CORRELATION OF SOL-AIR TEMPERATURES AND HEAT GAIN THROUGH FARM BUILDING CONSTRUCTION MATERIALS

by

George W. A. Mahoney

Bachelor of Agricultural Engineering

University of Illinois

Urbana, Illinois

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THESIS AND ABSTRACT APPROVED:

Thesis Adviser

Faculty Representative

Dean of the Graduate School

PREFACE

The experimental work carried on in this thesis was carried out under the Oklahoma Agricultural Experiment Station Project "Summer Temperature Control in Dairy Cattle Loafing Barns." One of the objectives set forth in the project outline is: "To obtain data indicating wherein temperature control in dairy cattle loafing barns can be achieved through: (a) low heat gain construction, (b) operation of ventilating equipment, (c) operation of cooling equipment." The study and analysis made herein deal with the correlation of sol-air temperatures of samples of various materials of construction and summertime heat gain through certain parts of experimental livestock shelters utilizing these materials of construction.

Helpful contributions were made by Mr. Jack I. Fryrear, who made sol-air temperature readings of material samples, Mr. William Hardy of the Meteorology Department who made available pyrheliometer data and weather data collected by the College Meteorology Department, and especially Mr. G. L. Nelson who was the writer's adviser for this thesis.

TABLE OF CONTENTS

CORRELATION OF SOL-AIR TEMPERATURES AND HEAT GAIN THROUGH FARM BUILDING CONSTRUCTION MATERIALS

I. INTRODUCTION

Most investigations of the needs of animal shelters have been made in relation to wintertime needs with little emphasis on summertime conditions. In many parts of the country, however, shelters designed for summer conditions may be needed. Except in the extreme western part of Oklahoma, winters are relatively mild and minimum shelter is usually sufficient while summers are long and hot. Five year records of the U. S. Weather Bureau[1] show that all of central Oklahoma, approximately half the state, has at least 1,000 hours yearly with temperatures above 85° F.

These long, hot summers are a handicap to the dairyman. Experiments[2] by animal physiologists at the University of Missouri psychroenergetic laboratory at Columbia, Missouri, indicate that 50° F is the optimum temperature for Jersey and Holstein cows. If temperatures are raised above 50° F, the undesirable effects are much more pronounced than if temperatures fall below 50°. These laboratory experiments also show that 80° to 85° F is the critical temperature for dairy cows. If temperatures rise above this, cows have an especially difficult time adjusting their body regulatory mechanisms to the higher temperatures and milk production drops. In actual practice, hot summer weather usually is accompanied by a drop in milk production. Studies are now being conducted to determine if this is due mainly to management practices, decreases in pasture late in the summer, or if shelters play an important role.

The rate of heat gain through the walls and roof of a livestock shelter is influenced by the difference between indoor and outdoor air temperatures and the amount of incident solar radiation received on the wall or roof in question. It may be possible to reduce the effect of solar radiation at little or no additional cost. Reducing the absorption of solar radiation would reduce some of the heat gain of a structure. Although it would not always eliminate the need for cooling, it would, by minimizing the effect of solar radiation, decrease the number of hours that mechanical cooling would be needed.

A project entitled "Summer Temperature Control in Dairy Cattle Loafing Barns" has been initiated by the Oklahoma Experiment Station. Some of the results of this project are expected to provide performance data on heat gain through component parts of a mechanically cooled, enclosed shelter and an open front shelter for dairy cattle. Such data need to be made available to farm buildings specialists to take measures to reduce heat gain to structures.

II. OBJECTIVES

The general objectives of this study were to develop information that would be helpful in predicting the effects of solar radiation on heat gain through materials used in construction of dairy cattle loafing barns. Specific objectives were:

1. To measure sol-air temperatures of six different types of concrete masonry samples as influenced by color and texture; and to correlate these sol-air temperatures with solar radiation and outdoor air temperatures.
2. To correlate these sol-air temperatures with heat gain through twelve panels in a west facing wall of a temperature controlled dairy cattle shelter.
3. To measure sol-air temperatures of galvanized steel and aluminum roof coverings; and to correlate these sol-air temperatures with solar radiation and outdoor air temperatures.
4. To correlate these sol-air temperatures with surface temperatures of galvanized steel and aluminum roof coverings in place on an open front, dairy cattle loafing shelter.

III. REVIEW OF LITERATURE

The rate of summertime heat gain through a wall of given construction and orientation can be computed in various ways. The 1950 Guide[3] presents a method for instantaneous heat gain that requires data on heat gain decrement and time lag for materials in the wall; and is based on the formula:

$$(q/A)_i = U(t_m - t_i) + \lambda U(t_e^* - t_m),$$

where:

$(q/A)_i$ = Instantaneous rate of heat gain to indoor air, btu per hour per square foot.

U = Overall air-to-air heat transfer coefficient for the wall, btu per hour per degree F per square foot.

t_m = 24 hour average sol-air temperature, degrees F,

t_i = Constant temperature of indoor air, degrees F.

λ = Heat gain decrement factor, dimensionless.

t_e^* = Sol-air temperature, degrees F, at a time earlier than the instant for which heat gain is being computed by the amount of time lag for the material in the wall.

A simplified procedure is also suggested for computing summertime heat gain by the equation:

$$q/A = U(t_p - t_m),$$

where:

$$t_p = t_m + \lambda (t_e* - t_m).$$

Values for $(t_p - t_m)$ have been developed using the basic method reported by Mackey and Wright.[4] These tables, which used the design sol-air temperature for New York City, are for light or dark surfaces only and temperature differences of 15° F between indoor and outdoor air temperatures. No color variations are given for roofs since all are assumed to be dark.

In the expressions, values for t_m, λ, t_e and U are determined experimentally or estimated on the basis for comparable walls or roofs. Values for stone, solid concrete, brick, wood and insulating board are given but no values are given for clay tile or concrete masonry units.

The sol-air temperature, t_e, is a computed air temperature, which, in contact with the weathered side of a material that is receiving no solar or sky radiation, would give the same rate of heat transfer into that surface as would exist with the actual combination of incident solar radiation and outdoor air temperature. Sol-air temperature is defined by the expression:

$$t_e = t_o + bI/f_o,$$

where:

t_e = Sol-air temperature, degrees F.

t_o = Outdoor dry-bulb temperature, degrees F.

b = Absorptivity of a surface exposed to incident solar and sky radiation, dimensionless.

I = Rate of incidence of solar and sky radiation, btu per hour per square foot.

f_o = Unit convective conductance of outside surface, btu per hour per square foot per degree F.

Mackey and Wright[5] have developed an instrument which they have named the sol-air thermometer. This instrument consists of an 8 inch cube of cork mounted on a wood base and covered with five layers of aluminum foil, alternated with 1/4 inch air spaces so that each face of the thermometer is well insulated from the other faces. To obtain the sol-air temperatures of a material, a thin slice of the material is cemented to the face of the cube. When the sol-air thermometer, with the sample mounted, is then exposed to incident solar and sky radiation and outdoor air temperatures, the sample of material will give a close approximation to the actual sol-air temperature for that material and the orientation corresponding to that particular face of the thermometer. Assuming the cube to be perfectly insulated, there would be no heat flow from the sample to the interior of the cube. If this is true, all heat flow due to solar heating of the material will be from the sample to the outside air. Under steady state conditions, the heat gain, bI, due to solar radiation will be equal to the heat loss due to convective cooling, $f_o(t_s - t_o)$ as shown by the equation:

$$f_o(t_s - t_o) = bI,$$

Solving for t_s:

$$t_s - t_o = bI/f_o.$$

$$t_s = t_o + bI/f_o,$$

where:

t_s = Temperature of the sample material.

but:

$t_e = t_o + bI/f_o$ (from definition).

therefore, the temperature of the sample and the sol-air temperature will be the same. Experiments by Mackey and Wright[5] were made using black cork samples to obtain sol-air temperature characteristics.

When making measurements of heat flow through walls or roofs of buildings in service, temperatures on the surface or within walls and roofs must be determined. This is usually done by imbedding thermocouple junctions within the materials or attaching them to the surface where temperature data is desired. Kelley[6] recommends that thermocouple junctions be of as small diameter wire as possible. He also suggests that, in obtaining surface temperatures, the surface should be grooved so that the thermocouple junction can be imbedded one-half the diameter of the wire. The junction can then be taped to hold it in place.

A heat meter, composed of thermopiles on opposite faces of a thin, 4 inch square, bakelite slab, has been developed by Gier and Dunkle.[7] When the thin bakelite slab is put in contact with a wall through which heat is being transmitted, a temperature difference occurs across the slab. The temperature difference generates an electromotive force in the thermopiles which can be measured with a potentiometer.

Coctong and Dill[8] made studies on the effects of paint on solar heating of roofing materials. The purpose of these simple experiments was to obtain data for recommendations for the color of roofing materials for low cost housing. The white painted sample exhibited a rise of 8.9° F whereas the green painted specimen under the same conditions exhibited a rise of 20.4° F. The Guide[3] states that fresh, white paint normally absorbs only 40% of solar radiation but dusty or weathered white paint and most light colored surfaces absorb 50% and reflect 50% of solar radiation. Dale and Giese[9] have completed an extensive study on the effects of roofing materials on temperatures in farm buildings. Least heat gain for unpainted roofs was found through aluminum roofing on solid decking. Lowest surface temperature of all roofs tested was on white painted, steel roofing. Painting the interior surface of the roofing with aluminum paint to lower the inside emissivity was found to be beneficial.

IV. EXPERIMENTAL EQUIPMENT AND PROCEDURES

Temperature Controlled Shelter

The temperature controlled shelter used for this study was constructed in the late spring and early summer of 1950 for the Oklahoma Agricultural Experiment Station Project "Summer Temperature Control in Dairy Cattle Loafing Barns." It is a single story, gable roofed building, 26 by 50 feet. The shelter, shown in Fig. 1, is located on the southwest slope of high ground approximately 300 yards south of the New Dairy Center, 1 1/2 miles northwest of the A. & M. Campus. The site is unshaded except for the shading effect of high ground west of the building that occurs just before sunset in early summer. The design and construction of the structure is described in detail by Nelson.[10]

The west wall of the shelter incorporates 12 special panels which were exceptions to the regular wall construction. This wall is shown in Fig. 2 and the dimensions, details and panel numbers are shown in Fig. 3. Panels 3, 6, 7 and 10 were constructed with pumice aggregate block, panels 2, 5, 8 and 11 with sand and gravel aggregate block, and panels 1, 4, 9 and 12 with expanded shale aggregate block, respectively. The cores of the block in the upper panels, 1, 2, 3, 7, 8 and 9, were left empty. The cores of the block in panels 4 and 12 were filled with expanded shale aggregate. Block cores in the other lower panels, 5, 6, 10 and 11, were filled with pumice aggregate. The north panels

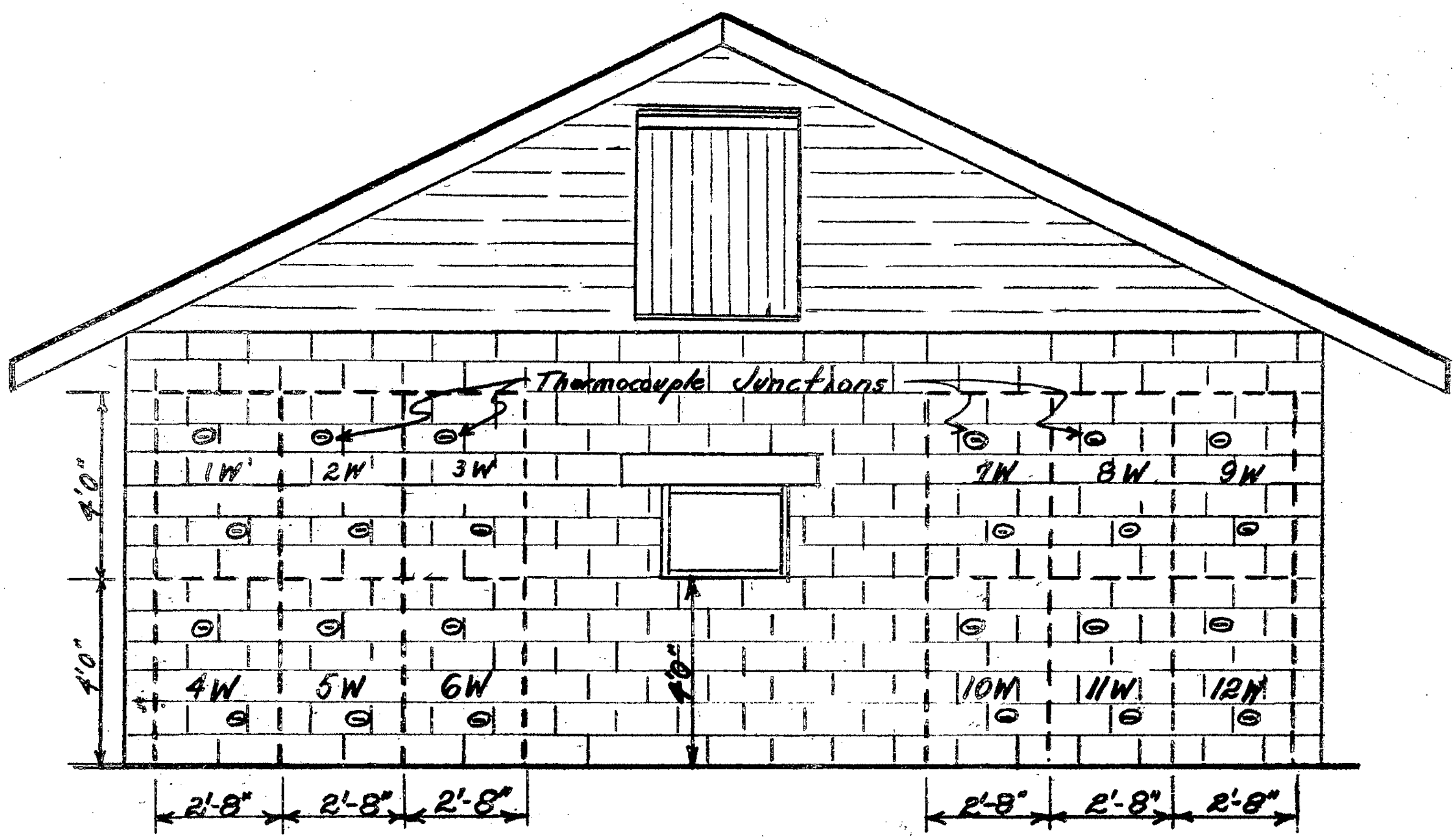

Fig. 3- TEMP. CONTROLLED BARN
WEST ELEVATION
Scale 1/4" = 1'-0"

Fig. 1 - Experimental Temperature-Controlled Shelter For Dairy Cattle Showing Entrance on the East Side.

Fig. 2 - West Wall of Temperature-Controlled Shelter Showing the Unpainted Panel on the North and the Painted Panel on the South.

of the west wall, panels 1 through 6, were left unpainted on the outer wall surface. The other panels, panels 7 through 12, as well as the rest of the structure were given two coats of portland cement base white paint. Other special panels were also included in the structure but were not used in this study. Since the west wall panels are the only part of the structure concerned in this study, only these panels will be discussed further.

Physical properties of the three kinds of masonry units used in the special panels are listed in Table I. The bulk density of the aggregates and the weights of the blocks were determined after the materials had been held in dry storage for a period of more than 30 days. Bulk density was determined by the rodding method. To obtain the weights of the units with the cores filled, they were weighed after they had been filled, rodded 10 times, and the surplus aggregate struck off. Samples used in these weighings were selected at random from stockpiles at the building site. Testing of these samples and the construction of the west wall panels were carried out by Nelson.[10] Kluge, Sparks and Tuma[11] conducted tests on thermal conductivity of various types of lightweight aggregate concrete using 8 by 8 by 1 inch samples on a guarded hot plate. These tests, made on oven dry specimens, show that in most cases, the lighter the concrete of a given aggregate, the greater the thermal resistance. Average thermal conductivity in btu per hour per sq. ft. per degree F per inch of thickness for mixtures of approximately 1 to 6, cement to aggregate, by volume were 1.89 for pumice aggregate concrete, 4.03 for expanded shale aggregate concrete, and 9.57 for sand and gravel aggregate concrete. Specimens were of a plastic consistency when mixed and therefore may not have the same conductivities as a dry concrete mix as is used in the manufacture of concrete block.

The shapes of the three types of block and the relative textures and shades are shown in Figs. 4, 5, 6 and 7.

Sol-air Thermometer

The sol-air thermometer used for this study was an insulated cube upon which specimens of specific materials can be mounted. The sol-air thermometer and the construction details are shown in Fig. 8. Samples were mounted on an 8 inch square panel composed of four 1/4 inch thick light wood frames separated by a curtain of aluminum foil, shown in Fig. 9. The completed panels, 8 by 8 inches square and one inch deep, were then flush mounted on the 12 inch cork cube by placing them in recesses, 8 by 8 by 1 inch, cut in the faces of the cube. After the recesses had been cut in each face of the cube, the cube was covered with aluminum foil, bright side out, to minimize absorption of solar energy by the dark cork surface. The block of cork was then glued to a plywood base and a screw plate attached so the sol-air thermometer could be mounted on a tripod. Casein glue was used to attach the sections of the cork cube together and to fasten the cube to the plywood base. Rubber cement attached the foil to the panels and the cork. The aluminum foil used was standard freezer weight foil. The shiny side

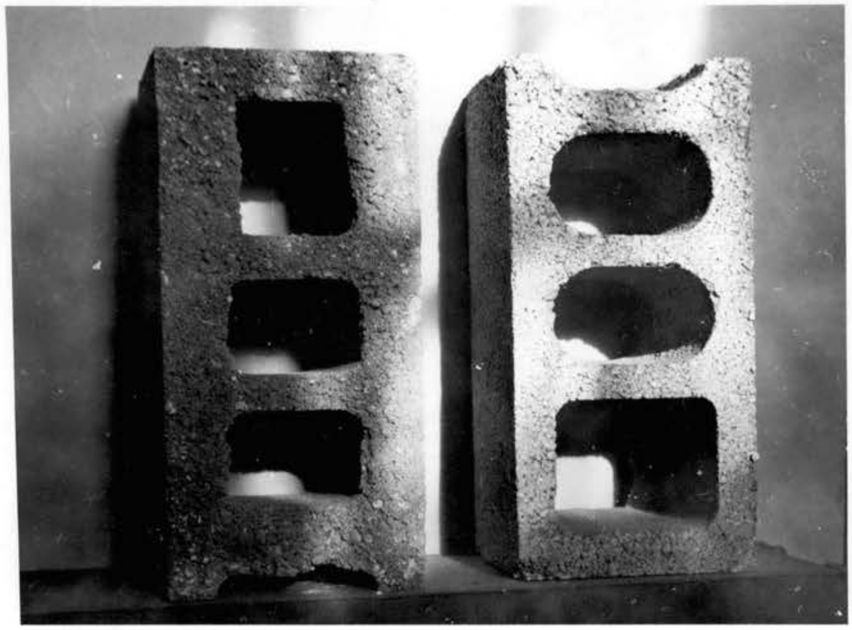

Fig. 4 - Opposite Core Ends of Pumice Aggregate Concrete Block Used in Walls of Temperature-Controlled Shelter.

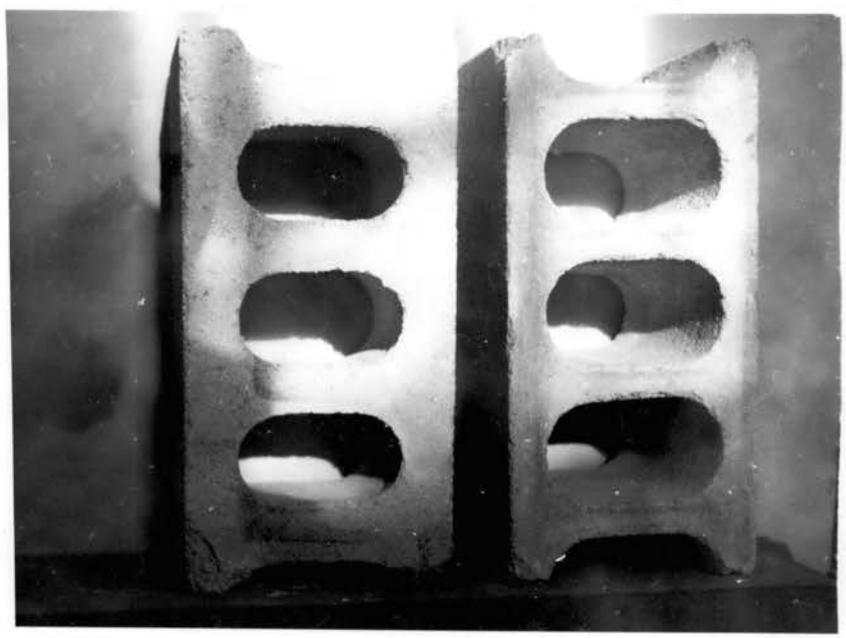

Fig. 5 - Opposite Core Ends of Sand and Gravel Aggregate Concrete Block Used in Walls of Temperature-Controlled Shelter.

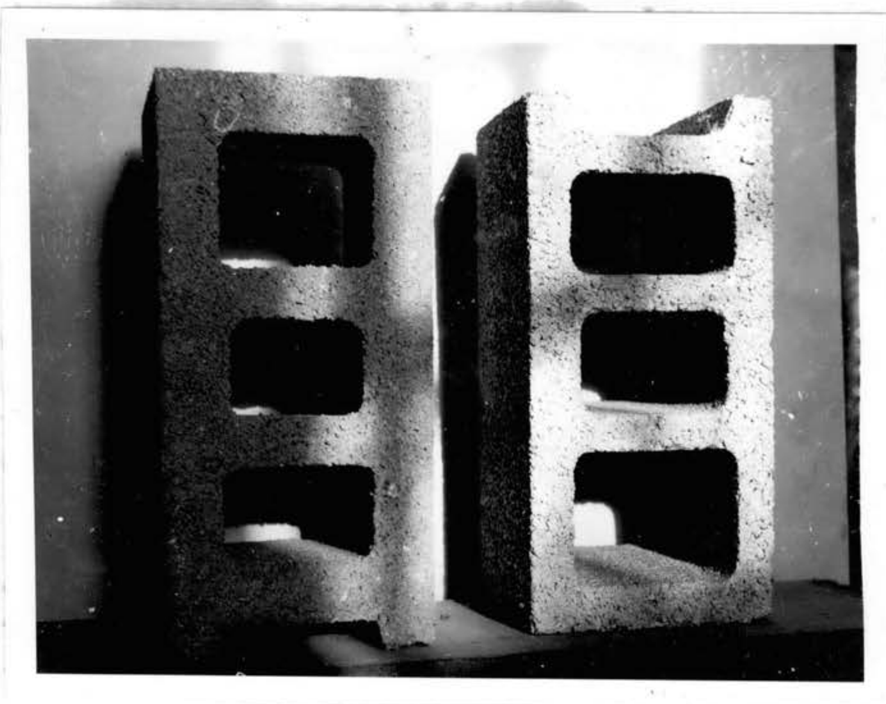

Fig. 6 - Opposite Core Ends of Expanded Shale Aggregate Block Used in Temperature-Controlled Shelter.

Fig. 7 - Comparative Surface Textures and Shades of Pumic Aggregate Concrete Block, Top, Expanded Shale Aggregate Concrete Block, Middle, and Sand and Gravel Aggregate Concrete Block, Bottom.

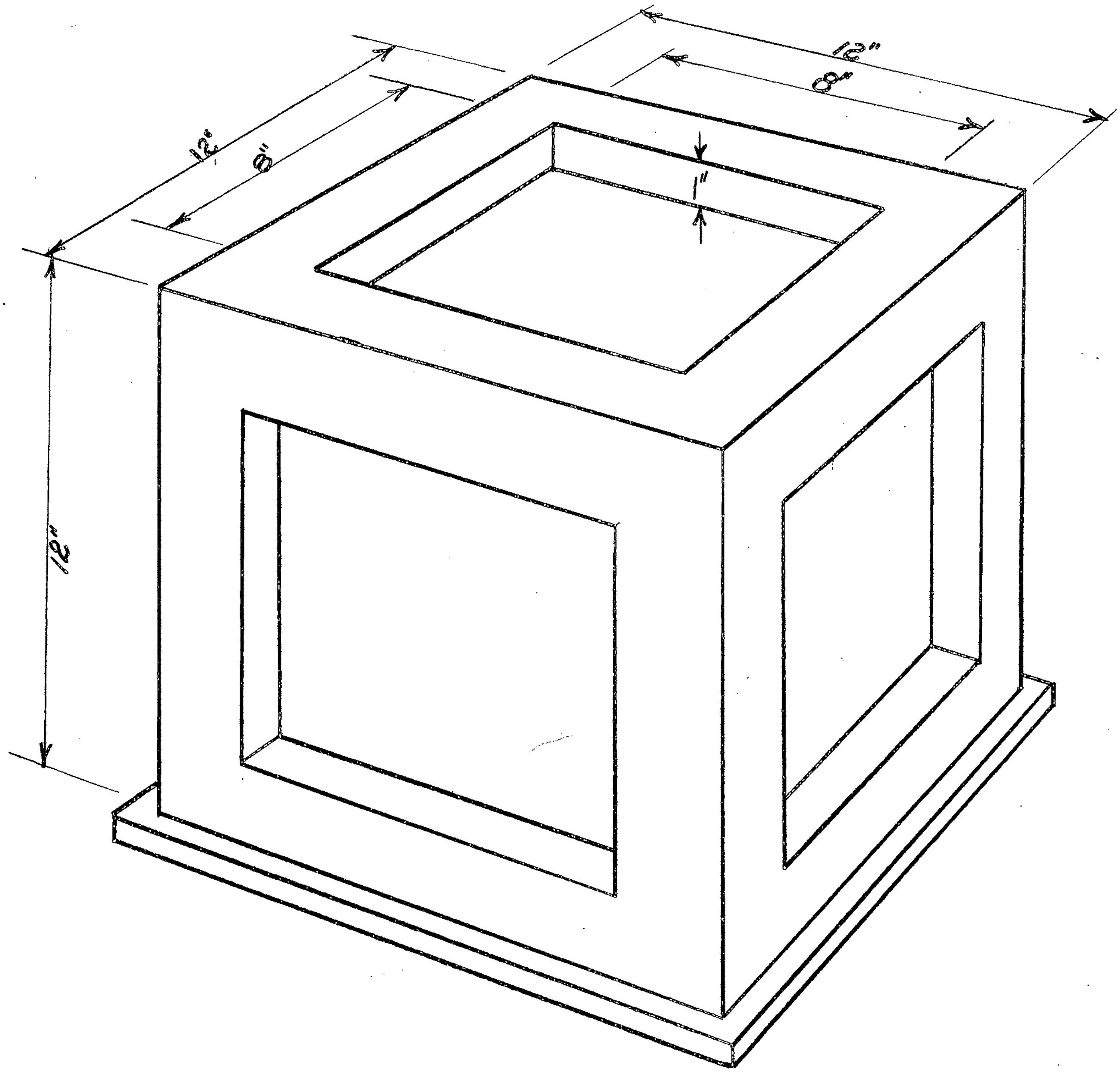

Fig. 8
SOL-AIR THERMOMETER
Note: Recesses for foil panels

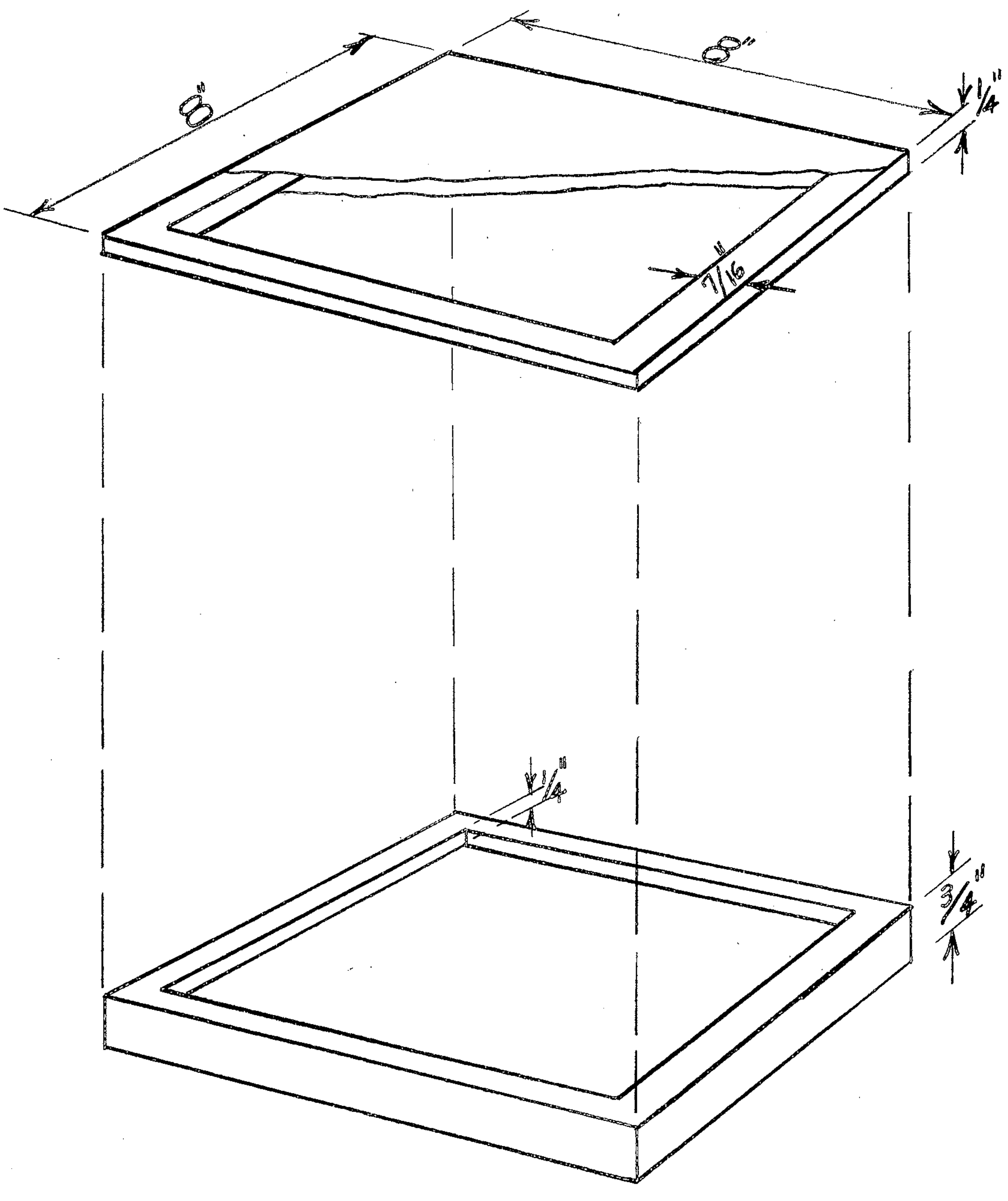

Fig. 9
ALUMINUM FOIL PANEL
Top section removed and foil cover cut to show construction of sections.

of the foil was used for all outward facing surfaces of the foil covered panels and the cork cube.

The sol-air thermometer was located in the pasture approximately 50 yards south of the temperature control shelter to obtain sol-air temperatures. Specimens for the study were mounted on the west vertical surface and the top horizontal surface of the sol-air thermometer. The instrument was mounted on a tripod 4'0" above the ground level. A small wire enclosure around the instrument protected it from livestock.

Concrete samples for the sol-air temperature studies were made of portland cement and aggregate. Aggregates used were the same as those used in the manufacture of the masonry units in the west wall of the shelter; expanded shale, pumice, and sand and gravel. A mixture of one part of portland cement to 4 parts aggregate was used for making the samples. The mixture had to be rich to meet strength requirements. Leaner mixes had resulted in samples that were brittle and broke in handling. The samples were all 2 1/2 inches in diameter and averaged 1/4 inch in thickness. Three samples of each aggregate, sand and gravel, pumice and expanded shale were left with the natural finish. The other 9 samples, 3 of each mix, were painted white to duplicate the white finish of the south panels of the west wall. Each sample was given one coat of an oil base, white flat paint. Relative textures are shown in Figs. 10 and 11.

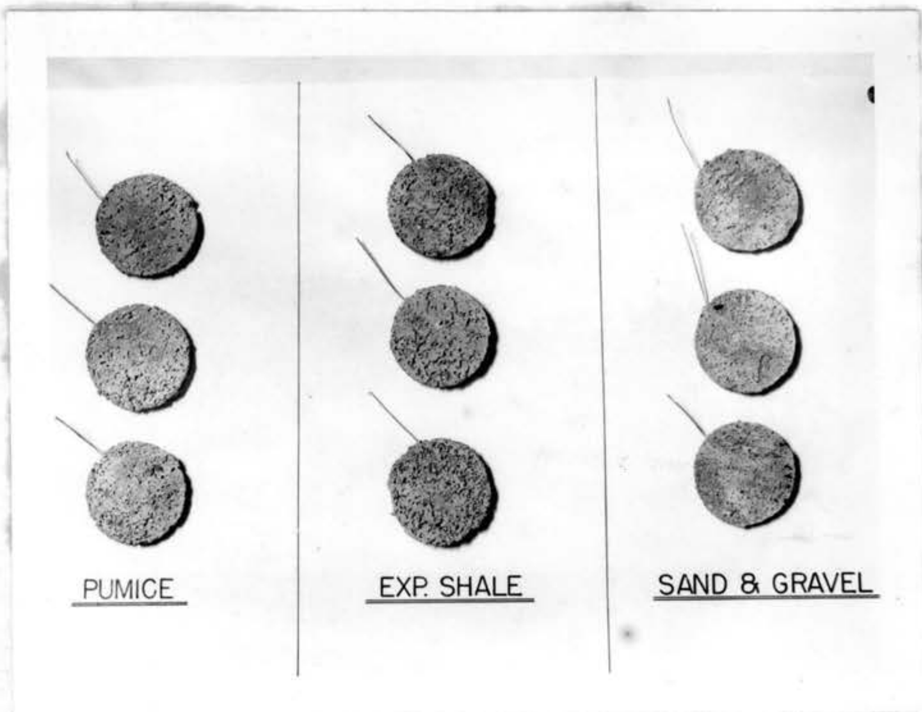

Fig. 10 - Unpainted Masonry Samples Used to Obtain Sol-air Temperatures.

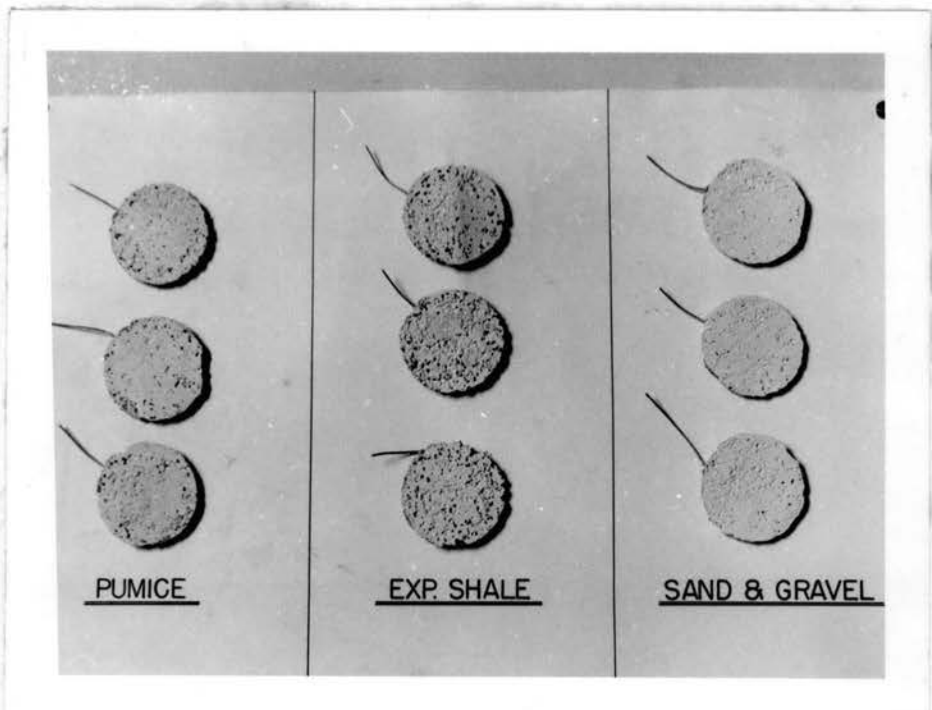

Fig. 11 - Painted Masonry Samples Used to Obtain Sol-air Temperatures.

Attempts were made to cut masonry samples from concrete masonry units but these samples were too fragile and could not be used. The objective of obtaining samples from the masonry units was to obtain samples that had the same surface properties as the wall test panels. The samples that were made were small and very thin to maintain low thermal capacity. This low capacity allowed quick response of the surface temperatures to changes in external conditions of solar radiation, wind movement, or air temperature.

Samples of metal roofing materials were also used in obtaining sol-air temperatures. Materials used for samples were weathered aluminum roofing, weathered glavanized steel roofing, and steel roofing coated with a silicon based enamel. Size, number and finish of samples were:

Type of Material	Surface Finish	Size	Number Tested
Aluminum	Weathered, plain	2 1/4" dia.	3
Steel	Weathered, galv.	2 1/4" dia.	3
Aluminum	Weathered, plain	3 3/4" square	1
Steel	Weathered, galv.	3 3/4" square	1
Steel	New, silicon enamel	5" x 6"	1

One 30 gauge iron-constantan thermocouple junction was soldered to each of the small samples and three junctions were soldered to each of the larger samples. The roofing samples are shown in Fig. 12.

An open front shelter, 26 by 50 feet, located 50 yards east of the temperature control shelter, was used for the studies of the roofing in place. This barn is shown in Fig. 13. The shelter roof is composed of 0.024 corrugated aluminum roofing on 2 by 4 inch purlins, 24 inches

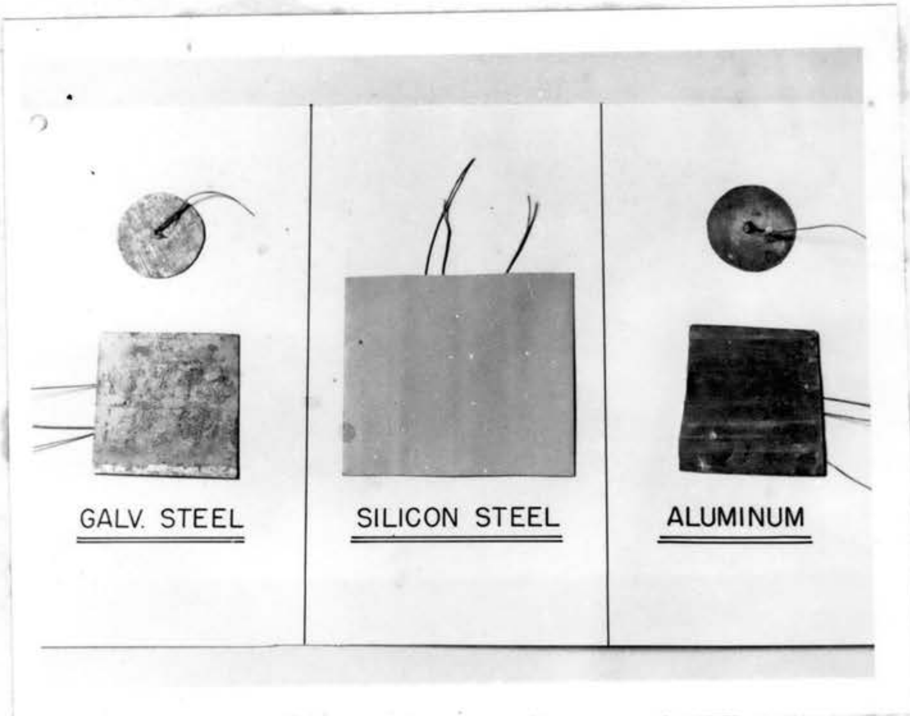

Fig. 12 - Metal Roofing Samples Used to Obtain Sol-air Temperatures.

Fig. 13 - Experimental Open Front Shelter for Dairy Cattle Showing Open Front Facing South. Galvanized Roofing Sheets Appear As Two Light Colored Strips on South Slope of Roof.

on centers, with two sections of 26 gauge galvanized steel roofing, one sheet wide, from the ridge of the roof to the eaves. These galvanized steel sections are located on the south slope of the roof. Roof slope is 6 inch rise for each foot of horizontal run. Roofing materials on this shelter had been in place two years at the time the data was taken.

Instrumentation

Dry bulb temperatures of outdoor air were measured with a recording thermograph manufactured by the Henry J. Green Company. The thermograph provides a weekly continuous trace of dry-bulb temperatures on a 3 1/2 inch wide strip chart graduated from 30° to 130° F at 2° intervals. The instrument was mounted in an instrument shelter located in the pasture 100 yards north of the temperature control shelter. The calibration was checked weekly with a mercury thermometer for temperature accuracy and semi-weekly for accuracy in time.

Dry bulb temperatures within the shelter were measured with a recording hygro-thermograph manufactured by the Brown Instrument Company. It provided a continuous trace of dry bulb temperatures on a 7 1/2 inch diameter circular chart, graduated from 0° to 100° F at 2° intervals. Calibration of the instrument was checked each morning with a Bendix-Friez hand aspirated psychrometer.

The temperatures on the inside and the outside surfaces of the west wall panels were measured using 20 gauge iron-constantan thermocouple junctions and a Brown electronically-balanced potentiometer. The potentiometer, manufactured by the Brown Instrument Company, is equipped with a switching panel which allows as many as 48 thermocouple circuits to be brought in to it. Temperatures are read on a lighted, revolving circular chart with a graduation from 0° to 300° F by one-half degree intervals.

Thermocouple junctions were made by twisting together and soldering one inch of the iron and constantan wire ends. These wires were carried to the potentiometer to complete the thermocouple circuit. The junctions were installed in the surface of the wall by cutting shallow grooves the depth of the wire diameter and approximately 2 inches long, in the wall surface. The junctions were then placed in the grooves, covered with a mortar of sand and portland cement, and struck off even with the masonry wall surface. This left the junction covered with a thin coating of mortar with the same characteristic as the rest of the wall panel. Figure 14 shows these grooves cut in the unpainted wall surface. Locations of thermocouple junctions are shown in Fig. 3. Readings of wall surface temperatures were taken at half hour intervals from noon until midnight.

Heat flow through the west wall panels was measured with a Gier and Dunkle[7] heat flow meter, previously described under "Review of Literature". Imbedded in the center of the meter is a thermocouple junction so temperatures of the heat meter can be obtained. Eight holes are located at the corners and edges of the heat meter for attaching the slab to the surface to be tested. The heat meter is calibrated in btu per hour per square foot per millivolt. The calibration constant

Fig. 14 - Unpainted West Wall Panel in Temperature-Controlled Shelter For Dairy Cattle Showing Shades and Textures of Expanded Shale, Left, Sand and Gravel, Center, and Pumice Aggregate Concrete Block, Right, and Grooves for Thermocouple Junctions.

of the meter used in these studies is 5.54 btu per hour per square foot per millivolt at a meter temperature of 120° F. For computing heat flow at meter temperatures other than 120° F, a correction was applied.

To attach the meter to the wall, four dowels, 1/4 inch in diameter by 1/2 inch long, were placed in the center of each test panel by drilling holes in the masonry units and driving the wood dowels into the holes, flush with the wall surface. The heat meter was then affixed with four screws. To prevent possible air movement under the heat meter, drafting tape was attached to the edges of the meter to seal it to the wall. Figure 15 shows the meter attached to a test panel.

Leads from the heat flow meter to the recording instruments were made using 30 gauge iron-constantan fabric covered thermocouple wire and 30 gauge enamelled copper wire. The copper wires were attached to the external lugs of the heat meter and carried to the recording potentiometer to measure heat flow. The iron constantan wires were attached to the central lugs, iron to iron and constantan to constantan, and carried to the other recording potentiometer to obtain meter temperatures. This completed the circuits of both the heat meter thermopiles and the heat meter thermocouple junction.

Heat flow and meter temperatures were measured using one point recording potentiometers manufactured by the Brown Instrument Company. The potentiometers, electronically balanced units, provided continuous trace of both temperature and heat flow on 12 inch circular

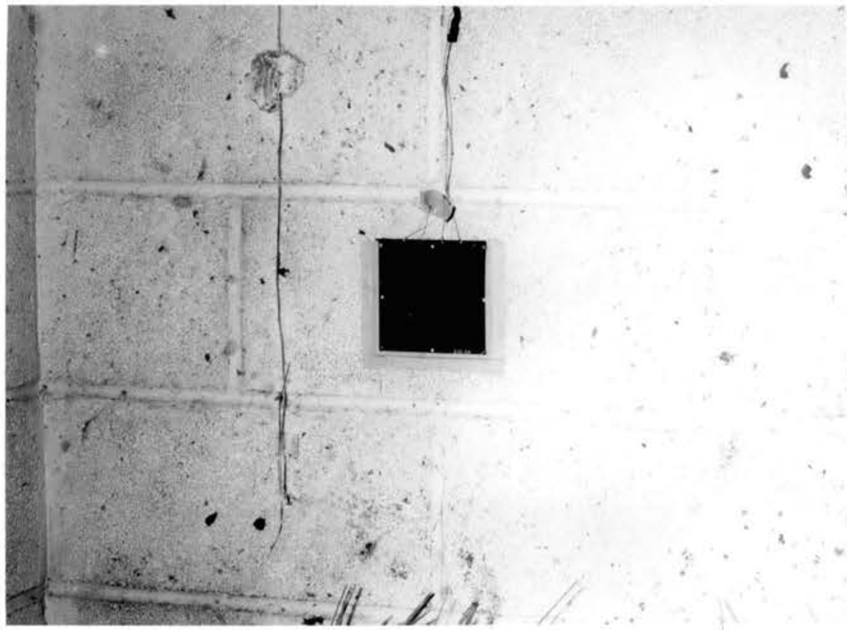

Fig. 15 - Heat Flow Meter Mounted on West Wall of Temperature-Controlled Shelter.

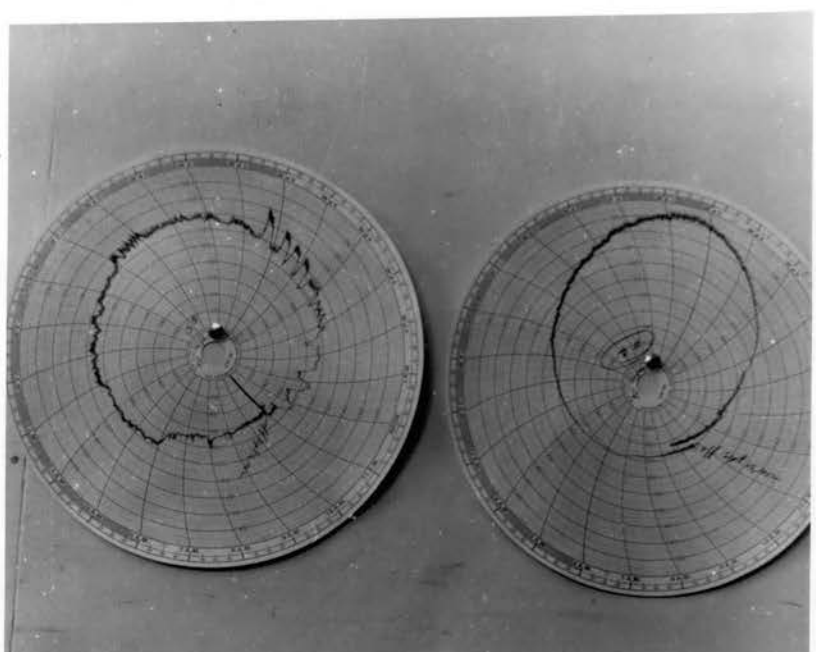

Fig. 16 - Typical Heat Flow Charts Showing Effect of Cooler, Left, and Cooler Off, Right.

charts, graduated from 0° to 200° F at 2° intervals. Figure 16 shows two typical heat flow charts. Since the potentiometer used to record heat flow recorded in degrees F, it had to be calibrated to determine the equivalent emf flow in millivolts. The Brown electronic balancing potentiometer has a balancing unit which uses compensated air temperatures as the reference junction. Therefore, when used with a heat meter, the circuit is composed of three junctions in series. For this reason, the emf equivalent of chart temperatures could not be determined by reference to standard thermocouple conversion tables. To accomplish this calibration, a Leeds-Northrup potentiometer was connected in parallel to the Brown instrument, both of which were connected to the heat flow meter which was mounted on a heat source. Readings were then taken simultaneously on emf as indicated on the Leeds-Northrup potentiometer through the range of the Brown instrument. These readings were then plotted to determine the millivolt equivalents of the readings of the recording potentiometer. This curve of correction is shown in Fig. 17.

Readings for heat flow in west wall panels and temperatures of the heat meter were continuous. Charts were changed in the mornings. Potentiometers were located in the loft of the temperature control shelter, over the west wall panels.

Sol-air temperatures of samples were obtained using the same Brown potentiometer as was used to obtain surface temperatures of wall panels. The potentiometer, located in the enclosure with the

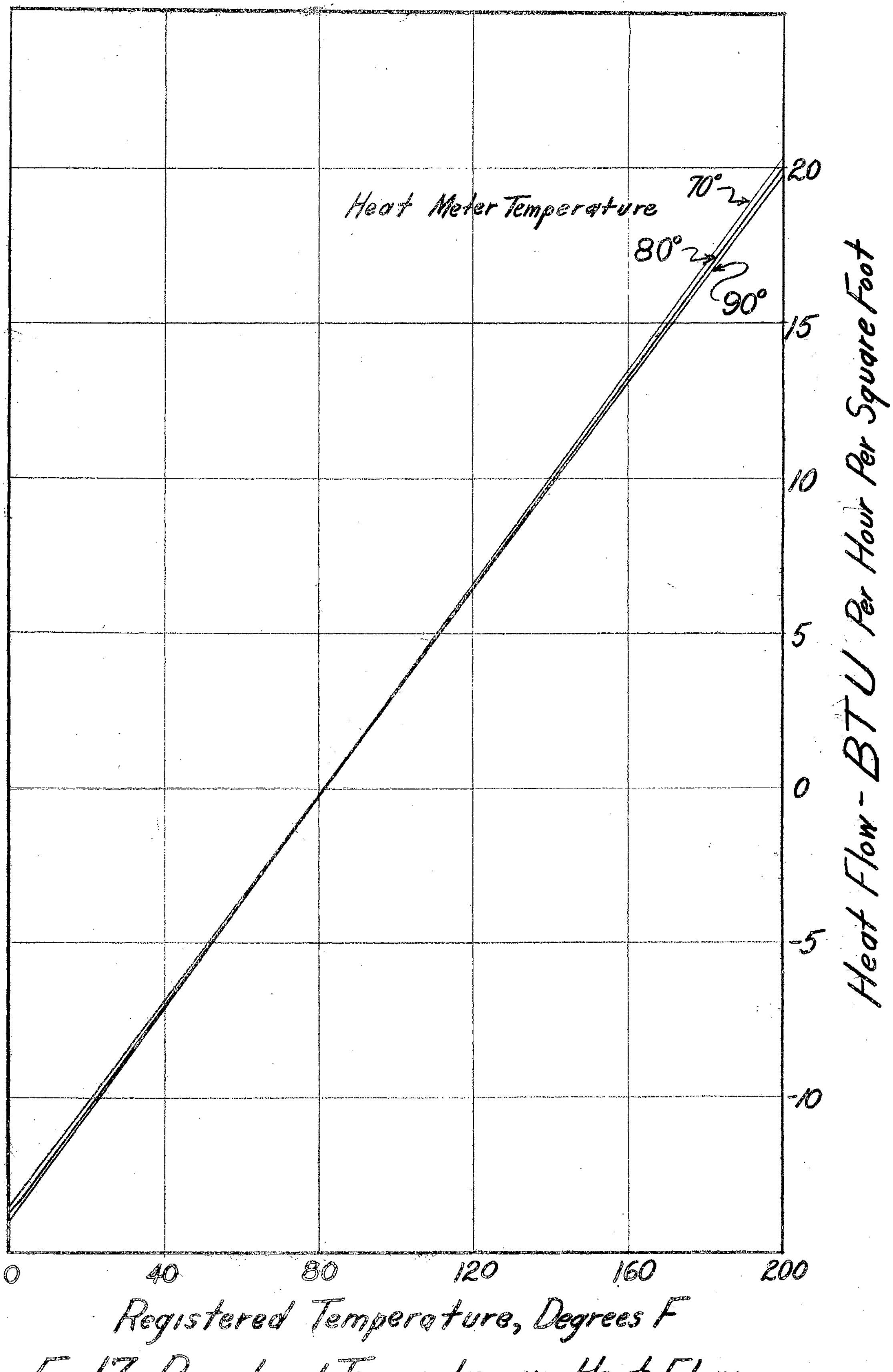

Fig. 17- Registered Temperature vs. Heat Flow For Heat Meter

sol-air thermometer, was mounted in a special stand and placed about 6 feet northeast of the thermometer. Samples to be tested were placed on the top surface and the west surface of the sol-air thermometer. Since the potentiometer could not be "seen" by the samples, it would not radiate to the samples or absorb radiation from them. Figure 18 shows the enclosure with the sol-air thermometer and potentiometer. Figure 19 shows the sol-air thermometer with samples undergoing tests mounted on the upper horizontal surface and the west facing vertical surface.

Thermocouple junctions for the samples were made by twisting together 1/4 inch of the iron and constantan wire ends and soldering them together. These junctions were then imbedded in the concrete masonry samples as the samples were cast. Junctions attached to the roofing samples were soldered in place. Leads from the junctions to the potentiometer were made using 30 gauge iron-constantan thermocouple wire. Readings were made at 10 minute intervals from 1:00 P.M. until an hour before sunset. Due to the fact that late afternoons were often hazy, most readings were terminated shortly after 5:00 P.M.

Wind direction and velocity readings were recorded by visual observation. Instruments used for this were a simple wind vane, a Gallet decimal stop watch, and a 4 inch diameter anemometer manufactured by Keuffel and Esser Company. The stop watch and the anemometer were started simultaneously immediately before sol-air temperature readings were taken and stopped immediately after the

Fig. 18 - Enclosure and Instruments Used in Recording Sol-air Temperatures.

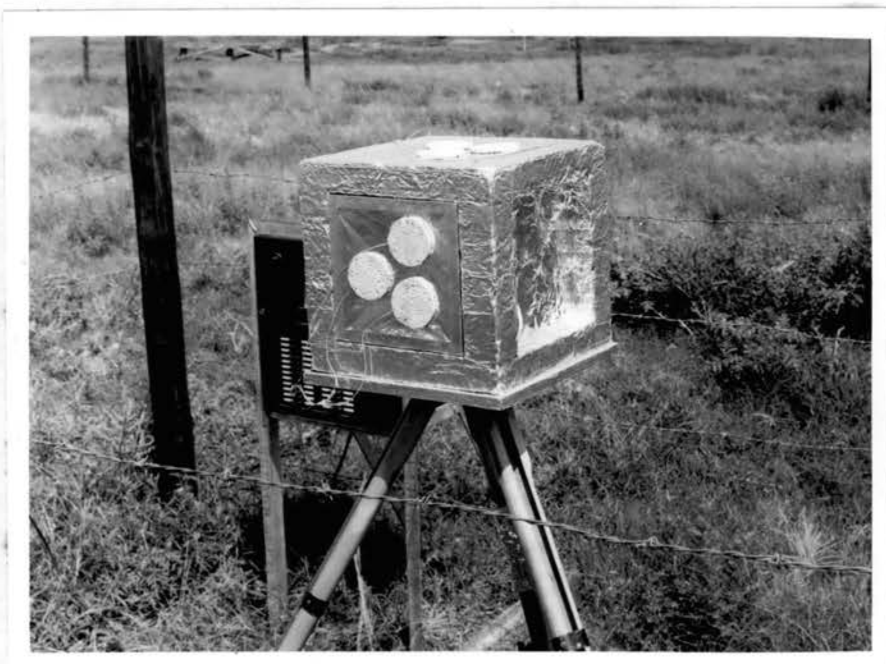

Fig. 19 - Sol-air Thermometer With Painted Masonry Samples Undergoing Tests.

readings were completed. This provided both wind direction and velocity at the site during the time the sol-air temperature readings were being made.

Instantaneous solar and sky radiation intensities were obtained from the trace of a recording pyrheliometer maintained by the College Meteorology Department. The recording pyrheliometer includes a Eppley horizontal disc sensing element and a Leeds and Northrup recording potentiometer. The sensing element is located on the roof of the Meteorology Department Office, located on the A. & M. Campus. The installation has been inspected and approved for obtaining U. S. Weather Bureau records by a representative of that Bureau. The instrument is timed using Central Standard Time rather than solar time. It is calibrated for charts recording intensity of radiation in Langleys, gram calories per square centimeter per minute. To convert Langleys to btu per square foot per hour, a multiplication factor of 221.21 was used.

V. PRESENTATION AND ANALYSIS OF DATA

Data presented in the following pages are from temperature and heat flow observations and records for July 27, 1951, June 27 and 28, 1952, August 20, 24, 25, 28, 29 and 30, 1952 and September 2, 3, 5, 12, 15, 23, 24, 25, 26, 28, 29 and 30, 1952. Data was not taken on days when pyrheliometer traces were seriously broken due to cloudiness. Cloudiness causes extreme fluctuations in the pyrheloimeter trace which makes analysis of the data very difficult. Slight haze or overcast will cause a depression of the curve, lowering the maximum peak, but if it is even, fluctuations are slight and analysis of the data is not too difficult.

All temperatures shown in the data that follows are on the Fahrenheit scale; and, to avoid needless repetition in continuous reference to temperature data, this specification will be omitted.

Sol-air Temperatures of Construction Materials

The sol-air temperatures of construction materials were measured for horizontal, upward facing surfaces and for vertical, west-facing surfaces. The sol-air temperatures of various samples of construction materials are shown in Table II. These values are the average temperatures of three samples mounted on the west-facing surface of the sol-air thermometer. Table II also shows the dates on which these sol-air temperatures were taken. Temperatures of samples mounted on the sol-air thermometer quickly responded to changes in wind velocity or solar radiation. A slight change in wind velocity or a small cloud would often cause a drop of 5° in the sample temperature. When sol-air temperatures fluctuated greatly due to increase or decrease of wind velocity during the time sol-air temperatures were being read, sol-air temperatures and wind velocity were re-taken.

The absorptivity coefficients, "b", of solar radiation for the surfaces of each of the various types of construction materials were computed using the expression:

$$b = \frac{f_o \ (t_e - t_o)}{I}$$

where:

b = Absorptivity of the surface for incident solar and sky radiation, dimensionless.

f_o = Coefficient of convective heat transfer for air film at surface, btu per hour per square foot per deg. F.

t_e = Measured sol-air temperature.

t_o = Measured outdoor dry-bulb temperature.

I = Incident solar radiation, btu per hour per square foot.

Values for f_o were obtained from the Guide[3], Fig. III, page 178, corresponding to wind velocities measured at the site at the time of sol-air temperature readings, Table III. Since no values were listed in the Guide[3] for metal roofing, the f_o values for glass and paint on smooth pine were used. Using these values of f_o, values of "b" for both the upward facing, horizontal surface and the west-facing, vertical surface of each material were computed. Values for outdoor air temperature, t_o, for days on which sol-air studies were made are given in Table IV.

Values of "b" obtained using the data for the upward facing, horizontal surfaces were very low. Investigation of this characteristic showed that values of f_o in the Guide[3] are for vertical surfaces and do not necessarily apply to horizontal surfaces. Wilkes and Peterson[12] found that for air spaces in various positions, bounded by materials with an emissivity of 0.83 and with a temperature difference of 15^o between surfaces, vertical heat flow upward is 1.95 btu per hour per square foot, vertical heat flow downward is 1.21 btu per hour per square foot, and horizontal heat flow through vertical surfaces is 1.52 btu per hour per square foot. For reflective surfaces, the difference is even greater in proportion. Because of this and because there were no known data available on the values of f_o for surfaces in other positions than vertical, the data obtained for upward facing samples could not be used. Sol-air temperatures of west-facing, vertical samples were therefore used for all computations to determine the value of "b".

To compute the total incident solar radiation and sky radiation received on unshaded, vertical west-facing samples, the following expression was used:

$$I_t = KI_n + I_{sv}$$

where:

I_t = Intensity of total solar radiation, btu per hour per square foot of absorbing surface.

K = Cosine of the angle of incidence of the sun's rays on a vertical, west-facing surface.

I_n = Intensity of direct radiation on a plane normal to the sun's rays, btu per hour per square foot.

I_{sv} = Intensity of sky radiation received on any vertical surface, btu per hour per square foot.

It is apparent that before I_t can be computed, the values of I_n and I_{sv} must be known. The pyrheliometer measurements, however, gave but a single value, I, for the total solar and sky radiation intensity on a horizontal surface. Therefore a supplementary analysis was needed to compute I_n and I_{sv} from the pyrheliometer data. This analysis was based on the ratio:

$$e = I_n \sin \beta \,/\, I_{sh}$$

where I_{sh} is the instantaneous sky radiation intensity on a horizontal surface. The Guide[3] lists values for "e" as a function of β, the altitude angle of the sun, and states: "For rough estimates, assume that the sky radiation on a vertical surface is one half of that on a horizontal surface. Sky radiation can be assumed independent of vertical surface orientation."

Total solar and sky radiation intensity, I, on a horizontal surface can be expressed by:

$$I = I_{sh} + I_n \sin \beta$$

or: $$I_n = (I - I_{sh}) \,/\, \sin \beta$$

Substituting for I_n in the expression defining "e":

$$e = (I - I_{sh}) / I_{sh}$$

or: $I_{sh} = I / (e + 1)$

and $I_{sv} = 0.5\, I / (e + 1)$

In order to apply these expressions, the altitude of the sun and the angle of incidence of the sun on vertical west facing walls must be known for all times during each of the chosen days. These values were computed for 20 minute intervals from 1:00 p.m. until sunset using a Sun Angle Calculator. This special device, developed by Libby Owens Ford Glass Company, is a calculator used to quickly compute the elevation of the sun and the angles of incidence for any vertical wall. This device was sufficiently accurate for the work being done since the margin of error of the calculator was less than the possible error in the potentiometer recording sol-air temperatures. Sun elevation and angles on incidence for vertical, west-facing walls are shown in Table V. Using these values for the sun elevation and angles of incidence, the values for I_n and I_{sh} were computed for days on which sol-air temperature data and heat flow data were taken. This data is given in Table VI. These calculations are for Stillwater, Oklahoma, (36^{o} 07' N. - 97^{o} 03' W.) using the longitude 97^{o} W. to compute solar time and the latitude 36^{o} N. to compute sun elevations. Time shown in the tables is Central Standard Time.

Using 10 instantaneous values of sol-air temperature and wind velocity obtained at 20 minute intervals on a single afternoon for each sample, instantaneous values for "b" were computed and averaged.

These average values are shown in Table VII. The following example will illustrate this computation for unpainted sand and gravel aggregate concrete with the surface exposed to solar radiation. Data was taken at 3:20 p.m., August 28, 1952. The expression used was:

$I_{sh} = I \;/\; (e + 1)$

$I = 212.3$ btu per hour per square foot. (pyrheliometer measurement)

$e = 3.98$ at $\beta = 42^{o}$ (Table V)

$I_{sh} = 212.3 \;/\; (3.98 + 1) = 43$ btu per hour per square foot.

Compute $I_n = (I - I_{sh}) \;/\; \sin\beta$

$\sin\beta = \sin 42^{o} = 0.669$

$I_n = (212.3 - 43) \;/\; 0.669 = 254$ btu per hour per square foot.

Compute $I_{sv} = 0.5\, I_{sh}$

$I_{sv} = 0.5 \times 43 = 21.5$ btu per hour per square foot.

Compute $I_t = I_n \cos\theta + I_{sv}$

$\theta = 47^{o}$ (Table V)

$\beta = 42^{o}$ (Table V)

$I_t = 254 \times \cos 47^{o} + 21.5$

$I_t = 195$ btu per hour per square foot

Compute $b/f_o = (t_e - t_o) \;/\; I_t$

$t_e = 116.7^{o}$ (Table II)

$t_o = 92^{o}$ (Table IV)

$b/f_o = (116.7 - 92) \;/\; 195 = 0.127$

Compute $b = b/f_o \times f_o$.

Wind velocity = 4.4 m.p.h. (Table III)

$f_o = 3.408$ (Guide[3], Fig. 3, page 178)

$b = 0.127 \times 3.408$

$b = 0.433$

Using the values obtained for "b", absorptivity of the surface for solar radiation, the values of b/f_o for various wind velocities for all construction materials tested were computed and plotted. These values are shown in Figs. 20 through 23. The b/f_o values for unpainted specimens were much higher than those obtained for the white painted specimens. White painted sand and gravel aggregate concrete exhibited the lowest "b" value. These sand and gravel specimens were more smooth than were the specimens of either the pumice or expanded shale aggregate concrete. Unpainted sand and gravel specimens also had, by a slight margin, a lower "b" value than either of the lightweight aggregate specimens. Of the metal roofing materials, the silicon enameled steel roofing exhibited the lowest "b" value. Weathered samples of this material were not available since this is a new product. Samples of the other roofing materials, the galvanized steel and the alumunum roofing specimens, were moderately weathered.

Temperatures of the Inner and Outer Surfaces of West Facing Wall Panels.

Temperatures of the inner surfaces and the outer surfaces of the test panels in the west wall of the temperature-controlled dairy

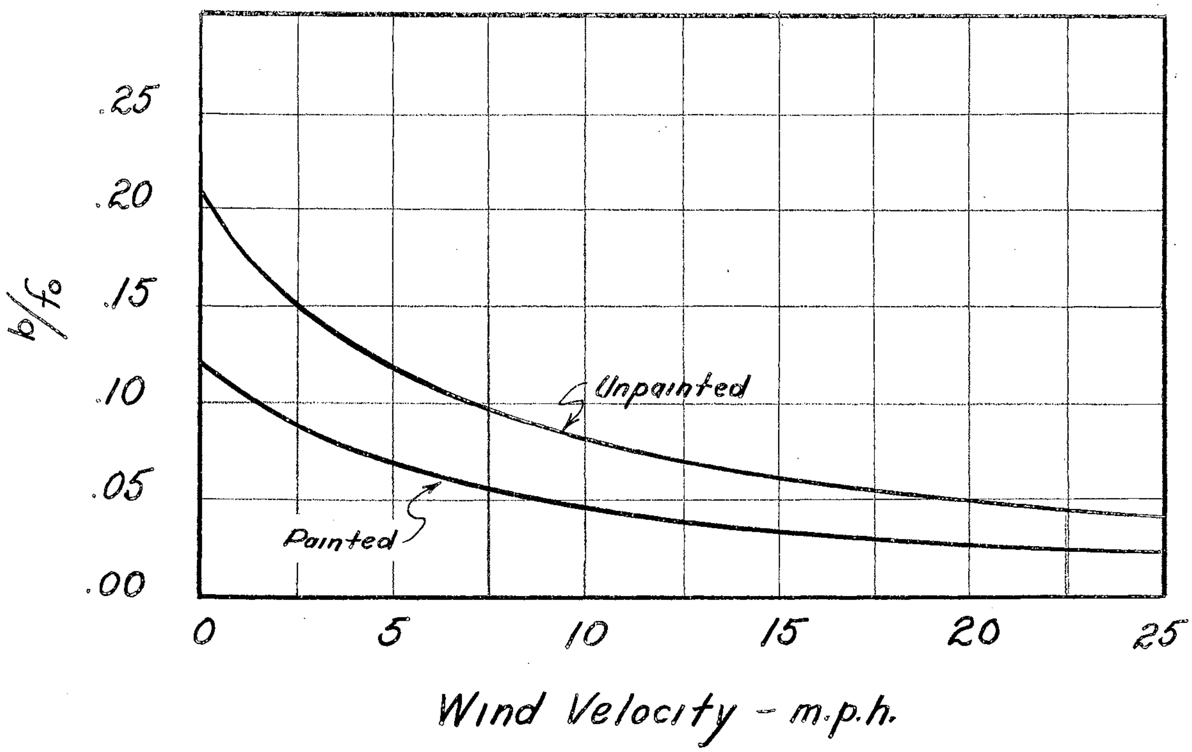

Fig. 20 - Values of b/f_o for Sand and Gravel Aggregate Concrete.

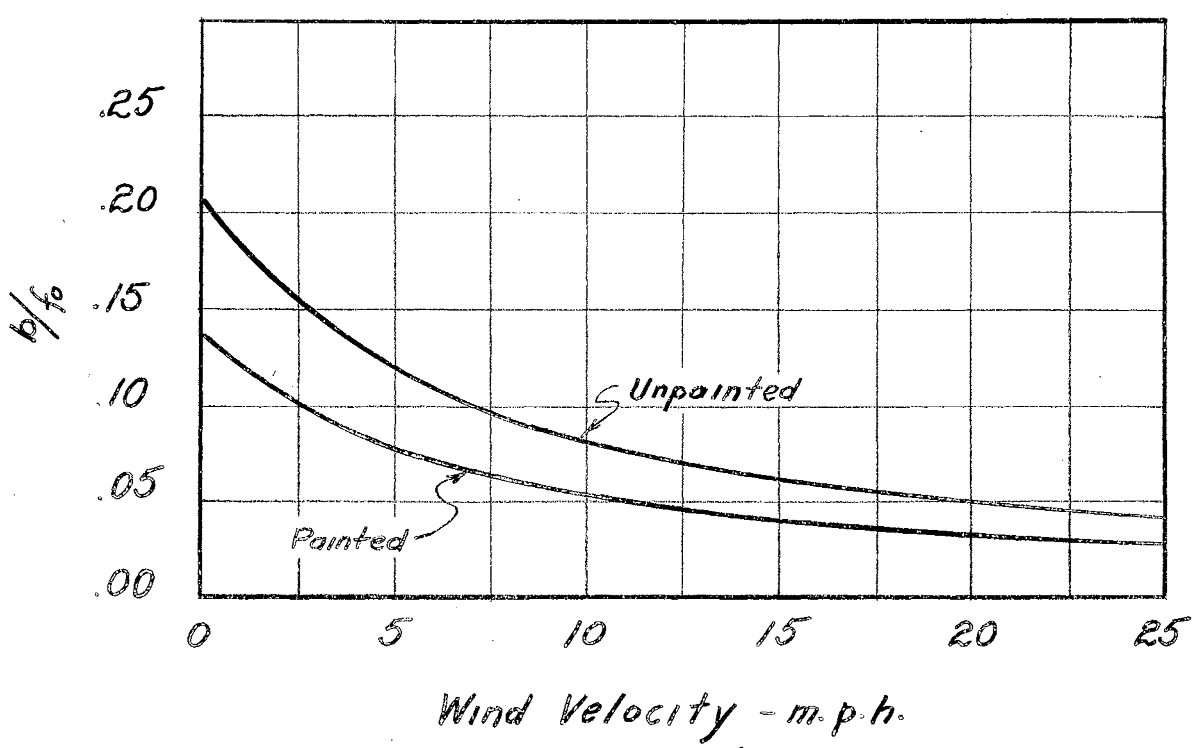

Fig. 21 - Values of b/f_o for Expanded Shale Aggregate Concrete

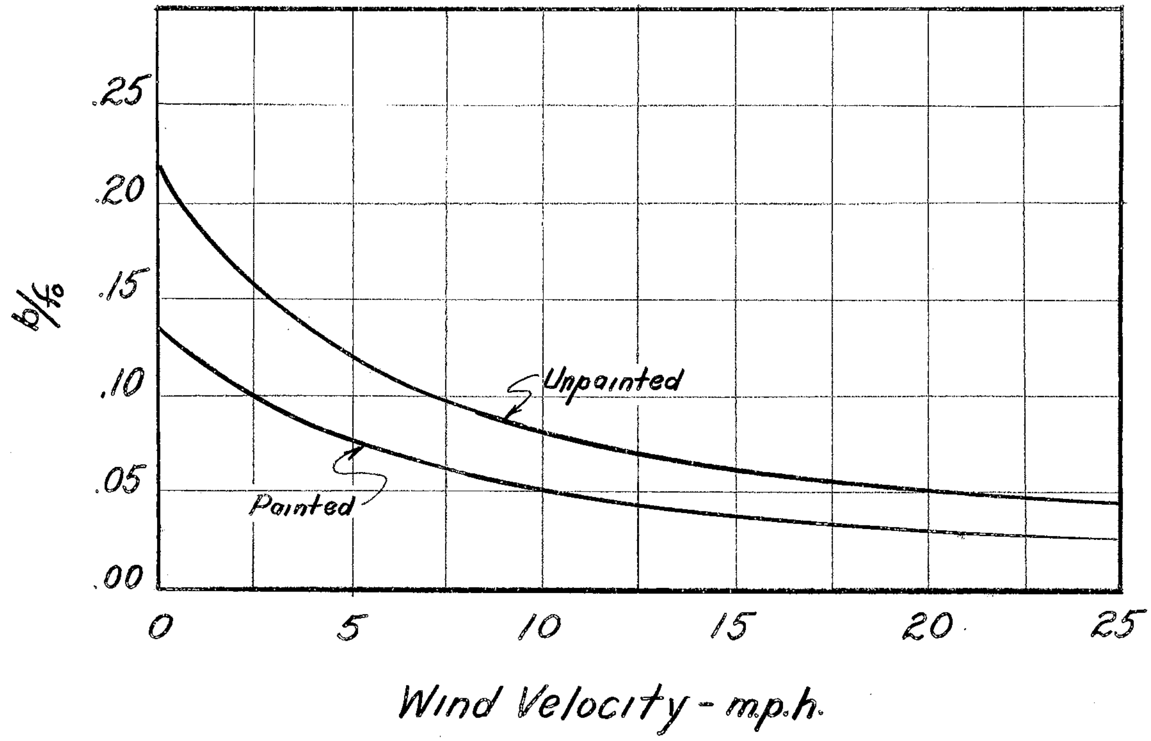

Fig. 22 - Values of b/f_o for Pumice Aggregate Concrete

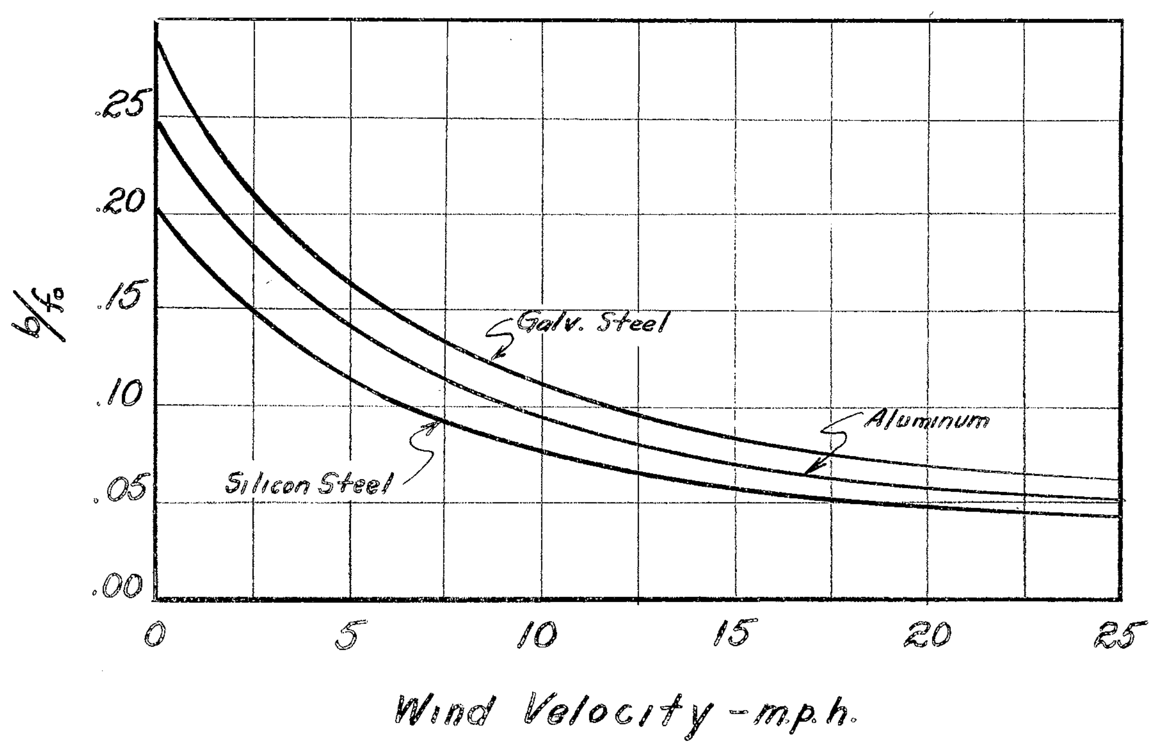

Fig. 23 - Values of b/f_o for Roofing

cattle loafing shelter are shown in Table VIII. Each of these temperatures is the average of two temperatures obtained on either the inner or the outer surfaces of each of the 12 test panels. Wall temperatures on the outer surfaces increased steadily until about 5:00 p.m. each day at which time they would reach their peak and start to decrease. Outer surfaces of the wall cooled quickly after sunset.

The effect of painting half the panel surfaces white was readily noticeable. All temperatures shown are for July 27, 1951. For the unpainted panel of expanded shale aggregate concrete block, panel 1W (see Fig. 3), the average outer surface temperature at 5:00 p.m. was 138° while another panel of the same construction but with the outer surface painted white, panel 9W, had an average surface temperature of only 108°, a difference of 30°. Mud and dirt splashed on the lower blocks also made a large difference, often as much as 20° between thermocouples in the outer surface of the same panel.

Heat Gain Through West Facing Wall Panels

Instantaneous heat gain to the inner surface of each of the 12 west-facing wall panels was measured using the Gier and Dunkle heat meter. Table IX gives the heat flow through each of the 12 panels, and the date heat flow was measured for each. Data is given at half hour intervals from 1:00 p.m. until 11:00 p.m. Maximum heat gain to the inner surface usually occurred between 8:00 and 10:00 p.m., depending upon time lag of that particular type of wall construction.

Values for f_o were obtained from the Guide[3], Fig. III, Page 178 using the wind velocity for days when sol-air temperature observations were made concurrently with heat flow observations, Table III. For days when wind data were not available, an average wind velocity of 6 m.p.h. was used. This was the average of wind velocities taken on days sol-air studies were made. Since heat flow data was taken only on days that were clear and relatively quiet, the same type days that sol-air studies were made, this assumed wind velocity should be very close to actual average wind velocities.

The outdoor dry-bulb temperatures for each of the afternoons during which heat flow data were taken are shown in Table X. Highest temperatures were recorded on the afternoon of August 20, 1952, when the temperature reached 99°. This was not the hottest of Oklahoma weather since peak temperatures had been 10° to 12° higher the previous summer. Temperatures exceeding this high of 99° are quite common.

Indoor dry-bulb temperatures for the temperature-controlled dairy cattle loafing shelter are shown in Table XI. High temperatures in mid-afternoon in the shelter were usually due to feeding or barn cleaning. Both the north and south side doors were often opened at the same time and temperatures rose rapidly. This was not too serious however since maximum heat gain to the interior through the test panels did not occur until 4 to 6 hours later.

To find a more simplified procedure for computing heat gain for design purposes, the relationship existing between $(t_e^* - t_i)$ and

$(q/A)_i$ was investigated for the 12 west wall panels. If $(q/A)_i$ is divided by $(t_e^* - t_i)$, a quantity which has the same dimensions as an overall coefficient of heat transfer for a wall is obtained. This quantity could be named an effective overall coefficient of heat transfer and be defined by:

$$U_e = (q/A)_i \, / \, (t_e^* - t_i)$$

where:

U_e = Effective overall (air to air) coefficient of heat transfer under summertime conditions of periodic heat flow, btu per hour per square foot per degree F.

$(q/A)_i$ = Instantaneous rate of heat gain to indoor air, btu per hour per square foot.

t_e^* = Sol-air temperature at a time earlier by the time lag of the wall material than the time for which heat gain is computed.

t_i = Indoor air temperature at time of heat gain.

Values for U_e are plotted for the hours from 1:00 p.m. through 6:00 p.m. for each of the 12 test panels. These values for U_e are shown in Figs. 24 through 29. The time shown on these graphs is the time of instantaneous heat gain to the interior of the structure. The time lag, in hours, for the various types of wall construction are:

Type of Concrete Block Construction	Cores Filled	Cores Empty
Sand and gravel aggregate	5 1/2 hrs.	4 1/2 hrs.

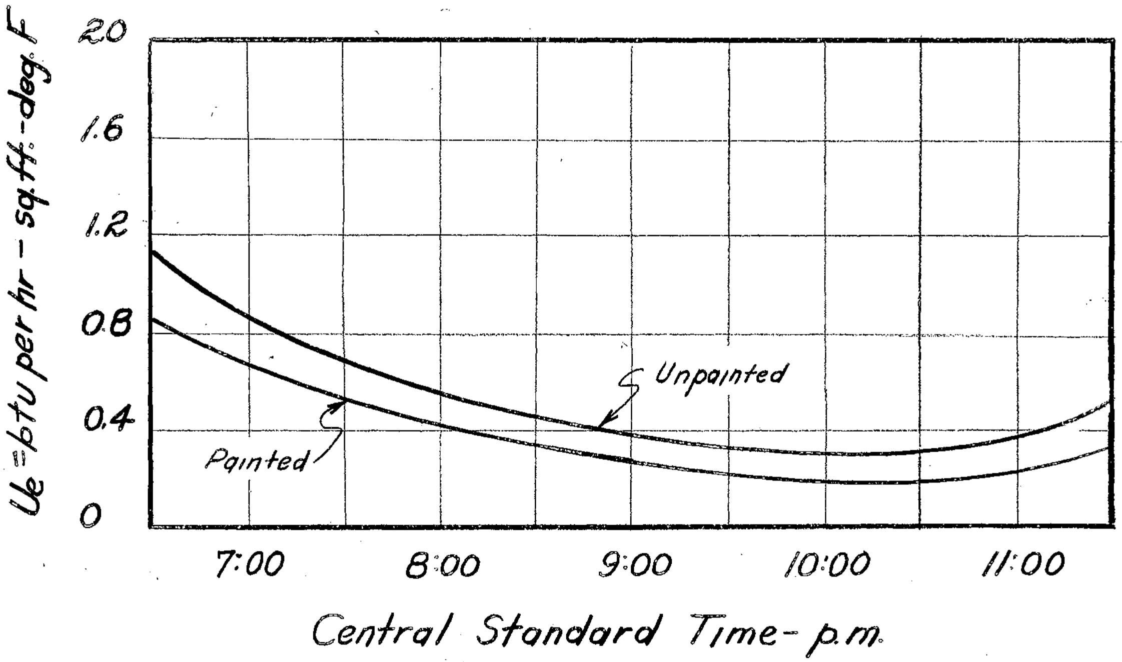

Fig. 24 - U_e for Sand and Gravel Concrete Block With Cores Filled-West-Facing

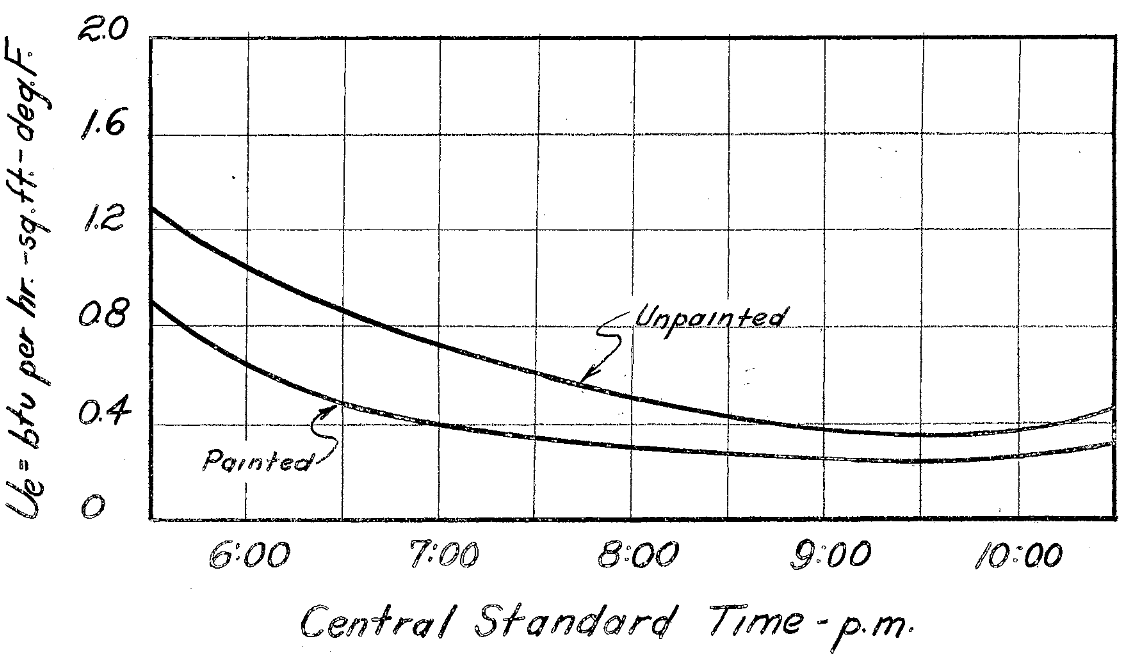

Fig. 25 - U_e for Sand and Gravel Concrete Block With Cores Empty-West-Facing

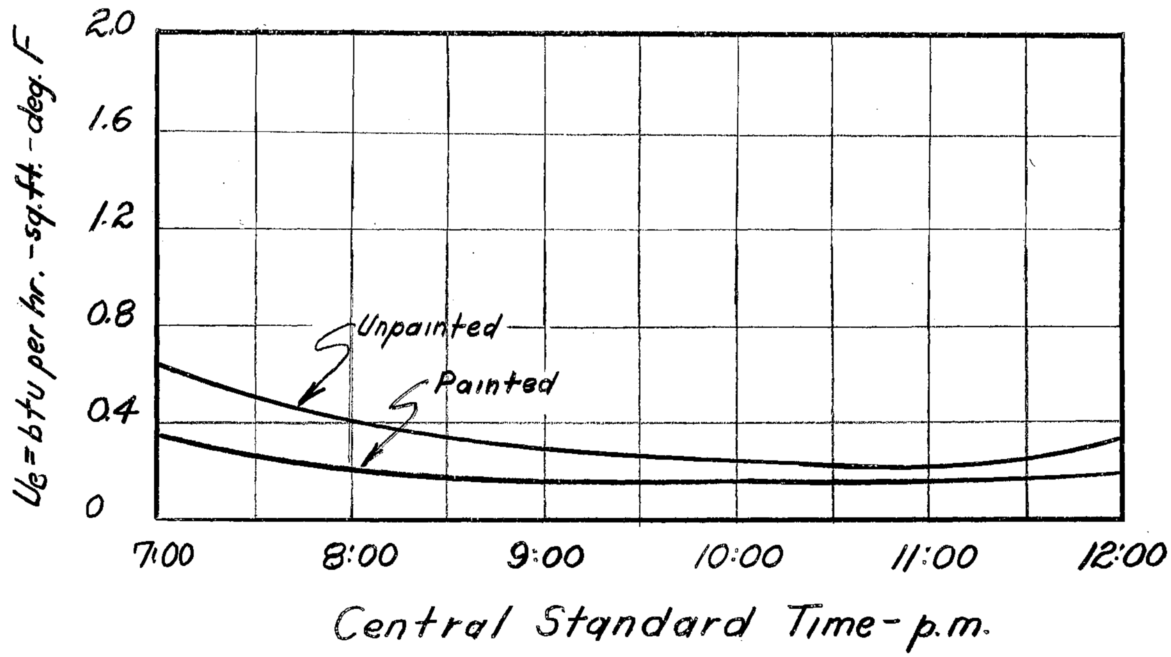

Fig. 26 - U_e for Expanded Shale Aggregate Concrete Block With Cores Filled-West-Facing

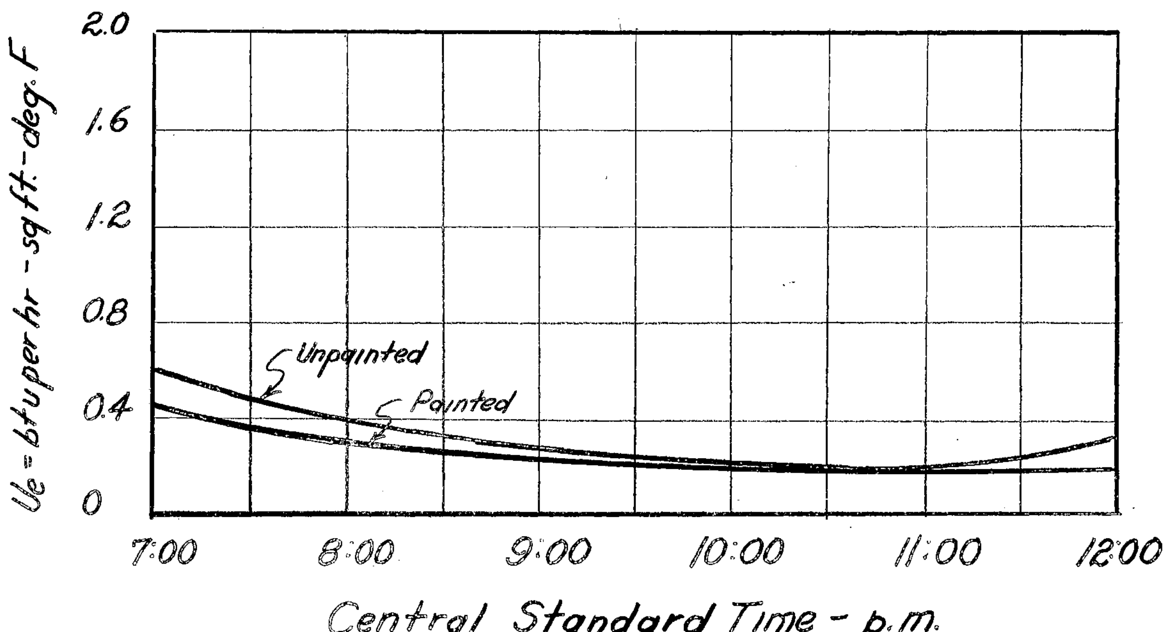

Fig. 27 - U_e for Expanded Shale Aggregate Concrete Block With Cores Empty-West-Facing

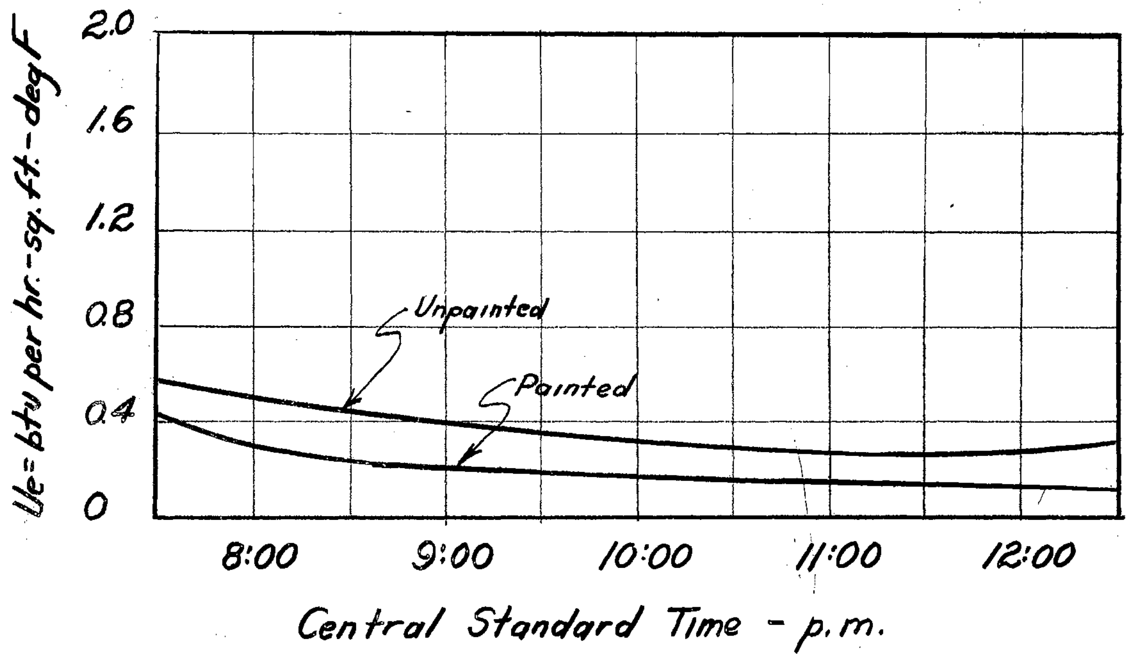

Fig. 28 - Ue for Pumice Aggregate Concrete Block With Cores Filled - West-Facing

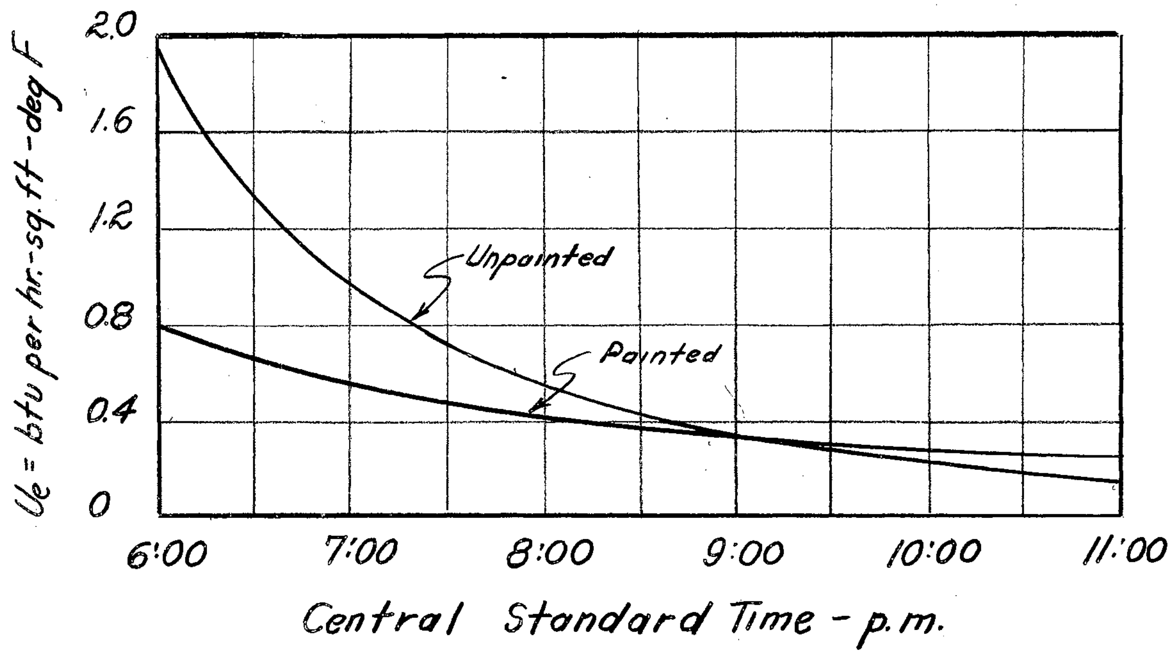

Fig. 29 - Ue for Pumice Aggregate Concrete Block With Cores Empty - West-Facing

Expanded shale aggregate	6 hrs.	6 hrs.
Pumice aggregate	6 1/2 hrs.	5 hrs.

These values for time lag were obtained by Nelson[10].

The following example will illustrate the computation of U_e for a white painted, expanded shale aggregate concrete block wall, cores of blocks empty, for August 30, 1952 for an observed heat gain at 9:00 p.m.:

$$U_e = (q/A)_i \;/\; (t_e^* - t_i)$$

where:

$t_e^* = t_o + (b/f_o)\, I_t$, at 3:00 p.m., time lag = 6 hours.

$t_o = 94^\circ$ (Table X) at 3:00 p.m.

$b/f_o = 0.073$ (Fig. 21) for wind velocity of 6 m.p.h.

Compute $t_e^* = t_o + (b/f_o)\, I_t$

$t_e^* = 94 + 0.073 \times 166 = 106^\circ$

$(q/A)_i = 7.95$ btu (Table IX) at 9:00 p.m.

$t_i = 75^\circ$ (Table XI) at 9:00 p.m.

Compute $U_e = (q/A)_i \;/\; (t_e^* - t_i)$

$U_e = 7.95 \;/\; (106^\circ - 75^\circ) = 0.256$

Therefore, the value U_e, shown in the graph for 9:00 p.m. is the resultant of the outdoor air temperature and the incident solar radiation on a west-facing wall that had occurred at 3:00 p.m.

The graphs of U_e vs. time, Figs. 24 through 29, follow a similar pattern for all 12 types of wall construction. It can be also seen that the values for U_e for white painted masonry are appreciably lower than for unpainted masonry and that the variations with time for the white painted panels were appreciably lower. Due to the time lag of the wall and the fact that appreciable solar radiation was not received on the wall until after 1:00 p.m., values of U_e for the west wall for hours earlier than shown in the graph would be extremely high. These values would increase until they would reach the time where heat flow would be reversed. At this point, U_e would be negative. In a heavy, masonry wall, the peak heat flow through a west-facing wall due to solar radiation will follow well after the peak heat load of the building. Values shown would be important for buildings used late in the evening. The only appreciable gain made through the west wall of any heavy masonry structure would be through windows where heat gain would be instantaneous. For these reasons, only heat flow due to direct solar radiation plus incident solar radiation and temperature difference occurring between the hours of 1:00 p.m. and sunset was considered in constructing the graphs.

The values for b/f_o and U_e obtained from graphs can be used to compute heat flow through similar west-facing walls. Values were obtained for Stillwater, Oklahoma, during late summer. This data is applicable only for this time of the year and for locations approximately 36^o N. For other latitudes, for other times of the year, or for wall orientations other than west, other values would need to be computed. This is true because the pattern of sol-air temperature variations would be different at other times of the year or for other latitudes and orientations.

An illustrative example problem will be given to show how the foregoing data might be applied: Find the heat flow through a west-facing wall of 8 inch sand and gravel aggregate concrete block, natural finish with cores empty, located in Knoxville, Tennessee. Heat gain to the interior is to be computed for 8:00 p.m. CST, August 25 when indoor air temperature is 80^{o}.

The location of Knoxville is $35^{o}58'$ N, $83^{o}57'$ W. Since time difference, sun time, is 4 minutes per degree longitude, the solar time difference is equal to 4 (97^{o} - 84^{o}) = 52 minutes. Effective time for the graph to determine U_e would therefore be 8:52.

U_e for 8:52 p.m. = 0.380 (Fig. 25)

Time lag for wall = 4 1/2 hours

Effective time for t_e* = 8:00 p.m. - 4 1/2 hours = 3:30 p.m.

Assuming the wind velocity to be 4 m.p.h. and outdoor air temperature to be 95^{o} at 3:30 p.m.

$t_o = 95^{o}$

$b/f_o = 0.131$ (Fig. 20)

I_t = 208.1 btu per hour per square foot at 4:22 p.m.

(assuming clear, cloudless sky: Table V and VI)

Compute $t_e^* = t_o + (b/f_o \times I_t)$

$t_e^* = 95^{o} + (0.131 \times 208.1) = 122.25^{o}$

Compute $(q/A)_i = U_e\,(t_e^* - t_i)$

$(q/A)_i = 0.380\,(122.25 - 80) = 16.05$ btu per hour per square foot

If a sol-air thermometer had been used to obtain t_e*, solar radiation and the altitude and angle of incidence of the sun would not be needed since the value of t_e* could have been read directly. This would be especially important if values for solar radiation were not available for the location in question.

Metal Roofing Temperatures

The temperatures of the under-surfaces of aluminum and galvanized steel roofing, and the outdoor air temperatures for the same period, for 20 minute intervals from 1:00 p.m. to 7:00 p.m., June 27 and 28, 1952, and the wind direction and velocity at 5:00 p.m. on these days, are shown in Table XII. Maximum roofing temperatures for these days are included and the data clearly demonstrates the lower solar radiation absorptivity characteristics of the aluminum roofing. All data is taken from roofing sheets on the south slope of the roof of the open front dairy cattle experimental shelter.

Heat flow through the metal roofing was not measured nor were air temperatures immediately below the roofing materials. Temperatures of the indoor air were taken at a level approximately 3 feet above the floor. This air temperature seldom exceeded the outdoor air temperature by more than one or two degrees. Indoor air temperatures at this level would therefore be of little aid in determining the heat gain through the roof of the structure. The radiation effect of the roofing however is often greater, in this type shelter, than the convective heat gain from the roof to indoor air. This radiation is dependent upon the temperature and emissivity of the lower surface of the roof only. For this reason, the surface temperature data could be used in comfort studies in livestock shelters of the type commonly used in Oklahoma.

The instantaneous intensities of solar and sky radiation, I_t, were computed for the south slope of the roof by the expression:

$$I_t = I_n (- \sin \theta \cos \beta \cos \alpha + \cos \theta \sin \beta) + 0.85 I_{sh}$$

where:

I_t = Total solar and sky radiation intensity on the roof surface, btu per hour per square foot.

I_n = Solar radiation intensity at normal incidence, btu per hour per square foot.

β = Altitude angle on the sun.

α = Azimuth angle of the sun.

θ = Slope angle of the roof, measured from the horizontal. (θ = 26° 34' for open front shelter)

I_{sh} = Sky radiation intensity on a horizontal surface, btu per hour per square foot.

Using the data in Table XIII, sun altitude and azimuth angles, and Table VI, solar radiation data, the values for I_t were computed. Values for b/f_o for weathered aluminum and galvanized steel, previously discussed, were obtained from the graph in Fig. 23. Using these data and the outdoor air temperatures, Table XII, the sol-air temperatures of the metal roofing were computed. These computed values were then plotted against actual roofing temperatures, Fig. 30, to show the

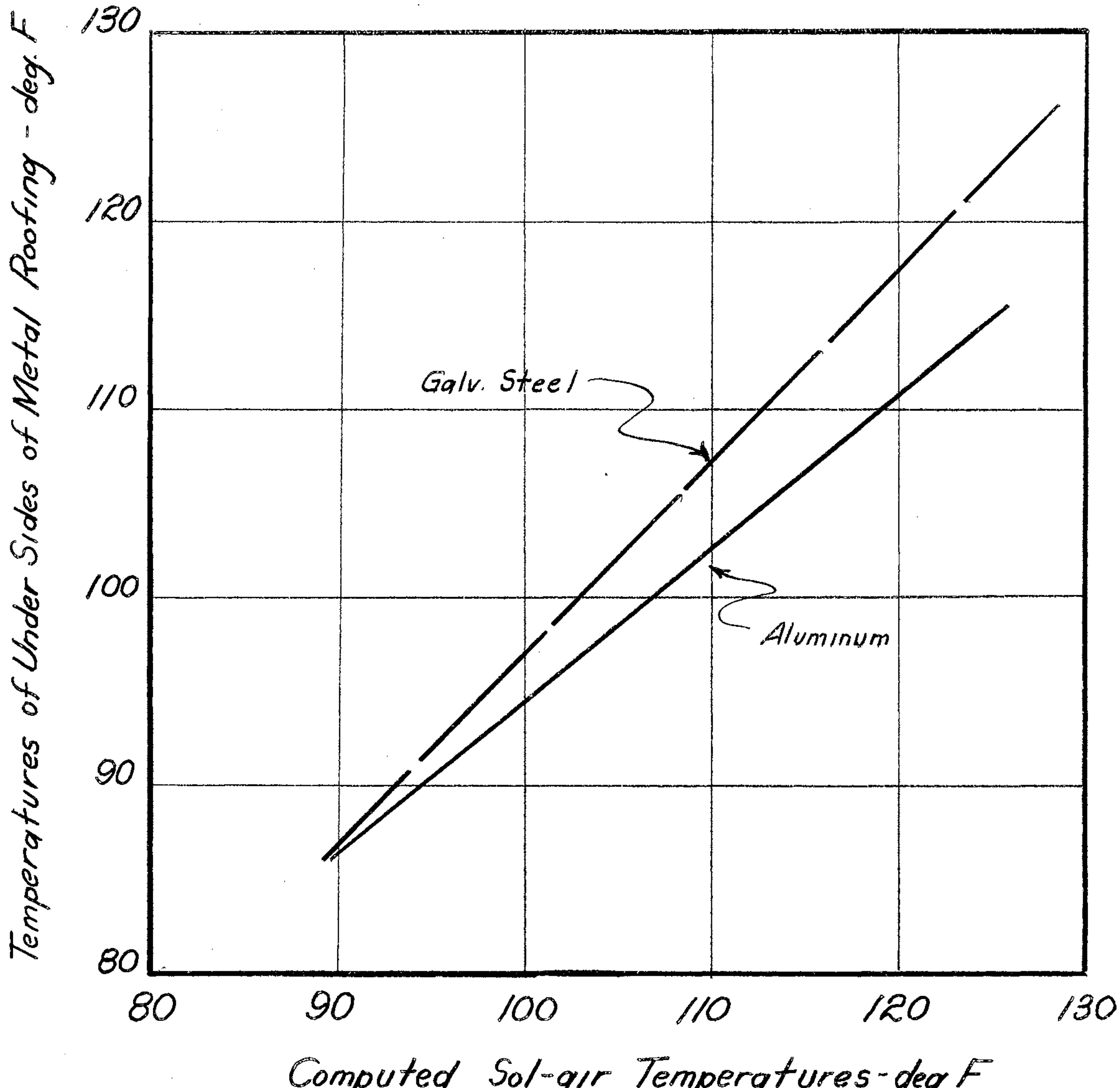

Fig. 30 - Comparison of Sol-air Temperatures and Actual Temperatures of Metal Roofs on Open Front Dairy Cattle Shelter.

characteristics of the sol-air temperatures vs. actual temperatures.

The graph of t_e vs. actual roofing temperatures obtained is for an open front shelter only and would not apply to a completely enclosed shelter.

VI. SUMMARY AND CONCLUSIONS

1. By painting the outer surface of a masonry structure white, the amount of solar radiation absorbed by the walls and transmitted to the interior of the structure can be reduced. This reduction was about 48% for concrete block with the cores filled and 28% for concrete block with the cores empty. This is accomplished by reducing the "b" or solar radiation absorptivity coefficient. If "b" is reduced, U_e, the effective overall coefficient of heat transfer is also reduced. Since most structures constructed of lightweight aggregate concrete block must have the outer surfaces painted to make them weather-tight, using white paint for this operation would increase the costs little if any and would reduce the time cooling would be needed.

2. An effective overall heat transmission coefficient for summertime periodic heat flow through walls exposed to solar radiation could be used as a quick, simple method for estimating heat gain through building walls. The graph of the "effective" overall heat transmission coefficient, $U_e = (q/A)_i / (t_e^* - t_i)$, shows that U_e varied with time in a consistent manner for all 12 concrete masonry panels in the west-facing wall of the temperature controlled shelter. Each curve was drawn from data obtained on a single, representative day. By increasing the number of days of obser-

vations, the values for U_e would probably be more representative of summer heat gain characteristics. The effect of solar radiation on west-facing walls during the early afternoon hours, 1:00 to 5:00 p.m., would be very small due to time lag of the masonry construction. Additional study would be needed to establish a pattern of U_e for these hours.

3. The sol-air thermometer was a very helpful tool in heat gain studies. It could be used to obtain the values of t_e direct for any material at any orientation or in any position. It is not limited to construction materials only but would be most helpful in determining the effect of heat gain of livestock due to the absorptivity of solar radiation of different colors of animal hides. The sol-air thermometer is new and there are many ways in which it can be improved. Materials other than cork may be more economical for construction. Cork, however, was used in this study since it was easy to shape and formed a structure for mounting the panels. A simplified method of mounting samples could eliminate the use of detachable panels and would eliminate the problem of air circulating around and under the panel. Strips of foil were cemented in place to seal the panels in these studies. Thermocouple junctions mounted in the air spaces between the foil layers of the panel and in the cork block could be used to determine heat flow to the interior of the sol-air thermometer. Construction of samples and mounting thermocouple junctions on or in them should be done

with care to make sure the surface of the sample has the same characteristics as the material being studied. Wind direction and velocity at the time of readings is also of great importance because of the cooling effect on the samples. Studies to determine the effect of wind velocities vs. sol-air temperatures would be most helpful in determining f_o for surfaces of various samples. The size of the samples to use to obtain accurate values for t_e could be investigated. Sol-air temperatures for the galvanized steel roofing samples varied somewhat with sample size. Samples larger than those used would have less edge cooling effect since they would have a greater surface area in proportion to the perimeter. For this reason, circles are the ideal shape. The size used in the studies would probably be the minimum size, studies of samples being restricted to this and larger size samples.

4. The values obtained using the Gier and Dunkle heat meter were very close to computed heat flow and were probably more accurate. For this reason, the heat meter should be very effective for measuring heat flow. Care should be taken in mounting though to obtain intimate contact between the heat meter and the surface through which heat flow is to be measured. By sealing the edges of the meter, possible air flow under the meter can be eliminated. Mounting the heat meter on a handle to measure heat flow at various points in a short time was found to be impractical since readings obtained varied greatly. A recording potentiometer that

would record millivolt flow would also be most helpful since much time was spent calibrating the potentiometer used to find the millivolt equivalent of recorded temperatures.

5. Values for f_o, surface film conductances for outside surfaces in various positions should be more fully investigated. For research work, especially in the case of sol-air temperature studies where the film resistance is the only insulation between the sample and the outside air, these studies would be most helpful. This film coefficient is also very important in farm buildings where the surface film resistance of metal roofs and walls is a large portion of the thermal resistance of the structures.

6. The advantage of the reflective value of aluminum roofing in reducing roofing temperatures is very apparent. However, the magnitude of radiant heat exchange between the roof covering and livestock in an open shelter, as are used in Oklahoma, is not known. In most Oklahoma livestock shelters, adequate ventilation keeps indoor air temperatures approximately the same as outdoor air temperatures. Therefore, the effect of reduction of roofing temperatures on the comfort of the livestock can not be evaluated at the present. Studies to evaluate the factors which control radiant heat exchange between livestock and roof coverings would be most important.

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APPENDIX

TABLE I

WEIGHTS AND CORE VOLUMES FOR MASONRY UNITS
IN WALLS OF TEMPERATURE CONTROLLED SHELTER

Kind of Concrete In Unit	Specimen Number	Kind of Core Filling	Weight of Unit, Lb.		Weight of Core Filling, Lb.	Core* Volume Cu. Ft.
			Cores Empty	Cores Filled		
Sand and Gravel	1	Pumice Aggr.	42.5	49.1	6.6	0.167
	2		42.4	48.5	6.1	0.154
	3		42.5	49.6	7.1	0.180
	Av. of 1, 2, 3		42.8	49.1	6.6	1.167
Pumice	1	Pumice Aggr.	24.6	33.0	8.4	0.213
	2		22.6	31.3	8.7	0.220
	3		26.1	34.8	8.7	0.220
	Av. of 1, 2, 3		24.4	33.0	8.6	0.218
Expanded Shale	1	Expanded Shale Aggr.	26.1	38.2	12.1	0.202
	2		27.5	39.3	11.8	0.198
	3		25.6	38.3	12.7	0.212
	Av. of 1, 2, 3		26.4	38.6	12.2	0.204

* Core volumes were computed from the weight of the core filling and a bulk density of 59.8 lb. per cu. ft. for expanded shale aggregate and 39.5 lb. per cu. ft. for pumice aggregate.

TABLE II

SOL-AIR TEMPERATURES, DEGREES F, OF SAMPLES OF MATERIALS, STILLWATER, OKLAHOMA, 1952

TIME CST	Expanded Shale, Painted 8-20	Expanded Shale, Unpainted 8-24	Sand & Gravel, Unpainted 8-25	Sand & Gravel, Painted 8-28	Pumice, Painted 9-2	Pumice, Unpainted 9-3	Galvanized Steel, Single 9-5	Aluminum, Single 9-12	Silicon Painted Steel, Single 9-15	Galvanized Steel, Three 9-29	Aluminum, Three 9-30
1:00 PM						105.8	112.8	120.5	117.0		
1:20					86.2	104.0	113.9	122.2	107.5	117.0	104.8
1:40				100.8	89.2	104.6	113.4	106.8	114.4	119.0	113.5
2:00	108.0		102.0	103.5	88.5	106.2	113.3	104.2	114.6	127.8	110.2
2:20	108.5	101.0	104.2	103.8	86.6	104.2	111.6	107.9	118.6	112.5	105.0
2:40	107.5	101.0	104.0	103.4	86.5	106.4	110.7	105.1	116.4	115.3	114.3
3:00	107.2	99.4	105.0	103.8	86.7	104.1	108.9	104.4	109.0	112.8	106.2
3:20	106.0	98.6	103.1	100.6	88.2	102.2	104.6	103.7	109.0	114.0	106.5
3:40	105.0	98.8	102.0	99.6	86.3	99.9	105.7	103.8	111.4	107.8	107.0
4:00	104.1	97.5	100.4	98.8	83.7	98.7	104.0	102.2	106.4	103.8	99.0

TABLE II (Continued)

4:20	103.2	96.7	99.0	95.8	84.0	97.3	100.8	97.7	96.5	106.4	97.4
4:40	101.8	94.2	98.3	95.0	82.4	95.5	99.0	97.3	97.3	97.7	93.0
5:00	101.0	92.3	96.7	94.0	81.5	93.4	96.0	95.6	95.4	95.5	89.7
5:20	99.4	90.2	95.0	93.0	80.0	91.0	94.6	93.3		91.7	85.7
5:40	98.5	87.8	93.1	87.5						87.0	82.5
6:00	96.7	85.6	87.5							83.0	
6:20	94.5	84.0									
6:40	92.6	82.1									
7:00	91.0	80.2									

TABLE III

WIND DIRECTION AND VELOCITY, MPH, EXPERIMENTAL PASTURE
STILLWATER, OKLAHOMA, 1952

TIME	8-20 S	8-24 E	8-25 SE	8-28 S	9-2 NW	9-3 S	9-5 S	9-12 S	9-15 NE	9-29 S	9-30 S
1:00 PM						7.2	10.2	3.4	3.4		
1:20					3.8	6.3	5.1	5.6	5.3	6.1	8.6
1:40				6.3	6.7	4.4	6.2	5.7	7.7	2.6	2.6
2:00			10.8	3.6	5.8	4.1	7.2	6.4	4.5	0.0	3.0
2:20	9.8	5.2	5.7	4.9	5.4	5.4	7.5	8.4	1.9	5.7	6.0
2:40	9.8	6.8	5.7	5.3	8.0	9.1	6.8	6.4	5.0	4.5	0.0
3:00	9.3	5.7	5.5	1.3	2.8	7.9	6.8	6.8	4.4	7.0	5.4
3:20	8.9	5.1	6.5	3.6	3.0	6.3	10.6	4.1	3.4	2.3	3.5
3:40	11.4	3.3	6.5	4.7	7.6	7.7	7.6	6.2	3.4	3.4	1.3
4:00	10.8	6.1	5.7	4.8	4.8	4.9	8.5	7.0	5.5	4.5	3.4
4:20	9.1	5.1	7.4	6.7	8.7	8.9	8.8	8.6	2.2	5.0	4.9
4:40	8.5	5.7	5.9	4.0	4.0	9.9	6.0	6.6	3.9	5.7	2.5
5:00	10.4	6.3	6.0	5.1	4.8	7.3	8.3	6.4	2.7	2.8	2.5
5:20	10.3	5.4	5.7	6.0	6.1	6.6		7.7		3.0	1.8
5:40	9.7	7.7	7.1	5.3						1.7	2.3
6:00	5.1	6.6	4.3	5.9						1.9	1.9
6:20	6.6	6.7									
6:40	5.7	4.3									
7:00	5.7	2.9									
Average	8.7	5.5	6.3	5.2	5.5	6.8	7.6	6.4	4.1	4.0	3.5

TABLE IV

OUTDOOR DRY-BULB TEMPERATURES, DEGREES F, EXPERIMENTAL PASTURE, STILLWATER, OKLAHOMA, 1952

TIME	8-20	8-24	8-25	8-28	9-2	9-3	9-5	9-12	9-15	9-29	9-30
1:00 PM	98.0	83.0	86.0	88.0	76.0	86.0	90.0	89.0	88.0	91.0	91.0
1:20	98.0	83.5	88.0	88.4	77.0	86.0	90.0	90.0	89.0	91.5	91.0
1:40	98.5	84.0	88.5	88.8	78.0	87.0	90.5	90.0	89.0	92.0	91.5
2:00	98.5	84.5	89.0	90.0	78.5	88.0	91.0	91.0	90.0	93.0	92.0
2:20	98.5	85.0	89.0	90.0	79.0	88.0	91.0	90.5	90.0	92.0	91.5
2:40	98.5	85.3	89.5	91.0	79.5	88.0	91.0	90.5	90.0	91.0	91.0
3:00	99.0	85.5	90.0	92.0	79.0	88.0	91.0	90.0	90.0	92.0	91.0
3:20	98.5	85.5	90.0	92.0	78.5	88.5	91.0	90.0	90.0	92.0	91.0
3:40	98.5	85.5	90.5	92.0	79.0	89.0	91.0	90.0	90.0	91.0	91.0
4:00	98.0	85.5	91.0	92.0	80.0	89.0	91.0	89.5	91.0	90.0	90.0
4:20	97.6	85.5	91.5	92.0	80.0	88.5	91.0	89.5	89.0	90.0	89.5
4:40	97.3	85.0	92.0	91.5	80.0	88.5	90.5	89.0	89.0	88.5	89.0
5:00	97.0	85.0	92.0	91.0	80.0	88.0	90.0	89.0	88.5	88.0	88.0
5:20	96.5	84.5	91.5	91.0	80.0	88.0	89.5	88.0	88.5	86.0	86.0
5:40	96.0	84.0	91.0	90.5	79.5	87.5	89.0	86.0	89.0	84.0	83.0
6:00	95.5	83.0	91.0	90.0	79.5	87.0	88.5	84.0	88.0	82.0	81.0
6:20	94.2	82.0	90.0	88.0	79.0	84.0	86.5	82.0	84.0	81.0	80.0
6:40	93.0	81.0	88.0	86.0	78.5	82.0	84.0	81.0	82.0	80.0	79.0
7:00	92.0	80.0	87.0	84.0	78.0	80.0	83.0	80.0	81.0	78.0	78.0

TABLE V

ALTITUDE, B, OF THE SUN AND ANGLE OF INCIDENCE, θ, IN DEGREES ON WEST FACING WALLS, STILLWATER, OKLAHOMA, 1952

TIME	Aug. 20		Aug. 24		Aug. 25		Aug. 28		Aug. 29		Aug. 30	
CST	B	θ	B	θ	B	θ	B	θ	B	θ	B	θ
1:00 PM	64.5	82.0	63.5	82.0	63.0	82.0	62.0	82.0	61.5	82.0	61.5	82.0
1:20	62.5	77.0	62.0	77.0	61.5	77.0	60.5	77.0	60.0	77.0	59.5	77.0
1:40	61.0	72.5	59.5	72.5	59.0	72.5	58.0	72.0	58.0	72.0	58.0	72.0
2:00	58.0	67.5	57.0	67.0	57.0	67.0	56.0	67.0	55.5	67.0	55.0	67.0
2:20	54.5	62.5	53.5	62.5	53.5	62.5	53.0	62.0	52.5	62.0	52.0	62.0
2:40	51.5	57.5	50.5	57.5	50.5	57.5	49.5	57.0	49.0	57.0	48.5	57.0
3:00	47.5	52.5	47.0	52.5	47.0	52.5	46.0	52.0	45.5	52.0	45.5	52.0
3:20	44.0	48.0	43.0	47.5	43.0	47.5	42.0	47.0	42.0	47.0	42.0	47.0
3:40	40.5	43.0	39.5	43.0	39.5	43.0	38.5	42.5	38.0	42.5	38.0	42.5
4:00	37.0	38.5	36.0	38.0	36.0	38.0	35.0	37.5	34.5	37.5	34.0	37.5
4:20	32.5	34.0	32.0	33.5	32.0	33.5	31.0	33.0	31.0	33.0	31.0	33.0
4:40	28.0	29.0	27.5	28.5	27.5	28.5	27.0	28.0	27.0	28.0	27.0	28.0
5:00	24.0	24.0	24.0	24.0	23.5	24.0	22.5	23.0	22.0	23.0	22.0	23.0
5:20	21.0	21.0	20.0	20.0	20.0	20.0	19.0	19.0	18.5	19.0	18.0	19.0
5:40	17.0	17.0	15.5	15.5	15.5	15.0	14.5	14.5	14.0	14.0	14.0	14.0
6:00	12.0	13.0	11.5	12.0	11.5	11.5	10.5	11.0	10.0	10.5	10.0	10.0
6:20	8.0	12.0	7.5	10.0	7.5	9.5	7.0	9.0	6.5	8.0	6.5	7.0
6:40	3.0	12.0	3.0	10.5	3.0	10.5	2.0	9.5	2.0	8.5	2.0	7.5
7:00	1.0	13.0	0.0	0.0								

TABLE V (Continued)

TIME CST	Sept. 2 B	Sept. 2 θ	Sept. 3 B	Sept. 3 θ	Sept. 5 B	Sept. 5 θ	Sept. 12 B	Sept. 12 θ	Sept. 15 B	Sept. 15 θ	Sept. 23 B	Sept. 23 θ
1:00 PM	60.5	82.0	60.0	82.0	58.5	82.0	57.0	81.5	56.0	81.5	52.0	80.0
1:20	58.5	77.0	58.5	77.0	57.5	77.0	55.5	76.0	53.5	76.0	50.0	75.0
1:40	57.0	72.0	56.5	72.0	56.0	72.0	53.0	71.0	52.0	71.0	48.0	70.0
2:00	54.0	67.0	53.5	67.0	53.0	67.0	51.0	66.0	49.5	66.0	46.5	65.0
2:20	51.0	62.0	51.0	62.0	50.5	62.0	48.0	61.0	47.0	61.0	43.0	60.0
2:40	48.0	57.0	48.0	57.0	47.5	57.0	45.0	56.0	43.5	56.0	40.0	55.0
3:00	44.5	52.0	44.5	52.0	44.0	52.0	41.5	51.0	41.0	51.0	37.0	50.0
3:20	41.0	47.0	41.0	47.0	40.5	47.0	38.0	46.0	37.0	45.5	33.5	45.0
3:40	37.0	42.0	37.0	42.0	37.0	42.0	34.0	40.5	33.0	40.5	30.0	40.0
4:00	33.0	37.0	33.0	37.0	33.0	37.0	31.0	36.0	29.5	36.0	26.5	35.0
4:20	30.0	32.5	29.5	32.5	29.0	32.5	27.0	31.0	26.0	31.0	22.5	30.0
4:40	26.0	28.0	26.0	28.0	25.5	27.5	23.0	26.0	22.0	26.0	19.0	25.0
5:00	22.0	22.0	22.0	23.0	21.5	23.0	18.5	21.5	18.0	21.0	15.0	20.0
5:20	18.0	18.5	18.0	18.5	17.5	18.0	15.0	16.5	14.0	16.0	11.5	15.0
5:40	13.5	13.5	13.5	13.5	12.5	12.5	11.0	11.5	10.0	11.0	7.0	10.0
6:00	9.0	9.5	9.0	9.5	8.5	8.5	7.0	7.0	6.0	6.0	3.0	5.0
6:20	6.0	7.0	6.0	7.0	5.0	6.5	2.0	3.5	1.0	2.5	0.0	0.0
6:40	1.5	7.5	1.5	7.5	1.0	7.0						

TABLE V (Continued)

TIME CST	Sept. 24 B	Sept. 24 θ	Sept. 25 B	Sept. 25 θ	Sept. 26 B	Sept. 26 θ	Sept. 29 B	Sept. 29 θ	Sept. 30 B	Sept. 30 θ
1:00 PM	52.0	80.0	51.5	80.0	51.0	80.0	49.0	80.0	48.5	80.0
1:20	50.0	75.0	49.5	75.0	49.0	75.0	48.0	75.0	47.5	75.0
1:40	48.0	70.0	47.5	70.0	47.5	70.0	46.5	70.0	46.0	70.0
2:00	46.0	65.0	45.5	65.0	45.0	65.0	43.5	65.0	43.0	65.0
2:20	43.0	60.0	42.5	60.0	42.5	60.0	41.5	60.0	41.0	60.0
2:40	40.0	55.0	39.5	55.0	39.5	55.0	38.5	55.0	38.0	55.0
3:00	37.0	50.0	36.5	50.0	36.5	50.0	35.5	50.0	35.0	50.0
3:20	33.5	45.0	33.0	45.0	33.0	45.0	32.0	45.0	31.5	45.0
3:40	30.0	40.0	29.5	40.0	29.5	40.0	28.5	40.0	28.0	40.0
4:00	26.5	35.0	26.0	35.0	26.0	35.0	25.0	35.0	24.5	35.0
4:20	22.5	30.0	22.0	30.0	22.0	30.0	21.0	30.0	21.0	30.0
4:40	19.0	25.0	18.5	25.0	18.0	25.0	17.0	25.0	17.0	25.0
5:00	14.5	20.0	14.0	20.0	13.5	20.0	12.5	20.0	12.5	20.0
5:20	11.0	15.0	10.5	15.0	10.5	15.0	9.0	15.5	8.5	15.5
5:40	7.0	10.0	7.0	10.0	7.0	10.0	6.0	10.5	6.0	10.5
6:00	3.0	5.0	2.5	5.0	2.0	5.0	1.5	6.5	1.5	6.5

TABLE VI

DIRECT SOLAR RADIATION INTENSITY, I_n, AT NORMAL INCIDENCE AND SKY RADIATION, I_{sh}, ON A HORIZONTAL SURFACE, STILLWATER, OKLAHOMA, 1952

TIME	June 27		June 28		Aug. 20		Aug. 24		Aug. 25	
CST	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}
1:00 PM	273.0	45.3	277.0	45.3	263.0	43.7	266.8	44.0	280.3	46.7
1:20	276.0	45.8	280.8	45.8	267.1	44.1	266.0	44.0	280.8	47.1
1:40	276.7	46.1	279.0	46.1	266.0	44.1	266.3	44.4	285.2	47.3
2:00	272.3	45.4	283.0	47.0	272.8	45.5	264.0	44.2	264.0	44.2
2:20	273.0	45.4	260.0	43.3	275.0	46.2	254.7	43.0	266.8	44.7
2:40	269.1	44.8	273.7	45.6	272.0	45.8	258.8	43.6	261.4	44.0
3:00	264.1	44.6	273.2	46.0	273.5	46.2	206.6	34.8	258.0	43.4
3:20	262.0	44.1	252.7	42.5	271.8	45.6	245.7	41.4	252.4	42.5
3:40	260.0	43.8	262.9	44.3	271.0	45.3	247.9	41.4	247.8	41.5
4:00	258.9	43.1	253.2	42.3	262.6	43.2	237.8	39.3	237.8	39.3
4:20	253.4	41.9	245.0	40.6	255.2	44.2	226.9	36.8	226.9	36.8
4:40	240.9	39.6	242.7	39.6	261.0	41.3	217.5	34.4	217.5	34.4
5:00	234.7	37.8	231.1	37.4	252.0	39.0	200.9	31.1	201.0	31.1
5:20	216.9	34.3	216.9	34.3	234.8	35.4	185.0	27.5	185.0	27.5
5:40	206.5	31.6	206.1	31.6	223.9	32.0	168.5	23.6	168.5	23.6
6:00	186.6	27.1	186.6	27.1	208.5	27.4	141.7	18.3	141.7	18.3
6:20	160.4	21.9	160.4	21.9	189.9	22.3	107.0	12.5	107.0	12.5
6:40	129.8	16.2	136.9	17.1	215.0	20.2	103.8	10.1	103.8	10.1
7:00	98.5	11.4	98.5	11.4	138.9	10.8				

TABLE VI (Continued)

TIME CST	Aug. 28		Aug. 29		Aug. 30		Sept. 2		Sept. 3	
	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}	I_n	I_{sh}
1:00 PM	260.8	43.2	257.0	42.9	233.8	37.8	282.1	46.8	267.2	44.8
1:20	260.2	43.3	258.9	42.9	259.5	41.4	282.0	47.3	266.5	44.7
1:40	264.9	44.2	260.0	42.9	202.5	33.9	279.1	46.8	265.0	44.5
2:00	259.9	43.7	223.2	37.3	269.0	45.2	276.2	46.3	266.8	44.6
2:20	256.0	43.0	230.2	38.6	245.0	41.3	276.1	46.4	262.1	44.2
2:40	259.0	43.3	237.2	37.8	243.0	41.3	275.2	46.3	257.0	43.3
3:00	251.7	42.4	220.7	37.2	238.2	40.1	270.0	45.3	257.1	43.2
3:20	253.6	42.6	211.1	35.6	228.1	39.8	263.2	44.1	254.7	43.1
3:40	249.8	41.4	246.1	40.7	223.2	37.2	268.1	44.2	253.9	41.8
4:00	243.0	39.9	127.5	20.8	211.0	34.6	267.6	42.8	245.1	40.0
4:20	239.0	38.5	122.8	19.8	197.5	31.0	247.6	40.0	233.2	37.7
4:40	235.0	37.1	130.2	20.6	188.0	29.7	241.8	37.9	223.0	35.1
5:00	222.8	34.2	148.0	23.0	163.6	25.8	208.2	33.3	209.8	32.1
5:20	206.0	30.2	88.0	12.1	141.4	20.5	197.9	27.4	199.8	29.0
5:40	171.1	23.6	140.1	19.3	170.2	17.5	180.2	24.4	192.7	26.0
6:00	29.1	3.6	89.0	11.0	91.9	10.5	148.8	17.7	165.0	19.7
6:20	38.5	4.3	33.6	3.9	49.6	3.3	81.0	9.2	101.0	11.5
6:40							69.2	5.9	100.0	8.5

TABLE VI (Continued)

TIME CST	Sept. 5 I_n	Sept. 5 I_{sh}	Sept. 12 I_n	Sept. 12 I_{sh}	Sept. 15 I_n	Sept. 15 I_{sh}	Sept. 23 I_n	Sept. 23 I_{sh}	Sept. 24 I_n	Sept. 24 I_{sh}
1:00 PM	270.9	45.4	257.0	43.2	259.9	43.5	272.9	46.0	268.0	45.3
1:20	269.6	44.9	254.1	42.5	257.0	43.2	279.5	47.0	269.8	45.4
1:40	266.3	44.6	256.0	43.1	259.1	43.6	281.2	47.5	272.2	45.7
2:00	266.6	44.8	254.8	43.0	264.9	44.4	269.8	45.5	269.1	45.3
2:20	262.8	44.3	252.1	42.5	263.2	44.3	270.5	45.6	267.9	45.2
2:40	261.3	44.2	252.7	42.4	265.0	43.3	267.3	44.8	273.0	45.6
3:00	256.1	43.1	252.8	42.3	241.9	40.5	265.3	43.7	262.2	43.2
3:20	252.1	42.3	249.0	41.3	236.5	39.0	259.8	42.4	260.2	42.4
3:40	249.3	41.1	245.0	40.0	243.7	39.8	254.2	41.0	261.0	42.0
4:00	239.0	38.9	232.5	37.5	240.8	38.6	241.8	38.2	246.8	40.3
4:20	226.2	36.3	220.2	34.9	149.1	23.3	226.8	34.8	239.2	36.7
4:40	210.9	33.1	212.0	32.5	191.6	30.0	215.2	31.6	224.3	33.0
5:00	196.4	29.8	191.1	27.8	187.0	27.6	184.0	25.3	205.8	28.2
5:20	169.6	24.4	159.5	23.1	164.0	22.3	135.2	17.4	180.5	23.0
5:40	152.6	20.2	134.1	18.8	171.3	21.1	102.5	11.8	141.0	18.2
6:00	108.1	12.8	95.9	10.4	110.5	10.5	59.6	5.8	103.9	10.1
6:20	56.3	6.2	71.4	6.4	88.9	7.1				

TABLE VI (Continued)

TIME CST	Sept. 25 I_n	Sept. 25 I_{sh}	Sept. 26 I_n	Sept. 26 I_{sh}	Sept. 29 I_n	Sept. 29 I_{sh}	Sept. 30 I_n	Sept. 30 I_{sh}
1:00 PM	265.0	44.6	263.0	44.5	264.0	44.4	260.7	43.9
1:20	262.2	43.9	267.0	45.2	264.6	44.5	260.0	43.9
1:40	268.5	45.2	263.7	44.5	263.9	44.5	257.0	43.3
2:00	268.9	45.2	265.2	44.6	263.7	44.4	265.3	44.7
2:20	272.6	45.7	259.3	43.6	258.7	43.3	231.0	38.7
2:40	272.0	43.8	263.0	42.8	265.2	43.8	240.8	39.8
3:00	265.2	43.2	262.0	43.2	249.1	41.0	246.2	40.3
3:20	271.1	42.4	257.9	41.8	243.0	39.3	242.2	39.2
3:40	258.8	40.7	254.2	40.7	231.1	37.7	236.0	37.5
4:00	250.7	38.5	245.3	38.5	219.1	34.7	217.2	33.8
4:20	246.8	35.8	234.9	35.8	205.4	30.8	200.0	30.2
4:40	232.0	32.6	222.0	33.1	198.9	28.3	193.4	27.7
5:00	217.2	27.1	203.8	27.7	171.7	22.7	139.9	18.5
5:20	173.0	22.2	180.2	22.6	128.3	15.4	149.3	17.7
5:40	131.2	17.2	147.6	17.4	61.9	9.2	85.5	9.5
6:00	116.3	10.5	94.2	14.4	57.6	5.1	57.6	5.1

TABLE VII

RADIATION ABSORPTIVITY COEFFICIENT, "b", OF VARIOUS SURFACES

Type of Surface	"b"
Sand and gravel aggregate concrete, natural finish.	0.43
Sand and gravel aggregate concrete, painted white.	0.25
Pumice aggregate concrete, natural finish.	0.44
Pumice aggregate concrete, painted white.	0.28
Expanded shale aggregate concrete, natural finish.	0.43
Expanded shale aggregate concrete, painted white.	0.29
Aluminum roofing, weathered.	0.38
Galvanized steel roofing, weathered.	0.45
Silicon enameled steel roofing, new.	0.31

TABLE VIII

TEMPERATURES OF INSIDE SURFACES, T_{si}, AND OUTSIDE SURFACES, T_{so}, OF WEST WALL PANELS, EXPERIMENTAL BARN, STILLWATER, OKLAHOMA, JULY 27, 1951

TIME	1W		2W		3W		4W		5W		6W	
CST	T_{so}	T_{si}	T_{so}	T_{si}	T_{so}	T_{si}	T_{so}	T_{si}	T_{so}	T_{si}	T_{so}	T_{si}
1:00 PM	96	81	92	83	95	84	92	79	89	81	92	81
2:00	104	83	100	85	108	86	108	81	100	82	106	83
3:00	124	86	113	88	122	90	124	85	112	85	121	85
4:00	131	87	120	92	129	92	132	86	119	88	128	86
5:00	138	88	126	95	134	94	133	87	126	91	134	86
6:00	137	90	126	97	131	95	133	87	126	94	135	87
7:00	128	91	121	99	122	95	125	89	119	95	119	88
8:00	104	92	105	98	98	93	104	89	104	96	99	88
9:00	95	92	97	95	90	90	93	89	96	94	92	87
10:00	90	91	92	92	86	87	88	88	92	92	88	87
11:00	87	90	88	90	83	86	85	88	89	91	85	86
12:00	84	88	85	88	81	84	82	86	85	89	83	86

Note: See Fig. 3 for panel designations.

TABLE VIII (Continued)

TIME CST	7W T_{so}	7W T_{si}	8W T_{so}	8W T_{si}	9W T_{so}	9W T_{si}	10W T_{so}	10W T_{si}	11W T_{so}	11W T_{si}	12W T_{so}	12W T_{si}
1:00 PM	91	82	89	81	91	80	95	81	87	81	91	80
2:00	98	84	94	83	94	82	100	82	96	82	96	82
3:00	104	88	98	86	102	85	106	84	99	85	106	84
4:00	107	89	101	88	106	86	110	85	102	86	110	85
5:00	110	89	102	90	108	86	112	86	105	88	113	86
6:00	108	90	103	91	108	86	111	87	106	89	112	87
7:00	101	89	100	91	102	86	103	87	102	90	105	88
8:00	90	88	93	90	92	86	93	87	96	91	96	88
9:00	86	86	89	88	88	86	88	86	92	89	88	87
10:00	83	84	86	86	85	85	86	85	88	88	85	86
11:00	81	84	84	85	83	85	83	85	86	87	83	86
12:00	80	83	82	84	81	84	81	84	84	86	81	85

TABLE IX

RATE OF HEAT FLOW, H, BTU PER HOUR PER SQUARE FOOT, AND METER TEMPERATURES, DEGREES F, FOR WEST WALL PANELS, STILLWATER, OKLAHOMA, 1952

TIME	Sept. 25		Sept. 24		Sept. 2		Sept. 26		Sept. 23		Sept. 5	
	1W		2W		3W		4W		5W		6W	
CST	H	Tm	H	Tm	H	Tm	H	Tm	H	Tm	H	Tm
1:00 PM	-2.53	66	-2.71	63	-2.87	67	-1.86	67			-0.17	72
1:30	-2.03	66	-1.69	64	-2.20	68	-1.18	68			1.86	72
2:00	-1.52	67	-0.17	66	-1.18	69	-0.85	69			2.20	72
2:30	-1.18	68	1.18	68	0.0	70	-0.17	70			0.0	73
3:00	0.17	69	3.89	70	1.18	72	0.68	71			3.04	73
3:30	1.52	70	6.42	72	3.38	74	1.69	72			4.23	73
4:00	2.53	71	8.62	74	5.58	75	3.89	73	2.53	68	5.75	73
4:30	3.21	72	10.82	76	7.78	76	4.90	74	5.24	70	3.55	75
5:00	4.56	74	13.53	78	9.64	76	5.58	76	6.93	71	4.23	76
5:30	5.92	75	15.54	80	10.65	78	6.59	78	8.62	73	4.90	76
6:00	6.93	76	17.07	81	11.67	79	7.95	79	10.65	75	5.92	77
6:30	7.78	78	17.68	82	13.02	80	9.13	80	12.51	76	6.59	78
7:00	8.45	78	17.07	82	13.69	80	9.98	81	13.69	76	8.28	79
7:30	9.47	79	16.05	81	14.03	80	10.48	82	14.03	76	7.95	80
8:00	9.80	79	14.71	80	12.34	78	11.16	82	14.20	76	9.64	80
8:30	9.64	79	13.36	78	10.65	77	10.82	81	12.68	75	9.13	80
9:00	8.79	78	11.50	76	9.47	75	10.31	80	11.50	74	9.30	80
9:30	8.45	78	9.80	75	8.28	74	9.80	80	10.31	73	9.30	79
10:00	7.95	77	8.62	74	6.26	72	9.47	79	9.98	72	9.98	78
10:30	7.27	76	6.93	72	4.90	71	8.96	78	8.12	71	8.96	77
11:00	6.59	75	5.75	70	3.55	70	7.61	77	7.24	70	8.79	76

Note: See Fig. 3 for panel designations.

TABLE IX (Continued)

TIME CST	Aug. 20 7W H	Aug. 20 7W Tm	Sept. 12 8W H	Sept. 12 8W Tm	Aug. 30 9W H	Aug. 30 9W Tm	Sept. 15 10W H	Sept. 15 10W Tm	Aug. 28 11W H	Aug. 28 11W Tm	Aug. 29 12W H	Aug. 29 12W Tm
1:00 PM	2.87	78	1.86	75	0.0	74	-0.17	70	-1.35	74	0.51	73
1:30	3.21	79	0.0	76	0.17	75	-4.23	72	-1.01	75	0.68	74
2:00	3.55	80	3.72	76	1.18	75	-1.52	73	-0.51	75	0.85	74
2:30	4.39	81	-3.55	77	0.68	76	1.52	73	0.68	76	2.20	74
3:00	5.58	82	-5.07	78	2.36	76	4.39	72	1.52	77	2.20	75
3:30	6.76	82	-1.18	78	2.20	77	4.90	72	3.04	77	2.53	75
4:00	7.61	83	3.21	78	2.36	77	4.90	73	4.56	78	3.21	76
4:30	8.62	84	3.21	78	3.38	78	3.89	75	5.58	79	5.07	76
5:00	9.64	84	12.51	79	3.89	78	6.26	74	6.93	80	5.24	76
5:30	10.31	85	13.36	79	4.90	78	5.41	76	8.45	80	5.58	76
6:00	11.33	85	14.71	79	5.92	78	5.75	77	9.47	80	5.58	76
6:30	13.36	85	9.98	79	6.76	78	8.45	75	10.48	80	6.26	76
7:00	13.86	85	8.62	80	7.44	78	6.59	77	10.48	80	7.44	76
7:30	14.03	84	9.64	78	7.61	78	6.42	78	10.82	80	7.27	76
8:00	13.36	84	8.28	80	8.12	78	6.26	78	10.65	79	4.90	76
8:30	12.68	83	7.27	78	8.28	77	5.24	78	9.98	78	4.06	76
9:00	10.99	82	6.24	78	7.95	77	4.90	77	6.59	78	3.89	76
9:30	9.98	81	5.58	78	7.44	76	4.90	77	6.26	78	3.72	76
10:00	9.64	80	4.73	78	7.10	76	4.73	76	5.92	78	3.72	76
10:30	9.13	80	4.39	78	4.90	76	4.39	75	4.90	77	3.72	76
11:00	8.28	79	3.72	77	6.08	76	4.56	74	4.73	77	3.89	76

TABLE X

OUTDOOR DRY-BULB TEMPERATURES
DEGREES F, EXPERIMENTAL PASTURE, 1952

CST	8-20	8-28	8-29	8-30	9-2	9-5	9-12	9-15	9-23	9-24	9-25	9-26
1:00 PM	98	88	89	91	77	90	90	88	77	79	85	90
1:30	98	89	90	92	77	91	90	89	78	80	85	90
2:00	98	90	91	93	78	91	91	90	78	81	86	90
2:30	98	91	91	91	79	91	91	90	79	82	84	91
3:00	98	92	91	94	80	91	91	90	78	82	86	91
3:30	98	92	91	94	79	91	90	90	79	81	85	90
4:00	98	92	91	94	80	91	90	91	78	80	86	91
4:30	97	92	91	94	80	91	89	90	77	80	86	90
5:00	97	91	90	94	80	90	89	89	76	79	85	89
5:30	96	91	91	93	80	89	88	89	74	77	82	89
6:00	95	90	89	92	79	88	84	88	72	74	79	85
6:30	93	87	87	90	78	87	82	85	69	72	77	82
7:00	91	85	84	87	75	83	80	80	66	71	74	78
7:30	89	83	82	86	73	79	77	79	65	69	71	77
8:00	88	82	80	85	70	78	76	78	63	67	70	74
8:30	88	81	79	84	69	77	75	77	62	65	69	72
9:00	88	80	79	83	67	76	73	75	62	63	69	71
9:30	88	79	78	83	66	74	74	73	59	62	69	69
10:00	87	78	78	83	65	73	73	72	57	61	68	69
10:30	87	77	77	82	64	72	74	72	59	61	66	69
11:00	86	76	75	82	62	70	73	71	57	60	67	68

TABLE XI

DRY-BULB TEMPERATURES, DEGREES F,
TEMPERATURE-CONTROLLED BARN, 1952

CST	8-20	8-28	8-29	8-30	9-2	9-5	9-12	9-15	9-23	9-24	9-25	9-26
1:00 PM	83	80	78	80	73	79	78	78		70	73	76
1:30	84	80	79	80	74	78	78	78		71	74	76
2:00	84	81	79	79	75	80	77	80		72	75	77
2:30	84	81	79	80	76	78	80	78		72	76	79
3:00	84	82	79	81	75	77	83	76		73	76	79
3:30	85	81	79	81	76	78	85	76		73	76	80
4:00	87	82	79	80	77	77	87	75	74	74	77	80
4:30	86	82	79	82	78	78	86	79	74	74	77	80
5:00	86	82	79	82	76	78	81	76	74	75	78	81
5:30	86	82	78	81	77	78	79	79	74	75	78	81
6:00	86	81	78	80	77	78	78	81	74	75	78	81
6:30	85	80	78	79	77	76	77	76	74	75	78	81
7:00	84	80	77	78	77	77	80	79	73	75	78	81
7:30	84	79	76	77	77	80	76	79	72	75	78	81
8:00	83	78	76	76	75	80	78	78	72	74	78	80
8:30	82	77	78	75	75	79	78	79	72	74	77	79
9:00	82	78	78	75	73	77	78	79	71	73	76	78
9:30	82	78	78	75	69	77	78	79	71	72	76	78
10:00	81	78	78	75	70	76	78	77	70	71	76	77
10:30	81	78	78	77	70	75	76	77	69	71	75	77
11:00	80	78	78	76	70	76	76	75	69	70	75	76

TABLE XII

TEMPERATURES OF ROOFING SHEETS, ALUMINUM, T_{al}, AND GALVANIZED STEEL, T_{gs}, ON OPEN SHELTER, AND AIR TEMPERATURE, T_o, DEGREES F, STILLWATER, OKLAHOMA, 1952

TIME	June 27			June 28		
CST	T_{al}	T_{gs}	T_o	T_{al}	T_{gs}	T_o
1:00 PM	110	125	92.0	112	128	92.5
1:20	111	127	92.0	112	127	93.0
1:40	111	126	93.0	110	125	93.5
2:00	111	124	93.0	110	124	94.0
2:20	111	123	93.0	111	124	94.0
2:40	109	120	93.5	109	121	94.5
3:00	107	118	94.0	107	118	95.0
3:20	106	116	94.0	106	117	95.0
3:40	106	116	94.0	106	115	95.5
4:00	104	112	94.0	105	113	95.0
4:20	103	110	94.0	102	110	94.5
4:40	100	106	94.0	100	107	94.5
5:00	99	104	93.5	98	104	94.0
5:20	97	101	93.0	96	102	94.0
5:40	95	98	92.5	94	98	94.0
6:00	93	96	92.0	93	96	94.0
6:20	91	93	91.5	90	92	93.0
6:40	89	90	91.0	87	89	92.5
7:00	87	87	90.0	86	87	92.0
	Wind, SSW-10-15			Wind, S-5-10		

TABLE XIII

ALTITUDE, B, AND AZIMUTH, α, OF THE SUN IN DEGREES
STILLWATER, OKLAHOMA, 1952

TIME	June 27 & 28	
CST	B	α
1:00 PM	76.0	208
1:20	73.0	224
1:40	69.5	235
2:00	67.0	242
2:20	62.5	249
2:40	58.5	274
3:00	55.0	259
3:20	51.0	262
3:40	47.0	266
4:00	42.5	269
4:20	38.5	272
4:40	34.5	275
5:00	30.5	277
5:20	27.0	280
5:40	22.5	282
6:00	18.5	285
6:20	14.5	288
6:40	10.5	290
7:00	7.5	297

VITA

George William Arthur Mahoney
candidate for the degree of
Master of Science

Thesis: CORRELATION OF SOL-AIR TEMPERATURES AND HEAT FLOW THROUGH FARM BUILDING CONSTRUCTION MATERIALS

Major: Agricultural Engineering

Bibliographical:

Born: The writer was born in Springfield, Illinois, January 23, 1925, the son of Edward J. and Mercedes M. Mahoney.

Undergraduate Study: He attended elementary school in Peoria, Illinois, and graduated from Cathedral Boys High School, Springfield, Illinois. In August, 1949, he received his Bachelor of Science Degree from the University of Illinois with a major in Agricultural Engineering.

Graduate Study: In September, 1949, he entered the Graduate School of the Oklahoma Agricultural and Mechanical College and completed the requirements for a Master of Science Degree in July, 1953.

Experience: The writer entered the United States Army Air Force in May, 1943, and served as a Bombardier-Navigator in the 15th Air Force in Italy. He was Discharged a First Lieutenant in October, 1945, at which time he re-entered school. After graduating from the University of Illinois, he accepted the position of Instructor of Agricultural Engineering, teaching and research in farm structures, at the Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, the position he now holds at the present time.

Organizations: American Society of Agricultural Engineers and Phi Theta Kappa.

Articles Published: "Cattle Handling Made Easy", <u>Progressive Farmer</u>, November, 1952.

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AUTHOR: George W. A. Mahoney

THESIS ADVISER: Gordon L. Nelson

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TYPIST: Jean Hagers