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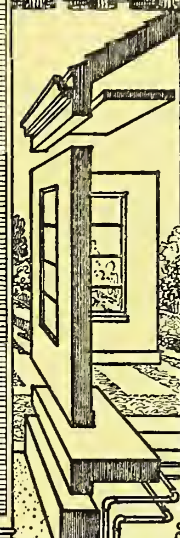


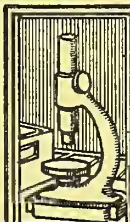
BUILDING MATERIALS AND STRUCTURES

REPORT BMS52

Effect of Ceiling Insulation Upon Summer Comfort

by

THOMAS D. PHILLIPS



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BUILDING MATERIALS *and* STRUCTURES

REPORT BMS52

Effect of Ceiling Insulation Upon Summer Comfort

by THOMAS D. PHILLIPS

ISSUED JULY 1, 1940

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

This paper is one of a number planned for the Building Materials and Structures series, dealing with the general problem of making houses comfortable both in summer and winter. Other subjects to be treated will be heating systems and appliances, heat transmission and insulation, the latter serving both for conserving heat and making a house more comfortable in winter and for keeping it cooler during the hot days in summer.

This is a report of an investigation showing that even comparatively small amounts of insulation, applied over a previously unprotected ceiling, may make the upper floor of a house or apartment more comfortable in the summer.

Lyman J. Briggs, *Director.*

Effect of Ceiling Insulation Upon Summer Comfort

by THOMAS D. PHILLIPS[1]

CONTENTS

ABSTRACT

This investigation deals with the effect of insulation in limiting the temperature rise of the rooms in the upper story of a building with a flat roof. For test purposes a structure was built on the roof of one of the buildings at the National Bureau of Standards. This structure has a "flat" (slightly sloping) roof, below which is a low attic separated from the room below by a ceiling of plasterboard. Various types of insulation were installed just above this ceiling to insulate it from the attic space. The temperature of the ceiling in the room below was measured, and the effect of the insulation in limiting the rise in the temperature of the ceiling was determined.

The results show that a lath and plaster or equivalent ceiling exposed directly to the heat of the attic will be so hot on warm summer days as to add materially to the discomfort of persons in the room below. Even a moderate amount of insulation will make the room much more comfortable.

I. INTRODUCTION

Although there are abundant data on heat transfer through building structures and insulating materials under winter conditions, there is a scarcity of information on the effectiveness of roof or ceiling insulation in helping to keep a building comfortable during hot weather.

The rooms in the upper story of a building become warmer on a summer day than those on lower floors because the ceilings of such rooms become warmer, owing to roof exposure, than do the ceilings of rooms lower down. In other respects, the exposure of the top story is, in many cases, substantially the same as that of the lower stories. The ceiling temperatures observed in similar rooms on the top floor in a typical building with various kinds of ceiling insulation would therefore afford a direct index to the effectiveness of the insulations used The identical conditions for the insulations to be tested can be most readily attained by dividing the ceiling of a single room into panels and applying the various insulations to the different spaces. In this way the air temperatures both above and below the ceiling would be very nearly the same for all the spaces, and a measurement of the temperature under each space would yield the desired information. This method of comparing insulations was used in the experiments to be described.

II. METHOD

Figure 1 is a view, from south-southeast, of the test structure built on the roof of one of the buildings at the National Bureau of Standards. The west end is exactly like the east end, except that in the former the lower door is omitted. The structure measures 20 feet by 8 feet and is divided into an attic and a room below by a ceiling consisting of ½-inch plasterboard nailed to the lower sides of 2 by 4 joists. Figure 2 shows the plan of this ceiling separated into 10 spaces by the joists placed 2 feet apart, center to center. The distance between ceiling and roof is about 40 inches at the front and about 16 inches at the back. The height of the room is about 7 feet. The roof consists of ¾-inch sheathing covered with 1/16-inch asphalt felt roofing.

The east and west walls were insulated from roof to floor with 2 inches of fibrous insulating material placed between the studs and covered on the inside with plasterboard. In the attic

[1] Dr. Phillips, professor of physics at Marietta College, Marietta, Ohio, conducted experimental work at the National Bureau of Standards during the summers of 1938 and 1939.

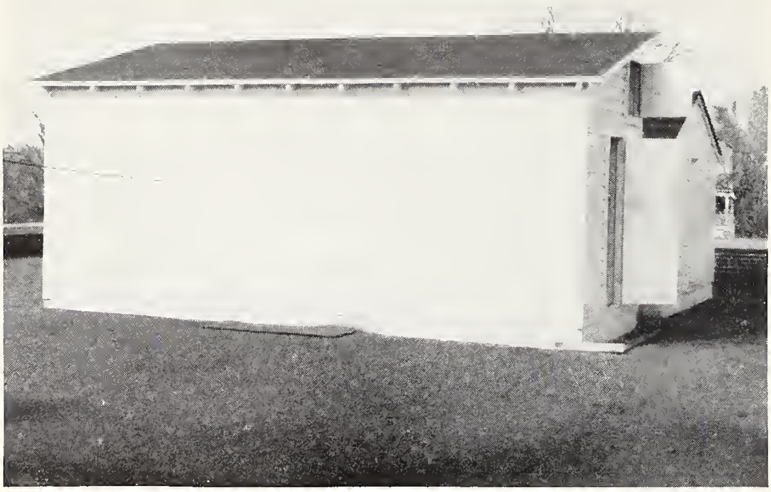

FIGURE 1.—*Test structure.*

space the north and south walls were also covered with 2 inches of insulation. All cracks where the roof joined the wall were packed with loose-fill insulation. Except in the case of observations on September 1, 1939, the north and south walls of the room below were uninsulated. The doors are of double-thickness ⅞-inch board, fitted snugly in their frames.

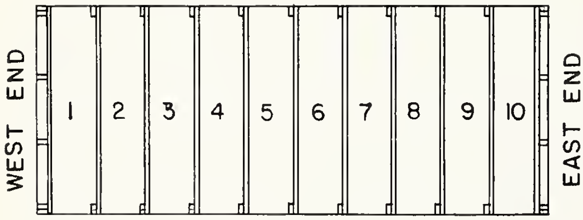

FIGURE 2.—*Plan of ceiling showing numbering of spaces between joists.*

A multiple-point recorder was used to measure temperatures at the following points by means of resistance thermometers:

1. Outdoor air on the north side of the structure at the 4½-foot level.

2. Room air temperature within the structure 8 inches below the middle of the ceiling.

3. Attic air temperature 8 inches below the middle of the roof.

4. Surface temperature under the roof boards. This resistance thermometer was made of wire about 0.5 mm in diameter and about 5 feet long. It was placed in contact with the lower surface of the roof boards and ran north and south at the middle of the roof. Thermocouples were used to measure surface temperatures on the lower side of the plasterboard ceiling. These thermocouples were located at the midpoints of the joist spaces shown in the plan, figure 2.

The 10 spaces between the joists in the ceiling were numbered from 1 to 10, with space number 1 at the west and space number 10 at the east end of the structure. Throughout all the tests the two end spaces (1 and 10) were insulated with full-thick (3⅝ in.) rock-wool bats. These two spaces were not considered in the tests; they served only as a guard against uncertain temperature conditions at the ends of the building.

III. TEMPERATURE OF THE UNINSULATED CEILING

During the observations made on August 3, 1939, the condition of spaces 2 to 9, inclusive, was as listed below:

Numbers 2, 6, and 9.—Uninsulated. The space between the joists was left open at the top, so that there was nothing but air between the plasterboard ceiling of the room and the roof of the building.

Number 3.—Insulated with 2-inch blanket of wood fiber enclosed in strong paper. The flanges of the blanket were tacked to the tops of the 2-by-4 joists, so that there was an air space between the blanket and the plasterboard ceiling of the room below.

Number 4.—Insulated with 2-inch rock-wool bats laid on the plasterboard.

Number 5.—Insulated with a single layer of aluminum foil tacked over the tops of the joists, thus introducing two reflecting surfaces.

Number 7.—Insulated with two layers of aluminum foil, one tacked between the joists and the other over the tops of the joists, so as to divide the joist space into two horizontal air spaces, each about 1¾ inches thick. Both surfaces of each layer were reflecting.

Number 8.—Insulated with full-thick (⅝-in.) rock-wool bats laid directly on the plasterboard ceiling of the room below.

The insulating materials compared in this investigation were selected as being typical of those ordinarily used.

Figure 3 represents graphically the temperatures observed in the attic, in the room at a distance 8 inches below the ceiling, and of the outdoor air. These curves simply represent the conditions to which the ceiling was subjected. It is interesting to note that at about 4:00 p. m. the temperature of the attic roof fell below that of the attic air. This represents the time when the attic began to cool by transfer of heat outward through the roof. This shift happened at about the same time on each of the days on which observations were made.

Table 1 shows the temperatures of the lower surfaces of the plaster-board ceiling under the uninsulated joist spaces (2, 6, and 9) and also under insulated joist space 7. In addition, column X gives the highest temperature measured under any of the insulated spaces, 3, 4, 5, and 8.

Figure 4 shows temperature differences obtained by subtracting the temperature of the ceiling under space 7 from the other temperatures taken at the same time and given in table 1. Space 7 was selected for this purpose, as it was the coolest throughout the tests. Table 1 shows that under the uninsulated spaces the ceiling temperature was 13 or 14 degrees F, higher than that under the coolest of the insulated spaces, and about 12 degrees F higher than that under the warmest of the insulated spaces. The large amount of heat coming in through the uninsulated spaces made impracticable any comparison of the relative values of the different kinds of insulation used. The insulated spaces are therefore represented in figure 4 by the shaded area. This shaded area is so drawn that the difference between the

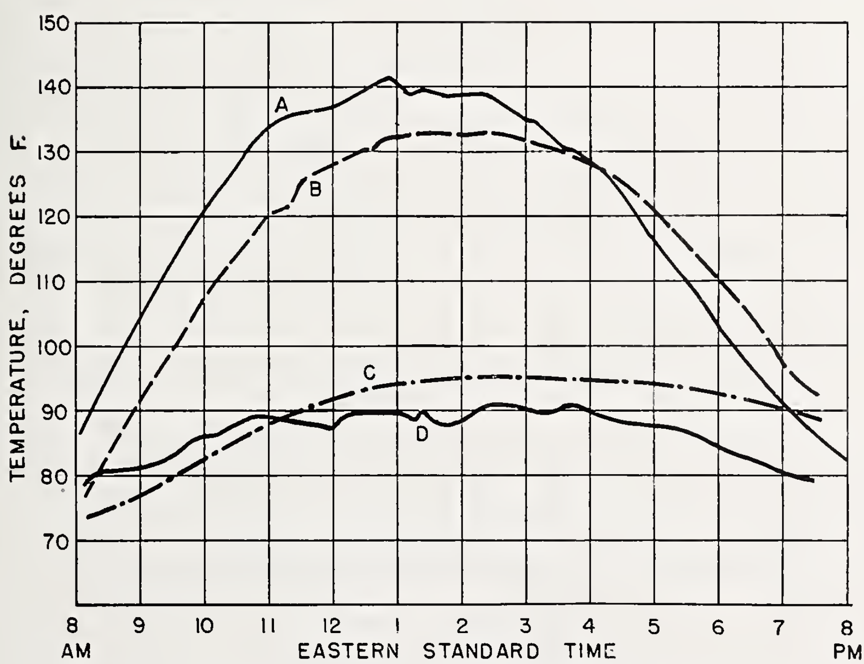

Figure 3.—*Temperature-time curves from observations of August 3, 1939.*

A, under surface of roof; *B*, attic air; *C*, air, 8 inches below ceiling; *D*, air, outdoors.

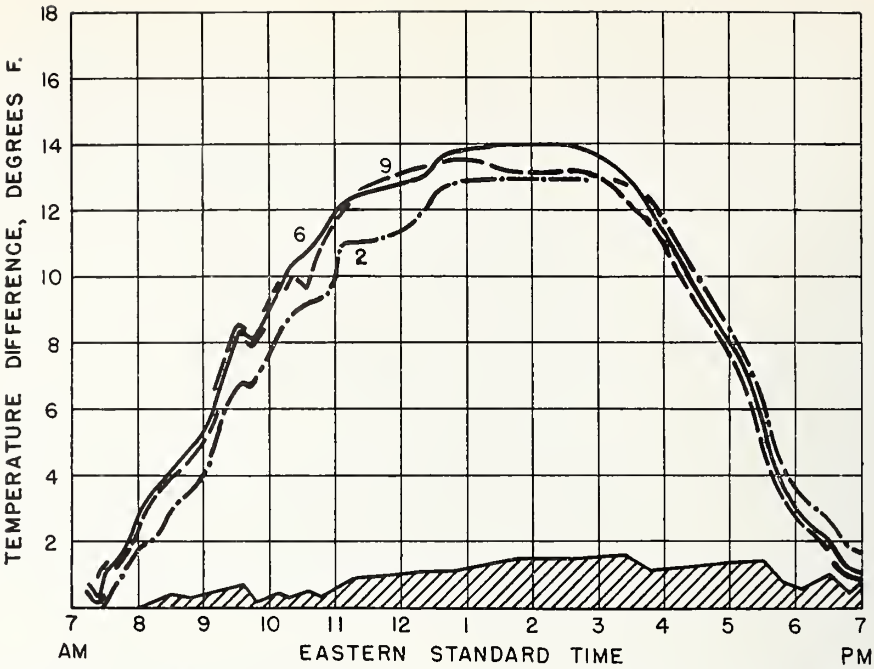

FIGURE 4.—*Temperature-difference–time curves from observations of August 3, 1939.*

Curves 2, 6, and 9 for ceiling under uninsulated spaces. Curves 3, 4, 5, and 8 for ceiling below insulated spaces fall within the shaded area. Curve 7, for ceiling insulated with two sheets of aluminum foil, is the base line.

TABLE 1.—*Temperatures measured on ceiling under several spaces*

[Observations of August 3, 1939.]

Time	Space numbers—				
	2	6	9	7	X
a. m.	°F	°F	°F	°F	°F
7:15	78.6	79.3	79.0	78.6	78.6
7:25	79.2	79.7	79.7	79.4	78.9
7:33	79.9	80.5	80.6	79.4	97.4
7:45	80.6	81.2	81.1	79.7	79.7
8:00	81.7	82.7	82.2	79.9	79.9
8:33	84.7	85.8	85.7	81.6	82.0
8:43	85.7	86.9	86.8	82.4	82.7
9:08	88.3	89.7	89.7	84.0	------
9:18	89.9	90.8	90.8	84.0	------
9:35	91.7	93.2	93.4	84.9	85.6
9:45	92.8	94.3	94.2	86.1	86.2
10:08	95.6	96.9	97.1	87.6	88.0
10:18	96.8	98.2	98.1	88.1	88.4
10:35	98.3	99.9	98.8	89.2	89.7
10:45	99.0	100.9	100.7	89.7	90.1
11:10	100.9	102.2	102.1	89.9	90.6
11:19	102.7	100.2	104.1	91.7	92.6
p. m.					
12:18	106.2	107.3	107.7	94.4	95.5
12:45	108.5	109.5	109.3	95.8	96.9
1:45	110.2	111.2	110.3	97.2	98.7
2:37	110.8	111.8	111.0	97.8	99.3
3:20	110.8	111.2	110.5	97.9	99.5
3:36	110.9	111.0	110.3	98.4	99.8
3:45	111.1	111.1	110.7	99.1	100.2
5:12	104.2	103.9	103.4	96.6	98.0
5:30	101.9	101.5	101.0	96.0	97.4
5:48	100.0	99.3	99.2	95.5	96.3
6:05	98.0	97.5	97.6	94.6	95.2
6:30	95.9	95.3	95.1	93.2	94.2
6:48	94.3	93.7	93.7	92.5	93.0
7:12	92.6	91.8	91.8	90.9	91.6

temperature of the ceiling under any insulated space and the temperature of the ceiling under space 7 falls within the area.

IV. TEMPERATURE OF THE CEILING UNDER AN ATTIC FLOOR

During the observations made on August 7, 1939, the condition of the joist spaces was the same as on August 3, except that space 6 was insulated with full-thick (3⅝ in.) glass-wool strip, and space 2 was covered with ½-inch insulating board nailed over the tops of the joists. This space, 2, may be considered, for all practical purposes, as equivalent to one with a floored attic. As in figure 3, figure 5 gives the general temperature distribution. Table 2 gives the temperatures of the ceiling under the various spaces, and figure 6 shows the amount that the respective ceiling temperatures exceeded that under space 7 at the times noted. Column X shows the highest temperature measured under any of the insulated spaces, 3, 4, 5, 6, and 8. Here the uninsulated spaced allowed a ceiling temperature 16 degrees higher than the temperature of the coolest insulated ceiling. The fact that the difference in temperature between the roof and the room

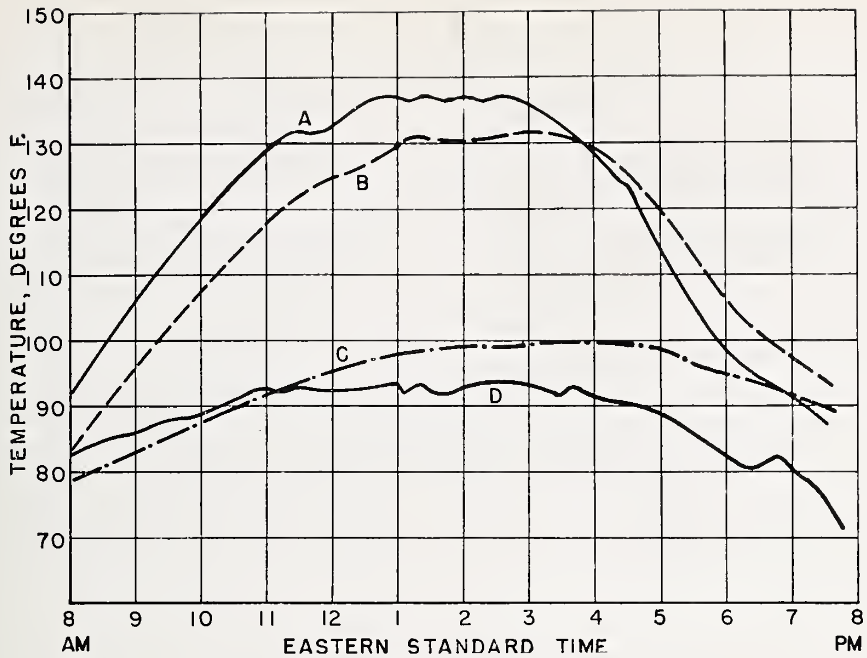

FIGURE 5.—*Temperature-time-curves from observations of August 7, 1939.*

A, under surface of roof; *B*, attic air; *C*, air, 8 inches below ceiling; *D*, air ,outdoors.

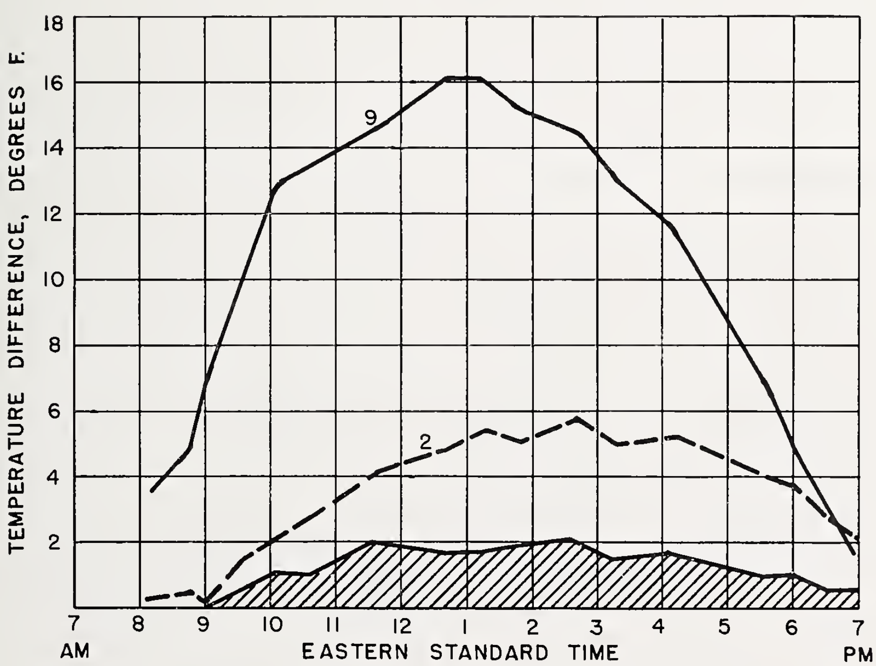

FIGURE 6.—*Temperature-difference-time curves from observations of August 7, 1939.*

Curve 9, ceiling under uninsulated space; Curve 2, ceiling under ½-inch insulating board nailed over tops of joists (approximately equivalent to a floor in the attic). Curves 3, 4, 5, 6, and 8 for ceiling under insulated spaces fall within the shaded area. Curve 7, for ceiling under two sheets of aluminum foil, is the base line.

air was 45° instead of 35° F, as on August 3, probably accounts for the fact that the uninsulated space was relatively hotter than on August 3.

TABLE 2.—*Temperatures measured on ceiling under several spaces*

[Observations of August 7, 1939.]

Time	Space numbers—			
	2	9	7	X,
a. m.	°*F*	°*F*	°*F*	°*F*
8:10	74.8	78.0	74.5	74.9
8:45	77.6	81.9	77.1	77.1
9:03	77.7	84.8	77.7	77.7
9:40	80.6	89.4	79.1	79.8
10:11	84.3	95.1	82.2	83.3
10:37	86.8	97.5	84.0	85.0
11:38	92.6	103.2	88.5	90.5
p. m.				
12:38	94.8	106.2	90.0	91.7
1:14	97.7	107.3	92.3	94.0
1:48	97.3	107.4	92.2	94.1
2:40	98.8	107.5	93.0	95.1
3:15	98.9	106.9	93.9	95.4
4:08	98.8	105.1	93.6	95.3
5:35	96.2	98.9	92.2	93.2
6:00	95.1	96.2	91.3	92.3
6:30	92.9	93.2	90.1	90.6
7:10	90.7	90.1	89.0	89.5

The data here reveal particularly the effects of ½-inch insulating board or an equivalent attic floor laid over the joists. The result is a ceiling over 10 degrees cooler than was obtained without this protection, as shown by the difference between space 9 (uninsulated) and space 2 (½-in. insulating board), but still 4 or 5 degrees warmer than a well-insulated ceiling.

V. COMPARISON OF TYPES OF INSULATION

In the preceding discussion, no attempt has been made to distinguish between the effects of the various insulations used. Before making the observations of August 23 and September 1 presented below, two changes were made. Space 9 was insulated with 2-inch rock-wool bats. The insulating board was removed from space 2, and the space was insulated with full-thick (3⅝ in.) rock wool. The insulation of the spaces was then as follows:

Spaces 2 and 8—full-thick rock-wool bats.

Spaces 4 and 9—2-inch rock-wool bats.

Space 3—2-inch wood-fiber blanket.

Space 5—one layer of aluminum foil.

Space 6—full-thick glass wool strip.

Space 7—two layers of aluminum foil.

In spite of the fact that the east and west walls of the structure were insulated and the joist spaces at the two ends were left out of consideration, there was some differential in temperature due to location. In order to decrease this effect screens of aluminum foil were placed outside the structure so as to shade its east and west walls.

Figures 7 and 8 give the temperature conditions to which the insulation was subjected on August 23 and September 1, 1939, respectively. Tables 3 and 4 give the ceiling temperatures observed under each of the spaces and the means for the similarly insulated spaces 2 and 8 and 4 and 9. Temperature differences were obtained by subtracting the ceiling temperature of space 7, the coolest, from the corresponding ceiling temperatures under each of the other insulations. In order to prevent confusion, these data are presented in two graphs. Figures 9, 10, 11, and 12 show graphically the amounts by which the various ceiling temperatures exceeded that under space 7 (insulated with two layers of aluminum foil). The numbers on the curves refer to the space numbers previously listed. Curve 2,8 is drawn from the data for the mean of the ceiling temperatures of the two spaces insulated with full-thick rock wool and curve 4,9 for the mean of the two spaces insulated with 2 inches of rock wool. Curve 4 (2 in. of rock wool) is also drawn in figures 9 and 10, because this space was adjacent to space 3 (2 in. of wood-fiber blanket), and is therefore more reliable for the comparison of these two types of insulation than would be the mean curve, 4,9.

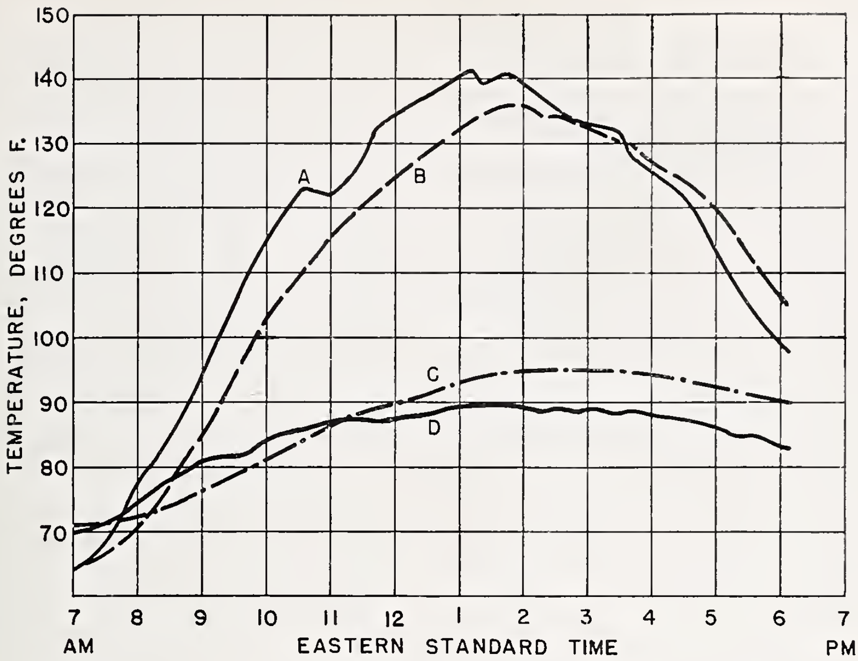

FIGURE 7.—*Temperature-time curves from observations of August 23, 1939.*

A, under surface of roof; *B*, attic air; *C*, air, 8 inches below ceiling; *D*, air, outdoors.

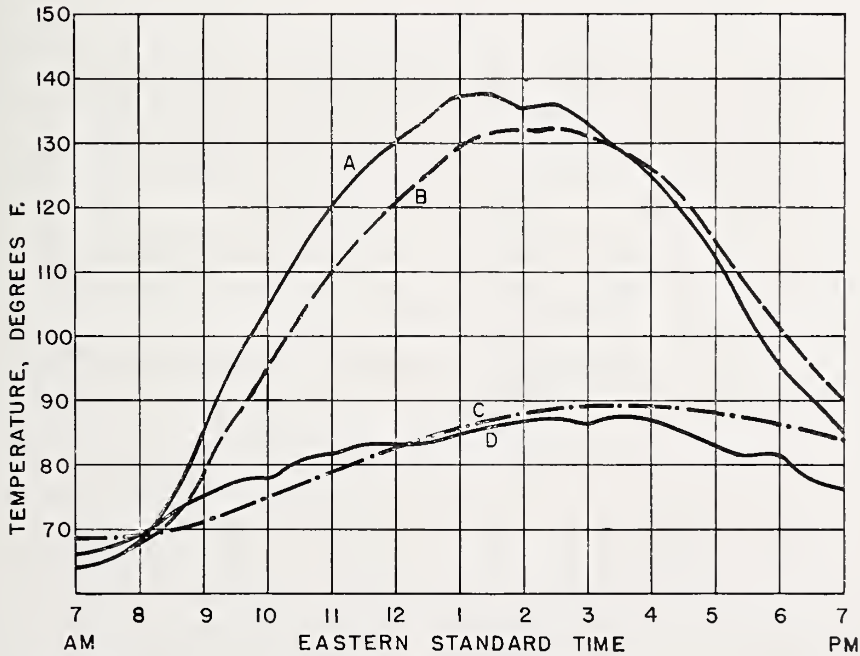

FIGURE 8.—*Temperature-time curves from observations of September 1, 1939.*

A, under surface of roof; *B*, attic air; *C*, air, 8 inches below ceiling; *D*, air, outdoors.

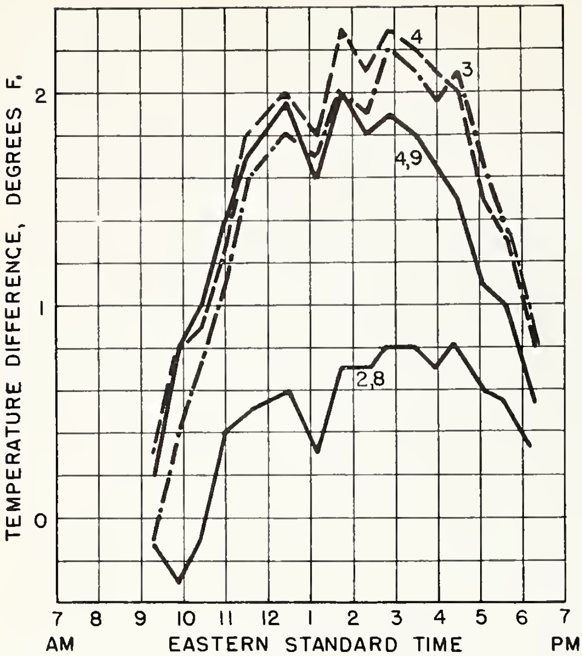

Figure 9.—*Temperature-difference–time curves from observations of August 23, 1939.*

Curve 2,8, average for ceiling under two spaces insulated with 3⅝ inches of rock wool; Curve 3, for ceiling under 2 inches wood-fiber blanket; Curve 4, for ceiling under 2 inches of rock wool; Curve 4,9, average for ceiling under two spaces insulated with 2 inches of rock wool; Curve 7, for a ceiling under two sheets of aluminum foil, is the base line.

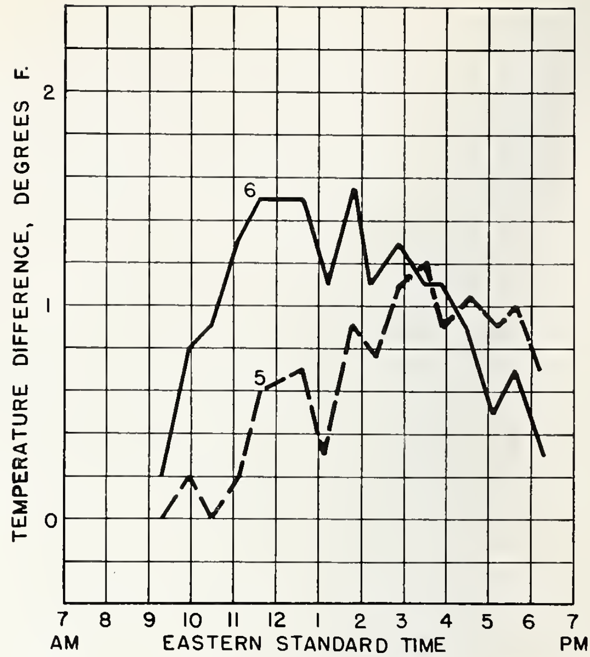

Figure 11.—*Temperature-difference–time curves from observations of August 23, 1939.*

Curve 5, for ceiling insulated with one sheet of aluminum foil; Curve 6, for ceiling insulated with 3⅝ inches of glass wool; Curve 7, for ceiling insulated with two sheets of aluminum foil, is the base line.

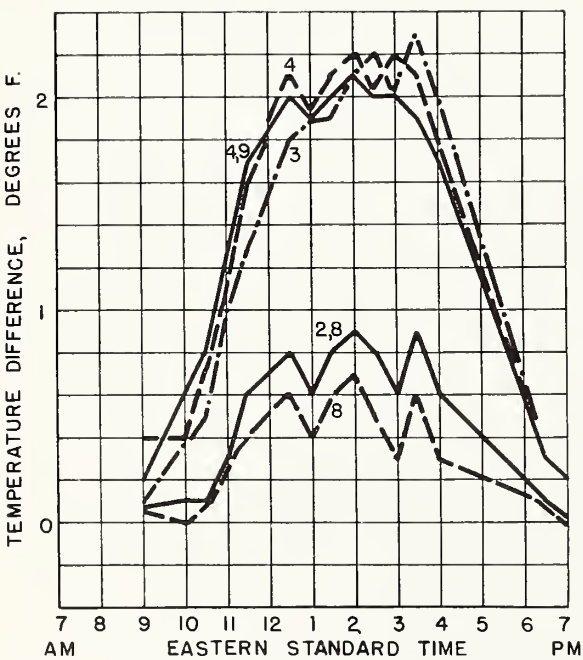

Figure 10.—*Temperature-difference–time curves from observations of September 1, 1939.*

Curve 2,8, average for ceiling under two spaces insulated with 3⅝ inches of rock wool; Curve 3, for ceiling under 2 inches of wood-fiber blanket; Curve 4, for ceiling under 2 inches of rock wool; Curve 4,9, average for ceiling under two spaces insulated with 2 inches of rock wool; Curve 8, for ceiling insulated with 3⅝ inches of rock wool; Curve 7, for ceiling under two sheets of aluminum foil, is the base line.

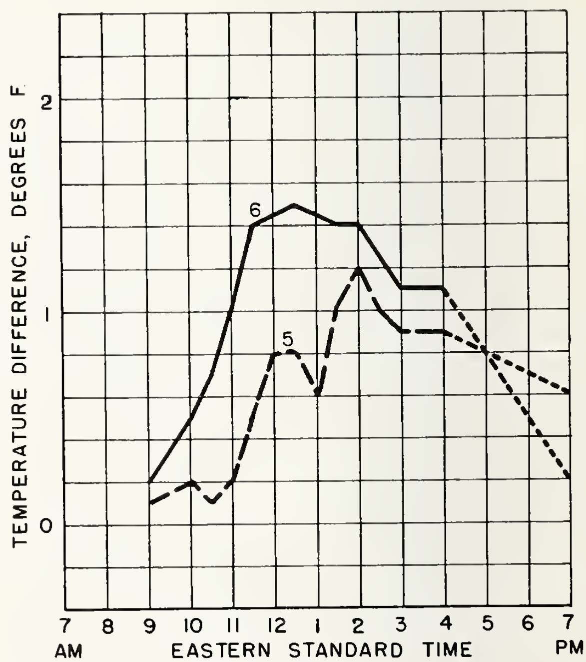

Figure 12.—*Temperature-difference–time curves from observations of September 1, 1939.*

Curve 5, for ceiling insulated with one sheet of aluminum foli; Curve 6, for ceiling insulated with 3⅝ inches of glass wool; Curve 7, for ceiling insulated with two sheets of aluminum foil, is the base line.

Table 3.—*Temperatures measured on ceiling under insulated spaces*

[Observations of August 23, 1939]

Time	Space number and insulation									
	2 (4 in. of rock wool)	3 (2 in. of wood fiber)	4 (2 in. of rock wool)	5 (1 layer of Al foil)	6 (4 in. of glass wool)	7 (2 layers of Al foil)	8 (4 in. of rock wool)	9 (2 in. of rock wool)	Mean of 2 and 8 (4 in. of rock wool)	Mean of 4 and 9 (2 in. of rock wool)
a. m.	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
9:18	77.1	77.3	77.7	77.4	77.6	77.4	77.4	77.4	77.3	77.6
9:54	79.1	79.8	80.2	79.6	80.2	79.4	79.8	80.3	79.5	80.2
10:28	81.8	82.7	82.9	82.0	82.9	82.0	82.0	83.1	81.9	83.0
11:02	84.6	85.3	85.5	84.4	85.5	84.2	84.6	85.7	84.6	85.6
11:35	86.5	87.6	87.8	86.6	87.5	86.0	86.5	87.5	86.5	87.7
p. m.										
12:38	90.1	91.3	91.5	90.2	91.0	89.5	90.0	91.2	90.1	91.4
1:10	91.9	93.2	93.3	91.8	92.6	91.5	91.7	92.9	91.8	93.1
1:47	93.2	94.3	94.6	93.2	93.8	92.3	92.8	94.0	93.0	94.3
2:20	94.2	95.1	95.3	94.0	94.3	93.2	93.5	94.7	93.9	95.0
2:55	94.2	95.3	95.4	94.2	94.4	93.1	93.5	94.6	93.9	95.0
3:30	94.9	95.8	95.9	94.9	94.8	93.7	94.1	95.1	94.5	95.5
3:55	94.7	95.5	95.6	94.6	94.6	93.5	93.7	94.7	94 2	95.2
4:30	94.2	95.0	94.9	93.9	93.8	92.9	93.1	93.9	93.7	94.4
5:07	92.7	93.3	93.2	92.6	92.2	91.7	91.9	92.4	92.3	92.8
5:38	91.9	92.2	92.2	91.9	91.6	90.9	90.9	91.6	91.4	91.9
6:15	90.1	90.3	90.3	90.2	89.8	89.5	89.5	89.8	89.8	90.1

Table 4.—*Temperatures measured on ceiling under spaces*

[Observations of September 1, 1939]

Time	Space number and insulation									
	2 (4 in. of rock wool)	3 (2 in. of wood fiber)	4 (2 in. of rock wool)	5 (1 layer of Al foil)	6 (4 in. of glass wool)	7 (2 layers of Al foil)	8 (4 in. of rock wool)	9 (2 in. of rock wool)	Mean of 2 and 8 (4 in. of rock wool)	Mean of 4 and 9 (2 in. of rock wool)
a. m.	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
9:00	71.7	71.7	72.0	71.7	71.8	71.6	71.7	71.6	71.7	71.8
10:00	74.0	74.2	74.2	74.0	74.3	73.8	73.8	74.5	73.9	74.4
10:30	75.6	76.0	76.2	75.6	76.2	75.5	75.6	76.4	75.6	76.3
11:00	77.4	78.1	78.2	77.3	78.1	77.1	77.4	78.4	77.4	78.3
11:30	79.3	79.9	80.2	79.1	80.0	78.6	79.0	80.3	79.2	80.3
p. m.										
12:30	82.8	83.6	83.9	82.6	83.3	81.8	82.4	83.7	82.6	83.8
1:00	84.3	85.4	85.4	84.1	------	83.5	83.9	85.3	84.1	85.4
1:30	85.7	86.6	86.8	85.7	86.1	84.7	85.3	86.6	85.5	86.7
2:00	86.3	87.4	87.5	86.5	86.7	85.3	86.0	87.2	86.2	87.4
2:30	87.2	88.3	88.1	87.1	------	86.1	86.6	88.1	86.9	88.1
3:00	87.8	88.9	89.1	87.8	88.0	86.9	87.2	88.6	87.5	88.9
3:30	87.9	89.0	88.8	87.8	87.8	86.7	87.3	88.4	87.6	88.6
4:00	87.8	88.9	88.7	87.8	88.0	86.9	87.2	88.2	87.5	88.6
6:30	84.1	84.4	84.4	84.7	84.1	84.1	84.2	84.4	84.2	84.4
7:00	83.4	83.6	83.6	84.0	83.6	83.4	83.3	83.6	83.4	83.6

Between the observations of August 23 and those of September 1, the south wall of the structure was insulated with a single layer of aluminum foil tacked to the inner edges of the studs. This was done in order to decrease the entrance of heat to the room by paths other than through the ceiling.

A comparison of the curves for these 2 days shows that this addition produced no material change either in relationship or relative magnitude of the temperatures observed. The data for September 1 will be discussed in detail. Those for August 23 are presented only for confirming the results.

Figure 10 shows that 2 inches of rock wool, curve 4, corresponded very closely to 2 inches of wood-fiber blanket (curve 3), and that either of these insulations gave a ceiling temperature about 2 degrees higher at the maximum than that under space 7, insulated with two layers of aluminum foil. A comparison of curve 4, 9 with curve 2, 8 shows that at 2:00 p. m., when the difference was a maximum, the temperature of the ceiling under the spaces insulated with 3⅝ inches of rock wool was 1.2 degrees F lower than under the spaces insulated with only 2 inches of rock wool. Curve 8 provides a comparison between two layers of aluminum foil and 3⅝ inches of rock wool in adjacent spaces (7 and 8). The temperature of the ceiling under the rock-wool section was slightly higher, the maximum difference being 0.7 degrees F at 2:00 p. m. The corresponding curves for a single layer of aluminum foil (in space 5) and 3⅝ inches of glass wool (in space 6) are shown in figure 12. At the maximum, the ceiling under the single layer of aluminum foil was 1.2 degrees F warmer than the ceiling under the double aluminum foil. Accordingly, 3⅝ inches of glass wool and the single layer of aluminum foil are placed, as concerns effectiveness, between 2 inches and 3⅝ inches of rock wool, by the results of these tests.

Attempts were made to compare the rates of cooling at night. If differences in this respect exist between the insulations, the experimental method was not adequate to evaluate them.

VI. CONCLUSIONS

On sunny days the temperatures of an unshaded roof and of an unventilated attic air space beneath it rise very high, as much as 40 to 50 degrees F higher than the outdoor air temperature. This higher temperature produces, in the room below, ceiling temperatures which are also high enough to be a source of discomfort. A half-inch insulating board nailed over the ceiling joists, produced a marked improvement in the comfort condition, lowering the ceiling temperature by about 10 degrees. A tight wood floor in the attic would produce about the same effect. Even with this, however, the ceiling was about 5 degrees F warmer than the ceiling that had the maximum protection.

With the exception of the above, no great differences exist between the performance of the various insulations tested. It is questionable whether these differences, about 2 degrees F at the greatest, are large enough to make a sensible difference in comfort secured under summer conditions. With respect to such differences as do occur, however, the insulations tested may be listed in order of decreasing effectiveness in protecting the ceiling against summer heat, as follows:

1. Two layers of aluminum foil (both sides of each layer reflecting).
2. Full-thick (3⅝ in.) rock wool
3. One layer of aluminum foil (both sides reflecting).
4. Full-thick (3⅝ in.) glass wool.
5. Two inches of rock wool or 2 inches of wood-fiber blanket.

The above listing refers only to limiting the rise of temperature of the ceiling in summer. It does not apply to the escape of heat through the ceiling in winter.

The effectiveness of reflective types of insulation under summer conditions was to be expected, since, in a horizontal position, this type of insulation gives its best performance when resisting the flow of heat downward. The comparatively small differences between the effectiveness of one layer and two layers of such insulation, under summer conditions, would not be found under winter conditions, since two layers of reflective insulation would be nearly twice as effective as a single layer for restricting the flow of heat upward.

The building used was of relatively low heat capacity. It is due to this fact, that in spite of the insulation of walls and ceilings (during the observations on September 1) the temperature of the air inside the building was definitely higher after 2:00 p. m. than the temperature of the air outside. In buildings of more massive construction, this condition does not arise until considerably later in the day.

These data apply to a slightly sloping roof, with an unventilated attic space between the roof and ceiling. Substitution of a pitched roof or ventilated attic or both, would decrease the amount of heat coming through the ceiling and might therefore be expected to make the differences between the various kinds of insulation still smaller.

The results show only the relative effectiveness of the various ceilings tested. They do not answer the question, "How many degrees cooler will a room be if the ceiling is insulated, than it would be if the ceiling were uninsulated?" The answer to this question depends not only on the insulation used, but also on the type of building, the extent to which it is shaded, and other factors, so that no general answer which would be applicable to all kinds of structures is possible.

VII. SUMMARY

A room that has nothing but a plastered ceiling between the occupants and the roof boards will not be comfortable on hot summer days, especially if the attic is not ventilated. If there is no attic floor, a couple of inches of blanket or fill insulation put on top of the ceiling or a single layer of aluminum foil tacked over the tops of the joists, will greatly improve conditions. More than 2 inches of insulation will produce only slightly better results.

If the attic has a floor, about two-thirds of the improvement that would result from using insulation has already been attained. Placing additional insulation under such a floor may be rather expensive, and although the room may be perceptibly more comfortable with the insulation, there may be doubt as to whether the gain was sufficient to warrant the trouble and expense.

Some of the work of preparing this manuscript for publication was undertaken by E. F. Mueller and H. V. Cottony.

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