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SUPPLEMENTAL MILKROOM HEATING USING THE HEAT EXTRACTED BY THE BULK MILK COOLING SYSTEM

BY

HARVEY GORDON YOUNG

A thesis submitted
in partial fulfillment of the requirements for the degree
Master of Science, Department of Agricultural
Engineering, South Dakota State
College of Agriculture
and Mechanic Arts

December, 1959

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SUPPLEMENTAL MILKROOM HEATING USING
THE HEAT EXTRACTED BY THE
BULK MILK COOLING SYSTEM

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head of the Major Department

ACKNOWLEDGEMENTS

The author wishes to express his most sincere appreciation to Professor Dennis L. Moe and Doctor Charles N. Hinkle for their helpful suggestions and criticisms during the investigation of the problem and the preparation of the manuscript.

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INTRODUCTION

Since the initial installation of a farm bulk milk cooler in 1938, this method of handling and cooling milk has experienced rapid and widespread acceptance until at the present time there are in excess of 114,000 units in operation on farms throughout the United States.[1] The primary motivation for the trend toward bulk milk cooler acceptance has been furnished by the dairy farm operator's quest for equipment and methods to counteract the narrowing margin of profit that has been experienced in all farming operations during the past decade. This milk cooling method has made possible lower operating costs since in most cases the following savings may be realized:

1. Less labor involved in handling milk.
2. Sanitary conditions are more easily maintained due to the accessibility of all surfaces in contact with the milk and smooth stainless steel construction of the tank.
3. Lower milk cooling costs.

Bulk milk cooling also results in maintenance of a better quality product which will usually yield a higher net return to the dairy farm operator. Greater savings in the labor required in handling milk may be realized by incorporating a pipeline milking system with the bulk milk cooler installation since this system eliminates manually transferring milk from the milking room to the cooler.

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[1] <u>Report of a Survey of Trends in Bulk Milk Tank Use -- January, 1959</u>, Agricultural Extension Bureau, United States Steel Corporation: Cleveland, Ohio.

Problems Encountered In Bulk Milk Cooler Operation

Conversion to bulk milk cooling systems has not been without certain problems however; the major one being in maintaining satisfactory temperatures in the milkhouse for efficient cooling unit operation during warm weather. On relatively small bulk milk tanks ranging in size from 100 to 400 gallons, the condensing unit is mounted on the tank frame, thus the heat removed from the milk is released in the milkhouse causing an increase in milkhouse air temperature. The magnitude of this temperature rise will be governed by the amount of milk cooled, the period over which the cooling unit must operate to absorb the cooling load, and the rate at which heat is lost from the structure. While the heat extracted from the milk is desirable for supplementing the heating-unit in the milkhouse during cold weather, its presence during warm weather adds considerably to the operating costs of the bulk milk cooler. Hall[2] states that costs of operating the tank will increase 30 to 40 percent as the temperature of the air surrounding the condensing coil is increased from 60° to 90° F. Under extreme conditions compressor motors have failed due to extended operation at above rated operating temperatures.

Several solutions have been devised to correct the above situation, one of these being an increase in ventilation capacity. However, this becomes rather expensive because of the large volume of air required in maintaining adequate conditions when the difference between inside and out-

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[2] Carl W. Hall, "Which Bulk Tank For You?", Hoards Dairyman, Vol. 102, 909, W. D. Hoard and Sons Company: Fort Atkinson, Wisconsin, 1957.

side air temperature becomes relatively small. The most common practice has been to mount the compressor in a remote position so that outside air can be used as a cooling medium. This system has proved satisfactory but a housing must be constructed over the compressor for weather protection and a heat source installed to insure satisfactory winter operation. This practice is necessary with both air and water cooled systems.

Another method of lowering cooling costs during warm weather has been the use of water as a cooling medium for the condensing coil. Water cooling systems are generally incorporated in bulk milk coolers with a capacity of over 400 gallons and may either be a combination water-air cooled system or completely water cooled. A reliable source of water under pressure is required for these systems and water quality is of importance since any tendency to cause the formation of deposits in the cooling coil will reduce the cooling effect of the water. The water cooling equipment adds to the initial cost of the installation; however, the resulting increase in efficiency more than offsets the added costs.

To date, emphasis has been directed toward eliminating the heat released by the condenser coil during the cooling process with little thought being given to utilising this source of heat. Since approximately 400 BTU's of heat are rejected in cooling a single gallon of milk to storage temperature, it would appear that this heat source deserves further investigation to determine what possibilities it might have for future installations.

Statement of Problem

This investigation dealt with an evaluation of the heat extracted from the milk during the cooling operation as a supplementary heat source for maintaining milkhouse temperatures during cold weather. It involved the design of a bulk milk cooler installation incorporating remote placement of the compressor to eliminate the summer ventilation problem and a venting system whereby air from the milkhouse may be circulated over the condenser coil during cold weather to pick up the heat rejected by the cooling unit.

A comparison study was made of the energy requirements of an electric space heater in maintaining milkhouse temperatures both with and without the aid of supplemental heat from the milk cooling operation. The results of the heating requirements at various differences between inside and outside temperature were compared and analyzed taking into consideration the other factors that influenced the rate of heat loss from the structure.

Bulk Milk Cooling Systems

There are two types of cooling systems employed in bulk milk tanks; the direct-expansion and the ice-bank systems. In the direct-expansion system the evaporator coils of the refrigeration unit are constructed as an integral part of the inner walls of the tank and the milk is in direct contact with the cooling surface. During the cooling process, heat from the milk is absorbed directly by the refrigerant and the condensing unit must be of sufficient capacity to absorb the cooling load in the time specified to lower milk temperature to the storage point. The capacity of the condensing unit for a direct-expansion system is from two-thirds to one horsepower per 100 gallons of milk tank capacity.[3]

With the ice-bank system the evaporator coils of the cooling unit are immersed in water at the bottom of the tank and during compressor operation a bank of ice is built up around the coils. The ice forms the cooling source as water is pumped over it, chilled, and sprayed over the walls of the tank to cool the milk. The size of the ice-bank will be governed by the cooling capacity required of the tank. The major portion of the compressor operating time will occur in the period between milkings and thus the condensing unit does not require the capacity of a direct-expansion system of comparable size since the cooling load may be absorbed over a much longer period of time. The size of the condensing unit usually ranges from one-third to one-half horsepower per 100 gallons of tank capacity.[4]

The actual value of the heat extracted from the milk for supplementing the milkhouse heating system will be governed by the rate at which it is rejected by the bulk milk cooling system. Heat released at a slow rate over a relatively long period of time, as would be the case with the ice-bank system, should be more beneficial. The more uniform delivery of heat in this instance would aid in placing a lower demand on the heating

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[3] W. H. M. Morris, B. A. McKenzie, H. F. Ford, and J. M. Schlegel, "How to Select, Install, Operate, Maintain, and Sanitize Farm Bulk Milk Tanks", Agricultural Extension Bulletin, ID-7, Purdue University: Lafayette, Indiana, 1955.

[4] *Ibid.*, p. 8.

system. The direct-expansion system will release large quantities of heat over a relatively short period of time and should cause the temperature in the milkhouse to increase considerably during the milk cooling period. If the temperature increase is of sufficient magnitude to exceed necessary conditions, then heat is being wasted. Since the direct-expansion system operates only during the milk cooling period, its duration of operation is governed by cooling requirements set forth in 3A Sanitary Standards.

The 3A Standards for farm holding and/or cooling tanks include specifications on the minimum requirements for performance of refrigeration systems under prescribed conditions. These standards are for the design of bulk milk coolers and are formulated by a committee known as the 3A Committee, consisting of representatives of the International Association of Milk and Food Sanitarians, Inc., United States Public Health Service, and the Dairy Industry Committee. The following section is reprinted from these standards:

> Cooling:[5] Farm cooling tanks equipped with either direct-expansion or refrigerated water cooling surface shall be furnished with sufficient cooling surface in tank and sized Freon refrigerating unit, when testing at 90° ambient temperature for air cooled units, or 120 lb. head pressure for water cooled units, to cool as follows:
>
> (a) Tanks used for every day pick-up shall cool 50 percent of the rated volume of the tank containing raw milk, from 90° to 50° F. in one hour after the tank has been filled to 50 percent of its capacity, with the compressor in operation during the filling period. Unit then to cool above volume from 50° to 40° F., in one hour.

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[5] 3A Sanitary Standards, Journal of Milk and Food Technology, Vol. 16, 191, International Association of Milk and Food Sanitarians, Inc., 1953.

(b) Tanks used for every other day pick-up shall cool 25 percent of the rated volume of the tank containing raw milk, from 90° to 50° F. in one hour after the tank has been filled to 25 percent of its volume, with the compressor in operation during the filling period. Unit then to cool above volume from 50° to 40° F., in one hour.

Work of Other Investigators

Experiments conducted in utilizing the heat released during the milk cooling process have been directed mainly toward perheating water to be used for cleaning the milk handling equipment. Tap water was drawn into a preheat tank and its temperature increased by heat rejected from the condenser coil of the milk cooling unit. The temperature to which the wash water was preheated was governed by the point at which optimum efficiency of the cooling unit could be obtained. All prior studies were conducted under controlled laboratory conditions using water as a milk substitute, a practice sanctioned by the 3A Standards Committee for bulk milk cooler tests.[6] The reasoning behind these arrangements was that year-round utilization could be made of the heat extracted from the milk while the operating efficiency of the cooling unit would be at constant high levels.

Investigations conducted by Charity, Baker, and Earp[7] using the cooling unit of a 4-can milk cooler as a heat pump to preheat water showed savings of approximately 50 percent of the electrical energy nor-

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[6] Ibid., p. 191.

[7] L. F. Charity, V. H. Baker and V. F. Earp, "Heating Water With a Milk Cooler Using the Heat Pump Principle", Agricultural Engineering, Vol. 33, 216 - 219, American Society of Agricultural Engineers: Saint Joseph, Michigan, 1952.

mally required in heating water. The procedure included mounting the condenser coil in the preheat tank and heating 68 gallons of water daily from 60° to 120° F. with the heat extracted in cooling 40 gallons of milk- Results showed that the electrical energy required for raising the temperature of the preheated water to 150° F. in a water heater was 8.45 kilowatt-hours compared to 17.13 kilowatt-hours consumed in heating an equal amount of water when no preheat cycle was used. This represented a saving of 8.68 kilowatt-hours per day in heating water. No significant difference was observed in either the total operating time or energy consumption of the cooling unit over conventional methods.

Studies carried on by the Agricultural Engineering Research Division, United States Department of Agriculture[8] using a 400 gallon direct-expansion bulk milk cooling tank with a two horespower remote compressor designed for every other day pick-up showed savings of up to 4000 kilowatt-hours per year in preheating wash water. The experiment involved preheating wash water to temperatures ranging from 102° to 125° F. in a 42 gallon preheat tank and checking cooling unit efficiencies as well as the electrical energy saved in preheating the water.

Savings were maximum when preheating water to a point between 120° and 125° F. Any preheat temperature above or below this level resulted in decreased savings due to either inefficient operation of the cooling unit at the elevated preheat temperature or less than full utilization

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[8] M. C. Ahrens, "Bulk-Milk Cooler Heats Water", Agricultural Engineering, Vol. 40, 22 - 25, American Society of Agricultural Engineers: Saint Joseph, Michigan, January, 1959.

of the available heat in the milk. Of the 9000 kilowatt-hours of heat that would be extracted annually from milk cooled in a tank this size, the resulting 4000 kilowatt-hours of energy saved represented an efficiency of almost 50 percent for the installation. Fewer kilowatt-hours were required to operate the cooling unit using the heat pump principle to preheat water to 120° F. than to operate the conventional condenser in an ambient temperature of 76° F. or more.

While the material stated above does not deal directly with the study involved in this investigation, the author felt that the information was pertinent. The principle involved is similar except for the utilization of the heat extracted from the milk during cooling. An investigation of the literature revealed no information in this particular field although Ahrens[9] and Davis[10] cite the possibility of heating the milkhouse with the bulk milk cooler. All prior investigations have taken place in locations where moderate winter climatic conditions exist and milkhouse heating does not present problems of the magnitude that would exist in South Dakota.

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[9] _Ibid_., p. 22.

[10] Davis, C. P., "Possible Farm Applications of the Heat Pump" _Agricultural Engineering_, Vol. 34, 323-325, American Society of Agricultural Engineers: Saint Joseph, Michigan, May 1953.

EQUIPMENT AND MATERIALS

The site selected for this investigation was the South Dakota State College Dairy Department production unit. It was chosen due to the interest and cooperation shown by the Dairy Department. This department made available the facilities for the experiment and followed the author's suggestions and plans in making the bulk milk cooler installation.

The milkroom in which the study was conducted was built as an integral part of the main dairy barn. A milkroom is defined by the American Society of Agricultural Engineers[11] as: "A room with one or more sections for handling raw milk, wholly or partially enclosed by the structure in which the cows are milked." This room occupied the northeast corner of the structure and had only two exterior walls, one facing north and the other east. The two interior walls of the milkroom separated the structure from the milking room to the west and an observation room on the south. The temperatures maintained in the milking room and observation room during cold weather were approximately 45° and 70° F. respectively.. The bulk milk tank used during the course of the investigation was located in the milkroom.

Milkroom Construction

The milkroom measured 19' 6" in length, 8' 8" in width and had a ceiling height of 8' 9". Three windows with a total glass area of 72.8

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[11] Dairy Housing Terminology, Agricultural Engineers Yearbook, p. 128, American Society of Agricultural Engineers: Saint Joseph, Michigan, 1959.

square feet were located in the exterior walls while observation windows totaling 66.2 square feet were constructed in the interior walls. The exterior walls were concrete block surfaced on the outside with stucco and on the inside with plaster. The wall dividing the milkroom and milking room was a combination of structural types. The first 32 inches consisted of a six-inch concrete wall over which a row of observation windows running the entire length of the room were located. The portion of the wall above the observation windows was wood frame surfaced with plaster board and plaster on both sides.

The wall in the south end of the milkroom was wood frame construction with asbestos sheeting. This wall contained two observation windows and the access door.

Ceiling construction consisted of conventional wood framing surfaced on the underside with plaster board and plaster. An attic above the ceiling left an average space of one foot between the ceiling joists and the sloping roof.

Insulation was not used in the walls of the milkroom while the ceiling contained a two-inch fiber glass blanket. All of the windows in the structure were single glazed and no provisions for installing storm sash were made for the exterior windows.

Bulk Milk Cooler

The bulk milk cooler employed in this study was a 600 gallon direct-expansion tank designed for every other day milk pick-up. The condenser capacity was 3 horsepower and cooling for the condenser coil was accomplished by a combination of air and water. The compressor was located in a remote position outside the east wall of the milkroom.

Compressor Housing

A housing four feet wide and five feet long was constructed over the compressor to provide protection during inclement weather. The exterior and interior surfaces of the compressor housing walls were one-fourth-inch exterior plywood. Insulation for the housing consisted of two inches of fiberglass insulation in the walls and roof. Two heat lamps controlled by a thermostat maintained above-freezing temperatures in the compressor housing during cold weather. Figure 1 shows an external view of the compressor housing.

Two vents were made in opposite sides of the compressor housing for use during summer operation. When the vents were open, outside air was drawn in through one opening, passed over and cooled the condenser coil and was exhausted from the other opening. The location of the exterior vents of the compressor housing are shown in Figures 1 and 2. During winter operation these vents were closed to seal the housing from the outside. Two additional vents were constructed in the wall between the milkroom and the compressor housing for use during winter operation. These vents, when opened, allowed circulation of air from the milkroom over the condenser coil for heating purposes. Figure 3 shows the vents between the milkroom and compressor housing as viewed from the milkroom side. In addition to the four vents, a partition, was built in the compressor housing dividing it longitudinally so that the intake and exhaust sides of

Figure 1. Exterior View of Compressor Housing

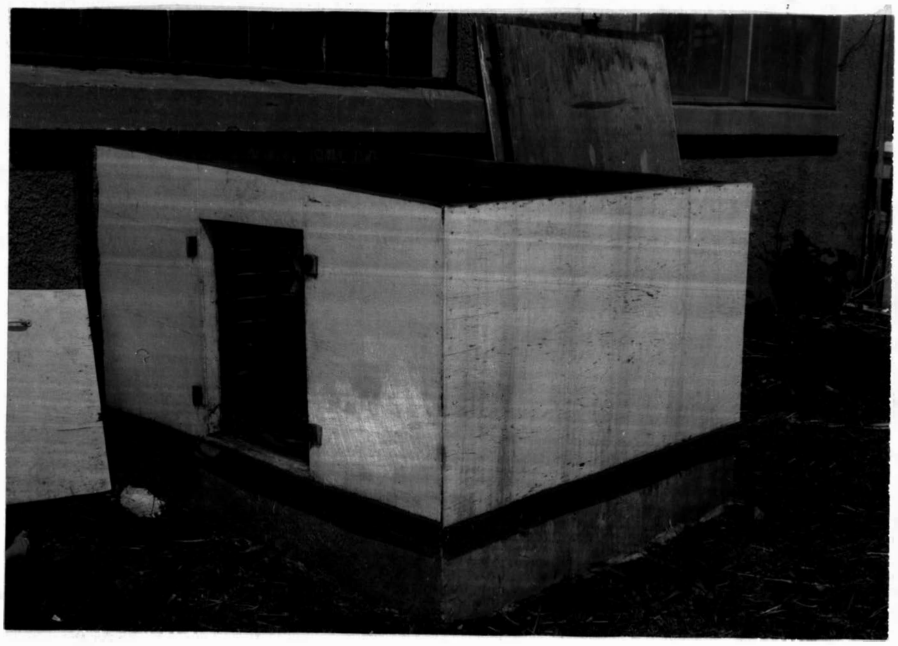

Figure 2. Compressor Housing With Top and Exterior Vent Covering Removed

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Figure 3. Adjustable Vents Joining the Compressor Housing and Milkroom Viewed from the Milkroom Side

the condenser cooling fan were in separate chambers. In effect this arrangement was similar to dividing the compressor housing into two air ducts; an intake duct on one side drawing air from either the milkroom or outside and an exhaust duct directing air either into the milkroom or exhausting it to the outside. Figure 4 shows a top view of the compressor housing with the cover removed and Figure 5 illustrates schematically the direction of air flow during summer and winter operation.

Milkroom Heating

An electric forced air heater rated at 4000 watts was installed in the milkroom to furnish the main source of heat. The operation of the heater was controlled by a thermostat and the energy consumption was measured with a kilowatt-hour meter. The actual metered rate of consumption of the heater was 3600 watts. Figure 6, looking towards the common wall between the milkroom and milking room, shows the heater and thermostat installation.

Milkroom Ventilation

Ventilation for the milkroom was provided by an electrically operated ventilating unit installed in the ceiling. The unit consisted of a ventilating fan rated at 600 cfm and a motor-operated damper which controlled the flow of fresh air into the milkroom. Outside air was drawn through a filter on the roof of the milkroom and directed radially from the unit by a deflector below the fan. The radial movement of air along the walls minimized drafts and aided somewhat in keeping the windows free of condensation.

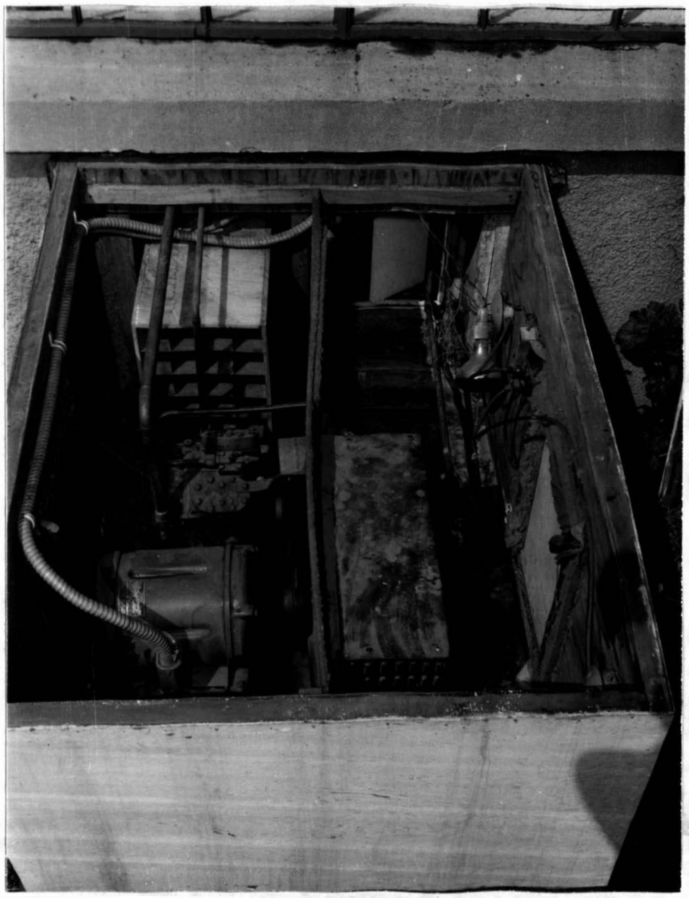

Figure 4. Compressor Housing With Top Removed Showing the Components of the Installation

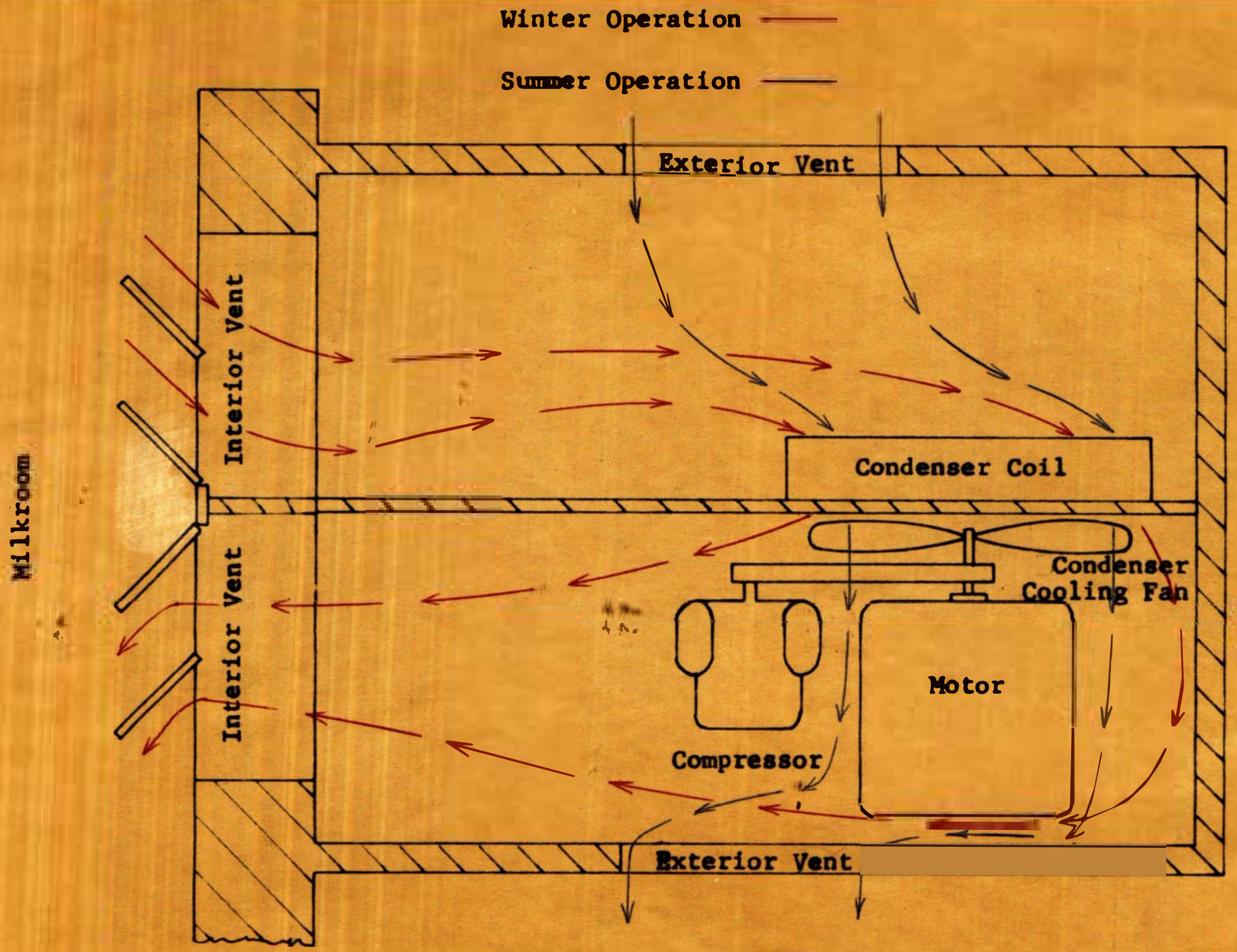

Figure 5. Schematic Diagram of Air Flow Patterns Through the Compressor Housing During Summer and Winter Operation

Figure 6. Milkroom Heater and Thermostat Installation

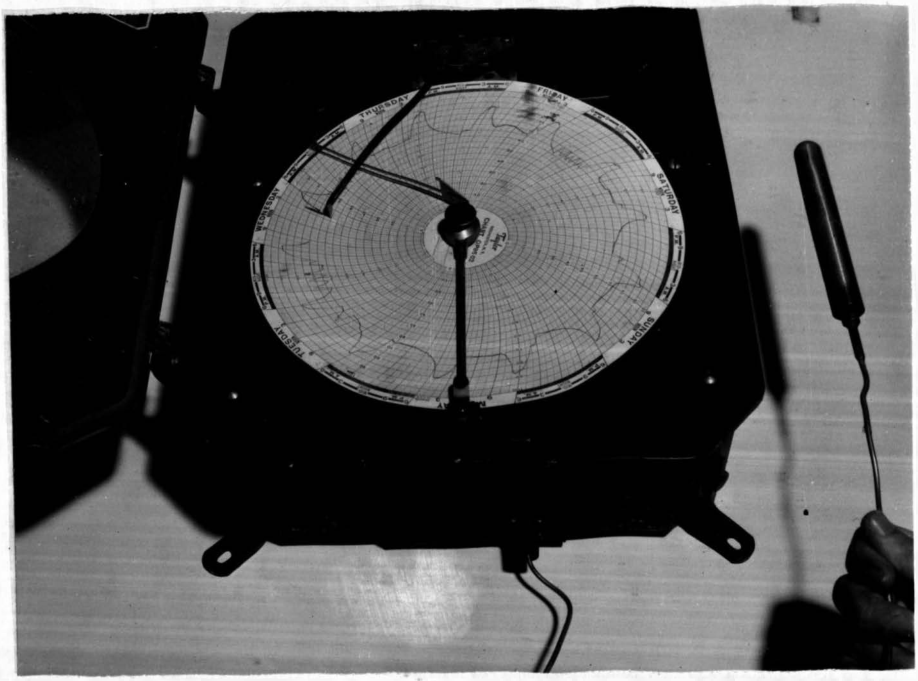

Figure 7. Milkroom Temperature Recorder and Sensing Element

The ventilating fan motor was installed so that it could be operated continuously for summer ventilation or so that it could be switched to the bulk milk cooler controls to operate only when the cooling unit was in operation. The damper motor was controlled by a thermostat so that the damper would be forced open when the temperature in the structure raised above a predetermined point. Thus if the fan were operating continuously, the modulation of the damper would control the temperature within the prescribed limits.

Temperature Measurement

A gas filled recording thermometer was used in obtaining a continuous record of milkroom temperatures. The sensing element of the thermometer was located near the center of the room at a height of six and one-half feet. This position was chosen to obtain an average temperature and also to prevent its being disturbed during cleaning and sanitizing operations. This location also kept the sensing element clear of the flow of warm air from either the heater or the exhaust vent from the compressor housing. Figure 7 shows the temperature recorder, chart and sensing element. In Figure 7 the sensing element was removed from its stated position in order to show in the picture.

PROCEDURE

Since this investigation dealt with the cold weather phase of the bulk milk cooler operation and the benefit received in using the heat extracted from the milk to supplement the milkroom heating system, a comparison study of the heating requirements of the milkroom with and without the aid of the heat released by the bulk milk cooling unit was made.

This comparison was made by conducting the test in two phases. During Phase I of the study the vents between the milkroom and the compressor housing were opened and air from the milkroom was drawn over the condenser coil, heated and recirculated in the structure. In effect, the bulk milk cooling unit was operated as a heat pump to heat the milkroom during the milk cooling operation.

Phase II was conducted without using the heat extracted from the milk. The compressor housing was sealed from the milkroom and the heat rejected from the condenser coil was released to the atmosphere.

The investigation was conducted from January 3 to March 1, 1958 and over the same period in 1959. Phase I was studied throughout the test period in 1958 and continued until February 15 during 1959. Phase II of the study was conducted from February 15 to March 1, 1959. This period was sufficient to determine the normal heating requirements of the milkroom since conditions remained constant and the heating trends were easily established. The same periods in 1958 and 1959 were chosen so that any solar heat gains would be comparable in magnitude. Phase I was conducted over a longer period of time since outside temperatures during the test period in 1958 were above normal and continued observations were needed to establish a definite trend in the results.

Since the study involved a comparison of the heating requirements between Phases I and II, consideration was given to the factors that influenced the rate of heat loss from the milkroom. The factors studied were inside and outside temperatures, and wind velocity and direction. The latter two factors were deemed important since only two walls of the milkroom were exposed to the elements and thus the direction and velocity of the wind would have considerably more bearing on the heat loss of the structure when blowing directly against either of the exposed walls than from other directions.

Weather Conditions

Data on weather conditions during the test period were obtained from the South Dakota State College weather station. The information was in the form of continuous recordings of temperatures, wind velocities and directions made at that station.

Milkroom Temperature

The temperature controls in the milkroom were set so that the electric heater would maintain a temperature of 65° F. throughout the test. The thermostat on the ventilating fan damper was set so that the damper would open and admit fresh air when the milkroom temperature rose above 85° F. The reasoning was that a setting of this magnitude would allow for efficient use of the heat extracted from the milk during the cooling process. The fan was set to operate only during the period when the milk was being cooled and functioned as an air circulating device except for the periods when the damper was opened.

Continuous records of milkroom temperatures were made throughout the study to indicate the effect of the introduction of the heat extracted during the milk cooling process on milkroom temperatures as well as to yield information on average temperature conditions.

Heat Requirements

Daily readings of the kilowatt-hour consumption of the milkroom heater during both phases of the study were recorded. Since these readings were made during the day, the values were adjusted to span a 24 hour period starting at midnight so they would correspond to the temperature and wind data which were computed on a midnight to midnight basis. The adjustment was accomplished by examining all the milkroom temperature recordings and determining the total indicated period that the electric heater was in operation. The total indicated operating time multiplied by the rate of energy consumption of the electric heater gave the indicated kilowatt-hour consumption. A comparison of this value to the kilowatt-hour meter readings indicated close correlation and thus the adjustment of the actual readings was simply a matter of totaling the indicated time of heater operations for the 24 hour period starting at midnight and multiplying by the rate of energy consumption of the electric heater.

The data recorded during the study were analyzed to determine the electrical energy required to heat the milkroom at different levels of temperature difference between inside and outside conditions. The heating requirements during Phase I and Phase II were compared to determine the savings realized in using the heat extracted from the milk in supplementing the milkroom heating system. The results were calculated in the form of kilowatt-hours and the percentage of total heat saved in utilizing the heat extracted from the milk.

DATA AND DISCUSSION OF RESULTS

The data tabulated in this study with the exception of the kilowatt-hour consumption of the milkroom heater, were obtained from continuous recordings of the variables under consideration. The kilowatt-hour readings were taken at daily intervals. All values shown were the average readings for the particular period indicated.

Outside Temperatures

Tables I, II, III, and IV indicated the average outside temperature as well as the high and low readings for each day of the test. The temperatures were compiled in the form of degree days and the total degree days for the month were compared to the normal number for the month. The degree days were determined by the use of a planimeter. The area on the temperature charts between the recorded temperature and the 65 degree base was measured and the degree days accumulated for the 24 hour period were obtained by dividing the measured area by the area equaling one degree day. The equation used was of the following form:

$$\text{No. of Degree days} = \frac{\text{measured area}}{\text{area/degree day}}$$

Inside Temperatures

The average daily milkroom temperatures were computed and tabulated on Tables V and VI. The average daily temperatures were obtained by totaling the hourly temperatures from the charts for the 24 hour period and then averaging the result. Typical charts of the inside temperature

TABLE I. TEMPERATURE DATA RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA FOR JANUARY, 1958

Date	Degree Days	Temperature °F	
		High	Low
January, 1958			
1	51.4	28	3
2	57.9	18	- 3
3	50.4	25	3
4	45.9	30	8
5	36.9	47	12
6	49.9	30	1
7	54.7	22	- 3
8	31.2	56	11
9	28.5	54	20
10	31.4	46	21
11	27.1	51	27
12	29.8	43	27
13	35.8	40	21
14	40.5	35	19
15	38.8	31	20
16	36.1	36	22
17	42.0	27	15
18	38.4	29	18
19	41.3	28	20
20	42.8	25	18
21	45.0	24	16
22	44.1	31	12
23	43.5	26	15
24	37.3	37	20
25	38.8	28	23
26	42.2	24	19
27	43.9	24	17
28	44.1	24	9
29	46.7	30	7
30	46.5	22	7
31	49.4	24	6

TOTAL Degree Days 1292.3

AVERAGE Degree Days 1597.0 (Huron, South Dakota)*

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*Source: Heating Ventilating Air Conditioning Guide. 34th Ed., Vol. 34, New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1956. p. 453.

TABLE II. TEMPERATURE DATA RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA FOR FEBRUARY, 1958

Date	Degree Days	Temperature °F High	 Low
February, 1958			
1	46.5	22	10
2	56.5	15	- 1
3	44.3	30	0
4	44.9	29	12
5	44.7	28	10
6	54.7	20	0
7	61.6	14	- 3
8	69.6	8	- 6
9	63.5	14	- 8
10	60.4	17	- 7
11	64.2	11	- 9
12	54.4	21	- 1
13	52.2	25	- 3
14	56.5	12	-10
15	73.0	4	-16
16	70.2	9	-19
17	65.6	4	-16
18	59.4	18	- 7
19	52.2	24	- 4
20	36.3	35	16
21	36.9	32	18
22	31.4	54	13
23	22.0	67	26
24	22.6	54	34
25	19.1	60	32
26	20.2	47	41
27	24.5	46	31
28	34.4	31	22
TOTAL Degree Days	1341.8		
AVERAGE Degree Days	1327.0 (Huron, South Dakota)*		

*Source: Heating Ventilating Air Conditioning Guide. 34th Ed., Vol. 34, New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1956. p. 453.

TABLE III. TEMPERATURE DATA RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA FOR JANUARY, 1959

Date	Degree Days	Temperature °F	
		High	Low
January, 1959			
1	48.6	22	8
2	64.1	8	- 6
3	70.1	- 4	-11
4	67.0	2	-13
5	63.2	14	- 8
6	51.3	23	4
7	47.9	24	10
8	55.5	28	4
9	43.8	20	8
10	44.2	21	16
11	40.8	26	21
12	39.5	44	26
13	29.6	45	26
14	36.4	37	8
15	61.8	7	- 6
16	66.6	2	- 7
17	62.0	10	- 9
18	49.4	28	0
19	58.6	19	- 3
20	60.5	11	- 5
21	67.2	5	-15
22	65.9	2	-11
23	58.6	16	-12
24	47.0	23	2
25	57.9	7	2
26	51.5	17	3
27	49.2	30	1
28	39.1	37	16
29	51.0	24	0
30	60.5	9	-11
31	66.8	8	-14

TOTAL Degree Days 1675.6

AVERAGE Degree Days 1597.0 (Huron, South Dakota)*

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*Source: *Heating Ventilating Air Conditioning Guide.* 34th Ed., Vol. 34, New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1956. p. 453.

TABLE IV. TEMPERATURE DATA RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA FOR FEBRUARY, 1959

Date	Degree Days	Temperature °F High	Temperature °F Low
February, 1959			
1	61.4	13	- 2
2	54.7	25	2
3	50.2	21	12
4	56.4	13	5
5	62.5	13	- 5
6	56.0	25	-12
7	58.0	24	- 4
8	62.6	8	- 6
9	59.8	9	- 2
10	59.5	17	- 6
11	55.6	22	- 8
12	43.4	34	7
13	51.6	21	1
14	53.4	25	3
15	47.0	33	2
16	51.6	20	7
17	56.0	17	0
18	64.0	10	-11
19	73.5	7	-19
20	57.4	21	- 5
21	52.2	30	- 5
22	41.2	33	12
23	43.4	28	12
24	46.4	34	5
25	44.1	32	8
26	38.9	40	11
27	33.6	35	23
28	38.3	37	19

TOTAL Degree Days 1472.7
AVERAGE Degree Days 1327.0 (Huron, South Dakota)*

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*Source: Heating Ventilating Air Conditioning Guide. 34th Ed., Vol. 34, New York: American Society of Heating and Air-Conditioning Engineers, Inc., 1956. p. 453.

TABLE V. AVERAGE MILKROOM TEMPERATURES FOR JANUARY AND FEBRUARY, 1958

January, 1958		February, 1958	
Date	Average Temperature °F	Date	Average Temperature °F
4	69.5	1	70.4
5	69.8	2	69.3
6	70.7	3	69.5
7	71.5	4	69.7
8	72.6	5	68.4
9	71.9	6	65.0
10	70.4	7	74.3
11	72.0	8	81.3
12	73.8	9	81.7
13	72.3	10	80.9
14	69.2	11	74.2
15	71.6	12	72.8
16	72.4	13	74.3
17	71.2	14	73.5
18	72.4	15	73.3
19	75.6	16	75.8
20	72.2	17	81.5
21	74.1	18	81.4
22	71.9	19	70.2
23	70.4	20	63.8
24	67.4	21	65.6
25	68.4	22	67.0
26	69.0	23	71.3
27	68.7	24	70.4
28	69.8	25	68.8
29	69.0	26	67.8
30	68.9	27	60.2
31	70.4	28	59.4

TABLE VI. AVERAGE MILKROOM TEMPERATURES FOR JANUARY AND FEBRUARY, 1959

January, 1959		February, 1959	
Date	Average Temperature °F	Date	Average Temperature °F
4	68.5	1	71.2
5	72.9	2	68.5
6	75.7	3	69.8
7	70.9	4	69.8
8	77.6	5	68.7
9	63.0	6	72.7
10	62.0	7	67.0
11	64.8	8	70.0
12	65.4	9	69.4
13	64.7	10	57.0
14	65.7	11	72.3
15	62.1	12	74.0
16	63.5	13	74.1
17	66.3	14	73.4
18	71.4	15	73.6
19	72.3	16	73.4
20	72.6	17	71.2
21	68.1	18	66.9
22	67.6	19	66.9
23	68.0	20	67.4
24	70.4	21	66.8
25	71.0	22	66.7
26	70.1	23	65.6
27	69.8	24	64.2
28	68.4	25	64.1
29	69.9	26	64.1
30	70.3	27	64.6
31	69.7	28	68.7

recordings are shown in Figures 8, 9, 10 and 11. These charts indicated temperature trends under four different operating conditions.

Figure 8 shows temperature recordings during a week of mild weather while Phase I was in operation. The large, regular increases in temperature indicated the period over which the milk cooling unit was in operation and the heat released by the unit increased the temperature of the milkroom by a considerable amount. The small temperature increases occurring between milk cooling periods indicated when the milkroom heater was operating.

Figure 9 shows milkroom temperature trends during normal winter operation in Phase I of the study. The temperature increases resulting from the heat added to the milkroom are not as great as indicated in Figure 8, but are still prominent. The frequency of the milkroom heater operation is greater and more uniform.

Figure 10 shows a chart recorded during cold weather in Phase I of the study. It will be noted that the temperature rise in the milkroom during the milk cooling operation is less than in Figures 8 and 9 due to the increased rate of heat loss from the structure. The temperature increases which indicated heater operation were also much more numerous during this period.

Figure 11 illustrates the temperature trends during Phase II in cold weather operation. The only fluctuations in the temperature recordings were caused by the milkroom heater operation and the difference in the chart is primarily in the frequency of occurrence of the heating cycle.

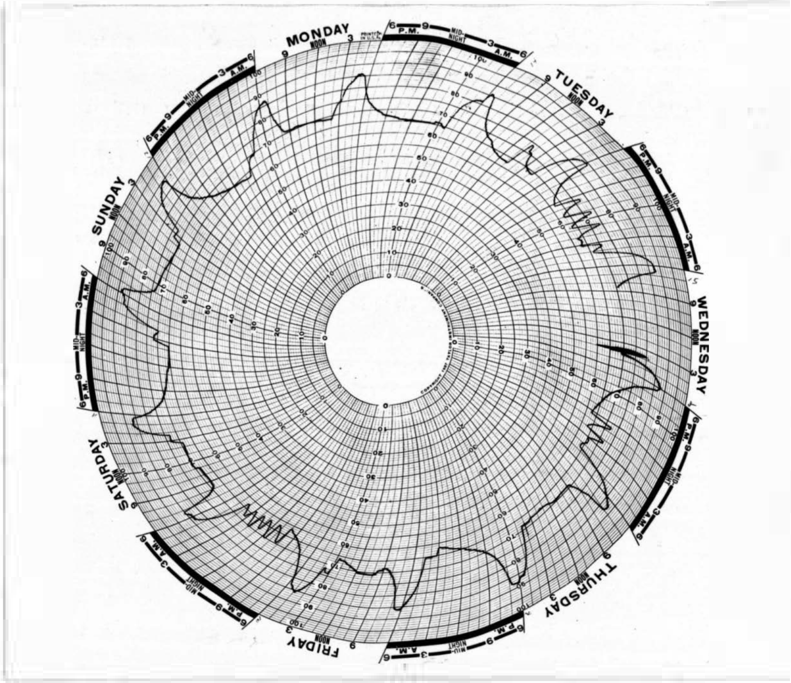

Figure 8. Temperature Chart Recorded in Warm Weather During Phase I

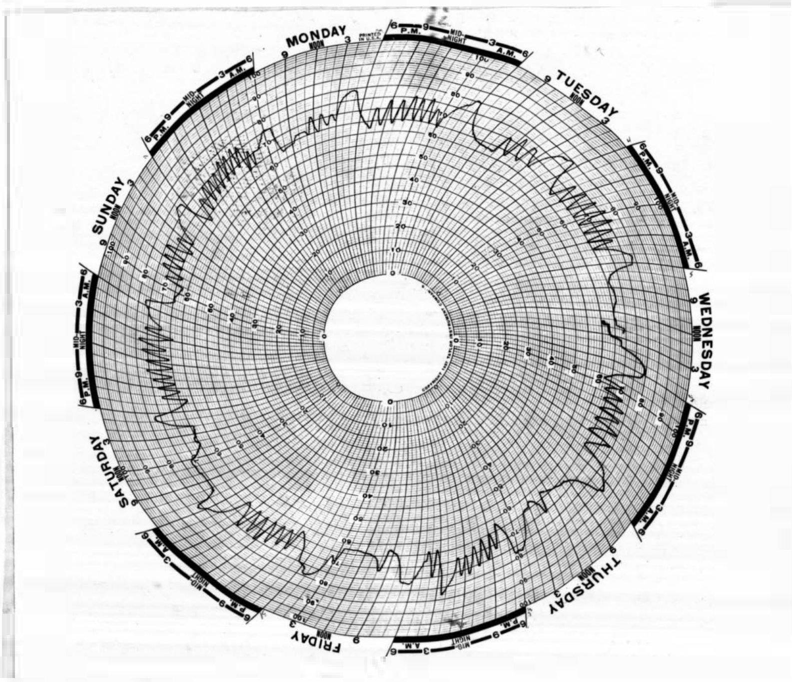

Figure 9. Temperature Chart Recorded in Normal Winter Weather During Phase I

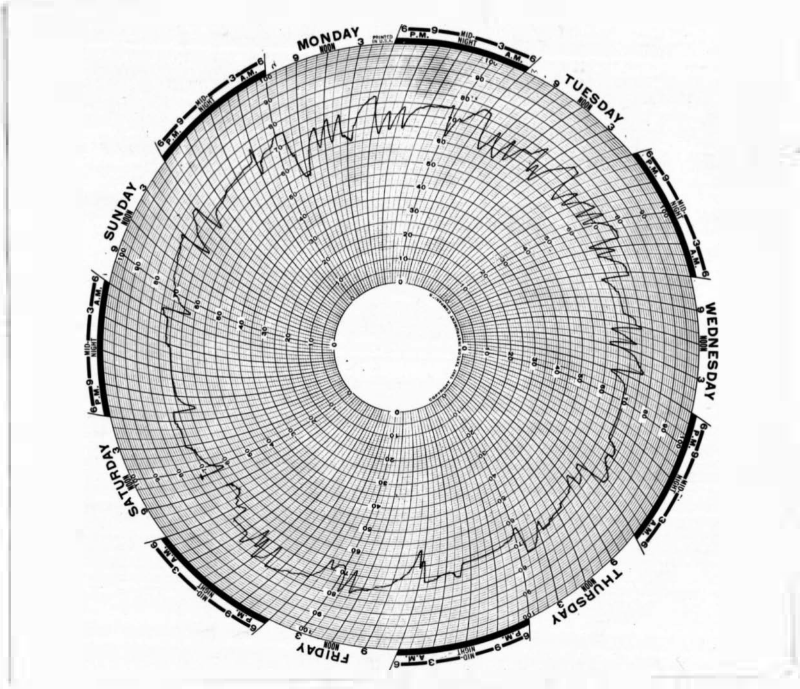

Figure 10. Temperature Chart Recorded in Cold Weather During Phase I

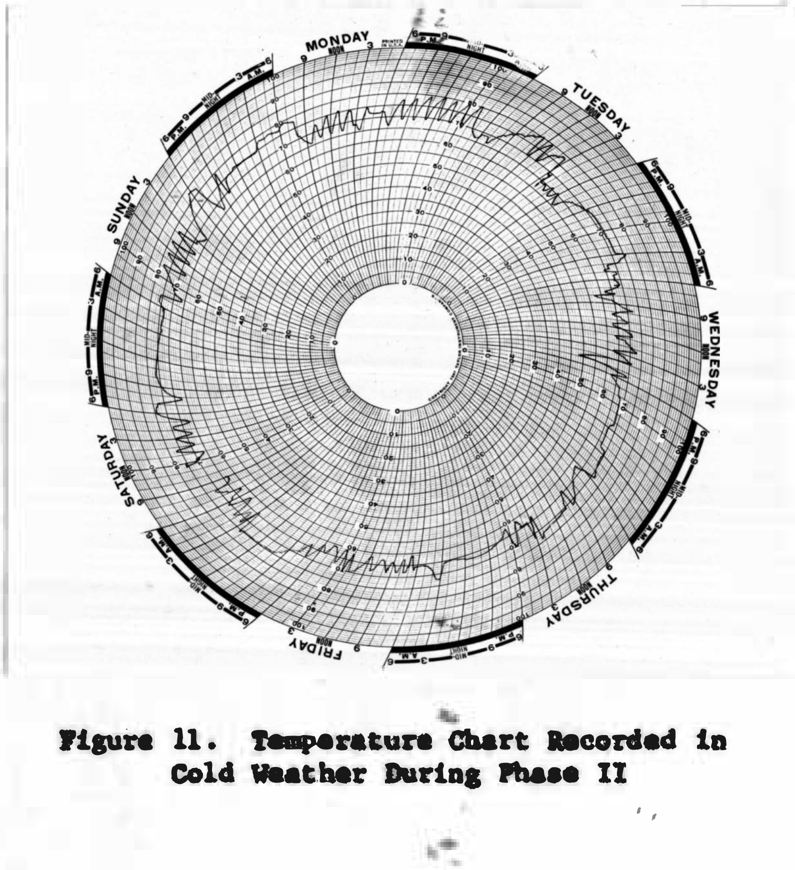

Figure 11. Temperature Chart Recorded in Cold Weather During Phase II

Energy Consumption of the Milkroom Heater

The daily kilowatt-hour consumption of the milkroom heating system is shown on Tables VII and VIII. In addition, the difference between milkroom and outside temperatures are shown for comparison with the energy consumed in heating the milkroom. This temperature difference was computed from information in Tables I through VI. An example of the computation of the temperature differences follows:

January 4, 1958, degree days = 45.9;

Average milkroom temperature = 69.5

Average outside temperature = 65 - degree day

= 65 - 45.9

= $\underline{19.1^{\circ}}$ F.

Temperature difference = Inside temperature - outside temperature

= 69.5 - 19.1

= $\underline{50.4^{\circ}}$ F.

Wind Conditions

The wind velocities, directions, and duration for each day of the study are listed chronologically as they occurred during the day in Tables IX, X, XI, and XII. For example, an interpretation of the data for January 5, 1958 would be as follows: The wind was from the south at an average velocity of 3.8 miles per hour for a period of 16 hours, it then switched to the west and the average velocity increased to 8.3 miles per

TABLE VII. DAILY TEMPERATURE DIFFERENCE AND MILKROOM HEATER ENERGY CONSUMPTION FOR JANUARY AND FEBRUARY, 1958

January, 1958			February, 1958		
Day	Temp. Diff. °F	Kilowatt-hour Consumation	Day	Temp. Diff. °F	Kilowatt-hour Consumation
4	50.4	12.3	1	51.9	15.6
5	41.7	15.0	2	60.8	28.4
6	55.6	10.8	3	48.8	22.4
7	61.2	16.8	4	49.6	18.4
8	38.8	2.4	5	48.1	4.8
9	35.4	1.8	6	54.7	13.7
10	36.8	4.5	7	70.9	42.5
11	34.1	3.3	8	85.9	67.0
12	38.6	1.5	9	80.2	63.4
13	43.1	3.0	10	76.3	42.8
14	44.7	3.3	11	73.4	36.0
15	45.2	3.5	12	62.2	23.3
16	43.5	2.0	13	61.5	36.7
17	58.2	16.4	14	65.0	45.1
18	45.8	15.0	15	81.3	48.4
19	51.9	19.5	16	81.0	48.0
20	50.0	11.4	17	82.1	52.0
21	54.1	14.4	18	75.8	44.7
22	51.0	8.4	19	57.4	14.7
23	48.9	11.9	20	35.1	3.3
24	39.7	6.3	21	37.5	2.4
25	42.2	8.6	22	33.4	1.5
26	46.2	9.2	23	28.3	2.1
27	47.6	8.6	24	28.0	00.0
28	48.9	6.4	25	22.9	00.0
29	50.7	10.8	26	23.0	00.0
30	50.4	16.8	27	19.7	00.0
31	54.8	19.6	28	28.8	00.0

TABLE VIII. DAILY TEMPERATURE DIFFERENCE AND MILKROOM HEATER ENERGY CONSUMPTION FOR JANUARY AND FEBRUARY, 1959

January, 1959			February, 1959		
Day	Temp. Diff. °F	Kilowatt-hour Consumation	Day	Temp. Diff. °F	Kilowatt-hour Consumation
4	70.5	60.3	1	73.3	73.8
5	71.1	63.3	2	67.0	60.0
6	62.0	58.2	3	55.0	48.0
7	53.8	59.4	4	61.2	69.1
8	68.1	61.2	5	66.2	60.6
9	41.8	25.2	6	63.7	63.0
10	41.2	11.1	7	60.0	54.3
11	40.6	3.6	8	67.6	54.6
12	39.9	3.0	9	64.2	57.9
13	32.0	3.6	10	51.5	53.4
14	37.1	4.3	11	62.9	74.7
15	58.9	28.4	12	52.4	36.9
16	65.1	52.4	13	60.7	74.7
17	63.3	48.6	14	61.8	61.5
18	55.8	51.6	15	55.6	57.3
19	65.9	60.3	16	60.0	52.5
20	68.1	60.3	17	62.2	58.2
21	70.3	40.8	18	65.9	61.8
22	68.5	52.8	19	75.4	69.6
23	61.6	50.4	20	59.8	54.3
24	52.4	47.5	21	54.0	39.6
25	63.9	73.5	22	42.9	41.7
26	56.6	45.6	23	44.0	23.9
27	54.0	33.3	24	45.6	19.1
28	42.5	13.5	25	43.2	15.6
29	55.9	35.7	26	38.0	6.3
30	65.8	61.8	27	33.3	7.1
31	71.5	73.2	28	42.0	4.2

TABLE IX. DAILY WIND DIRECTION, VELOCITY, AND DURATION FOR JANUARY, 1958
RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION,
BROOKINGS, SOUTH DAKOTA

Day	Direction	Velocity mph	Hours
4	S	9.0	24
5	S, W, N	3.8, 8.3, 13.0	16, 4, 4
6	N, W, NW	14.6, 14.8, 15.0	18, 5, 1
7	N, W, S	5.0, 5.0, 6.8	8, 6, 6
8	W, S	4.9, 1.3	11, 12
9	N, NW, W, S, E	8.0, 15.0, 9.2, 2.8, 2.0	5, 2, 9, 4, 3
10	NW, W, S, E	0.7, 5.0, 7.0, 4.8	3, 14, 2, 5
11	S	12.9	24
12	N, S, E	4.0, 5.4, 1.4	4, 7, 9
13	S	4.7	24
14	N, W, S, E	7.0, 1.0, 5.0, 1.0	18, 2, 1, 3
15	W, S	2.3, 5.3	12, 12
16	N, NW, E	5.1, 1.8, 1.0	15, 4, 2
17	N, W, S, NE	7.0, 2.3, 4.2, 1.0	5, 6, 11, 2
18	S	6.8	21
19	N, S	4.2, 6.3	20, 4
20	N, W, E	2.9, 2.7, 2.4	14, 3, 7
21	N, NW, W, S, E	2.6, 2.4, 2.0, 1.3, 3.0	11, 5, 3, 4, 1
22	W, S, E	4.2, 1.0, 1.8	17, 1, 4
23	W, S, E	6.0, 4.9, 3.3	2, 16, 3
24	S	13.0	24
25	N, S, SE	7.9, 7.7, 5.7	12, 3, 6
26	NW, W	11.7, 10.5	18, 6
27	N, NW, W	9.0, 9.2, 8.9	11
28	N, W, S, E	5.8, 7.5, 1.0, 1.0	4, 15, 1, 1
29	E	3.2	14
30	N, E	2.7, 3.4	6, 14
31	N, W	3.8, 2.5	14, 2

TABLE X. DAILY WIND DIRECTION, VELOCITY, AND DURATION FOR FEBRUARY, 1958 RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA

Day	Direction	Velocity mph	Hours
1	N, NW	13.5, 10.8	4, 12
2	N, NW, W	8.1, 6.0, 5.0	21, 1, 2
3	S	8.4	20
4	N, S	3.1, 5.2	14, 6
5	N, NW, W	4.5, 6.3, 3.0	10, 13, 1
6	N, W	9.2, 2.0	22, 2
7	NW, W	9.0, 3.7	12, 12
8	N, NW, W	9.3, 6.4, 6.1	3, 11, 10
9	N, NW, W	4.8, 3.0, 3.0	18, 1, 5
10	N, NW	5.0, 4.0	22, 2
11	N, NW	8.7, 7.3	18, 6
12	N, NW	7.9, 8.0	14, 10
13	N, W, SE, E	3.0, 1.0, 4.8, 6.1	3, 1, 4, 8
14	N, E, NE	5.1, 5.0, 5.5	16, 4, 4
15	N, W	1.8, 5.1	11, 7
16	SW	1.7	3
17	S, E	2.6, 1.1	9, 7
18	NE	1.0	6
19	S, E	5.8, 2.0	14, 1
20	S	8.9	24
21	N, W, S	6.3, 1.0, 3.5	19, 1, 2
22	S	10.6	16
23	S, E	2.0, 2.0	5, 4
24	N, NW, W	1.0, 7.2, 11.3	1, 6, 4
25	S	16.8	16
26	S, E	10.8, 9.3	12, 12
27	N, E	15.3, 9.3	16, 4
28	N	13.5	24

TABLE XI. DAILY WIND DIRECTION, VELOCITY, AND DURATION FOR JANUARY, 1959
RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION,
BROOKINGS, SOUTH DAKOTA

Day	Direction	Velocity	Hours
4	W, SW, S	7.9, 5.0, 8.3	14, 1, 9
5	S	7.2	24
6	S, SE, E	8.9, 6.3, 5.7	9, 3, 12
7	N, E, NE	4.0, 6.5, 5.5	9, 8, 6
8	N, SW, S, SE, E	1.7, 2.0, 1.8, 1.5, 2.1	3, 1, 8, 2, 7
9	W, SW, S, SE, E	10.9, 10.8, 5.4, 7.0, 5.7	7, 5, 5, 1, 6
10	W, S	10.8, 5.6	12, 12
11	S	2.5	24
12	N, S, E	1.7, 2.4, 6.9	3, 7, 11
13	N, NW, W, S	6.0, 3.3, 2.7, 7.1	9, 3, 3, 9
14	N, NW, W	10.8, 11.4, 6.1	10, 7, 7
15	NW	12.8	24
16	N, NW	8.4, 6.3	17, 7
17	N, NW, W, S, NE	4.2, 3.3, 3.5, 2.1, 2.0	7, 4, 2, 10, 1
18	N, S	9.7, 7.0	9, 15
19	N, NW, W, SW, S	6.0, 3.7, 4.6, 4.0, 3.9	1, 6, 5, 1, 10
20	N, NW	7.7, 7.3	16, 8
21	NW, W	5.9, 9.2	8, 16
22	W	10.3	24
23	W, S, E	3.0, 6.4, 3.0	4, 16, 2
24	N, S, NE	4.8, 4.0, 7.8	4, 6, 12
25	E, NE	3.0, 6.5	6, 10
26	S	3.9	24
27	S	7.0	24
28	S, SE	6.3, 3.5	20, 4
29	N, NW	10.3, 6.5	18, 6
30	N, W	5.8, 3.2	19, 5
31	N, NW, W	2.7, 1.3, 2.7	13, 6, 5

TABLE XII. DAILY WIND DIRECTION, VELOCITY, AND DURATION FOR FEBRUARY, 1959 RECORDED AT SOUTH DAKOTA STATE COLLEGE WEATHER STATION, BROOKINGS, SOUTH DAKOTA

Day	Direction	Velocity mph	Hours
1	S, E	4.8, 3.6	14, 10
2	S	12.0	24
3	N, NW, W, S	14.4, 4.0, 2.5, 4.0	13, 1, 2, 4
4	N, NW, W, E	12.0, 7.5, 9.7, 8.6	8, 2, 6, 8
5	NW, W	16.0, 10.1	2, 22
6	W, S, SE, E	3.0, .88, 6.6, 6.8	1, 14, 5, 4
7	N, S, SE, NE	12.1, 7.7, 7.0, 10.3	16, 3, 1, 4
8	N, SE, E, NE	5.1, 2.0, 8.6, 3.0	9, 1, 13, 1
9	N	6.5	24
10	N, NW, W, S	7.8, 8.8, 2.0, 2.5	10, 10, 2, 2
11	S	13.7	24
12	N, S, SW, W	7.6, 9.2, 3.0, 4.0	12, 10, 1, 1
13	N, W, S, E, NE	5.8, 8.0, 4.0, 8.0, 7.0	5, 2, 2, 14, 1
14	N, NW, W, SW, S	11.0, 9.8, 8.4, 4.0, 2.0	3, 9, 8, 1, 3
15	NW, W, SW, S	12.0, 10.0, 6.0, 10.5	3, 1, 1, 19
16	N, NW, W, SW, S	4.0, 5.8, 4.3, 2.5, 2.7	5, 11, 3, 2, 2
17	N, NW	7.0, 5.6	19, 5
18	N, NW, W	5.7, 5.8, 5.3	3, 9, 12
19	W	4.9	24
20	W, SW	9.1, 5.2	18, 6
21	S, SE, E	2.3, 2.0, 3.1	9, 1, 13
22	N, E	8.1, 3.1	9, 15
23	N, NW, W	8.5, 8.0, 7.4	2, 7, 15
24	W, SW, S	3.6, 1.0, 6.5	14, 1, 6
25	W, SW	4.3, 6.0	22, 2
26	W, S, SE	2.5, 5.3, 1.5	8, 12, 4
27	W, S	11.3, 5.5	18, 6
28	W	6.6	24

hour for four hours and finally came from the north at 13.0 miles per hour for the remaining four hours of the day.

Wind Effect Analysis

Initial comparisons of the milkroom heating requirements to the average difference between outside and inside temperatures failed to establish a reliable trend upon which to base any prediction of heat required for any specific temperature difference. This lead the author to believe that additional factors existed that had a definite effect on the heating requirements of the milkroom. The management of the milkroom which included washing milking equipment twice daily, washing the bulk tank every other day, and cleaning the milkroom daily, would add a certain amount of heat since hot water was used in all of these operations. The effect of these operations would not tend to alter the results of this investigation because they were conducted following approximately the same pattern and schedule throughout the course of the experiment. The remaining factor of measurable magnitude which affected heat loss from the milkroom was wind velocity and direction.

The milkroom was sheltered by the dairy barn on the north, west, and south sides. The east side was unprotected and received the full force of any winds from an easterly direction. Studies of wind velocity and direction compared to heat requirements of the milkroom lead to the conclusion that winds from an easterly direction caused a definite increase in the kilowatt-hour consumption of the milkroom heating unit at any given temperature below approximately 32° F. South winds had less effect while winds from the north and westerly directions had the least effect.

A detailed study of the effect of wind velocity and direction resulted in the development of a method of ranking wind conditions according to their effect on heat loss. The object of this ranking system was to enable the adjustment of the heating requirements to standard conditions where it could be assumed that the wind effect had been reduced to a minimum. This ranking system made possible the placing of a particular day in one of five categories depending upon the wind conditions for that 24 hour period. The numerical values assigned to the categories were from 1 to 5 with a rating of 1 representing wind conditions of negligible effect. The higher numbers indicated winds of increased effect on heat loss from the structure. Table XIII shows the five ratings and the wind velocity range and direction for each category.

TABLE XIII. WIND RATINGS ACCORDING TO THEIR EFFECT ON HEAT LOSS

Wind Direction	Wind Effect Ratings				
	1	2	3	4	5
	Wind Velocity	Wind Velocity	Wind Velocity	Wind Velocity	Wind Velocity
N	0 - 10	10 - 20			
NW	0 - 10	10 - 20			
W	0 - 10	10 - 20			
SW	0 - 10	10 - 20			
S	0 - 3	3 - 6.0	6 - 9	9 - 12	over 12
SE	0 - 1.5	1.5 - 3.0	3.0 - 4.5	4.5 - 6	over 6
E	0 - 1.5	1.5 - 3.0	3.0 - 4.5	4.5 - 6	over 6
NE	0 - 1.5	1.5 - 3.0	3.0 - 4.5	4.5 - 6	over 6

In classifying a 24 hour period during which the wind changed directions, the rating for each particular wind condition was multiplied by the fraction of the day over which the condition existed. The products of these conditions were then totaled to obtain the final rating. For example, on January 5, 1958 the following wind directions, velocities and durations were recorded:

Wind direction	Velocity (mph)	Duration (hours)
S	3.81	16
W	8.25	4
N	13.00	4

Calculations for the ratings would be

Rating	Fraction of 24 hr. period	Product
2	16/24	1.33
1	4/24	.167
2	4/24	.333
		1.830 or 2.00

All fractional parts were rounded to the nearest whole number so that only five distinct categories would result. Table XIV gives the wind effect ratings for the period over which the investigation was conducted.

The results of the investigation were based on data recorded during periods when the effect of wind velocity, direction and duration was considered negligible. The information recorded on days when the wind effect was rated at two or over was rejected as being representative of conditions other than the standards set up for the investigation. No attempt was made to correct the readings made on days having wind effects greater than one since it was the author's opinion that this practice would not change the results in any manner.

TABLE XIV. WIND EFFECT RATINGS FOR THE TEST PERIOD

1958				1959			
January		February		January		February	
Date	Rating	Date	Rating	Date	Rating	Date	Rating
4	3	1	2	4	2	1	1
5	2	2	1	5	3	2	4
6	2	3	3	6	3	3	2
7	1	4	1	7	3	4	4
8	1	5	1	8	1	5	2
9	1	6	1	9	3	6	4
10	2	7	1	10	2	7	3
11	1	8	1	11	1	8	3
12	5	9	1	12	3	9	1
13	2	10	1	13	2	10	1
14	1	11	1	14	2	11	5
15	2	12	1	15	2	12	2
16	1	13	3	16	1	13	4
17	1	14	2	17	1	14	1
18	3	15	1	18	2	15	4
19	1	16	1	19	1	16	1
20	1	17	1	20	1	17	1
21	1	18	1	21	1	18	1
22	1	19	1	22	2	19	1
23	2	20	3	23	2	20	1
24	5	21	1	24	3	21	3
25	2	22	4	25	3	22	3
26	2	23	1	26	2	23	1
27	1	24	1	27	3	24	2
28	1	25	5	28	3	25	1
29	3	26	5	29	2	26	2
30	3	27	3	30	1	27	2
31	1	28	2	31	1	28	1

Comparisons of the energy consumed in heating the milkroom to the difference between inside and outside temperatures are shown in Figure 12 for Phase I and in Figure 13 for Phase II of the study. The data for the comparisons are shown on Tables XVI and XVII. The calculations for fitting the curves are in appendix A.

The milkroom did not require added heat during Phase I when the difference between milkroom and outside temperatures was less than 35.5 degrees. During Phase II of the operation no heat was required at temperature differences of less than 32.5 degrees. This condition was due to the heat gain from the observation room where the air temperature was maintained approximately 10 degrees higher than the milkroom and to the heating load supplied by lights and management practices.

Deviation of the data from the plotted curves could logically be attributed to the following factors:

1. Management practices over which the author had no control including failure to keep the door adjoining the milkroom and the observation room closed at all times and periodic checks of the butter fat content of the milk produced by each animal which necessitated keeping the door of the milkroom open for the entire milking period and loading the milk in the cooler manually.
2. Normal fluctuation in the amount of milk cooled at each milking period.
3. Heat lag due to the residual effects of cold weather on the structure resulting in increased demands on the heating system

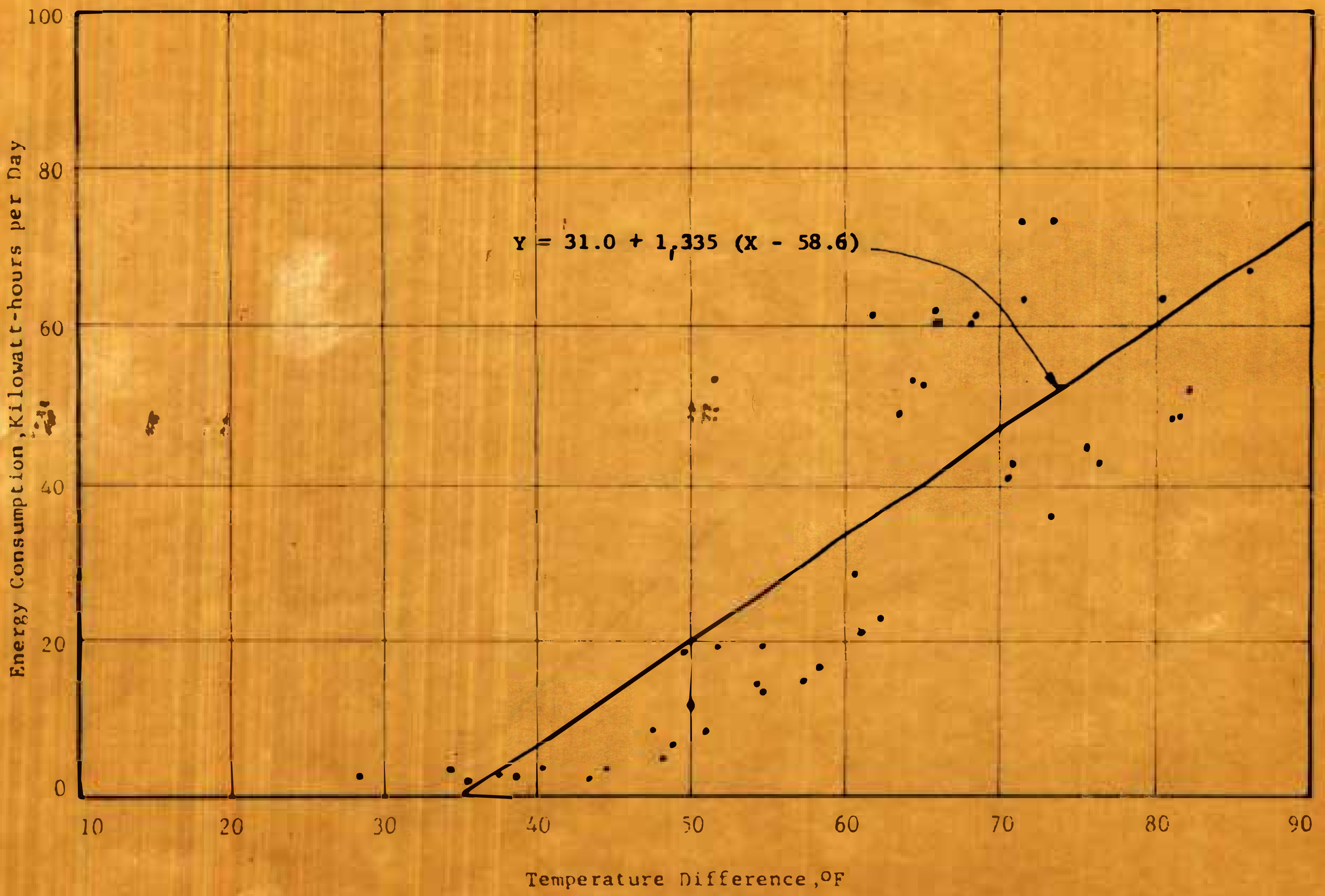

Figure 12. Comparison of the Energy Consumed in Heating the Milkroom to the Difference between the Average Daily Inside and Outside Temperatures for Phase I.

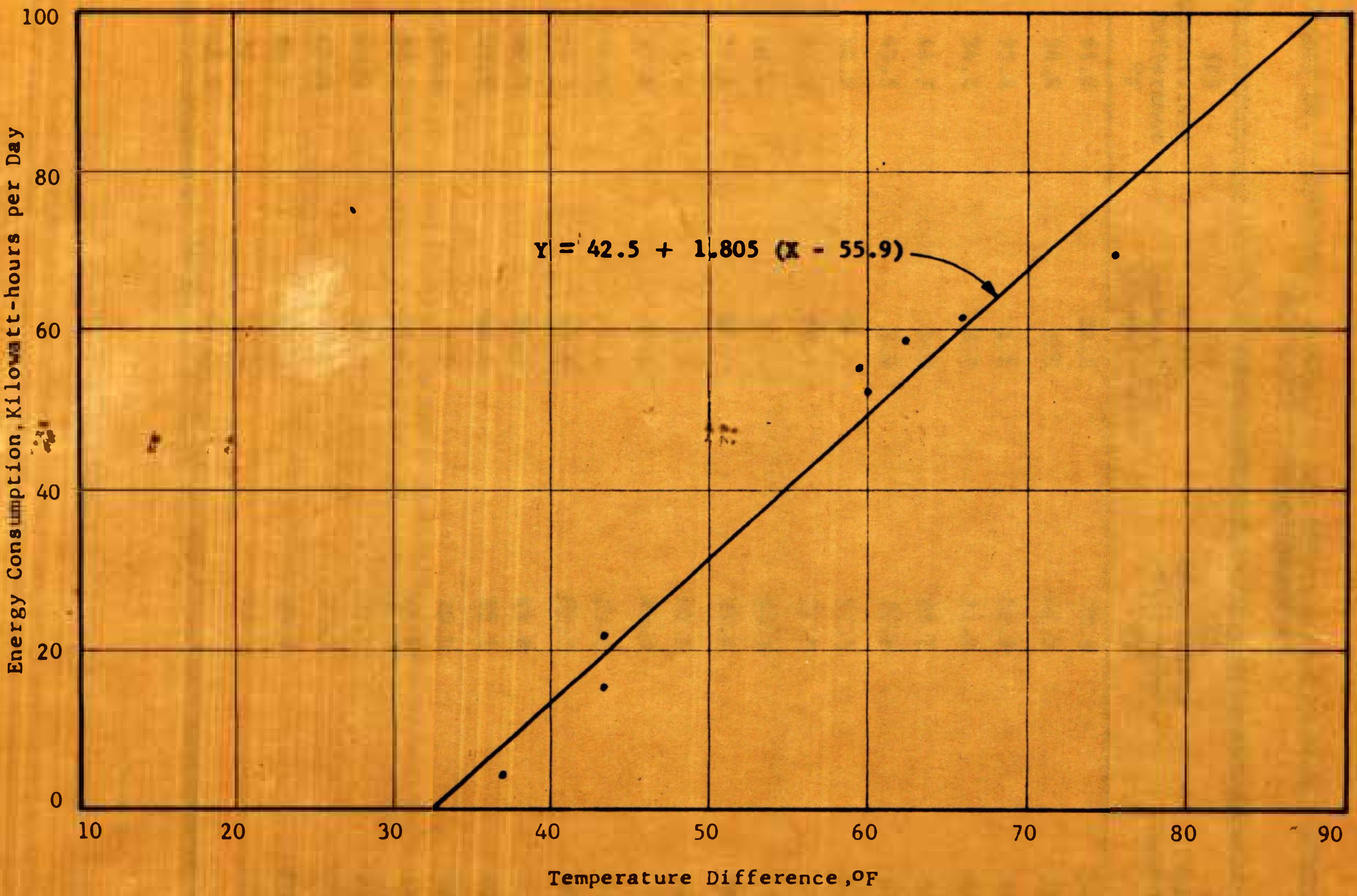

Figure 13. Comparison of the Energy Consumed in Heating the Milkroom to the Difference Between the Average Daily Inside and Outside Temperatures for Phase II.

TABLE XV. TEMPERATURE DIFFERENCE AND MILKROOM HEATER ENERGY CONSUMPTION FOR PHASE I, WIND CONDITION I

(X) Temperature Difference °F	(Y) Energy Consumption Kilowatt-hour	(X) Temperature Difference °F	(Y) Energy Consumption
61.2	21.5	73.4	36.0
38.8	2.4	62.2	23.3
35.4	1.8	81.3	48.4
34.1	3.3	81.0	48.0
44.7	3.3	82.1	52.0
43.5	2.0	75.8	44.7
58.2	16.4	57.4	14.7
51.9	19.5	37.5	2.4
50.0	11.4	28.3	2.1
54.1	14.4	28.0	00.0
51.0	8.4	68.1	61.2
47.6	8.6	40.6	3.6
48.9	6.4	65.1	52.4
54.8	19.6	63.3	48.6
60.8	28.4	65.9	60.3
49.6	18.4	68.1	60.3
48.1	4.8	70.3	40.8
54.7	13.7	65.8	61.8
70.9	42.5	71.5	73.2
85.9	67.0	73.3	73.8
80.2	63.4	64.2	52.9
76.3	42.8	51.5	53.4
61.8	61.5		

TABLE XVI. TEMPERATURE DIFFERENCE AND MILKROOM HEATER ENERGY CONSUMPTION FOR PHASE II, WIND CONDITION I

(X) Temperature Difference °F	(Y) Energy Consumption Kilowatt-hour
60.0	52.5
62.2	58.2
65.9	61.8
75.4	69.6
59.8	54.3
43.4	23.9
43.2	15.6
37.3	4.2

during warmer weather weather that followed. The reverse situation would exist during the transition from warm to cold weather.

Figure 14 shows the curves from Figures 12 and 13 superimposed on one graph for comparison purposes. The shaded area between the lines represents the heat supplied to the milkroom by the bulk milk cooler through the range of temperature differences recorded during the study.

The heat extracted from the milk was utilized to a lesser degree at small temperature differences since the heat released from the cooling unit entered the milkroom at such a high rate that the temperature was elevated resulting in accelerated heat losses. At large temperature differences more of the heat extracted from the milk was utilized since the existing heat loss from the structure prevented temperature elevation of any great magnitude.

Figure 15 shows the percent of the total heating requirement of the milkroom that was supplied by the heat extracted from the milk. The values ranged from 100 to 29.9 percent at the greatest temperature differences. The values for this graph were determined by dividing the heat saved by the total heat required for the particular temperature difference at which the percent saving was desired.

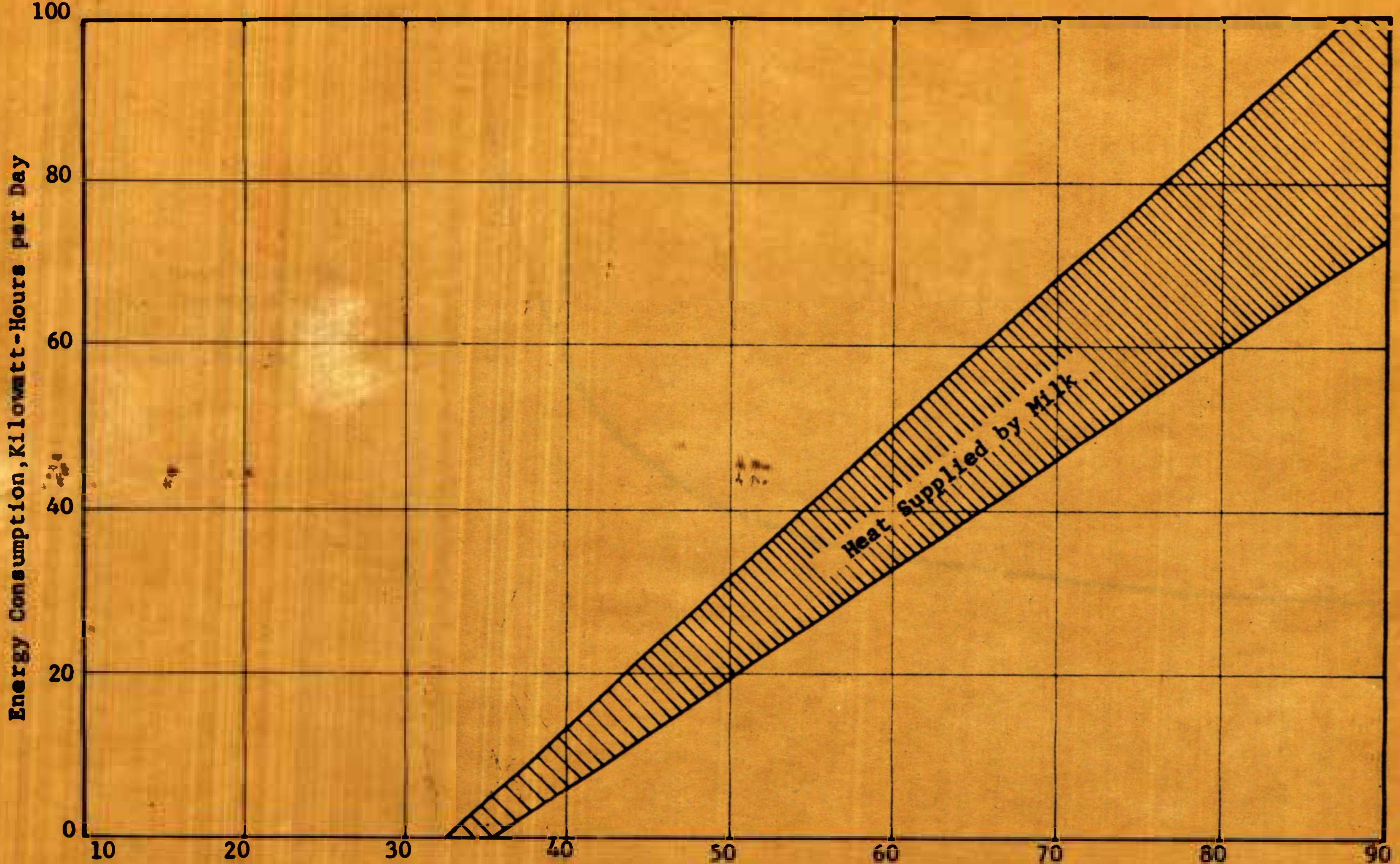

Figure 14. A Comparison of the Energy Required to Heat the Milkroom During Phase I and Phase II

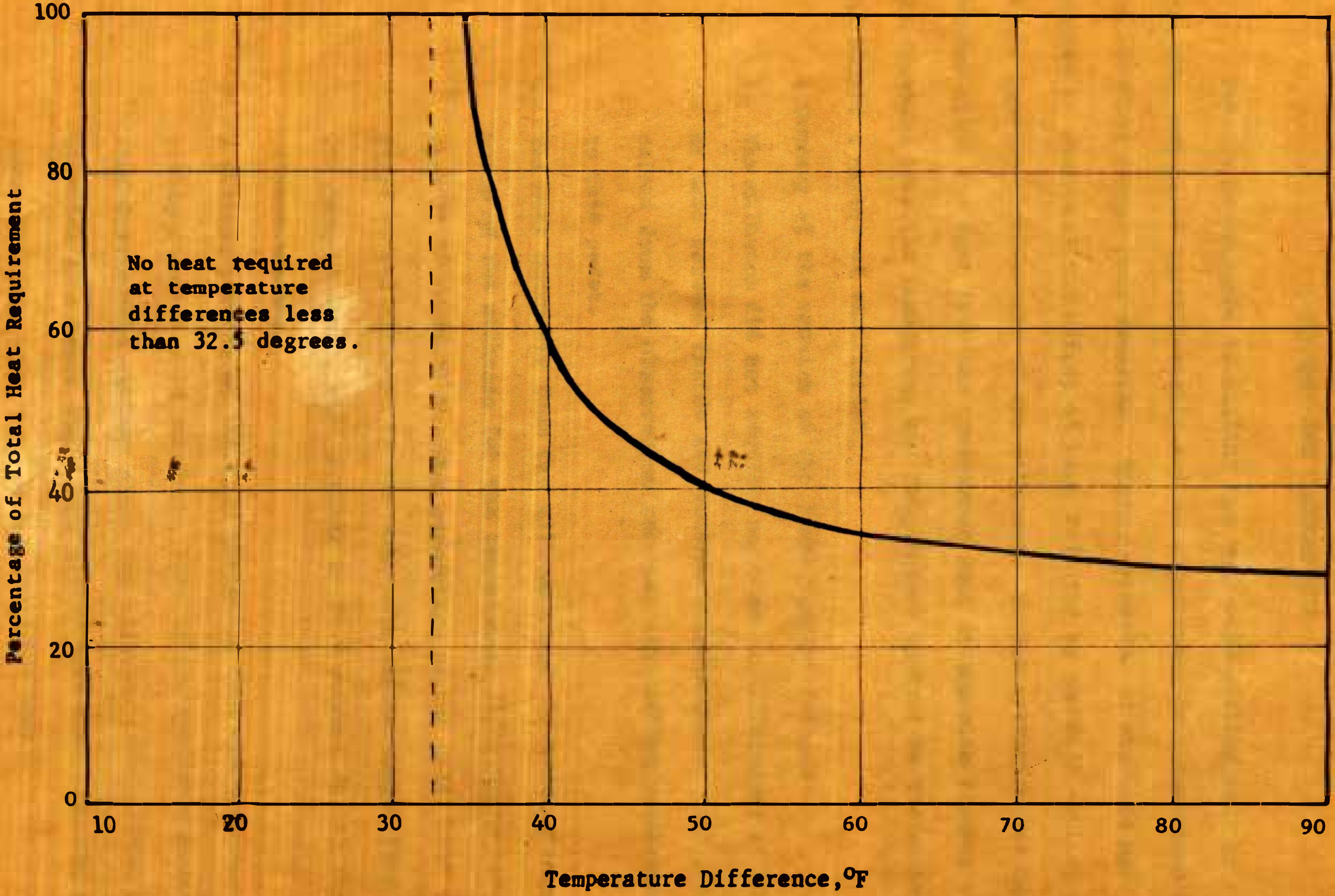

Figure 15. Percentage of the Total Milkroom Heating Requirement Supplied By the Heat Extracted From the Milk

SUMMARY AND CONCLUSIONS

The system designed to utilize the bulk milk cooling unit as a heat pump performed satisfactorily and no adjustments or alterations of the original design were required. Winter operation of the unit was studied to determine the effect of heat rejected by the milk cooling unit on the heating requirements of the milkroom. Summer operation was not studied since the heat from the condensing coil of the milk cooling unit was released into the atmosphere and temperature control in the milkroom was simply a matter of ventilation.

A summary of the results of the investigation follows:

1. The milkroom did not require any heat at differences of 32.5° F. or less between inside and outside temperatures. Heat gain received from the observation room met the heating requirements to this point.
2. The heat extracted from the milk supplied the heating requirements of the milkroom for the temperature differences ranging from 32.5° to 35.5° F. The percentage of the total heat supplied to the milkroom by the bulk milk cooler ranged from 100 percent during mild weather to 29.9 percent during the coldest weather.
3. A greater portion of the heat extracted from the milk was utilized during cold weather. Less of the available heat was used during mild weather since the milkroom temperatures were elevated to a point where accelerated heat loss from the structure occurred, thus wasting the available heat.

4. Results indicated that the system was effective in supplying heat to the milkroom for approximately 4 months of the year.
5. While year-round use of the heat from the milk could not be realized with the system, a considerable amount of the total heat required during winter operation was supplied to the milkroom. The material and labor costs of constructing the vents and duct work necessary to convert the milk cooling unit to a heat pump were relatively small.
6. The system supplied heat to the milkroom during a period when warmer temperatures were most desirable. The heat was supplied during the milking period and for sufficient time thereafter so that its effect would be felt when the milk handling equipment was washed and cleaned.
7. Part of the efficiency of the system was lost due to the necessity of partially cooling the condenser with water since air cooling did not have sufficient capacity. The heat carried away in the cooling water was not usable for milkroom heating.

The above results are based on studies made at one location and under one particular set of circumstances. It is the author's belief that with a properly designed milkroom and bulk milk cooler installation, a much greater portion of the heat released during the milk cooling operation could be utilized in heating the milkroom. Adequate insulation in the milkroom would reduce heat loss considerably and an ice-bank milk cooling system would release the heat at a slower and more usable rate than the direct-expansion system used in this investigation.

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APPENDIX

CALCULATIONS FOR FITTING REGRESSION CURVES TO DATA PRESENTED IN TABLES XV AND XVI

The equation for fitting a straight line to a series of observations by the least squares method[13] is the form:

$$Y = \bar{Y} + b\,(X - \bar{X})$$

Where Y = the daily kilowatt-hour consumption of the milkroom heater; $\bar{Y}$ = the average Y value; X = the difference between the average daily milkroom and outside temperature; $\bar{X}$ = average X value and b is a regression coefficient designating the slope of the line.

The value of b can be found from the following equation:

$$b = \frac{\Sigma XY - \frac{\Sigma X \Sigma Y}{N}}{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}$$

The calculations for Phase I are taken from the data shown on Table XV. The following tabulations were made from Table XV.

$\Sigma X = 2637.2$

$\Sigma Y = 1395.4$

$\bar{X} = 58.6$

$\bar{Y} = 31.0$

$\Sigma X^2 = 164{,}508.04$

$(\Sigma X)^2 = 6{,}954{,}823.84$

$\Sigma X \Sigma Y = 3{,}679{,}948.88$

$\Sigma XY = 95{,}070.50$

$N = 45$

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[13] W. J. Dixon and F. J. Massey, Introduction to Statistical Analysis, p. 191, McGraw-Hill Book Company, Inc.: New York, 1957.

Solving for b:

$$b = \frac{95{,}070.50 - \frac{3{,}679{,}948.88}{45}}{164{,}508.04 - \frac{6{,}954{,}823.84}{45}}$$

$b = 1.335$

This gives the equation:

$Y = 31.0 + 1.335\ (X - 58.6)$

The calculations for Phase II were obtained from the data shown on Table XVI and the resulting tabulations were as follows:

$\Sigma X = 447.2$

$\Sigma Y = 340.1$

$\bar{X} = 55.9$

$\bar{Y} = 42.5$

$\Sigma X^2 = 26{,}213.94$

$(\Sigma X)^2 = 199{,}987.84$

$\Sigma XY = 21{,}205.48$

$N = 8$

Solving for b:

$$b = \frac{21{,}205.48 - \frac{152{,}092.72}{8}}{26{,}213.94 - \frac{199{,}987.84}{8}}$$

$b = 1.805$

This gives the equation:

$Y = 42.5 + 1.805\ (X - 55.9)$