

# Factors Affecting Heat Transmission through Insulated Walls

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# Factors Affecting Heat Transmission through Insulated Walls

## INTRODUCTION

Heat transmission through insulation in combination with the various materials used in the construction of a building brings up many problems in addition to that of the thermal conductivity of the material itself. While the laws governing the heat flow through insulating materials and through walls have been rather thoroughly investigated, there are still some points about which there are controversies and differences of opinion. There are also some conditions and combinations of materials under which it is impossible to make accurate calculations and where approximate methods must be used.

The direction of heat flow through the wall—that is, whether it is flowing horizontally, vertically upward or vertically downward—will, in certain cases, have some effect on the total amount of heat flow under given temperature conditions. There has been some controversy as to whether the orientation of the wall would affect the rate of heat conductivity sufficiently to make changes necessary in the heat transmission coefficients that are in general use. Since a part of the heat is transferred by convection, it is natural to expect more rapid heat flow upward than downward across an air space and also to expect a variation in the relative values of the coefficients due to the sizes of the air spaces. It is impossible to determine these differences by calculation, but it is possible to determine them by tests on actual wall sections so positioned that the heat will flow in different directions.

Insulation is added to walls, ceilings, and exposed parts of a building in varying thicknesses. The assumption is that its insulating value is in direct proportion to the thickness of insulation used. Questions have arisen recently as to whether or not there may be some variation in thermal conductivity for each successive layer of insulation as the thickness becomes greater and whether or not the thicker applications may not be less effective per inch of thickness.

In the case of fill insulation, particularly mineral wool, the question often arises as to its effectiveness when applied by different methods. For instance, it is sometimes applied by hand as loose insulation and sometimes it is blown into the open spaces in the frame walls. The same type of insulation is also applied in the form of bats and blankets. In making calculations for the thermal conductivity through the insulation applied by the different methods, the conductivity coefficients have usually been assumed to be the same regardless of the method

of application. These assumptions can be readily checked by insulating walls of the same type with the same materials, using different methods of application.

There are now on the market several types of mineral wool insulation varying somewhat in density and other physical properties, and the question often arises as to whether or not one type has any major advantages over another. Naturally, the physical properties of the materials may be such as to affect greatly their thermal conductivity. However, for practical purposes, there may be a rather wide range in density without showing any significant difference in thermal conductivity for the mean temperature range under consideration in this report. Likewise, when each of the various types of wool is properly applied, there is very little difference in thermal conductivity.

A factor which is present in all frame walls or ceilings in which insulation is applied between the studs, joists, or rafters is the effect of these structural members on the overall coefficient of the insulated wall or ceiling. It seems evident that for the uninsulated wall the studs might have a relatively high insulating effect over the space covered by them and to a lesser extent on the overall conductivity coefficient of the wall, whereas, for the heavily insulated wall, the conductivity through the area of the studs might be greater than it is through the insulation. At some point between an entire absence of insulation and very heavy insulation the thermal conductance over the area covered by the studs might be equal to that over the area covered by the insulating material. In any case, it is difficult to calculate the exact overall conductivity coefficient for frame walls in which fill insulation is used, and for the average case the practical method is to consider the insulation as covering the full area of the wall.

Other points that have arisen in connection with fill insulating materials used for upper floor ceilings are the possible increase in the overall coefficient for exposed insulation due to convection air currents circulating through the exposed upper surface of the insulation and the effect on the coefficient of placing a paper lining over the top of the insulation and in contact with it.

It was for the purpose of investigating the above problems that the present research was undertaken. Since all of the problems were related to loose or fill insulation, the major part of the investigation was concerned with walls insulated with this type of material.

## METHODS OF INVESTIGATION

Because most of the problems under consideration could not be accurately solved by calculation, it was necessary to devise and set up test apparatus by which the results could be obtained experimentally for the various combinations of materials under the different conditions required. As the results were to be applied to ordinary building

construction, it was desirable to subject the test specimens to temperature conditions which would be met in practice by common types of insulated walls. Air temperatures of 70 F on the warm side and of -10 F on the cold side were selected as practical. The relative values of the various types of construction under these temperature conditions should hold for any ordinary conditions under which the walls might be used. To achieve these conditions, a test box, to be described later, was devised in which a five-foot square test wall could be placed. The temperature within the test box was controlled at around 70 F. The test box was placed in a cold room, the temperature of which could be controlled as low as -10 F, and it was so arranged that the box could be rotated to place the test wall in either a horizontal or vertical position, thus simulating a ceiling or side wall of a house. Proper test equipment and instruments were then provided for setting up the required temperature conditions and for measuring the actual heat flow through the insulated wall. Walls of various types were constructed, placed in the test apparatus and held under constant temperature conditions for a sufficient length of time to establish a uniform rate of heat flow through them. Test data were then taken over an extended period to insure accurate results. In many cases, tests were made in sequence without changing the test wall and without changing the air temperatures on either the high or low side of the wall. Thus, for a wall which was to be tested in a vertical and horizontal position, it was only necessary to rotate the test box to change the position of the test wall between two tests.

In applying insulation, care was taken to get the proper thickness and density. A special gage was used to determine average thickness. The densities were determined from the volume of the insulation as measured in the wall and the weights of the insulation as applied. As it was impossible to hold loose or fill insulation in the test wall when the wall was in a vertical position and the insulation was exposed on its outer or cold surface, a special quarter-inch mesh retaining screen was placed over it. For the horizontal position, the tests were made with and without the screen over the insulation to determine the effect of the screen.

### TEST APPARATUS

The test apparatus consisted of a low-temperature control room, refrigerating apparatus for cooling the same, a double or guarded box construction for metering the heat supplied to the test wall, control instruments for measuring the amount of heat supplied to the inner box of the double box construction and passing through the test wall, temperature recording and measuring instruments for measuring the temperatures of the air on the two sides of the wall, throughout the metering box and throughout the various sections of the test wall.

Figures 1, 2, 3, and 4 show line drawings and photographs of the essential features of the test apparatus.

### Cold Room

The low-temperature room, shown in vertical cross section in Figure 1 is substantially 10 feet square and 10 feet high. The exposed walls are insulated throughout with mineral wool approximately 6 inches thick. The cooling coils are placed on top of the cold room and the test box is supported on trunnions within the cold room as shown. A large door is provided for moving the test apparatus and test sections into and out of the room.

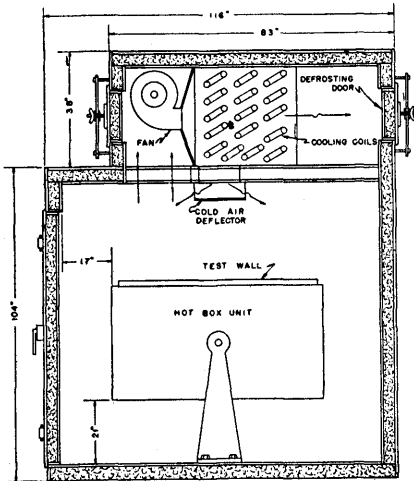


Figure 1. Cross-sectional view of cold room showing test box in position for conducting heat vertically upward through the walls

### Refrigerating Apparatus

The room is cooled by a five-ton Freon compressor and direct-expansion cooling coils through which the air of the room is circulated. The cooling coils are shown in cross section above the cold room in Figure 1. Air is drawn from the top of the cold room by a fan, passed through the cooling coils and then back to the cold room. It is possible by this method

to get uniform air temperatures in the cold room and also to hold them at any point desired. A cold room air temperature of  $-10^{\circ}\text{F}$  was closely adhered to throughout this investigation.

Two openings were provided through the walls enclosing the fan and cooling coils for defrosting the cooling coils, one at the intake side of the fan and one at the discharge side of the cooling coil. There were also shut-off dampers in the supply and return air ducts to the cold room. By the proper operation of these openings and shut-off dampers, the warm room air could be taken in by the fan, forced through the coils and discharged directly into the outside room. With this arrangement it was possible to defrost the coils without disturbing the operation of the cold room for any considerable period of time and without interfering with a test. In practice, however, it was never necessary to defrost during a test period.

### Metering Box

The metering box was of the standard guarded box construction of the type which has been used for several years at the University

of Minnesota for determining the overall thermal coefficients of walls. It consisted of an inner and outer box and was mounted on trunnions so that the test walls could be placed in either a horizontal or vertical position. The box is shown in a horizontal position in the cold room of Figure 1 and in two cross-sectional views in Figure 2.

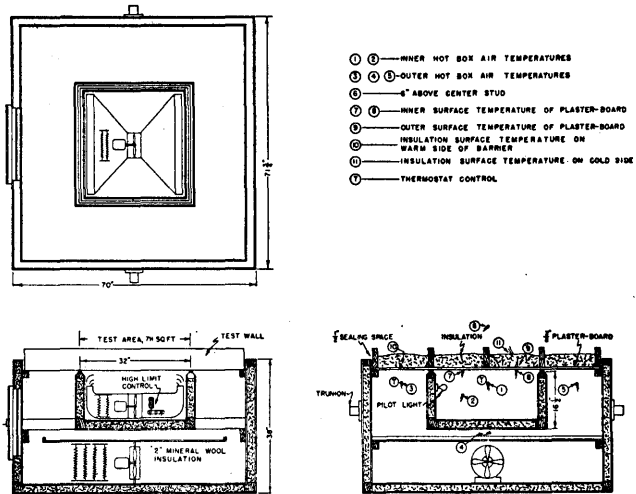


Figure 2. Details of test box with test wall in place

The inside dimensions of the outer, or guard box are 5 feet 6 inches square by 30 inches deep. One of the square faces is left open for the insertion of the test wall. The inner, or test box is approximately 16 inches deep and the center line of the walls around the open face is 32 inches square. Thirty-two inches were selected in order to cover the face area over two standard stud spaces, thus giving average results for frame constructed walls.

The inner box was so placed in the guard box that when the test wall was inserted within the guard box its inner surface would come in contact with the open face of the inner box. Thus there were two spaces which were sealed by the test wall: (1) that within the inner or heat metering box and, (2) that between the inner and outer boxes. The area of the test wall covering the inner box was the test area; that covering the space between the two boxes was the guard area. The temperature of the air in the inner box and in the space between the two boxes was maintained equal during a test period. The heat supplied to the inner box was metered and used to calculate the thermal coefficients of the wall. As the air temperatures on the two sides of the five walls of the inner box were the same, heat could not pass through these walls and the heat required to maintain the inner box

air temperature was a measure of that flowing through that section of wall over the open face of the inner or test box. Also, as the air temperatures on the warm side of the wall over the test area and over the guard area were the same, the lines of heat flow through the walls would necessarily be normal to its surfaces and that part passing through the test area would all be supplied by the heating elements of the inner or metering box.

### **Temperature Controls for Cold Room**

The temperature of the cold room was controlled first by the operation of the compressor. This was operated to give a temperature slightly below that required. The temperature was then brought up to test conditions by a thermostatically controlled electric heating element within the cold room. It was possible by this method to get more sensitive control than could be obtained by the compressor alone and yet, by proper operation of the compressor, very little refrigerating effect was lost. The controls were all automatic and as there was good air circulation through the cold room, temperature distribution was not a problem. The defrosting of the refrigerating coils was accomplished by operating the by-pass dampers shown in Figure 1 as previously explained. It was always possible to select the periods for defrosting at times when they would not interfere with test data.

### **Temperature Controls for Heat Metering Box**

Figure 3 shows the wiring plan for the control instruments. The air temperatures in the space between the inner box and outer box were maintained uniform by thermostatically controlled electric heaters which were placed within this space. Air was circulated over these heaters with small electric fans, the heat from which was added to that used by the heaters. Ducts were provided for carrying the air past the heaters and for distributing it uniformly throughout the space to be heated. The electricity through the heating element was controlled by switches placed outside of the cold room, and during a test period these switches were regulated so that the major part of the heat passed through the heating elements continuously. A small part was carried through a thermostatically controlled circuit which was operated by an on-and-off switch. The heat supplied to this space was not metered as it was not a part of that passing through the test area of the wall.

The heat required to maintain the temperature of the inner or heat metering box was supplied by electric heating elements, the air being directed over the element and throughout the space by a circulating fan. All of the electricity passing through either the heating element or circulating fan was metered. The elements of the heating unit were controlled by switches and rheostats outside the test box which were adjusted during a test to pass the greatest percentage of the heating

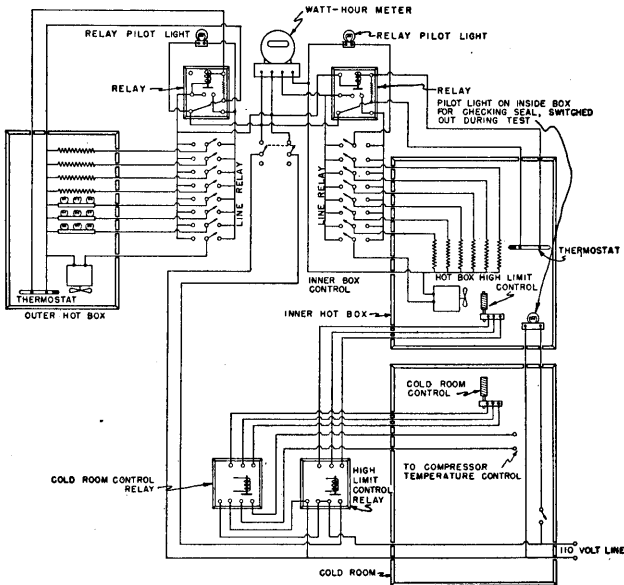


Figure 3. Wiring diagram for heating elements and controls

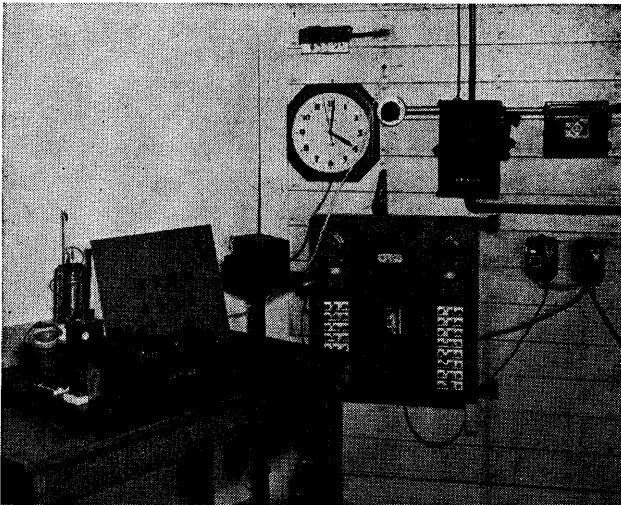


Figure 4. Control panel and test instruments

current continuously through the heating elements. A small percentage was passed through an on-and-off thermostatically controlled circuit to maintain the exact temperature desired. The heating element, together with fan and circulating duct as well as the thermostatic control element, is shown in the sectional drawing, Figure 2. The meter and control switches are located on the control panel shown in Figure 4.

### Temperature Measuring Instruments

All temperatures were measured with copper constantan thermocouples and a Leeds and Northrup Type K potentiometer. The vertical cross section drawing in Figure 2 shows in general the arrangement of thermocouples within the test boxes and throughout the walls. Thermocouples were arranged to give sufficient temperatures (1) within the test box proper and in the space between the two boxes; (2) of the air within the cold room; and (3) throughout the test wall as required. All thermocouple wires were carried to the control panel outside of the cold room shown in Figure 4.

### TEST PROCEDURE

All test sections were constructed approximately  $5\frac{1}{2}$  feet square, thus giving four full 16-inch width stud spaces for the test walls. The test sections were then placed in the test box in such positions that the inner, or warm face completely sealed the space between the two boxes and that of the inner or test box proper. This arrangement is shown in Figure 2. The test box was then set with the wall in either a vertical or a horizontal position as required for the test and the air temperatures on the two sides of the test wall were adjusted, that on the warm side at 70 F and that on the cold side at -10 F. These temperatures were maintained constant throughout the test period. Test data were taken after uniform temperature gradients had been established through the wall and uniform heat flow was assured. The tests were then continued for periods of from six to eight hours with data recorded every 15 minutes. The average of these constant readings constituted the final test results. The heat supplied to the inner box during this period was taken as that passing through the test area of the wall. In many cases the wall was left in the same position in the test box, while the box was rotated to new positions or some slight change was made in the insulation of the wall without the necessity of taking the wall out and disturbing the temperature gradient. Under these conditions it was possible to take test data in a very short period after the changes were made as very little time was necessary for establishing uniform temperature gradients.

When the walls were tested in a vertical position, especially those in which loose fill insulation was used between the joists, it was necessary to place a screen over the surface of the insulation to hold it in place. It was also necessary to test the wall in a horizontal position with and without the screen to determine the effect of the screen. Changes of this nature were made without changing the temperature of the test apparatus or walls.

The various types of walls tested, periods of test, data taken, etc. will be found in the tables covering test results.

### Description of Walls Tested

With the exception of the wall in test 38, all of the walls were six inches thick. In general, they were constructed of 2-inch by 6-inch framing members spaced 16 inches on center with a 2-inch by 6-inch member at each end of the wall. The inner, or warm surface of the wall was covered with  $\frac{3}{8}$ -inch gypsum plasterboard and, unless specifically designated in the table giving descriptions of walls, the cold side of the framing members was left uncovered. Test 38 was built in the same manner as the others, except that 2-inch by 4-inch framing members were used. In several instances in which it was desired to measure the heat flow through the insulation without the effect of framing members, the studs or joists were omitted, using 2-inch by 6-inch framing members around the outside of the wall only. The type of framing member used over the test area of the wall is indicated in the second column of Table II.

### Method of Applying Insulation

The type of insulation used is described in the various tables giving results of tests. When granular mineral wool was applied by hand, it was poured into the space between the framing members and was leveled off as closely as possible to the required thickness with a strike. The exact thickness was measured by use of a special gage which gave the exact distance from the surface of the framing member to the insulating materials at designated points. The average thickness for the test area was gaged at approximately 60 points uniformly spaced over this area.

In applying machine-blown mineral wool to the open construction, that is without flooring or covering on the cold side of the wall, the wall was placed in a horizontal position and the end of the blowing hose was held horizontally at about 24 inches above the upper surface of the joists. The space between the joists was filled as closely as possible to the desired thickness after which it was leveled off with the strike and the exact thickness measured in the same manner as described for the hand-applied granular wool.

For the wall in test 36 with six-inch joists, the wool was first blown to the approximate thickness and then accurately measured after which the floor boards were applied with screws in order not to disturb the mineral wool in the wall. For test 37, the floor boards were applied and the mineral wool was blown between the joists to fill completely the space between the gypsum board on the warm side and the floor boards on the cold side.

In all cases where insulation was applied without specifically designating any space between the insulation and the warm surface lining of the wall, it was applied next to the gypsum board on the warm side of the wall.

In cases where either bats or blankets are described as having the barrier lapped on the warm side, it indicates that the insulation was applied to the warm side of the wall and the paper flap which extends from the sides of the bat or blanket was nailed to the face of the joists or studs before the gypsum plasterboard was applied. In cases where bats or blankets were placed between the joists, they were applied from the cold side, and the flap, if present, was snugly fitted against the side of the joist or stud to give as nearly as possible the same effect that it would have if nailed to the face of the framing member.

When walls with loose or fill insulation between the framing members were tested in a vertical position, it was necessary to add some retaining member over the insulation to hold it in place. For this purpose a ¼-inch mesh wire screen was placed in contact with the surface of the insulation and nailed to the sides of the framing members. The wall was then tested in a horizontal position both before and after the application of the screen and tested in a vertical position with the screen in place. The comparisons between horizontal and vertical heat flow were made with the screen in place. However, in all cases the results in horizontal position were substantially the same with and without the wire screen.

The density and thickness of fill insulation were measured after the insulation was applied to the wall. The density and thickness of the bat or blanket insulation was measured before the insulation was applied.

**Table I. Identification of Materials**

Identification	Description of Insulation
A	Granular mineral wool of a type commonly used for hand application or blowing
B	Four-inch mineral wool blanket without vapor membrane attached
C	Three-inch mineral wool blanket with vapor membrane attached to one surface and extended at edges
D	Expanded mica, coarse granules
E	Resilient crepe blanket with no vapor barrier attached
F	Mineral wool bat with vapor barrier attached to one surface. Barrier extended at edges of bat
G	Wood fiber blanket insulation enclosed in vapor-proof paper, flaps extending from one surface at edges to be attached to surface of studs or joists
H	Loose mineral wool fill commonly used for hand application
I	Mineral wool bat with vapor membrane attached to one surface and extended at edges
J	Mineral wool blanket insulation enclosed in paper, one surface vapor-proofed with extending flaps to be nailed to surface of studs or joists
L	Cotton fibers between two layers of asphalt-coated kraft paper, flaps extended for nailing to the surfaces of studs or joists
M	Ground newspaper
N	Cellular cotton batten blanket in 48-inch strips
O	Shredded newspaper between two layers of asphalt-coated kraft paper extended for nailing to studs or joists

### Identification of Materials

Since various types of insulating materials were used and since it was impractical to give a complete description of each material in the different tables giving the test results, each of these materials has been given an identification letter. The letter with a brief description is given in the various tables of test results. A more complete description of the materials corresponding to each letter is given in Table I.

## TEST RESULTS

The results for the various tests are given in Tables II through VIII, inclusive. Table II gives a general description of the wall and insulation, the position of the wall during the test, and the overall coefficient of heat transmission for all of the walls tested. Table III gives the position of the wall as horizontal or vertical, the temperatures of the air as taken throughout the wall for the test and the overall coefficient of heat transmission. Tables IV through VIII, inclusive, give test data for walls selected from the general list and are grouped according to the specific purpose of the test in each case.

### Effect of Wall Position on Thermal Conductivity

In Table IV the tests are grouped to show any differences in overall coefficients for the same wall when tested in a horizontal position with heat flowing upward and in a vertical position with heat flowing horizontally. There were five walls tested in both the horizontal and vertical position and for two of the walls there were two tests with the walls in a horizontal position. For the tests in each group, the same wall was used with no change in insulation or construction except for test 9 of the second group. For this test, a heavy kraft paper was laid over and in contact with the upper surface of the mineral wool. For tests 10 and 11 of this group, the paper was removed and the retaining wire placed over the surface of the insulation. In the third group, tests 16 and 18 were duplicate tests, 18 being made as a check on 16 which appeared to be low.

By comparing overall coefficients,  $U$ , for tests 5 with 6, 10 with 11, the average of 16 and 18 with 17, 27 with 28, and 24 with 25, it will be observed that the results are substantially the same for the walls tested in the vertical as for the same walls tested in the horizontal position. It is therefore evident that the same results may be expected from fill types of insulation as used in these tests whether they are applied with the wall in a vertical or horizontal position, that is, for side walls or for ceilings and roofs.

Table II. Description and Position of Walls as Tested

Test No.	Framing Members	Identification	Insulation		Density, lbs per cu ft	Wall Position	"U"
			Description and application	Thickness, Inches Rated Measured			
1	2" x 6"		No insulation			H	0.803
2	2" x 6"	A	Hand-applied granular mineral wool	3 3.00	6.62	H	0.103
3	2" x 6"	A	Hand-applied granular mineral wool	3 3.00	6.62	H	0.097
4	2" x 6"	A	Hand-applied granular mineral wool	3 3.00	6.62	H	0.105
5	2" x 6"	A	Hand applied granular mineral wool with wire screen support	3 3.00	6.62	H	0.101
6	2" x 6"	A	Hand-applied granular mineral wool with wire screen support	3 3.00	6.62	V	0.098
7	2" x 6"	A	Hand-applied granular mineral wool	4 4.05	6.14	H	0.081
8	2" x 6"	A	Hand-applied granular mineral wool	4 4.05	6.14	H	0.088
9	2" x 6"	A	Hand-applied granular mineral wool, paper covering laid over top surface of insulation	4 4.05	6.14	H	0.080
10	2" x 6"	A	Hand-applied granular mineral wool with wire screen support	4 4.05	6.14	H	0.082
11	2" x 6"	A	Hand-applied granular mineral wool with wire screen support	4 4.05	6.14	V	0.080
12	2" x 6"	A	Hand-applied granular mineral wool	3 3.06	6.54	H	0.104
14	2" x 6"	A	Machine-blown granular mineral wool	4 4.04	5.57	H	0.082
15	2" x 6"	A	Machine-blown granular mineral wool	4 4.04	5.57	H	0.082
16	2" x 6"	A	Machine-blown granular mineral wool with wire screen support	4 4.04	5.57	H	0.073
17	2" x 6"	A	Machine-blown granular mineral wool with wire screen support	4 4.04	5.84	V	0.077
18	2" x 6"	A	Machine-blown granular mineral wool with wire screen support	4 4.09	5.84	H	0.080
19	2" x 6"	A	Hand-applied granular mineral wool	2 2.12	6.05	H	0.139
20	2" x 6"	B	Glass wool blanket without vapor barrier	4 3.99	1.77	H	0.082
21	2" x 6"	C	Glass wool blanket, barrier on warm side	3 2.646	2.24	H	0.106
22	2" x 6"	C	Glass wool blanket, barrier on warm side	3 2.646	2.24	V	0.102
23	2" x 6"	D	Hand-applied expanded mica	4 4.013	7.15	H	0.116
24	2" x 6"	E	Resilient creped paper blanket, no vapor barrier	1 1.583	1.72	H	0.165
25	2" x 6"	E	Resilient creped paper blanket, no vapor barrier	1 1.583	1.72	V	0.162
26	2" x 6"		No insulation			H	0.804
27	2" x 6"	F	Mineral wool bats in 48" strips, barrier lapped on warm side of studs	4 3.89	2.99	H	0.085
28	2" x 6"	F	Mineral wool bats in 48" strips, barrier lapped on warm side of studs	4 3.89	2.99	V	0.088
29	None	A	Hand-applied granular mineral wool	4 3.875	6.67	H	0.075
30	None	A	Hand-applied granular mineral wool	2 1.906	6.36	H	0.136
31	2" x 6"	G	Wood fiber blanket between joists, barrier on both sides	2.25 2.25	4.51	H	0.104
32	None	A	Hand-applied granular mineral wool	3 2.940	6.05	H	0.101

Note—"U" designates overall thermal conductivity of wall (air to air), including framing member as used.

Table II. Description of Position of Walls as Tested—Continued

Test No.	Framing Members	Identification	Description and application	Insulation		Density, lbs per cu ft	Wall Position	"U"
				Thickness, Inches Rated	Measured			
33	2" x 6"		No insulation				H	0.843
34	2" x 6"	H	Machine-blown loose mineral wool	4	4.14	6.39	H	0.083
35	2" x 6"	A	Machine-blown granular mineral wool	3	3.21	5.90	H	0.096
36	2" x 6"	A	Machine blown granular mineral wool with 1" flooring	4	3.87	5.82	H	0.069
37	2" x 6"	A	Machine-blown granular mineral wool with 1" flooring	6	5.125	7.27	H	0.059
38	2" x 4"	A	Machine-blown granular mineral wool	4	3.625	5.76	H	0.089
39	2" x 6"	I	Mineral wool bats lapped on warm side of studs	3	3.478	3.67	H	0.092
40	2" x 6"	J	Mineral wool blanket between joists, barrier on warm side	1	1.510	1.933	H	0.169
41	2" x 6"	J	Mineral wool blanket between joists, barrier on warm side	2	3.094	1.79	H	0.098
42	2" x 6"	I	Mineral wool bats, barrier on warm side	2	2.19	4.074	H	0.115
43	2" x 6"	G	Wood fiber blanket on warm side of joists, barrier on both sides	1	1.107	3.372	H	0.217
45	2" x 6"	L	Processed cotton blanket on warm side of joists, barrier on both sides	1	1.025	5.27	H	0.228
46	None	A	Hand-applied granular mineral wool	3	2.635	6.80	H	0.107
47	None	A	Hand-applied granular mineral wool	6	5.00	7.127	H	0.061
48	None	A	Hand-applied granular mineral wool	6	5.125	7.13	H	0.058
49	None	A	Hand-applied granular mineral wool	3	2.625	6.05	H	0.106
51	2" x 6"	M	Hand-applied ground newspaper	3	3.044	3.869	H	0.097
52	None	I	Mineral wool bats, barrier on warm side	3	3.281	3.62	H	0.086
53	None	A	Hand-applied granular mineral wool	6	5.219	7.103	H	0.055
54	None	C	Mineral wool blanket, barrier on warm side	3	3.05	1.92	H	0.089
55	None	B	Mineral wool blanket, no vapor barrier	4	4.117	1.79	H	0.071
56	2" x 6"	J	Mineral wool blanket between joists, barrier on warm side	1	1.121	4.536	H	0.170
57	2" x 6"	J	Mineral wool blanket between joists, barrier on warm side	2	1.630	4.594	H	0.141
58	None	A	Hand-applied granular mineral wool with 3/8" gypsum board on cold side	4	3.912	6.60	H	0.073
59	2" x 6"	J	Mineral wool blanket on top of joists, barrier on warm side	1	1.121	4.536	H	0.162
60	2" x 6"	J	Mineral wool blanket on warm side of joists, barrier on warm side	3	2.932	2.834	H	0.097
61	2" x 6"	N	Cellular cotton batten blanket on warm side, barrier on warm side	3	2.44	1.188	H	0.098
62	2" x 6"	O	Shredded newspaper between two layers asphalt-coated kraft paper	.294	.294	1.151	H	0.295
63	2" x 6"		Half-inch plaster board, no insulation				H	0.774
65	2" x 6"	C	Wood fiber blanket on warm side of joists, barrier on both sides	1	1.107	3.372	H	0.212
66	2" x 6"	L	Processed cotton blanket on warm side of joists, barrier on both sides	1	1.025	5.27	H	0.226
67	None	N	Cellular cotton blanket, barrier on warm side	3	2.44		H	0.088

Note—"U" designates overall thermal conductivity of wall (air to air), including framing member as used.

Table III. Summary of Test Results

Test No.	Date	Position of Wall	Air Temperature, Deg F			Surface Temperature, Deg F				"U"
			Inner box	Outer box	Outside	Plasterboard		Insulation		
						Warm side	Cold side	Warm side	Cold side	
1	2-11-43	H	70.1	71.6	- 9.1	42.6	23.2			0.803
2	2-12-43	H	70.2	70.3	-10.7	67.4	65.6		- 8.4	0.103
3	2-13-43	H	70.1	70.2	-10.3	67.3	65.5		- 8.2	0.097
4	2-15-43	H	70.1	70.4	- 9.4	67.4	65.2		- 6.9	0.105
5	2-17-43	H	70.0	70.3	-10.6	67.5	65.8		- 6.1	0.101
6	2-18-43	V	70.2	70.5	- 6.2	67.8	66.1		- 1.2	0.098
7	2-20-43	H	70.1	70.3	+ 0.1	68.5	67.3		+ 3.3	0.081
8	2-22-43	H	70.0	70.5	-10.5	68.1	66.7		- 7.9	0.088
9	2-23-43	H	70.0	70.6	-10.5	68.1	66.8		- 5.3	0.090
10	2-24-43	H	70.1	70.7	-10.6	68.1	66.7		- 8.1	0.082
11	2-25-43	V	70.1	71.2	-11.4	68.2	67.0		- 8.1	0.080
12	2-26-43	H	70.1	70.4	-10.5	67.6	65.7		- 7.9	0.104
14	3- 2-43	H	70.0	70.3	-10.4	68.0	66.6		- 8.6	0.082
15	3- 3-43	H	70.0	70.3	-10.3	68.1	66.6		- 8.4	0.082
16	3- 5-43	H	70.1	70.3	-10.3	68.1	66.7		- 6.1	0.073
17	3- 6-43	V	70.1	70.6	- 9.8	68.2	67.0		- 6.5	0.077
18	3- 8-43	H	70.1	70.4	-10.3	68.2	66.8		- 8.6	0.080
19	3-10-43	H	70.0	70.3	-10.5	66.4	63.7		- 6.7	0.139
20	3-13-43	H	70.1	70.3	-10.3	68.1	66.8		- 7.8	0.082
21	3-16-43	H	70.2	70.3	-10.2	67.4	65.5	63.7	- 6.8	0.106
22	3-18-43	V	70.0	70.5	-10.2	67.6	66.2	63.9	- 6.1	0.102
23	3-20-43	H	69.9	70.3	-10.3	66.7	64.3		- 7.7	0.116
24	3-23-43	H	70.0	70.3	-10.3	65.6	62.5		- 5.7	0.165
25	3-24-43	V	70.1	70.5	-10.3	65.9	62.8		- 4.7	0.162
26	3-25-43	H	70.1	70.8	- 9.0	43.6	24.8			0.304
27	3-27-43	H	70.0	70.2	-10.3	68.0	66.5	63.8	- 7.8	0.085
28	3-30-43	V	70.0	70.2	-10.8	67.9	66.6	63.8	- 8.0	0.088
29	3-31-43	H	70.0	70.1	-10.2	67.9	66.1		- 8.1	0.075
30	4- 1-43	H	69.9	70.0	-10.2	66.0	62.6		- 4.3	0.136
31	4- 2-43	H	70.1	70.2	-10.4	67.4	65.2	58.3	- 7.2	0.104
32	4-26-43	H	70.2	70.2	-10.2	67.1	64.5		- 7.3	0.101
33	4-27-43	H	70.3	70.9	- 9.2	43.5	24.7			0.843

Note—"U" designates overall thermal conductivity of wall (air to air), including framing members as used.

Table III. Summary of Test Results—Continued

Test No.	Date	Position of Wall	Air Temperature, Deg F			Surface Temperature, Deg F				"U"
			Inner box	Outer box	Outside	Plasterboard		Insulation		
						Warm side	Cold side	Warm side	Cold side	
34	4-28-43	H	70.1	70.3	-10.3	68.0	66.2		- 7.3	0.083
35	4-29-43	H	70.1	70.3	-10.0	67.8	65.7		- 6.1	0.096
36	4-30-43	H	70.1	70.3	-10.0	68.5	67.0		+ 3.6	0.069
37	5- 2-43	H	70.3	70.3	-10.2	69.0	68.0		- 0.7	0.059
38	5- 3-43	H	70.5	70.3	-10.2	68.5	66.7		- 6.6	0.089
39	5- 3-43	H	70.2	70.3	-10.5	68.6	66.1		- 8.1	0.092
40	5- 5-43	H	70.3	70.3	-10.2	66.6	62.9	57.9	- 3.2	0.169
41	5- 6-43	H	70.0	70.2	-10.4	68.1	65.7	61.3	- 6.0	0.098
42	5- 7-43	H	70.0	70.2	-10.6	67.4	64.9	62.7	- 4.3	0.115
43	5- 8-43	H	70.1	70.4	-10.1	65.6	59.9	53.2	- 2.5	0.217
45	5-11-43	H	70.0	70.3	-10.1	64.9	59.3	45.2	- 2.6	0.228
46	5-12-43	H	70.0	70.2	-10.3	67.5	64.0		- 5.4	0.107
47	5-13-43	H	70.0	70.1	-10.3	68.7	67.0		- 7.8	0.061
48	5-13-43	H	70.0	70.1	-10.8	68.5	66.7		- 8.0	0.058
49	5-17-43	H	69.9	70.2	-10.2	67.3	64.1		- 5.7	0.106
51	5-19-43	H	70.0	70.2	- 9.8	67.9	65.8	65.8	- 2.3	0.097
52	5-20-43	H	70.0	70.2	- 9.9	68.1	65.8	64.9	- 4.4	0.086
53	5-21-43	H	70.1	70.2	- 9.9	68.7	67.2	67.2	- 7.8	0.055
54	5-24-43	H	70.0	70.2	-10.0	67.4	65.4	54.2	- 4.9	0.089
55	5-25-43	H	70.1	70.4	- 9.8	68.3	66.2	66.2	- 6.2	0.071
56	5-26-43	H	70.0	70.3	- 9.8	66.5	61.6	57.3	- 1.7	0.170
57	5-27-43	H	69.9	70.2	-10.2	66.7	64.1	60.3	- 6.2	0.141
58	5-28-43	H	70.0	70.1	-10.2	68.2	66.2	66.2	- 6.0	0.073
59	6- 1-43	H	70.0	70.0	- 9.9	65.9	61.5	50.6	- 5.3	0.162
60	6- 2-43	H	70.1	70.1	- 9.9	68.1	66.4	64.6	- 7.5	0.097
61	6- 3-43	H	69.9	70.1	-10.1	67.8	65.6	60.5	- 5.0	0.098
62	6- 4-43	H	69.8	70.6	- 9.7	61.2	53.3	33.8	+ 2.7	0.295
63	6- 5-43	H	69.7	71.2	- 9.2	46.6			+23.2	0.774
65	6- 8-43	H	69.9	70.2	- 9.7	65.4	61.5	51.6	- 3.7	0.212
66	6- 9-43	H	70.0	70.2	- 8.9	64.6	58.8	42.7	- 3.5	0.226
67	6-10-43	H	70.0	70.1	- 9.8	67.8	65.3	62.7	- 5.4	0.088

Note—"U" designates overall thermal conductivity of wall (air to air), including framing members as used.

Table IV. Heat Flow as Affected by Orientation of Wall

Test No.	Identification	Insulation Description and application	Thickness, Inches		Density, lbs per cu ft	Wall Position	"U"
			Rated	Measured			
5	A	Hand-applied granular mineral wool with wire screen support	3	3.00	6.62	H	0.101
6	A	Hand-applied granular mineral wool with wire screen support	3	3.00	6.62	V	0.098
9	A	Hand-applied granular mineral wool with paper covering laid over top surface of insulation	4	4.05	6.14	H	0.080
10	A	Hand-applied granular mineral wool with wire screen support	4	4.05	6.14	H	0.082
11	A	Hand-applied granular mineral wool with wire screen support	4	4.05	6.14	V	0.080
16	A	Machine-blown granular mineral wool with wire screen support	4	4.04	5.57	H	0.073
17	A	Machine-blown granular mineral wool with wire screen support	4	4.04	5.84	V	0.077
18	A	Machine-blown granular mineral wool with wire screen support	4	4.09	5.84	H	0.080
27	F	Mineral wool bats, barrier lapped on warm side of studs	4	3.89	2.99	H	0.085
28	F	Mineral wool bats, barrier lapped on warm side of studs	4	3.89	2.99	V	0.088
24	E	Resilient creped paper blanket, no vapor barrier	1	1.583	1.72	H	0.165
25	E	Resilient creped paper blanket, no vapor barrier	1	1.583	1.72	V	0.162

Note—"U" designates overall thermal conductivity of wall (air to air), including framing members as used.

### Machine-Blown and Hand-Applied Mineral Wool

In order to determine the relative insulating values of granular mineral wool when applied by machine blowing and when applied by hand, test sections were insulated with the same type of wool by both methods and tested under the same conditions. Table V shows the test results for a group of walls, some of which were insulated by

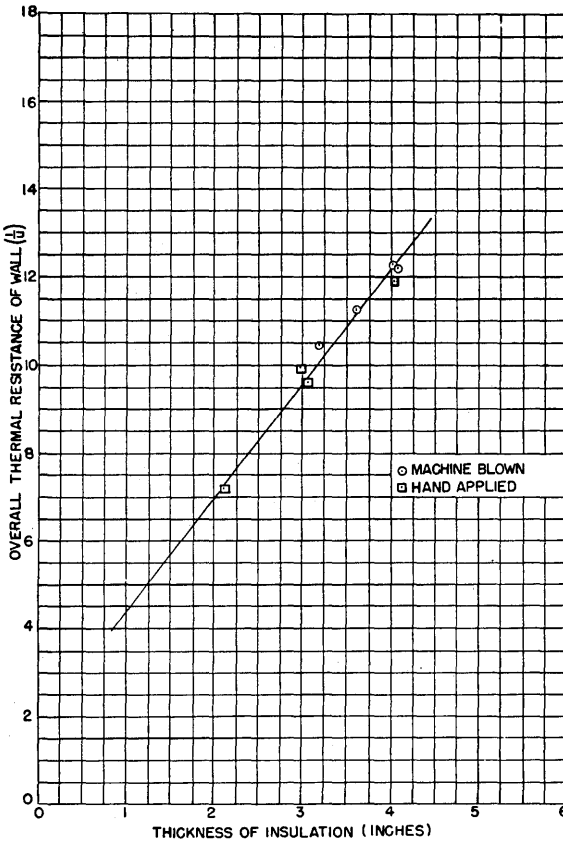


Figure 5. Comparison between machine-blown and hand-applied mineral wool insulation

hand application and some by machine-blown insulation. The walls were all of the same construction for these tests, but it was difficult to get exactly the same thickness and density of insulation by the two methods of application. In order to make a comparison between the results, the curve of Figure 5 was plotted with overall thermal resistance of wall,  $\frac{1}{U}$ , as ordinate and thickness of insulation in inches as abscissa. On this curve, the method of application is indicated for each

point. Since there is a direct relation between thickness of insulation and the overall coefficient of heat transmission, the points would all lie in a straight line if the insulating value of the material was the same for the two methods of application. A line drawn through the test points does not indicate any advantage for either method of application. The small deviations of any point from the straight line are within the limits of error that would be expected in test results on walls insulated in this manner. The variations from either side of the line are substantially the same for both methods of application and in so far as can be determined from the tests, the insulating value of the material is the same for both methods of application.

**Table V. Overall Transmission "U" for Hand-Applied and Machine-Blown Mineral Wool**

Test	Method of Application	Measured Thickness, Inches	Density	"U"	$\frac{1}{U}$
2-3-4	Hand-applied	3.00	6.62	.101	9.9
7-8	Hand-applied	4.05	6.14	.084	11.9
12	Hand-applied	3.06	6.54	.104	9.61
19	Hand-applied	2.12	6.05	.139	7.19
14	Machine-blown	4.04	5.57	.082	12.2
34	Machine-blown	4.14	6.39	.083	12.05
35	Machine-blown	3.21	5.90	.096	10.4
38	Machine-blown	3.625	5.76	.089	11.23

### Effect of Thickness of Insulation

The effect of thickness of insulation on the thermal conductivity values,  $k$ , with heat flowing upward through the insulation was investigated by constructing a test wall without any framing members over the test area. The wall was constructed with two-inch by six-inch framing members around the outside and a continuous sheet of plasterboard over the warm surface. Granular mineral wool was applied to this wall in various thicknesses and the overall thermal conductivity obtained with the wall in horizontal position and with the heat flowing upward. The results of these tests are shown in Table VI and on the curve of Figure 6. In Table VI, the overall conductivity coefficient,  $U$ , for the wall without any insulation, that is, with a single layer of plasterboard only, was taken as .90 from previous test data. All other overall coefficients for insulated walls were obtained from tests on the wall with the insulation as applied. The thermal conductivity value,  $k$ , per inch of added insulation as given in the last column of the table was calculated from the additional thermal resistance resulting from the additional thickness of insulation.

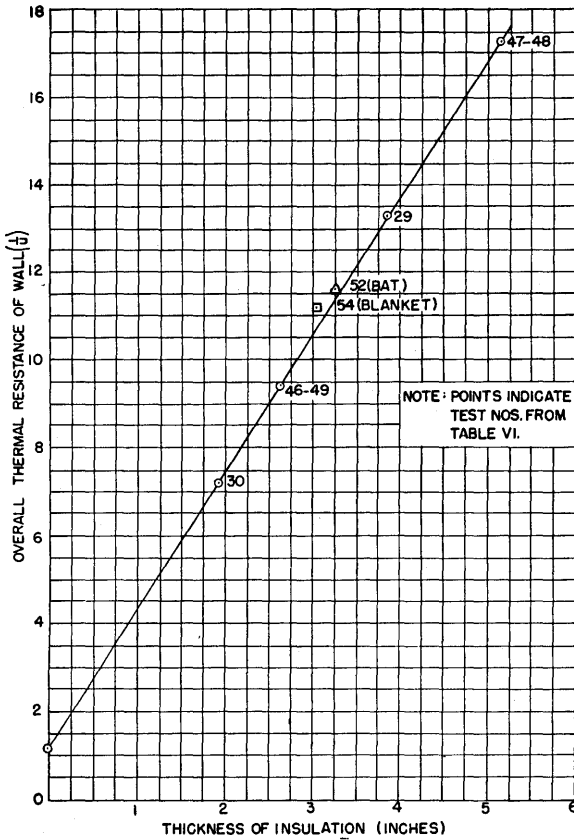


Figure 6. Overall thermal resistance of hand-applied fill insulation in walls without framing members, comparisons with bat and blanket-type insulation

Table VI. Thermal Conductivity of Added Thicknesses of Hand-Applied Fill Insulation on the Basis of Differences in Test Coefficients for Insulated Walls without Normal Framing Members

Test No.	Thickness of Insulation, Inches	Overall Coefficient "U"	Thermal Resistance $\frac{1}{U}$	Additional Thickness of Insulation over Previous Test	Additional Heat Resistance	Conductivity, k per Inch of Added Insulation
	none	.90	1.11			
30	1.906	.136	7.2	1.906	6.1	.313
Av. 46-49	2.630	.1065	9.43	.724	2.23	.324
29	3.875	.075	13.33	1.245	3.9	.319
Av. 47-48	5.114	.058	17.24	1.239	3.91	.317
52	3.281	.086	11.62			Mineral wool bats with barrier on warm side
54	3.05	.089	11.23			Mineral wool blanket with barrier on warm side

For test 52, a mineral wool bat was used and for test 54, a mineral wool blanket was used. The results of these tests have been shown on the curve sheet as a matter of comparison, but were not used in determining the character of the curve. All of the other test results have been plotted on the curve with overall heat resistance,  $\frac{1}{U}$ , as ordinate and thickness of insulation in inches as abscissa.

The thermal conductivity,  $k$ , per inch of added insulation as shown in the last column of Table VI are all substantially the same and the overall coefficients plotted on Figure 6 lie substantially on a straight line. Thus, the thermal conductivity per inch of insulation is the same regardless of thickness of insulation used in a wall.

### **Effect of Framing Members on the Insulating Value of Fill Materials**

When fill insulation is applied to a wall, it is usually applied between the framing members and does not, therefore, cover the complete area of the wall. The question thus arises as to how to calculate the overall conductivity of a wall so insulated. The simplest method is to consider the insulation as covering the full area of the wall. A more accurate method is that of calculating the coefficient on the basis of parallel heat flow through the insulated section and through the framing members. There are, however, many uncertainties as to this method. For walls without any insulation between framing members, these members would reduce the actual overall coefficient,  $U$ , from that calculated without taking them into consideration. On the other hand, for a wall with very thick material between the framing members, the actual overall coefficient might be somewhat larger than that resulting from calculations in which the insulating materials were assumed to cover the full area of the wall.

Because, in this investigation, walls were tested with various thicknesses of insulating materials both with and without normal framing members over the test area, a direct comparison may be made between the results with and without framing members taken into consideration. In Table VII, a group of tests have been selected: (1) for walls having framing members and with different thicknesses of mineral wool insulation placed between the members and, (2) for walls having no framing members and with different thicknesses of mineral wool insulation. The results of these tests have been plotted and give the two curves of Figure 7. These curves are plotted with overall thermal resistance of wall,  $\frac{1}{U}$ , as ordinate and thickness of insulation in inches as abscissa. The straight line gives the results for the wall insulation without framing members and the curved line for the various walls insulated with framing members. These lines cross near the two-inch thickness of insulation, thus indicating that for this thickness of insu-

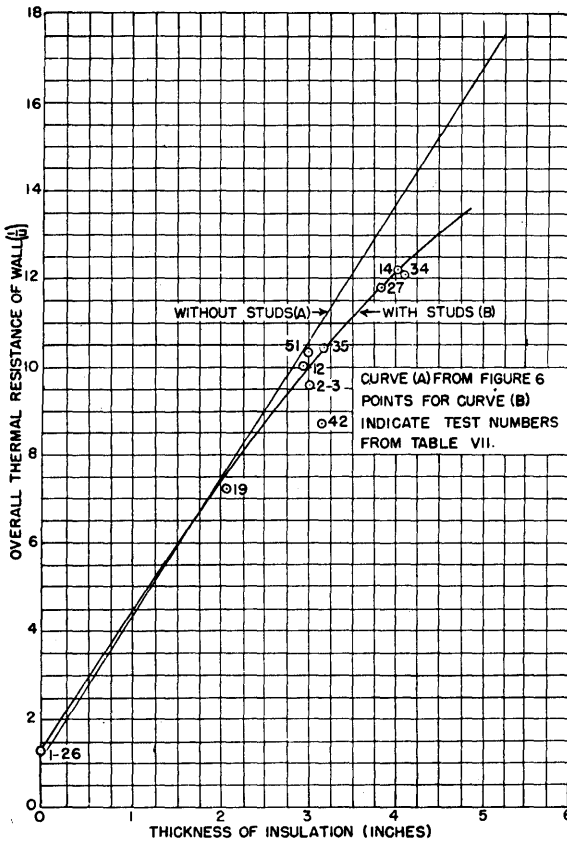


Figure 7. Effect of 2" x 4" wood studs on overall thermal resistance using fill insulation

lation there would be no practical difference as to whether the overall coefficient was calculated by assuming the insulation to cover the full area of the wall or whether it was calculated on the basis of parallel heat flow through the insulation and the framing members. Below this thickness of insulation the framing members have only a small effect on the overall coefficient and above it the effect is not large, but for accurate calculations the framing member should evidently be taken into consideration for thicknesses of insulation above three inches.

**Effect of Paper Covering over Surface of Insulation**

Test 9 was made on the same wall and with the same insulation as for tests 7 and 8, the only difference being that for test 9 a heavy kraft paper was laid over the top and in contact with the insulation. For test 9, the overall coefficient was .080, while the average for tests 7 and 8 was .084, indicating a small improvement as might be expected, but

Table VII. Overall Conductivity of Wall Having 2" x 6" Framing Members and Different Thicknesses of Fill Insulation

Wall No.	Identification	Description	Thickness of Insulation	"U"	$\frac{1}{U}$
<b>Walls with Framing Members</b>					
1-26		No insulation		.803	1.245
2-3	A	Hand-applied granular mineral wool	3.00	.10	10.000
12	A	Hand-applied granular mineral wool	3.06	.104	9.61
14	A	Machine-blown granular mineral wool	4.04	.082	12.19
19	A	Hand-applied granular mineral wool	2.12	.139	7.19
27	F	Mineral wool bats in 48" strips, vapor barrier attached and lapped on warm side of studs	3.89	.085	11.77
34	H	Machine-blown, loose mineral wool	4.14	.083	12.05
35	A	Machine-blown, granular mineral wool	3.21	.096	10.4
42	I	Mineral wool bats, barrier on warm side	2.19	.115	8.7
51	M	Hand-applied ground newspaper	3.04	.097	10.32
<b>Walls without Framing Members</b>					
		No insulation		.90	1.11
30	A	Hand applied granular mineral wool	1.906	.136	7.2
46-49	A	Hand-applied granular mineral wool	2.630	.1065	9.43
29	A	Hand-applied granular mineral wool	3.875	.075	13.33
47-48	A	Hand-applied granular mineral wool	5.114	.058	17.24
52	I	Mineral wool bats, barrier on warm side	3.281	.086	11.62
54	C	Mineral wool blanket, barrier on warm side	3.05	.089	11.23

not indicating that there was any considerable amount of air circulation up through the insulation without the paper applied.

### Effect of One-inch Flooring on Joists over Insulation

In the two tests, 36 and 37, one-inch floor boards were laid over the insulation. In test 36, the floor boards were laid on after the insulation was applied; and in test 37, they were laid on before it was applied and the insulation was blown in to fill the space. If the overall thermal resistance values for these two tests are superimposed on the curves of Figure 6, it will be noted that for test 36, the overall resistance is slightly greater than that for a wall with equal thicknesses of insulation but with no floor boards, whereas for test 37, it is substantially the same. In test 36, there would be some air space which would account for the additional insulating value. For test 37, a slightly better value would be anticipated on account of the insulating value of the floor boards. However, for thickly insulated walls, small variations are not so apparent in making a comparison.

**Blanket Insulation**

There were several different types of blanket insulating materials used. The test results for the walls in which the blankets were used are given in Table VIII. The greater part of these have been plotted in Figure 8, with overall thermal resistance,  $\frac{1}{U}$ , as ordinate and thickness of insulation in inches as abscissa. The curved line from Figure 7 has

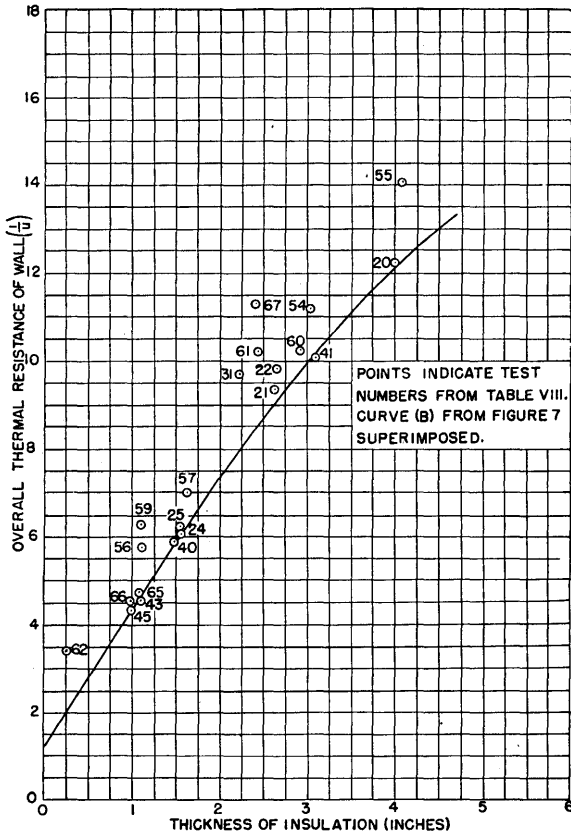


Figure 8. Overall thermal resistance of walls using various types of blanket insulation compared with curve for the same walls with fill insulation

been drawn through the points merely to show the comparison between the insulating value of the wall for various types of blanket insulation and those for various thicknesses of fill insulation. The comparison can be made only in a general way as there are other factors

Table VIII. Blanket Insulation

Test No.	Identification	Insulation		Density, lbs per cu ft	Wall Position	"U"	$\frac{1}{U}$	
		Description and application	Thickness, Inches Rated Measured					
20	B	Mineral wool blanket, no barrier	4	3.99	1.77	H	0.082	12.20
21	C	Mineral wool blanket, barrier on warm side	3	2.646	2.24	H	0.106	9.43
22	C	Mineral wool blanket, barrier on warm side	3	2.646	2.24	V	0.102	9.8
54	C	Mineral wool blanket, barrier on warm side	3	3.05	1.92	H	0.089	11.23
55	B	Mineral blanket, no vapor barrier	4	4.117	1.79	H	0.071	14.1
40	J	Mineral wool blanket between joists, barrier on warm side	1	1.510	1.933	H	0.169	5.92
41	J	Mineral wool blanket between joists, barrier on warm side	2	3.094	1.79	H	0.098	10.1
56	J	Mineral wool blanket between joists, barrier on warm side	1	1.121	4.536	H	0.170	5.89
57	J	Mineral wool blanket between joists, barrier on warm side	2	1.630	4.594	H	0.141	7.1
59	J	Mineral wool blanket on top of joists, barrier on warm side	1	1.121	4.536	H	0.162	6.17
60	J	Mineral wool blanket on warm side of joists, barrier on warm side	3	2.932	2.834	H	0.097	10.2
31	G	Wood fiber blanket between joists, barrier on both sides	2.25	2.25	4.51	H	0.104	9.62
43	G	Wood fiber blanket on warm side of joists, barrier on both sides	1	1.107	3.372	H	0.217	4.60
65	G	Wood fiber blanket on warm side of joists, barrier on both sides	1	1.107	3.372	H	0.212	4.72
24	E	Resilient creped paper blanket, no barrier	1	1.583	1.72	H	0.165	6.06
25	E	Resilient creped paper blanket, no barrier	1	1.583	1.72	V	0.162	6.17
45	L	Processed cotton blanket on warm side of joists, barrier on both sides	1	1.025	5.27	H	0.228	4.39
66	L	Processed cotton blanket on warm side of joists, barrier on both sides	1	1.025	5.27	H	0.226	4.43
62	O	Shredded newspaper between two layers of asphalt-coated kraft paper	.294	.294	1.151	H	0.295	3.39
61	N	Cellular cotton batten blanket on warm side of joists, barrier on warm side	3	2.44	1.188	H	0.098	10.2
67	N	Cellular cotton batten blanket barrier on warm side of joists	3	2.44		H	0.088	11.37

entering in the case of blanket insulation. In some cases it was very difficult to measure the exact thickness of the insulating material and in others an air space was provided between the blanket insulation and the plasterboard on the warm side of the wall.

### CONCLUSIONS

The main purpose of this investigation was to determine certain facts about the thermal conductivity of insulating materials when applied to structures and to determine whether or not the methods of application and use of these materials had any appreciable effect on their thermal values in the structure. The purpose was not to make direct comparisons between different types of insulation. The investigation was confined to fill and blanket insulating materials as it was this type of material about which questions had been raised as to the effect of application on the coefficients used. There are naturally differences in materials of the same type and even from the same manufacturer. Thus, small differences in test value may not be taken to indicate the superiority of a material of a given type over another of the same type. Furthermore, in comparing materials of different types, such as blanket materials with fill materials, there are differences in methods of application and in characteristics of materials when fabricated for different methods of application which must be taken into consideration.

A summary of the conclusions is as follows:

1. That the thermal conductivity of fill insulating materials as investigated is the same for a structure in a horizontal position with the heat flowing upward as it is for the same structure in a vertical position with the heat flowing horizontally.
2. That materials of the nature investigated are effective in accordance with their thickness and the insulating value per inch of thickness is the same for heavier applications as for lighter applications of the material.
3. That for all practical purposes, the insulating value of hand-applied granular mineral wool is the same as for machine-blown when the same material is used and when the densities are comparable.
4. For many practical cases, the effect of wood studs may be omitted in calculating the overall coefficients of insulated walls, but for walls having three or more inches of insulation between studs, the effect of the studs is appreciable.
5. For all practical purposes, the calculated coefficient for fill-insulated walls and blanket-insulated walls gives results which are sufficiently accurate and reliable, providing thickness of insulation and air spaces are properly accounted for.

