensing element of the radiometer was held 1 inch from the back, right side, left side, and belly of each cow. These four measurements were averaged to give a mean-radiant-heat-exchange value. Figure 6 shows the relative position of animal and radiometer during a measurement on the back.

The ambient air temperature above each cow's back was measured daily with the touch thermocouple. The touch thermocouple was held 8 inches above the back and moved slowly back and forth until the potentiometer indicated a constant response.

The mean radiant temperature of the environment was continually measured with a 6-inch diameter globe thermometer suspended 8 inches above the back of each cow. Each thermometer, a seamless copper float, was covered with one coat of flat-black paint having an emissivity of 0.870 to 0.925; each contained a 30-gage copper-constantan thermocouple at its center.

Two 30-gage copper-constantan thermocouples were embedded in the chamber walls nearest the outside control and experimental cows for measuring the wall surface temperature. The thermocouples on each wall were located 4 feet above the floor and 3 feet apart horizontally. The mean wall-surface temperature

[4]The touch thermocouple was designed by the junior author.

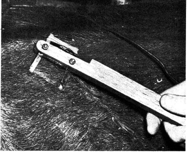
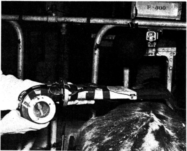


Figure 5—Touch thermocouple for measuring skin and hair temperature.

Figure 6—Measuring the radiant heat exchange between the cow and its environment with a non-selective, net-exchange-radiometer of the Gier-Dunkle type. The lower surface of the heat-flow meter is 1-inch from the cow's hair.



was considered the average of the two thermocouple measurements as constantly measured during the fifth week of the study.

The temperature differential across the partition separating the experimental and control group was measured by two 30-gage copper constantan thermocouples embedded in the aluminum surface. The thermocouples, which were 4 feet above the floor and opposite each other, continuously measured the temperature during the fifth week of the study.

Air velocities along each refrigerated panel surface and around each globe thermometer were measured with a thermoanemometer. Six measurements, 1 inch from each object, were averaged to represent the mean air velocity.

Experimental Procedure

The experimental design for this study limited the variable to refrigerated panel surface temperature. Panel surface temperatures were scheduled as follows: first week, 40°F; second week, 20°F; third week, 35°F; fourth week, 30°F; and fifth week, 40°F.

The chamber air temperature was held constant at 90° ± 1°F and 50 ± 2 percent relative humidity.

Thermocouple measurements were recorded on two Minneapolis-Honeywell automatic balance 16-point recording potentiometers with an accuracy of ½ percent of scale-span. One potentiometer had a range of 0° to 50°C; the other had a range of 0° to 200°F. Net-exchange-radiation measurements were recorded on a Leeds and Northrup automatic-balance millivolt recorder with an accuracy of 0.7 percent on the 0 to 1.0 millivolt scale and 0.3 percent accuracy on the 1.0 to 10.0 millivolt range scale.

Six non-lactating Guernsey cows were selected from the University of Missouri dairy herd and randomly divided into an experimental and control group of three each. The control group, which occupied three adjacent stanchions at one end of the chamber, had identifying numbers of F-235, F-282, and F-334. The experimental group occupied the other three adjacent stanchions and had F-260, F-300, and F-339 as herd numbers. These numbers will be used in future reference to individual cows. Each cow occupied the same stanchion throughout the study. Figure 7 shows the relative position of each cow in the chamber.

The cows, having already become acclimated[8] to winter conditions, entered the chamber with long, dense hair coats. Initial chamber conditions of 65°F and 50 percent relative humidity were changed gradually over the two-week acclimatization period to test conditions of 90°F and 50 percent humidity. The refrigeration system was started at the end of the second week and the refrigeration panel surface temperature adjusted to 40°F. Thereafter, each panel temperature remained constant for 6½ days; the remaining portion of the week was used to adjust the panel surface to another scheduled temperature.

The daily measurements of rectal temperature, skin and hair temperature, ambient air temperature above the animal, and respiration rates were made in

[8]Acclimate, as used herein, will mean becoming adjusted to the environment and is indicated by rectal temperature, respiration rate, etc. when such measurements approach a constant value.

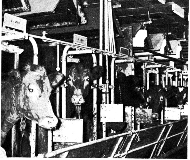


Figure 7—Interior of radiation chamber. From left: Control cows, F-235, F-282, and F-334, with dummy heat sinks suspended above them; experimental cows, F-260, F-300, and F-339, with refrigerated heat sinks suspended above them. The polished aluminum partition between experimental and control cows appears in center.

that order as follows: Each set of measurements started with cow F-235 and progressed across the chamber to cow F-339. After the thermocouple measurements were concluded, a short time interval was allowed for respiration rates to stabilize; then the respiration rate of each cow was taken.

DISCUSSION OF DATA

Analysis of Variance

An analysis of variance was made involving rectal temperature, respiration rate, skin temperature, back skin temperature, hair temperature, back hair temperature, ambient air temperature above the cow's back and globe thermometer temperature.[6] Results are presented in Table 1. The analysis of each variable involved three steps: (1) Determination of variation within the experimental group due to interaction of treatments[7], days, and individual cows; (2) determination of variation within the control group due to interaction of weeks, days,

[6]The authors are grateful to Mr. Cecil L. Gregory of the Missouri College of Agriculture Statistical Service Laboratory and Mr. Ivan L. Berry, Agricultural Engineer with the Agricultural Research Service of the United States Depatment of Agriculture at Columbia, Missouri, for their assistance in making the analysis of variance.
[7]Treatment will be used to refer to the refrigerated panel surface temperature.

TABLE 1-ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
RECTAL TEMPERATURE				
Between E and C	1	0.0000	0.000	0.000
Within E	104	24.7655	0.238	NT
T	4	4.1930	1.048	4.385**
D	6	1.6578	0.276	1.155
D x T	24	5.7472	0.239	1.272
Error	70	13.1675	0.188	NT
Within C	104	23.2582	0.224	NT
W	4	1.6419	0.411	2.025
D	6	1.6446	0.274	1.350
D x W	24	5.7546	0.240	1.183
Error	70	14.2171	0.203	NT
RESPIRATION RATE				
Between E and C	1	21,930.0761	21,930.076	66.508**
Within E	104	20,949.7143	201.440	NT
T	4	6,869.3333	1.717.331	5.058**
D	6	1.796.3810	299.397	5.068**
D x T	24	8,148.6667	339.527	5.747**
Error	70	4,135.3333	59.076	NT
Within C	104	47,637.4652	458.053	NT
W	4	2,826.6095	706.650	3.544*
D	6	432.2667	72.044	0.361
D x W	24	4,785.9238	199.413	0.393
Error	70	35,561.3333	508.019	NT
SKIN TEMPERATURE				
Between E and C	1	30.5281	30.528	19.152**
Within E	104	188.3510	1.811	NT
T	4	148.0729	37.018	41.039**
D	6	2.6979	0.450	0.498
D x T	24	21.6478	0.902	3.974**
Error	70	15.9324	0.227	NT
Within C	104	143.2442	1.377	NT
W	4	99.8383	24.960	82.649**
D	6	2.1934	0.366	1.212
D x W	24	20.1084	0.838	2.775**
Error	70	21.1051	0.302	NT
BACK SKIN TEMPERATURE				
Between E and C	1	12.5800	12.580	21.724**
Within E	104	75.7510	0.728	NT
T	4	57.4259	14.356	97.000**
D	6	0.9339	0.156	0.154
D x T	24	7.0198	0.295	1.993*
Error	70	10.3714	0.148	NT

TABLE 1-CONTINUED

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Within C	104	44.9222	0.432	NT
W	4	30.3099	7.577	62.106**
D	6	0.7424	0.124	1.016
D x W	24	5.3157	0.221	1.811**
Error	70	8.5542	0.122	NT
HAIR TEMPERATURE				
Between E and C	1	229.2771	229.277	391.250**
Within E	104	66.1022	0.636	NT
T	4	24.3570	6.089	22.552**
D	6	3.0274	0.505	1.870
D x T	24	19.8266	0.826	3.059**
Error	70	18.8912	0.270	NT
Within C	104	55.7326	0.536	NT
W	4	28.1266	7.032	43.950**
D	6	1.2036	0.120	0.750
D x W	24	15.2083	0.634	3.963**
Error	70	11.1941	0.160	NT
BACK HAIR TEMPERATURE				
Between E and C	1	207.1500	207.150	900.869**
Within E	104	28.2930	0.272	NT
T	4	6.3753	1.593	10.764**
D	6	1.6798	0.279	1.885
D x T	24	9.8576	0.411	2.777**
Error	70	10.3803	0.148	NT
Within C	104	20.1148	0.193	NT
W	4	7.4817	1.870	20.326**
D	6	0.5804	0.097	1.054
D x W	24	5.6508	0.235	2.554**
Error	70	6.4055	0.092	NT
WATER CONSUMPTION				
Between E and C	1	200.5101	200.510	18.35**
Within E	104	450.5983	4.333	NT
T	4	186.7927	46.698	24.133**
D	6	40.6931	6.782	3.505**
D x T	24	87.6992	3.654	1.888*
Error	70	135.4133	1.935	NT
Within C	104	1,822.3704	17.523	NT
W	4	165.1070	41.277	1.838
D	6	19.8312	3.305	0.147
D x W	24	65.2982	2.721	0.121
Error	70	1,572.1340	22.459	NT

TABLE 1-CONTINUED

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
AMBIENT TEMPERATURE OF THE AIR ABOVE THE COW'S BACK				
Between E and C	1	461.4721	461.472	441.178**
Within E	104	84.7616	0.815	NT
T	4	27.0746	6.769	17.766**
D	6	5.9973	0.999	2.622*
D x T	24	25.0360	1.043	2.738*
Error	70	26.6533	0.381	NT
Within C	104	132.8075	1.277	NT
W	4	16.4670	4.117	13.413**
D	6	18.7889	3.131	10.199**
D x W	24	76.0396	3.168	10.319**
Error	70	21.5200	0.307	NT
GLOBE THERMOMETER TEMPERATURE				
Between E and C	1	539.5200	539.520	4495.833**
Within E	104	15.6753	0.151	NT
T	4	8.1784	2.045	52.436**
D	6	0.5729	0.095	2.436**
D x T	24	4.1441	0.172	4.410**
Error	70	2.7799	0.039	NT
Within C	104	9.5702	0.092	NT
W	4	5.2923	1.323	330.750**
D	6	0.3784	0.063	15.750**
D x W	24	3.5862	0.149	37.250**
Error	70	0.3133	0.004	NT

NOTE: Symbols E, C, T, D and W are, respectively, Experimental, Control, Treatment or the various refrigerated panel surface Temperatures, Days, and Weeks. Significance at 1 per cent level is indicated by (**), and at the 5 per cent level by (*). Those variables not tested are designated with (NT).

and individual cows; and (3) the determination of variation between the experimental and control group.

The error term used in computing the F ratio corresponded to the listing Error under the heading, Source of Variation, in Table 1. The error, Sum of Squares, resulted from adding the sum of squares of cows, cows x treatments or weeks, cows x days, and cows x days x treatment or weeks. Since the error term contains all possible experimental error, the F ratios obtained were the most conservative.

The variables, rectal temperature, respiration rate, skin and hair temperature, and water consumption, are plotted against time in days in Figures 8, 9, 10, 11 and 12, respectively. Each point on the curve is the average of conditions for

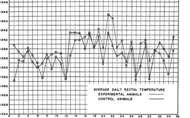


Figure 8—Comparison between experimental and control group's average daily rectal temperatures.

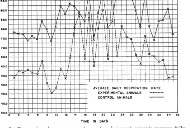


Figure 9—Comparison between experimental and control group's average daily respiration rates.

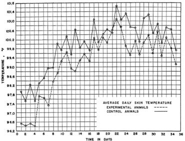


Figure 10—Comparison between experimental and control group's average daily skin temperature.

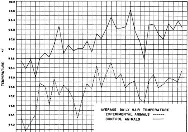


Figure 11—Comparison between experimental and control group's average daily hair temperatures.

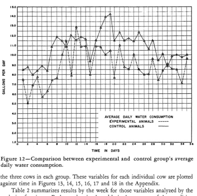


Figure 12—Comparison between experimental and control group's average daily water consumption.

the three cows in each group. These variables for each individual cow are plotted against time in Figures 13, 14, 15, 16, 17 and 18 in the Appendix.

Table 2 summarizes results by the week for those variables analyzed by the analysis of variance. Each number in the table is the average of the condition for the three cows in a group.

Except for rectal temperature, which was not significant at any level, there was a significant difference at the 1 percent level between the control and experimental groups on all variables tested. For all variables tested there was a significant difference at the 1 percent level between the effects the refrigerated panel surface temperatures had upon the experimental group. A portion of this variation between treatments was accredited to acclimatization rather than to the difference in panel surface temperature.

Except for rectal temperature, water consumption, and respiration rate, there was a significant difference at the 1 percent level between the weeks within the control group. This indicates the changes in hair and skin temperature from week to week were due to acclimatization, since the control group had constant environmental conditions throughout the study.

Figures 10 and 11 indicate that acclimatization over the study period approached, asymptotically, a horizontal line and, apparently, complete acclimati-

TABLE 2
SUMMARY OF RESULTS

EXPERIMENTAL AND CONTROL ANIMALS												
EXPERIMENTAL PERIOD-SCHEDULED SURFACE TEMPERATURES	GROUP	RECTAL TEMP. °F	RESPIRATIONS PER MINUTE	SKIN TEMP. °F	BACK SKIN TEMP. °F	HAIR TEMP. °F	BACK HAIR TEMP. °F	WATER CONSUMPTION GALLONS/DAY	AMBIENT TEMP. ABOVE BACK °F	RADIANT HEAT EXCHANGE BETWEEN ANIMAL AND ENVIRONMENT BTU/(HR-FT^2)	MEAN RADIANT TEMPERATURE OF ENVIRONMENT °F
FIRST WEEK 40°F	E	103.45	57.6	97.0	96.6	94.7	93.3	6.7	91.6	6.8	84.0
	C	103.56	77.2	98.2	98.2	96.6	96.5	8.9	94.1	2.7	92.0
SECOND WEEK 20°F	E	103.63	57.1	99.1	99.0	95.3	93.2	10.3	91.6	8.4	84.0
	C	103.66	87.4	99.9	99.7	97.5	97.2	11.7	95.0	2.7	92.0
THIRD WEEK 35°F	E	104.09	75.1	100.0	99.9	96.0	94.1	10.2	92.3	7.5	84.0
	C	103.94	87.3	100.4	100.3	97.8	97.6	12.3	94.8	2.7	92.5
FOURTH WEEK 30°F	E	103.81	75.1	100.2	100.5	95.7	93.5	8.9	90.7	8.3	84.0
	C	103.62	93.2	100.9	100.1	98.0	97.8	11.5	94.6	2.7	92.0
FIFTH WEEK 40°F	E	103.67	63.3	99.9	99.2	95.9	94.3	8.4	91.3	6.8	85.0
	C	103.75	83.9	100.5	100.6	98.1	97.1	10.3	94.6	2.7	92.5

zation with respect to hair and skin temperatures was being approached. Only small changes occurred in rectal temperature, respiration rate, and water consumption, indicating acclimatization with respect to these variables was nearly complete when the study began. The experimental and control group curves in Figures 9, 10, 11 and 12 more or less paralleled each other throughout the study period. The difference between the curves must reflect the physiological effect of the refrigerated panels upon the experimental animals.

The experimental group had approximately a 2°F lower average hair temperature than the control group. This difference was approximately 3.5°F when the back hair temperature only was considered. The control group had a 0.7°F higher average skin temperature than the experimental group, while back skin temperature was nearly 1°F higher. The rectal temperature was nearly the same for each group, and the experimental group had a 2.7°F greater temperature difference between its rectal and hair temperatures than the control group. Apparently, then, the experimental group was better able to conduct heat from the "deep-body" region to the surface than the control group.

Water consumption per day was consistently higher for the control group than for the experimental group. This might indicate that heat transfer by vaporization was used more extensively as a temperature-regulating method by the control group than by the experimental group.

The mean radiant temperature of the environment was computed for both groups by the equation derived by Bond and Kelly (2). The mean radiant temperature of the experimental group's environment (84°F) was 8°F lower than that of the control group (92°F). The 84°F temperature was the effective environmental temperature to which the globe thermometers over the experimental group radiated. This does not mean that the experimental animals "saw" this same environment, but does indicate that the environment of the experimental group was more effective in transferring heat by radiation than the control's environment.

The average radiant heat exchange between each group and its environment was 7.6 BTU/(hr-ft^2) for experimental animals and 2.7 BTU(hr-ft^2) for control animals. Therefore, the experimental cows were able to exchange heat by radiation approximately 2.8 times faster than the control group.

Since the chamber air temperature and velocity were nearly constant throughout the chamber and the study period, the lower ambient temperature above the backs of the experimental cows suggests that those animals were transferring a much larger percentage of heat from the skin and hair by radiant means than were the control cows.

Experimental and control cows gradually replaced their long, dense hair coats with smooth, flat, shiny coats during the study period. This suggests that acclimatization with respect to hair coat orientation (defined as ratio of hair depth to hair length) occurred during the period, thereby increasing heat transfer through the coats of all cows. (1)

Observations throughout the study indicated the experimental cows generally consumed a larger quantity of feed, more readily, and with more vigor, than did the control cows.

Heat Exchange Characteristics of Refrigerated Panels

The heat exchange characteristics of the refrigerated panels were studied by considering the heat transferred to the refrigerating fluid and the radiant heat exchanged with the panel surface.

Table 3 presents the total heat transferred to the refrigerating fluid, radiant heat exchange to panels, and surface conditions corresponding to the five mean

TABLE 3
SUMMARY OF RESULTS

REFRIGERATED PANELS				
EXPERIMENTAL PERIOD	MEAN PANEL SURFACE TEMPERATURE °F	TOTAL HEAT TRANSFERRED TO BRINE BTU/(HR-PANEL)	RADIANT HEAT EXCHANGE TO PANELS BTU/(HR-PANEL)	SURFACE CONDITIONS
FIRST WEEK	41.7	1735.0	819.0	THIN LAYER OF LIQUID CONDENSATE
SECOND WEEK	21.2	2573.0	1255.0	HOARFROST 1-INCH DEEP ON EACH PANEL SURFACE
THIRD WEEK	36.9	2313.0	1480.0	LIQUID CONDENSATE WITH THIN CLEAR ICE NEAR BRINE TUBES
FOURTH WEEK	31.0	2532.0	1360.0	THIN HOARFROST COVERED ENTIRE SURFACE
FIFTH WEEK	41.5	1873.0	820.0	THIN LAYER OF LIQUID CONDENSATE

panel surface temperatures. Table 4 presents the heat transferred at the various surface temperatures expressed as a percent of the heat transferred at the 41.6°F surface temperature. Each value in the tables is the average of the three panel conditions.

Total heat transfer was greatest during the 21.2°F surface temperature. This was to be expected because, during this low-temperature period, the burden of absorbing the heat of fusion of the condensate greatly increased.

TABLE 4
SUMMARY OF RESULTS

REFRIGERATED PANELS			
MEAN PANEL SURFACE TEMPERATURE °F	TOTAL HEAT TRANSFERRED TO BRINE % OF 41.6 °F PANEL TEMP.	RADIANT HEAT EXCHANGE TO PANELS % OF 41.6 °F PANEL TEMP.	SURFACE CONDITIONS
41.6	100.0	100.0	THIN LAYER OF LIQUID CONDENSATE
36.9	128.0	180.8	LIQUID CONDENSATE WITH THIN CLEAR ICE NEAR BRINE TUBES
31.0	140.2	166.0	THIN HOARFROST COVERED ENTIRE SURFACE
21.2	142.4	153.3	HOARFROST 1-INCH DEEP ON EACH PANEL SURFACE

The maximum radiant heat exchanged with the panels occurred when the refrigerated panel surface temperature was 36.9°F. At this temperature liquid condensate with thin clear ice was on the panel surface. Panel surface temperatures below 36.9°F caused frosting-over of entire surface and, thus, a 32°F surface was presented to all incoming radiation regardless of panel surface temperature.

CONCLUSIONS

1. There is a highly significant difference between Guernsey cows in their ability to withstand high temperature and humidity.
2. Responses of the experimental group to the discrete differences in panel surface temperatures were significant at the 1 percent level.
3. Acclimatization during the study period was a major factor contributing to the significant difference between "treatments" (panel surface temperatures) within the experimental group and "weeks" within the control group.
4. The refrigerated panels were effective in reducing respiration rate, skin temperature, hair temperature, water consumption, ambient air temperature above the cow's back, and globe thermometer temperatures of the experimental group as compared to control group, but not effective in reducing rectal temperatures.
5. The most effective panel surface temperature for maximum radiant heat transfer was the lowest temperature at which ice or frost were not present.

BIBLIOGRAPHY

1. Berry, Ivan L., "Factors Affecting Insulation Values of Bovine Hair Coats," *Unpublished Master of Science Dissertation Submitted to the Graduate Faculty of the University of Missouri*, June, 1961.
2. Bond, T. E. and C. F. Kelly, "The Globe Thermometer in Agricultural Research," *Agricultural Engineering*, XXXVI (April, 1955), 251-255.
3. Brody, Samuel, *Bioenergetics and Growth*. New York: Reinhold Publishing Corporation, 1945.
4. Brooker, Donald B., "An Investigation of the Effects of Sunshine and Shade Upon the Surface Temperature of Dairy Cattle," *Unpublished Research Report, Department of Agricultural Engineering University of Missouri*, 1948.
5. Dunkle, R. V., J. T. Shimazaki, J. T. Gier and L. Passner, "Non-selective Radiometer for Hemispherical Irradiation and Net Radiation Interchange Measurements," *Report No. 9, Code NR-C15-202, Thermal Radiation Project*, University of California, Department of Engineering, October 1, 1949.
6. Hutchinson, F. W., "Influence of Gaseous Radiation in Panel Heating," *American Society of Heating and Ventilating Engineers Transactions*, LIII (1947), 285-294.
7. Kibler, H. H. and Samuel Brody, Environmental Physiology with Special Reference to Domestic Animals, VII. Influence of Temperatures, 50° to 5°F and 50° to 95°F on Heat Production and Cardiorespiratory Activities of Dairy Cattle," *Missouri Agricultural Experiment Station Research Bulletin No. 450*, October, 1949.
8. Leedy, R. M., "Controlling Radiant Heat," *Product Engineering*, XXV (October, 1954), 174-179.
9. Ragsdale, A. C. and Samuel Brody, H. J. Thompson and D. M. Worstell, "Environmental Physiology with Special Reference to Domestic Animals, IX. 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," *Missouri Agricultural Experiment Station Research Bulletin No. 260*, September, 1950.
10. Shanklin, M. D. and R. E. Stewart, "Relief of Thermally-Induced Stress in Dairy Cattle by Radiation Cooling," *Missouri Agricultural Experiment Station Research Bulletin No. 670*, July, 1958.

11. Smith, A. D., "Surface Emissivity as a Factor in Appliance Design," *Electrical Engineering*, LXXXIX (December, 1955), 1054-1058.
12. Stewart, R. E. and M. D. Shanklin, "Environmental Physiology and Shelter Engineering with Special Reference to Dairy Cattle, XLVIII. Effects of Growth and Environmental Temperatures on Surface Temperatures of Beef Calves," *Missouri Agricultural Experiment Station Research Bulletin No. 656*, February, 1958.
13. Stoecker, W. F., "Frost Formation on Refrigeration Coils," *Journal of the American Society of Heating, Refrigerating and Air-Conditioning Engineers*, (January, 1960), 51-52.
14. Taylor, C. S. and Jumis D. Edwards, "Some Reflection and Radiation Characteristics of Aluminum," *American Society of Heating and Ventilating Engineers Transactions*, VL (1939), 179-194.
15. Thompson, H. J., D. M. Worstell and Samuel Brody, "Environmental Physiology with Special Reference to Domestic Animals, XV. Influence of Environmental Temperature, 0° to 105°F, on Hair and Skin Temperatures and on the Partition of Heat Dissipation Between Evaporative and Non-Evaporative Cooling in Jersey and Holstein Cattle," *Missouri Agricultural Experiment Station Research Bulletin No. 481*, July, 1951.

APPENDIX

This appendix contains a plot of original data for rectal temperature, respiration rate, skin and hair temperature, and water consumption for each cow against time (Figure 13, 14, 15, 16, 17 and 18). Tables 5 through 15 present the following information:

Globe thermometer temperatures.
Chamber air temperature.
Chamber air humidity.
Air velocity adjacent to globe thermometers.
Radiant heat exchange with panels.
Radiant heat exchange between each cow and its environment.
Mean surface temperature of the chamber walls nearest the outside control and experimental Cows.
Temperature differential across the partition separating the control and experimental group.
Ambient air temperature above the animal's back.
Refrigerated panel surface temperatures, influent fluid temperatures and effluent fluid temperatures.
Quantity of refrigerating fluid circulating through panels.

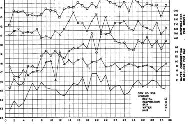


Figure 13—Original data for experimental cow F-339.

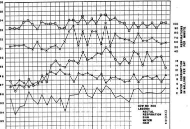


Figure 14—Original data for experimental cow F-300.

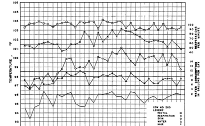


Figure 15—Original data for experimental cow F-260.

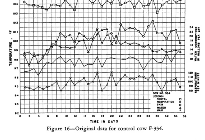


Figure 16—Original data for control cow F-334.

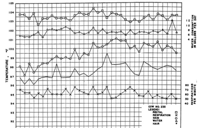


Figure 17—Original data for control cow F-282.

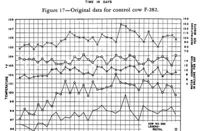


Figure 18—Original data for control cow F-235.

TABLE 5–GLOBE THERMOMETER TEMPERATURE
(Degrees Centigrade)

Refrigerated Panel Surface Temperature	Day	Experimental Group F-339	Experimental Group F-300	Experimental Group F-260*	Control Group F-334	Control Group F-252	Control Group F-235
41.7°F	1	30.9	30.7	30.9	33.8	33.8	33.8
	2	30.1	30.4	30.4	33.1	33.1	33.1
	3	31.3	31.2	31.4	34.2	34.2	34.3
	4	31.3	31.1	31.3	34.2	34.0	34.3
	5	31.3	31.3	31.3	34.1	34.1	34.1
	6	31.2	31.1	31.1	33.9	33.9	34.1
	7	31.0	31.0	31.2	34.2	34.2	34.2
21.2°F	8	31.3	30.7	31.1	34.3	34.4	34.4
	9	30.9	30.6	30.9	34.3	34.2	34.2
	10	30.8	30.4	30.8	34.2	34.4	34.4
	11	30.6	30.2	31.0	34.1	34.1	34.1
	12	30.9	30.7	30.6	34.2	34.2	34.2
	13	30.8	30.2	30.8	34.1	34.1	34.1
	14	30.2	30.2	31.3	34.0	34.2	34.2
36.9°F	15	31.2	31.2	31.6	34.3	34.4	34.5
	16	31.2	31.6	31.3	34.7	34.8	34.8
	17	31.2	31.2	31.2	34.5	34.5	34.5
	18	31.1	30.5	31.4	34.2	34.3	34.4
	19	31.4	31.3	31.5	34.6	34.6	34.6
	20	31.4	31.5	31.6	34.7	34.7	34.7
	21	31.6	31.4	31.3	34.4	34.5	34.5
31.0°F	22	31.3	31.2	31.3	34.5	34.5	34.6
	23	31.2	31.2	31.1	34.5	34.5	34.5
	24	31.3	31.1	31.3	34.6	34.6	34.5
	25	30.9	30.5	31.1	34.3	34.4	34.3
	26	31.1	30.6	31.1	34.2	34.2	34.2
	27	31.2	30.7	31.2	34.3	34.5	34.5
	28	31.2	30.4	31.2	34.4	34.4	34.4
41.5°F	29	31.4	31.3	31.5	34.5	34.5	34.5
	30	31.5	31.7	31.5	34.6	34.6	34.6
	31	31.6	31.6	31.6	34.5	34.6	34.6
	32	31.5	31.1	31.5	34.3	34.5	34.5
	33	31.4	31.2	31.4	34.4	34.5	34.5
	34	31.7	31.7	31.8	34.6	34.6	34.6
	35	31.6	31.4	31.6	34.3	34.5	34.5

*The globe thermometer number corresponds to the herd number of the cow beneath the globe.

TABLE 6-CHAMBER AIR TEMPERATURE

Refrigerated Panel Surface Temperature	Day		Temperature - °F
41.7°F	1		89.7
	2		89.0
	3		90.8
	4		90.4
	5		90.5
	6		90.1
	7		90.6
		Average	90.1
21.2°F	8		90.6
	9		90.1
	10		90.1
	11		90.1
	12		91.0
	13		90.9
	14		90.4
		Average	90.4
36.9°F	15		90.6
	16		90.6
	17		90.5
	18		90.4
	19		91.1
	20		90.6
	21		90.1
		Average	90.6
31.0°F	22		90.5
	23		90.8
	24		90.7
	25		90.3
	26		90.3
	27		90.4
	28		90.6
		Average	90.5
41.5°F	29		90.2
	30		90.3
	31		90.1
	32		90.2
	33		90.0
	34		90.3
	35		90.1
		Average	90.2

TABLE 7–CHAMBER AIR HUMIDITY

Refrigerated Panel Surface Temperature	Day		Relative Humidity (Percent)
41.7°F	1		50
	2		47
	3		44
	4		49
	5		51
	6		51
	7		52
		Average	49
21.2°F	8		52
	9		52
	10		52
	11		51
	12		51
	13		51
	14		52
		Average	52
36.9°F	15		50
	16		51
	17		51
	18		51
	19		48
	20		48
	21		49
		Average	50
31.0°F	22		49
	23		49
	24		48
	25		48
	26		48
	27		48
	28		49
		Average	48
41.5°F	29		49
	30		49
	31		48
	32		47
	33		45
	34		46
	35		47
		Average	47

TABLE 8-AIR VELOCITY ADJACENT TO GLOBE THERMOMETERS
(Feet Per Minute)

Location	F-339*	F-300	F-260	F-334	F-282	F-235
Top	18	17	30	26	25	18
Side	20	24	24	25	30	35
Side	22	18	20	35	41	28
Bottom	22	23	30	41	50	36
Top	24	19	25	26	13	19
Side	25	20	36	32	40	23
Side	18	18	26	39	54	22
Bottom	24	24	32	21	50	20

*The globe thermometer number corresponds to the herd number of the cow beneath the globe.

TABLE 9-RADIANT HEAT EXCHANGE WITH PANELS
Btu/(hr-ft^2)

Refrigerated Panel Surface Temperature	Panel* Number	Section of Panel Where Radiometer Was Positioned: West End Left	West End Right	Center Left	Center Right	East End Left	East End Right
41.7°F**							
21.2°F	F-339	63.4	65.1	57.5	60.0	61.7	63.0
	F-300	62.6	62.2	62.2	59.6	59.6	61.3
	F-260	66.4	69.3	69.3	67.2	67.2	58.8
36.9°F	F-339	51.5	38.9	38.6	62.7	28.9	38.9
	F-300	67.5	84.0	72.9	73.5	75.6	85.8
	F-260	136.5	163.1	78.0	119.1	23.9	85.1
31.0°F	F-339	37.6	61.5	134.2	54.7	18.8	37.1
	F-300	52.9	74.8	55.1	94.8	102.2	67.4
	F-260	61.9	90.3	68.7	72.2	54.5	90.0
41.5°F	F-339	41.4	41.4	41.0	38.0	42.0	40.1
	F-300	41.8	41.0	41.0	41.3	41.0	41.4
	F-260	41.5	42.8	40.9	41.5	40.7	41.5

*The panel number corresponds to the herd number of the experimental cow beneath the panel.
**The net exchange radiometer was not available during the first week. Radiant heat exchange between each panel and its environment for this period was based on the fifth week, when the refrigerated panel surface temperature was 41.5°F.

TABLE 10-RADIANT HEAT EXCHANGE BETWEEN EACH COW AND ITS ENVIRONMENT
Btu/(ft^2-hr)

Refrigerated Panel Surface Temperature	Herd Number	Body Region Where Radiometer Was Positioned			
		Back	Left Side	Right Side	Belly
41.7°F*					
21.2°F	F-339	15.0	4.7	4.0	8.5
	F-300	16.2	5.5	6.3	8.9
	F-260	12.1	5.3	4.4	9.9
	F-334	0.0	2.5	2.2	10.4
	F-282	0.0	2.0	3.2	4.6
	F-235	0.0	1.8	1.5	4.8
36.9°F	F-339	14.6	4.6	4.1	8.0
	F-300	15.1	5.6	6.1	7.5
	F-260	11.5	5.2	4.4	3.3
	F-334	1.0	2.0	2.3	12.3
	F-282	0.0	2.3	3.0	4.1
	F-235	0.5	1.2	1.8	2.5
31.0°F	F-339	14.8	4.8	3.8	8.3
	F-300	16.1	5.3	6.5	9.3
	F-260	12.4	5.1	4.7	9.1
	F-334	0.0	1.7	1.9	9.7
	F-282	0.1	2.7	2.9	5.6
	F-235	0.0	0.8	2.3	5.0
41.5°F	F-339	10.1	5.3	1.4	7.2
	F-300	15.6	5.8	2.4	8.1
	F-260	10.3	5.0	3.0	7.2
	F-334	0.7	2.5	2.0	13.3
	F-282	0.3	2.1	3.0	3.1
	F-235	0.0	1.5	1.6	2.6

*The net exchange radiometer was not available during the first week. Radiant heat exchange between each animal and its environment for this period was based on the fifth week when the refrigerated panel surface temperature was 41.5°F.

TABLE 11-MEAN SURFACE TEMPERATURE OF THE CHAMBER WALLS NEAREST THE OUTSIDE CONTROL AND EXPERIMENTAL COWS

Refrigerated Panel Surface Temperature	Day	Thermocouples Nearest Experimental Group °F		Thermocouples Nearest Control Group °F	
41.5°F	29	88.5	88.5	90.0	90.0
	30	88.5	88.5	90.0	90.0
	31	88.5	86.5	89.5	89.5
	32	88.5	86.5	90.0	90.0
	33	88.5	86.0	90.5	90.5
	34	89.5	87.0	90.5	90.5
	35	89.0	86.0	89.5	89.5
	Average	87.8		90.0	

TABLE 12-TEMPERATURE DIFFERENTIAL ACROSS THE PARTITION SEPARATING THE CONTROL AND THE EXPERIMENTAL GROUP

Refrigerated Panel Surface Temperature	Day	Thermocouple Nearest Experimental Group °F	Thermocouple Nearest Control Group °F
41.5°F	29	90.3	90.3
	30	90.7	90.7
	31	90.3	90.3
	32	90.7	90.7
	33	90.0	90.0
	34	90.7	90.7
	35	90.0	90.0
	Average	90.4	90.4

TABLE 13-AMBIENT AIR TEMPERATURE ABOVE THE COW'S BACK
(Degrees Fahrenheit)

Refrigerated Panel Surface		Experimental Group			Control Group		
Temperature	Day	F-339	F-300	F-260	F-334	F-282	F-235
41.7°F	1	91.9	90.6	91.7	95.1	94.5	94.3
	2	90.5	90.6	89.9	91.6	91.2	91.0
	3	91.1	90.5	90.8	94.6	94.5	94.8
	4	90.3	91.0	92.3	94.6	91.9	93.5
	5	92.7	91.4	93.6	95.5	94.9	94.9
	6	92.7	91.8	91.5	95.2	94.9	94.7
	7	91.9	91.9	92.4	94.5	94.2	93.8
21.2°F	8	92.4	92.4	92.4	96.8	95.1	95.4
	9	91.4	90.2	91.7	95.1	95.4	95.2
	10	93.6	92.0	91.8	96.9	94.8	94.6
	11	91.9	91.6	90.9	95.9	95.6	95.5
	12	93.6	91.6	92.9	94.8	95.5	94.6
	13	91.9	91.4	91.2	94.8	94.3	94.1
	14	91.2	90.6	90.6	96.8	94.4	94.2
36.9°F	15	92.6	92.4	91.6	95.0	94.6	94.5
	16	93.0	92.5	92.4	95.0	94.8	94.4
	17	93.5	92.4	92.0	95.4	96.2	96.0
	18	93.1	92.8	92.4	95.1	94.7	95.0
	19	91.9	92.1	91.8	95.1	94.7	94.8
	20	92.9	92.0	92.1	93.9	93.7	93.6
	21	92.4	92.1	91.9	94.1	93.9	93.9
31.0°F	22	91.7	90.8	91.9	95.9	95.6	95.6
	23	90.9	89.3	92.1	93.9	93.5	93.5
	24	91.4	90.9	91.3	95.1	94.9	95.1
	25	91.5	91.6	90.6	94.6	94.4	94.3
	26	90.6	90.5	90.3	94.2	94.1	94.5
	27	91.4	90.1	90.6	93.1	93.0	93.0
	28	90.6	89.3	89.8	95.1	95.4	94.8
41.5°F	29	92.5	92.8	92.0	91.8	93.7	93.7
	30	91.9	91.6	92.1	94.3	93.9	93.9
	31	90.8	91.6	91.2	95.0	94.4	94.8
	32	91.8	91.6	92.4	95.5	95.6	95.9
	33	92.3	92.0	92.0	93.6	93.6	91.9
	34	90.3	91.6	92.1	95.6	96.1	96.4
	35	92.4	91.7	91.4	95.6	96.7	96.0

TABLE 14-REFRIGERATED PANEL SURFACE TEMPERATURES, INFLUENT FLUID TEMPERATURES AND EFFLUENT FLUID TEMPERATURES

Day	Refrigerated Panel Surface Temperature °F			Influent Fluid Temperature °F			Effluent Fluid Temperature °F		
	F-339	F-300	F-260	F-339	F-300	F-260	F-339	F-300	F-260
1	41.8	40.8	44.0	30.5	28.5	28.9	31.7	32.7	32.5
2	41.3	40.1	43.7	29.7	28.2	28.1	31.0	31.4	31.2
3	41.6	40.3	43.2	30.1	28.5	29.3	31.7	32.7	32.5
4	42.0	41.1	42.9	30.0	28.1	28.7	31.5	32.8	31.9
5	41.7	41.0	43.8	30.0	27.8	28.2	31.1	32.4	31.8
6	40.4	40.3	44.3	27.1	26.0	27.1	29.8	31.3	30.9
7	40.8	40.0	42.5	27.9	25.5	26.3	29.2	31.0	30.1
8	23.5	22.5	23.2	10.2	9.2	9.4	13.6	14.5	14.5
9	23.9	24.1	23.7	10.4	9.7	7.3	12.8	12.7	12.3
10	24.5	24.5	24.9	11.0	10.5	9.7	13.1	13.9	14.5
11	18.9	19.0	21.0	8.9	8.0	8.4	12.9	13.1	12.7
12	20.0	21.3	20.5	7.6	7.0	8.0	12.0	12.2	12.8
13	16.7	18.2	18.5	7.7	6.7	7.1	12.1	12.4	12.3
14	16.9	18.0	18.7	7.9	6.8	7.7	12.0	12.2	12.0
15	34.5	39.7	38.4	24.7	25.0	24.8	28.7	29.3	29.1
16	35.8	39.1	37.1	24.1	24.0	24.8	28.3	29.1	29.0
17	35.6	38.4	37.8	23.5	23.7	24.2	27.8	28.5	28.6
18	35.4	37.3	36.3	23.8	24.0	23.7	27.2	28.1	28.2
19	34.8	38.1	36.0	23.1	23.0	23.2	26.9	27.6	27.8
20	34.9	37.9	37.1	23.1	23.5	23.9	27.3	27.9	28.0
21	35.7	38.0	37.5	24.5	24.8	24.0	28.5	28.2	27.6
22	31.5	31.5	33.5	21.2	21.7	21.3	25.7	26.0	26.5
23	31.1	21.1	33.0	20.3	20.5	20.4	24.9	25.7	26.1
24	30.7	31.8	32.1	19.7	19.5	20.1	24.7	24.8	25.7
25	30.1	31.0	32.9	16.3	18.7	18.7	23.3	24.5	25.2
26	29.5	30.7	31.8	19.1	19.3	20.2	24.5	22.0	25.0
27	29.7	30.3	30.8	20.1	20.8	20.6	24.3	26.5	24.0
28	30.4	31.6	33.7	20.3	20.3	21.0	24.8	24.9	23.2
29	41.5	44.7	42.9	32.8	32.8	32.9	34.5	36.3	35.7
30	40.7	43.8	41.6	32.8	32.7	33.2	33.6	35.8	35.2
31	39.8	41.1	40.9	30.3	30.1	30.7	34.2	35.4	34.7
32	40.2	42.7	41.6	30.4	30.5	30.1	33.1	34.9	34.1
33	38.7	41.3	40.7	29.3	28.3	29.1	32.4	33.4	33.6
34	40.1	42.6	41.3	30.1	29.2	30.1	34.0	33.7	33.3
35	40.3	42.8	41.5	30.0	30.2	31.3	33.6	34.3	34.6

TABLE 15-QUANTITY OF REFRIGERATING FLUID CIRCULATING THROUGH PANELS

Refrigerated Panel Surface Temperature	Day		Gallons Per Minute
41.7°F	1		4.85
	2		4.85
	3		4.85
	4		4.85
	5		4.85
	6		4.85
	7		4.36
		Average	4.78
21.2°F	8		4.73
	9		4.47
	10		4.43
	11		4.60
	12		4.40
	13		4.38
	14		4.37
		Average	4.48
36.9°F	15		4.76
	16		4.60
	17		4.87
	18		4.61
	19		4.61
	20		4.63
	21		4.41
		Average	4.65
31.0°F	22		4.79
	23		4.59
	24		4.58
	25		4.58
	26		4.59
	27		4.59
	28		4.66
		Average	4.63
	29		4.71
	30		4.69
	31		4.62
	32		4.67
	33		4.68
	34		4.69
		Average	4.68