Effect of Edge Insulation Upon Temperature and Condensation on Concrete-Slab Floors

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Effect of Edge Insulation Upon Temperature and Condensation on Concrete-Slab Floors

Harold R. Martin, Paul R. Achenbach, and Richard S. Dill

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By means of a special structure, with necessary refrigerating apparatus and auxiliary equipment, nine concrete-slab floor specimens, each about 4½ by 6½ ft, were subjected to temperature conditions simulating those to which such floors in basementless houses are exposed during cold weather. As installed in the structure, the exposed edge of each specimen abutted or overlapped a foundation typical of that around the perimeter of a house; the other three edges were insulated to reduce the heat exchange to a negligible amount. The air in the structure above the specimen was maintained at about 70° F, and that above the earth beyond the exposed edge was maintained at 32° F and 0° F for the different tests simulating winter conditions. The exposed edges of the several specimens were insulated in different ways to determine the effect of edge insulation on floor-surface temperatures and the possibility of condensation. It was found that the temperature of the floors with edge insulation was from 9 to 13 deg F higher at a point 1 in. from the cold wall and the average temperature of the 30-in. border next to the cold wall from 3 to 5 deg F higher than that of the floor without edge insulation, the simulated outdoor temperature being about 0° F in both cases. Condensation, which probably would occur on uninsulated floors under certain conditions, can be prevented by the use of edge insulation. Some recommendations concerning types and arrangements of edge insulation are included for outdoor temperatures as low as 0° F.

1. Introduction

As a result of economic conditions and construction material scarcity, there has been a great increase in the number of basementless houses constructed in recent years. The floor most generally used in this type of house is the concrete slab, sometimes placed on the ground but more often on a fill of gravel or similar material. Some low-cost houses have concrete floors containing heating pipes or ducts; others are equipped with space heaters or heating devices that deliver heat above the floor surface. Tests have been made on heated floors by others [1, 2, 3].[2] The present experiments concern only unheated floors.

Past experience and experimental work [4] have shown that the heat loss of unheated concrete floors on the ground is proportionately too small to be of material importance from an economic standpoint but that heat transfer in such floors merits consideration on account of its effect upon comfort and condensation. For this reason, no attempt was made during these tests to measure heat loss through the specimen floor, attention being concentrated on the determination of the effect of edge insulation on floor-surface temperatures for different outside temperatures.

Because concrete is a good conductor of heat, it can be expected that a floor constructed of this material will be relatively cool in the region near the outside walls in cold weather. This cool border area is often too chilly for the comfort of those who wish to occupy that part of the room. Two methods are possible for bettering the condition: (1) to apply heat in the border area or (2) to increase the resistance of the heat path through the concrete or through the earth beneath by thermal insulation. This paper is concerned with the latter method. It is well recognized that such a floor, even if of the best construction possible, will still be chilly if the room does not have the proper distribution of heat.

Water vapor will condense on any surface colder than the dewpoint of the air with which it is in contact; for this reason, condensation sometimes occurs on concrete floors in the cold region near an outside wall. To prevent such condensation and promote comfort, the temperatures in this region should be maintained at a higher level than those often found on uninsulated concrete floors. Thermal insulation applied near the outer, or exposed, edge of a concrete floor will reduce the heat flow and raise the floor-surface temperatures.

In order to obtain more detailed information on the arrangement and amount of insulation needed for concrete floors, a special structure was erected at the National Bureau of Standards in which specimen floor sections could be exposed to simulated winter conditions. As it was impracticable to test all conceivable edge arrangements for all climatic conditions, the present investigation was planned to extend existing knowledge and to provide a basis for prediction of the performance of floors with different edge arrangements in climates of different degrees of severity.

[1] This investigation was planned and conducted in cooperation with the Housing and Home Finance Agency, formerly the National Housing Authority, as a study of methods for improving the acceptability of concrete floors for dwellings.

[2] Numbers in brackets indicate the references at the end of this report.

2. Test Equipment

2.1. Test Structure

To obtain information on concrete-slab floors, the structure shown in figure 1 was erected at the National Bureau of Standards. This structure was a wood-frame building about 36 ft long and 12 ft wide attached to one wall of an existing insulated enclosure. The exposed walls and ceilings of the structure were filled with rock-wool insulation, one layer 3⅝ in. thick being used in the walls and twice this thickness in the ceilings, as shown in figure 2. The building was divided lengthwise into two nearly equal compartments by a frame partition simulating an outside wall, as shown in figures 2 and 3. The 2- by 4-in. studs of the wood-frame partition panels were faced with ½-in. plasterboard, and the stud spaces were filled with 3⅝ in. of rock wool. The partition rested directly on the edge of the floor slab or on a concrete-block wall, depending upon the design of the particular specimen. For the tests, one of these compartments was heated and the other cooled. There were no windows in the structure, and each compartment was made accessible by a refrigerator-type door. The cold compartment was not floored.

2.2. Description of Floor Specimens

The floor of the heated compartment consisted of seven concrete slabs, each about 4½ ft in width and 6½ ft in length.

A 4-in. air space was provided between adjacent floor test sections to diminish the passage of heat between specimens. This air space was formed between dams made of 1-in. boards nailed on 2- by 4-in. studs. These dams extended into the earth 4 ft below the floor surface and were left in place during the tests. The edges of the end floors and the edges of all floors opposite the cold space were similarly protected, as shown in figure 2. It was expected that the air space, the well-insulated structure, and the moderate temperature differentials involved would be such that heat exchange between floors and between floors and the outside air and earth would be unimportant. As an added precaution, test data were not taken on the floors at the two ends of the structure.

Floors 1, 3, 4, and 5 shown in figure 4 each had a partition simulating an insulated wood-frame wall at the edge of the floor. Only floor 5 of this group was without edge insulation. Floor 2, shown in figures 4 and 5, referred to hereinafter as floor 2A for the first year's tests and floor 2B for the second year's tests, and floors 6, 7, 8, and 9, also shown in figure 5, had concrete-block walls with 2-in. wood furring strips and ½-in. gypsum wallboard extending 12 in. above the floor. For these floors, the concrete-block walls were a continuation of the foundation construction for a height of 12 in. above the floor. All floors in this group were provided with edge insulation.

Floors 1, 2, 3, and 4, shown in figure 4, were insulated with fiberboard dipped in coal-tar mastic. The thermal conductivity of the fiberboard was about 0.37 Btu/(hr) (sq ft) (deg F/in.). The edge construction of these floors was as follows:

Floor 1. Fiberboard ¾ in. thick was placed in an L-shape between the floor and foundation and at the exposed edge of the floor. The insulation on the exposed edge was protected by a nominal 1- by 6-in. wood board.

Floor 2. A piece of fiberboard 2 in. thick an 10 in. high was placed vertically to separate the

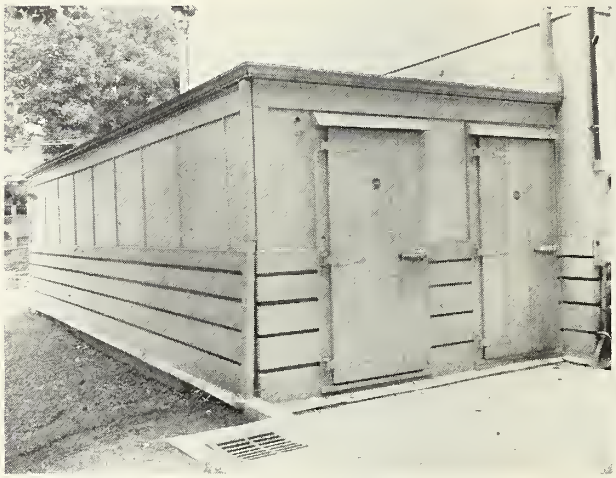

FIGURE 1. *Exterior view of test structure.*

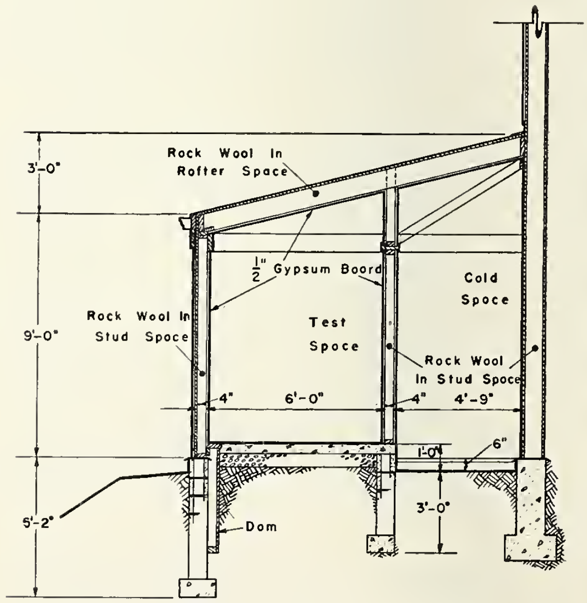

FIGURE 2. *Sectional view of test structure.*

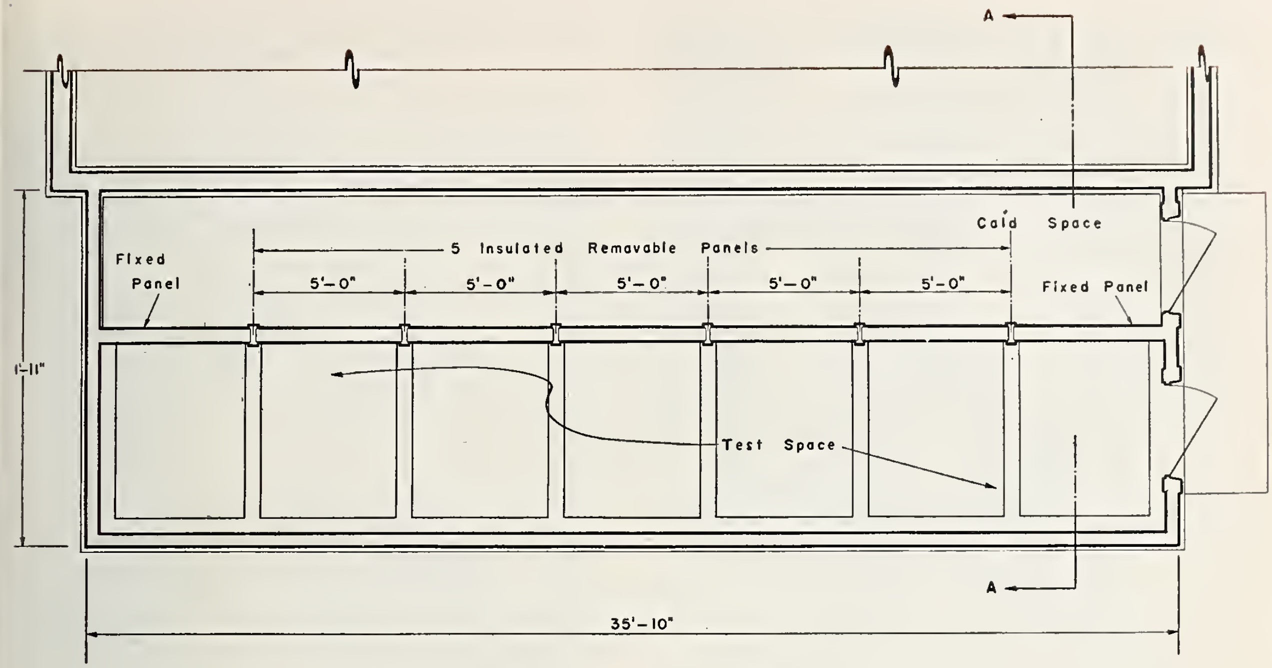

FIGURE 3. *Plan view of test structure.*

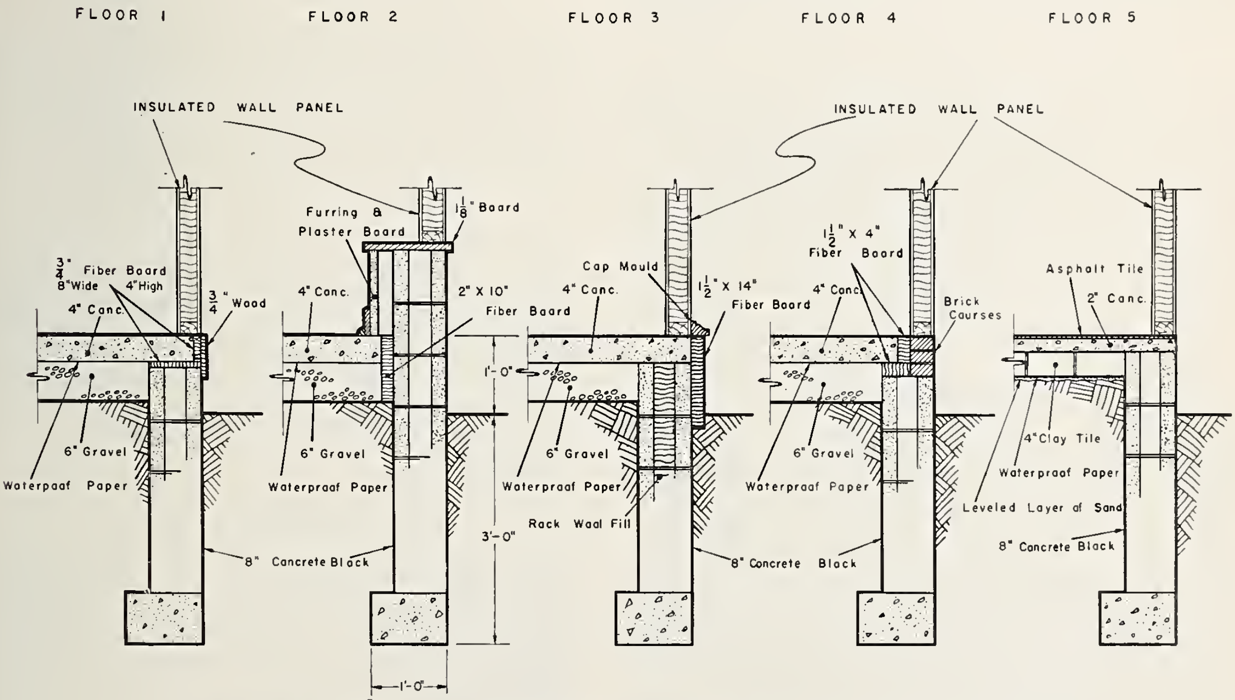

FIGURE 4. *Section showing construction details of floors tested in tests 1 and 2.*

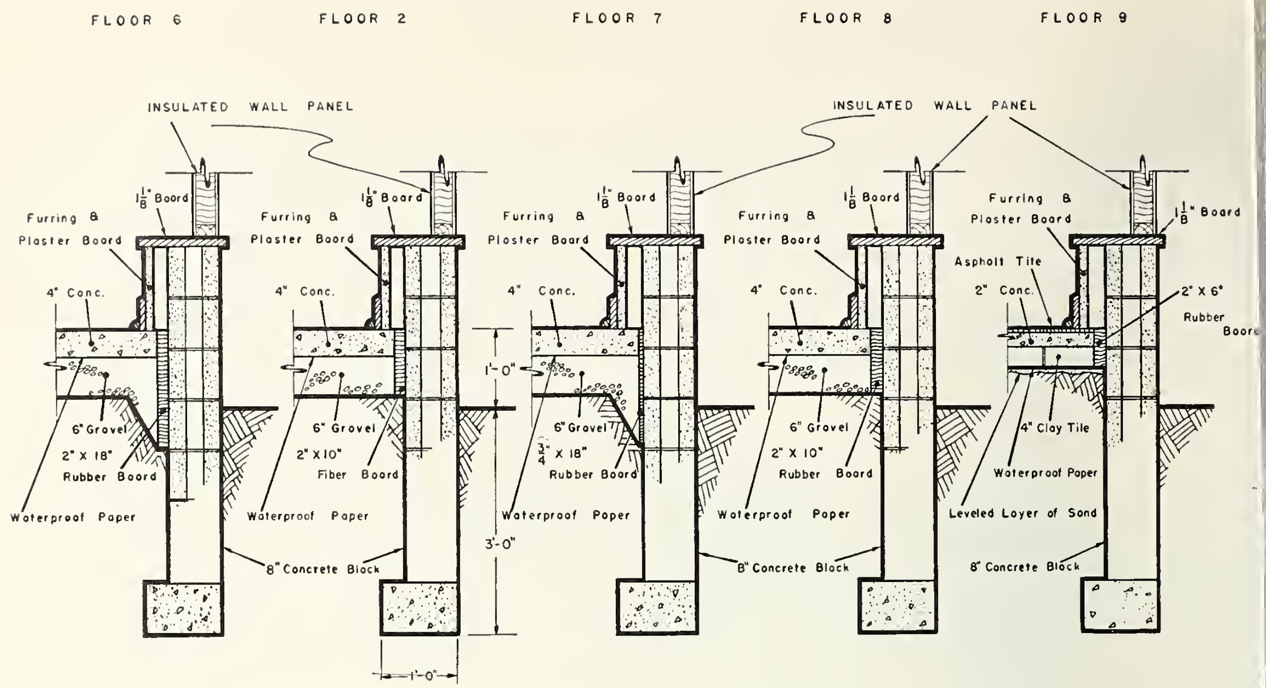

Figure 5. *Section showing construction details of floors tested in tests 3 and 4.*

foundation from the edge of the slab and the gravel beneath it.

Floor 3. A piece of fiberboard 1½ in. thick and 14 in. high was affixed externally to cover the exposed edge of the slab and the foundation and extended to a depth of 2 in. into the ground.

Floor 4. Fiberboard 1½ in. thick was placed in an L-shape between the floor and foundation and between the exposed edge of the floor and the facing brick on which the wall rested.

Floor 5. No insulation was used at the edge of this floor. The concrete slab rested upon the concrete-block foundation.

Floors 6, 7, 8, and 9 were insulated with rubber-board insulation having a thermal conductivity of about 0.25 Btu/(hr)(sq ft)(deg F/in.). These floors, shown in figure 5, were insulated with two different thicknesses (¾ in. and 2 in.) and three different depths (6 in., 10 in., and 18 in.) of rubber board in order to study the effect of insulation thickness and depth on the floor temperatures. Floor 2, designated as specimen 2A for the tests made during the first year, was left intact during the installation of floors 6, 7, 8, and 9, to provide a comparison between the results obtained with fiberboard and those obtained with rubber board. The edge constructions of specimens 6, 7, 8, and 9 were similar in that the same type of insulation, although of different thicknesses and depths, was placed in a vertical position in each case between the foundation and the slab and gravel. The thicknesses and depths of the rubber board for the several specimens were as follows:

Floor	Thickness	Depth
	in.	*in.*
6	2	18
7	¾	18
8	2	10
9	2	6

A view of the test space as arranged for tests 1 and 2 is shown in figure 6. Floors 1 to 5, inclusive, are shown in consecutive order, with floor 5 appearing in the foreground. A view of the test space for tests 3 and 4 is shown in figure 7 and floors 6, 2, 7, 8, and 9 are shown in the order mentioned, with floor 9 appearing in the foreground.

2.3. Heating Equipment

The heating equipment shown in figures 6 and 7 was used in the heated compartment of the test structure to produce and maintain temperatures simulating those in a house. The heater and distribution system were designed to provide heating almost entirely by convection and to provide uniform temperatures over all the test floors. The heater consisted of resistance-type electric heating elements mounted on the inside of a metal duct, which in turn was connected to the outlet of a centrifugal blower. The section of metal duct containing the electric heating elements was well

FIGURE 6. *View of floor specimens, wall construction, and equipment in the test space for tests 1 and 2.*

insulated to prevent appreciable radiation of heat. The air uptake from the heater was connected to a horizontal duct located about 7 ft above the floor. The duct was provided with outlets on the upper side to distribute warm air throughout the test space without creating high velocities near the floor. The heater was controlled automatically by a room thermostat and relay. The thermostat, visible in figures 6 and 7, was of the bimetallic type, with a relatively long temperature-sensing element to provide greater sensitivity. It was located at approximately the center of the heated compartment, 30 in. above the floor.

2.4. Cooling Equipment

Cooling of the air in the cold compartment of the test structure was effected by means of two banks of iron-pipe refrigeration coils mounted longitudinally in the test space. These coils were enclosed in sheet-metal housings, which were open at the bottom to reduce the transfer of heat by radiation yet permit forced circulation of air over them. A centrifugal blower was used to draw air over the coils and discharge it through a horizontal distribution duct near the ceiling of the cold compartment. Cooled air was discharged upward through several outlets to eliminate high-velocity air motion near the ground surface. The refrigeration coils were operated on the flooded principle, employing an accumulator tank and float.

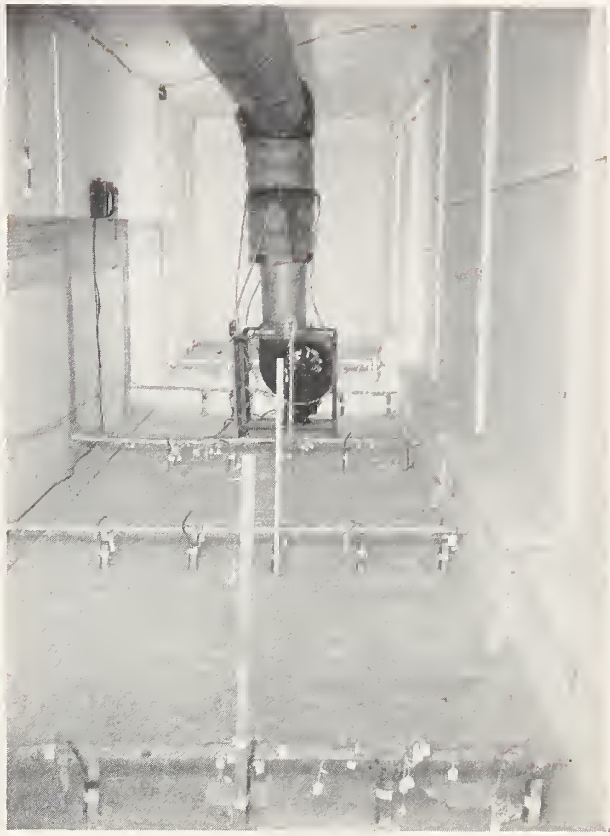

FIGURE 7. *View of floor specimens, wall construction, and equipment in the test space for tests 3 and 4.*

An automatic pressure-regulating valve was provided in the suction line to maintain constant pressures and temperatures in the coils at preselected values. With this equipment, nearly uniform temperatures were maintained in the cold compartment of the test structure, with a minimum of air motion opposite the edges of the test floors and at the ground level, these being the zones of principal interest.

2.5. Temperature Measurements

Temperatures were measured with copper-constantan thermocouples placed in a vertical plane passing through the center line of each floor specimen at selected stations indicated in figure 8 by small circles. A semiprecision potentiometer was used to measure the electromotive force developed by the thermocouples. Holes to the desired depth were made by driving a 1½-in. pipe into the soil. Because of cave-ins, the thermocouple wires were placed in the ground before final removal of the pipe. The thermocouples were enclosed in a rubber tube in order to protect them from dampness, and the tubes were filled with paraffin. The rubber tube and the thermocouples were supported on sticks that were inserted into the pipes to the desired level after sufficient earth had been re-

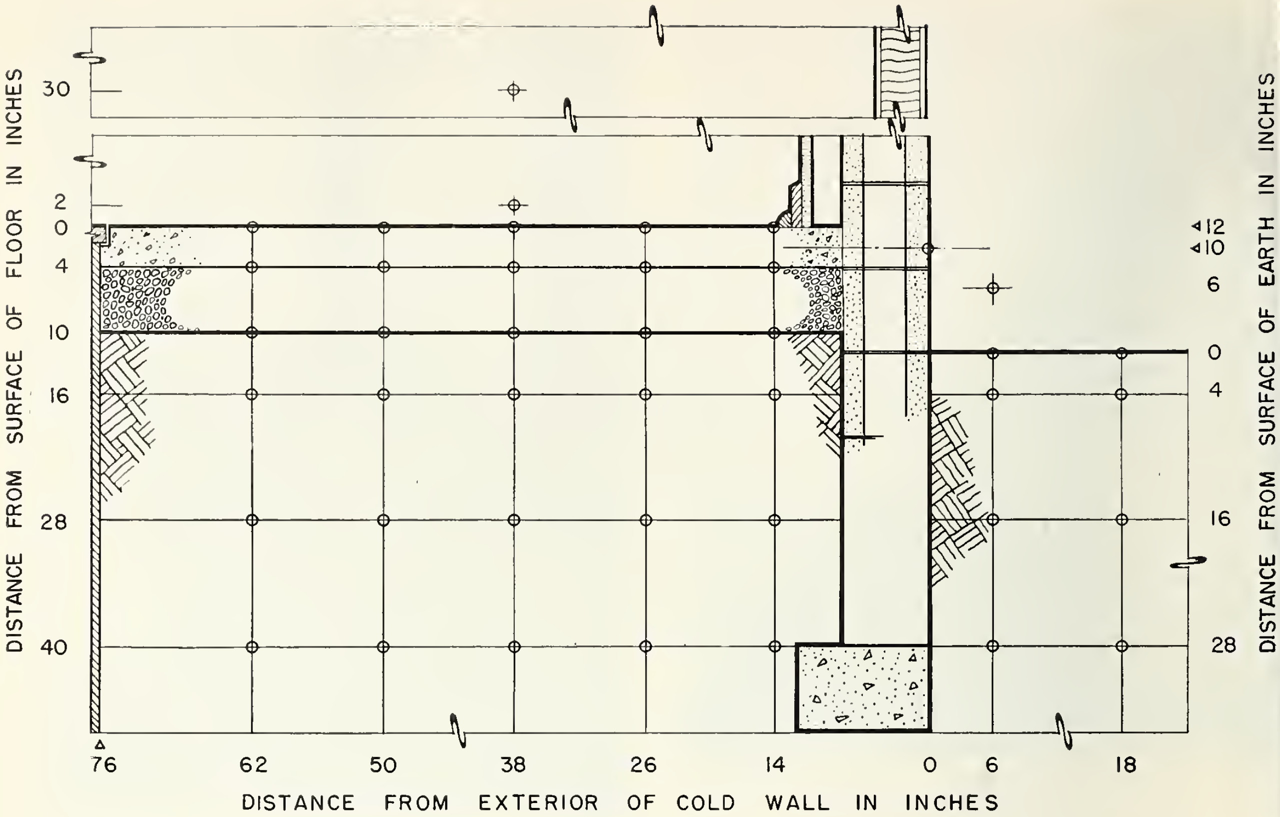

FIGURE 8. *Diagram of temperature stations for concrete-slab floor tests.*

In the case of floors 5 and 9, which had slabs only 2 inches thick, the measurements were made on the surface and at depths of 2, 6, 12, 28, and 40 inches instead of the stations shown. In addition to the stations shown, measurements were made on the surface of floors 1, 3, 4, and 5 at a distance of 6 inches from the exterior of the cold wall and at a distance of 13 inches from the same reference for the other floors. In the case of floor 1, which had a wood protective board and floor 3, which had fiberboard over the outer edges of the floors, temperature measurements were made on the outer surface of these materials at the extended centerline of the floor slab instead of on the outer surface of the edge of the wall.

moved from the holes. The pipe was then removed, and earth was tamped into the holes around the sticks and the rubber tubes. Because the wall of the rubber tube was thin and because the earth was a considerably better conductor of heat than either the tube, paraffin, or supporting stick, it was considered unlikely that these materials would cause significant error in the temperature measurements.

3. Test Procedure

The duration of the tests ranged from 25 to 37 days. Readings were taken at the start of each test and daily thereafter throughout the week. No readings were taken during weekends. The "day of test" referred to in this report was the elapsed time from the start of each test. A comparison of the temperatures taken on successive days indicated that the 25-day test period would be satisfactory because the heat flow had closely approached the steady-state at the end of this period of time. Two tests were made on the first set of floor specimens shown in figure 4. The first test began May 6 and lasted 31 days, and the second test began June 10 and lasted 37 days, with the cold compartment maintained at about 0° F and 32° F, respectively. The following year, two additional tests were made on the second set of floor specimens shown in figure 5. The third test began on June 30 and lasted 25 days, and the fourth test began on July 29 and lasted 25 days, with the cold compartment maintained at about 0° F and about 32° F, respectively. The heated compartment, or test space, was maintained at about 70° F throughout all tests. Any moisture condensation on the floors was noted.

4. Test Results and Discussion

4.1. Approach to Steady-State Conditions

The approach to steady-state conditions of heat transfer was determined by plotting and com-

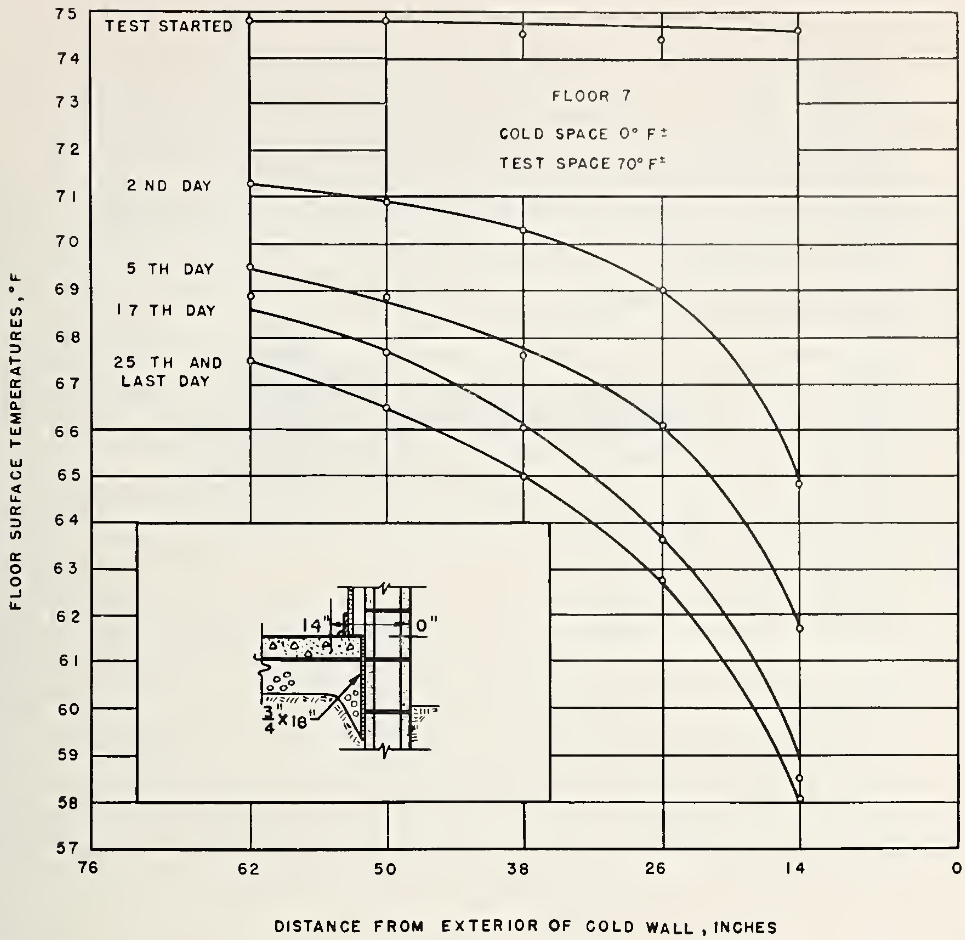

FIGURE 9. *Variation in floor-surface temperature with distance from the exterior of the cold wall for floor 7 on selected days during test 3.*

paring daily floor-surface temperatures, subsoil temperatures, and other pertinent temperatures. To illustrate this, data pertaining to floor 7 were considered representative, and these data are shown graphically in figures 9 and 10 for the test with temperatures in the cold space maintained at about 0° F.

Figure 9 shows the temperature gradient on the surface of floor 7 for selected days from a point about 2 in. from the quarter round of the mop board to a point 62 in. from the exterior of the cold wall. The test was started with all parts of the floor and edge construction near the surface at temperatures between 74° and 75° F.

The changes in the temperatures on the floor surface, in the cold space, and beneath the ground surfaces in both the test space and the cold space for floor 7 during the 25 days of test 3 are shown in figure 10. It may be seen in this figure that practically no change occurred in the temperature on the surface at either edge of the floor or on the exterior surface of the cold wall at station E after the first 10 days of the test. The temperature in the earth at a depth of 28 in. below the surface in the cold space was still decreasing, though very slowly, after 25 days of exposure. Figure 10 indicates that the decrease in floor-surface temperature shown in figure 9 between the 17th and 25th days probably resulted from variations in the air temperature in the test space.

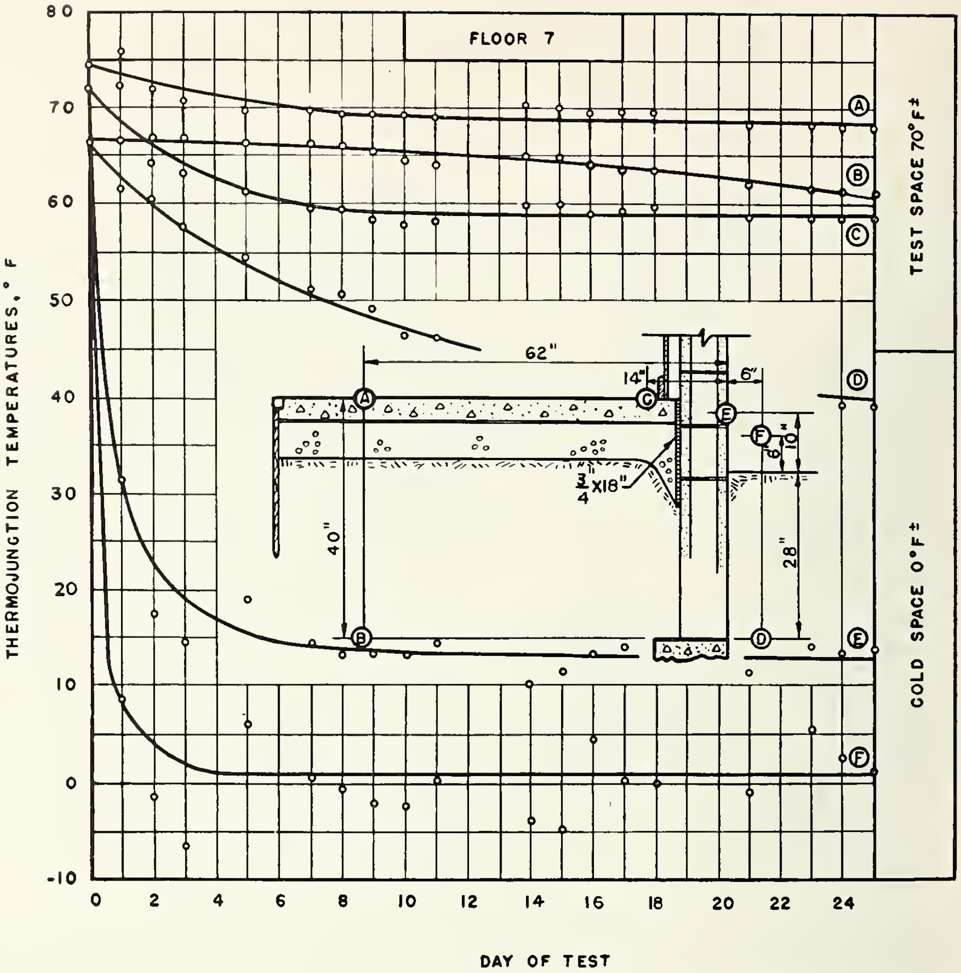

FIGURE 10. *Variations of temperatures on floor 7 and in associated edge construction during 25 days of exposure in test 3.*

4.2. Floor-Surface Temperatures

The heating and cooling systems in the test structure were designed to produce uniform air temperatures in the test space over all the floor specimens and to expose all of the floor-edge constructions to the same temperature in the cold space. The range of air temperature in the test space and in the cold space, as well as the range in floor-surface temperatures on the 18th day for all floors, are shown in table 1 for tests 1 to 4. Some of the more significant temperature differences in the test space are summarized in table 2 for tests 1 to 4.

Table 1 shows that the air temperatures over the five specimen floors differed less than 1 deg F at the 30-in. level for tests 1 and 2. The differences in floor-surface temperature at distances of 38 in. and 62 in. from the exterior side of the cold wall were also less than 1 deg F for the five floors for these same tests. The air temperatures were not quite as uniform for tests 3 and 4 as for the earlier tests. The differences in air temperature for the five floors were 1.5 deg F in test 3 and 1.7 deg F in test 4 at the 30-in. level. Table 1 also shows that the average air and floor-surface temperatures were 1 to 3 deg higher for tests 3 and 4 than for tests 1 and 2. In the cold space, the five floors were exposed to air temperatures differing as little as 0.7 deg F in test 2 and as much as 1.7 deg F in test 3.

The vertical temperature differences in the test space between the 2- and 30-in. levels were relatively small, as shown in table 2. This result is attributed to the well-insulated walls and roof of the test space and to the fact that heat was lost from the test space largely through one wall and the floor during most of each test period.

The floor temperatures along the center line of the specimen floors on the 18th day of the tests are shown in figure 11 for tests 1 and 2 and in figure 12 for tests 3 and 4. The floor-edge construction associated with each graph of floor-surface temperature is shown at the right in each of these two figures. Figures 11 and 12 show that the temperature in the cold space had very little

Table 1. *Temperatures at selected stations on 18th day for all floors*

Location of thermocouple junctions	Test 1			Test 2			Test 3			Test 4		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
Test space air:												
30 in. above floor	70.1	69.7	69.9	70.2	69.5	69.8	73.9	72.4	72.9	71.9	70.2	70.9
2 in. above floor	69.5	68.2	68.6	69.6	68.5	69.1	70.4	68.7	69.5	71.3	69.7	70.4
Floor surface:												
62 in. from exterior of cold wall	68.5	68.0	68.1	68.7	68.0	68.3	70.3	68.5	69.3	70.7	68.9	69.5
38 in. from exterior of cold wall	66.8	66.0	66.3	67.3	66.5	66.9	68.6	66.0	67.1	69.2	67.5	68.0
Cold space air:												
6 in. from wall and 6 in. above earth	1.6	0.1	1.1	34.9	34.2	34.4	2.5	0.8	1.4	33.1	32.2	32.6

Table 2. *Temperature differences between selected stations in the test space on 18th day for all floors*

Location of thermocouple junctions	Test 1			Test 2			Test 3			Test 4		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
Test space air between 30 in. and 2 in. levels	1.7	0.4	1.3	1.0	0.4	0.7	3.8	2.8	3.4	0.6	0.2	0.5
Test space:												
Between 2 in. level and floor surface 38 in. from cold wall	2.7	1.9	2.3	2.6	1.9	2.2	2.8	1.8	2.4	3.0	2.1	2.4
Between 2 in. level and floor surface 62 in. from cold wall	1.0	0.2	0.5	1.0	0.4	0.8	0.5	−0.2	0.2	1.3	0.6	0.9
Between 30 in. level and floor surface 62 in. from cold wall	1.9	1.4	1.7	1.7	1.3	1.5	4.0	3.3	3.6	1.9	1.2	1.4

Table 3. *Floor-surface temperatures on 18th day of tests 1 and 3 with cold space at 0° F±*

Floor number	Distance from exterior of cold wall						
	62 in.	50 in.	38 in.	26 in.	14 in.	13 in.[1]	6 in.
	°F	°F	°F	°F	°F	°F	°F
1	68.5	68.0	66.8	65.2	61.6	61.2	56.2
2A [2]	68.0	67.5	66.3	64.5	60.0	59.2	----
3	68.0	67.5	66.6	65.5	62.5	62.0	56.6
4	68.0	67.1	66.0	64.4	61.9	61.6	59.4
5	68.2	67.2	66.0	64.4	58.8	57.9	46.8
6	69.7	68.8	67.7	66.0	61.6	60.7	----
2B [2]	69.2	68.5	66.9	65.2	59.7	59.3	----
7	68.9	67.7	66.0	63.7	58.5	57.8	----
8	68.5	67.8	66.4	63.8	58.5	57.7	----
9	70.3	69.7	68.6	66.3	60.0	58.8	----

[1] Temperatures at this station were obtained by interpolation for floors 1, 3, 4, and 5.
[2] Floor 2A (test 1) and floor 2B (test 3) are the same floor tested during successive years.

Table 4. *Floor-surface temperatures on 18th day of tests 2 and 4 with cold space at 32° F±*

Floor number	Distance from exterior of cold wall						
	62 in.	50 in.	38 in.	26 in.	14 in.	13 in.[1]	6 in.
	°F	°F	°F	°F	°F	°F	°F
1	68.7	68.1	67.3	66.3	63.9	63.5	58.4
2A [2]	68.1	67.5	66.5	65.0	61.3	60.8	----
3	68.0	67.6	66.9	66.1	64.1	63.8	60.3
4	68.3	67.5	66.7	65.6	64.4	64.2	63.0
5	68.6	67.9	67.2	65.7	62.2	61.6	54.6
6	69.2	68.6	68.0	67.2	64.9	64.1	----
2B [2]	68.9	68.4	67.6	66.4	62.9	62.0	----
7	69.1	68.4	67.5	66.0	63.0	62.3	----
8	69.4	68.5	67.7	66.2	63.5	63.0	----
9	70.7	70.1	69.2	68.1	64.3	63.6	----

[1] Temperatures at this station obtained by interpolation for floors 1, 3, 4, and 5.
[2] Floor 2A (test 2) and floor 2B (test 4) are the same floor tested during successive years.

effect on the floor-surface temperatures at distances greater than 38 in. from the exterior of the cold wall. Figure 11 reveals this result more clearly than figure 12, because the air temperatures in the test space differed only slightly for the five specimen floors for tests 1 and 2. At a distance of 14 in. from the exterior of the cold wall, the cold-space temperature did have a significant effect on the floor-surface temperature. Lowering the cold-space temperature from about 32° F to a nominal value of 0° F lowered the floor-surface temperature at this station from 1.3 deg F to 3.4 deg F in tests 1 and 2 and from 3.2 deg F to 5.0 deg F in tests 3 and 4.

The surface temperatures of the floor specimens shown in figures 11 and 12 are listed in tables 3 and 4. These tables summarize the temperatures for floors 1 to 9, inclusive, with floor 2, which was retained during tests 3 and 4 for comparison with tests 1 and 2, appearing twice, thereby making a total of 10 elements. This tabulation includes the floors with the insulated frame walls and the floors with the uninsulated concrete-block walls. Table 3 lists the floor-surface temperatures for a cold-space temperature of 0° F, whereas table 4 lists the floor-surface temperatures for a cold-space temperature of 32° F.

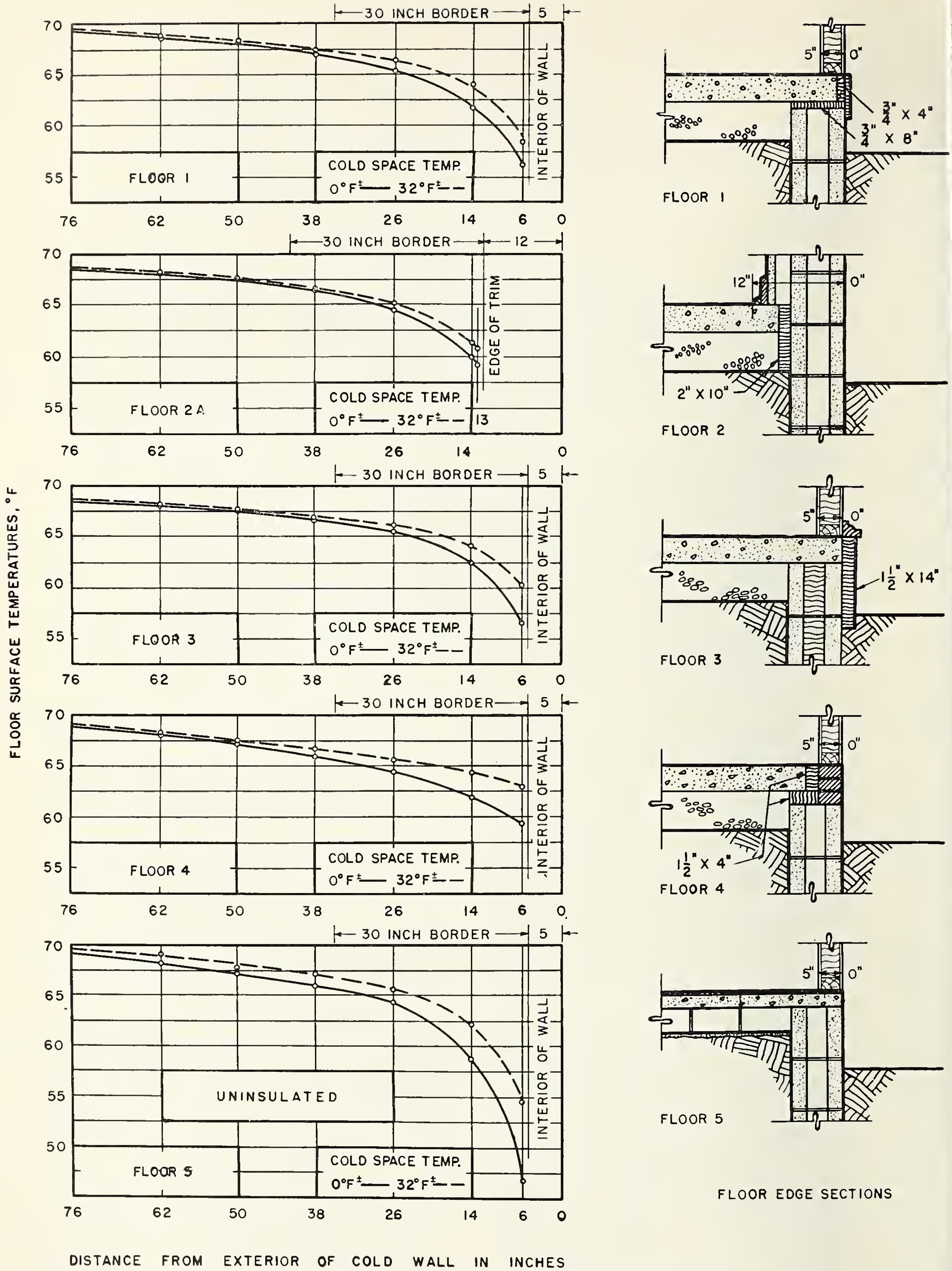

Figure 11. *Floor-surface temperatures on 18th day of tests 1 and 2.*

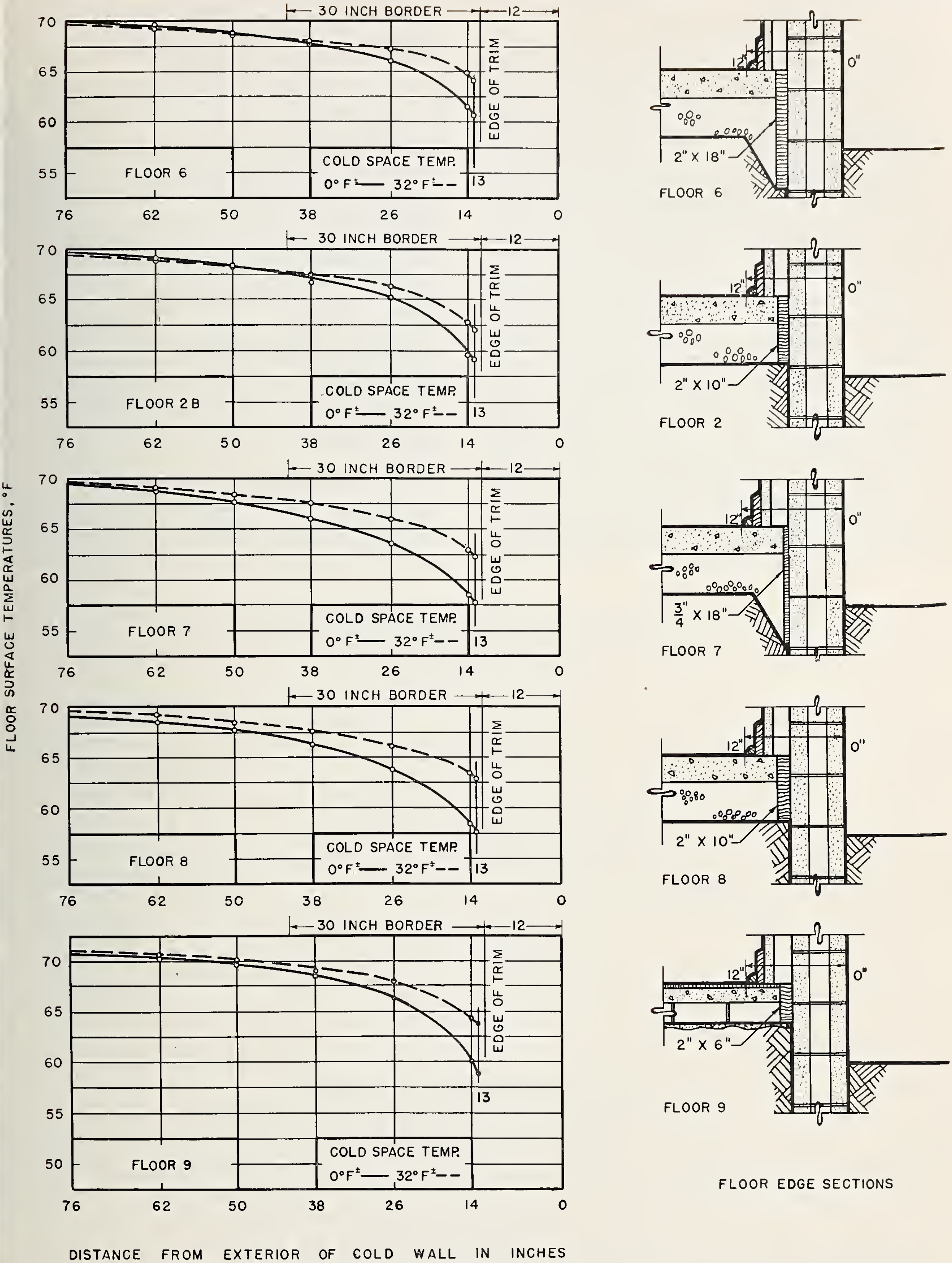

FIGURE 12. *Floor-surface temperatures on 18th day of tests 3 and 4.*

4.3. Comparison of Insulation Methods

The data in tables 1, 3, and 4 indicate that the temperature of the air in the test space, which differed somewhat between tests 1 and 3 and between tests 2 and 4, affected the floor-surface temperatures. As shown in table 1, the floor-surface temperatures at a distance of 62 in. from the exterior of the cold wall differed only slightly for floors 1 to 5, inclusive, for cold-space temperatures of 0° F and 32° F when the air temperatures in the test space above all floors were nearly uniform at the 30-in. level. For this reason, it was considered desirable to use the floor-surface temperature of each floor at a distance of 62 in. from the exterior of the cold wall as a basis for reference. The order of preference of the several specimens was based upon the temperature difference between this reference station and the designated stations between it and the cold wall, with the floor having the lowest temperature difference being rated the most desirable. The results derived in this manner are given in tables 5 and 6. The floors with insulated frame walls and those with uninsulated concrete-block walls are listed in separate groups. The difference in temperature between any given station and the 62-in. station for the same floor is recorded under the distance of that station from the exterior of the cold wall. The magnitude of these temperature differences was dependent upon the resistance to heat flow within the floor and the earth beneath it and was affected by the distance of the station from the cold wall and by the edge construction of the floor.

For floors 1, 3, 4, and 5 having insulated frame walls between the test space and the cold space, the station 6 in. from the exterior of the cold wall was about 1 in. from the inner surface of the cold wall. The comparable temperature station on the other floors having concrete-block walls was the one 13 in. from the exterior of the cold wall or 1 in. from the edge of the trim. The temperatures at these stations are of the greatest importance insofar as condensation on the floor is concerned. The likelihood of condensation on the specimen floors will be discussed later. From the standpoint of comfort, the temperatures of the floor surface at distances greater than 1 in. from the interior surface of the cold wall are of interest.

It may be seen in tables 5 and 6 that the same floor did not always appear in the same order of preference at all distances from the cold wall in either grouping and that there were some inconsistencies between the order of preference for

Table 5. *Order of preference based on temperature differences between reference and designated stations on the floor surface on 18th day of tests 1 and 3 with cold space at 0° F ±*

Order of preference	Distance from exterior of cold wall: 62 in.; Distance from interior of cold wall: 57 in.	50 in.; 45 in.		38 in; 33 in.		26 in.; 21 in.		14 in.; 9 in.		13 in.; 8 in.		6 in.; 1 in.	
	Temperature differences for floors with insulated frame wall												
		Floor	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*
1	Surface temperature at this station used as reference. Average temperature 68.2° F.	1	[a] 0.5	3	1.4	3	2.5	3	5.5	3	[b] 6.0	4	8.6
2		3	[a] .5	1	1.7	1	3.3	4	6.1	4	[b] 6.4	3	11.4
3		4	.9	4	2.0	4	3.6	1	6.9	1	[b] 7.3	1	12.3
4		5	1.0	5	2.2	5	3.8	5	9.4	5	[b] 10.3	5	21.4

Order of preference	Distance from exterior of cold wall: 62 in.; Distance from edge of trim: 50 in.	50 in.; 38 in.		38 in.; 26 in.		26 in.; 14 in.		14 in; 2 in.		13 in.; 1 in.	
	Temperature differences for floors with uninsulated concrete block wall										
		Floor	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*
1	Surface temperatures at this station used as reference. Average temperature 69.1° F.	[c] 2A	0.5	[c] 2A	[a] 1.7	[c] 2A	3.5	[c] 2A	8.0	[c] 2A	8.8
2		9	.6	9	[a] 1.7	6	3.7	6	8.1	6	9.0
3		[c] 2B	[a] .7	6	2.0	[c] 2B	[a] 4.0	[c] 2B	9.5	[c] 2B	9.9
4		8	[a] .7	8	2.1	9	[a] 4.0	8	10.0	8	10.8
5		6	.9	[c] 2B	2.3	8	4.7	9	10.3	7	11.1
6		7	1.2	7	2.9	7	5.2	7	10.4	9	11.5

[a] Designates different floors with equal temperature differences at a given station.
[b] Interpolated values.
[c] Floor 2A (test 1) and floor 2B (test 3) was the same floor tested in successive years.

temperatures of 0° F and 32° F in the cold space. In making comparisons, it is questionable whether or not temperature differences of less than 1 deg are significant from the standpoint of relative comfort. By comparing floors 1, 3, 4, and 5 with each other, all having insulated frame walls separating the test space and cold space, floor 4 was superior to floor 3 near the cold wall, but the reverse was true for the stations farther from the cold wall. This indicated that separation of the concrete slab from the foundation by insulation as in floor 4 was effective in raising the temperature at the extreme edge of the concrete slab, but that the greater depth of insulation applied to floor 3, together with the insulation in the voids of the concrete block in the foundation, reduced the heat transmission at distances of a foot or more from the cold wall. The temperatures of floor 1 near the cold wall, with thinner insulation between the concrete slab and foundation than floors 3 or 4, were lower than those of the latter floors; and floor 5, without edge insulation, was considerably colder than the other three floors at distances of less than 2 ft from the cold wall.

The average floor-surface temperature for a 30-in.-wide border adjoining the inside surface of the cold wall was determined from the graph of the floor-surface temperature for each specimen. When a comparison was made of floors 1, 3, 4, and 5, based upon the average temperatures observed on this 30-in.-wide border, as shown in table 7, floors 3 and 4 were practically equivalent, floor 1 rated third, and uninsulated floor 5 was appreciably colder than the other specimens.

Concrete-slab floors 6, 7, 8, and 9 were separated from the concrete-block foundation walls with different thicknesses and depths of rubber-board insulation, as shown in figure 5. Floor 2, which was tested twice, was separated from the foundation wall with a mopped-fiberboard insulation. Based only upon the thickness, depth, and thermal conductivity of the insulations used with the several floors in this group, it was expected that the sequence of the specimens in order of decreasing merit would be 6, 8, and 9, with floor 6 being preferable to floor 7 and floors 6 and 8 being preferable to floor 2, but with floors 7 and 2 being indeterminate with respect to the other floors, except by test. However, the data summarized in tables 5 and 6 do not support this expected order of merit in every respect. Instead, they indicate that floor 6 (shown by data in table 6) was superior to the other floors at the stations near the cold wall when the cold-space temperature was 32° F; whereas floor 6 (as shown by data in table 5) was second in order of prefer-

TABLE 6. *Order of preference based on temperature difference between reference and designated stations on the floor surface on 18th day of tests 2 and 4 with cold space at 32° F±*

Order of preference	Distance from exterior of cold wall: 62 in.	50 in.		38 in.		26 in.		14 in.		13 in.		6 in.	
	Distance from interior of cold wall: 57 in.	45 in.		33 in.		21 in.		9 in.		8 in.		1 in.	
	Temperature differences for floors with insulated frame wall												
		Floor	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*
1	Surface temperatures at this station used as reference. Average temperature 68.4° F.	3	0.4	3	1.1	3	1.9	3	[a] 3.9	4	[b] 4.1	4	5.3
2		1	.6	1	[a] 1.4	1	2.4	4	[a] 3.9	3	[b] 4.2	3	7.7
3		5	.7	5	[a] 1.4	4	2.7	1	4.8	1	[b] 5.2	1	10.3
4		4	.8	4	1.6	5	2.9	5	6.4	5	[b] 7.0	5	14.0

Order of preference	Distance from exterior of cold wall: 62 in.	50 in.		38 in.		26 in.		14 in.		13 in.	
	Distance from edge of trim: 50 in.	38 in.		26 in.		14 in.		2 in.		1 in.	
	Temperature differences for floors with uninsulated concrete block wall										
		Floor	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*	*Floor*	*Deg F*
1	Surface temperatures at this station used as reference. Average temperature 69.2° F.	[c] 2B	0.5	6	1.2	6	2.0	6	4.3	6	5.1
2		[c] 2A	[a] .6	[c] 2B	1.3	[c] 2B	2.5	8	5.9	8	6.4
3		6	[a] .6	9	1.5	9	2.6	[c] 2B	6.0	7	6.8
4		9	[a] .6	[c] 2A	[a] 1.6	[c] 2A	[a] 3.1	7	6.1	[c] 2B	6.9
5		7	.7	7	[a] 1.6	7	[a] 3.1	9	6.4	9	7.1
6		8	.9	8	1.7	8	3.2	[c] 2A	6.8	[c] 2A	7.3

[a] Designates different floors with equal temperature differences at a given station.
[b] Interpolated values.
[c] Floor 2A (test 2) and floor 2B (test 4) was the same floor tested in successive years.

Table 7. *Comparison of floors based upon the temperature difference (ΔT) between the 62-in. reference station and the average temperature for the 30-in. border adjacent to the cold wall*

Order of Preference	Cold-space temperature 32° F		Cold-space temperature 0° F	
	Floor	ΔT	Floor	ΔT
Floors with insulated frame wall				
	No.	*Deg F*	*No.*	*Deg F*
1	4	3.4	3	5.0
2	3	3.5	4	5.1
3	1	4.5	1	5.8
4	5	6.2	5	9.1
Floors with uninsulated concrete block wall				
1	6	2.4	2A	4.1
2	2B	3.0	6	4.5
3	9	3.2	2B	4.6
4	8	3.4	9	4.9
5	7	3.5	8	5.2
6	2A	4.0	7	5.8
All floors				
1	6	2.4	2A	4.1
2	2B	3.0	6	4.5
3	9	3.2	2B	4.6
4	4	3.4	9	4.9
5	8	3.4	3	5.0
6	3	3.5	4	5.1
7	7	3.5	8	5.2
8	2A	4.0	7	5.8
9	1	4.5	1	5.8
10	5	6.2	5	9.1

ence at the same stations when the cold-space temperature was 0° F. In the zone near the cold wall, the data shown in table 5 indicate that floor 2A was the best of the group, whereas the data for the same group in table 6 shows it to be the floor of least merit.

The position of floor 2A relative to the other floors in the order of preference at the stations 13 and 14 in. from the exterior of the cold wall was considered uncertain because the thermocouples at these stations were inoperative on the 18th day of tests 1 and 2, and the temperatures reported were obtained by extrapolation of the floor-surface temperature curves. The data on floor 2B, shown in table 5, at the same stations probably provide the best indication of the relative merit of floor 2 because reliable temperature data were available for this observation. Therefore, it is possible that floor 6 was also better than any other specimen investigated in tests 1 and 3 when the cold-space temperature was 0° F.

Comparing the floors having uninsulated concrete-block walls with each other, based on the average floor temperatures of a 30-in. border adjacent to the cold wall, it is shown in table 7 that, except for the gross inconsistency of floor 2A for the two different cold-space temperatures, the order of preference of the floors for both cold-space temperatures was 6, 2B, 9, 8, and 7. No reason is apparent for floor 2B being superior to floor 8, since the floor construction and edge construction were the same for both floors, and the only known difference was that the thermal conductivity of the insulation in floor 8 was lower than that for floor 2. Possible reasons for the unexpected relation between these two floors are differences in moisture content of the earth beneath the floors or variations in the infiltration of cold air through the concrete-block construction. Excepting floor 2A, tables 5 and 6 show floor 9 to be the one with the least merit at the stations adjacent to the cold wall. This result would be expected because the insulation between the slab and the foundation was only 6 in. deep for floor 9. However, at the 26- and 38-in. stations, floor 9 was superior to floors 7 and 8. This result indicated that the 4-in. hollow tile used under the concrete slab in floor 9 may have been useful in reducing the heat transmission through the floor as compared to the 6-in. gravel fill used beneath the other floors.

4.4 Effect of Wall Construction

From the data given in tables 5 and 6, direct comparisons regarding minimum floor temperatures and the possibility of condensation near the cold wall can be made between the floors constructed with insulated frame walls and those constructed with uninsulated concrete-block walls, although the wall constructions were of different thicknesses. The 6-in. station on the floor surface of floors 1, 3, 4, and 5 was 1 in. from the interior side of the cold wall, whereas the 13-in. station was 1 in. from the edge of the trim for floors 2, 6, 7, 8, and 9.

All nine specimen floors can be compared for comfort from the data in table 7. As shown in the last section of table 7, the inconsistency of floor 2A is still apparent in the tests conducted at two different temperatures in the cold space. With the exception of floor 2A, the order of preference of the other floors is fairly consistent in the tests made at different cold-space temperatures. Floors 6, 2B, and 9 were consistently better than any of the floors with insulated frame walls; floors 3, 4, and 8 were approximately equal in average surface temperatures; and floors 7 and 1 were consistently colder than the other floors with insulated edges. Floor 5, without edge insulation, was 3.3 deg colder than floor 1, the coldest of the insulated floors for a cold-space temperature of 0° F and 1.7 deg colder than floor 1, which was again the coldest of the insulated floors, for a cold-space temperature of 32° F.

The comparison of test data on floors shown in table 7 may not reflect the effect of different methods of edge insulation alone. The insulated frame wall used with floors 1, 3, 4, and 5 had a heat transmission factor of approximately 0.08 Btu/(hr) (sq ft) (°F), whereas the concrete-block wall with furring and plasterboard interior finish used with floors 2, 6, 7, 8, and 9 had a heat-transmission factor of about 0.34 Btu/(hr) (sq ft) (°F). For a temperature difference of 70 deg F between the test space and the cold space and with a cold-space temperature of 0° F, the temperature of the interior surface of the insulated frame wall would be about 66.5° F, whereas the interior surface temperature of the uninsulated concrete-block wall would be about 55.5° F. In the former case, the descending stream of air near the cold wall would assist in heating the floor; whereas in the latter case, the stream of air approaching the floor from the cold wall would not heat the floor and might even increase the cooling of the floor surface at the edge. In the test structure, this effect was not of great significance because the uninsulated concrete-block wall extended less than 2 ft above the surface of floors 2, 6, 7, 8, and 9. However, in an actual installation, uninsulated walls of normal height might have an appreciable effect on the surface temperatures at the edges of the floor. The comparison in table 7 of nine floors indicated that from the standpoint of comfort the wall construction in the test structure did not significantly affect the floor temperatures, because three of the floors with uninsulated concrete-block walls were superior to the four floors with insulated frame walls.

Only approximate comparisons are possible between earlier data on concrete floors reported by Dill, Robinson, and Robinson [4] and the results obtained in this investigation because of differences in floor and edge construction and differences in the heating systems used in the test space. Comparing floor 1 of the earlier investigation [4] with floor 5 in the present study, both of which were uninsulated, it will be noted that the surface temperatures at distances of 18 and 36 in. from the exterior side of the cold wall were about 3 to 4 deg F higher on floor 5 for an outdoor temperature of about 32° F. However, floor 5 had hollow clay tile under the slab, whereas floor 1 in the earlier investigation had gravel under the slab, and floor 1 had a thickened edge of concrete at the cold edge, whereas floor 5 was of uniform thickness edge to edge. These differences in construction would probably tend to make floor 1 a colder floor than floor 5.

Comparing floor 3 in the earlier investigation [4] having 1 in. of fiberboard 6 in. deep separating the slab from the foundation with floor 1 in the present study for an outdoor temperature of about 32° F, it is seen that the surface temperatures 8 in. from the exterior of the cold wall differed by less than one-half a degree but that floor 1 in the present study was approximately 3 deg warmer at distances of 24 and 40 in. from the same reference point. These differences may represent real differences in heat transfer through the two floors and the earth beneath, or they may be accounted for partly by the different heating systems used in the test space. Forced circulation of air was used in the present investigation, whereas cast-iron radiators at the opposite side of the test space with natural convection were used in the earlier investigation.

4.5. Isotherms

Temperatures were observed in the test space on the floor surface and below, and in the cold space on the ground surface and below along the center line of the floor specimens perpendicular to the cold wall. Representative isothermal curves below floor level in the test space and below ground level in the cold space for floor specimens 2A and 3 are shown in figures 13 and 14, respectively, for the 18th and the 31st days of tests 1 and 2. The temperatures observed on the 18th day are indicated by the numbers above and to the left of the corresponding grid intersections.

The temperature represented by each pair of isothermal lines is identified by the underlined number between or above the pairs. The distance between any given pair of isothermal lines along the path perpendicular to them indicates how much temperature change occurred after the 18th day of the test. The ground temperature beneath the floors and in the cold space was still increasing during tests 2 and 4 eighteen days after changing the cold-space air temperature from 0° F to 32° F. This was undoubtedly the result of performing the test with 32° F in the cold space immediately after completing a test with 0° F in the cold space. The results for test 2, as shown in figures 13 and 14, illustrate these changing conditions.

The isothermal lines in the concrete floor slabs, in the gravel, and in the earth, shown in figures 13 and 14, lie in the position and direction that would be expected from theoretical analysis. The changes in slope of the isotherms at the interface of the concrete and gravel and at the interface of the gravel and earth indicate the differences in thermal conductivity of the adjacent materials. The shape of the isotherms for these floors indicated that all of the heat transmitted through the floor surface flowed downward and to the right through the slab, the gravel, and the earth toward the foundation and footing. A trace of the probable heat-flow path from the floor surface at a distance of 76 in. from the exterior of the cold wall toward the cold space indicated that any heat that entered the earth from outdoors at the left of the test space, as shown in figures 13 and 14, traveled a path below the limits of the isotherms shown, and below the footings. It is concluded, therefore, that any heat transmitted from outdoors had little effect on the temperature distribution within the limits of figures 13 and 14.

A comparison of the isotherms in figures 13 and 14 reveals that the temperatures in the earth near the warm side of the foundation wall were appreciably lower for floor 2A than for floor 3. This result leads to the conclusion that the insulation in the voids of the concrete blocks of the foundation wall of floor 3 was effective in reducing the heat transmission through this floor as compared with floor 2A, having the foundation wall

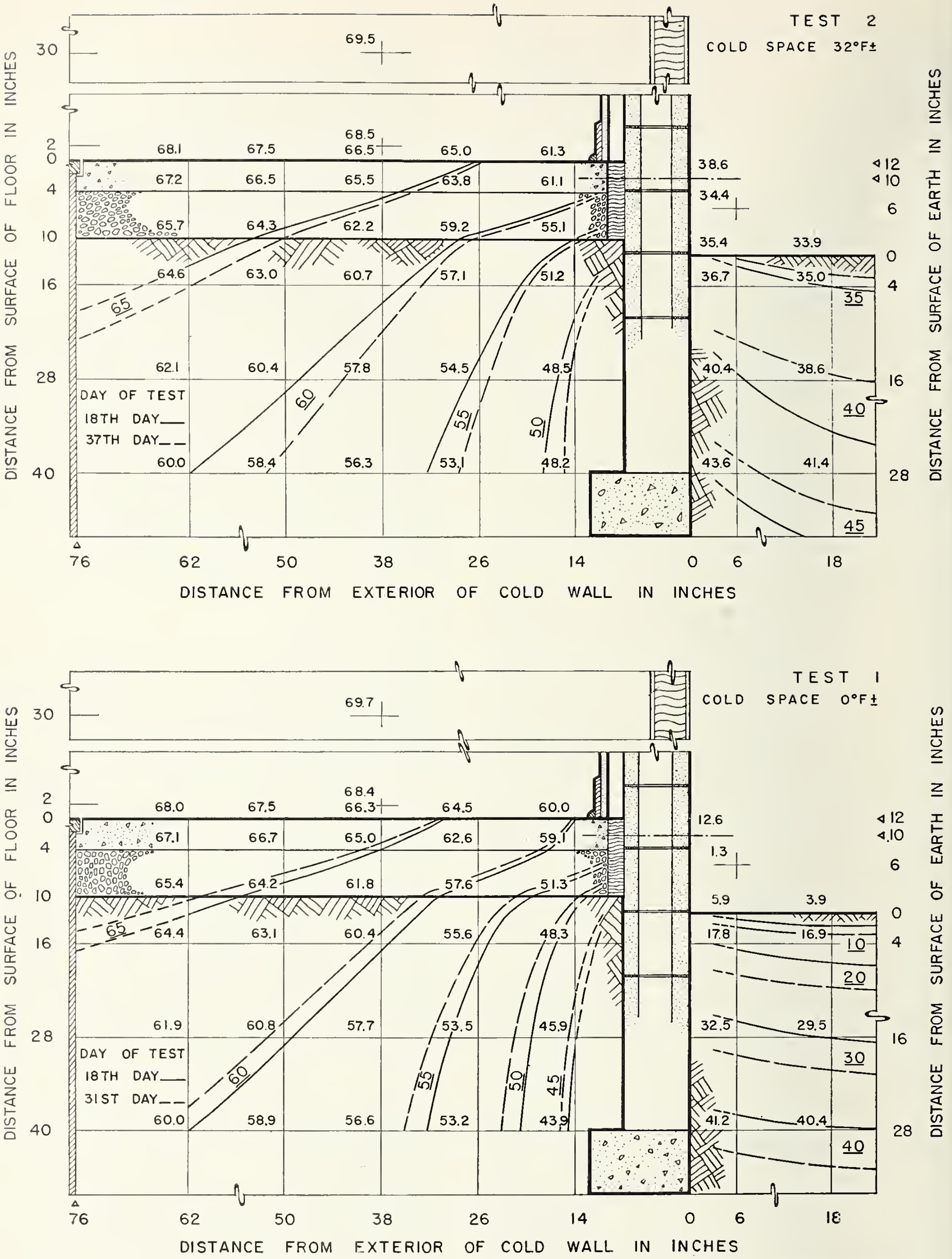

FIGURE 13. *Temperature pattern and isothermal lines during tests 1 and 2 for floor 2A, representing specimens with uninsulated concrete-block wall.*

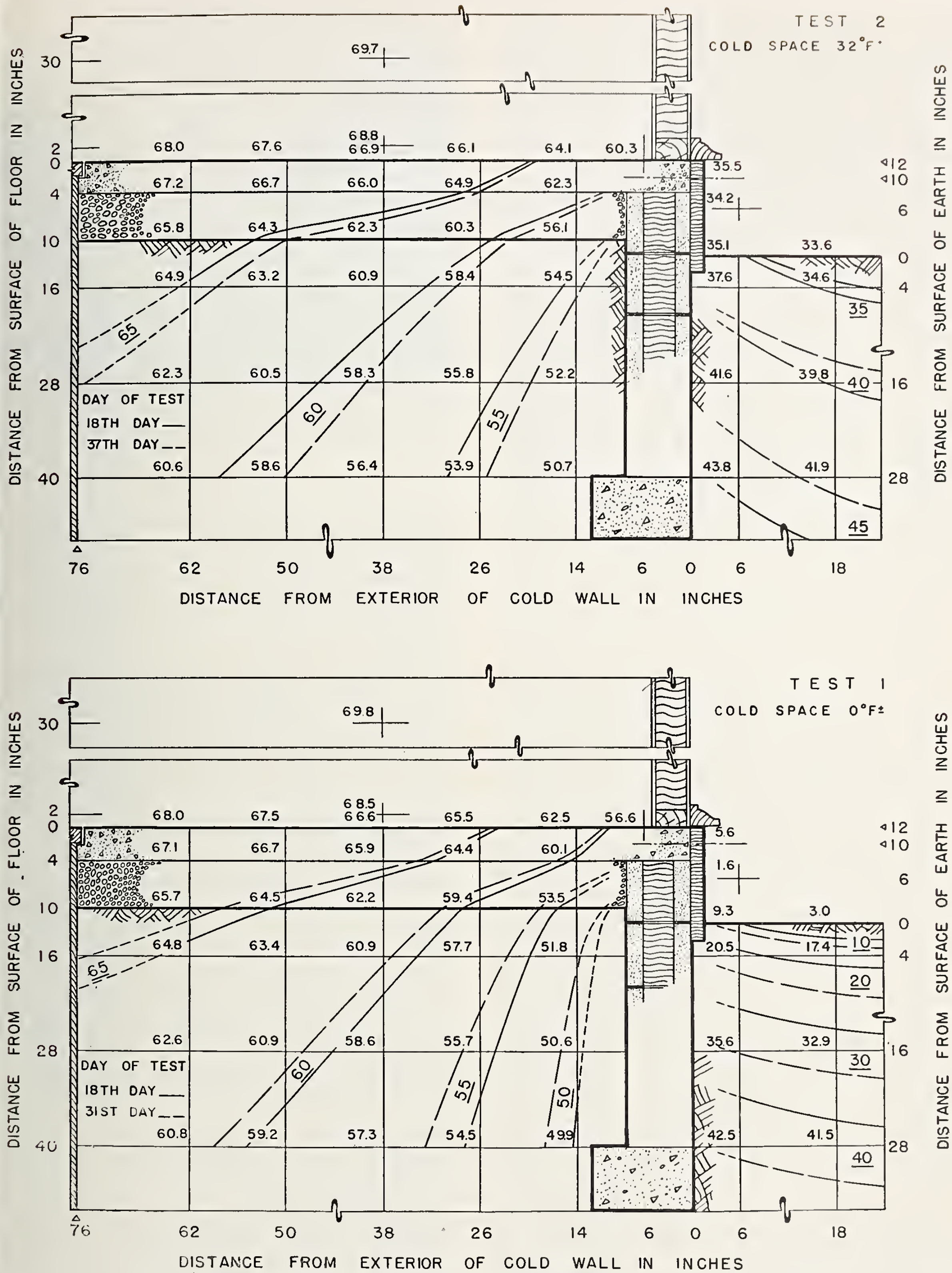

FIGURE 14. *Temperature pattern and isothermal lines during tests 1 and 2 for floor 3, representing specimens with insulated frame walls.*

unfilled. The unfilled voids in the foundation of floor 2A would permit circulation of air in the foundation wall in a clockwise direction as viewed in figure 13. The portion of the concrete blocks exposed to the cold outside air above the ground level would produce a downward current of cold air in the voids of these blocks that would continually remove heat by convection from the earth on both sides of the foundation wall, but with the greater amount being removed from the warm side. Filling the voids with insulation would prevent this circulation in the foundation wall and diminish the heat transmission through the foundation. It might also decrease the depth of freezing of the earth in a given climate. The frost line was about 3 in. deeper opposite floor 2A than opposite floor 3, as shown in figures 13 and 14, when the temperature in the cold space was 0° F.

The spacing of the isotherms provides an approximate measure of the rate of heat flow per unit area in any given material or in materials of comparable thermal conductivities. The time rate of heat flow through a material per unit area is given by the equation

$$H=\frac{k\Delta T}{d},$$

where k is the thermal conductivity of the material, d is the thickness of the material, and ΔT is the temperature difference across the portion under consideration.

Considering the earth between two isothermal lines 5 deg apart, ΔT is a constant, and k can be assumed to be nearly constant. Therefore, the heat flow is inversely proportional to the distance between adjacent isothermal lines in the earth beneath the concrete floor. The convergence of the isotherms below the floor surface near the cold wall indicates that the heat transmission increased significantly in this zone. If the concrete floor slab is considered as a heat-flow meter of low precision, and if the change in direction of the heat flow through the concrete is neglected, the increase in temperature difference between upper and lower surfaces of the concrete floor slab toward the cold wall is an approximate measure of the increase in the rate of heat flow through the floor as the cold wall is approached.

The isotherms below ground level in the cold space, indicated in figures 13 and 14, show that the earth was frozen to a depth ranging from 13 to 16 in. below the surface at a distance of 6 in. from the foundation after 18 days of exposure to a cold-space temperature of 0° F. An additional 13 days of exposure, as in test 1, increased the depth of frozen earth at this distance by 5 or 6 in. The depth of the frost line was probably affected somewhat by the heat flow from outdoors.

4.6. Condensation

As previously stated, the floor-surface temperature station 1 in. from the interior of the cold wall was the most important insofar as surface condensation on the floors is concerned. For tests 1 and 3, with a cold-space temperature of 0° F, the temperatures at this station ranged from 56.2° to 60.7° F for the insulated floors and was 46.8° F for the uninsulated floor. A photograph of floors 4 and 5 and one of the protective end slabs, in that order, with floor 4 in the foreground, is shown in figure 15. This photograph shows clearly the condensation at the edge of floor 5 and on the uninsulated protective end slab. Condensation did not occur on any of the insulated floors.

Daily observations of the relative humidity in the test space were taken with a sling psychrometer. As steady-state conditions were approached with respect to floor-surface temperatures, the relative humidity was nearly constant in the test space at about 55 percent for tests 1, 2, and 3, and at about 63 percent for test 4. The relative humidity was not controlled during the tests but was permitted to reach steady-state values, depending upon the rate of flow of water vapor from the outdoors to the test space and from the test space to the cold space. Daily variations in relative humidity of 1 or 2 percent were sometimes recorded.

Because condensation occurred on uninsulated floor 5 with a surface temperature of 46.8° F at the cold edge and did not occur on the coldest of the insulated floors with a surface temperature of 56.2° F, it would follow that the relative humidity in the test space was in the range between 44 percent and 62 percent at the levels where the dry-bulb temperature was 70° F. The observed relative humidity for test 1 was within this range.

During the first week of test 2, begun only 3 or 4 days after ending test 1, which was performed at a lower cold-space temperature, condensation was observed at the edges of some of the insulated floors. However, as test 2 progressed toward steady-state conditions, all condensation disappeared. These results showed that the concrete floors and earth beneath changed temperature so slowly that the rise in dewpoint temperature in the test space that resulted from the changed conditions in the cold space caused condensation to occur temporarily on floors with insulated edges. It is concluded that, during changing outdoor conditions, condensation might occur temporarily on insulated concrete floors that would otherwise be free of condensation.

The ASHVE Guide [5] shows that condensation will occur on single-glass windows at an indoor relative humidity of about 16 percent for an outdoor temperature of 0° F and at an indoor relative humidity of about 39 percent for an outdoor temperature of 32° F. These psychrometric conditions correspond to indoor dewpoint temperatures

FIGURE 15. *View of test space showing condensation on uninsulated floor 5, and protective end slab during test 1 with cold-space temperature at 0° F.*

of about 23.5° F and 44° F, respectively. Hence, it is unlikely that condensation would occur even on an uninsulated floor, such as floor 5, if it were used in a structure with several single-glass windows. The ASHVE Guide also shows that condensation will occur on double-glass windows at a relative humidity of about 42 percent for an outdoor temperature of 0° F and at an indoor humidity of about 65 percent for an outdoor temperature of 32° F. These indoor conditions correspond to dewpoint temperatures of about 46° F and 58° F, respectively. Therefore, it is possible that an uninsulated floor like floor 5 would condense moisture near the cold wall in a structure using double-glass windows. On the other hand, surveys of humidities in residences by Phillips [6] and Teesdale [7] indicate that very few residences have interior relative humidities and dewpoint temperatures high enough to cause condensation on a double-glass window or on the edge of a floor with temperatures equal to those observed on floor 5. The greatest danger of condensation occurring on uninsulated concrete floors would probably be in modern houses having low air infiltration or those with automatically controlled humidity. Floor 5 was covered with asphalt tile ⅛ in. thick, but it is improbable that this covering had a significant effect on the floor-surface temperatures observed thereon.

Floor-surface condensation would be highly improbable on concrete floors with edge constructions like any of the insulated specimens tested. With an outside temperature of 0° F and an inside temperature of 70° F, the maximum relative humidity that could be reached before condensation would occur on the floor surface at a distance of 1 in. from the interior side of the cold wall would range from 62 percent for floor 1 to 70 percent for floor 4 with insulated frame walls and from 59 percent for floor 9 to 65 percent for floor 6 with uninsulated concrete-block walls, if floor 2A, whose thermocouples were inoperative at this station, and floor 5, which was uninsulated, are not included.

The possibility of condensation occurring on some of the floors directly under the sill of the wall and consequent rotting of the sill should not be overlooked. For example, for walls of floors 4 and 5, temperatures under the sills might be low enough to allow condensation. Floors 1 and 3, with insulation protecting the area under the sills, would be expected to be relatively warmer and would be less likely to have condensation occur under the sill. In the same way, floors 2, 6, 7, 8, and 9 were reasonably well protected at the edges against temperatures likely to cause condensation on the floor under the baseboard.

The causes of condensation on concrete floors during summer and winter are different. Summer condensation on a concrete floor under some atmospheric conditions is caused by thermal lag resulting from the heat capacity of the floor and the earth underneath. When such a floor is subjected to a protracted period of cool weather followed by warm humid weather, the floor and the earth beneath it tend to remain cool for some time, and condensation would occur on the surface and would persist as long as the floor temperature was below the dewpoint of the air and would cease when the floor was warmed above this temperature either by the air or other means. In winter, condensation in a heated house would be most likely to occur near the outside or exposed walls; whereas in summer, it would be most likely to occur in protected areas, such as in closets, under furniture, or under rugs. A rug on a concrete floor reduces the heat flow from the air to the floor surface and retards the warming of the floor. However, the rug might be pervious to water vapor, and for this reason a damp spot might exist underneath it when the rest of the floor appeared to be dry.

Because the causes of condensation on concrete floors in summer and winter are not the same, different measures are required for the prevention of condensation in these two seasons. To decrease the probability of summer condensation, a conventional concrete floor should be as thin as practicable, and it should be insulated from the earth beneath. The use of lightweight concretes also performs the same function because of the relatively low thermal conductivity and volumetric heat capacity of these materials. Condensation on concrete floors during the winter was shown to be highly improbable when the floor edges were insulated by any of the methods that have been described.

4.7. Aging of Insulating Materials

Samples of the mopped fiberboard used in floor 2 and the rubber board used in floors 6, 7, 8, and 9 were removed for examination and determination of moisture content. At the time of removal, the

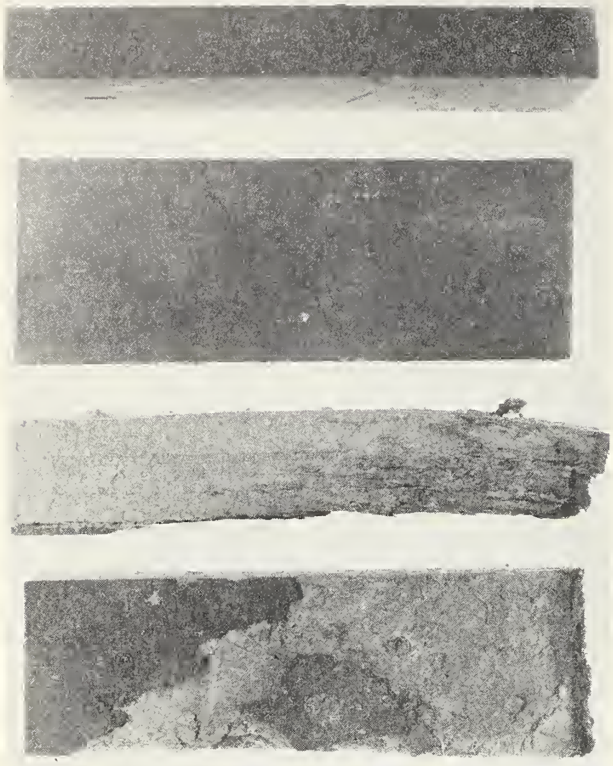

FIGURE 16. *Rubber board (above) and mopped fiberboard (below) after removal from test floors.*

fiberboard had been in place for 6 years and the rubber board for 5 years.

The effect of aging on the insulating materials while in the test floors, shown in figure 16, may be seen in the front and side views of the 3- by 6-in. portions taken from floors 2 and 8. It will be seen that there was no noticeable deterioration in the rubber board, whereas the mopped fiberboard had disintegrated considerably. Several portions were removed from the insulating barriers within the floor constructions and were immediately weighed. These sections were then dried and reweighed to determine the percentage of moisture absorbed by each. The average moisture absorbed, based upon the weight of the dry samples, for each of the insulating materials was as follows: Mopped fiberboard 28 percent and rubber board 9 percent. The relative amount of moisture absorbed by the two insulating materials does not provide any information, however, as to the moisture within the floors, gravel, or earth during the tests.

It is probable that the effectiveness of both of these insulating materials decreased after installation because of the moisture absorbed from the surrounding materials. The disintegration of the mopped fiberboard was such that its use as an insulating material for this type of construction is considered undesirable. The rubber board showed no apparent disintegration within the observed period.

5. Conclusions

This report contains information on concrete floors for buildings that are heated by systems liberating heat above the floor surface only. While some of the data may have application to heated concrete floors, such floors, in general, require greater amounts of insulation to prevent excessive heat loss to the earth and to the outdoor air through the exposed edges.

This study of various methods of insulating the edges of concrete floors laid on the ground leads to several conclusions about the amount of insulation, the methods of construction, and the characteristics of the insulation that should be used. These are as follows:

(a) The temperatures on the surface of the concrete floors laid on the ground and insulated at the edge reached nearly steady-state conditions in 10 days for outdoor temperatures of 32° F and 0° F. The temperatures in the earth outside of the structure continued to decrease for at least 30 days after the start of the tests with the cold space at 0° F, although the rate of change was very slow after that period of time, averaging about 0.15° F per 24 hr.

(b) Comparing the insulated floors with the uninsulated floor for an outdoor temperature of 0° F, the surface temperatures 1 in. from the cold wall ranged from 9 to 13 deg F higher on the insulated floors, the average surface temperatures for a 30-in. border ranged from 3.3 to 5.0 deg F higher for the insulated floors, and there was no significant difference in surface temperature between the insulated and uninsulated floors at distances of 3 ft or more from the cold edge.

(c) Floors having edge constructions protected by 1½ and 2-in.-thick insulation were consistently warmer than those having ¾-in. insulation. The best temperature distribution was obtained with insulation 2 in. thick and 18 in. deep. Thicker and deeper insulations would probably be still more effective.

(d) Filling the voids in the concrete-block foundation wall with mineral wool appeared to increase floor-surface temperatures at distances of 1 ft or more from the wall. A material not subject to damage by moisture should be used for this purpose. An air space beneath the concrete floor slab, such as was provided by 4-in. structural clay tile, appeared to provide warmer floor-surface temperatures than a 6-in. layer of gravel below the slab for otherwise similar conditions.

(e) No consistent increase in floor temperature was observed when using an insulation having a thermal conductivity of 0.25 Btu/(hr) (sq ft) (°F/in.) as compared with an insulation having a thermal conductivity of 0.37 Btu/(hr) (sq ft) (°F/in.) for floor-edge insulation. The moisture content of the two materials was not known at the time of the tests. However, the difference in absorbency of the materials would probably increase the disparity in the insulating value of the two materials.

(f) It was evident that complete separation of the concrete slab from the foundation wall by an insulating barrier was desirable. The results did not indicate outstanding superiority for either the "floating" floor with the slab entirely inside the foundation wall or the concrete slab supported on the foundation wall.

(g) Past experience indicates that the amount of insulation in the exterior walls of structures using concrete floor slabs affects the temperatures of the floor surfaces near the exterior walls. However, during the present tests no significant difference was observed between the specimen floors with insulated frame walls and those with uninsulated concrete-block walls that could be attributed to the wall construction, possibly because the concrete-block walls extended only a short distance above the floor surface or possibly because the greater thickness of those walls caused the useful portion of the floor surface to be more remote from the cold space.

(h) With the insulation methods used during these tests, condensation would be expected to appear in cold weather on the windows of a house before it would appear on the edges of concrete floors. Condensation would probably occur on the edges of uninsulated concrete floors in humidified houses or in houses with double-glazed windows under some winter conditions.

(i) The deterioration of the fiberboard insulation dipped in coal-tar mastic during 6 years of exposure in the foundation construction indicates the advisability of using materials for edge insulation of unheated concrete floor slabs that are not damaged by moisture or that are adequately protected against damage by moisture. Other desirable characteristics would be: rigidity, relative inertness, and low thermal conductivity.

(j) Existing concrete floors and foundation walls supporting them could be protected by covering the exposed edges of the floor and foundation wall with insulation. Such applications should cover the exposed edge of the floor slab, all of the exposed side of the foundation wall, and should extend into the earth.

(k) An arrangement of the insulation made up of a horizontal piece under the border of the floor and a vertical piece separating the edge of the floor from the foundation wall should be as good as vertical insulation of equal thickness and width placed against the foundation wall. A horizontal layer of insulation might permit more rapid changes in temperature of the concrete slab because it would partially isolate the slab from the heat capacity effects of the earth beneath. On the other hand, a horizontal layer of insulation would permit the frost line to approach nearer to the under side of the floor in severe climates and might increase the probability of frost heaving.

It should be pointed out that although the edge constructions used for this investigation are types that have been used in the building industry, the present study was planned to provide information only on temperature distribution upon the floor surfaces and susceptibility to condensation thereon and was not intended to develop conclusions about the structural advantages or disadvantages of the several constructions.

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