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Relief of Thermally-Induced Stress in Dairy Cattle By Radiation Cooling

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ABSTRACT

Cooling by radiation offers one means of relieving thermally-induced stress. The purpose of this investigation was to study the physiological effects of a refrigerated plate on thermally-stressed cows, and to study the influence of: (1) plate temperature, (2) plate position with respect to the animal, (3) plate surface condition, and (4) emissivity of the structural surround.

In essence, the experimental equipment consisted of an insulated chamber, approximately 11 x 5 x 7 feet, lined with polished aluminum sheets, wherein the air temperature and relative humidity could be controlled. The chamber was large enough to accommodate a Jersey cow whose rectal temperature and respiration rate could be measured while exposing the cow to a refrigerated plate (12.61 square feet in area).

Two Jersey cows were tested in all possible combinations of the following: (1) polished aluminum and flat-black lacquered chamber walls, (2) wall and ceiling plate positions, (3) plate bare and plate surface encapsulated in a double layer of four-mil polyethylene film separated by a $^{9}/_{16}$-inch air space, and (4) plate temperatures of 50°, 35° and 20° F, plate bare; and 50°, 35°, 20° and 5° F, plate encapsulated. All tests were run with chamber air held constant at 110° F and 65 percent relative humidity.

Straight-line regression coefficients of rectal temperature versus time were computed for the two-hour period during which the plate was refrigerated, or an equivalent period when the plate was not used. Based on the regression coefficients, a five-way analysis of variance of the five variables (plate temperature, plate surface condition, plate position, chamber emissivity, and cow) was made.

The conclusions drawn from the analysis of variance were:

1. There was a highly significant difference between the two Jerseys in their ability to withstand environmental conditions of high temperature and humidity.
2. The cold plate was effective in reducing the slope of the rectal-temperature-versus-time regression.
3. Chamber walls of polished aluminum were more effective than walls coated with flat-black lacquer in reducing the rectal temperature.
4. With chamber walls of polished aluminum, the plate was more effective when on the wall, facing a reflecting surface, than when on the ceiling, facing an absorbing surface.
5. Within a plate-temperature range of 20° to 50° F, a bare plate was more effective than a polyethylene-film-covered plate in reducing the rectal temperature of a thermally-stressed cow.

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The information in this bulletin was condensed from a dissertation submitted by the senior author to the Graduate Faculty of the University of Missouri in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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INTRODUCTION

High summer temperatures in the United States cause significant production losses in domestic animals. While air-conditioned structures offer an immediate and obvious solution to this problem, the cost of this solution may be economically unjustifiable. If, by using cold panels in a relatively inexpensive shelter, the heat-induced stresses could be reduced or relieved, an economically significant gain in production might be achieved. To this end, a laboratory-controlled investigation of the effects of radiant cooling on thermally-stressed animals was indicated.

The purpose of this investigation was to study the physiological effects of a refrigerated plate on thermally-stressed cows, and to determine the influence of (1) plate temperature, (2) plate position with respect to the animal, (3) plate surface condition, i.e., bare or covered with a film of polyethylene, and (4) the emissivity of the structural surround.

LITERATURE

C. A. Mills (7) found that objects in an aluminum-foil-lined chamber (six-foot cube) with wall temperatures controlled at 89° to 92° F and containing six 20 by 42-inch cold plates at 32° to 40° F, placed on opposite walls, assumed temperatures of approximately 83° F, while objects in a similar chamber, not foil-lined, assumed temperatures of approximately 90° F. He concluded that the passive reflections of foil linings would obviate the need for wall insulation. He later built an uninsulated frame house which he lined with aluminum foil (7, 8, 9). The house was heated and cooled by pipes contained in a cove near the ceiling. Mills concluded that "indoor air temperatures below 60° F are not well tolerated while the individual is in motion . . . (but) one might be comfortable quietly seated."

As a means of eliminating condensation in the cove, Mills suggested the cove be encapsulated with a material transparent to the 100° F radiant energy spectrum. He stated (10) that "a polyethylene sheet of as much as 0.006 inch thickness possessed 92% transparency." Hinkle (4) studied the effect of encapsulating a refrigerated plate with a double layer of four-mil polyethylene film separated by a half-inch air space, and found the encapsulation had an effective transmission for the 100° F radiant energy spectrum of 67 percent.

The condensation of moisture or the accumulation of frost will alter the emissivity value of a refrigerated surface. Smith (11) found that the condensation of moisture on a surface increased its emissivity to a value greater than 0.90, and that a visibly white hoar frost, spectrally reflective, "will absorb 98.6% of all incoming radiation in the infra-red range, for one of the highest emissivities known."

The emissivity of polished aluminum at 100° F is in the range of 0.03 to 0.10 (6); and when covered with a flat-black lacquer, about 0.95 (12).

Since the homeotherm regulates the temperature of its vital organs at an almost constant temperature, the rectal temperature is considered a good indicator of thermally-induced stress. In cattle the rectal temperature is above normal at an environmental temperature of 80° F (1). The average rectal temperature of Jersey cows is 101.1 ± 0.5° F (1).

The surface (skin and hair) temperature reflects the environmental temperature to a large degree. At about 105° F the surface temperature is equal to the environmental temperature (13).

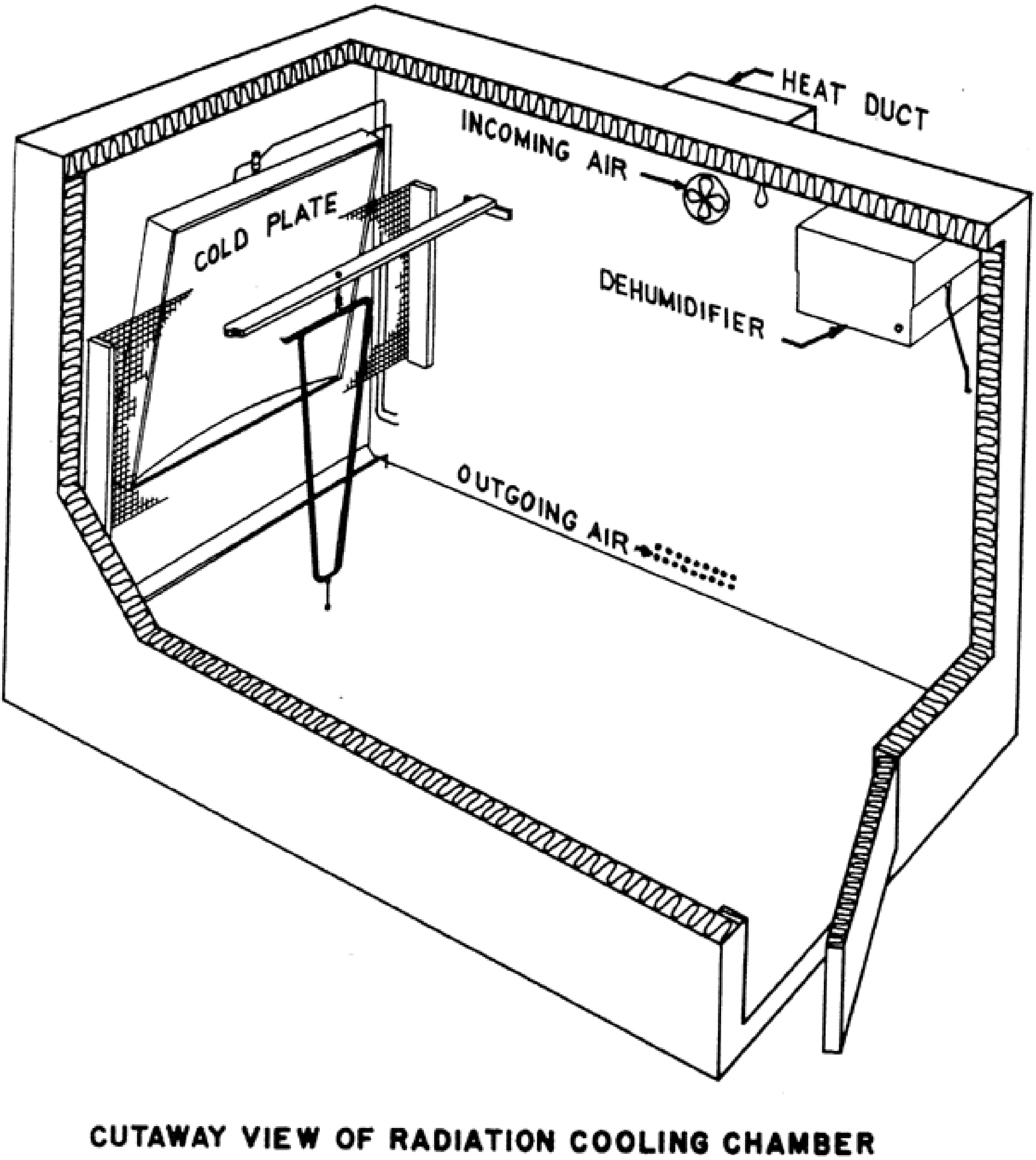
As the temperature difference between the surface of the animal and the ambient air decreases, the burden of heat dissipation is shifted to vaporization and a consequent increase in the respiration rate. However, the respiration rate has a limited use as an indicator of thermally-induced stress, since it reaches a maximum (about 150 respirations per minute in Jerseys at about 100° F) above which an increase in environmental temperature is not reflected in an increased respiration rate (5).

MATERIALS AND METHODS

Radiation Cooling Chamber: The chamber, of wood-frame construction, had exterior surfaces, walls and roof, covered with ¼-inch plywood. The interior surfaces, walls, floor and ceiling were covered with 3/16-inch polished aluminum plate. Four-inch mineral-wool insulation was installed in the wall, floor and roof cavities. The floor was covered daily with a six-inch layer of dry wood shavings to serve as a heat barrier and to absorb moisture. A close-fitting door, of the same construction as the walls, gave access to the chamber. The interior of the chamber could be observed through a small double peep-hole placed in the door at eye level.

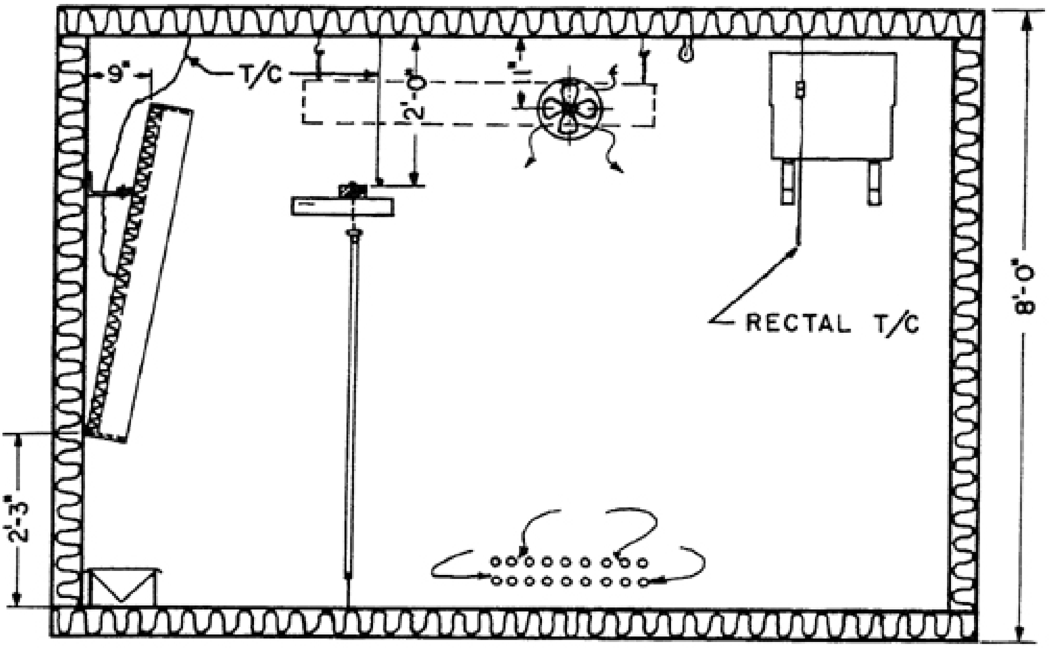
The inside dimensions of the chamber were: 11 ft. 4½ in. long; 5 ft. 4½in. wide; and 7 ft. 2 in. high. A cutaway illustration of the chamber is presented in Figure 1, and a plan and section view, in Figure 2. The dashed lines in Figure 2 indicate the ceiling position of the cold plate.

Air Temperature and Moisture Control: Temperature control was achieved by circulating the chamber air through a rectangular heating duct, 2 ft. 2 in. wide and 6 in. deep, as shown in Figure 2. Heat was added to the air by three 1,000-watt finned electric heaters designed to transfer heat to air. Each



CUTAWAY VIEW OF RADIATION COOLING CHAMBER

Figure 1.



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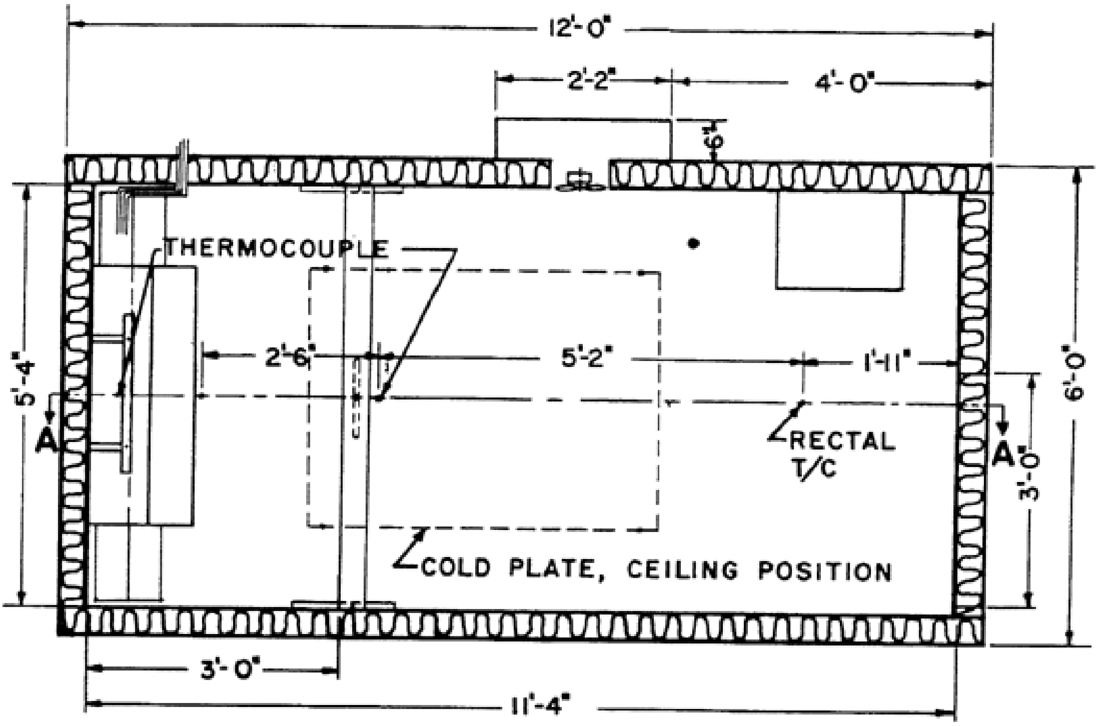

PLAN VIEW OF RADIATION COOLING CHAMBER

Figure 2.

heater was independently thermostatically controlled, which permitted a fairly precise control of the chamber air temperature.

Relative humidity regulation was accomplished by the addition of a fine mist of water in the heating duct, and the removal of air moisture with a commercial dehumidifier inside the chamber. The mist of water was created by an atomizing nozzle located at the bottom of the heating duct, and was directed upward so that the mist was vaporized in passing over the finned heaters. The rate of mist application was governed by the air pressure applied to the nozzle.

During the initial portion of the investigation, wet- and dry-bulb temperatures were measured by two dial-type bimetallic thermometers, one of which was equipped with a cotton wick which was periodically wetted. These thermometers were inserted into the air stream of the heating duct at a point opposite the return air grille. The relative humidity was determined at five-minute intervals. For the sake of convenience, the dial-type thermometers were replaced with a Henderson-design (3) constant-feed wet-bulb thermocouple and a dry-bulb thermocouple encased in a wax-filled glass tube to reduce its sensitivity. The two systems of temperature measurement were operated simultaneously for a period of time sufficient to determine that they were in agreement.

Cold Plate. The cold plate was constructed of 22-gauge anodized aluminum sheet with ⅜-inch outside diameter copper tubing welded to one side, and was curved to a radius of approximately 41 inches. The projected area of the cold plate was 12.61 square feet. The plate was fastened to a wooden frame, the inside of which was lined with heavy-gauge aluminum foil. The resulting box was filled with mineral-wool insulation, and a heavy-gauge sheet-metal back was sealed in place with a mastic. A front view and a section view of the cold plate are shown in Figure 3. The exposed surface of the plate was coated with a flat-black lacquer, giving it an emissivity of about 0.95 to 0.98.

A part of the investigation was conducted with the cold plate encapsulated (to remove the condensation load). Encapsulation consisted of covering the front of the plate with two layers of four-mil polyethylene film separated by a 9/16-inch air space. The plastic was sealed to the plate frame with a waterproof mastic. A 1½ horsepower York Freon-12 condensing unit was used to cool the plate. The temperature of the plate was measured by a thermocouple welded to the center of the front surface of the plate.

The plate was used in two positions: (1) hung vertically on the chamber wall facing the cow, and (2) suspended horizontally from the chamber ceiling over the cow's back. The two positions are indicated diagrammatically in Figure 2. Figures 4 and 5 show interior views of the chamber with the walls coated with flat-black lacquer and the encapsulated plate in its two positions. Figure 6 shows the bare plate in the chamber with walls of low emissivity. The trough located under the plate was to collect moisture condensed on the plate. The water was conducted outside the chamber by a hose connected to the trough.

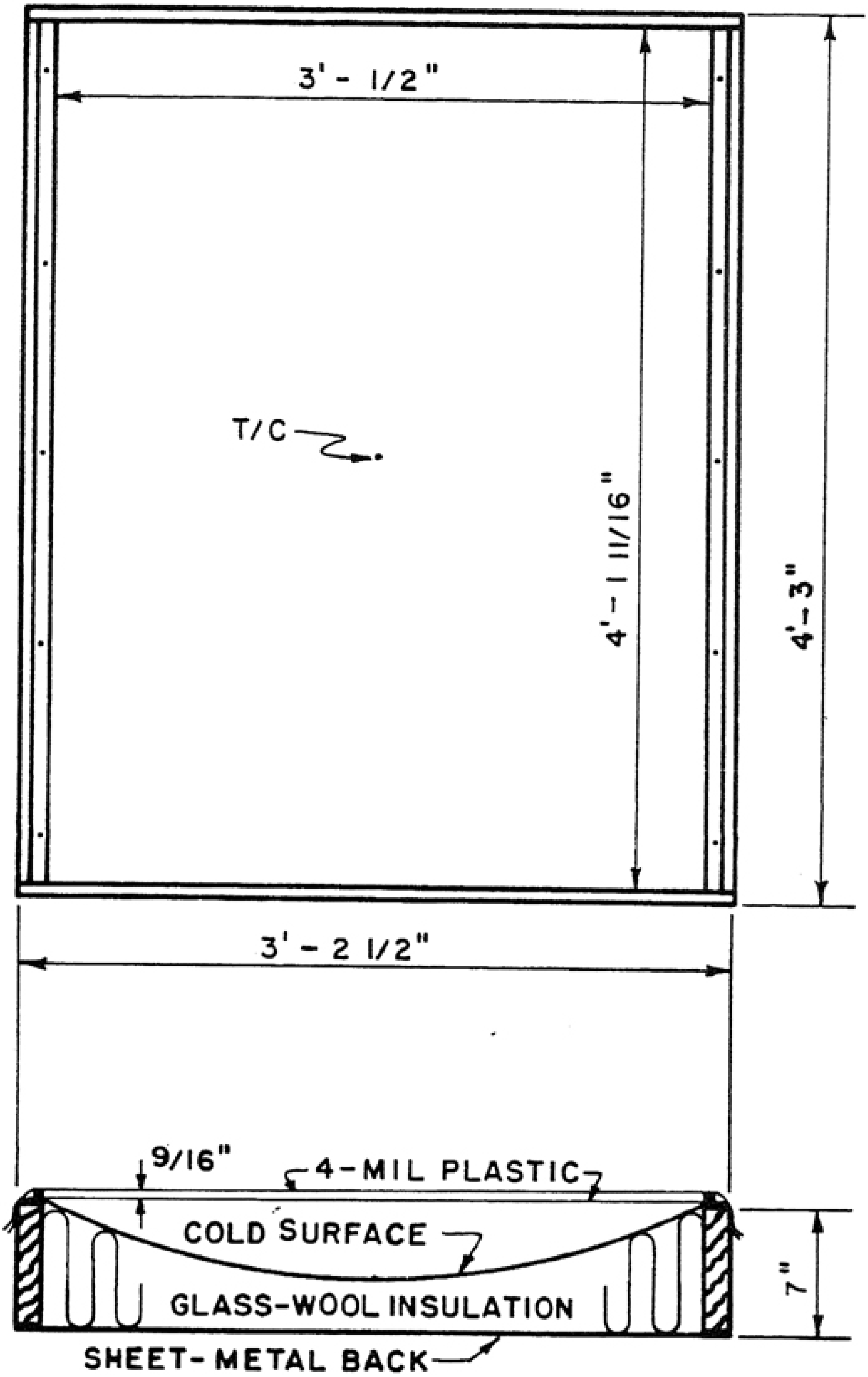

Figure 3.—Front view and section view of cold plate.

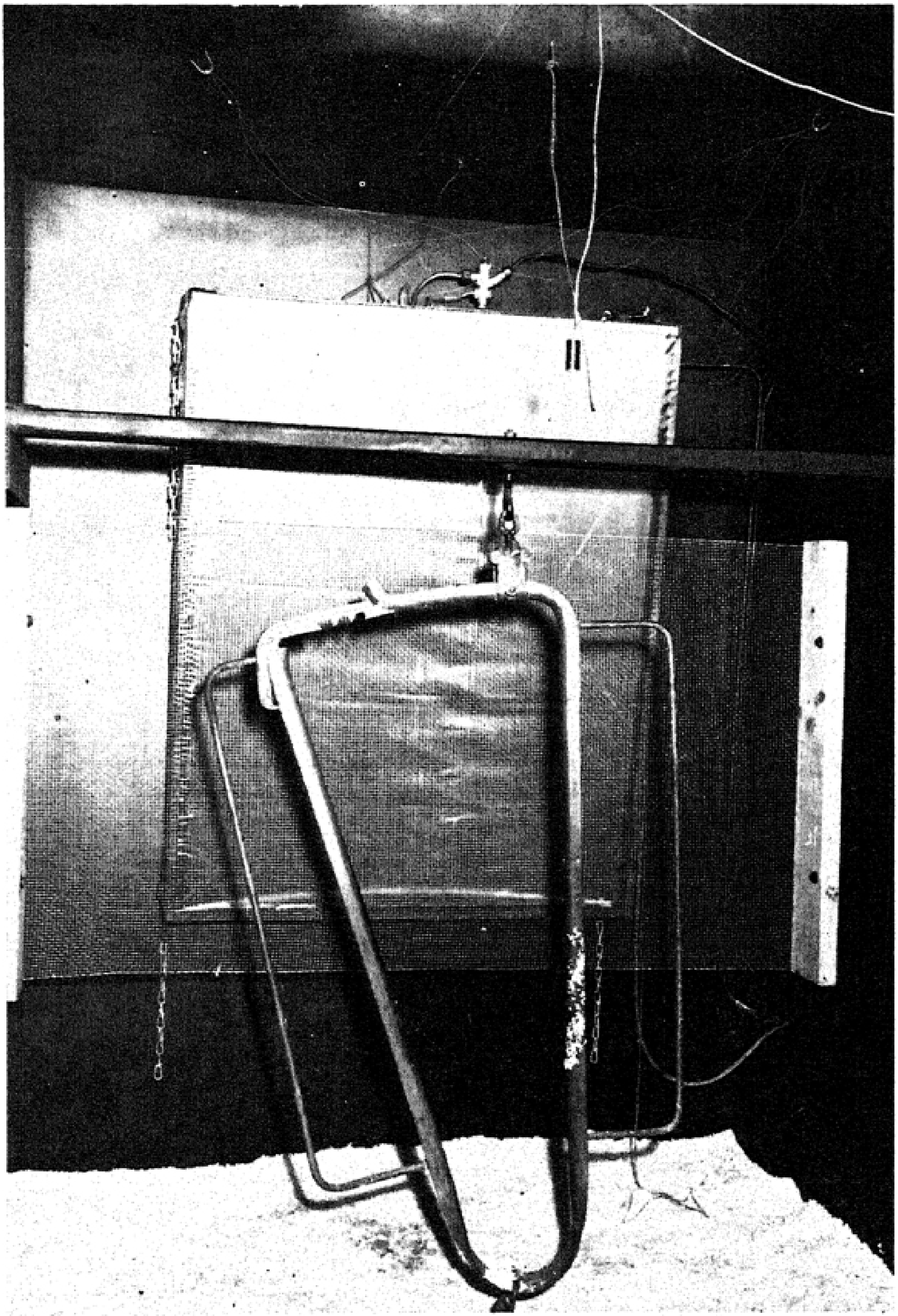

Figure 4.—Interior view of radiation-cooling chamber with encapsulated plate mounted on walls of high emissivity.

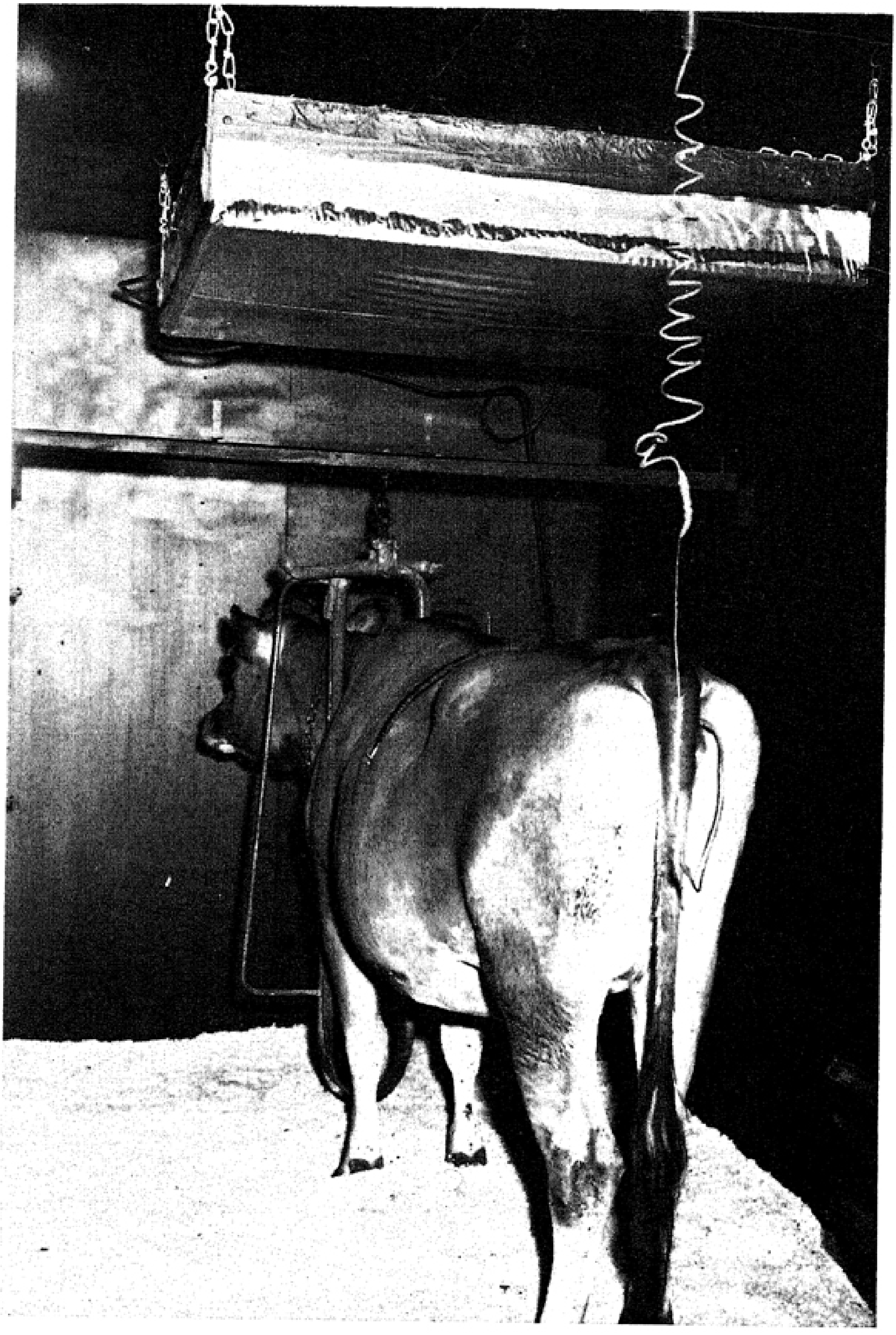

Figure 5.—Interior view of radiation-cooling chamber with encapsulated plate mounted on ceiling; cow in stanchion has pneumograph fastened to chest, rectal thermometer inserted.

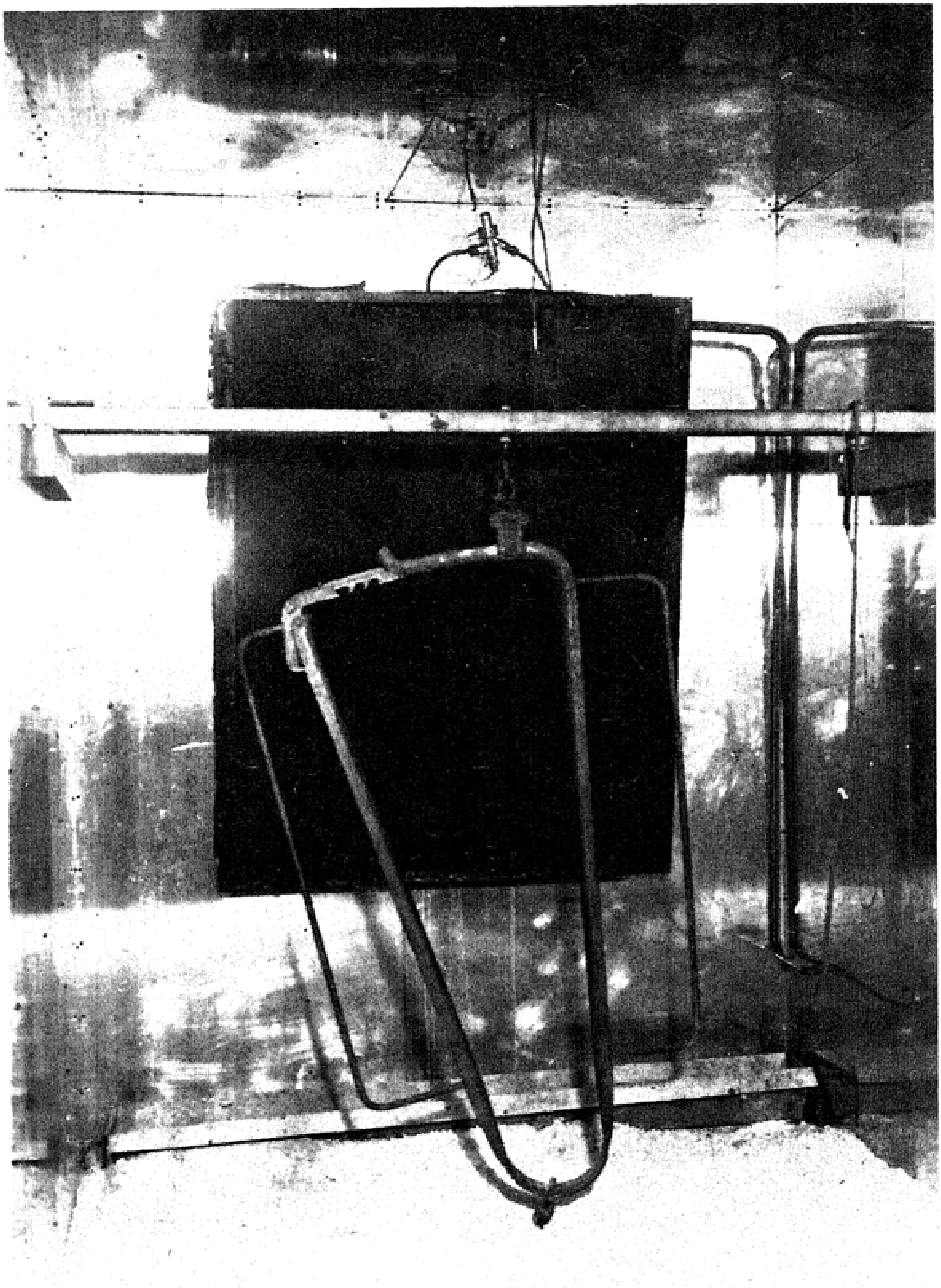

Figure 6.—Interior view of radiation-cooling chamber showing bare plate mounted on walls of low emissivity.

When the plate was used in the vertical position, a wire screen was stretched across the chamber in front of the cow to prevent her from licking the plate (Figure 4).

Physiological Measurements: The physiological indicators of thermally-induced stress used in this investigation were the respiration rate and the rectal temperature.

During tests, the respiration rate was measured for periods of 30 seconds at five-minute intervals. A pneumograph was fastened to the chest of the cow and connected to a tambour located on the outside of the chamber, so that the operator could conveniently count the movements of the tambour rather than entering the chamber to count the cow's flank movements.

The rectal temperature was measured with a thermocouple encased in an 8-inch length of 1/4-inch diameter rigid plastic tubing. The thermocouple lead-wires were encased in 1/4-inch diameter flexible plastic tubing for cleaning ease. The rectal thermocouple was inserted to a depth of 8 inches. Figure 5 shows the pneumograph and rectal thermocouple in their operating positions.

Experimental Procedure: The experimental design was based on the premise that the initial study using the radiation cooling chamber should include many variables briefly observed, rather than a few variables with many replications, in order to determine those variables having the greatest significance.

The experimental variables were:

1. *Chamber wall emissivity.* Two emissivities were considered, about 0.05 and about 0.95. For the low emissivity, the walls were of polished aluminum plate, and for the high, the walls were spray-painted with a flat-black lacquer.
2. *Experimental animals.* Two non-lactating, non-gestating Jersey cows, each weighing approximately 750 pounds, were used.
3. *Cold plate position.* Two positions of the cold plate were used. In one, the plate was hung vertically on the wall facing the cow; in the other, the plate was suspended horizontally from the ceiling directly over the cow's back (see Figures 4 and 5).
4. *Surface condition of the cold plate.* Two surface conditions, bare and encapsulated, were considered. Encapsulation consisted of covering the bare plate with a double-layer of four-mil polyethylene film separated by a 9/16-inch air space.
5. *Cold plate temperature.* Four temperatures, 50°, 35°, 20° and 5° F, were used with the encapsulated plate; three temperatures, 50°, 35°, and 20° F, were used with the bare plate.

The chamber air was held constant at 110° F ± 5° and 65 ± 10 percent relative humidity.

All thermocouple measurements were recorded on Minneapolis-Honeywell 16-point recording potentiometers having 30-second cycles and instrument errors of ½ percent of scale-span. The rectal, cold plate, chamber air and return air temperatures were recorded on a potentiometer having a range of 0° to 150° F and the wet- and dry-bulb temperatures, on a potentiometer having a range of -30° to 230° F.

An individual test was run as follows: a cow was put into the unheated chamber; the chamber air temperature was raised to, and maintained at, about 110° F; the cold plate was refrigerated after the cow's rectal temperature had risen an arbitrary 2.5° F; the plate was turned off after an arbitrary two-hour period; the cow was retained in the chamber for an additional two hours, or until her rectal temperature had risen a total of 5° F, whichever occurred first.

The cows were "rested" for one or two days after a test was run in order to minimize acclimatization. One test was made without refrigerating the cold plate at the beginning of the investigation, and two tests on each cow were made without refrigerating the cold plate at the half-way point in the investigation. All tests with the chamber walls of polished aluminum were run before the walls were painted. The order of conducting the tests was as follows:

1. With chamber walls of low emissivity, plate on the wall, and plate bare, tests at the various plate temperatures were run for each cow.
2. The plate was then encapsulated and tests at the various plate temperatures were run for each cow.
3. The encapsulated plate was then placed in the ceiling position, and tests at the various plate temperatures were run for each cow.
4. The encapsulation was then removed, leaving the plate bare; tests at the various plate temperatures were run for each cow.
5. The chamber walls were then painted and the above procedure followed in reverse order with respect to plate position and plate surface condition.

DATA AND DISCUSSION

The original data were too voluminous to include in this bulletin.

This investigation was concerned primarily with the two-hour period during which the plate was refrigerated.

The physiological effect of the experimental variables on the cow was measured by the rectal temperature and the respiration rate. At high environmental temperatures the respiration rate is not a good indicator of thermally-induced stress, since a maximum respiration rate is established (5). The discussion of the data presented in this section is based on the rate of change in rectal temperature as influenced by the various experimental variables. Regression coefficients were computed for the rectal temperature with respect to time for the two-hour period during which the cold plate was refrigerated. Three tests were run on each cow without using the cold plate in order to determine the slope of the rectal-temperature-versus-time curves in the absence of the cold plate. The regression coefficients for these tests were computed for a two-hour period following a rise in rectal temperature of 2.5° F. All regression coefficients were computed by the least-squares method. The regression coefficients and their corresponding coefficients of correlation were assembled and are presented in Table 1 and Table 2.

TABLE 1--REGRESSION COEFFICIENTS AND COEFFICIENTS OF CORRELATION OF RECTAL-TEMPERATURE-VERSUS-TIME REGRESSIONS FOR COW 620

Experimental Condition	Regression Coefficient	Coefficient of Correlation
I. Low Emissivity		
A. Plate not used	0.02531	0.9232
B. Plate on wall		
1. Bare		
a) 50°	-0.00498	-0.4700
b) 35°	-0.00278	-0.4550
c) 20°	-0.01009	-0.6260
2. Encapsulated		
a) 50°	0.01140	0.7990
b) 35°	0.01500	0.5390
c) 20°	0.00982	0.7460
d) 5°	-0.00686	-0.7198
C. Plate on ceiling		
1. Bare		
a) 50°	-0.00160	-0.2290
b) 35°	-0.02868	-0.8960
c) 20°	-0.01023	-0.6870
2. Encapsulated		
a) 50°	0.02270	0.8480
b) 35°	0.00800	0.8630
c) 20°	0.01881	0.9050
d) 5°	0.02410	0.9176
II. High Emissivity		
A. Plate not used	0.03160	0.8310
	0.03060	0.9220
B. Plate on wall		
1. Bare		
a) 50°	-0.00709	-0.6683
b) 35°	-0.00243	-0.5000
c) 20°	-0.00653	-0.5521
2. Encapsulated		
a) 50°	0.02040	0.8600
b) 35°	0.02360	0.8630
c) 20°	0.01442	0.2860
d) 5°	0.00072	0.6860
C. Plate on ceiling		
1. Bare		
a) 50°	-0.00315	-0.4330
b) 35°	-0.00782	-0.6180
c) 20°	0.00281	0.2850
2. Encapsulated		
a) 50°	-0.00604	-0.7108
b) 35°	-0.00523	-0.3650
c) 20°	0.00682	0.6680
d) 5°	0.00472	0.4440

TABLE 2--REGRESSION COEFFICIENTS AND COEFFICIENTS OF CORRELATION OF RECTAL-TEMPERATURE-VERSUS-TIME REGRESSIONS FOR COW 621

Experimental Condition	Regression Coefficient	Coefficient of Correlation
I. Low Emissivity		
A. Plate not used	0.04690	0.9217
B. Plate on wall		
1. Bare		
a) 50°	0.00555	0.5540
b) 35°	-0.00240	-0.1820
c) 20°	0.00028	0.5639
2. Encapsulated		
a) 50°	0.01260	0.9400
b) 35°	-0.00678	-0.6300
c) 20°	0.01400	0.6869
d) 5°	0.00513	0.5310
C. Plate on ceiling		
1. Bare		
a) 50°	0.01120	0.8380
b) 35°	0.01270	0.7460
c) 20°	0.01010	0.6548
2. Encapsulated		
a) 50°	0.00949	0.7448
b) 35°	0.02770	0.9500
c) 20°	0.01930	0.8255
d) 5°	0.01940	0.8950
II. High Emissivity		
A. Plate not used	0.02863	0.9584
	0.02217	0.9321
B. Plate on wall		
1. Bare		
a) 50°	0.02460	0.8800
b) 35°	0.03430	0.9240
c) 20°	-0.00532	-0.4110
2. Encapsulated		
a) 50°	0.02678	0.9549
b) 35°	0.03160	0.9325
c) 20°	0.02560	0.9600
d) 5°	0.04040	0.9620
C. Plate on ceiling		
1. Bare		
a) 50°	0.02972	0.9440
b) 35°	0.02306	0.9270
c) 20°	0.01730	0.7670
2. Encapsulated		
a) 50°	0.00939	0.5510
b) 35°	0.01110	0.8900
c) 20°	0.01680	0.9150
d) 5°	0.01447	0.8930

Five-Way Analysis of Variance: A five-way analysis of variance (2) of the five variables was made, based upon the regression coefficients of the rectal temperature. The five variables were: (1) temperature of plate, (2) plate surface condition (bare or covered with polyethylene film), (3) plate position (on wall or on ceiling), (4) chamber emissivity (polished aluminum. low, or flat-black lacquered, high), and (5) cow. The variables were symbolized T, S, P, E and C, respectively. The 5° F temperature for the encapsulated plate was not used in the analysis in order to make the temperatures for both plate surface conditions identical. Table 3* gives the results of the analysis of variance. The discussion of Table 3 will be separated into a discussion of main effects, first-order interactions,

TABLE 3--FIVE-WAY ANALYSIS OF VARIANCE

Source of Variation	Sums of Squares	Degrees Freedom	Mean Squares	F Observed
I. Main Effects:				
(T)	0.000048	2	0.000024	0.49
(S)	0.001395	1	0.001395	**28.47
(P)	0.000015	1	0.000015	0.31
(E)	0.000372	1	0.000372	* 7.59
(C)	0.001894	1	0.001894	**38.65
II. First-Order Interactions:				
T x S	0.000180	2	0.000090	1.84
T x P	0.000254	2	0.000127	2.59
T x E	0.000159	2	0.000080	1.63
T x C	0.000112	2	0.000056	1.14
S x P	0.000176	1	0.000176	3.59
S x E	0.000239	1	0.000239	* 4.88
S x C	0.000719	1	0.000719	**14.67
P x E	0.000426	1	0.000426	* 8.69
P x C	0.000215	1	0.000215	4.38
E x C	0.000346	1	0.000346	* 7.06
III. Second-Order Interactions:				
T x S x P	0.000127	2	0.000064	1.31
T x S x E	0.000040	2	0.000020	0.41
T x S x C	0.000162	2	0.000081	1.65
T x P x E	0.000174	2	0.000087	1.78
T x P x C	0.000257	2	0.000128	2.61
T x E x C	0.000178	2	0.000089	1.82
S x P x E	0.000645	1	0.000645	**13.16
S x P x C	0.000012	1	0.000012	0.24
S x E x C	0.000014	1	0.000014	0.29
P x E x C	0.000058	1	0.000058	1.18
IV. Pooled Higher-Order Interactions:				
Error Sums of Squares	0.000544	11	0.000049	
V. Total:	0.008761	47		

NOTE: Symbols T, S, P, E and C refer, respectively, to plate Temperature, plate Surface condition, plate Position, chamber Emissivity, and Cow. Significance at 1 percent level is denoted by (**), and at 5 percent level by (*).

*The analysis of variance was made by Cecil L. Gregory and Phillip Stark at the Missouri College of Agriculture Statistical Service Laboratory.

second-order interactions and higher-order interactions.

Main effects: The between-cows effect and the between-plate-surface-conditions effect were significant at the 1 percent level; the between-chamber-emissivities effect was significant at the 5 percent level; and the between-plate-temperatures effect and the between-plate-positions effect were not significant.

The between-cows effect was not expected to be as highly significant as it was. Since rectal temperature was the dependent variable, the between-cows effect influenced the interpretation of the interactions between the independent variables, as will be shown later.

The cows were differentiated by their Dairy Department herd numbers, 620 and 621; these numbers will be used in future reference to the cows.

The accepted maximum respiration rate for Jersey cows is approximately 150 respirations per minute at about 100° F when the temperature is raised rapidly allowing no time for acclimatization (5). During this investigation, the average maximum respiration rate reached by cow 620 was 193 respirations per minute, with a peak value of 224 respirations per minute, while the average maximum respiration rate reached by cow 621 was 171 respirations per minute, with a peak value of 192 respirations per minute.

The ability of cow 620 to breathe more rapidly than cow 621 may explain, in part, the significance of the between-cows effect. However, it should be pointed out that the relation between respiration rate and ventilation rate is not known. Breathing is deeper and, consequently, ventilation per respiration greater, at low respiration rates than at high respiration rates. When cow 620 was breathing at her peak respiration rate, it was observed that the breathing was very shallow, i.e., the flank-movement was small compared with the flank-movement at lower (125-130 respirations per minute) respiration rates. The original data indicated that cow 620 maintained her peak respiration rate over a prolonged period of time, while cow 621 tended to reach her peak respiration rates in short bursts and then drop back to a lower rate.

The average time required for the rectal temperature to rise 2.5° F was 2.55 hours for cow 620, and 1.38 hours for cow 621. The greater length of time is attributed to the hyperpnea of cow 620, and indicates that cow 620 was inherently better able to withstand the temperature and humidity levels imposed by the experiment than cow 621.

Since the between-plate-temperatures effect was not significant, the regression coefficients were averaged within each plate surface condition. The temperature-averaged regression coefficients from each plate surface condition are in Table 4; graphs of these statistics are presented in Figures 7, 8, 9 and 10, which show the temperature-averaged regressions of rectal temperature versus time plotted for each plate position and surface condition. Each graph (Figures 7, 8, 9 and 10) represents one cow at one chamber emissivity, and each includes the average of all no-plate-used regressions for the cow.

TABLE 4--REGRESSION COEFFICIENTS OF RECTAL-TEMPERATURE-VERSUS-TIME REGRESSIONS, AVERAGED FOR EACH PLATE SURFACE CONDITION

Experimental Condition	Regression Coefficient Cow 620	Regression Coefficient Cow 621
I. Low Emissivity		
A. Plate not used	0.02917	0.03257
B. Plate on wall		
1. Bare	-0.00595	0.00114
2. Encapsulated	0.00734	0.00624
C. Plate on ceiling		
1. Bare	-0.01350	0.01133
2. Encapsulated	0.01840	0.01897
II. High Emissivity		
A. Plate not used	0.02917	0.03257
B. Plate on wall		
1. Bare	-0.00535	0.01786
2. Encapsulated	0.01660	0.03110
C. Plate on ceiling		
1. Bare	-0.00272	0.02336
2. Encapsulated	0.00007	0.01294

NOTE: Plate-not-used values are the average of all plate-not-used values at both low and high chamber emissivities (see Table 1 and Table 2). All other values are the average of the regression coefficients for all plate temperatures at one plate surface condition.

The temperature-averaged regression coefficients for cow 620 were negative for the bare plate in both positions of the plate (see Table 4 and Figures 7 and 8), while those for the encapsulated plate were positive in both positions of the plate (see Table 4 and Figures 9 and 10). The regression slopes in all cases were less than the slope of the no-plate-used regression.

In no case was the temperature-averaged regression coefficient for cow 621 negative. At the low chamber emissivity, the bare plates produced regression slopes that were less than those produced by the encapsulated plates at each plate position, although the encapsulated plate on the wall produced a regression slope that was less than that produced by the bare plate in the ceiling position (see Figure 9). However, at the high chamber emissivity the lowest slope occurred with the encapsulated plate on the ceiling, while the highest (with the exception of the no-plate-used regression) occurred with the encapsulated plate on the wall. In no case did the presence of the cold plate produce a negative temperature-averaged regression coefficient for cow 621. A comparison of the graphs concerning cow 620 (Figures 7 and 8) with those concerning cow 621 (Figures 9 and 10) indicates that the cold plate was more effective in relieving thermally-induced stress in cow 620 than in cow 621, which may again point out that cow 620 was inherently better able to withstand the experimentally-imposed temperature and humidity levels than was cow 621. That the slopes of the no-plate-used regressions were in all cases greater than the plate-used regres-

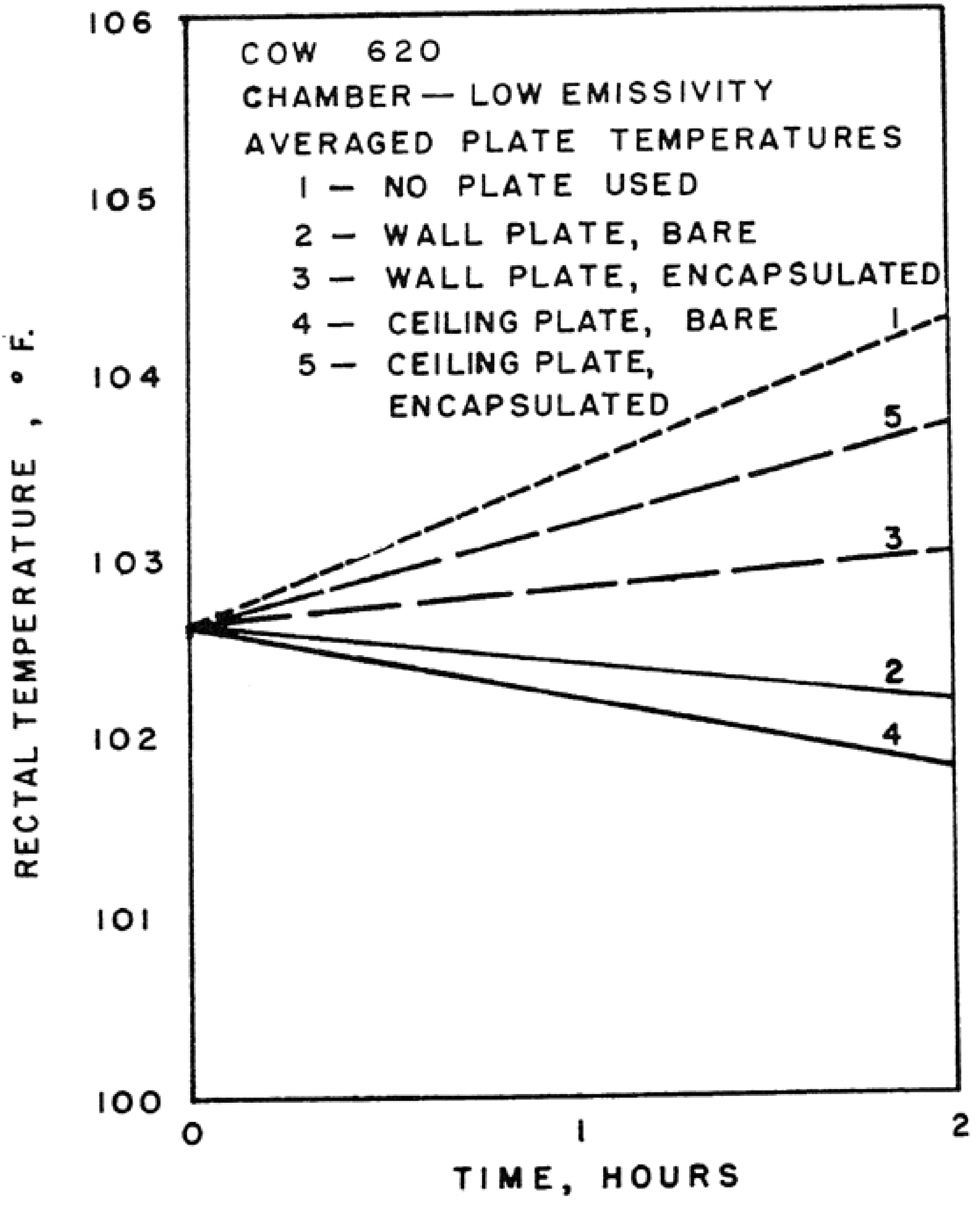

Figure 7.—Comparison of rectal-temperature-versus-time regressions for Cow 620 in chamber with walls of low emissivity for both plate positions and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures at a given plate position and surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 620. Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 620.

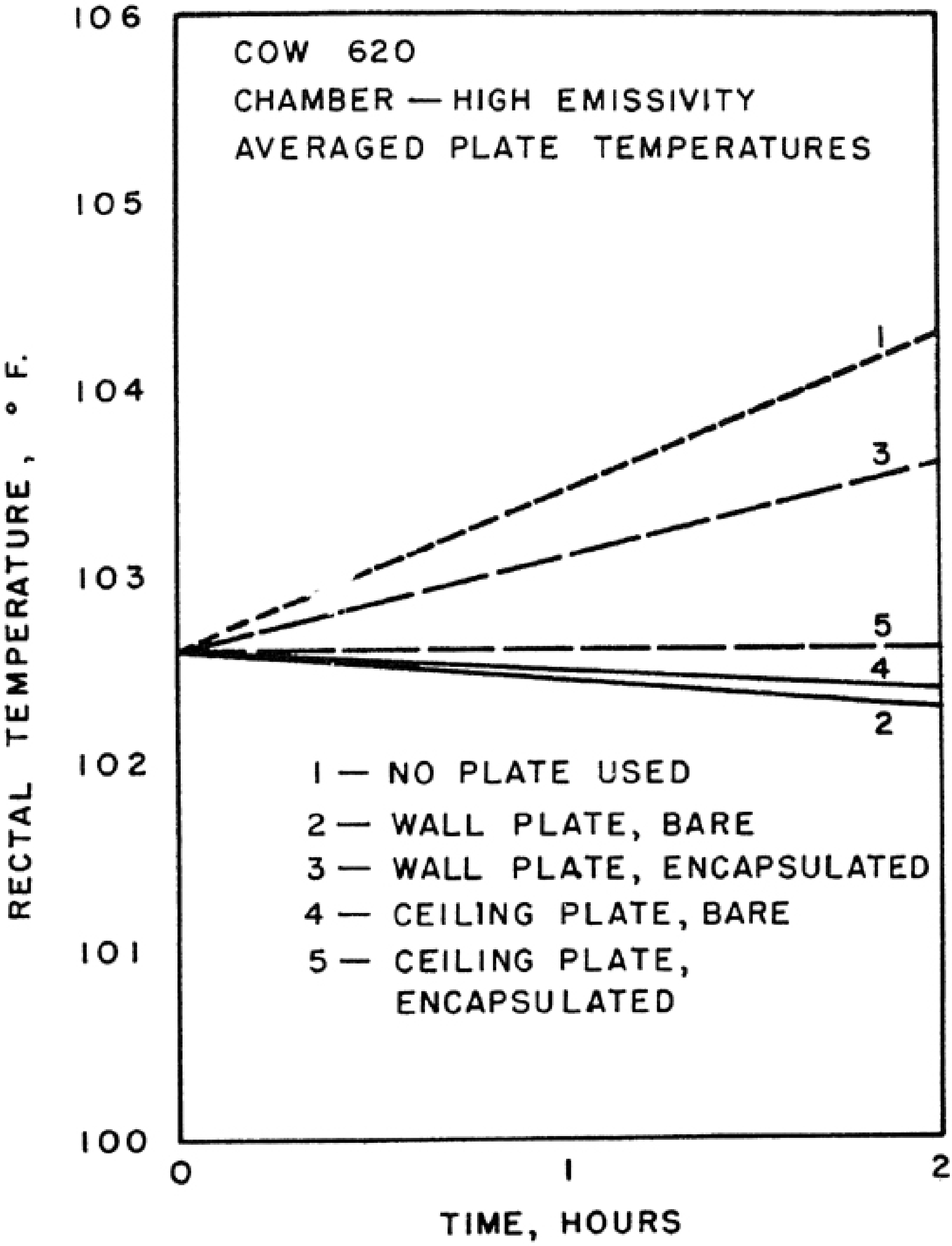

Figure 8.— Comparison of rectal-temperature-versus-time regressions for Cow 620 in chamber with walls of high emissivity for both plate positions and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures at a given plate position and surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 620. Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 620.

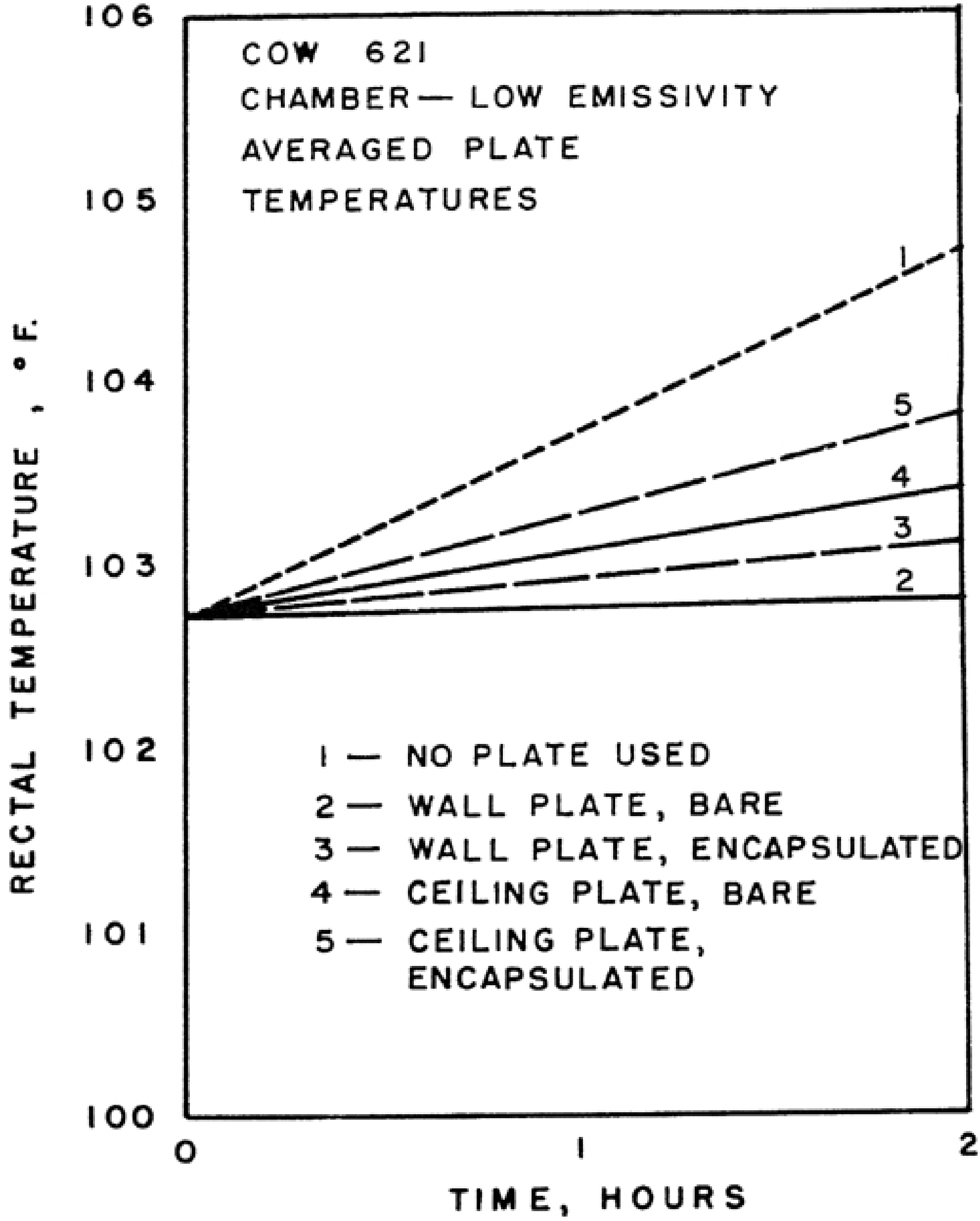

Figure 9.—Comparison of rectal-temperature-versus-time regressions for Cow 621 in chamber with walls of low emissivity for both plate positions and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures at a given plate position and surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 621. Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 621.

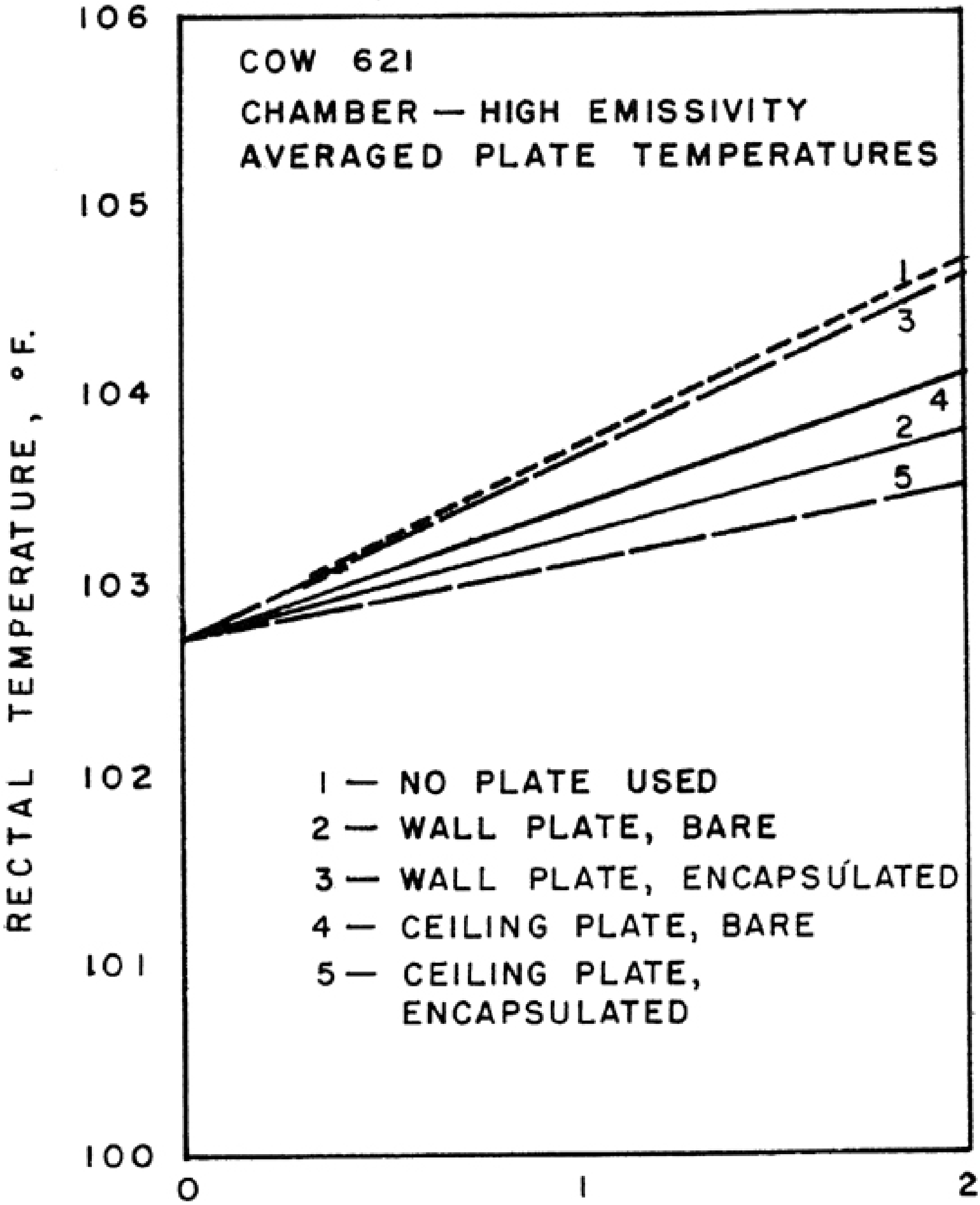

Figure 10.—Comparison of rectal-temperature-versus-time regressions for Cow 621 in chamber with walls of high emissivity for both plate positions and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures at a given plate position and surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 621. Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the figure) for Cow 621.

sions indicates that, even in the case of cow 621, the presence of the cold plate affected the rectal temperature and, in the case of cow 620, the bare plate was effective enough to cause a reduction in the rectal temperature.

Since the between-plate-positions effect was not significant, the regression coefficients in Table 4 were averaged with respect to plate position, and the resulting position-temperature-averaged regression coefficients are presented in Table 5. Graphs of these statistics were prepared as follows: Figures 11 and 12 show the rectal temperature versus time regressions of cow 620 and 621, respectively, for both surface conditions, and include the average of all no-plate-used regressions; Figures 13 and 14 show the rectal temperature versus time regressions for both cows at low and high chamber emissivities and each includes the average of all no-plate-used regressions for both cows.

TABLE 5--REGRESSION COEFFICIENTS OF RECTAL-TEMPERATURE-VERSUS-TIME REGRESSIONS, AVERAGED FOR EACH PLATE SURFACE CONDITION AND EACH PLATE POSITION

Experimental Condition	Regression Coefficient Cow 620	Regression Coefficient Cow 621
I. Low Emissivity		
A. Plate not used	0.02917	0.03257
B. Bare plate	-0.00972	0.00624
C. Encapsulated plate	0.01287	0.01260
II. High Emissivity		
A. Plate not used	0.02917	0.03257
B. Bare plate	-0.00404	0.02061
C. Encapsulated plate	0.00834	0.02202

NOTE: Plate-not-used values are the average of all plate-not-used values at both low and high chamber emissivities (see Table 1 and Table 2). All other values are the average of the regression coefficients for all plate temperatures at one plate surface condition for both plate positions.

An examination of Figures 11 and 12 indicates that cow 620 was influenced more by plate surface condition than by chamber emissivity, and that cow 621 was influenced more by chamber emissivity. This is shown again in comparing Figures 13 and 14; the low chamber emissivity (Figure 13) had a greater effect on cow 621 than the high chamber emissivity (Figure 14). Apparently the significance of the between-chamber-emissivities effect is influenced more by cow 621 than by cow 620, while the significance of the between-plate-surface-conditions effect is influenced more by cow 620.

First-order interactions: The interaction between plate surface condition and cow (S x C) was significant at the 1 percent level; interactions between plate surface condition and chamber emissivity (S x E), plate position and chamber emissivity (P x E), and chamber emissivity and cow (E x C) were significant at the 5 percent level.

The significance of the interaction S x C was attributed chiefly to cow 620,

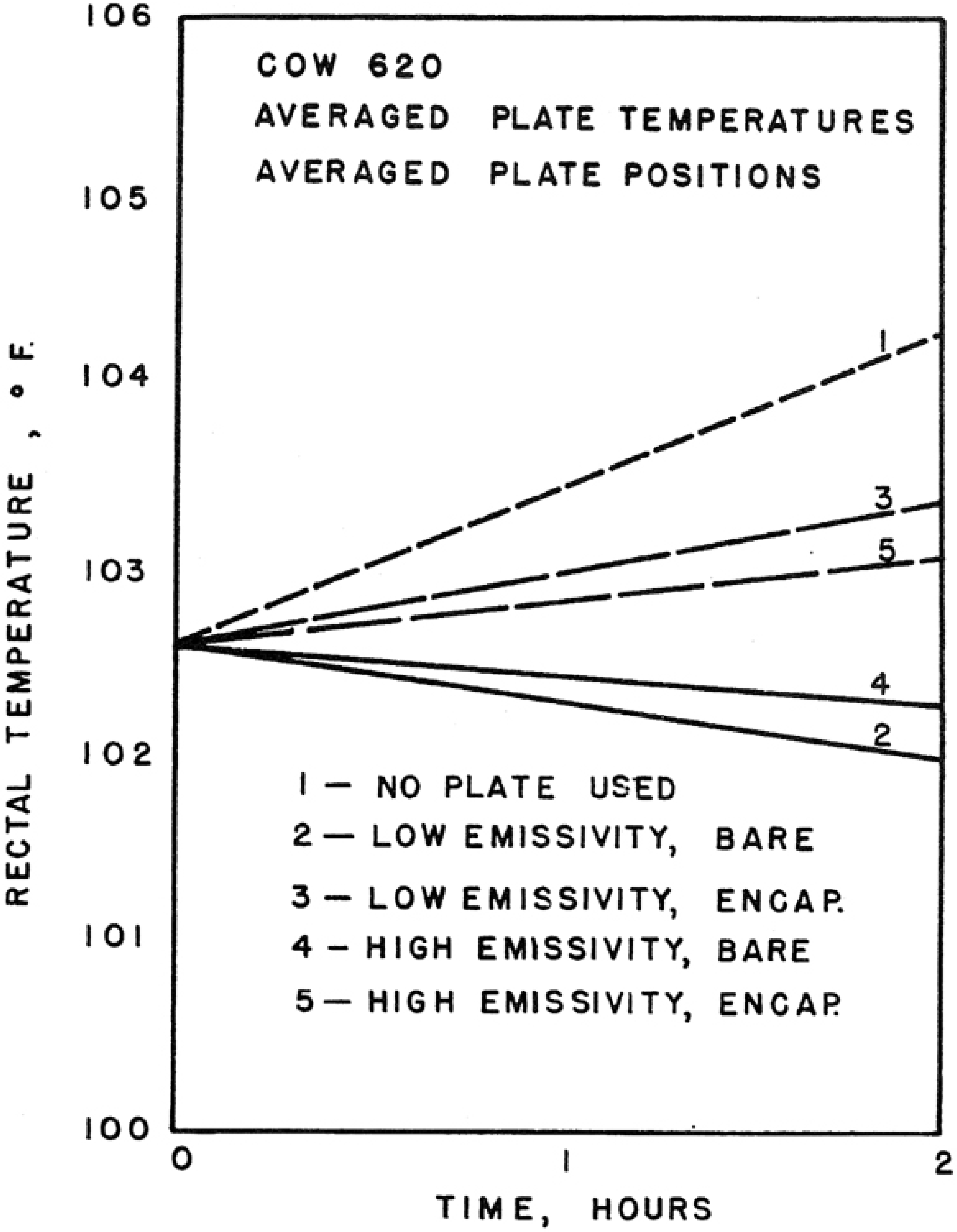

Figure 11.—Comparison of rectal-temperature-versus-time regressions for Cow 620 for both chamber wall emissivities and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures and plate positions at a given plate surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 620.

Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 620.

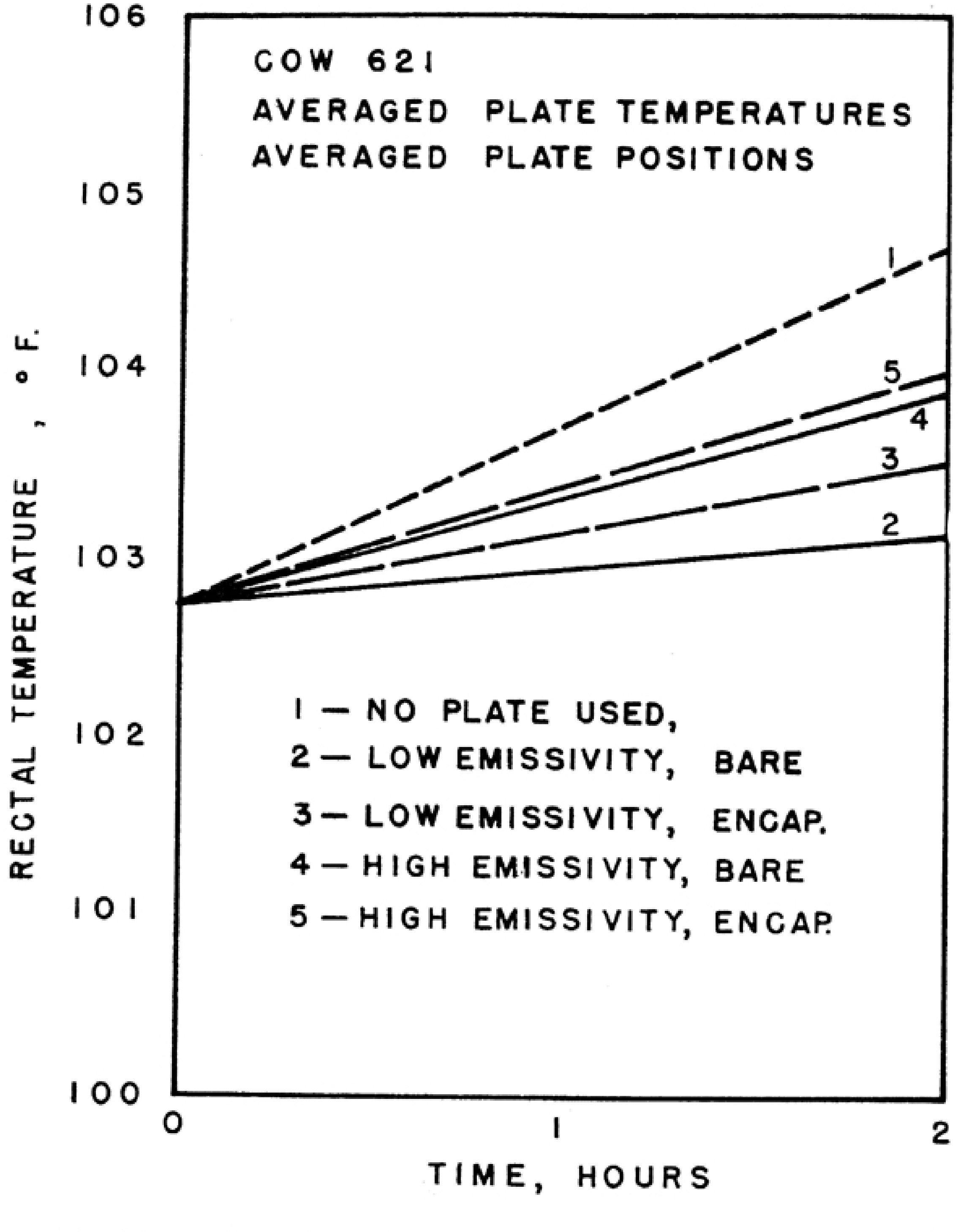

Figure 12.—Comparison of rectal-temperature-versus-time regressions for Cow 621 for both chamber wall emissivities and both plate surface conditions. Curves 2, 3, 4 and 5 represent average regressions for all temperatures and plate positions at a given plate surface condition. No-plate-used regression (1) represents average of all no-plate-used regressions for Cow 621.

Point of origin of curves represents average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 621.

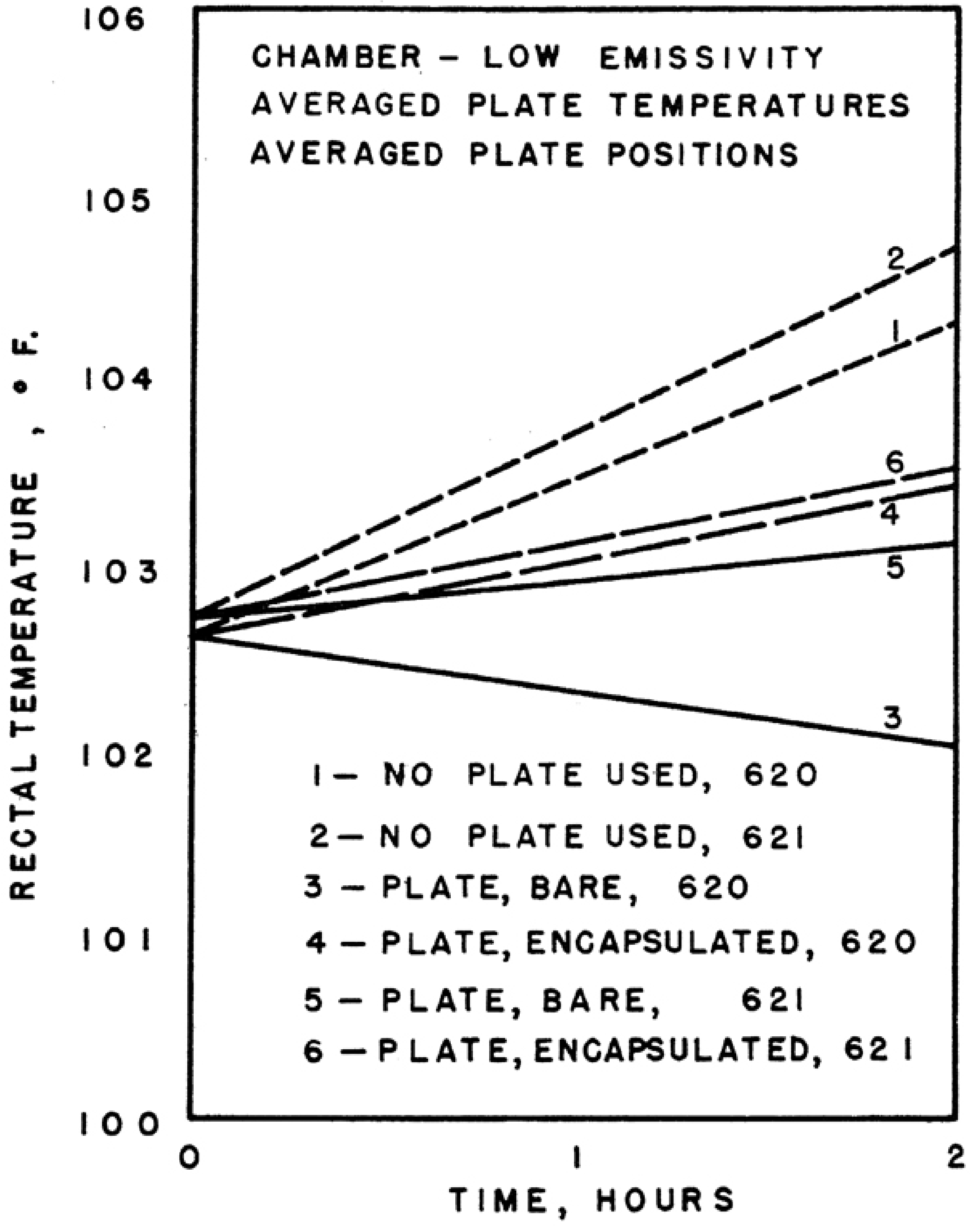

Figure 13—Comparison of rectal-temperature-versus-time regressions for both cows at both plate surface conditions in chamber with walls of low emissivity. Curves 3, 4, 5 and 6 represent average regressions for all temperatures and plate positions at a given plate surface condition. Curves 1 and 2 represent average of all no-plate-used regressions for Cow 620 and Cow 621, respectively.

Points of origin of curves represent average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 620 and Cow 621, respectively.

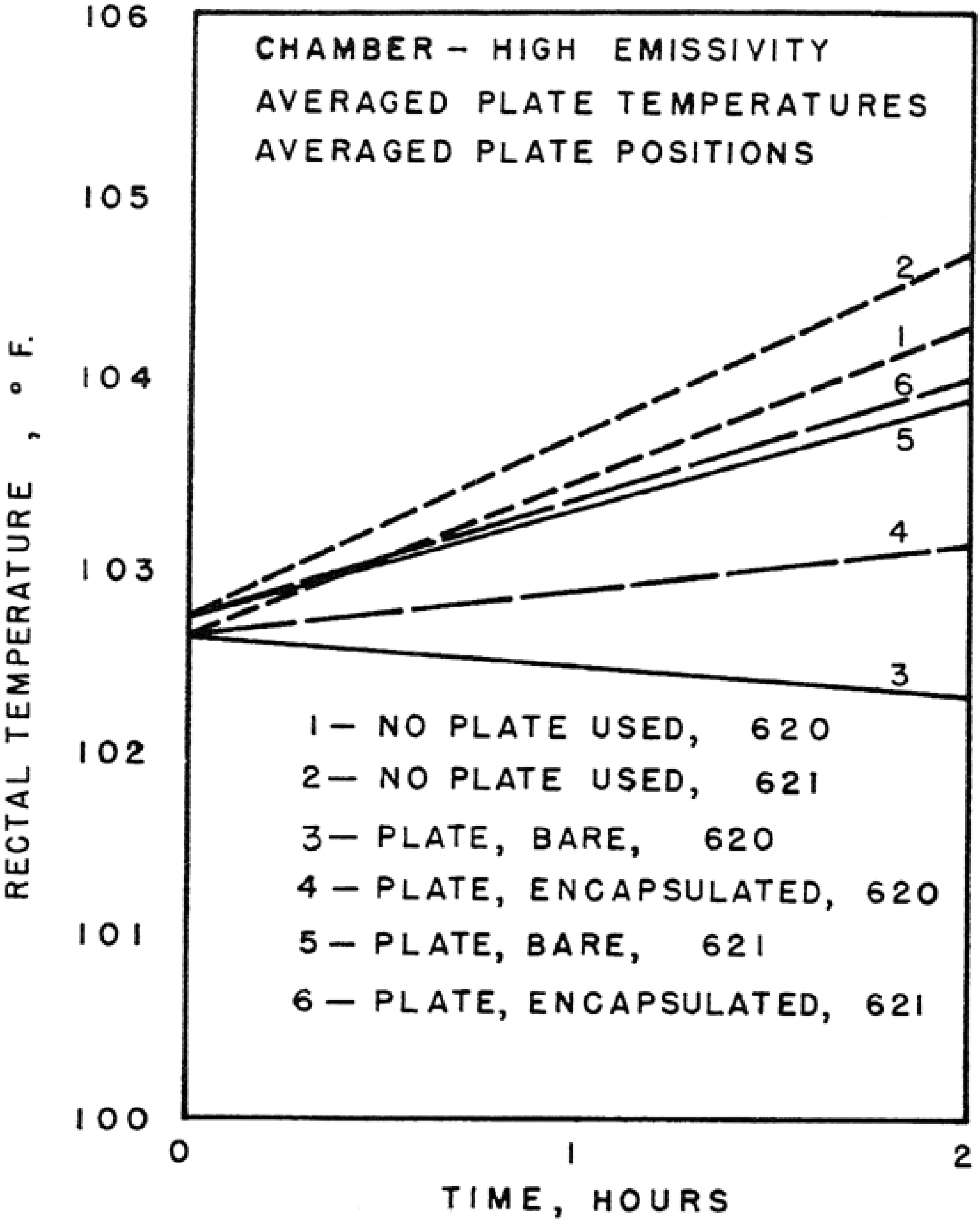

Figure 14—Comparison of rectal-temperature-versus-time regressions for both cows at both plate surface conditions in chamber with walls of high emissivity. Curves 3, 4, 5 and 6 represent average regressions for all temperatures and plate positions at a given plate surface condition. Curves 1 and 2 represent average of all no-plate-used regressions for Cow 620 and Cow 621, respectively.

Points of origin of curves represent average of all regression values at the time when the plate was refrigerated (Time = 0 in the Figure) for Cow 620 and Cow 621, respectively.

whose regression coefficients were negative when the plate was bare and positive when encapsulated. Plate surface condition apparently had little effect on the regressions of cow 621 (see Tables 4 and 5 and Figures 11 and 12). This is also indicated by the sums of regression coefficients tabulated as follows:

		C	
		620	*621*
S)	Bare	-0.08257	+0.16109
	Encapsulated	+0.13970	+0.19758

The significance of the interaction P x E was due primarily to the wall position of the plate, where the sum of regression coefficients at the high chamber emissivity was more than four times the sum of regression coefficients at the low chamber emissivity, as shown in the following table:

		E	
		Low	*High*
P)	Wall	+0.04162	+0.17993
	Ceiling	+0.09949	+0.09476

On the other hand, the difference between the sums of regression coefficients at the two chamber emissivities when the plate was on the ceiling was negligible. It is entirely reasonable that, if the between-emissivities effect were significant, it would be due to the wall position of the plate rather than the ceiling position, since in the wall position the plate faced a reflecting surface, while in the ceiling position the plate faced an absorbing surface.

The interaction S x E was significant at the 5 percent level due chiefly to the bare plate, where the sum of regression coefficients at the high chamber emissivity was more than five times the sum of regression coefficients at the low chamber emissivity (as shown below),

		E	
		Low	*High*
S)	Bare	-0.02093	+0.09945
	Encapsulated	+0.16204	+0.17524

while the difference in the sums of regression coefficients at the two chamber emissivities for the encapsulated plate was negligible.

The significance of the interaction E x C was due primarily to cow 621, who was influenced more by chamber emissivity than cow 620 (Figures 11 and 12), as was pointed out in the discussion of the between-chamber-emissivities effect, and as is shown by the sums of regression coefficients,

		C	
		620	*621*
E)	Low	+0.02737	+0.11374
	High	+0.02976	+0.24493

Second-order interactions. The only significant second-order interaction was between plate surface condition, plate position and chamber emissivity (S x P x E; see Table 3). The interaction was significant at the 1 percent level and is explained on the basis of the first-order interaction factors, P x E and S x E, i.e., the significance is due to the wall position of the bare plate at the low chamber emissivity. This is pointed out by the sums of regression coefficients,

		P (Wall)		*P (Ceiling)*	
		E		*E*	
		Low	*High*	*Low*	*High*
S)	Bare	–0.01442	+0.03753	–0.00651	+0.06192
	Encapsulated	+0.05604	+0.14240	+0.10600	+0.03284

Higher-order interactions: The higher-order interactions were pooled to form the error term for two reasons: (1) to avoid reducing the degrees of freedom of the error term to a value of two, which would in turn reduce the probability of significance of the main effects and first- and second-order interactions and (2) the significance of higher-order interactions would have added little if anything to the interpretation of the results, since this investigation was concerned primarily with determining the significance of the main effects.

CONCLUSIONS

Results of this investigation indicate:

There is a highly significant difference between Jersey cows in their ability to withstand environmental conditions of high temperature and high humidity.

Within the limits of the experiment, the cold plate was effective in reducing the slope of the rectal-temperature-versus-time regression..

In the experimental radiation-cooling chamber, walls of polished aluminum are more effective than walls coated with flat-black lacquer in reducing the rectal temperature.

With walls of polished aluminum, the plate is more effective when on the wall (facing a reflecting surface) than when on the ceiling (facing an absorbing surface).

Within a plate-temperature range of 20° to 50° F, a bare plate is more effective than an encapsulated plate in reducing the rectal temperature of a thermally-stressed cow.

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