TEMPERATURE AND HEAT-LOSS CHARACTERISTICS OF CONCRETE FLOORS LAID ON THE GROUND

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ABSTRACT

The heat loss, temperature, and moisture-permeation characteristics of nine types of concrete slab floor construction laid on the ground were investigated in a specially built structure. The room air above the floors was maintained at 70 deg. F. by electrical convection heaters, but there were no heating elements placed in the floors. An extensive thermocouple system was installed to measure temperatures throughout the floors and air spaces of each compartment.

The best overall performance was obtained with a floor construction in which a two-inch thickness of rigid waterproof insulation extended six inches down parallel to the exposed edge of the floor and two feet back under the concrete slab. The floor surface temperature six inches from the exposed edge for an outside temperature of zero deg. F. was 62 deg. F. for this insulated floor as compared with 45 deg. F. at the same location on the surface of an uninsulated floor of similar construction. The heat loss through the insulated floor was about 70 per cent of that through the uninsulated floor.

Isotherm patterns drawn for each type of floor construction indicated that beyond a distance of three feet from the exposed edge of the floor, the path of heat flow was essentially straight downward and that the magnitude of heat flow was practically constant. The isotherms for the bordering three feet of the floor section showed the effect of different amounts and placements of insulation. The heat flow was downward through the floor into the ground and then upward to the outside, as well as directly through the exposed edge of the floor to the outside.

Moisture permeation tests were being continued as the data and results obtained to date were not considered conclusive. The data available indicated that a vapor barrier may be more effective in the spring and summer months than in the winter.

CONTENTS

LIST OF FIGURES

I. INTRODUCTION

1. Preliminary Statement. -- The estimation of heat losses through floors vary with the arrangement of the floors which may be classified as: a floor over a basement or heated space, a floor over an unheated space, and a floor laid directly on the ground.

For small homes having a basement in which the heating device is located, the heat loss of the floor has never been a serious problem and in most cases has been neglected in the heat loss calculations because the basement is warmed by radiation and convection from the heating device and distributing ducts or pipes. When the basement is small and has few windows, the temperature under the floor may be above 70 deg. F. and actually warm the floor, resulting in a heat gain to the room above. Such cases account for the satisfactory performance of some heating systems that would not otherwise provide uniform heat in the living space.

When floors are constructed over unheated spaces, the heat loss is large and must be taken into consideration. If the space below is ventilated, the heat loss of the floor is calculated with the assumption that the temperature of the unheated space is the same as the outside design temperature, whereas if the space is not ventilated the temperature of the space is considered as the average of the inside and outside temperatures.

In the case of floors laid directly on the ground little data are available on the heat losses through the floor and the materials suitable for floor construction. Due to the shortage of building materials, high labor costs, and the need for swift house construction, the concrete slab floor on the ground has been widely used as a floor construction for homes. Therefore information on the thermal characteristics of concrete slab floors on the ground should be useful for designers of basementless homes.

Previous work[1] by the National Bureau of Standards has indicated that the heat loss of concrete slab floors on the ground is proportional to the perimeter of the building. Design factors were given for calculating the heat loss of a number of slab floors in which the only variables were the perimeter and design temperature difference. However, as these tests were conducted during a period when the average outside temperature was not below 35 deg. F. for more than three successive days, the need became evident for additional data on the heat loss characteristics of slab floors in a climate where the ground would be frozen for a major part of the heating season.

2. Objects and Scope of Investigation. -- The main objectives of this investigation may be stated as follows:

1. To study the heat loss characteristics of different types of slab floors and to obtain data useful for designers of basementless homes.

2. To determine the temperatures at various points throughout the slab floors and thereby to predict the proper placement of insulation for floors laid on the ground.

[1] See numbered reference in Bibliography

3. To determine the amount of moisture permeating upward from the ground to the upper surface of the concrete.

The general plan for conducting the test was similar to that of the National Bureau of Standards, namely to provide a heavily insulated structure above each floor and to observe the amount of heat in the form of electrical energy necessary to maintain the inside temperature at 70 deg. F. Although the ceiling and walls were heavily insulated some loss through them was inevitable. Suitable corrections were made and the net heat losses of the floors were determined.

3. Acknowledgements. -- This investigation was conducted under a cooperative agreement between the U. S. Department of Commerce, Office of Technical Services, Industrial Research and Development Division, and the Small Homes Council of the University of Illinois. The work was carried on as a project of the Department of Mechanical Engineering.

The investigation was conducted under the general administrative direction of James T. Lendrum, Associate Coordinator of the Small Homes Council, and Seichi Konzo, Professor of Mechanical Engineering, under whose supervision this report was written.

Acknowledgement is made to John J. Adaska Jr. and Charles C. Lehmkuhl, students in the Department of Mechanical Engineering for their services in recording the data.

II. DESCRIPTION OF PLANT

4. General Arrangement. -- In order that slab floors of different construction might be tested simultaneously under similar conditions, a special building 76 feet long and 16 feet wide with the long dimension east and west was constructed as shown in Fig. 1 (a). The interior of the building was divided into a corridor and eleven compartments as shown in Fig. 1 (b). Ten of these compartments, A through K, contained test floors of different construction, and the compartment located on the west end of the building was used as the instrument room. All interior dimensions of the compartments were 5 ft.-8 in. by 11 ft.-8 in. with the exception of compartment A located on the east end which was 11 ft.-4 in. by 11 ft.-8 in. The exposed walls of all compartments faced north except compartment A which had an additional exposure to the east. The northern exposures eliminated any sun effect upon the walls or the edges of the slab floors. Since the width of the average small home is 24 feet, the arrangement of test compartments B through K was equivalent to investigating a section of floor with an exposed edge of 5 ft.-8 in. extending to the center of the home. In order to determine the effect of a comparable floor with two exposed edges as is the case with the corners of a home, compartment A was constructed with a slab of the same type as compartment D.

The corridor was along the south wall of the building and had a door at each end. Access to each compartment was by a door between the corridor and the compartment.

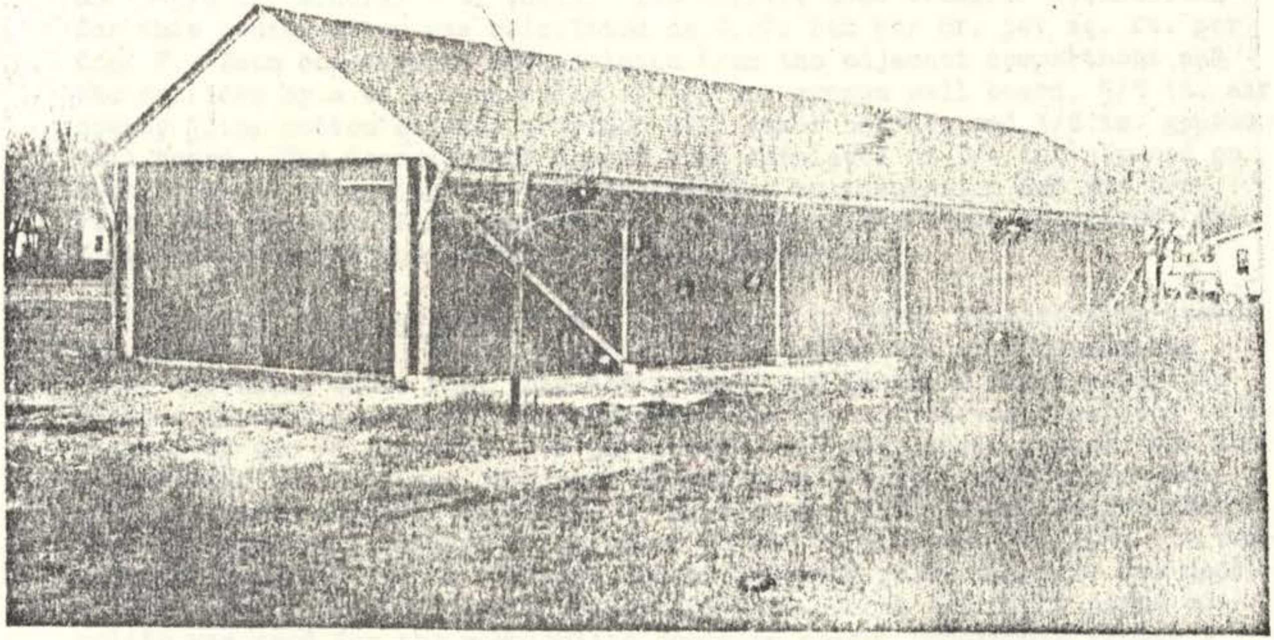

FIG. 1A VIEW OF BUILDING

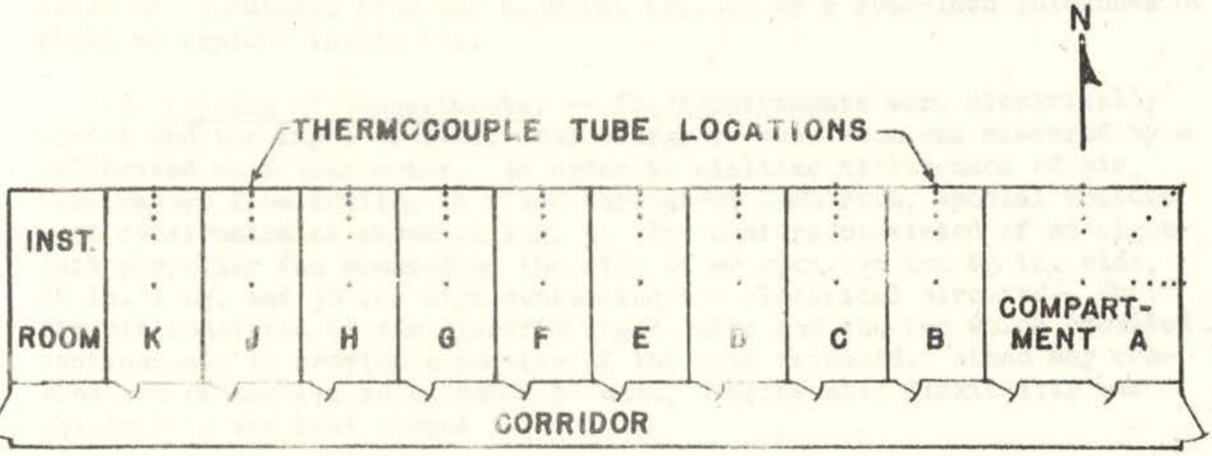

FIG. 1B BUILDING FLOOR PLAN

5. Wall and Ceiling Construction. -- The exterior wall construction of the building consisted of 3/8 in. plywood, 5/8 in. air space, 3 in. cotton blanket provided with vapor barrier, and 3/8 in. gypsum wall board. The overall heat transfer coefficient for this construction was calculated as 0.074 Btu per hr. per sq. ft. per deg. F. The ceiling construction of the building consisted of 3/8 in. gypsum wall board, aluminum vapor barrier, and 3-5/8 in. mineral wool batts. The overall heat transfer coefficient for this construction was calculated as 0.071 Btu per hr. per sq. ft. per deg. F. Each compartment was isolated from the adjacent compartment and the corridor by a wall consisting of 3/8 in. gypsum wall board, 5/8 in. air space, 3 in. cotton blanket provided with vapor barrier, and 3/8 in. gypsum wall board. The door to each compartment consisted of 1/4 in. plywood on both sides of a two-inch cotton blanket used as insulation and was provided with one-inch felt weather-stripping along the edges to prevent infiltration between the corridor and test compartment.

6. Floor Construction. -- The nine types of floor construction tested are shown in Fig. 2. Floors A through H were provided with foundation walls extending three feet into the ground, and floors J and K were laid without foundation walls. The concrete used for the floors consisted of a mixture of one part cement, two parts sand, and four parts gravel; and the mixture for the footings consisted of one part cement, three parts sand, and five parts gravel. Floors A, C, E, G, and J were poured on November 18, 1947 and the remaining floors were poured on November 21, 1947. A vermiculite concrete mix of one part cement and four parts zonolite was used for the top of floor K, and a mix of one part cement and eight parts zonolite was used for the vermiculite concrete placed underneath floors F and H as insulation.

To prevent any heat transfer between adjacent floors, a space 4 inches wide and 12 inches deep filled with mineral wool insulation was provided between each slab. In order to prevent any moisture collecting in this insulation a 50 lb. roofing felt vapor barrier was placed between the ground and the insulation as shown in Fig. 2. The foundation wall of each floor was insulated from the adjacent footing by a four-inch thickness of rigid waterproof insulation.

7. Heating of Compartments. -- The compartments were electrically heated and the input of electrical energy to each room was measured by a calibrated watt-hour meter. In order to minimize differences of air temperature from ceiling to floor throughout each room, special heaters were constructed as shown in Fig. 3. The heaters consisted of an eight-inch propeller fan mounted on the side of an open top box 8½ in. wide, 20 in. long, and 30 in. high containing two electrical circuits. One circuit consisted of six electric light bulbs and the fan which operated continuously to provide a portion of the heat required. Since any combination of the six bulbs could be used, considerable flexibility was obtained in the heat output.

The other circuit consisted of an electric heating mat with a capacity of approximately 500 Btu per hr. controlled by a room thermostat operating a relay. In each compartment the thermostat was placed on the interior wall 24 inches from the exposed wall and 30 inches above the floor. The thermostats were of the low-voltage, heat-anticipating type commonly used for domestic heating devices and were adjusted to maintain a one deg. F. temperature differential.

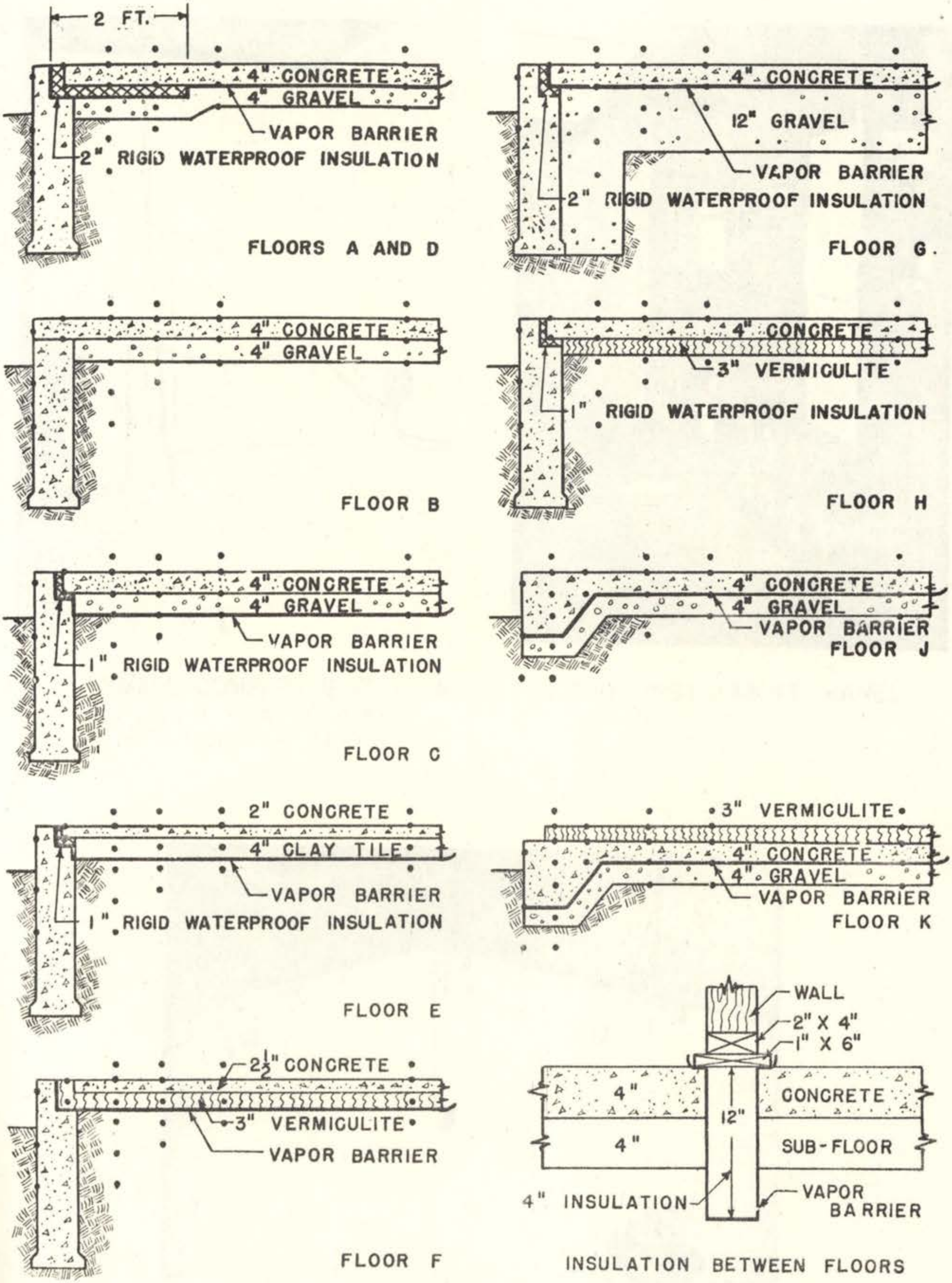

FIG. 2 CROSS-SECTIONAL VIEWS OF ALL FLOORS INVESTIGATED

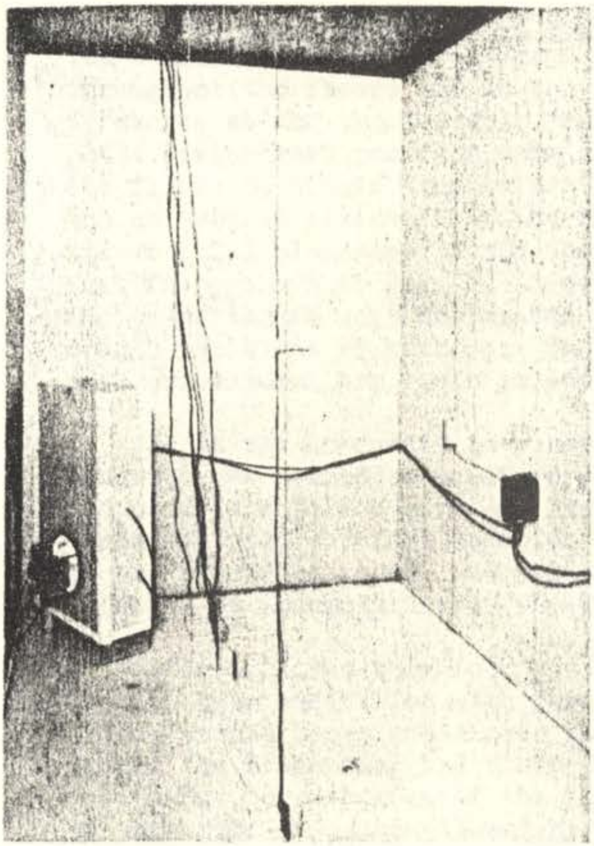

FIG. 3 SMALL COMPARTMENT VIEW SHOWING HEATER AND THERMOCOUPLE WIRES

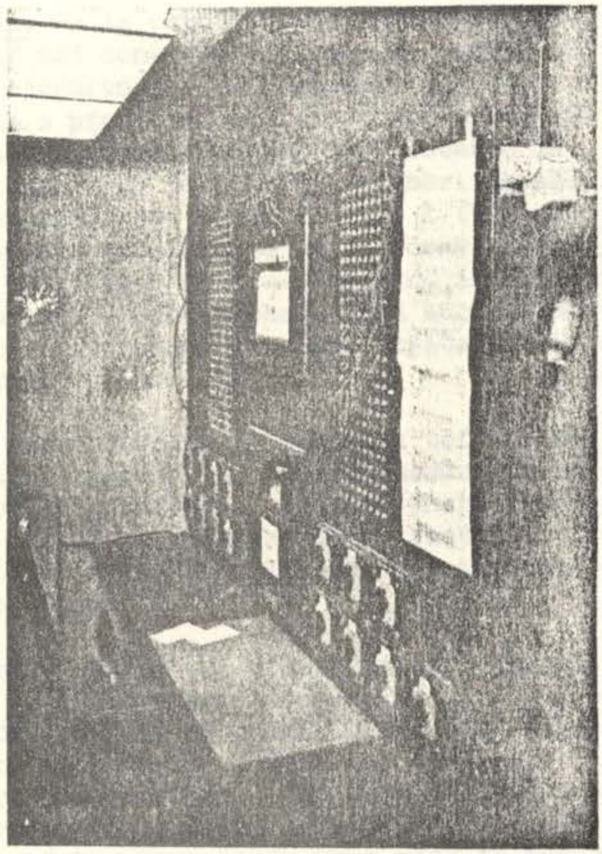

FIG. 4 INSTRUMENT PANEL

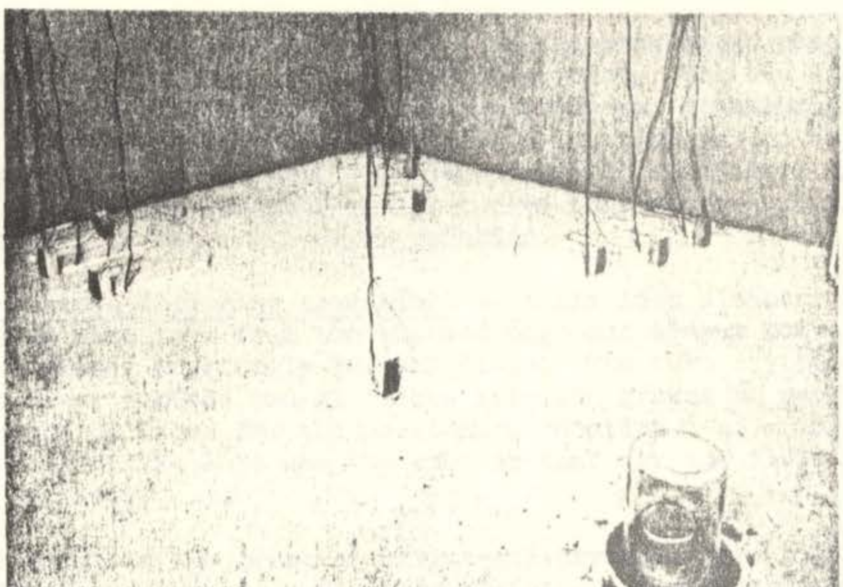

FIG. 5 VIEW OF COMPARTMENT A SHOWING MOISTURE MEASURING APPARATUS

8. Temperature Measuring Apparatus. — An extensive thermocouple system consisting of number 24 gage copper and constantan wires was installed throughout the floors and in the test compartments. To measure the temperatures at the thermocouple junctions a precision indicator and a twelve-point strip-chart recorder were installed. Thermocouples were located in the floors to obtain temperature gradients both vertically and horizontally. The horizontal placement of the thermocouples are shown in Fig. 1 (b), and the vertical placement of the thermocouples are located on the drawings of each floor shown in Fig. 2. A number and letter code was devised in which the compartments were designated by letters of the alphabet and the thermocouple positions by numbers. The general location of thermocouples within each compartment are given in Appendix A.

As it was necessary to place the thermocouples in position before the concrete was poured, a moisture resistant tube of low thermal conductivity was used to hold the wires in their correct position. The two thermocouple wires for each vertical location were pulled through the tube, brought out at the proper position, and soldered to a brass ring slipped over the tube in order to securely fasten the thermocouple.

After all the thermocouples for this horizontal position were constructed, the tube was filled with paraffin to prevent any moisture or air circulation around the wires inside the tube. A film of paraffin was also placed around the brass ring and thermocouple junction to prevent any galvonic action due to corrosion of the thermocouple junction. The proper placement of each tube was accomplished by inserting the tube in a hole prepared by driving a 3/8 in. rod into the ground. Laboratory tests were made to insure that thermocouples placed in this manner would give temperature readings consistent with experimental accuracy.

The thermocouples for measuring the air temperatures of the room and surface temperatures of the concrete were placed with six inches of the wire in the same temperature zone as the junction to prevent conduction of heat along the wires.

All thermocouple leads terminated at the instrument panel shown in Fig. 4, which was located in the instrument room. The two wires from each thermocouple junction were soldered to a jackboard junction and a selector switch. By means of the selector switches the temperature at any measuring point could be determined with the precision indicator, and by selecting the proper jackboard connections any twelve temperatures could be continuously recorded on the strip-chart recorder.

9. Moisture Measuring Apparatus. -- A six inch diameter galvanized iron tube located nine feet from the exposed edge and midway between the sidewalls, was placed vertically in each floor. The tube extended one inch above the floor surface and 12 inches into the ground to provide an isolated portion of floor for the moisture permeation test. The floor construction inside the tube was the same as that for the floor in which the tube was located.

Approximately 100 grams of silica-gel crystals were placed on a stand above this isolated portion of floor surface, and a glass jar eight inches high and six inches in diameter was placed over the crystals and sealed to the outside surface of the galvanized iron tube with paraffin. The moisture measuring apparatus in compartment A is shown in Fig. 5.

III. PROCEDURE

10. Determination of Heat Losses. -- The operational period of the investigation was from January 14, 1948 to April 23, 1948. Readings of each of the watt-hour meters were observed once each day at the same respective minute of the day starting at 1312 hours and ending at 1322 hours. Thus the gross heat input to any compartmtne for a 24-hour period could be obtained by subtracting from the observed reading the meter reading of the previous day.

11. Temperature Measurements. -- Between 1300 and 1400 hours daily the temperatures at all measuring points in each floor were recorded. Fig. 6 shows a portion of the temperatures and watt-hour meter readings taken for compartment D. Similar data were taken for all compartments. Additional temperature measurements were recorded continuously on the twelve-point strip-chart recorder. The twelve thermocouples connected to the recorder were changed from time to time during the four months test period except for the outside and attic temperatures which were recorded continuously throughout the period. The remaining ten positions on the recorder were connected to those thermocouples located at points considered as being significant in the comparative performance of each floor. For example, if a comparison were desired of the floor surface temperatures six inches from the exposed edge, thermocouple No. 20 from each compartment would be connected to the recorder.

Ground temperatures were also measured at one-foot intervals down to six feet at a point fifteen feet outside the exposed edge and also at a point seven feet inside the exposed edge of compartment H.

12. Moisture Permeation Measurements. -- Once each week weighed amounts of silica-gel were placed under the glass jars in each compartment and the jars were resealed. The crystals which had been under the jars for the previous seven-day period were then weighed to determine the amount of moisture absorbed.

IV. RESULTS

13. Heat Losses - Derivation by the First Method. -- The total amount of heat supplied to each compartment is shown in Figs. 7 to 16 in which the daily heat input in thousands of Btu is plotted against the indoor-outdoor temperature difference. The deviations of the points from the mean curve are caused by the difference in heat input brought about by variable wind and sun effects which cannot be represented on a curve in which the abscissa is temperature difference alone. However, these deviations resulting from wind and sun tend to compensate for each other when a number of tests are conducted at the same temperature difference, and the curve is therefore representative of the actual heat input when considered from the standpoint of the season as a whole.

COMPARTMENT D

Gradient location		6 feet from exposed edge						3 feet from exposed edge				2 feet from exposed edge				
Date	Time	Center of room 4 feet high	3 inches from ceiling	3 inches above surface	Surface	4 inches below surface	8 inches below surface	3 inches above surface	Surface	4 inches below surface	8 inches below surface	3 inches above surface	Surface	4 inches below surface	8 inches below surface	12 inches below surface
2-19-48	1334	70.0	70.0	70.0	69.3	69.0	67.9	69.9	67.5	66.3	62.5	69.7	68.5	67.0	56.0	54.3
2-20-48	1347	70.6	70.6	70.8	68.3	67.5	66.6	70.1	66.1	65.0	61.6	69.7	66.4	65.0	55.0	53.6
2-21-48	1345	70.0	70.5	70.5	68.9	68.0	66.7	70.0	66.7	65.2	61.5	70.0	67.0	65.7	54.3	52.5
2-22-48	1308	70.1				Sunday - all temperatures not recorded										
2-23-48	1338	71.8	72.0	72.0	69.1	68.1	66.9	71.5	67.2	65.8	61.7	71.5	68.0	66.3	54.1	52.3
2-24-48	1332	73.1	73.5	73.3	70.5	69.1	67.5	73.0	68.7	67.4	62.1	73.0	69.9	68.0	55.0	53.2
2-25-48	1335	72.4	72.6	72.5	71.0	70.0	68.1	72.1	69.1	67.8	63.0	72.1	70.5	69.1	56.0	54.0
2-26-48	1332	71.0	71.0	71.2	69.5	68.5	67.2	71.0	67.5	66.1	62.1	70.5	68.1	67.0	56.0	54.2
2-27-48	1330	70.0	70.1	70.2	69.0	68.2	67.0	70.0	67.3	66.0	62.3	70.0	68.0	66.9	56.2	54.4
2-28-48	1330	70.5	70.6	71.0	69.0	68.0	67.0	70.3	67.3	66.0	62.2	70.3	68.1	67.0	56.5	55.0
2-29-48	1302	70.3				Sunday - all temperatures not recorded										
3-1-48	1401	70.8	71.0	71.0	68.5	67.9	66.5	70.2	67.0	65.8	62.0	70.3	67.8	66.2	55.6	54.0
3-2-48	1330	70.0	70.1	70.1	68.1	67.3	66.0	69.9	66.5	65.1	61.2	69.9	67.3	66.0	55.0	53.5
3-3-48	1335	70.2	70.5	70.8	68.1	67.5	66.1	70.0	66.5	65.2	61.3	70.0	67.0	65.8	55.0	53.5
3-4-48	1334	69.5	70.0	70.0	67.4	66.6	65.7	69.2	65.4	64.3	61.0	68.7	65.6	64.1	54.5	53.0
3-5-48	1334	71.0	71.5	71.3	68.5	67.5	66.0	70.9	66.8	65.1	61.0	70.5	67.3	65.8	54.1	52.5
3-6-48	1332	71.7	72.0	72.0	70.0	69.0	67.2	71.6	68.1	66.8	62.0	71.5	69.5	68.0	55.2	53.4
3-7-48	1302	70.1				Sunday - all temperatures not recorded										
3-8-48	1330	71.0	71.0	71.0	68.9	68.0	66.2	70.3	67.0	65.5	61.3	70.4	68.0	61.2	54.5	53.0
3-9-48	1334	70.9	71.0	71.0	68.7	67.7	66.1	70.1	66.8	65.4	61.2	70.1	67.5	66.0	54.3	52.5
3-10-48	1333	68.0	68.1	68.2	66.0	65.2	65.0	67.8	64.0	62.9	60.0	67.0	63.8	62.1	53.5	52.1
3-11-48	1333	69.0	69.4	69.6	66.5	65.9	65.0	68.9	64.7	63.4	60.0	68.2	64.7	63.3	53.0	51.5
3-12-48	1330	71.0	71.5	71.5	68.0	67.0	65.1	71.0	66.0	64.8	60.1	71.0	67.0	65.0	53.1	51.4

Fig. 6. Sample Data Sheet Showing a Portion of the Data Recorded for Compartment D

COMPARTMENT D

Gradient location		15 inches from exposed edge						6 inches from exp. edge		Exposed edge					
Date	Time	3 inches above surface	Surface	4 inches below surface	8 inches below surface	14 inches below surface	20 inches below surface	Surface	4 inches below surface	3 inches below surface	12 inches below surface	20 inches below surface	Average outdoor temperature	Watthour meter reading	Watts used per 24 hours
2-19-48	1334	69.5	68.0	65.6	51.5	49.0	48.3	66.5	63.2	50.7	46.0	44.0	51.6	382676	2454
2-20-48	1347	68.7	65.0	62.0	48.3	47.0	47.3	61.9	57.0	29.3	37.0	41.7	23.9	390188	7512
2-21-48	1345	68.9	66.0	63.0	47.8	46.0	46.5	63.2	58.2	35.1	37.2	40.7	20.5	397560	7372
2-22-48	1308	Sunday - all temperatures not recorded											20.2	404586	7026
2-23-48	1338	71.0	67.3	64.0	48.0	45.9	46.0	65.8	60.5	42.5	38.5	40.3	29.4	409791	5205
2-24-48	1332	72.3	69.1	66.0	49.9	47.1	47.0	68.0	63.0	46.9	41.2	41.7	38.8	414807	5016
2-25-48	1335	71.9	70.3	67.5	51.2	48.6	47.9	68.8	64.5	48.9	44.0	43.2	42.2	419489	4682
2-26-48	1332	70.2	67.9	65.0	52.1	49.0	48.5	66.1	62.0	45.5	43.5	44.0	41.4	422735	3246
2-27-48	1330	69.7	67.6	65.0	51.7	49.3	48.9	66.5	62.5	50.5	45.1	44.5	44.3	425761	3026
2-28-48	1330	70.0	67.9	65.1	52.5	50.5	49.9	66.5	62.5	47.1	45.5	45.9	47.3	428973	3212
2-29-48	1302	Sunday - all temperatures not recorded											35.4	434325	5352
3-1-48	1401	69.9	67.0	64.1	50.2	48.1	48.1	65.0	60.8	40.0	41.0	43.3	30.9	439798	5473
3-2-48	1330	69.4	66.7	63.8	49.7	47.6	47.7	65.0	60.7	43.2	41.1	42.5	32.9	444875	5077
3-3-48	1335	69.5	66.3	63.8	49.5	47.9	47.9	64.0	60.0	38.0	40.1	43.0	32.0	450416	5541
3-4-48	1334	68.0	64.3	61.5	48.0	46.6	47.0	61.4	57.0	32.0	37.4	41.6	26.6	457359	6943
3-5-48	1334	70.0	66.4	63.3	48.0	46.0	46.5	64.0	59.0	35.5	37.5	41.0	24.9	464580	7221
3-6-48	1332	71.2	69.0	66.0	49.8	47.4	47.3	67.1	62.2	38.3	39.5	42.0	34.0	470338	5758
3-7-48	1302	Sunday - all temperatures not recorded											34.1	474478	4140
3-8-48	1330	70.0	67.1	64.1	49.0	46.9	47.0	65.3	60.5	42.0	39.8	41.5	28.9	480166	5688
3-9-48	1334	69.5	66.5	63.5	48.2	46.3	46.4	64.0	59.2	35.1	38.0	41.2	27.9	485927	5761
3-10-48	1333	66.0	62.3	59.6	47.1	45.9	46.1	59.1	55.0	33.4	37.1	41.0	24.8	491835	5908
3-11-48	1333	67.3	63.4	60.4	46.7	45.3	46.0	59.7	55.4	30.3	37.6	40.9	14.9	501533	9698
3-12-48	1330	70.0	66.0	62.5	47.4	45.5	46.0	63.5	58.1	31.1	38.0	41.0	11.7	509798	8265

Fig. 6 (cont'd). Sample Data Sheet Showing a Portion of the Data Recorded for Compartment D

The net heat loss through the floor of each compartment is shown in Figs. 7 to 16 and was determined by subtracting from the gross heat input the corrected tare loss. The method of obtaining the corrected tare loss, which was the sum of the heat losses through the wall and ceiling and that due to infiltration, is explained in Appendix B. The curve for corrected tare loss is shown on Fig. 10 only and is not shown in the other curves because the method was identical for all compartments.

In order to determine the path of the flow of heat through the floors at various outside temperatutes, isotherm patterns shown in Figs. 17 to 25 were drawn for each floor for average daily outside temperatures of 3.7 deg. F. (maximum 14.5 deg. F., minimum -5.0 deg. F.); 16.2 deg. F. (maximum 25 deg. F., minimum 7.7 deg. F.); and 24.9 deg. F., (maximum 36.1 deg. F., minimum 17.4 deg. F.). The average daily temperature of 3.7 deg. F. occurred on January 28 which was the coldest day of the heating season. The average daily temperature of 16.2 deg. F. occurred on January 26 and was approximately the average daily temperature for the nine days previous to January 26. The temperature of 24.9 deg. F. occurred on March 9 and was approximately the average for the seven days previous to March 9. Therefore these isotherms can be considered as representative of fairly steady conditions of heat flow.

A comparison of the isotherms of each floor at the three outdoor temperatures indicate that beyond a distance of three feet from the exposed edge, the isotherm patterns appear to be the same. Hence, it appeared necessary to divide the heat loss through the floor into two components -- (1) the heat loss through the exposed edge including the floor area within three feet of the edge, and (2) the heat loss through the remaining floor area, which was designated as the inner floor.

As no direct measurement of heat flow through the floor was obtained, it was necessary to use previous experimental work for the determination of the heat flow through the inner floor. Upon examination of the paper by F. C. Houghton and associates,[2] it was found that the isotherm pattern for the east uninsulated wall compared almost exactly with those obtained in the present investigation for the inner floor. The average heat flow as indicated by the Nicholl's heat flow meter (position "F" in Fig. 2 of the Houghton report) was 2.0 Btu per sq. ft. per hr. In view of the identical isotherm patterns for these two investigations, the 2.0 Btu per sq. ft. per hr. value obtained by Houghton and associates was considered as applicable to the heat loss of the inner floors used in the present series of tests.

As the heat loss through the inner floor remains constant, the heat loss through the exposed edge, including the floor area within three feet of the edge, could be determined by subtracting the heat loss through the inner floor from the net floor heat loss.

It was also observed from the isothermal curves that within the distance of three feet from the exposed edge, the lines of constant temperature shifted when the average daily outside temperature changed. Thus it was decided to evaluate the heat loss through the exposed edge in terms of a factor based upon the length of exposed edge and the indoor-outdoor temperature difference. This factor, in Btu per hr. per linear ft. of exposed edge per deg. F. temperature difference, was determined by dividing the

[2] See numbered reference in Bibliography

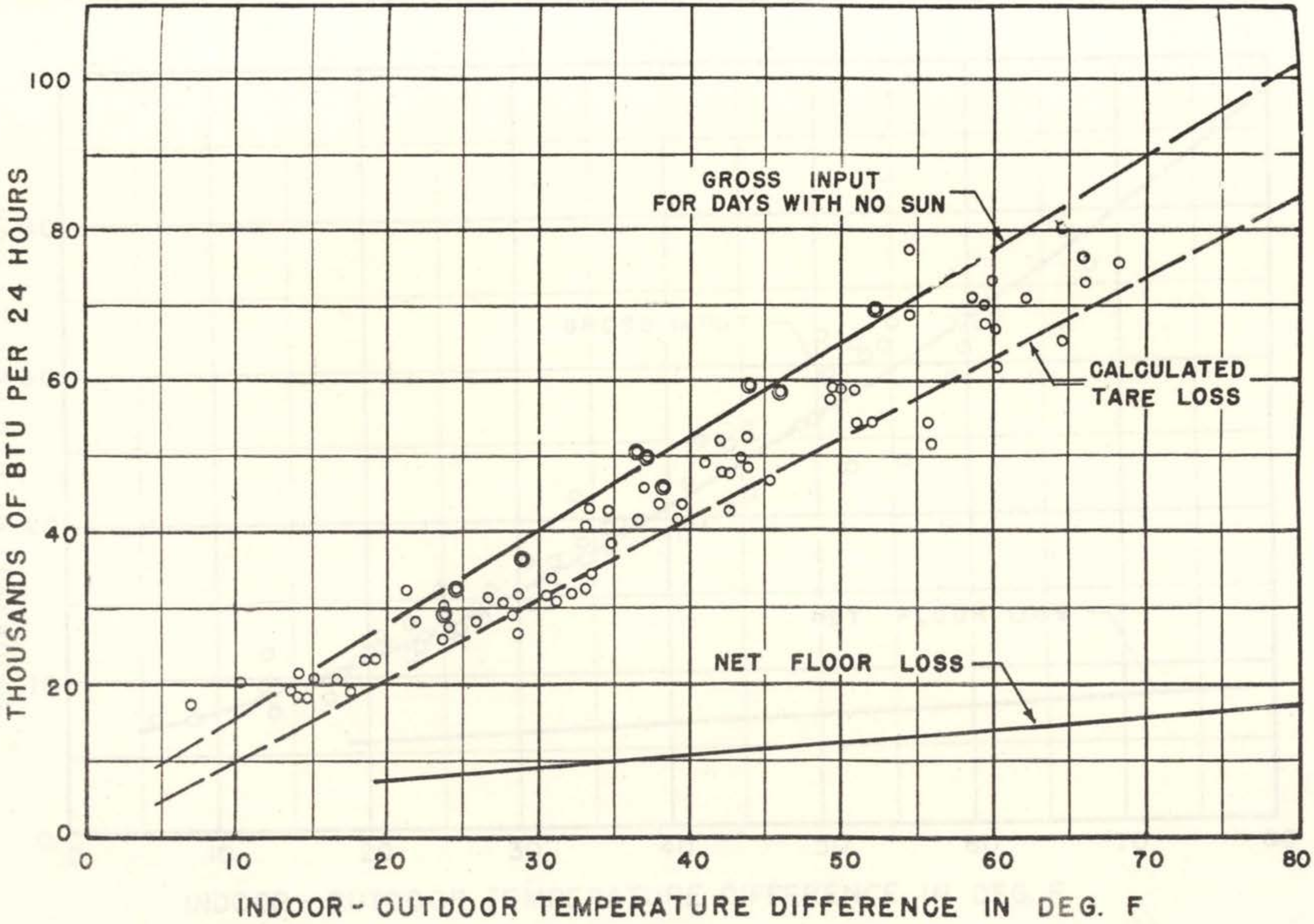

FIG. 7 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "A"

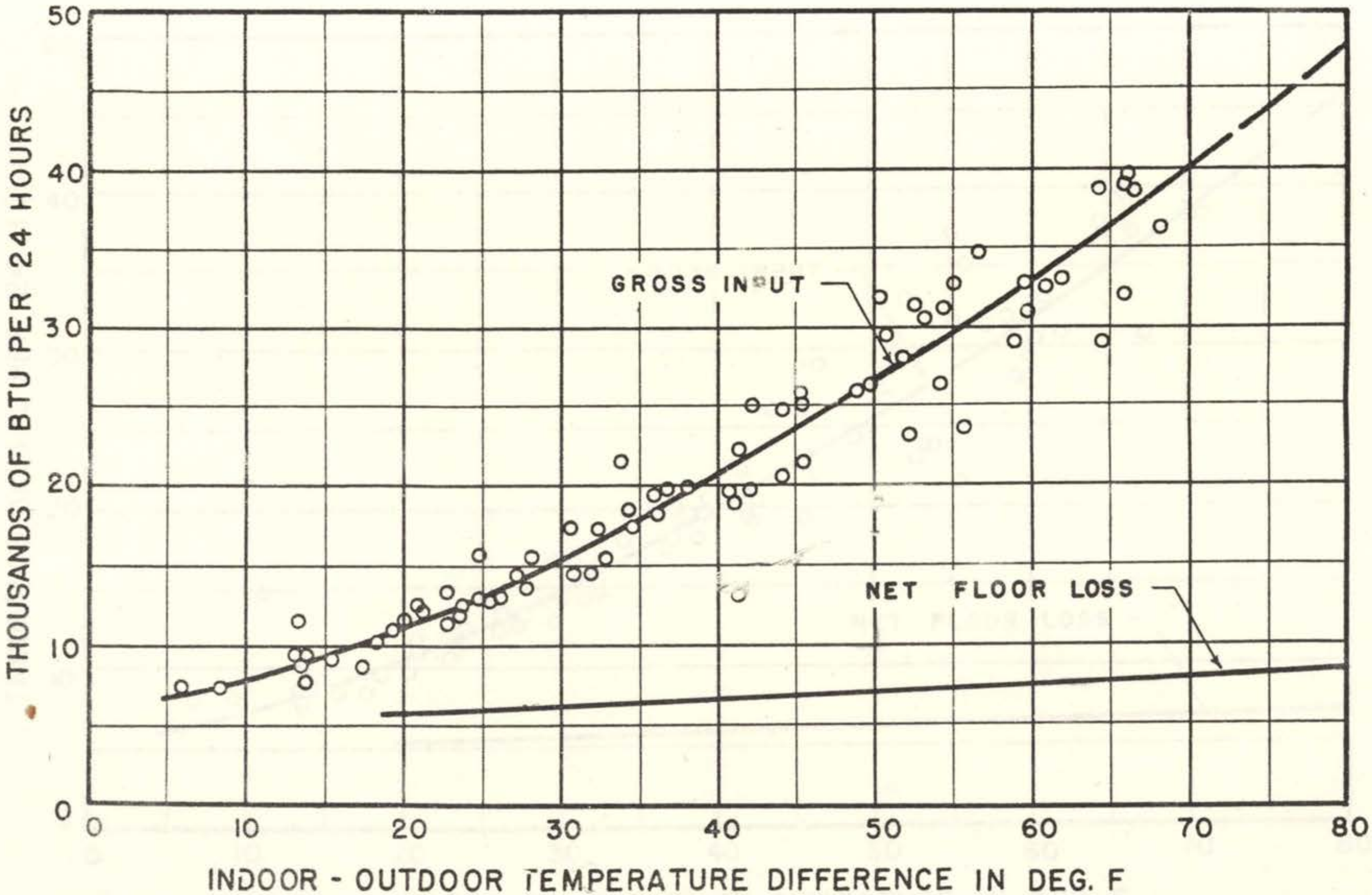

FIG.8 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "B"

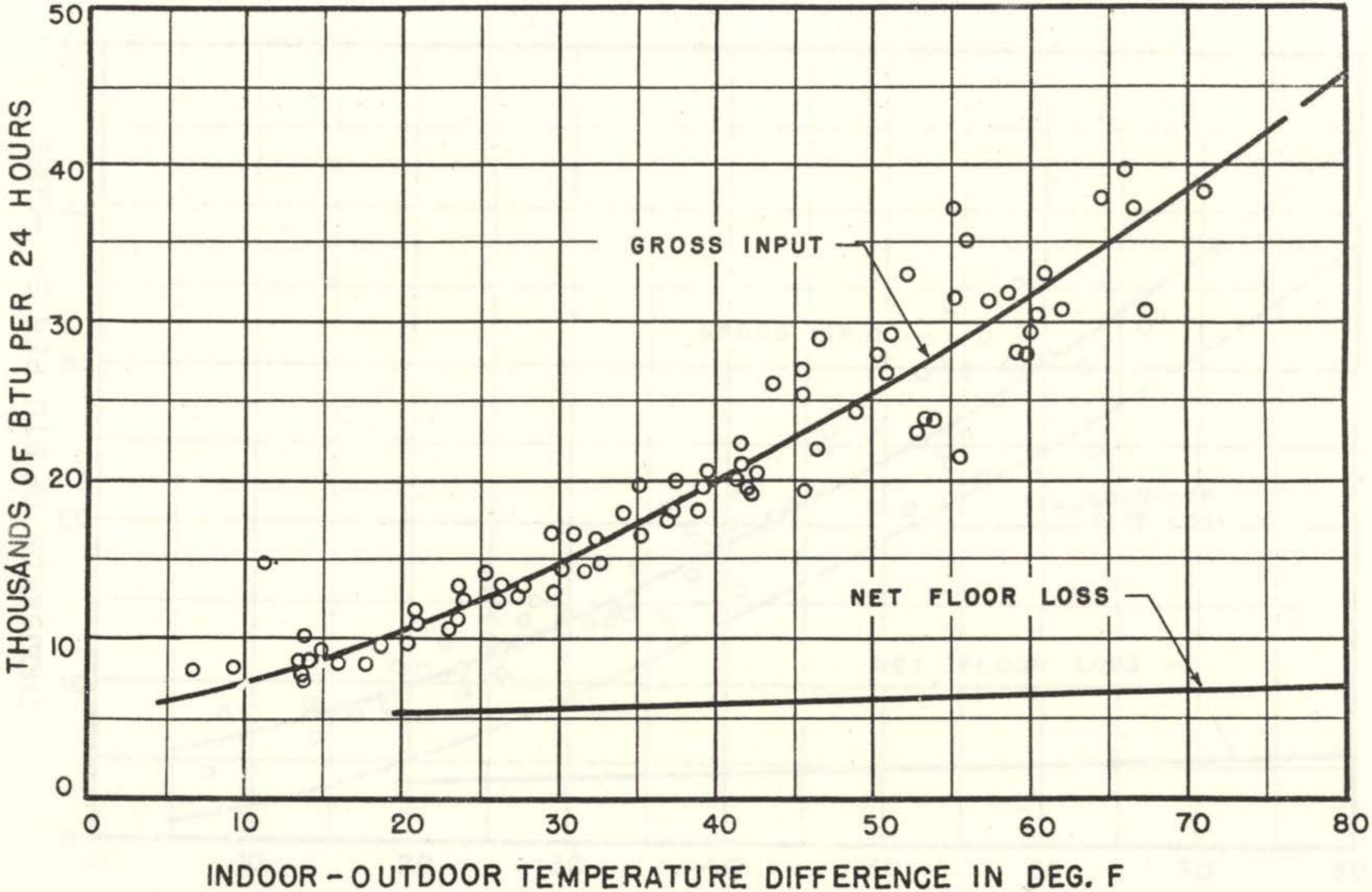

FIG.9 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "C"

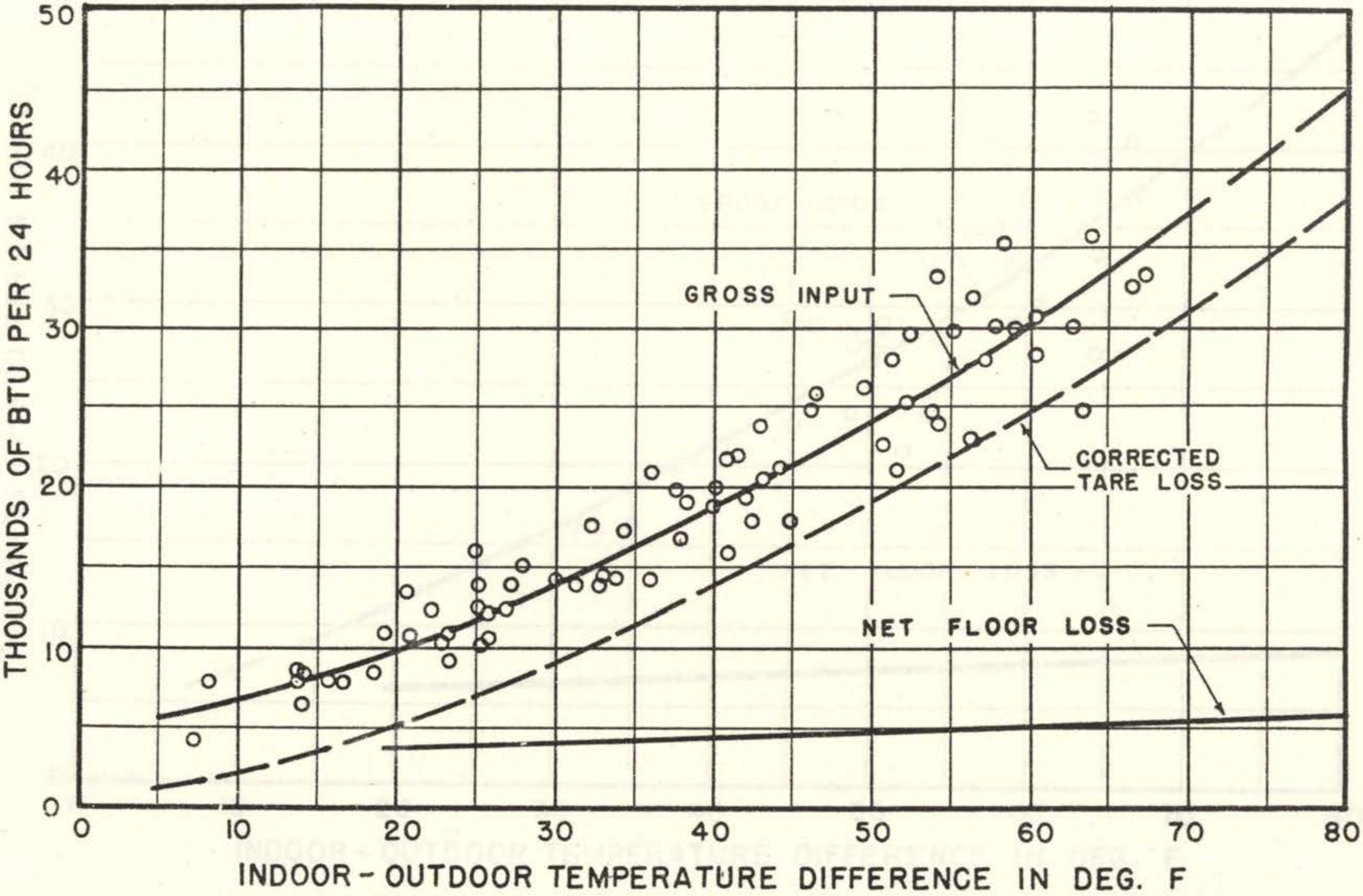

FIG.10 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "D"

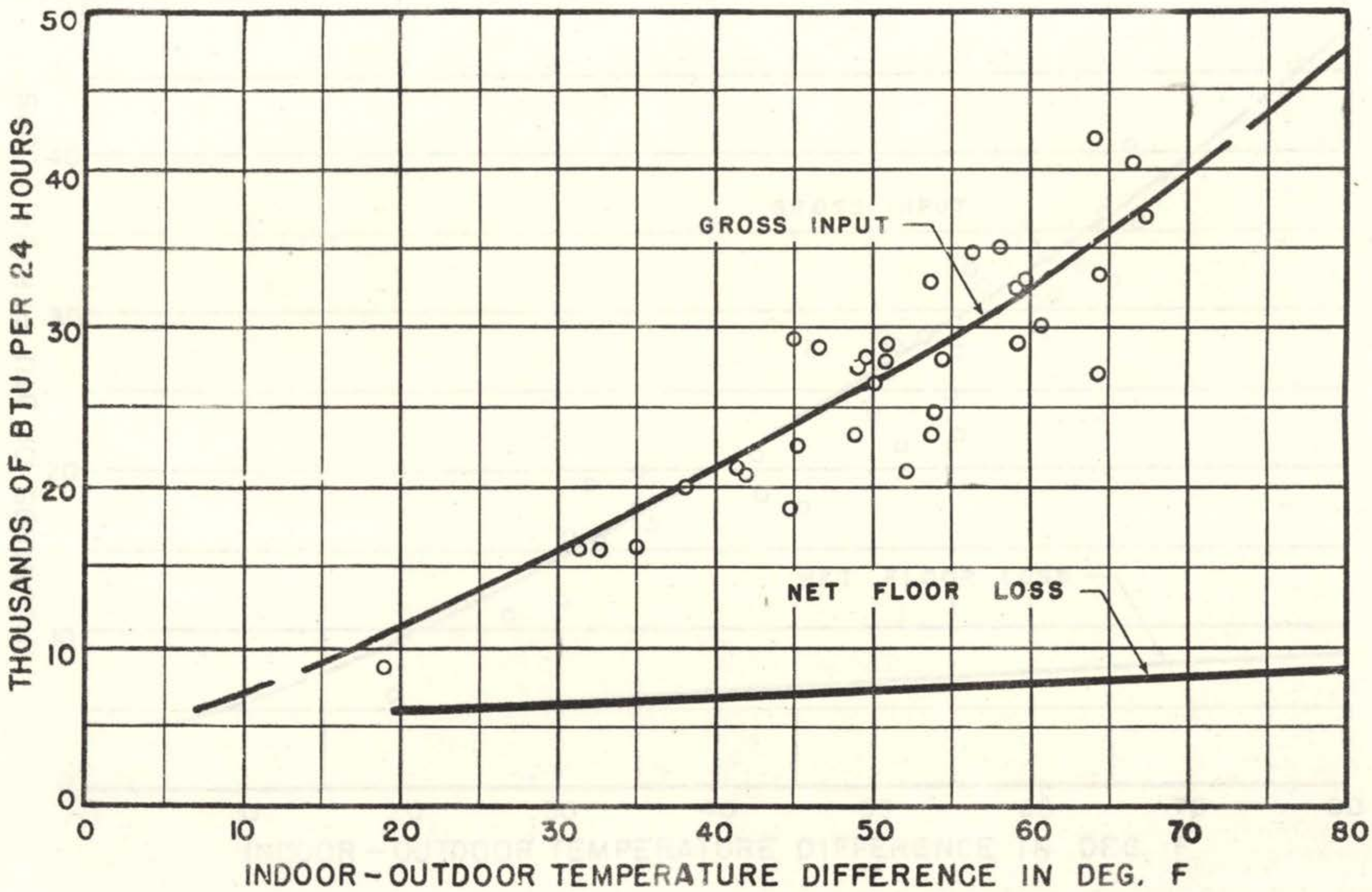

FIG. 11 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "E"

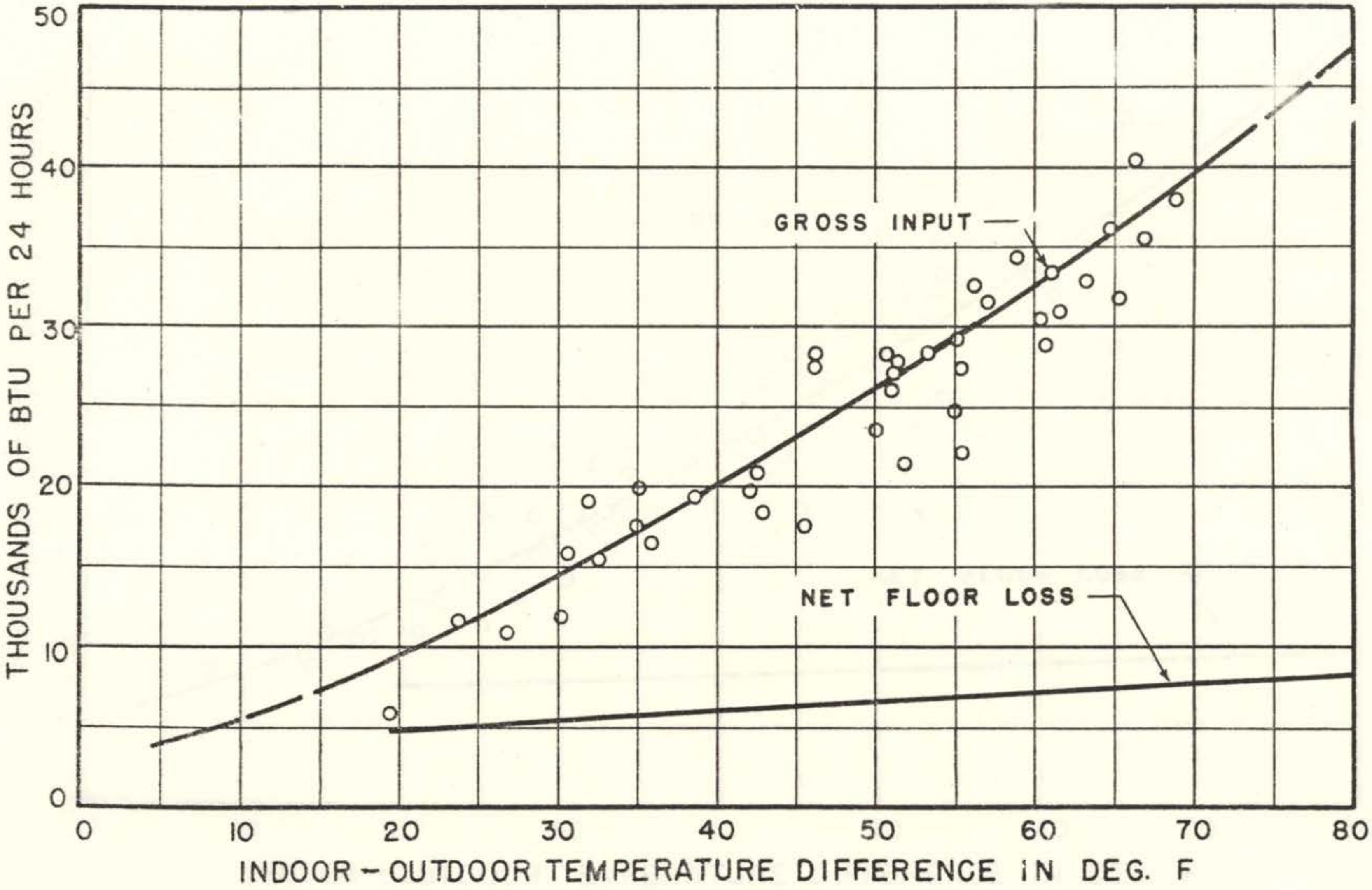

FIG. 12 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "F"

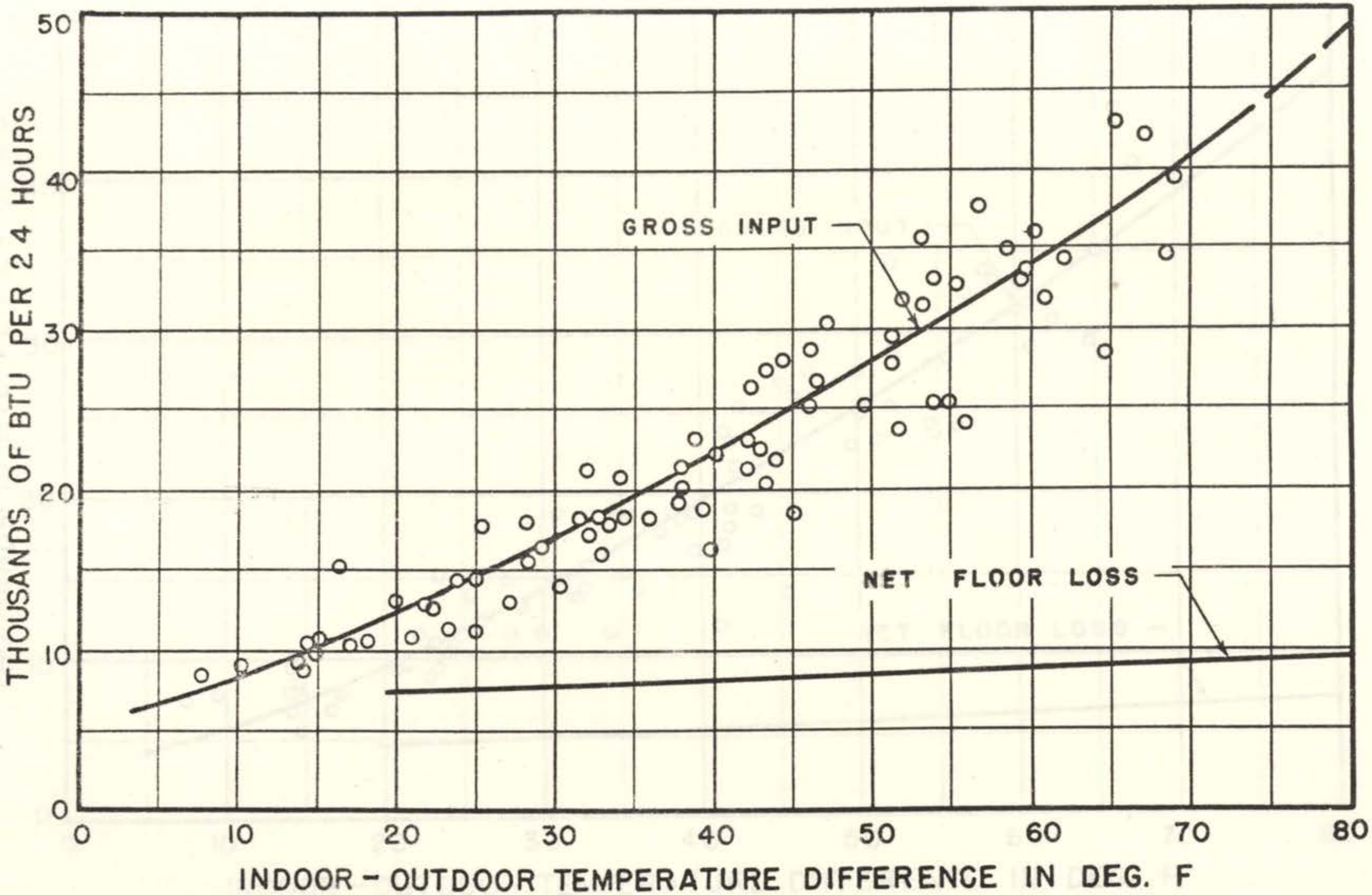

FIG.13 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "G"

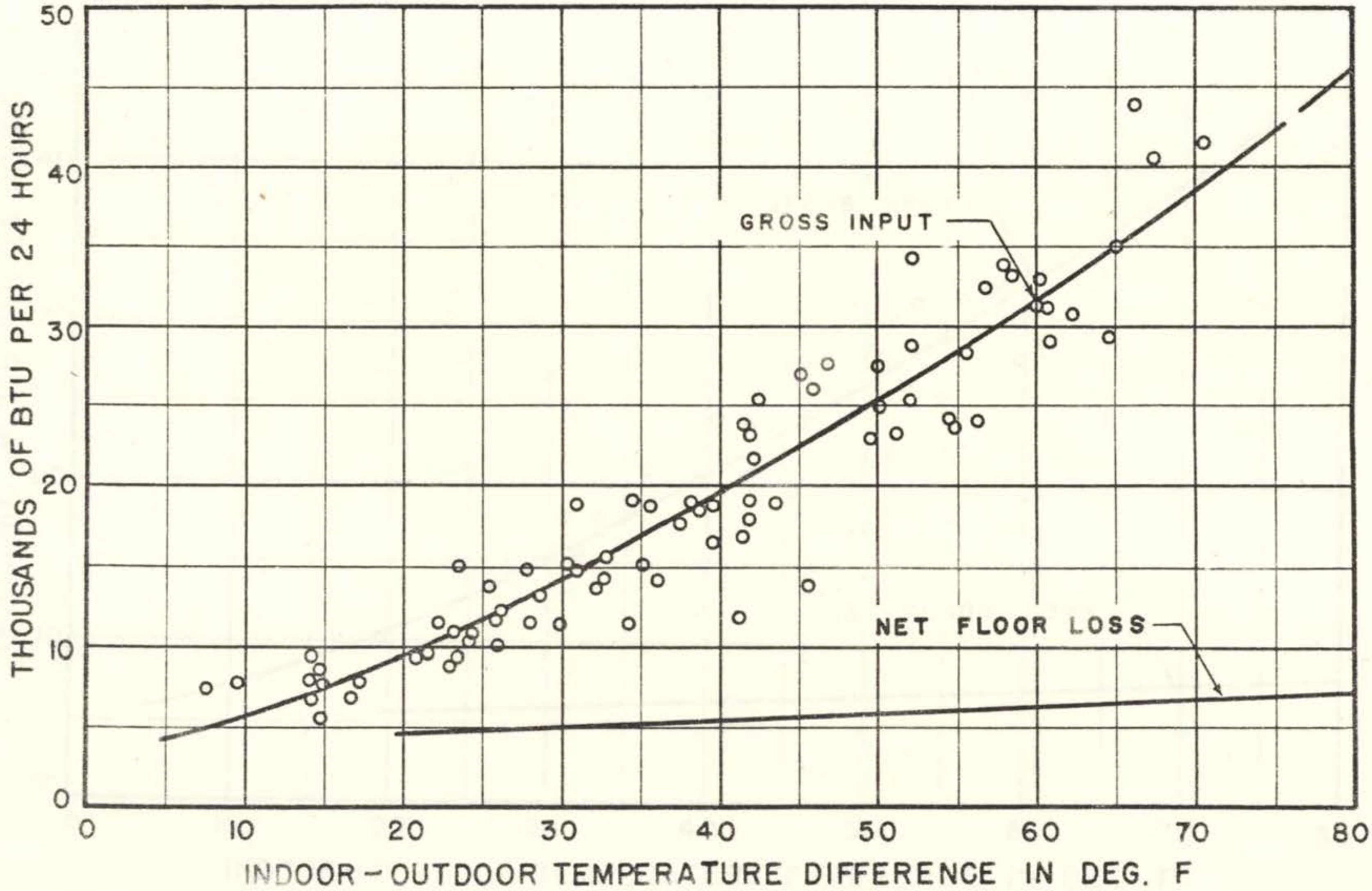

FIG. 14 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "H"

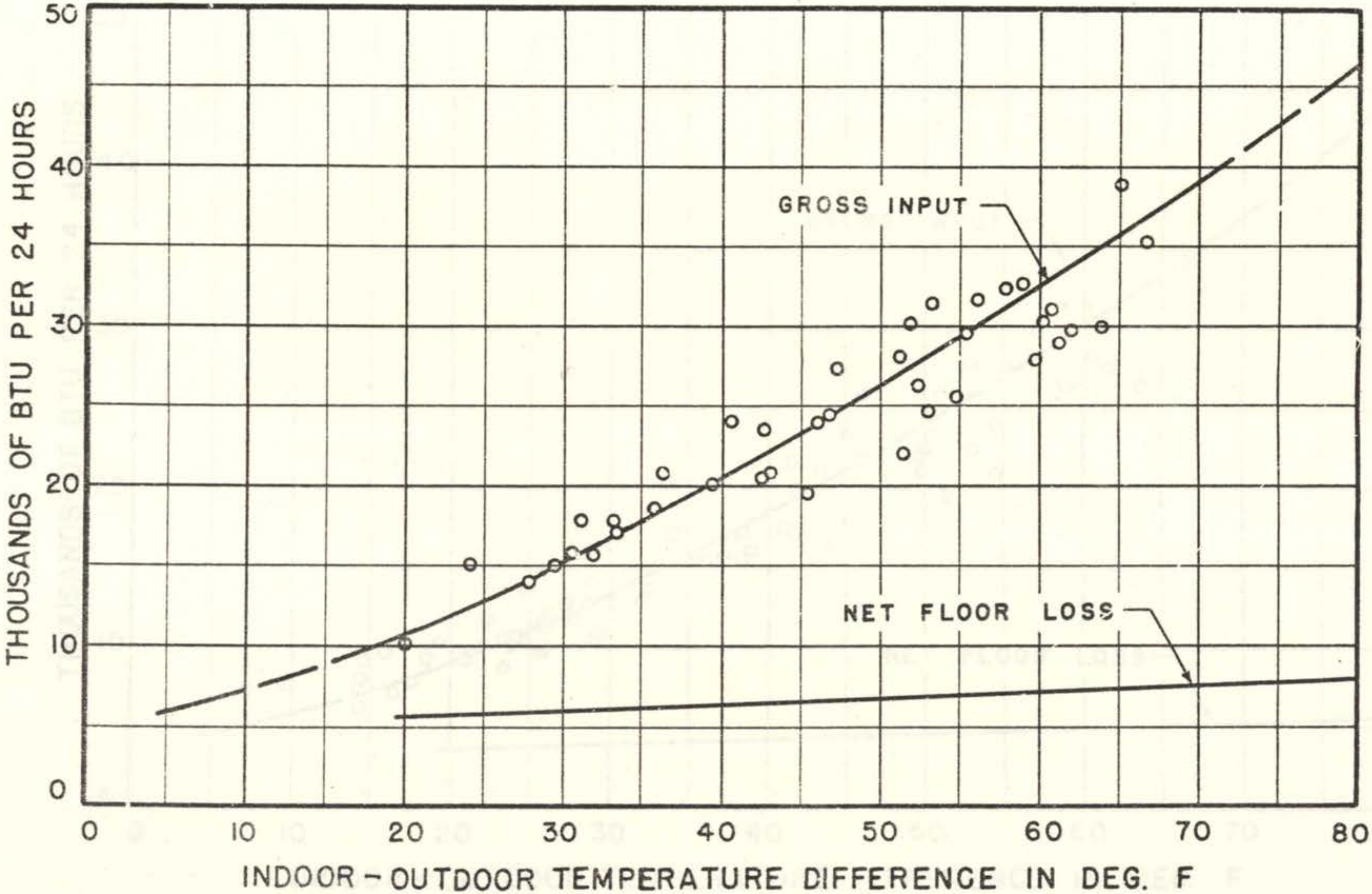

FIG.15 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "J"

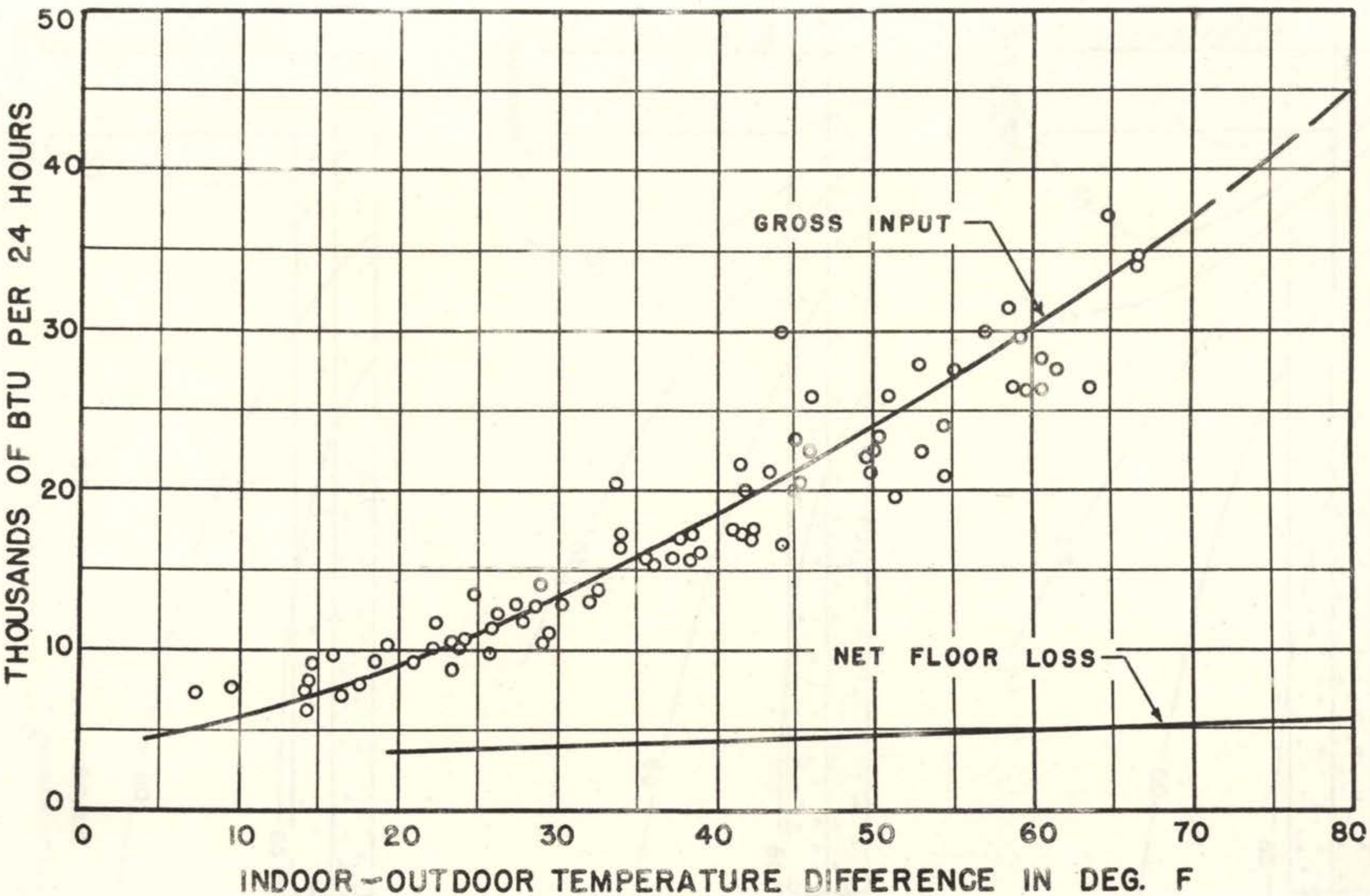

FIG. 16 GROSS INPUT AND NET FLOOR LOSS FOR COMPARTMENT "K"

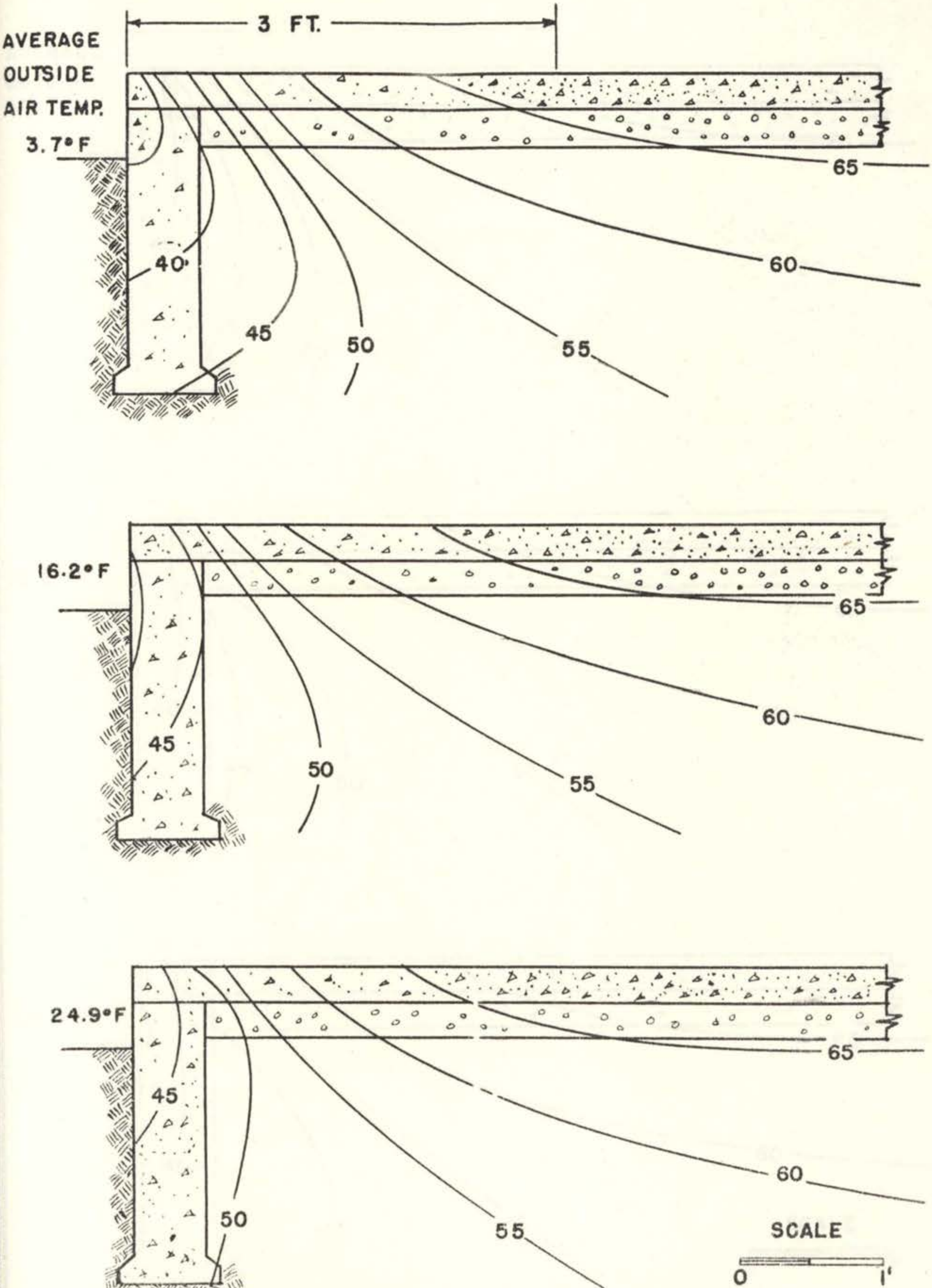

FIG. 17 ISOTHERMS FOR FLOOR "B" AT VARIOUS OUTSIDE AIR TEMPERATURES

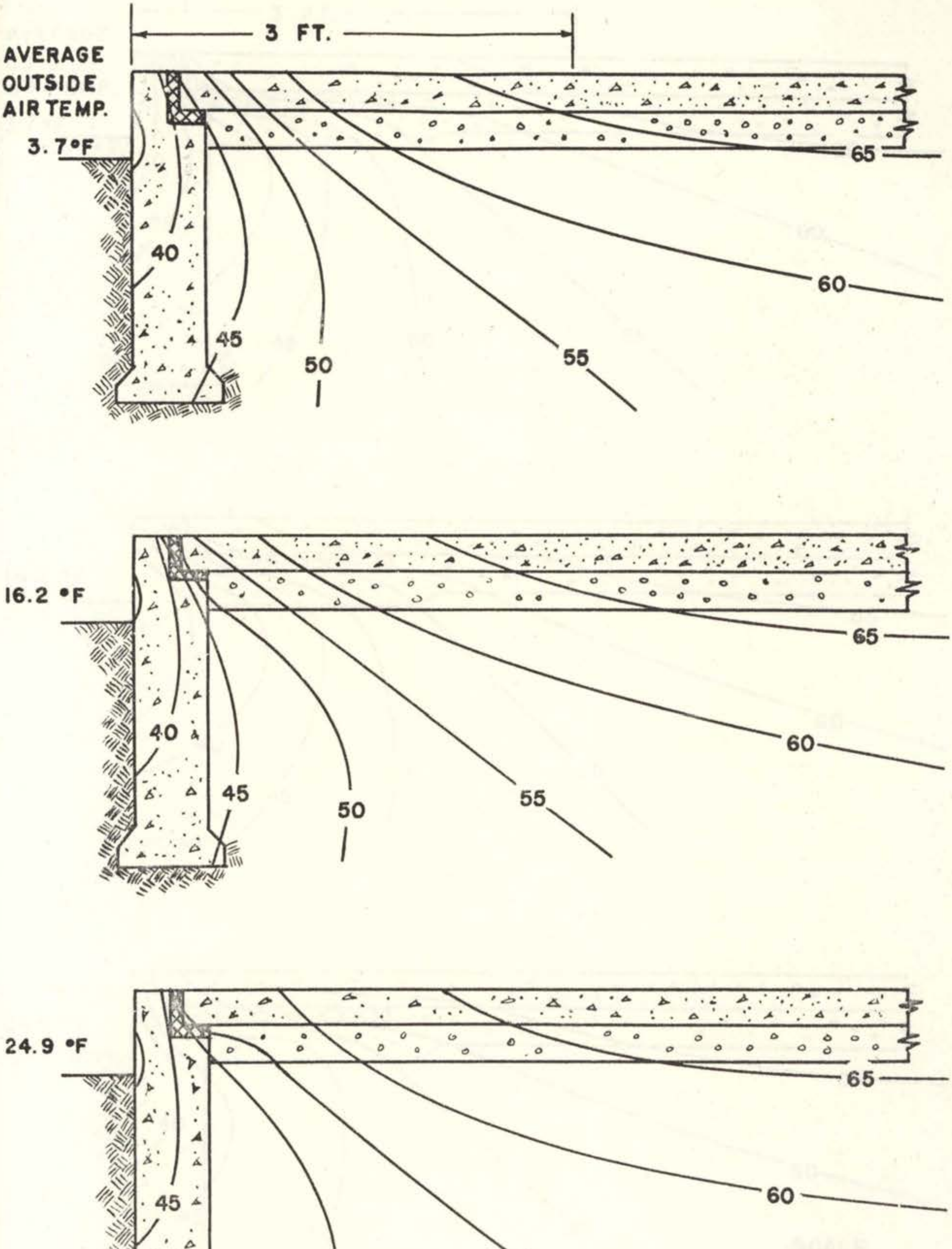

FIG.18 ISOTHERMS FOR FLOOR "C" AT VARIOUS OUTSIDE AIR TEMPERATURES

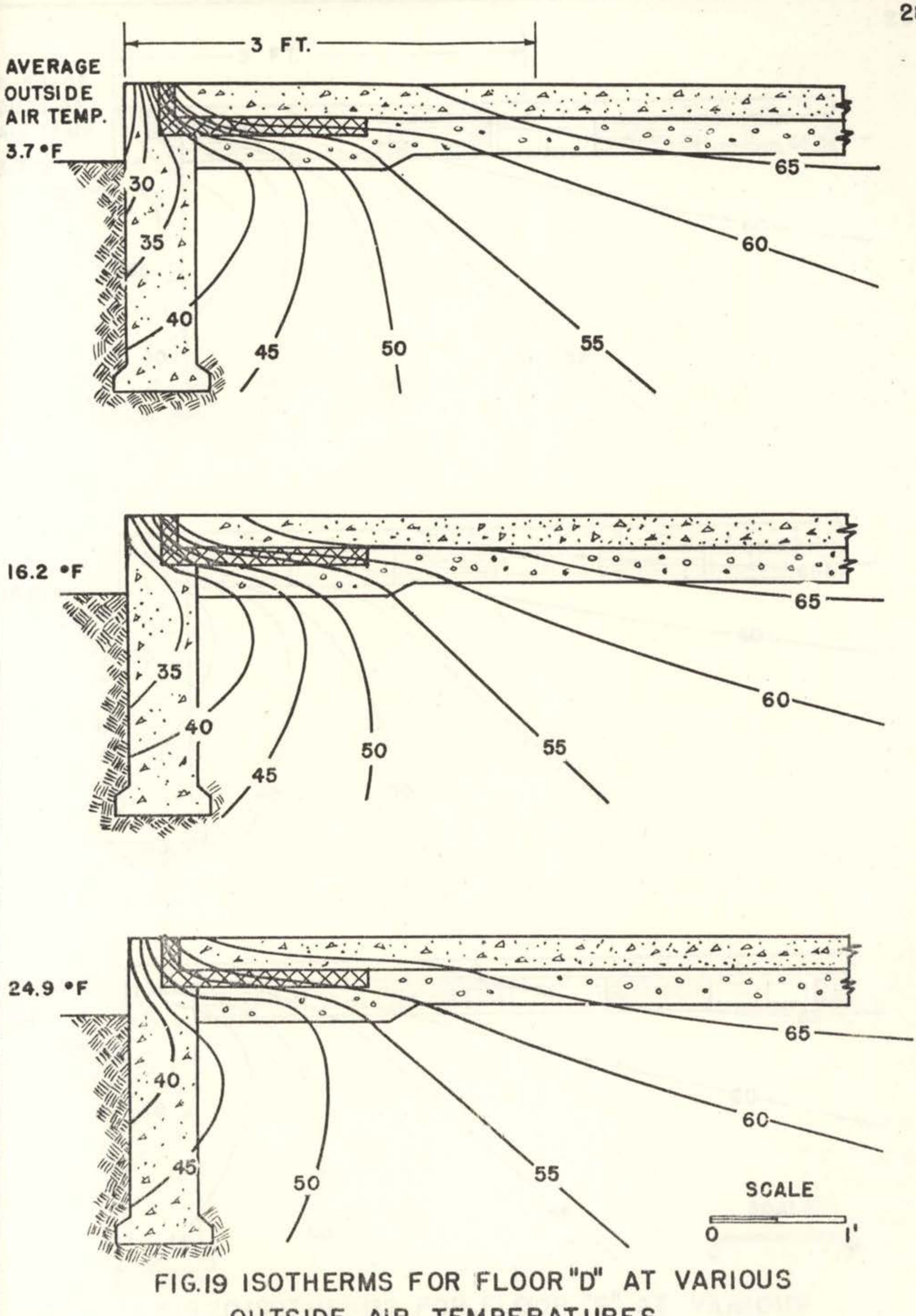

FIG.19 ISOTHERMS FOR FLOOR "D" AT VARIOUS OUTSIDE AIR TEMPERATURES

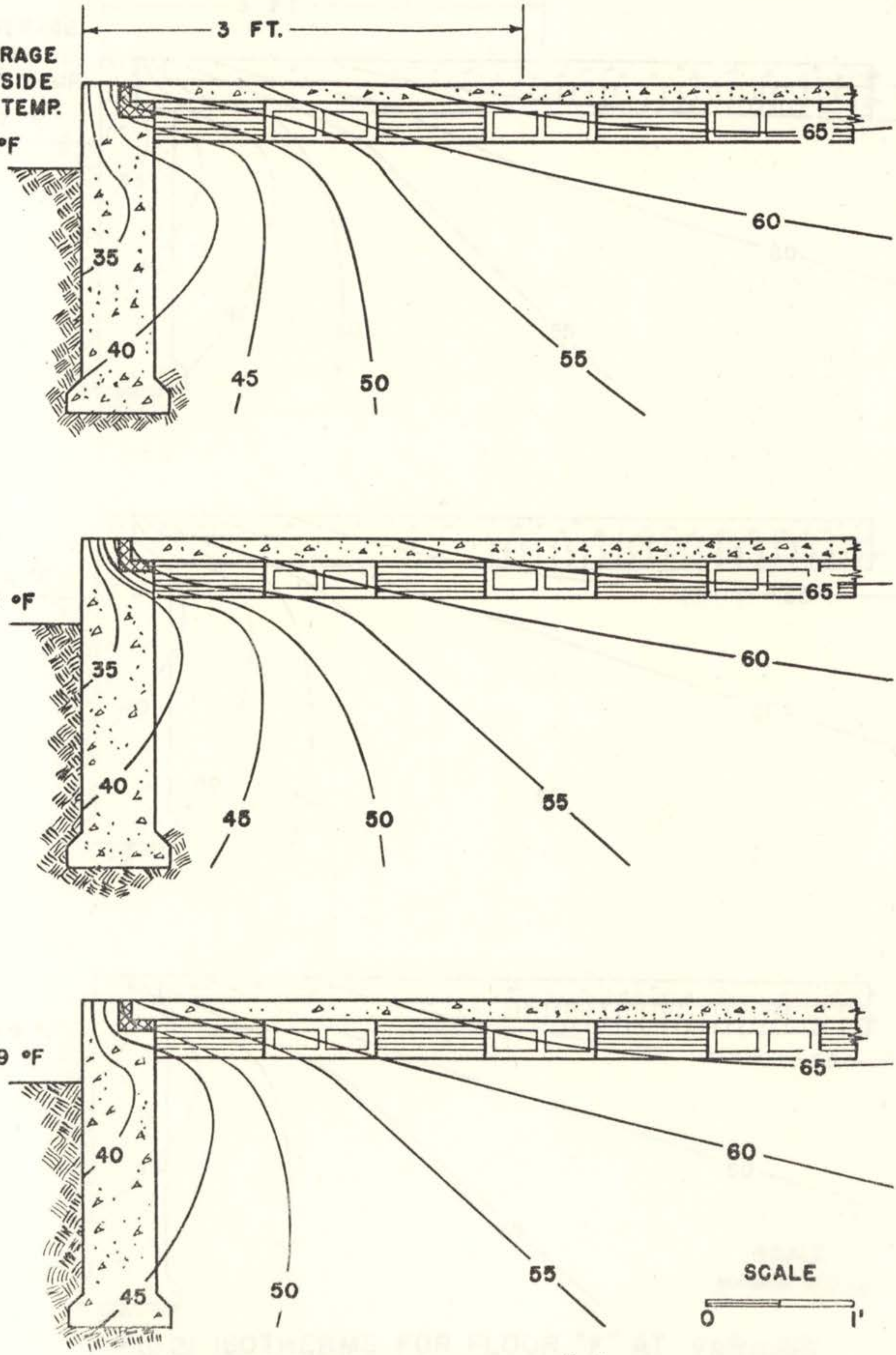

FIG.20 ISOTHERMS FOR FLOOR "E" AT VARIOUS OUTSIDE AIR TEMPERATURES

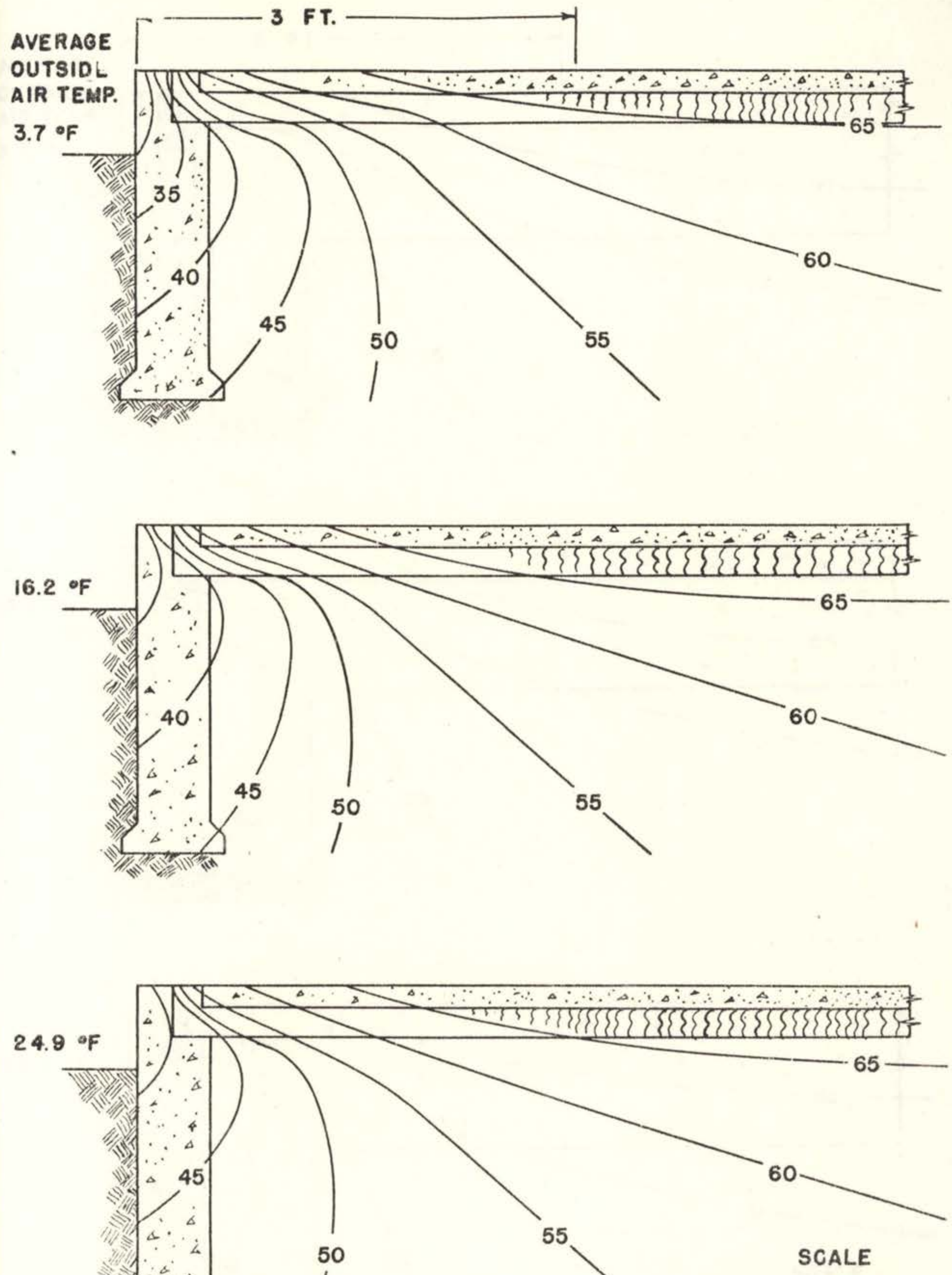

FIG.21 ISOTHERMS FOR FLOOR "F" AT VARIOUS OUTSIDE AIR TEMPERATURES

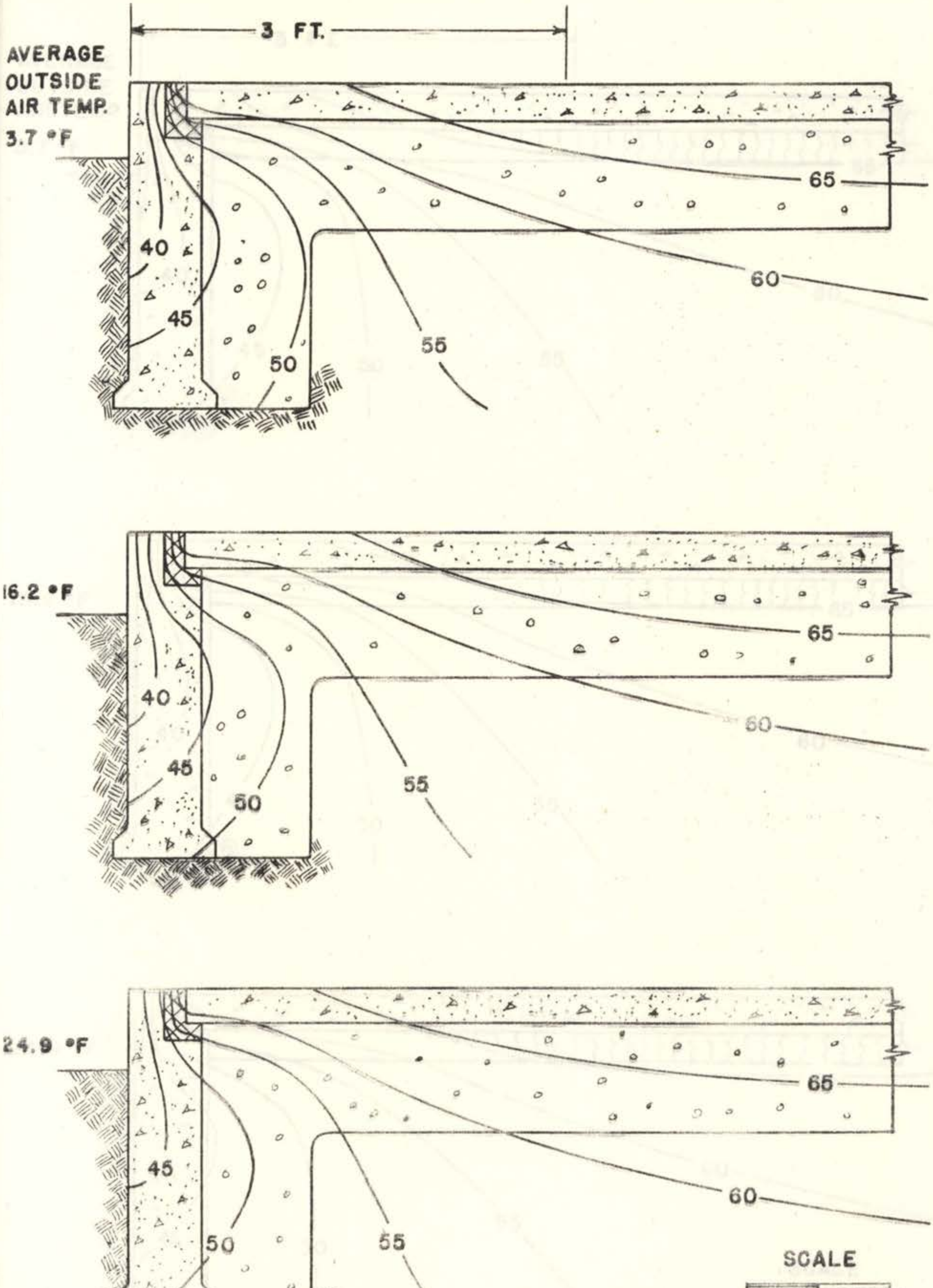

FIG. 22 ISOTHERMS FOR FLOOR "G" AT VARIOUS OUTSIDE AIR TEMPERATURES

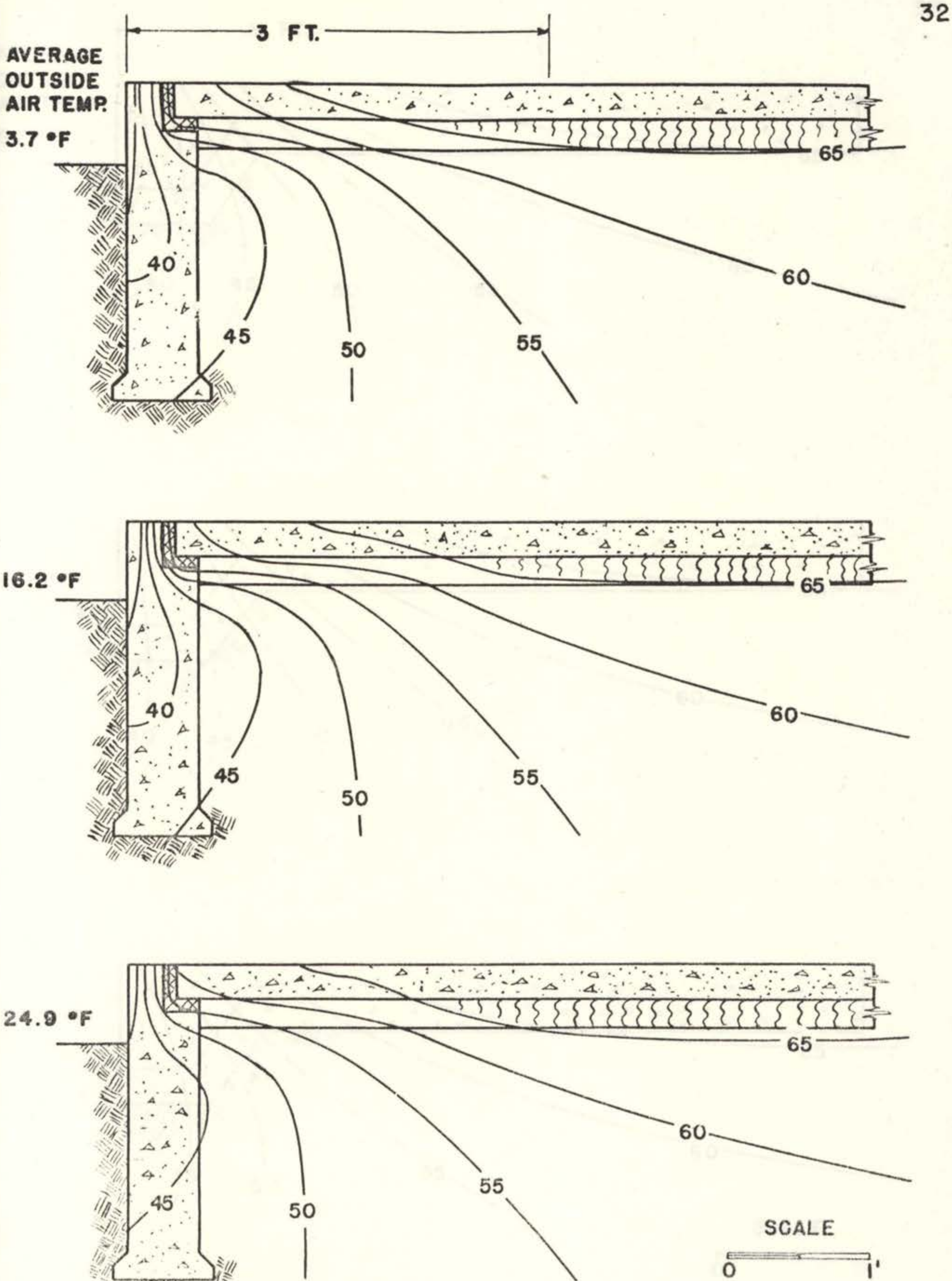

FIG.23 ISOTHERMS FOR FLOOR "H" AT VARIOUS OUTSIDE AIR TEMPERATURES

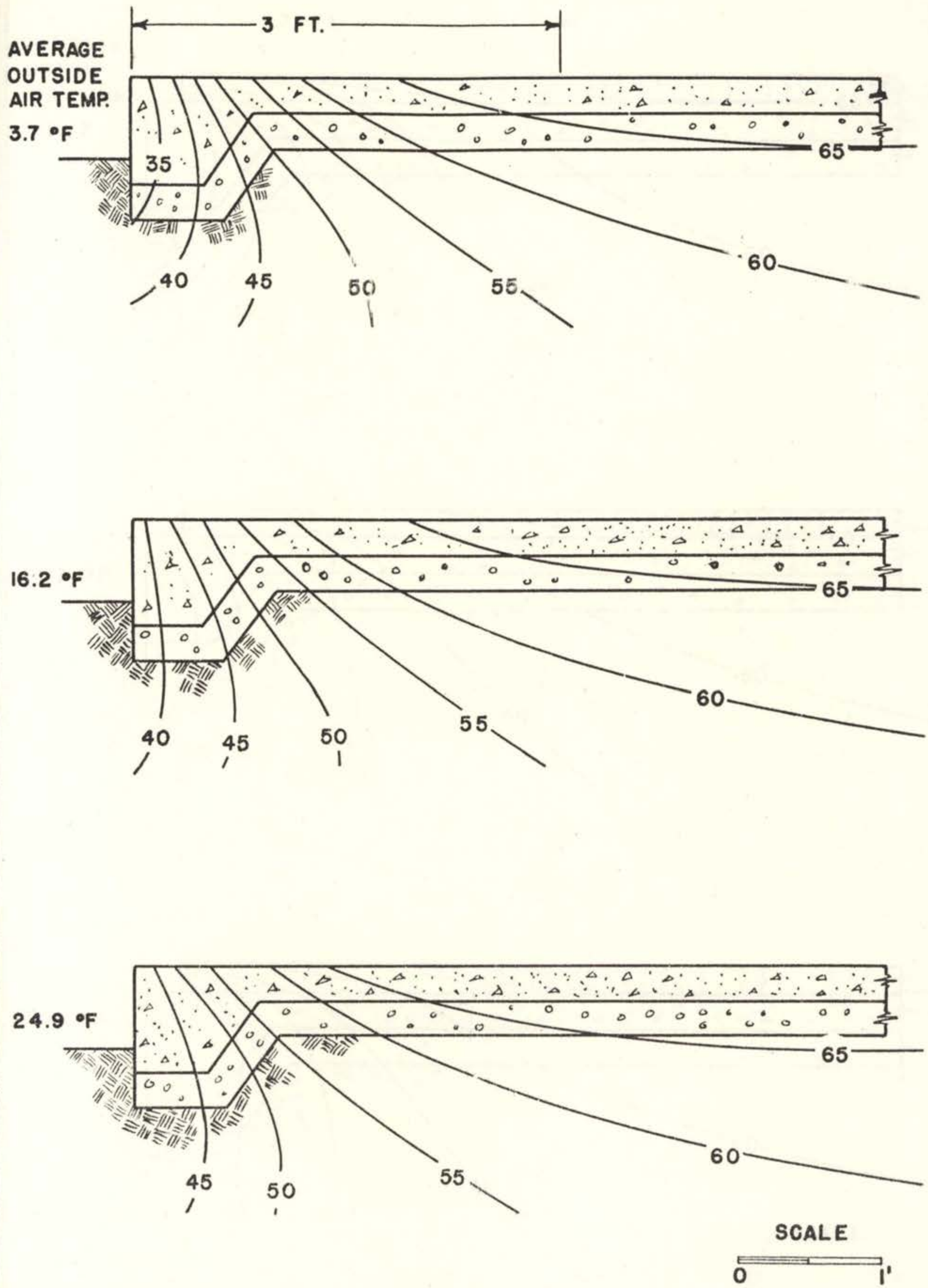

FIG.24 ISOTHERMS FOR FLOOR "J" AT VARIOUS OUTSIDE AIR TEMPERATURES

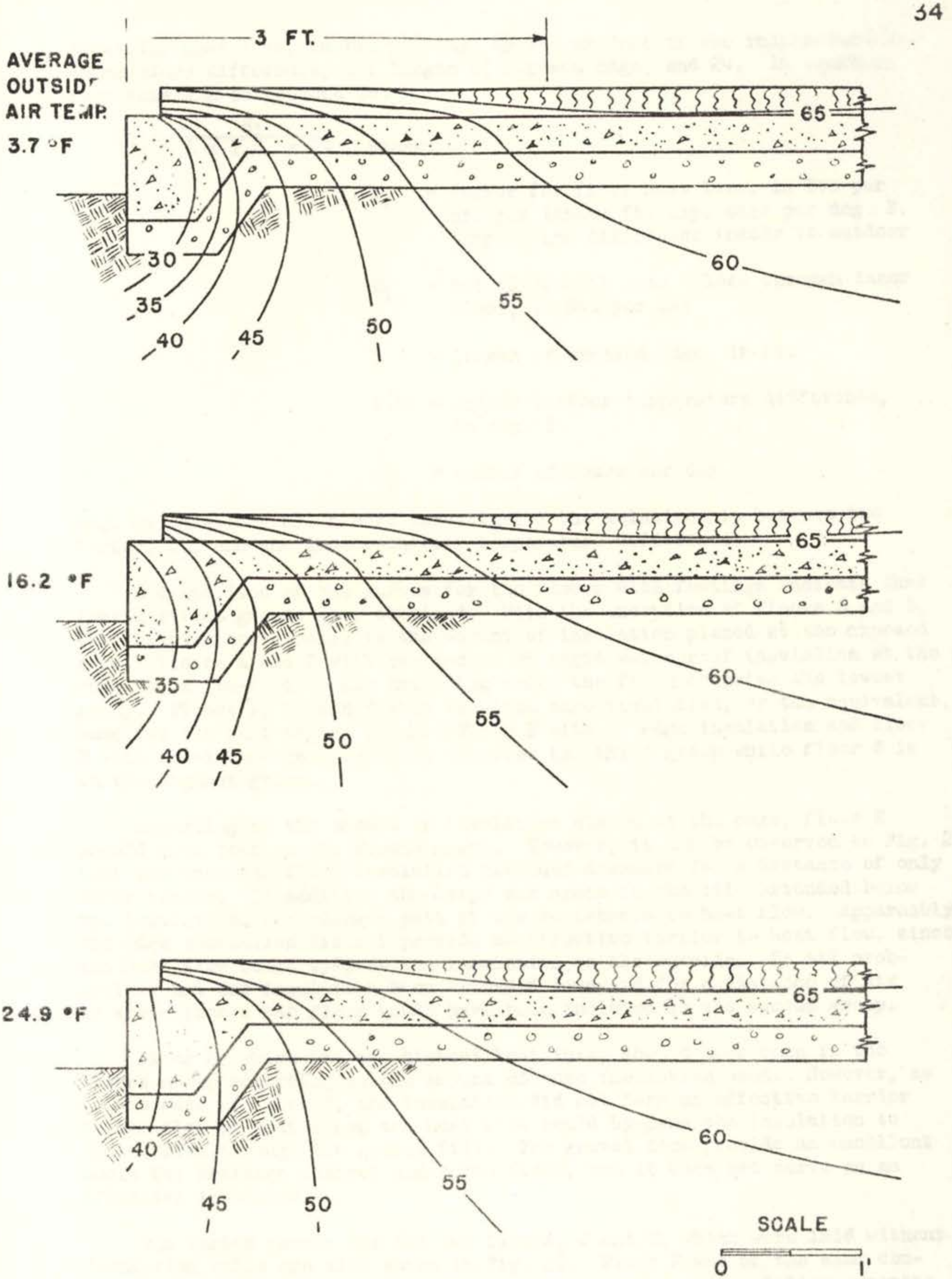

FIG.25 ISOTHERMS FOR FLOOR "K" AT VARIOUS OUTSIDE AIR TEMPERATURES

remaining heat loss, in Btu per day, by the product of the indoor-outdoor temperature difference, the length of exposed edge, and 24. In equation form this can be reduced to:

$$F_1 = \frac{H_1}{L \times T.D. \times 24}$$ where:

F_1 = factor for floor heat loss, in Btu per hr. per linear ft. exp. edge per deg. F. temperature difference indoor to outdoor

H_1 = net floor heat loss - loss through inner floor, in Btu per day

L = length of exposed edge, in ft.

T.D. = indoor-outdoor temperature difference, in deg. F.

24 = number of hours per day

Fig. 26 shows for all floors investigated the relationship between the factor, F_1, and the indoor-outdoor temperature difference.

A comparison of the curves for the floors with footings indicate that four distinct groups were obtained. With the exception of floors G and E, the grouping corresponds to the amount of insulation placed at the exposed edge. Floors A and D with two inches of rigid waterproof insulation at the edge and a two-foot border extending under the floor comprise the lowest group. Floors F, C, and H with one-inch edge insulation, or the equivalent, comprise the next higher group. Floor B with no edge insulation and floor E with one-inch edge insulation comprise the third group while floor G is in the highest group.

According to the amount of insulation placed at the edge, floor E should have been in the second group. However, it can be observed in Fig. 2 that the one-inch thick insulation extended downward for a distance of only three inches. In addition the large air space in the tile extended below the insulation, providing a path of low resistance to heat flow. Apparently the edge insulation did not provide an effective barrier to heat flow, since the heat flow could by-pass the insulation to the outside. In all probability had the insulation been extended downward for a distance of six to seven inches the floor would have been included in the second group.

Floor G, which has the highest heat loss, should have been in the lowest group according to the amount of edge insulation used. However, as in the case of floor E, the insulation did not form an effective barrier to the flow of heat since the heat flow could by-pass the insulation to the outside through the gravel fill. The gravel does provide an excellent media for drainage control under the floor, but it does not serve as an effective insulator.

The factor curves for the two floors, J and K, which were laid without foundation walls are also shown in Fig. 26. Floor K was of the same construction as J with the exception that three inches of insulating concrete was placed on the top of floor K.

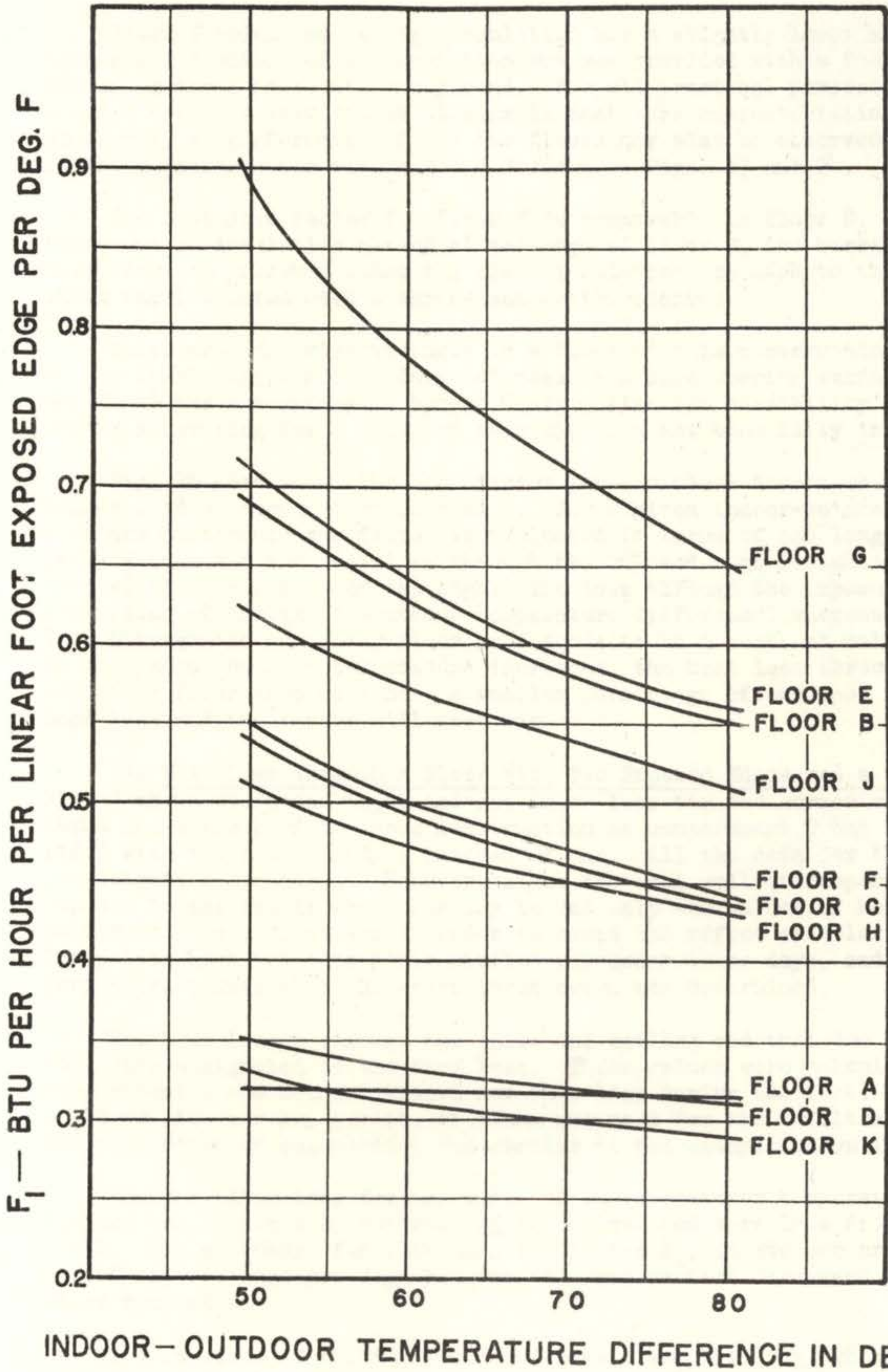

FIG. 26 VALUES OF F_1 FOR ALL FLOORS INVESTIGATED

Floor J which had no edge insulation has a slightly lower heat loss than floor B which had no insulation but was provided with a footing extending three feet into the ground. For all practical purposes floors B and J can be considered as similar in heat loss characteristics. The similarity in performance of the two floors may also be observed in the isotherm patterns for floors B and J shown in Figs. 17 and 24.

The heat loss factor for floor K is comparable to floor D. Although there was no insulation placed at the edge of floor K, the barrier to heat flow was unbroken since the floor insulation extended to the wall which was insulated with a three-inch cotton blanket.

There are some disadvantages to a floor of this construction, however, as the insulating concrete does not possess a hard wearing surface and the floor has a tendency to become dusty. Also the possibility of providing a covering for a floor of this type has not been fully investigated.

Fig. 26 also shows that the factor for any floor decreases as the indoor-outdoor temperature increases. For a given indoor-outdoor temperature difference the factor is evaluated in terms of the length of exposed edge and the heat loss through the exposed edge including the floor area within three feet of the edge. The loss through the exposed edge is a function of the indoor-outdoor temperature difference, whereas the heat loss through the remaining floor area tends to be a constant value. Thus as the indoor-outdoor temperature increases, the heat loss through this remaining floor area will have a smaller percentage effect upon the total heat loss and the factor will decrease.

14. <u>Heat Loss Through a Floor With Two Exposed Edges and a Corner.</u> -- Fig. 7 shows the gross input and net floor loss for the corner compartment A, which had a floor of the same construction as compartment D but was provided with two exposed edges instead of one. All the data for the entire investigation are shown. However, since the east wall of compartment A was exposed to the sun it was necessary to use only the values of heat input obtained on days without sun in order to avoid the effect of solar heat gain. The points with two concentric circles represent these days, and it was from these points that the gross input curve was determined.

The heat losses through the walls and ceiling and that due to infiltration were designated as the tare loss. These values were calculated since compartment A was not calibrated for tare loss during the test. A value of 15 cu. ft. per hr. per ft. of crack was used for the infiltration air, and the method of calculation was similar to the example shown in Appendix B.

The net floor loss for any value of indoor-outdoor temperature difference was obtained by subtracting the calculated tare loss from the gross input. The procedure for obtaining the factor F_1, in Btu per hr. per linear ft. of exposed edge per deg. F., was the same as that discussed for the other compartments.

A comparison of the factors for floors A and D in Fig. 26 shows that for all practical purposes they were similar in heat loss characteristics. Thus it was concluded that the heat loss for a floor with two exposed edges and a corner may be estimated by using the factors shown in Fig. 26.

15. Heat Losses - Alternate Method. -- Previous investigations of heat losses through concrete floors laid on the ground have evaluated the total heat loss in terms of the length of exposed edge and the indoor-outdoor temperature difference. This factor, in Btu per hr. per linear ft. of exposed edge per deg. F. temperature difference, was determined by dividing the heat loss, in Btu per day, by the product of the indoor-outdoor temperature difference, the length of exposed edge, and 24. In equation form, this can be reduced to:

$$F_2 = \frac{H_2}{L \times T.D. \times 24}$$ where:

F_2 = factor for heat loss, in Btu per hr. per linear ft. exposed edge per deg. F. temperature difference indoor to outdoor

H_2 = net floor heat loss, in Btu per day

For small buildings where the ratio of the area to the perimeter does not exceed 12 this method of estimating heat losses through concrete floors would be satisfactory. Similar factors determined from the present series of tests are shown in Fig. 27 and are applicable to ratios of area to perimeter of 12. However, the same factor may be used for lower ratios of area to perimeter without serious error. When applied to a room having area to perimeter ratio of six, the factor will give a calculated heat loss through the floor that is approximately thirty per cent higher than the method discussed in section 13.

Fig. 27 also shows that the factor decreases as the indoor-outdoor temperature difference increases. As previously explained the heat loss through the inner floor is almost constant and has a smaller percentage effect upon the total heat loss through the floor as the indoor-outdoor temperature increases.

16. Floor Surface Temperatures. -- Floor surface temperatures have an effect upon conditions for comfort. Obviously, if the floor is cold or feels cold to the touch of an individual, conditions of discomfort will result.

The surface temperature of a floor at a given point depends upon the rate at which heat is gained or lost at that point. If the surface temperature of the walls above the floor is low, the cold drafts of air descending along the walls will tend to lower the surface temperature of the floor. However, since the same type of construction and material was used for all exposed walls and the compartment temperatures were maintained at 70 deg. F., the surface temperature at the edge was dependent only upon the rate at which heat was lost at the edge of the floor.

As indicated by the isotherms shown in Figs. 17 to 25, the lowest surface temperature of the floor existed near the outside edge. The thermocouples located at a distance of six inches from the exposed edge, corresponding to the location near the base shoe in a normal wall structure, can be considered therefore as indicating the extreme temperature from the standpoint of floor comfort and the critical temperature from the standpoint of possible condensation.

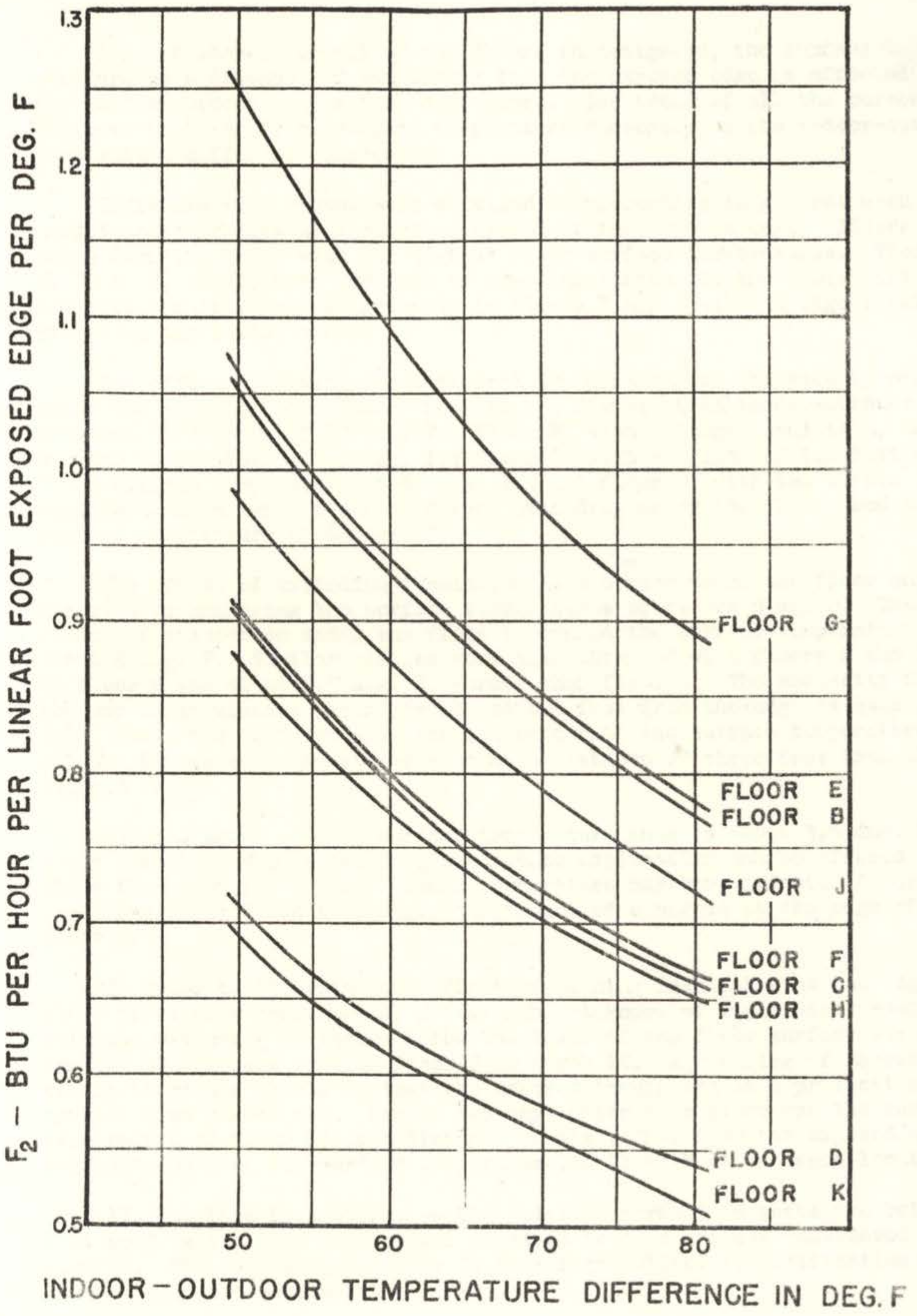

FIG. 27 VALUES OF F_2 FOR ALL FLOORS INVESTIGATED

Fig. 28 shows, for all of the floors investigated, the surface temperature at a distance of six inches from the exposed edge as affected by the indoor-outdoor temperature difference. The trend of all the curves indicate that the floor surface temperature decreases as the indoor-outdoor temperature difference increases.

Three distinct groups were obtained corresponding in general with the amount and thickness of insulation placed at the exposed edge. Floors D and G form the group with the highest floor surface temperatures. Floors H, E, K, C, and F, with one inch of edge insulation, or the equivalent, comprise the intermediate group while floors B and J with no edge insulation form the lowest group.

The effect of adding insulation at the edge can be observed by examining the surface temperatures for all the floors at an indoor-outdoor temperature difference of 70 deg. F. Floor B, with no edge insulation, had a surface temperature of 45 deg. F.; floor C, with one inch of insulation, had a surface temperature of 54 deg. F.; and floor D, with two inches of edge insulation and a two foot border extending under the floor, had a surface temperature of 62 deg. F.

The effect of extending insulation as a border under the floor may be observed by comparing the surface temperatures of floors G and D. The border of insulation under the floor increased the surface temperature about 2 deg. F. Similar results were also obtained with floors H and C, as floor H was about 2.5 deg. F. warmer than floor C. The necessity for the use of insulation extending beyond two feet from the edge is questionable, since the isotherm patterns indicate that the surface temperature for all the floors were almost the same at a distance of three feet from the exposed edge.

Floor J shows a floor surface temperature that is about 3.5 deg. F. lower than that for floor B. No adequate explanation can be offered other than that the outside ground temperature may have affected floor J more than floor B due to the greater amount of concrete at the edge of floor J.

In order to determine the effect of placing insulation at the edge of a floor previously constructed, a two-inch thickness of rigid waterproof insulation extending 12 inches below the level of the floor surface was placed against the exposed edge of floor J on March 10. A covering of asbestos cement board was placed against the exposed insulation as a protection against lawn mowers etc. Within two days after this placement the surface temperature of floor J, at a distance of six inches from the exposed edge, corresponded with the surface temperature of floor H at the same location.

17. Moisture Permeation. -- The moisture permeation tests are being continued as the data and results obtained to date are not considered conclusive. The following analysis is therefore subject to modification when further data are available.

For the purpose of analysis the floors were divided into three groups -- (1) floors with vapor barriers, which included A, C, D, G, and J, (2) floors without vapor barriers, which were B and H, and (3) floor K, the floor with the vermiculite covering. Moisture permeation data were not available in compartments E and F because of the insulation which was placed on the floors for the calibration tests. Fig. 29 shows the amounts of moisture permeation for these three groups as a function of time.

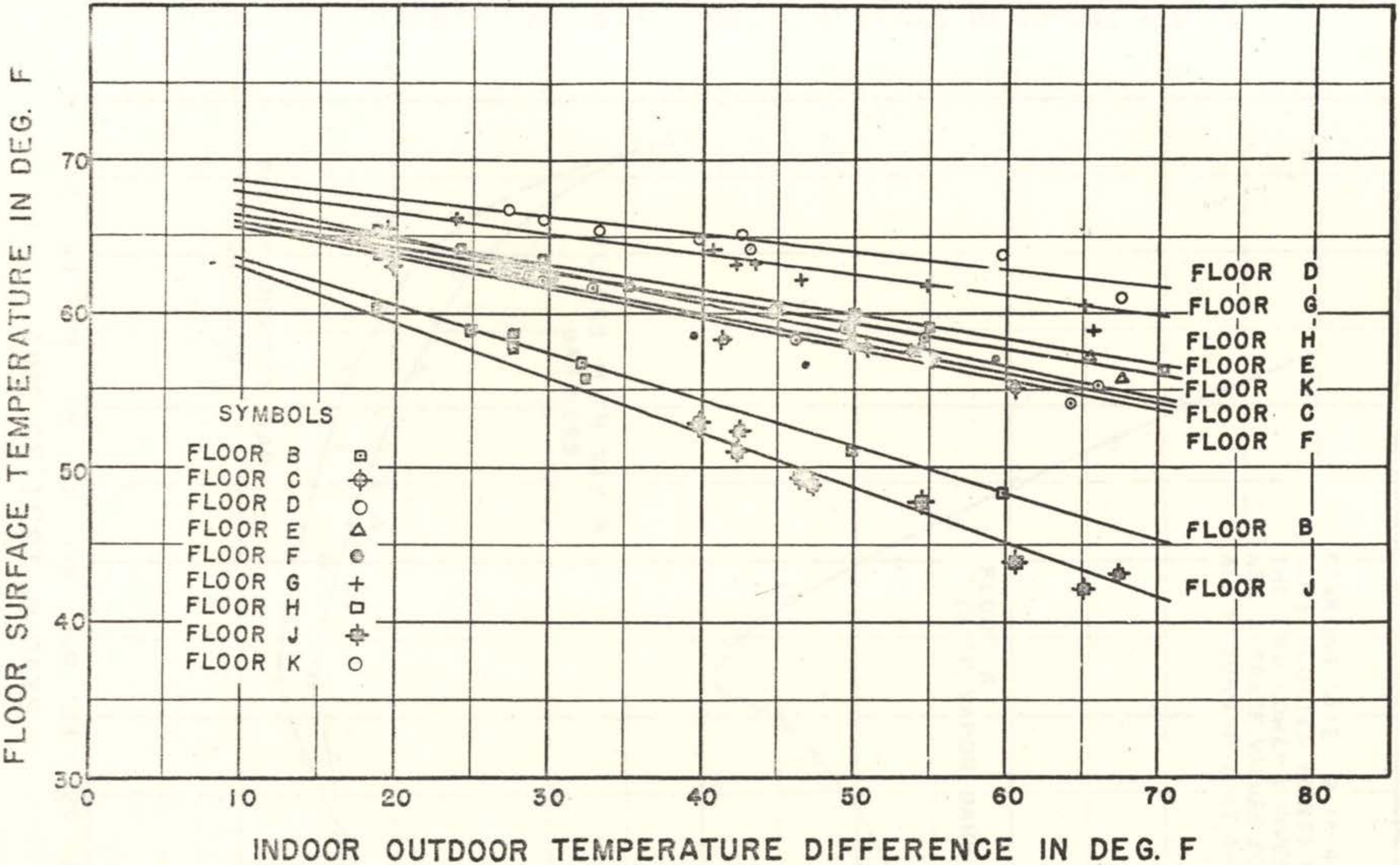

FIG. 28 FLOOR SURFACE TEMPERATURES 6 INCHES FROM EXPOSED EDGE FOR ALL FLOORS INVESTIGATED

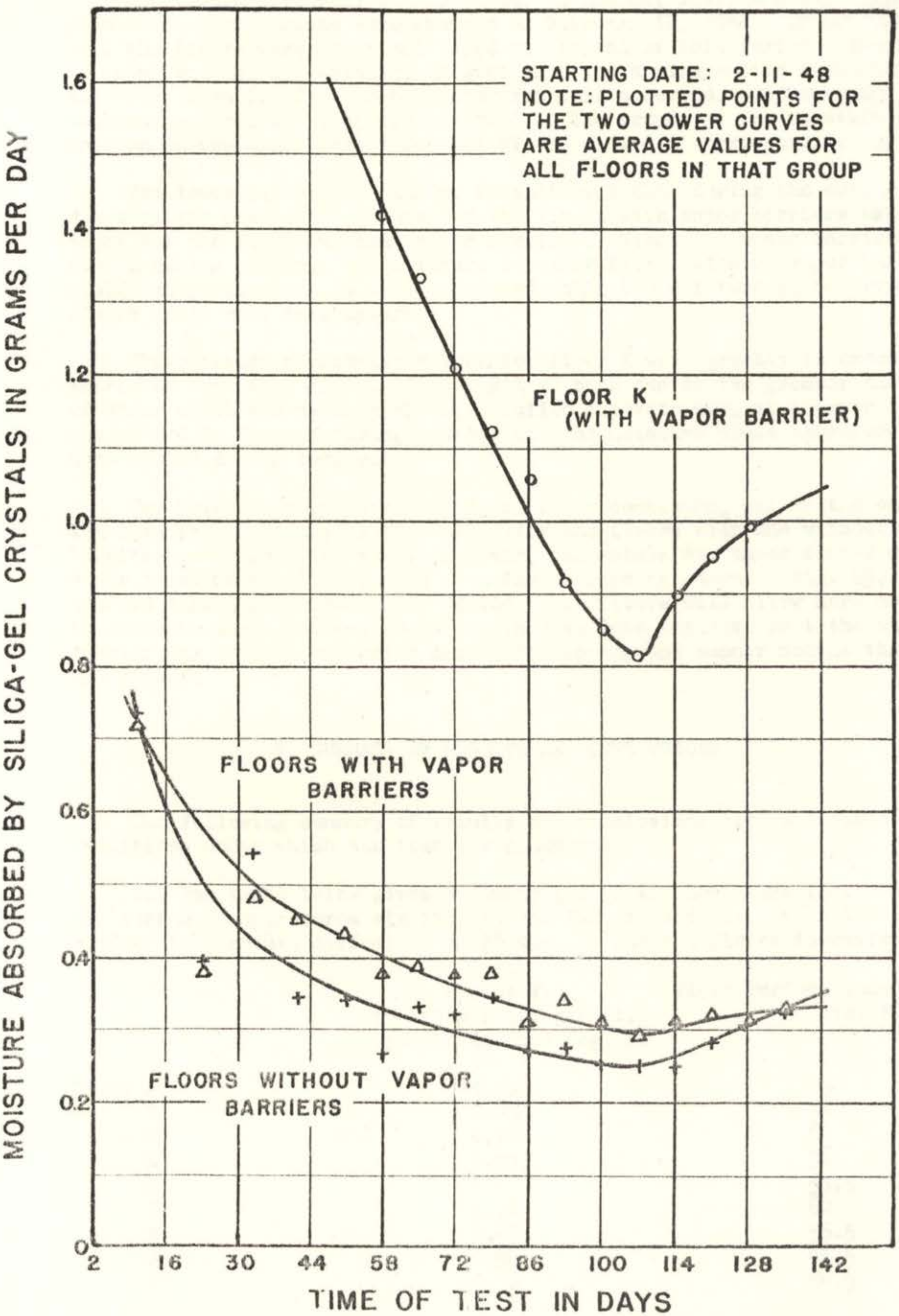

FIG. 29 MOISTURE PERMEATION FOR FLOORS WITH AND WITHOUT VAPOR BARRIERS

The floors were poured on November 18 and 21, 1947, and the moisture permeation measurements were started on February 11, 1948. It was thought that the floors were dried and cured at the end of this period. However, as shown on Fig. 29, evidence existed that the drying action continued until about June 1. On June 6 a heavy rainfall occurred, supplemented in the succeeding three weeks by more rainfall. The trends of the moisture permeation curves after June 1 for all floors showed a corresponding increase.

The lower two curves on Fig. 29 indicated that during the curing period the moisture permeation values for the floors with vapor barriers exceeded those for the floors without vapor barriers. Since the vapor barriers were placed during pouring, the moisture in those floors without vapor barriers could escape downward as well as upward while the moisture in the remaining floors could only pass upward.

The moisture permeation values for floor K were greatly in excess of those for any other floor. This may have been due to the greater amount of water which was used in the vermiculite concrete mix, as a vapor barrier was placed in floor K during pouring and the moisture could therefore only pass upward during curing.

The moisture permeation tests are being continued, and at the end of 135 days from February 11 the values for the floors with and without vapor barriers were about the same. However, the values for those floors without vapor barriers were increasing at a faster rate as shown in Fig. 29, and it appears that during the summer period these floors will allow more moisture to permeate through them. Data obtained to date indicate that the vapor barrier may be more effective during the spring and summer months than in the winter.

V. SUMMARY OF RESULTS AND CONCLUSIONS

The following summary of results and conclusions are applicable to the conditions under which the test was conducted.

(1) The table below gives a comparison of the heat loss factor F_1 and the surface temperatures six inches from the exposed edge at an indoor-outdoor temperature difference of 70 deg. F. for all floors investigated.

	Factor F_1, in Btu per hr. per ft. exposed edge per deg. F.	Floor Surface Temperature, in deg. F.
Floor B	0.58	45
C	0.46	54
D	0.32	62
E	0.59	56
F	0.47	53.5
G	0.71	60
H	0.45	56.5
J	0.54	41.5
K	0.30	54.5

From this table it appears that floor D with two inches of edge insulation and a two-foot border of insulation extending under the floor gives the best overall performance.

(2) The heat loss through a floor at a distance beyond three feet of the exposed edge is almost constant for any indoor-outdoor temperature difference.

(3) A large amount of the heat is lost through the exposed edge of a floor especially if the edge is above grade. A part of this heat is lost directly through the concrete to the air, and the remainder is lost through the floor for a distance of approximately three feet from the exposed edge. It is not only necessary to insulate the edge but also advisable to extend the insulation under the floor as a border for approximately two feet.

(4) A gravel fill provides a media for drainage control but is not an effective insulator.

(5) The heat loss through the floor of a basementless house may be small as compared to the total heat loss of the house. Therefore, the surface temperatures as affecting comfort are probably more important than the heat loss through the floor.

(6) Although insufficient data have been obtained, it appears that a vapor barrier beneath the concrete floor may be more useful in the spring and summer months than during the heating season.

(7) For estimating design heat losses through a concrete floor laid on the ground the following formulas and factors are suggested.

$H = F_1 \times L \times (t_i - t_o) + 2 \times (Ai)$

$H = F_2 \times L \times (t_i - t_o)$

in which,

H = heat loss through floor, in Btu per hr.

L = length of edge of floor adjacent to exposed wall of building, in ft.

t_i = inside temperature of the building, in deg. F.

t_o = outside design temperature, in deg. F.

Ai = area of inner floor = total floor area - floor area included within a three-foot border along the exposed edge, in sq. ft.

F_1 = heat loss factor based upon the amount of heat loss through the floor area included within a three-foot border along the exposed edge, in Btu per hr. per linear ft. of exposed edge per each deg. F. difference between indoor and outdoor temperatures. Values for this factor are shown in Fig. 26.

F_2 = heat loss factor based upon the total heat loss through the floor in Btu per hr. per linear ft. of exposed edge per each deg. F. difference between indoor and outdoor temperatures. Values for this factor are shown in Fig. 27.

Of these two factors, it is believed that F_1 will be more applicable to all constructions.

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2. Heat Loss Through Basement Walls and Floors, by F. C. Houghton, S. I. Taimuty, Carl Gutberlet, and C. J. Brown, Transactions - ASHVE, vol. 48, 1942, pp. 369-82.

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APPENDIX A

GENERAL LOCATION OF THERMOCOUPLES WITHIN EACH COMPARTMENT

Thermocouple No.	Horizontal Location	Vertical Location
1	6 ft. from exposed edge	3 in. above floor surface
2	6 ft. from exposed edge	Floor surface
3	6 ft. from exposed edge	4 in. below floor surface
4	6 ft. from exposed edge	8 in. below floor surface
5	3 ft. from exposed edge	3 in. above floor surface
6	3 ft. from exposed edge	Floor surface
7	3 ft. from exposed edge	4 in. below floor surface
8	3 ft. from exposed edge	8 in. below floor surface
9	2 ft. from exposed edge	3 in. above floor surface
10	2 ft. from exposed edge	Floor surface
11	2 ft. from exposed edge	4 in. below floor surface
12	2 ft. from exposed edge	8 in. below floor surface
13	2 ft. from exposed edge	12 in. below floor surface
14	15 in. from exposed edge	3 in. above floor surface
15	15 in. from exposed edge	Floor surface
16	15 in. from exposed edge	4 in. below floor surface
17	15 in. from exposed edge	8 in. below floor surface
18	15 in. from exposed edge	14 in. below floor surface
19	15 in. from exposed edge	20 in. below floor surface
20	6 in. from exposed edge	Floor surface
21	6 in. from exposed edge	4 in. below floor surface
22	Exposed edge	2 in. below floor surface
23	Exposed edge	12 in. below floor surface
24	Exposed edge	20 in. below floor surface
25	6 ft. from exposed edge	4 ft. above floor surface
26	6 ft. from exposed edge	3 in. below ceiling

APPENDIX B

DETERMINATION OF TARE LOSS FOR COMPARTMENTS B THROUGH K

The heat loss through the floor of any compartment was the difference between the gross heat input and the heat loss from the structure above, as shown in the following heat balance:

Gross heat input = wall loss (8 ft. high) + ceiling loss + infiltration loss + floor loss (1)

From which:

Floor loss (Btu per day) = gross heat input - (wall loss (8 ft. high) + ceiling loss + infiltration loss) (2)

The heat losses from the structure were grouped together as shown by the quantities within the parentheses and were designated as the tare loss. Equation (2) was thus reduced to:

Floor loss = gross heat input - tare loss (3)

It may be observed from Equation (3) that if the floor loss could be made equal to zero, the tare loss could be separately evaluated and would be equal to the gross heat input to the test compartments during calibration. Due to the identical construction of all compartments, compartments E and F were selected for the calibration tests. The floor loss could not be eliminated, but it was reduced to a minimum by placing 8 inches of mineral wool insulation on the floor. With this calibration arrangement the following heat balance was obtained:

Uncorrected tare loss = gross heat input during calibration = wall loss (7ft.-4in. high) + ceiling loss + infiltration loss + insulated floor loss (4)

A comparison of the right hand terms of Equation (4) with those in the parentheses in Equation (2) show that the wall heights differ and that an added term for the insulated floor loss appears in Equation (4).

Therefore in order to obtain a corrected tare loss it was necessary to make the following correction to Equation (4).

Corrected tare loss (Btu per day) = uncorrected tare loss + wall loss (8 in. high) - insulated floor loss (5)

Or:

Corrected tare loss (Btu per day) = gross heat input during calibration + wall loss (8 in. high) - insulated floor loss (6)

The two correction terms appearing in the right side of Equations (5) and (6) were calculated for a wide range of indoor-outdoor temperature differences by the use of the conventional heat transfer equation:

Heat loss (Btu per day) = 24 x area x heat transfer coefficient x temperature difference

The gross heat input during calibration for compartments E and F were obtained from the daily watt-hour meter readings and both were plotted against the corresponding indoor-outdoor temperature differences for the day. The two corrections indicated in Equation (6) were made, as shown in Fig. 30, and the corrected tare loss curve was thus obtained.

These measured values of the gross heat inputs during calibration were checked by calculated values of heat losses using the conventional heat transfer equations, as shown in the example to follow. The values of conductivities and conductances were obtained from the ASHVE Guide[3], and the temperatures used in the calculations were the daily averages of the temperatures from the strip-chart recorder. These calculated values of ceiling, wall, and insulated floor losses were subtracted from the uncorrected tare for each day, and the remainder was assumed to be the infiltration loss. Using the latter value in the equation for infiltration heat loss, the air leakage, in terms of cu. ft. per hr. per ft. of crack, could be calculated for the known length of crackage of the outer walls. The following example of the above procedure is for compartment E for March 6, 1948.

Example Showing Calculation of Heat Losses

A. Areas, (A)
- Exposed wall: 7.33 x 5.67 = 41.5 sq. ft.
- Ceiling: 12 x 5.67 = 68.0 sq. ft.
- Insulated floor: 12 x 5.67 = 68.0 sq. ft.

B. Calculated Coefficients of Overall Heat Transfer, (U)
- Wall: 0.0735 Btu per hr. per sq. ft. per deg. F.
- Ceiling: 0.0705 Btu per hr. per sq. ft. per deg. F.
- Floor insulation: 0.0332 Btu per hr. per sq. ft. per deg. F.

C. Average Temperatures
- Outdoor: 34.0 deg. F.
- Indoor: 70.0 deg. F.
- Attic: 42.7 deg. F.
- Floor surface (under insulation): 54.6 deg. F.

D. Temperature Differences, (T.D.)
- Indoor to outdoor: 70.0 - 34.0 = 36.0 deg. F.
- Indoor to attic: 70.0 - 42.7 = 27.3 deg. F.
- Indoor to floor surface: 70.0 - 54.6 = 15.4 deg. F.

E. Meter Readings (observed)
- March 6, 1948: 478149 watt-hr.
- March 5, 1948: 474961 watt-hr.
- Difference: 3188 watt-hr.

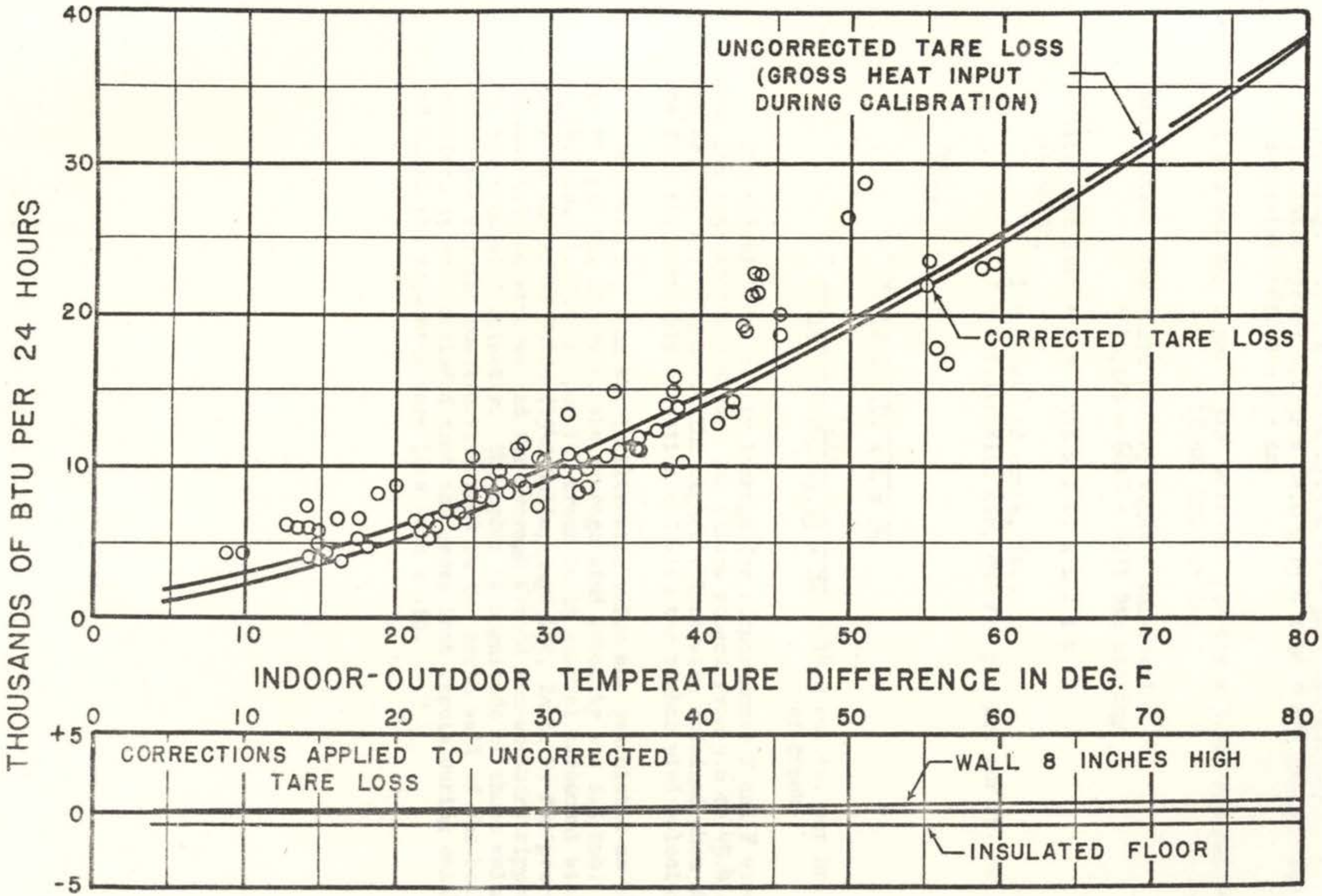

FIG. 30 TARE LOSSES OBTAINED FROM CALIBRATING COMPARTMENTS "E" AND "F"

F. Losses per 24 hrs. (Loss = U x A x T.D. x 24, in Btu per day)
Wall: 0.0735 x 41.5 x 36.0 x 24 = 2635 Btu per day
Ceiling: 0.0705 x 68.0 x 27.3 x 24 = 3141 Btu per day
Insulated floor: 0.0332 x 68.0 x 15.4 x 24 = 834 Btu per day
Sub-total: 6610 Btu per day

Total Btu per day input = 3188 watt-hr. per day x 3.413 Btu per watt-hr.
= 10,881 Btu per day

Infiltration loss = Btu per day input - sub-total
= 10,881 - 6610 = 4271 Btu per day

Infiltration loss = H_1 = 0.018 x T.D. x L x I x 24
in which,

L = length of crack, ft.
I = infiltration air, cu. ft. per hr. per ft. of crack

Then,

$$I = \frac{H_1}{0.018 \times T.D. \times L \times 24}$$

$$= \frac{4271}{0.018 \times 36.0 \times 19.33 \times 24} = 14.2 \text{ cu. ft. per hr. per ft. of crack}$$

The calculations of air leakage for compartments E and F were in agreement for corresponding days. The values ranged from 9.6 to 45.4 cu. ft. per hr. per ft. of crack. The higher values were obtained when the wind was from the northerly direction and with the higher wind velocities.

On March 10, when the infiltration value was calculated as 14.2 cu. ft. per hr. per ft. of crack, the average wind velocity was 8.3 mph. The value of 14.2 cu. ft. per hr. per ft. crack is in general agreement with those given in the ASHVE Guide (1948 Guide, page 152, Table 2) for poorly fitted weatherstripped windows and for average fitted non-weatherstripped windows for the same wind velocity. The order of magnitude of these values seem reasonable for the construction used in the north wall of the building, and therefore it was concluded that the gross heat inputs during calibration and hence the corrected tare loss were valid.