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TRANSMISSION OF HEAT THROUGH BUILDING MATERIALS

BY

FRANK B. ROWLEY
Professor of Mechanical Engineering

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INTRODUCTION

The work reported in this bulletin is the first of a series of tests being conducted on insulating materials and building construction at the Engineering Experiment Station, University of Minnesota. The work thus far has been confined to the thermal properties of these materials.

The object of the work was first to develop an improved method for testing insulating and building materials which would eliminate some of the uncertain heat losses in methods commonly in use; second, to determine the insulating value of certain classes of insulating material now on the market; and third, to determine the insulating value of these materials as applied to practical building construction.

While in the past many tests have been made and much data published along this line, there are many cases of conflicting results on the same type of construction due in part to the different methods used in obtaining the data.

Further, during the last few years several new types of building and insulating materials have come into use. In some cases reliable data may be obtained on these materials but in most cases the builder is at a loss to know how best to apply them in building construction to get most effective results. This is particularly true in small house construction.

In this work many different kinds of insulating materials have been tested but the list cannot be considered complete. New materials have recently come into the market and in some instances materials of standard make have been improved. It has not been the object to compare one material with another but rather to show what may be expected from certain classes of insulating materials and how these materials may be most effectively applied in wall construction.

When we consider the fact that the average house requires from ten to fourteen tons of coal per heating season and that the total coal burned for domestic purposes in the United States is approximately 100,000,000 tons per year, it is apparent that even a small percentage saved by better building construction would mean a large conservation in the aggregate.

The author wishes to express his appreciation to Professors B. J. Robertson and H. B. Wilcox for their assistance in this work and also to Mr. C. Floyd Olmstead for the excellent work which he did as research fellow in the Engineering Experiment Station during the year 1922-23.

These investigations will be continued and suggestions of other wall sections and insulating materials which should be tested will be welcomed.

TRANSMISSION OF HEAT THROUGH BUILDING MATERIALS

LOSS OF HEAT FROM BUILDINGS

Heat is lost from buildings by two distinct processes, first by infiltration or air leakages; and second, by conduction through the walls. The infiltration of air depends on the construction of the building, the openings around the doors and windows, and the wind velocity, while conduction through the walls depends upon the material with which the walls are constructed and the method of combining these materials, the temperature difference between inside and outside, and the air movement outside. The infiltration may vary in the same type of building and is variously estimated at from one to two changes of air in the building per hour. With the better constructed walls, less than one change might be expected. While infiltration losses may be partly compensated for by the ventilation obtained, the conduction losses through the wall are accompanied by no offsetting advantages.

The laws which govern the flow of heat through any material are similar to the laws which govern the flow of electricity along the conductor or the flow of water in a pipe. There must be a heat potential or drop in temperature along the line of flow. The quantity of heat is directly proportional to this difference in temperature and dependent upon the nature of the material through which the heat is flowing.

Figure 1 represents a simple homogeneous wall, the temperature of the air on one side being T_1 and on the other side T_0. In a body of this type there are three separate resistances to the passage of heat which must be overcome: first, a surface resistance on the side from which the heat enters the body; second, the resistance in the body itself; and third, the resistance at the surface from which the heat leaves the body. The heavy solid lines from T_1 to T_0 show the temperature gradient through the body. The temperature drop, T_1 to T_2, T_2 to T_3, etc., will be proportional to the corresponding resistances. For instance, if the surface resistance is high compared with the internal resistance, T_1 minus T_2 will be greater than T_2 minus T_3.

Figure 2 represents a double wall with an air space between the sections. In this case there are a greater number of resistances than in Figure 1 and if the wall is of the same construction the total resistance will be greater and the total heat transmitted less for the same total difference in temperature. Strictly speaking the drops in temperature

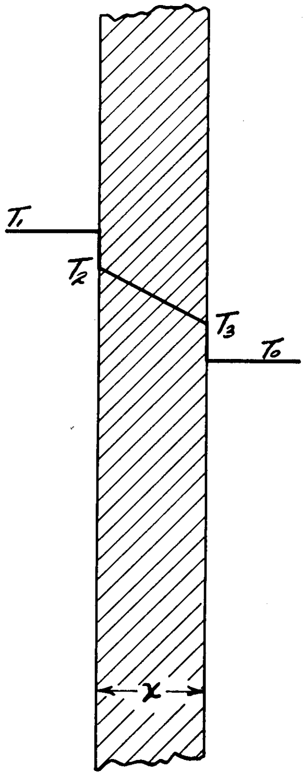


FIGURE 1. TEMPERATURE GRADIENT THROUGH A SINGLE SECTION OF HOMOGENEOUS MATERIAL

T_1 to T_2 and T_3 to T_0 are not straight lines as shown. The temperature T_1 gradually drops as it nears the surface of the wall leaving the drop at the surface somewhat less than shown. Likewise the drop T_3 to T_0 is not all in the surface. This point is not vital providing the air temperatures are taken far enough on each side of the surface to be constant.

The quantity of heat transmitted through any wall is proportional to the drop in temperature through the wall and the equation is generally written

$$Q = AK\ (T_1 - T_0) \qquad (1)$$

where Q is the quantity of heat in British thermal units per hour, A is the area of the wall in square feet, K is a conductivity constant representing the British thermal unit transmitted per square foot of surface per degree difference in temperature per hour and T_1 and T_0 are the temperatures on each side of the wall.

In this equation, the constant, K, is a composite of several constants for each wall and may be calculated if the individual constants are known. Referring to the wall in Figure 1, for example, and assuming that the conductivity constant of the entering surface is k_1, of the material is c, and of the leaving surface k_2, the thickness of the material being x, Q, the number of British thermal units passing through each square foot of the surface will be the same and we may write the three equations:

$$Q = k_1 (T_1 - T_2) \quad \text{or} \quad T_1 - T_2 = \frac{Q}{k_1} \tag{2}$$

$$Q = \frac{c}{x} (T_2 - T_3) \quad \text{or} \quad T_2 - T_3 = \frac{Qx}{c} \tag{3}$$

$$Q = k_2 (T_3 - T_0) \quad \text{or} \quad T_3 - T_0 = \frac{Q}{k_2} \tag{4}$$

Adding the three equations

$$T_1 - T_0 = Q \left\{ \frac{1}{k_1} + \frac{x}{c} + \frac{1}{k_2} \right\}$$

From equation (1)

$$T_1 - T_0 = Q \frac{1}{K}$$

Therefore

$$\frac{1}{K} = \frac{1}{k_1} + \frac{x}{c} + \frac{1}{k_2}$$

or

$$K = \frac{1}{\frac{1}{k_1} + \frac{x}{c} + \frac{1}{k_2} + \text{- - - - - - -}}$$

This method of calculation may be very useful where the individual constants are known but it is often very difficult to determine the surface constants and to apply them in practice. Therefore, in this series of tests the insulating materials themselves and the materials built up into wall sections were tested to determine directly the heat losses. With the heat loss and the temperature difference known, the heat transmission constant, *K*, is determined from equation (1).

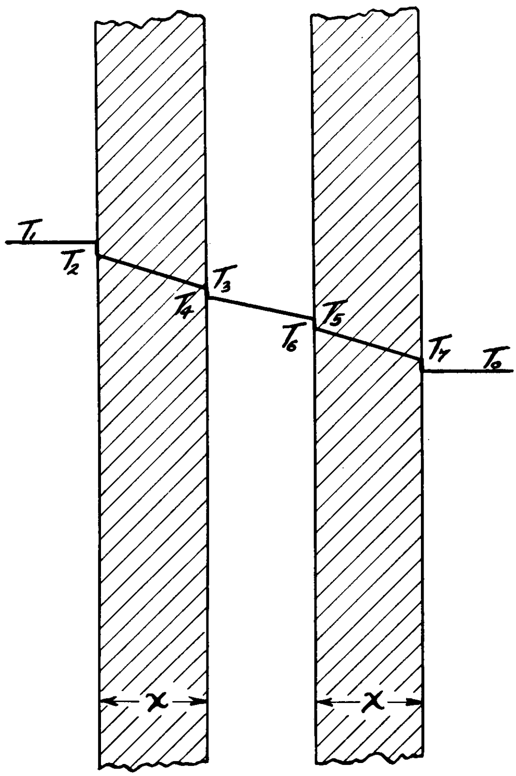


FIGURE 2. TEMPERATURE GRADIENT THROUGH MULTIPLE SECTIONS WITH AIR SPACES BETWEEN

METHODS OF TESTING

There are two general methods in use for determining the transmission constant, K, for building materials, the hot plate method and the hot box method. In the hot plate method the material to be tested is placed between two plates. These plates are in contact with the surface of the material, one plate furnishing the heat and the other receiving it. The heat is measured as given off by the hot plate or as received by the cold plate and the temperature difference between the surfaces of the two plates taken as the temperature drop through the material. In the hot box method the material to be tested is generally placed over the open end of a box, the temperature in the box being maintained higher than that outside and the heat measured which is supplied to the box. The temperature drop is taken as the difference between the temperatures of the air inside of the box and that on the outside of the box.

It will be readily seen by referring to Figure 1 that the hot plate in contact with the surface will reduce or eliminate the surface resistance of the material; therefore, more heat will be conducted through the wall by this method than by the hot box method. The difference between the two methods will depend upon the surface resistance of the material as compared with the total resistance. Thus in window glass where the greater part of the total resistance is the surface resistance, the hot plate method would show a much greater heat transmission than would the hot box method. In a thick, heavy wall construction in which the relative importance of the surface resistance is small, the results obtained by the two methods would be nearer the same. There would be difficulty, however, in getting a good contact between the average wall and the hot plate. Further the hot box method in which the heat is transmitted from air to air corresponds to practical conditions whereas the hot plate method does not. These considerations led to the selection of the hot box method for the present work.

Discussion of hot box methods.—Tests in which the hot box method has been used have usually been carried on either by placing the material over the open side of the cubical box as in Figure 3 or else by building up a complete cubical box of the material to be tested as in Figure 4.

Test box with open side.—Figure 3 is a cross-sectional view of test box with material A placed across the open face. Temperature T_1 is maintained at a higher level than T_0. With this apparatus the box must first be calibrated to determine its heat losses and corrections made

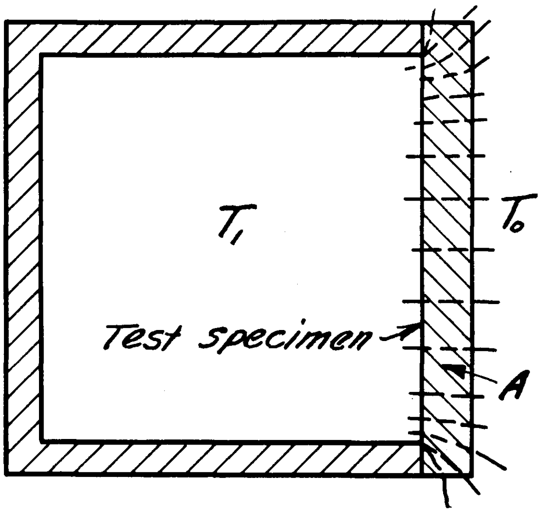


FIGURE 3. HOT BOX METHOD OF TESTING OVER ONE OPEN SIDE

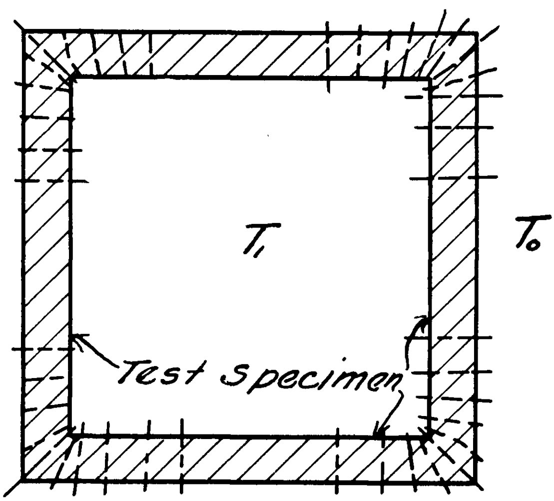


FIGURE 4. HOT BOX METHOD OF TESTING A COMPLETE CUBICAL BOX OF THE MATERIAL

accordingly. The lines representing the path of heat flow through the material would be practically normal to the surface in the center portion of the test section but near the edges these lines would bend outward as shown by the broken lines through the section. The objections to this method are: first, that it is difficult to get an accurate calibration of the box; second, that the lines of heat flow are not all perpendicular to the surface; third, that the true area of the surface under test cannot be determined for thick walls as this surface should be greater than the inner surface and not so large as the outer surface. The average might lead to unreasonable errors. A modification of this method has been used in which two sides of the box are left open, each being covered with the material under test. This eliminates part of the errors of calibration, but still has the objection of the indeterminate area and that the heat in passing through the material does not pass in lines normal to the surface.

Box constructed entirely of material to be tested.—Referring to Figure 4, which represents a sectional view of a cubical box built up of the material under test, in this case no calibration is necessary as there are no losses excepting those through the material under test. There is, however, the same uncertainty as to what would constitute the exact area of the test specimen and also the condition of heat passing through the material in lines which are not in all cases normal to the surface. These difficulties are increased as the thickness of the material becomes greater in proportion to the size of the box.

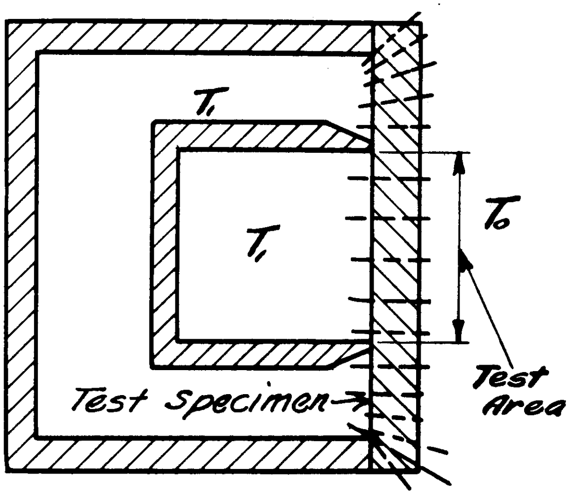


FIGURE 5. IMPROVED HOT BOX METHOD USING DOUBLE BOX

Double or guard ring box.—In order to overcome the difficulties stated, a double or "guard ring" type of test box was developed and used in these tests. Figure 5 shows a cross-sectional view of such a box. Both boxes are well insulated and the same temperature is maintained in each. The material under test is placed across the open faces of the two boxes. As before, the dotted lines represent the direction of flow or path of heat transmitted through the test section. The area under test is taken as that portion of the material over the inner box. It will be noted that in this section the flow of heat is normal to the surface and since the same temperature is maintained on both sides of the inner box, the only heat loss from the inner box is that passing through the test area.

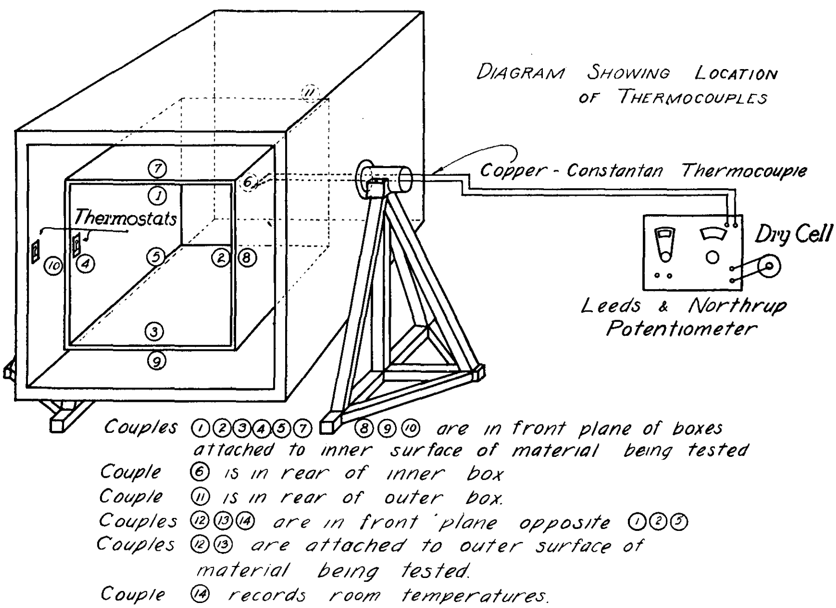
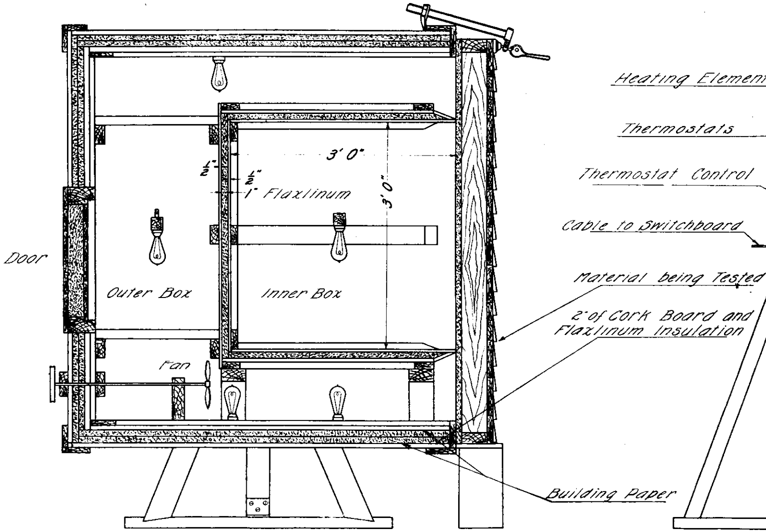


FIGURE 6. OBLIQUE DRAWING OF DOUBLE BOX SHOWING LOCATION OF THERMOCOUPLES AND THERMOSTATS

Description of apparatus used.—Figures 6, 7, and 8 are line drawings of the apparatus as used. Figure 6 is an oblique drawing of the double box showing the location of the thermocouples and thermostats. Figure 7 is a vertical cross-sectional view through the box with wall section in place, and Figure 8, a view looking into the open end with test section removed. The box was mounted on trunions so that tests might be made on wall or roof sections.



Section A-A

FIGURE 7. VERTICAL CROSS-SECTION THROUGH DOUBLE BOX WALL SECTION IN PLACE

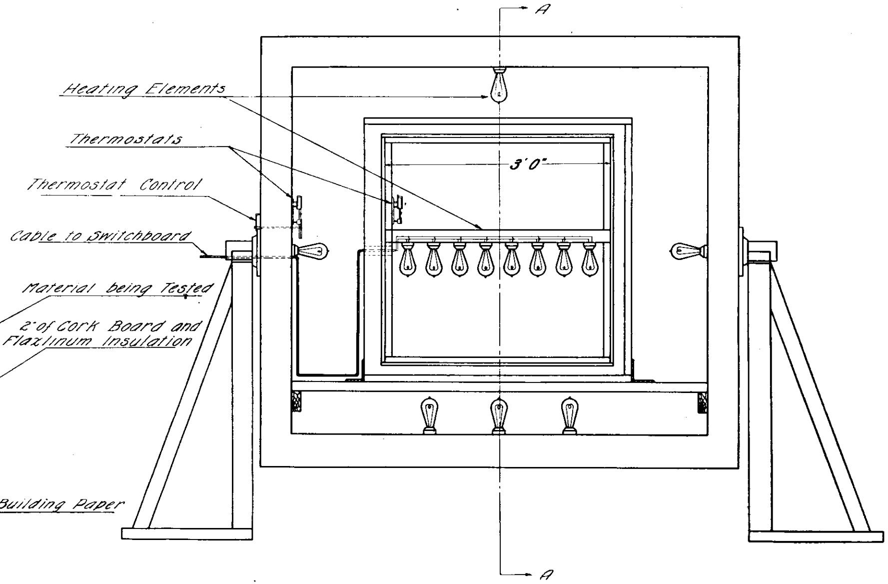


FIGURE 8. VIEW LOOKING INTO OPEN END OF DOUBLE BOX WITH TEST SECTION REMOVED

The heating elements used in this work were incandescent lights. In some of the tests shields were put around the lights to prevent losses which might occur from direct radiation. No difference was shown with and without the shields, except in the case of glass. Therefore, the lights were left bare for most of the opaque materials. A small fan placed in the outer box served to keep more uniform temperatures at the top and bottom of the box. A door was provided in the back of the outer box in order to make inspections and adjustments while tests were in progress. Both boxes were well insulated as shown. The temperatures of both the inner and outer boxes were maintained constant by thermostatic control, the thermostat being placed on the sides and near the front of its respective box.

Figure 9 is a diagram of the thermostatic control wiring showing the operation of the thermostats. Minneapolis Heat Regulator Co. thermostats were used, operated by alternating current motors.

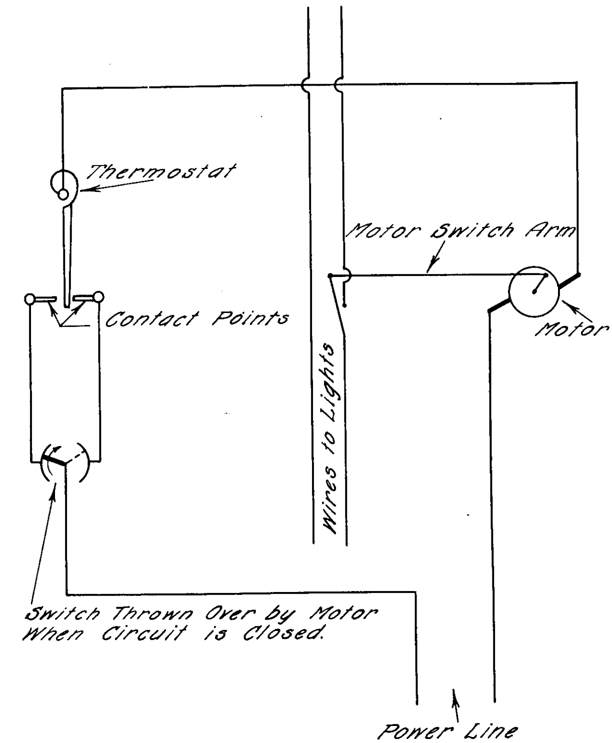


FIGURE 9. DIAGRAM OF THERMOSTATIC CONTROL

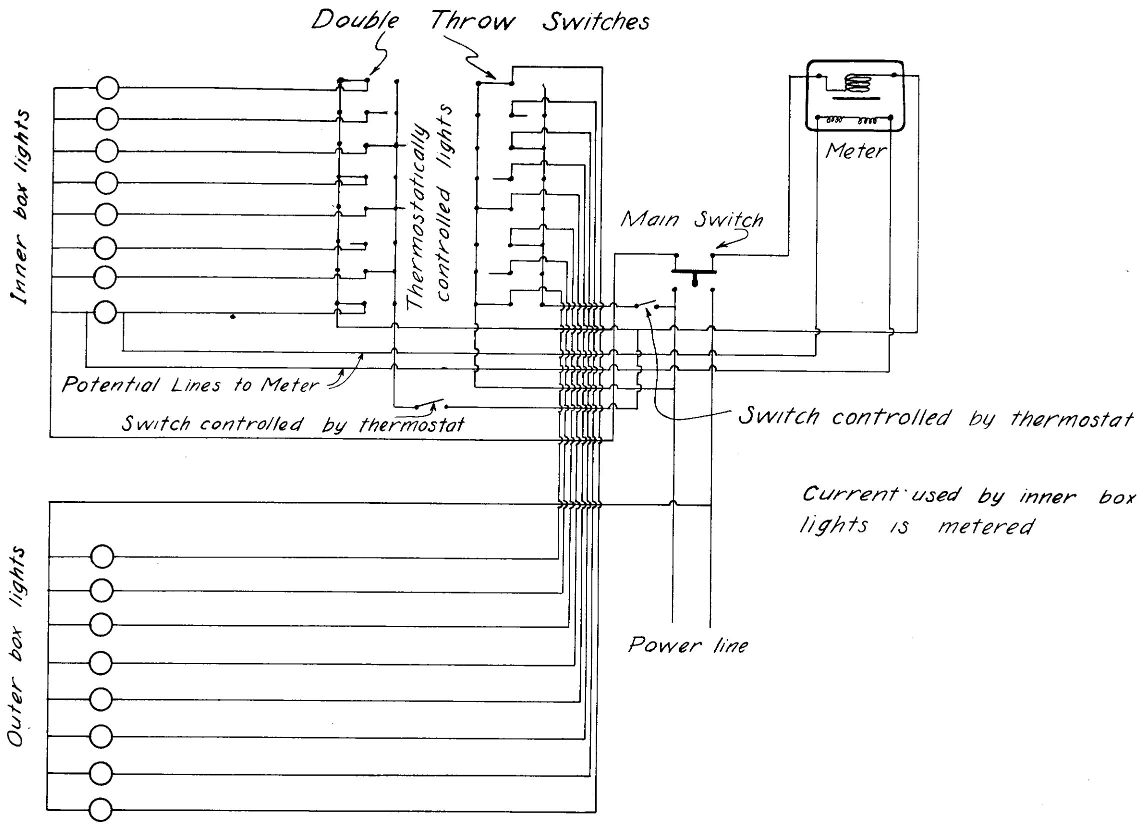


FIGURE 10. WIRING DIAGRAM OF HEATING ELEMENTS FOR BOTH INNER AND OUTER BOXES

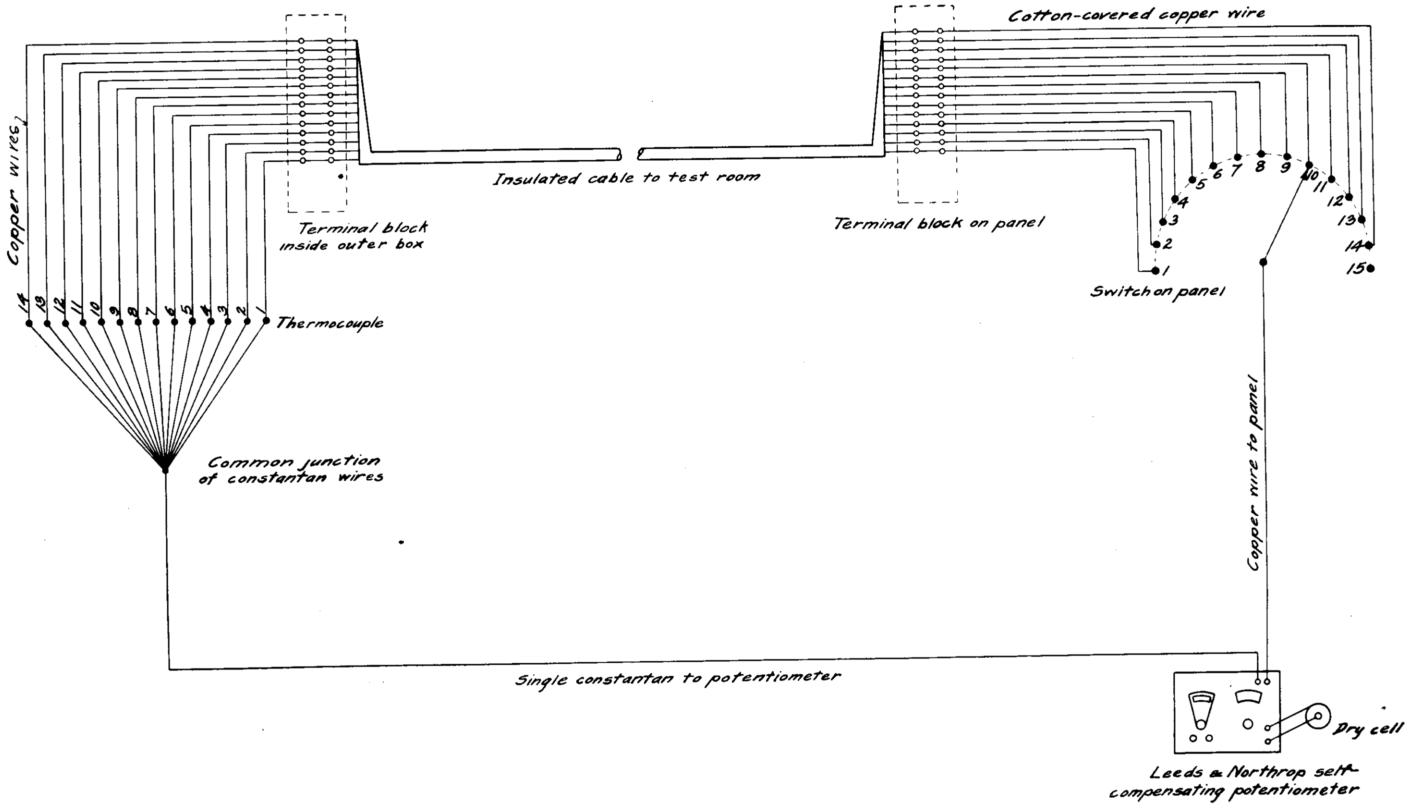


FIGURE 11. DIAGRAM OF THERMOCOUPLE WIRING

Figure 10 shows a wiring diagram of the heating elements for both inner and outer boxes. One lead from each heating element was brought to a double throw, single pole switch and so connected that the lights might either be thrown out of service, thrown on the continuous current side, or thrown on the thermostatic control side. Thus the load

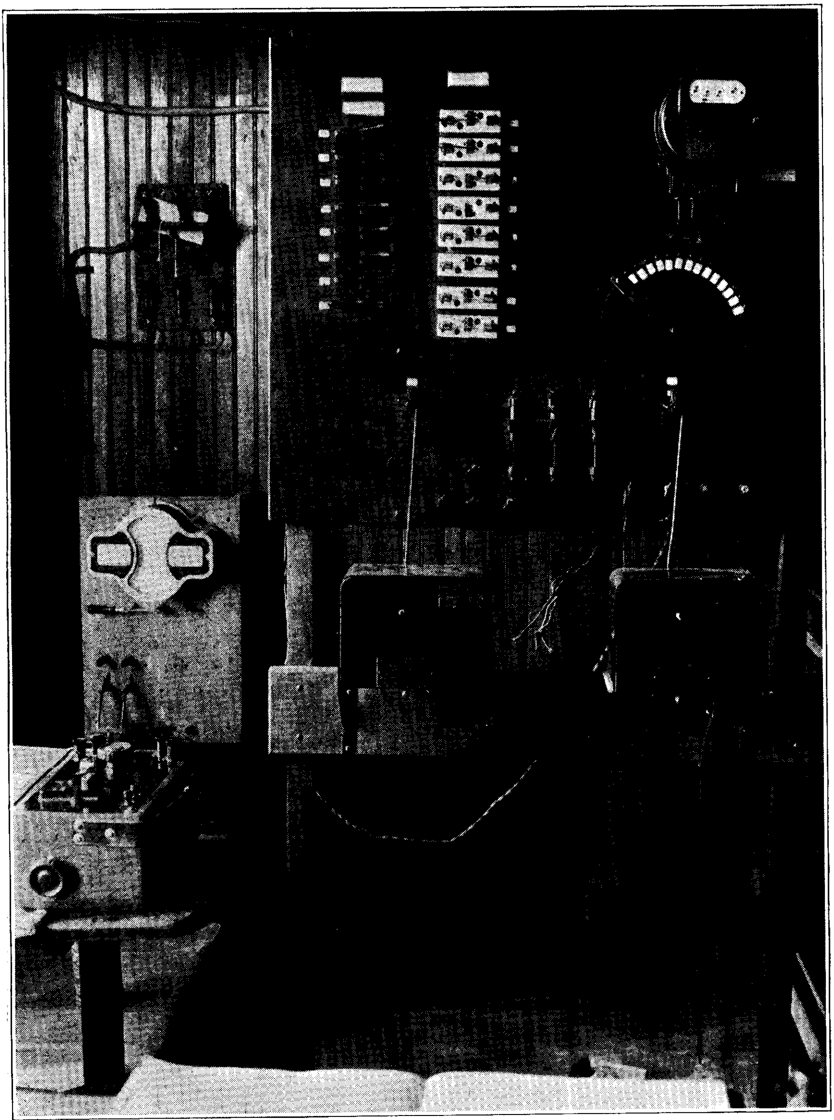


FIGURE 12. PHOTOGRAPH OF CONTROL PANEL, THERMOSTATS, AND POTENTIOMETER

was adjusted so that only a portion of it was controlled by the thermostats. The current supplying the heat to the inner box only was metered and from this the transmission constant for the material was determined. It was not necessary to meter the current to the outer box as the only object of this current was to maintain a temperature equal to the inner box temperature and prevent losses through the inner box and from the inner box through the wall area outside of the test area.

The temperatures were measured by copper-constantan thermocouples connected to a Leeds and Northrup potentiometer. The location of the thermocouples in the box is shown in Figure 6.

Figure 11 shows a diagrammatic drawing of the thermocouple wiring. The constantan elements of the thermocouples were all brought to a common junction from which one wire led to the instruments. The copper wire from each element was brought to a terminal box inside of the outer box and a cable carried from this point to the terminal block on the control panel. From this terminal block individual leads were carried to the points of a selective switch such that any one of the couples could be read by the same instrument.

Figure 12 shows a photographic view of the control panel, thermostats, and potentiometer. On the upper left-hand corner of the switchboard are shown the single pole, double throw switches which control

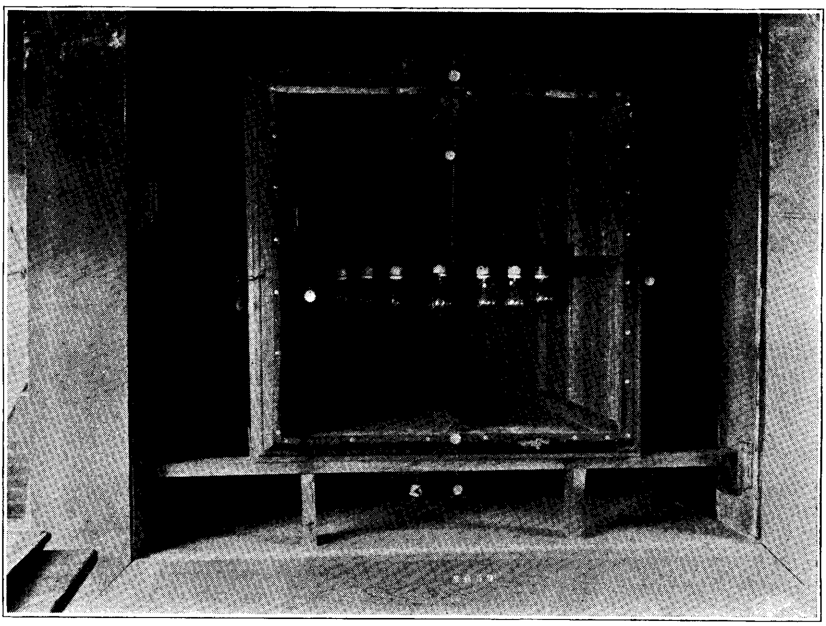


FIGURE 13. TEST BOX WITH WALL REMOVED

the heating elements. The meter, which is a Westinghouse Type O-A, 5 ampere, 100 volt, 2 wire, 60 cycle, is shown on the upper right-hand corner of the board with the selective switch for thermocouple elements immediately below. Figure 13 shows a photographic view of the open end of the box showing the location of the heating elements and thermostats. Figure 14 shows a photographic view of the test box with wall section partly removed.

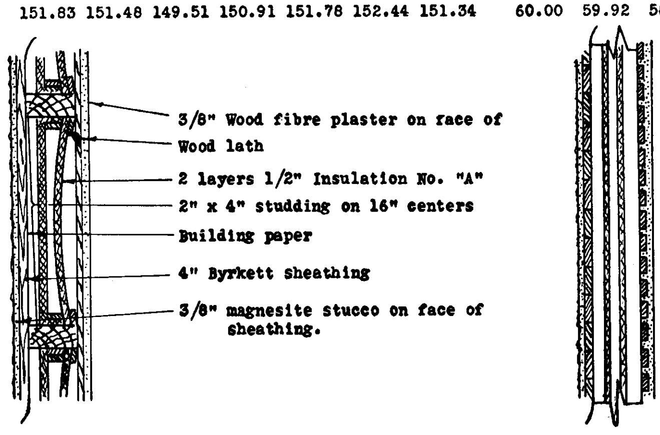
Method of procedure.—In performing these tests the insulating material or wall section to be tested was placed in position on the test box and the heating elements adjusted to give as nearly as possible the desired temperature on the constant current side of the switch. A small portion of the heating elements was then thrown on the thermostatic control in order to keep the temperature uniform. Both the inner and outer boxes were maintained at the test temperature for a period of at least twenty-four hours and in all cases until the heat flow was uniform before the actual test data were taken. The tests were run for an average period of eight hours, altho in some cases, where only a check test was desired and all conditions were uniform, the period was shortened to four hours. Every fifteen minutes throughout the test readings were taken of the electric meter and the fourteen thermocouples as well as of one mercury thermometer placed in the room to check the room thermocouple, and two mercury thermometers placed through the wall, one for the inner box and the other for the outer box. At the end of the test all thermocouple readings were averaged and the average of the averages for each box was taken as its temperature for the run. If there was any difference between the temperatures of the inner and outer boxes a correction factor was applied. The correction factor was taken from the curve, Figure 15. The full data and calculations for wall section No. 6 are shown on pages 16 and 17.

Calibration curves.—The calibration or correction curve, Figure 15, was designed to make corrections for any small differences in temperature between the inside and outside boxes. The abscissae represent the temperature difference and the ordinates a correction factor which is applied directly to the transmission constant, K, determined from the test. In applying the curve, the temperatures were averaged for both the inner and outer boxes. If the inner box temperature showed higher than the outer box, it would indicate that some heat had been lost through the wall of the inner box and charged against the material under test. In this case the correction factor would be subtracted and, in the case of a low temperature in the inner box, it would be added. The data for the curve were obtained by calculating the heat losses through the inner box and checking by experimental data.

LOG OF TEST

RUN NO. 253 WALL NO. 6 DATE 12-22-22 OBSERVER C. F. O.

TIME	THERMOCOUPLES Temperatures inside the inner box							THERMOCOUPLES Outer surface		Room
	(1)	(2)	(3)	(4)	(5)	(6)	Ave.	(12)	(13)	(14)
9:30	151.5	150.5	148.0	150.5	151.5	152.0	150.67	59.5	59.5	57.5
9:45	151.5	151.0	148.5	150.5	151.5	152.0	150.83	59.5	59.5	58.5
10:00	151.5	151.0	148.0	150.0	151.5	152.0	150.67	59.5	59.5	58.5
10:15	152.0	151.0	148.5	150.5	151.5	152.5	151.00	60.0	59.5	59.5
10:30	151.5	151.5	148.5	150.5	151.5	152.0	150.93	60.0	60.0	59.0
10:45	151.5	151.0	148.5	150.5	151.5	152.0	150.83	59.5	59.5	59.0
11:00	152.0	152.0	149.5	150.5	152.0	152.5	151.41	60.0	60.0	59.5
11:15	151.5	151.5	149.5	151.0	152.0	152.5	151.33	60.0	60.0	59.0
11:30	151.5	151.5	149.5	151.0	152.0	152.5	151.33	60.0	60.0	58.5
11:45	152.5	152.0	149.5	151.5	152.5	152.5	151.75	60.5	60.5	58.5
12:00	152.0	151.5	150.0	151.5	152.0	153.0	151.67	59.0	59.0	58.0
12:15	152.0	152.0	150.0	151.5	152.5	153.0	151.83	59.5	59.5	58.5
12:30	153.0	152.0	150.5	151.5	152.5	153.0	152.08	59.5	59.5	58.0
12:45	152.5	152.0	150.5	151.5	152.5	153.0	152.00	60.5	60.5	59.0
1:00	152.5	152.0	150.5	151.5	152.5	153.0	152.00	60.0	59.0	58.0
1:15	152.0	152.0	149.5	151.0	151.5	152.0	151.33	60.5	60.5	59.0
1:30	150.0	149.5	148.5	149.5	150.0	151.5	149.83	60.0	60.0	58.5
1:45	151.5	151.5	149.5	150.5	151.5	152.5	151.33	60.5	60.5	58.5
2:00	150.0	149.5	148.5	150.0	150.5	151.5	150.00	61.0	61.0	60.0
2:15	152.0	152.0	150.0	151.0	152.0	152.0	151.50	60.5	60.5	58.5
2:30	152.0	151.5	150.5	151.5	152.0	152.5	151.58	60.5	60.5	58.5
2:45	151.5	151.5	150.0	151.0	151.5	152.5	151.33	59.5	59.5	58.0
3:00	153.0	152.5	151.0	151.5	152.0	152.5	152.08	60.5	60.5	58.5
3:15	152.0	152.0	150.0	151.0	152.0	153.0	151.67	60.0	59.5	58.0
3:30	153.5	152.5	150.0	151.5	152.0	152.5	152.08	60.5	60.0	58.0
3:45	152.5	152.0	150.0	151.5	152.0	152.5	151.75	59.5	59.5	58.5
4:00	152.5	152.5	150.5	151.5	153.0	153.5	152.25	60.5	60.5	58.5
4:15	151.5	151.0	149.0	150.0	150.5	152.0	150.67	59.5	59.5	59.5
4:30	151.5	151.5	149.5	151.0	151.5	152.5	151.25	60.0	60.0	58.5
4:45	152.0	151.0	149.5	151.0	152.0	152.5	151.33	60.0	60.0	57.5
5:00	150.5	150.5	148.5	150.5	151.0	151.5	150.43	60.0	60.0	59.0
5:15	151.5	151.5	149.5	151.0	152.0	153.0	151.42	60.0	60.0	59.0
5:30	152.0	152.0	150.5	152.0	152.5	153.0	151.67	60.0	60.0	58.0
Ave. 8:00	151.83	151.48	149.51	150.91	151.78	152.44	151.34	60.00	59.92	58.57



LOG OF TEST

RUN NO. 253

THERMOCOUPLES Between the two boxes (7)	(8)	(9)	(10)	(11)	Ave.	MERCURY THERMOMETERS Inner Box	Outer Box	Center Room	One inch from wall	METER
153.5	152.5	147.5	151.5	154.5	151.90	151.0	150.5	59.5	62.5	7664.3
152.0	151.5	144.0	150.5	153.5	150.30	151.0	150.5	60.0	62.5	7666.0
153.0	151.5	149.0	151.0	153.5	151.60	151.0	150.5	60.0	62.5	7667.7
152.5	152.0	151.0	152.0	155.0	152.50	151.5	152.0	60.0	63.0	7669.1
149.5	149.0	145.5	149.0	151.5	148.90	151.5	149.0	60.0	63.0	7670.8
152.5	152.0	151.5	151.5	154.0	152.30	151.0	151.0	60.0	63.0	7672.2
152.0	151.5	152.5	151.0	153.5	152.10	151.5	150.5	60.0	63.0	7673.7
152.0	152.0	149.5	151.0	153.5	151.80	152.0	151.0	60.0	63.0	7675.2
150.0	150.5	149.0	150.5	153.5	150.70	152.0	151.0	60.0	63.0	7676.8
149.0	149.0	150.0	149.5	152.5	150.00	152.0	151.0	60.0	63.0	7678.3
151.5	151.5	151.0	151.0	153.0	151.80	152.0	151.0	60.0	62.5	7679.9
150.5	150.5	150.0	150.5	153.0	150.90	152.0	151.5	60.0	63.0	7681.6
148.5	148.5	151.0	148.5	151.0	149.50	152.5	151.0	60.0	63.0	7683.1
151.5	151.5	151.5	151.5	153.5	151.90	152.5	151.0	60.5	63.5	7684.6
150.5	150.5	150.0	150.5	152.0	151.00	152.0	151.0	60.0	62.5	7686.2
149.5	149.5	151.5	149.5	153.5	150.40	151.0	149.5	61.0	63.5	7687.3
152.0	152.0	151.5	152.0	154.5	152.40	151.5	151.5	60.5	63.5	7687.8
148.5	148.5	150.5	149.5	152.5	149.90	152.0	151.0	61.0	64.0	7689.3
150.5	150.5	151.5	150.0	152.5	151.00	151.0	151.0	61.0	64.0	7690.0
151.5	151.5	151.5	151.5	154.0	152.00	151.5	152.0	60.0	63.0	7691.4
148.5	148.5	151.5	149.5	152.5	150.00	151.5	151.0	60.5	63.5	7692.7
149.0	149.0	150.0	149.5	151.5	149.80	152.0	150.0	60.0	63.0	7694.2
151.5	151.5	151.5	151.5	152.5	152.00	152.0	152.0	60.0	63.0	7695.5
149.0	149.0	152.5	149.5	154.0	150.40	152.0	150.0	60.0	63.0	7697.1
152.5	152.5	149.0	151.0	153.0	151.70	151.0	151.0	60.0	63.0	7698.5
151.5	151.5	150.5	151.0	154.5	151.80	152.0	151.5	60.0	63.0	7699.6
152.5	152.5	152.0	152.0	155.5	152.90	152.0	152.0	60.0	63.0	7701.0
148.5	149.0	151.0	148.5	151.5	149.70	151.0	149.0	60.0	63.0	7701.8
148.5	148.5	148.5	148.5	151.5	149.10	151.5	150.0	60.0	63.0	7703.0
151.5	152.0	151.0	151.5	154.5	152.10	152.0	151.0	60.0	63.0	7704.4
149.0	149.0	150.5	149.0	151.5	149.70	152.0	151.0	60.0	63.0	7705.8
152.0	152.0	152.0	151.5	153.5	152.50	152.0	152.0	60.0	63.0	7707.1
149.5	149.5	151.5	149.5	151.5	150.40	152.0	150.0	60.0	63.0	7708.5
150.72	150.61	150.33	150.44	153.09	151.05	151.68	150.85	60.10	63.04	44.2

Calculations:

$$T_1 = 151.34 + .77 = 152.11$$

$$T_0 = 63.04 - .50 = 62.54$$

$$T_1 - T_0 = 89.57$$

$$K_a = \frac{\dfrac{44.2 \times 6.25 \times 3.415}{1.02}}{9 \times 8 \times 89.57} = .1433$$

Correction from curve = -.0033

Selected Constant = .1400

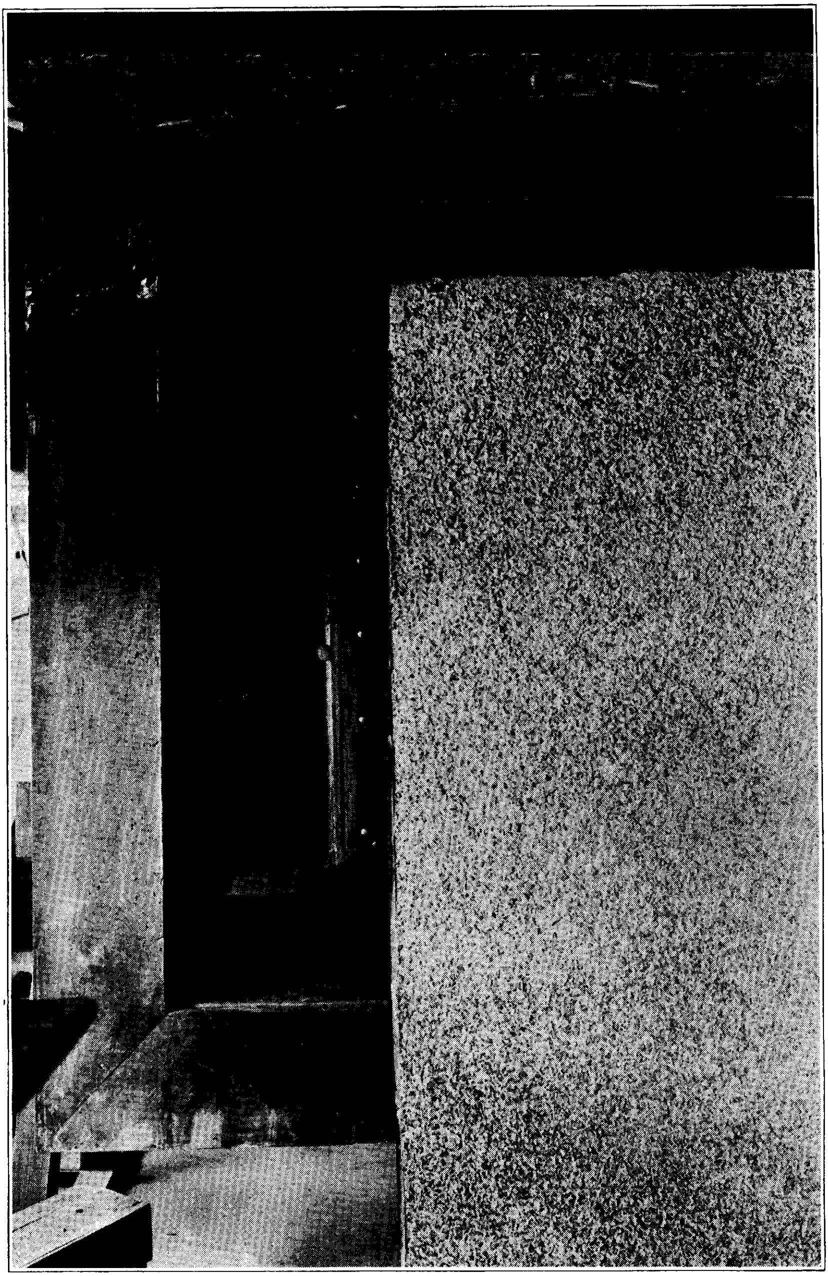


FIGURE 14. TEST BOX WITH WALL PARTLY REMOVED

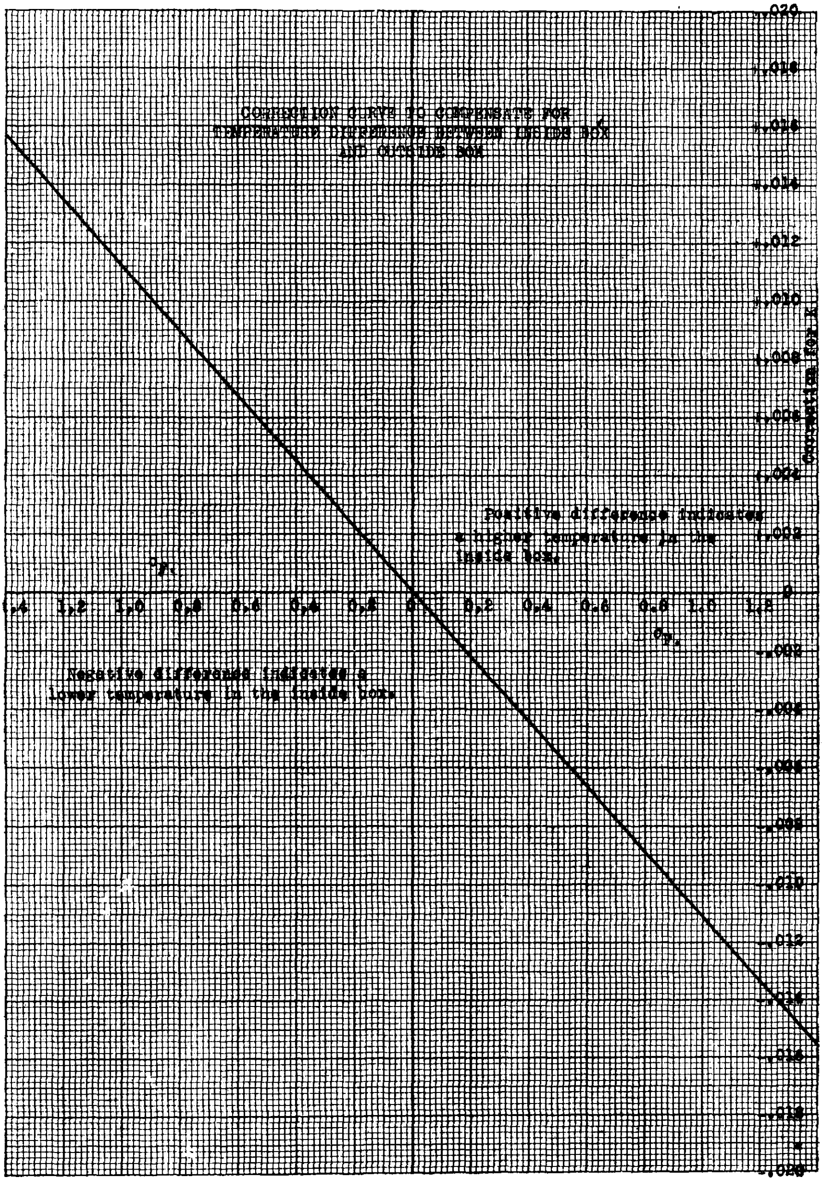


FIGURE 15. CORRECTION CURVE FOR THE TEMPERATURE DIFFERENCES BETWEEN INNER AND OUTER BOXES

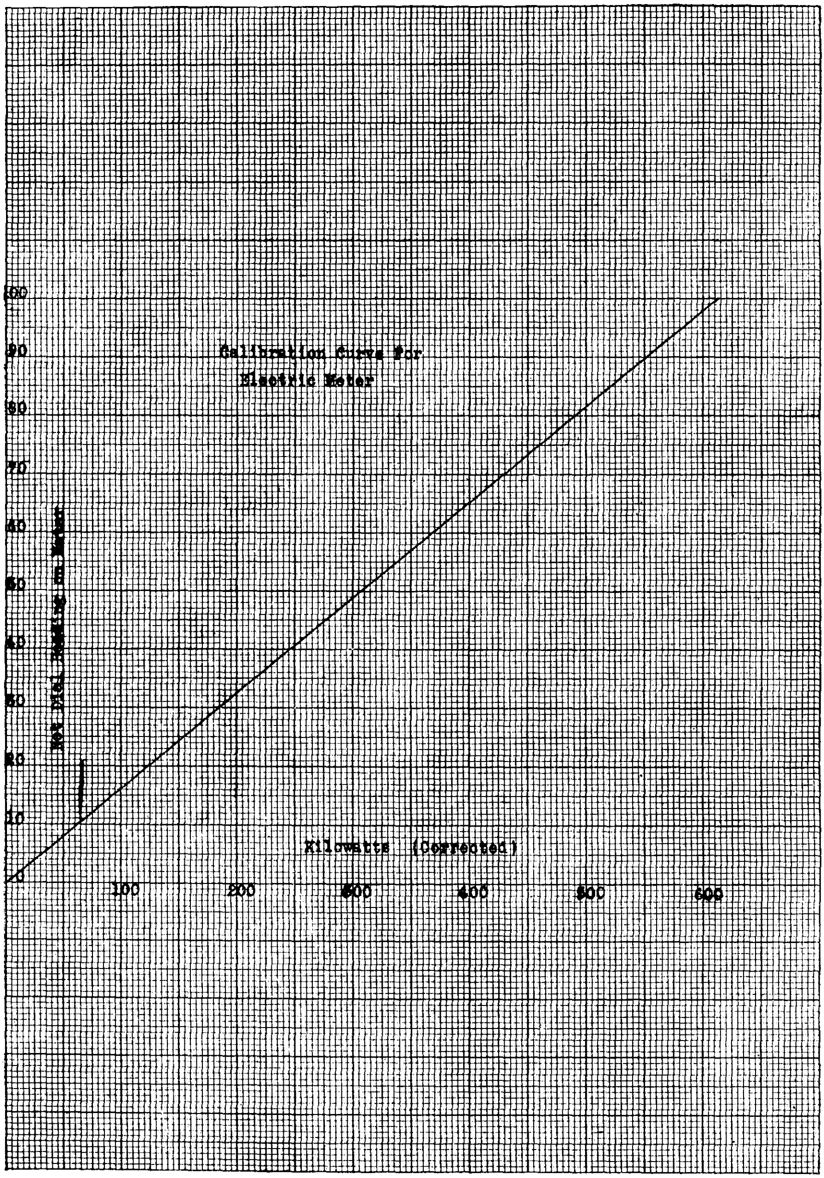


FIGURE 16. CALIBRATION CURVE FOR ELECTRIC METER

Calibration curve, Figure 16, was determined from the calibration of the meter, and from this curve the net dial readings on the meter were converted directly into kilowatts. The meter calibration showed that the readings were two per cent high. This correction was taken care of in the curve.

TESTS OF INSULATING MATERIALS

Statement regarding materials tested.—The object of this work is not to make a complete study of all insulating materials on the market but rather to study some typical materials and to determine the insulating value of these when used in certain types of wall construction. In many cases similar materials have very nearly the same insulating properties and in some instances materials of practically the same composition are manufactured by different companies and put on the market under different trade names. Further it was found that materials selected from the same stock would vary in insulating properties, these variations reaching as high as 20 per cent in some materials depending upon the thickness and quality of the material. It is therefore apparent that two materials which have similar properties might be so selected that either would show the better results. This series of tests has extended over a period of two years and in some cases the thermal qualities of the commercial materials have been changed and improved since samples were selected. For these reasons it was thought best not to use commercial or trade names but rather to represent the materials tested by description and photographs.

In every case test samples were selected from stock and, except where a wide variation is noted in the results on the same material, as near as possible to average quality and thickness.

The following is a list of materials with designating letters, photograph numbers, trade or commercial names, and approximate descriptions. The letters refer to the test data.

DESCRIPTIVE LIST OF INSULATING MATERIALS TESTED

A—Felted flax straw fibre. (Figure 17)
B—Wood pulp board, plaster base. (Figure 18)
C—Sugar cane fibre board firmly pressed, plaster base. (Figure 19)
D—Sugar cane fibre board, insulation base. (Figure 20)
E—Rye straw board. (Figure 21)
F—Hair sewed between two layers of paper. (Figure 22)
G—Paper pulp board keyed for plaster base. (Figure 23)
H—Beveled lath mounted on chemically treated cardboard. (Figure 24)
I—Plaster and paper in alternate layers, total thickness approximately 5/16 inch. (Figure 25)
J—Flax straw fibre stitched between layers of craft paper, loosely matted. (Figure 26)
K—Sea grass, loosely matted stitched between layers of craft paper, approximately 1/2 inch thick. (Figure 27)

L—Same as A, covered with 1/16 inch asbestos on each side. (Figure 28)
M—Same as A, covered on one side with waterproof paper and beveled wood lath. (Figure 29)
N—Black building paper.
O—Red resin building paper.
P—Material G covered with 3/8 inch wood fibre plaster.
Q—Material B covered on one side with 3/8 inch wood fibre plaster.
R—Material M covered on one side with 3/8 inch wood fibre plaster.
S—Material C, plaster base covered on one side with 3/8 inch wood fibre plaster.
T—Flax and cereal straw fibre board. (Figure 30)
U—Wood fibre between two layers of craft paper, approximately 1/2 inch thick. (Figure 30a)

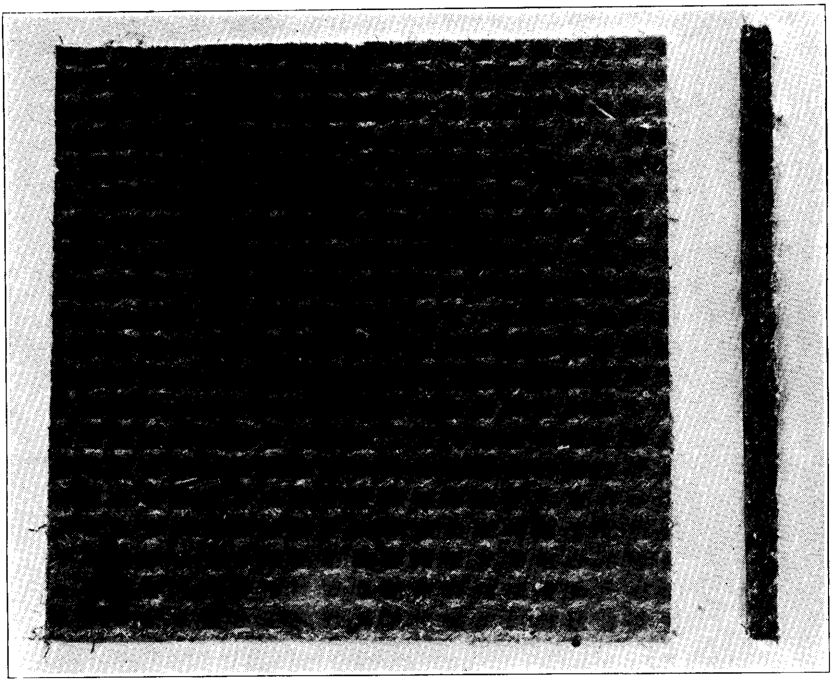


FIGURE 17. MATERIAL A—FELTED FLAX STRAW FIBRE

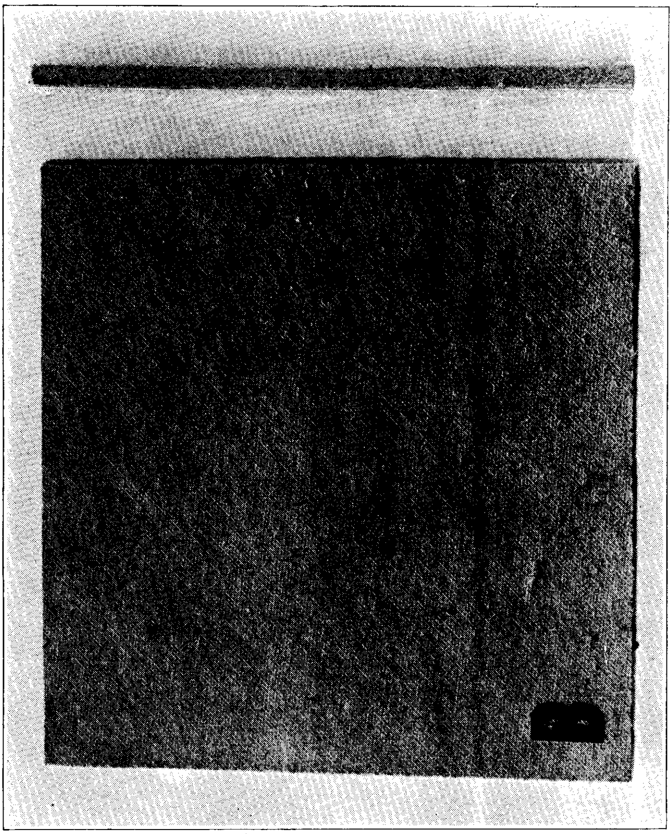


FIGURE 18. MATERIAL B—WOOD PULP BOARD, PLASTER BASE

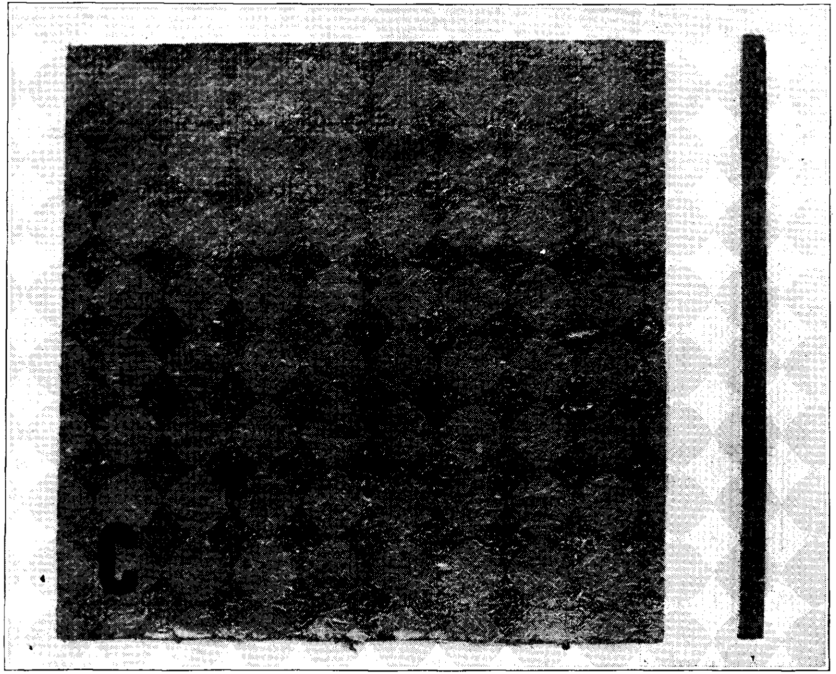


FIGURE 19. MATERIAL C—SUGAR CANE FIBRE BOARD FIRMLY PRESSED, PLASTER BASE

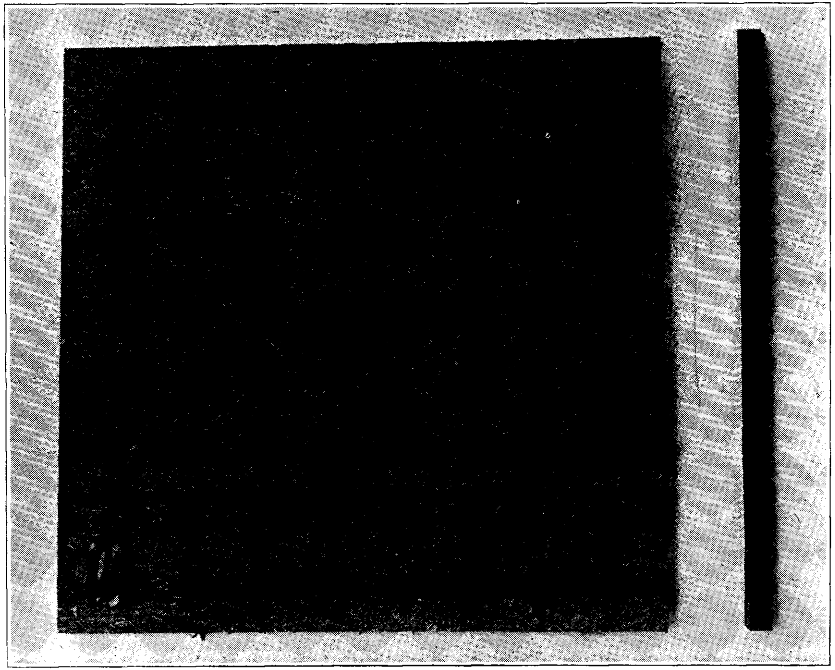


FIGURE 20. MATERIAL D—SUGAR CANE FIBRE BOARD, INSULATION BASE

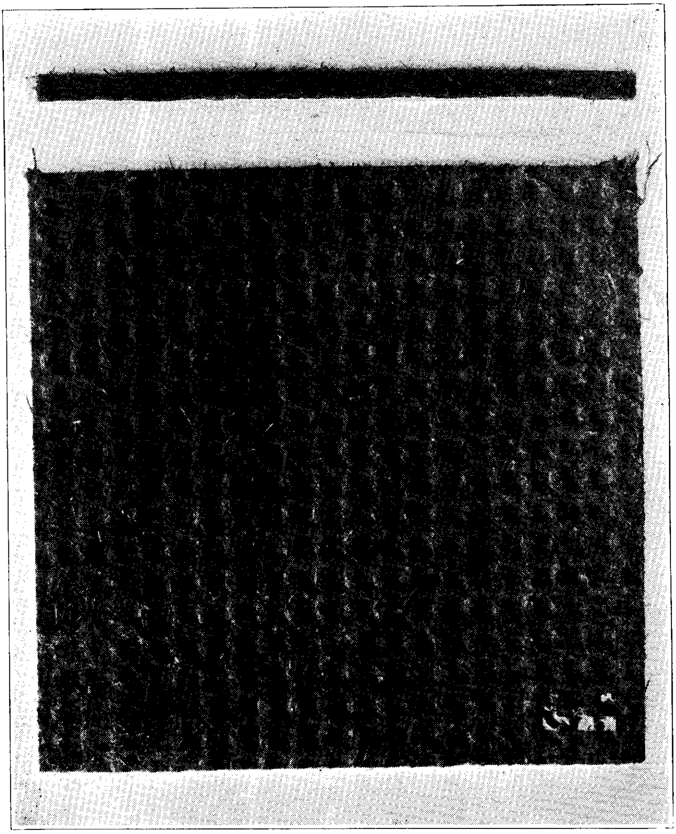


FIGURE 21. MATERIAL E—RYE STRAW BOARD

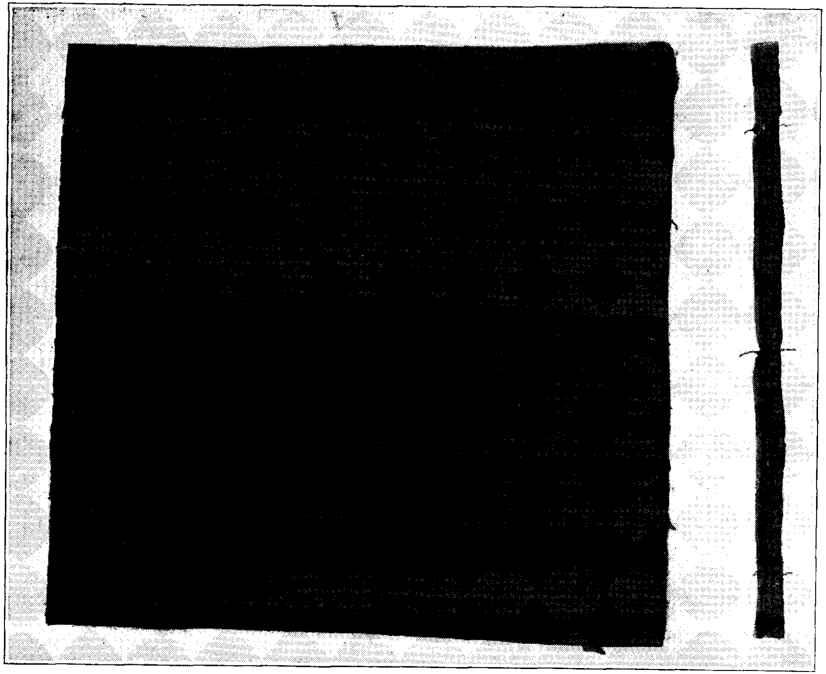


FIGURE 22. MATERIAL F—HAIR SEWED BETWEEN TWO LAYERS OF PAPER

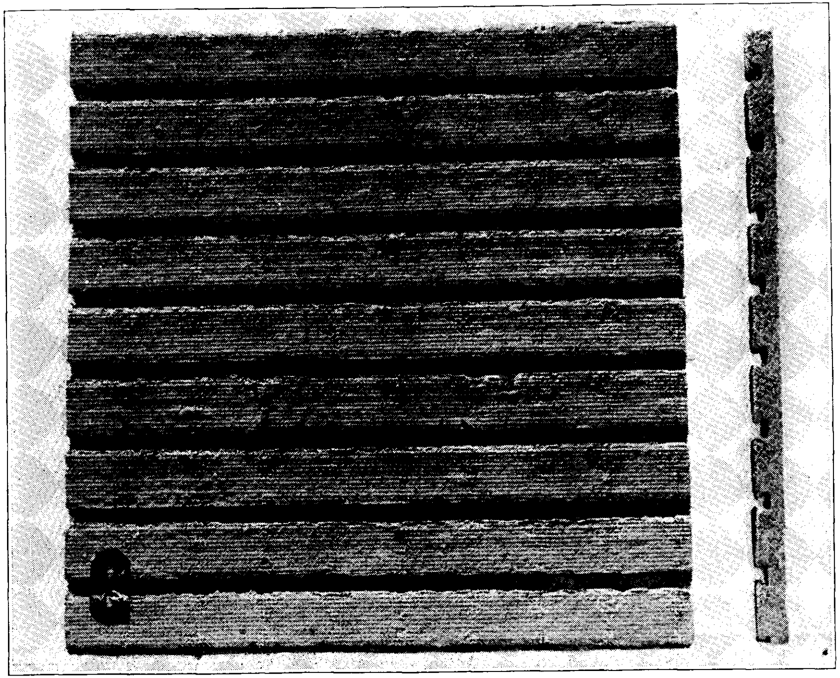


FIGURE 23. MATERIAL G—PAPER PULP BOARD KEYED FOR PLASTER BASE

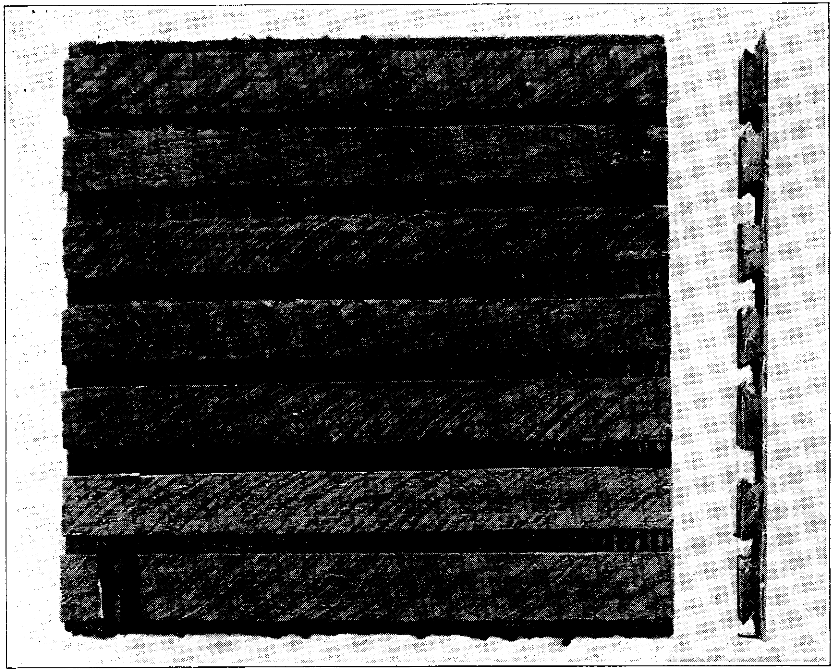


FIGURE 24. MATERIAL H—BEVELED LATH MOUNTED ON CHEMICALLY TREATED CARDBOARD

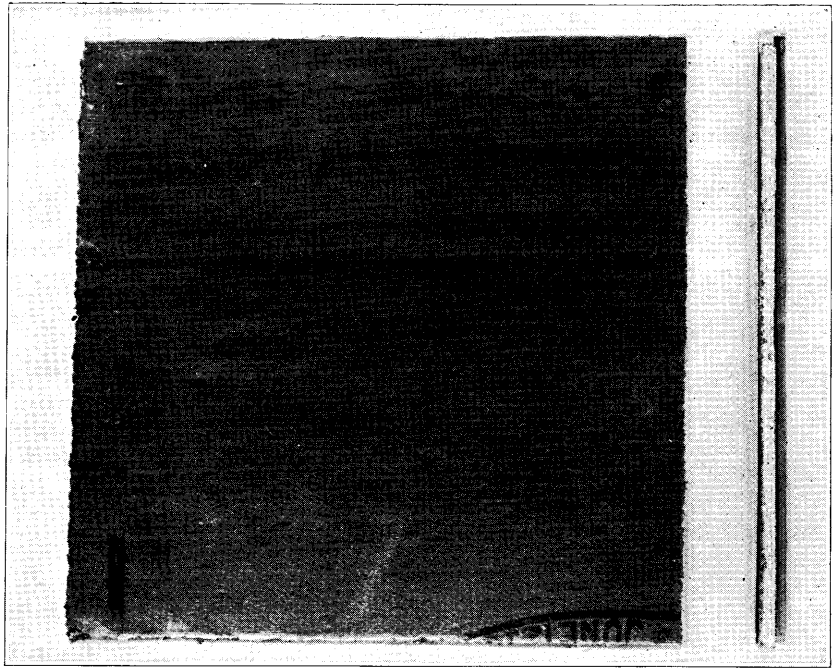


FIGURE 25. MATERIAL I—PLASTER AND PAPER IN ALTERNATE LAYERS (TOTAL THICKNESS APPROXIMATELY 5/16 INCH)

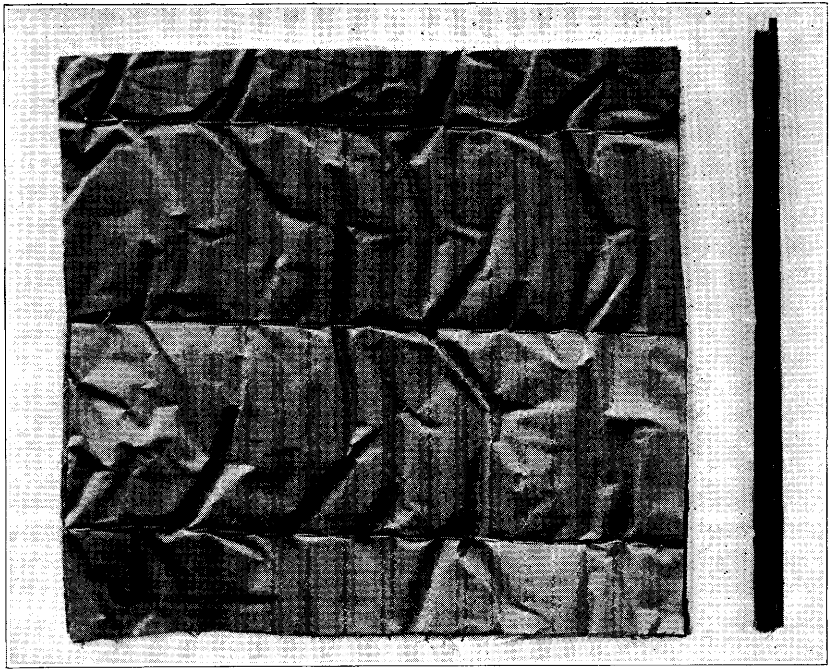


FIGURE 26. MATERIAL J—FLAX STRAW FIBRE STITCHED BETWEEN TWO LAYERS OF CRAFT PAPER, LOOSELY MATTED, APPROXIMATELY 1/2 INCH THICK

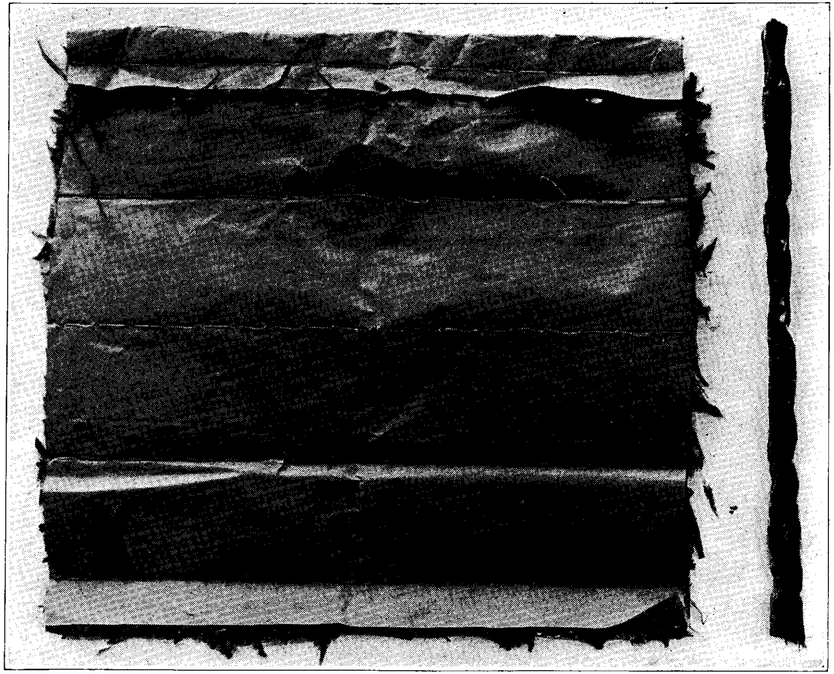


FIGURE 27. MATERIAL K—SEA GRASS, LOOSELY MATTED, STITCHED BETWEEN LAYERS OF CRAFT PAPER, APPROXIMATELY 1/2 INCH THICK

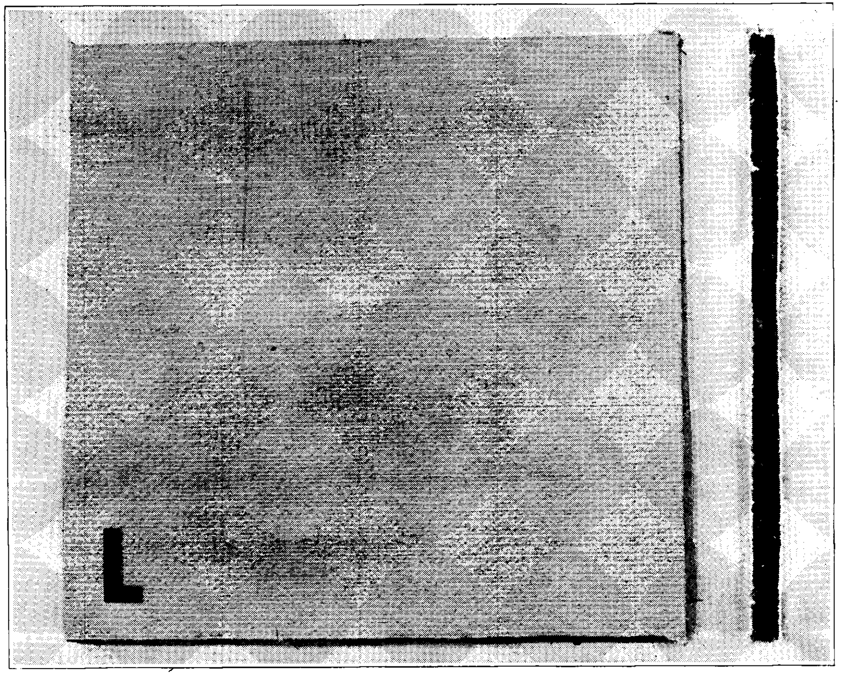


FIGURE 28. MATERIAL L—SAME AS A, COVERED WITH 1/16 INCH ASBESTOS ON EACH SIDE

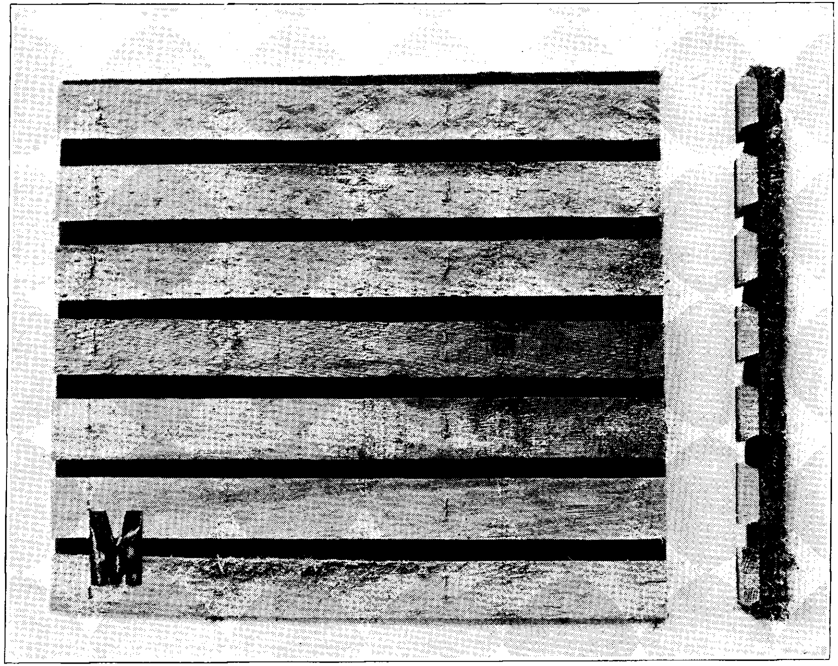


FIGURE 29. MATERIAL M—SAME AS A, COVERED ON ONE SIDE WITH WATER-PROOF PAPER AND BEVELED WOOD LATH

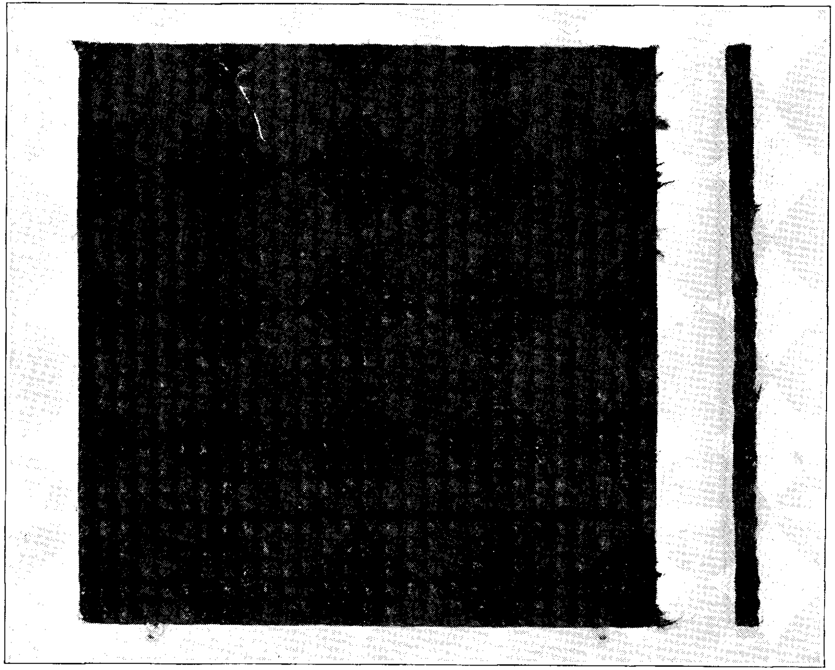


FIGURE 30. MATERIAL T—FLAX AND CEREAL STRAW FIBRE BOARD

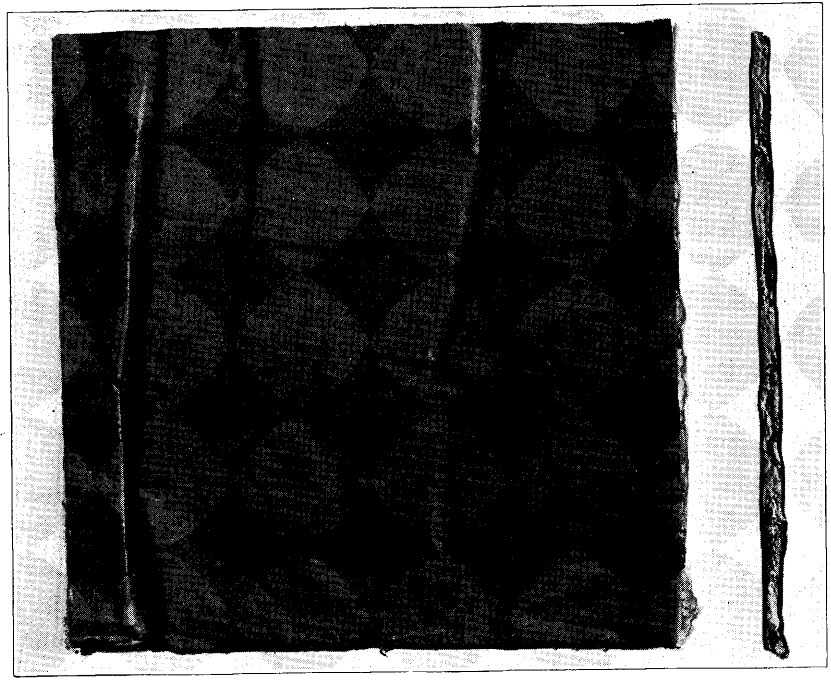


FIGURE 30a. MATERIAL U—WOOD FIBRE BETWEEN TWO LAYERS OF CRAFT PAPER, APPROXIMATELY 1/2 INCH THICK

RECORD OF TESTS OF INSULATING MATERIALS

Material Tested	A1	A1	A2	A2
Test number	184	185	186	187
Thickness, commercial, inches	1/2	1/2	1/2	1/2
Thickness, surface to surface, gauge, inches	39/64	39/64	38/64	38/64
Thickness, actual, inches	35/64	35/64	34/64	34/64
Weight per 100 sq. ft., lbs.	57.3	57.3	55.2	55.2
Temp. air, deg. F., high side	151.5	151.60	150.7	150.9
Temp. air, deg. F., low side	64.2	69.10	67.2	65.1
Difference in temperature	87.3	82.52	83.5	85.8
B.t.u. per sq. ft. per hr.	30.6	29.10	30.6	31.1
Value of K	.3507	.3530	.3665	.3622
Average for each sample	.3519		.3644	

Material Tested	A3	A3	A3	A4	A4
Test number	188	189	190	191	192
Thickness, commercial, inches	1/2	1/2	1/2	1/2	1/2
Thickness, surface to surface, gauge, inches	37/64	37/64	37/64	38/64	38/64
Thickness, actual, inches	33/64	33/64	33/64	34/64	34/64
Weight per 100 sq. ft., lbs.	53.6	53.6	53.6	54.1	54.1
Temp. air, deg. F., high side	150.3	151.2	150.0	150.5	151.5
Temp. air, deg. F., low side	67.9	70.8	74.5	76.1	74.1
Difference in temperature	82.4	80.4	75.5	74.4	77.4
B.t.u. per sq. ft. per hr.	32.25	30.95	29.95	27.98	27.40
Value of K	.3913	.3851	.3966	.3759	.3540
Average for each sample	.3882			.3649	

Material Tested	A5	A5	A6
Test number	124	125	128
Thickness, commercial, inches	1	1	1
Thickness, surface to surface, gauge, inches	1-3/64	1-3/64	1-4/64
Thickness, actual, inches	63/64	63/64	1
Weight per 100 sq. ft., lbs.	121.8	121.8	122.5
Temp. air, deg. F., high side	152.8	152.5	149.3
Temp. air, deg. F., low side	53.	54.8	58.8
Difference in temperature	99.8	97.7	90.5
B.t.u. per sq. ft. per hr.	25.97	24.70	21.68
Value of K	.2602	.2412	.2409
Average for sample	.2507		.2409

Material Tested	A	A
Test number	132	133
Thickness, commercial, inches	1/2	1/2
Thickness, surface to surface, gauge, inches	Four thicknesses 35/64+35/64+36/64+36/64	
Thickness, actual, inches	31/64+31/64+32/64+32/64	
Weight per 100 sq. ft., lbs.	58.8 +56.2 +59.7 +59.5	
Temp. air, deg. F., high side	149.6	150.0
Temp. air, deg. F., low side	55.2	56.1
Difference in temperature	94.4	93.9
B.t.u. per sq. ft. per hr.	12.64	12.68
Value of K	.1339	.1351
Average for sample	.134	

Material Tested	B1	B1	B2	B2
Test number	103	106	107	108
Thickness, commercial, inches	1/2	1/2	1/2	1/2
Thickness, actual, inches	35/64	35/64	35/64	35/64
Weight per 100 sq. ft., lbs.	66.6	66.6	66.6	66.6
Temp. air, deg. F., high side	150.6	150.8	151.0	152.0
Temp. air, deg. F., low side	67.3	66.1	66.8	64.7
Difference in temperature	83.3	84.7	84.2	87.3
B.t.u. per sq. ft. per hr.	32.75	33.78	33.45	33.35
Value of K	.3935	.3990	.3976	.3818
Average for each sample	.3963		.3897	

Material Tested	B2	B2	B2	B2	B2
Test number	104	105	135	129	130
Thickness, commercial, inches	Two thicknesses 1/2 inch		Three thicknesses 1/2 inch	Four thicknesses 1/2 inch	
Thickness, actual, inches	2×35/64		3×35/64	4×35/64	
Weight per 100 sq. ft., lbs.	2×66.6		3×66.6	4×66.6	
Temp. air, deg. F., high side	151.7	151.5	149.8	149.5	149.8
Temp. air, deg. F., low side	65.7	65.9	54.4	58.9	56.5
Difference in temperature	86.0	85.6	95.4	90.6	93.3
B.t.u. per sq. ft. per hr.	21.07	19.25	18.15	13.94	14.05
Value of K	.2451	.2248	.1903	.1539	.1507
Average for each sample	.2350		.1903	.1523	

Material Tested	C1	C1	C2	C2	C3	C3
Test number	144	145	195	196	197	198
Thickness, commercial, inches	1/2	1/2	1/2	1/2	1/2	1/2
Thickness, actual, inches	32/64	32/64	30/64	30/64	30/64	30/64
Weight per 100 sq. ft., lbs.	70.8	70.8	49.4	49.4	50.0	50.0
Temp. air, deg. F., high side	148.4	147.4	152.6	152.3	152.3	152.6
Temp. air, deg. F., low side	65.7	56.4	76.2	80.0	85.3	76.6
Difference in temperature	82.7	91.0	76.4	72.3	67.0	76.0
B.t.u. per sq. ft. per hr.	39.00	43.05	32.55	32.65	31.0	34.4
Value of K	.4718	.4730	.4258	.4517	.4626	.4526
Average for each sample	.4724		.4388		.4576	

Material Tested	D1	D1	D2	D2
Test number	182	183	193	194
Thickness, commercial, inches	1/2	1/2	1/2	1/2
Thickness, actual, inches	38/64	38/64	39/64	39/64
Weight per 100 sq. ft., lbs.	61.0	61.0	52.1	52.1
Temp. air, deg. F., high side	151.1	151.3	150.8	151.7
Temp. air, deg. F., low side	59.2	61.8	75.3	74.2
Difference in temperature	91.9	89.5	75.5	77.5
B.t.u. per sq. ft. per hr.	32.70	31.70	28.95	28.45
Value of K	.3558	.3505	.3833	.3669
Average for each sample	.3532		.3781	

Material Tested	E1	E1
Test number	174	175
Thickness, commercial, inches	1/2	1/2
Thickness, actual, inches	37/64	37/64
Weight per 100 sq. ft., lbs.	63.2	63.2
Temp. air, deg. F., high side	150.4	150.6
Temp. air, deg. F., low side	58.5	59.3
Difference in temperature	91.9	91.3
B.t.u. per sq. ft. per hr.	35.8	34.9
Value of K	.3895	.3823
Average for sample	.386	

Material Tested	F1	F1	F1	F1
Test number	93	100	94	99
Thickness, commercial, inches	1/2	1/2	1/2	1/2
Thickness, actual, inches	One thickness 7/16 inch		Two thicknesses 7/16 inch	
Weight per 100 sq. ft., lbs.	39.6	39.6	81.6	81.6
Temp. air, deg. F., high side	152.8	151.7	152.1	152.2
Temp. air, deg. F., low side	65.1	65.6	66.6	64.8
Difference in temperature	87.7	86.1	85.5	87.4
B.t.u. per sq. ft. per hr.	35.85	35.7	19.07	20.75
Value of K	.4084	.4147	.2231	.2376
Average for sample	.412		.230	

Material Tested	F1	F1	F1	F1
Test number	95	98	96	97
Thickness, commercial, inches	1/2	1/2	1/2	1/2
Thickness, actual, inches	Three thicknesses 7/16 inch		Four thicknesses 7/16 inch	
Weight per 100 sq. ft., lbs.	127.4	127.4	167.2	167.2
Temp. air, deg. F., high side	152.2	151.9	152.4	152.4
Temp. air, deg. F., low side	69.9	65.8	70.1	67.8
Difference in temperature	82.3	86.1	82.3	84.6
B.t.u. per sq. ft. per hr.	14.38	15.00	11.82	11.7
Value of K	.1748	.1743	.1437	.1383
Average for sample	.175		.141	

Material Tested	G1	G1
Test number	146	147
Thickness, commercial, inches	One thickness	
Thickness of material, surface to surface	37/64	37/64
Depth of grooves for plaster, inches	1/4	1/4
Weight per 100 sq. ft., lbs.	83.9	83.9
Temp. air, deg. F., high side	148.0	148 6
Temp. air, deg. F., low side	54.8	66.8
Difference in temperature	92.2	80.8
B.t.u. per sq. ft. per hr.	46.05	40.15
Value of K	.4942	.4967
Average for sample	.496	

Material Tested	H1	H1
Test number	199	200
Thickness, actual, inches	Beveled wood lath mounted on 1/16 inch paper chemically treated	
Weight per 100 sq. ft., lbs.	94.6	94.6
Temp. air, deg. F., high side	152.9	152.4
Temp. air, deg. F., low side	77.1	76.9
Difference in temperature	75.8	75.5
B.t.u. per sq. ft. per hr.	51.20	50.10
Value of K	.6753	.6631
Average for sample	.669	

Material Tested	I1	I1
Test number	201	202
Thickness, actual, inches	22/64	22/64
Weight per 100 sq. ft., lbs.	190.0	190.0
Temp. air, deg. F., high side	153.5	152.1
Temp. air, deg. F., low side	74.7	70.9
Difference in temperature	78.8	81.2
B.t.u. per sq. ft. per hr.	63.4	63.80
Value of K	.8052	.7860
Average for sample	.796	

Material Tested	J1	J1	J2	J2
Test number	267	273	277	278
Thickness surface to surface gauge, inches	11/16	11/16	½	½
Weight per 100 sq. ft., lbs.	30.4	30.4	27.2	27.2
Temp. air, deg. F., high side	152.15	152.91	158.02	159.54
Temp. air, deg. F, low side	81.6	81.05	95.65	93.50
Difference in temperature	70.55	71.88	62.37	66.04
B.t.u. per sq. ft. per hr.	17.21	18.55	21.00	21.40
Value of K	.244	.258	.3364	.3240
Average for sample	.251		.330	

Material Tested	K1	K1
Test number	213	214
Thickness, actual, inches	1/2	1/2
Weight per 100 sq. ft., lbs.	20.0	20.0
Temp. air, deg. F., high side	153.6	153.6
Temp. air, deg. F., low side	78.6	74.8
Difference in temperature	75.0	78.8
B.t.u. per sq. ft. per hr.	26.15	27.50
Value of K	.3487	.3490
Average for sample	.349	

Material Tested	L1	L1
Test number	165	168
Thickness, commercial, inches	1/2	1/2
Thickness, actual, inches	41/64 of which 4/64 is asbestos paper	
Weight per 100 sq. ft., lbs.	101.7	101.7
Temp. air, deg. F., high side	149.9	149.9
Temp. air, deg. F., low side	58.7	62.5
Difference in temperature	91.2	87.4
B.t.u. per sq. ft. per hr.	28.95	26.94
Value of K	.3176	.3080
Average for sample	.313	

Material Tested	N1	N1
Test number	211	212
Thickness, commercial, inches	One thickness	
Thickness, actual, inches	.017	.017
Weight per 100 sq. ft., lbs.	8.2	8.2
Temp. air, deg. F., high side	151.4	151.8
Temp. air, deg. F., low side	74.9	78.3
Difference in temperature	76.5	73.5
B.t.u. per sq. ft. per hr.	77.5	74.2
Value of K	1.013	1.01
Average for sample	1.010	

Material Tested	O1	O1
Test number	203	204
Thickness, commercial, inches	One thickness	
Thickness, actual, inches	.020	.020
Weight per 100 sq. ft., lbs.	7.2	7.2
Temp. air, deg. F., high side	151.3	150.3
Temp. air, deg. F., low side	73.5	80.4
Difference in temperature	77.8	69.9
B.t.u. per sq. ft. per hr.	65.6	58.4
Value of K	.8466	.8357
Average for sample	.841	

Material Tested	P1	P1	P1	P1
Test number	148	149	162	163
Thickness, actual, inches	37/64+3/8 of plaster			
Temp. air, deg. F., high side	148.2	148.6	149.9	149.3
Temp. air, deg. F., low side	64.5	63.5	61.9	60.6
Difference in temperature	83.7	85.1	88.0	88.7
B.t.u. per sq. ft. per hr.	41.45	41.80	42.95	43.25
Value of K	.4956	.4913	.4882	.4878
Average for sample	.491			

Material Tested	Q1	Q1	Q1	Q1	Q1
Test number	150	151	159	160	161
Thickness, commercial, inches	1/2	1/2	1/2	1/2	1/2
Thickness, actual, inches			35/64+3/8 plaster		
Temp. air, deg. F., high side	150.3	150.1	150.8	150.6	148.8
Temp. air, deg. F., low side	63.9	63.8	66.0	62.3	59.7
Difference in temperature	86.4	86.3	84.8	87.7	89.1
B.t.u. per sq. ft. per hr.	34.42	33.5	30.85	32.2	34.85
Value of K	.3968	.3880	.3588	.3670	.3912
Average for sample			.380		

Material Tested	R1	R1	R1	R1	R1	R1
Test number	152	153	154	155	157	158
Thickness, commercial, inches	1/2	1/2	1/2	1/2	1/2	1/2
Thickness, actual, inches			38/64+3/8 plaster			
Temp. air, deg. F., high side	151.3	151.4	151.2	151.3	150.5	150.6
Temp. air, deg. F., low side	60.6	65.3	64.6	62.6	57.4	62.8
Difference in temperature	90.7	86.1	86.6	88.7	93.1	87.8
B.t.u. per sq. ft. per hr.	29.8	27.42	26.68	26.7	28.76	26.43
Value of K	.3287	.3186	.3081	.3011	.3089	.3011
Average for sample			.311			

Material Tested	S1	S1	S1
Test number	171	172	173
Thickness, commercial, inches	1/2	1/2	1/2
Thickness, actual, inches		32/64+3/8 plaster	
Temp. air, deg. F., high side	150.6	150.6	149.9
Temp. air, deg. F., low side	66.0	62.8	58.8
Difference in temperature	84.6	87.8	91.1
B.t.u. per sq. ft. per hr.	36.36	37.27	39.12
Value of K	.4299	.4245	.4294
Average for sample		.428	

Material Tested	T1	T1	T2	T2	T3	T3
Test number	274	275	268	270	271	272
Thickness, surface to surface, inches ...	36/64	36/64	40/64	40/64	33/64	33/64
Weight per 100 sq. ft., lbs.	66.25	66.25	74.0	74.0	60.0	60.0
Temp. air, deg. F., high side	152.23	151.70	152.43	151.90	164.9	158.3
Temp. air, deg. F., low side	87.84	88.42	80.83	86.86	86.23	91.55
Difference in temp..	64.39	63.28	71.60	65.04	78.70	66.78
B.t.u. per sq. ft. per hour	26.97	27.3	25.27	23.35	35.45	31.41
Value of K	.419	.431	.353	.359	.450	.47
Average for sample	.425		.356		.46	

Material Tested	U1	U1
Test number	280	281
Thickness, commercial, inches	1/2	1/2
Thickness, actual, inches	1/2	1/2
Weight per 100 sq. ft., lbs.	21.84	21.84
Temp. air, deg. F., high side	153 1	152.3
Temp. air, deg. F., low side	84.6	86.1
Difference in temperature	68.5	66.2
B.t.u. per sq. ft. per hour	22.23	21.17
Value of K	.3244	.3198
Average for sample	.322	

DISCUSSION OF TESTS OF INSULATING MATERIALS

It is difficult to make a satisfactory classification of insulating materials. They might, however, be classified as follows: first, those used for insulation only; second, those used for insulation in combination with a plaster base; and third, those which may be used as either an insulating material or as a plaster base. In general the lighter and more loosely matted the material, the better the insulating value. This is shown by materials C and D, which are of the same composition with the exception that C was more dense than D. While this also holds in general for different materials, it cannot always be relied upon.

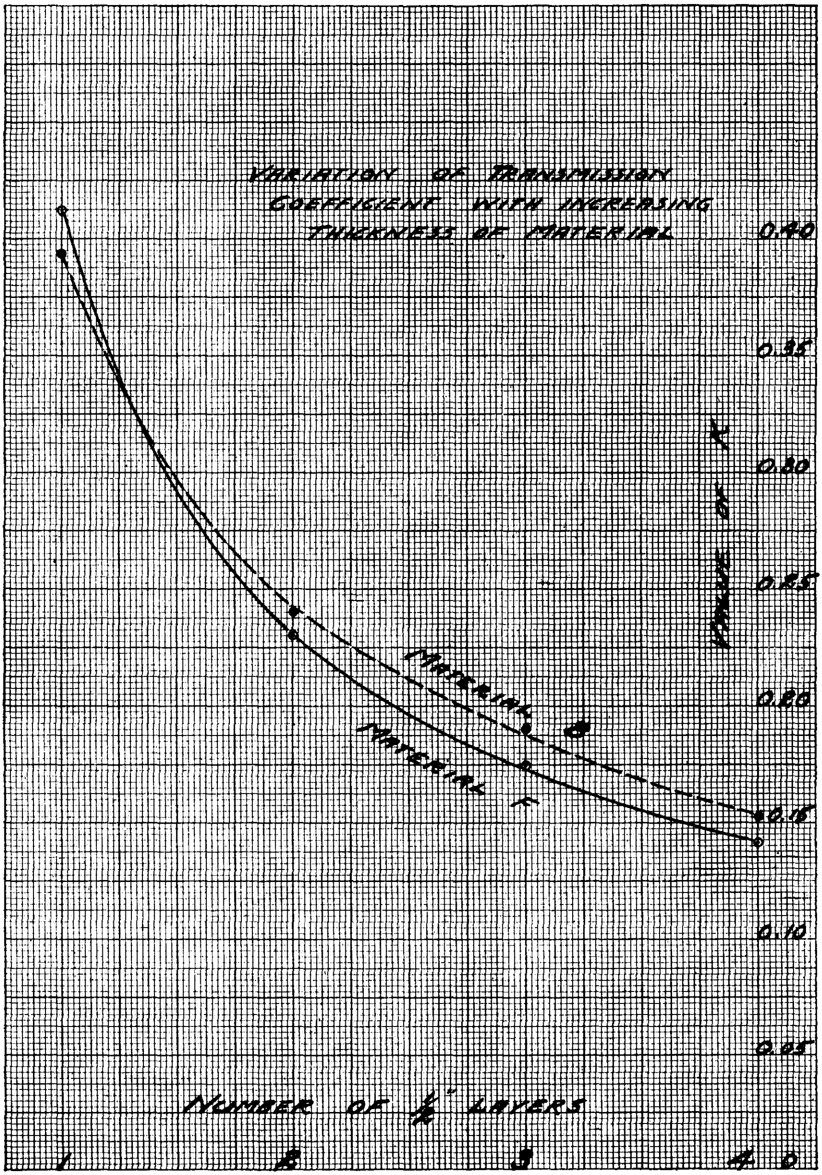


FIGURE 31. VALUE OF TRANSMISSION CONSTANT FOR INCREASING THICKNESS OF MATERIAL

As might be expected in materials which are loosely matted and built for insulating purposes, there is a variation in thickness and density, with a corresponding variation in insulating value. Thus materials of the same make may vary in their thermal properties and in some cases where one material shows a transmission constant slightly above or below a second material the samples might be so selected that the results would be reversed. In some cases where samples were selected for the purpose of determining the variations in the same run of material, differences as high as 20 per cent were obtained.

Most of the materials tested were commercially rated as one-half inch thick as this is the thickness most commonly used for insulating buildings. Materials which are loosely matted and stitched between two layers of paper showed the greatest variation in thickness and in insulating value. The actual thickness of these materials was measured by pressing a large sheet lightly between two boards and measuring the distance between the surfaces of the boards. In the case of materials A, B, and F tests were made using one, two, three, and four thicknesses. The results of these tests are shown in the curves, Figure 31.

A comparison of the tests made both with and without plaster on the face of the insulating materials shows that the insulating value of the plaster is very low, decreasing the transmission constant from two to four per cent. The percentage reduction will depend upon the transmission constant for the material.

TESTS OF WALL SECTIONS

General statement concerning wall sections tested.—The object of this series of tests was to determine the comparative insulating properties of different types of wall construction in common use and to determine the most effective method of using insulating materials in these walls.

Obviously it was impractical to use all of the different kinds of insulating materials in this series of tests and it would be misleading to use one type in part of the tests and some other in the remaining tests, even though their properties were similar. It was, therefore, thought best to use the same insulating material in all of the comparative tests. Many other wall sections and combinations might be added to the list. For instance wood and metal lath might have been interchanged on the inside surface of the walls, or insulating material

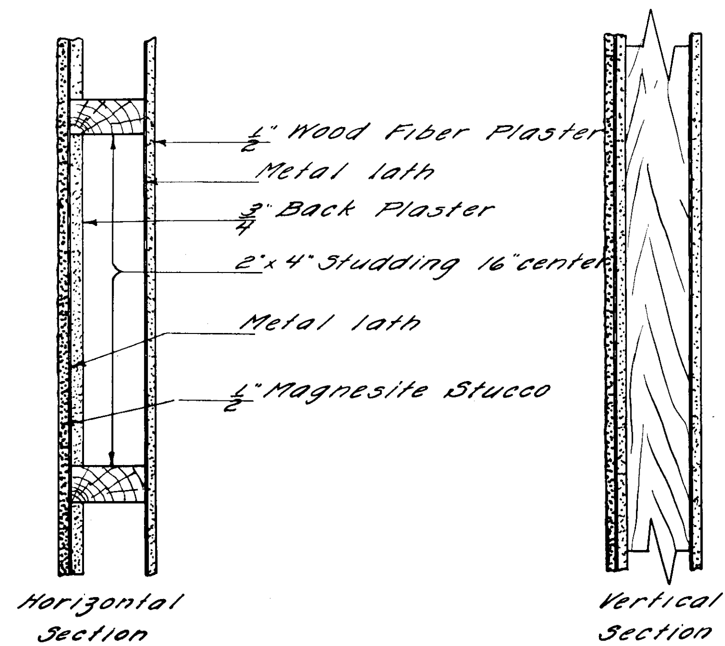


FIGURE 32. WALL NO. 1. AVERAGE VALUE OF K = .401

might have been added to Wall 1, etc. These changes and additions, however, would not affect the conclusions. While the series is not complete there are sufficient data from which to draw definite conclusions in regard to the value of insulating materials in walls of this class. The walls tested are shown in sectional view, Figures 32 to 39 inclusive. The walls are numbered and the test data are shown for each wall number

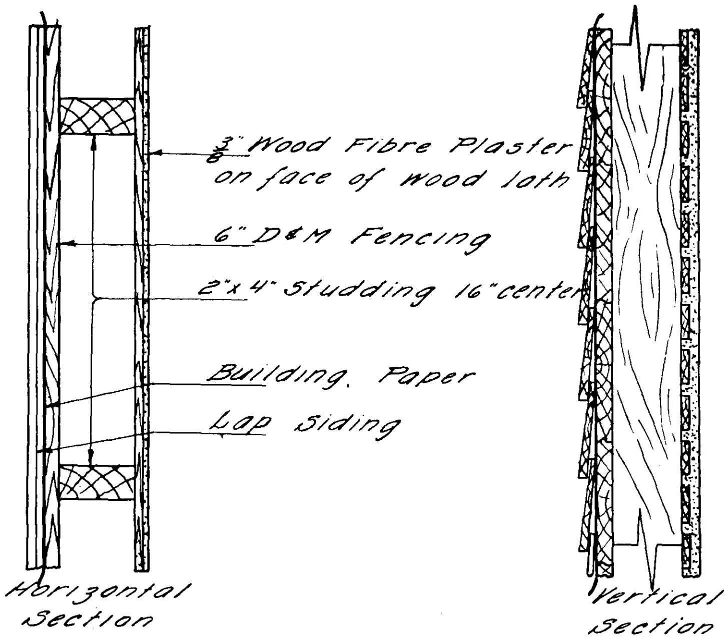


FIGURE 33. WALL NO. 2. AVERAGE VALUE OF K = .2368

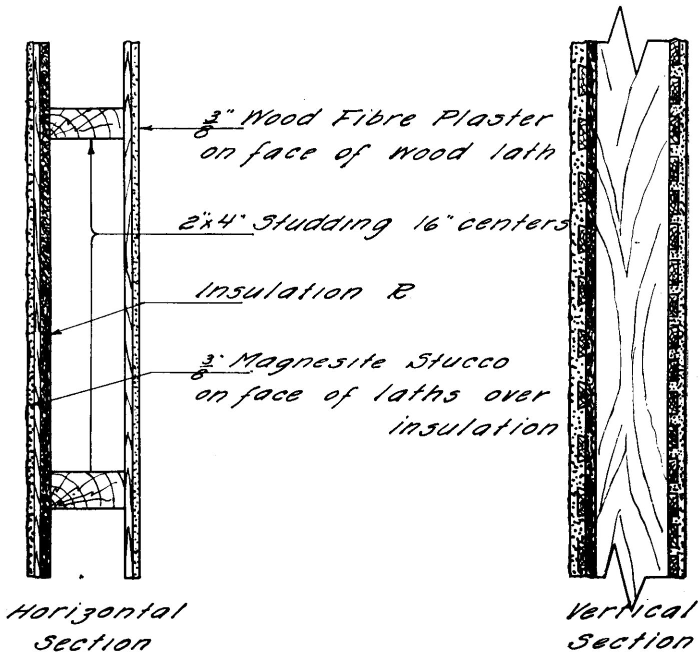


FIGURE 34. WALL NO. 3. AVERAGE VALUE OF K = .2191

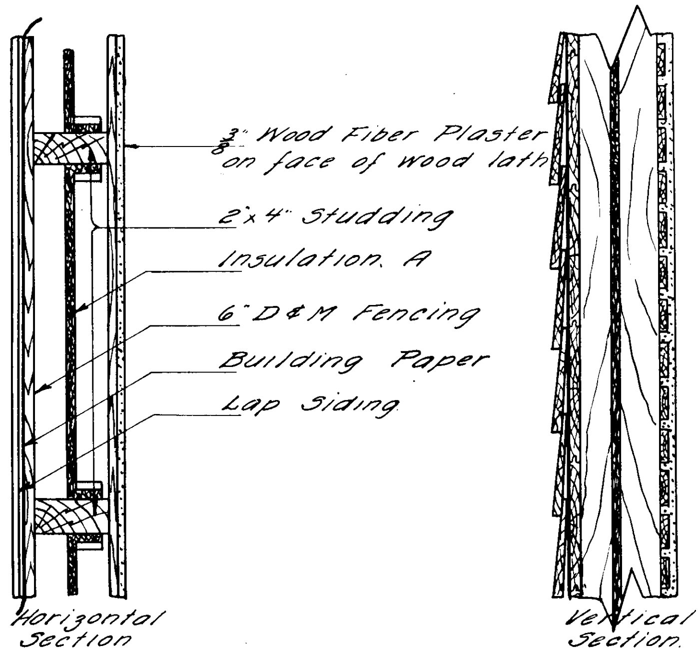


FIGURE 35. WALL NO. 4. AVERAGE VALUE OF K = .1747

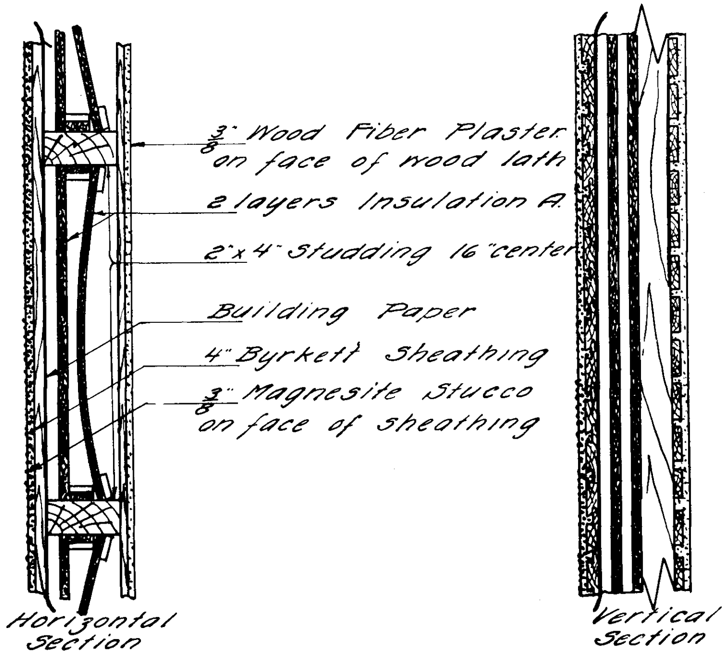


FIGURE 36. WALL NO. 5. AVERAGE VALUE OF K = .1332

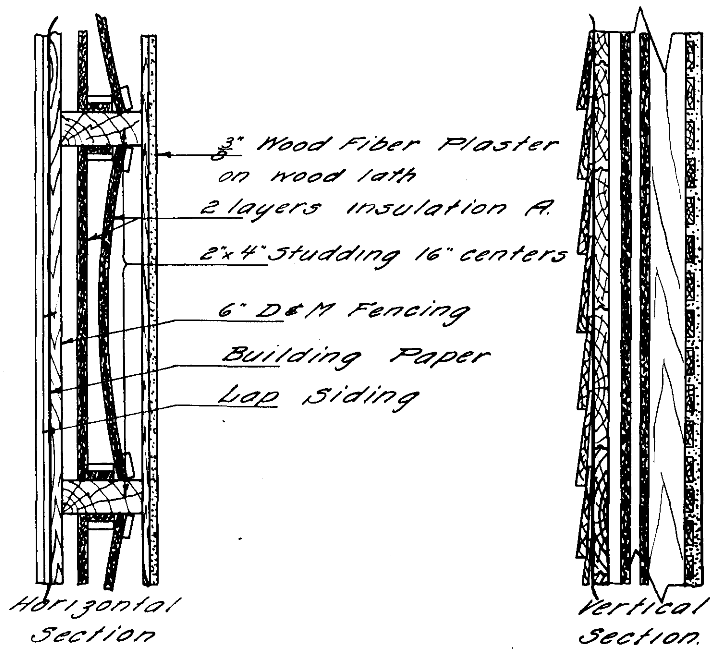


FIGURE 37. WALL NO. 6. AVERAGE VALUE OF K = .1439

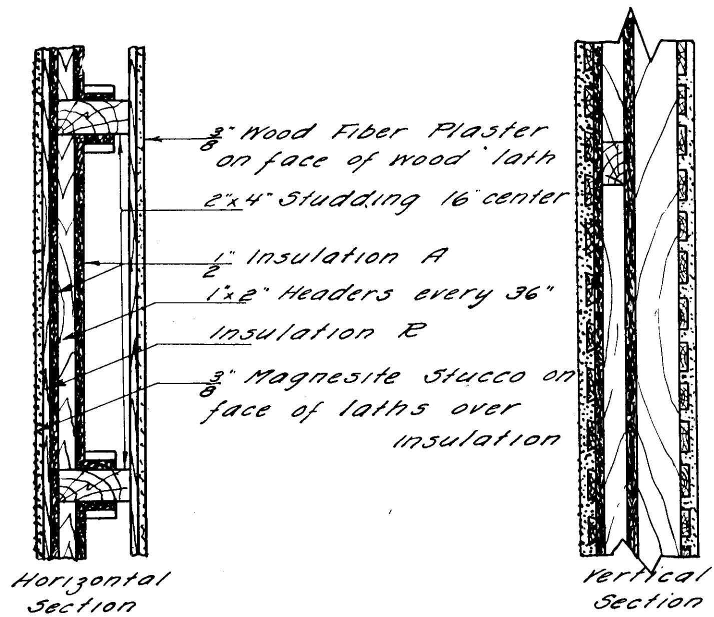


FIGURE 38. WALL NO. 7. AVERAGE VALUE OF K = .1583

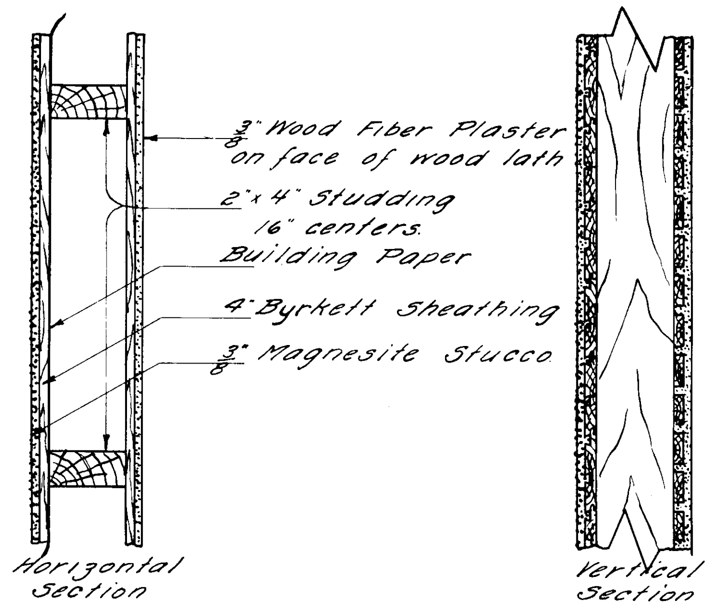


FIGURE 39. WALL NO. 8. AVERAGE VALUE OF K = .2635

RECORD OF TESTS OF WALL SECTIONS

Material Tested	Wall Number			
	1	1	1	1
Test number	218	220	222	260
Temp. air, deg. F., high side	152.6	150.8	153.1	151.49
Temp. air, deg. F., low side	80.1	85.0	80.7	60.43
Difference in temperature	72.5	65.8	72.4	91.06
B.t.u. per sq. ft. per hr.	29.10	26.38	28.84	36.70
Value of K	.4015	.4009	.3982	.4033
Average for wall	.401			

Material Tested	Wall Number			
	2	2	2	2
Test number	227	228	229	230
Temp. air, deg. F., high side	153.4	153.4	153.5	153.1
Temp. air, deg. F., low side	79.1	76.6	79.3	79.7
Difference in temperature	74.3	76.8	74.2	73.4
B.t.u. per sq. ft. per hr.	17.98	18.36	17.32	17.06
Value of K	.2421	.2392	.2335	.2325
Average for wall	.237			

Material Tested	Wall Number	
	3	3
Test number	262	263
Temp. air, deg. F., high side	152.24	152.48
Temp. air, deg. F., low side	59.50	58.12
Difference in temperature	92.74	94.36
B.t.u. per sq. ft. per hr.	19.57	21.44
Value of K	.2110	.2272
Average for wall	.219	

Material Tested	Wall Number			
	4	4	4	4
Test number	223	224	225	226
Temp. air, deg. F., high side	154.0	153.8	153.8	153.4
Temp. air, deg. F., low side	80.7	84.0	83.7	88.1
Difference in temperature	73.3	69.8	70.1	65.3
B.t.u. per sq. ft. per hr.	12.87	12.37	12.08	11.33
Value of K	.1756	.1772	.1725	.1735
Average for wall	.175			

Material Tested	Wall Number	
	5	5
Test number	239	242
Temp. air, deg. F., high side	155.0	153.1
Temp. air, deg. F., low side	80.8	75.8
Difference in temperature	74.2	77.3
B.t.u. per sq. ft. per hr.	10.00	10.17
Value of K	.1349	.1315
Average for wall	.133	

Material Tested	Wall Number	
	6	6
Test number	253	233
Temp. air, deg. F., high side	152.11	152.6
Temp. air, deg. F., low side	62.54	71.4
Difference in temperature	89.57	81.2
B.t.u. per sq. ft. per hr.	12.54	12.00
Value of K	.1400	.1478
Average for wall	.144	

Material Tested	Wall Number	
	7	7
Test number	237	238
Temp. air, deg. F., high side	154.2	154.2
Temp. air, deg. F., low side	79.6	82.3
Difference in temperature	74.6	71.9
B.t.u. per sq. ft. per hr.	11.83	11.36
Value of K	.1585	.1581
Average for wall	.158	

Material Tested	Wall Number	
	8	8
Test number	234	235
Temp. air, deg. F., high side	154.0	154.1
Temp. air, deg. F., low side	75.2	75.8
Difference in temperature	78.8	78.3
B.t.u. per sq. ft. per hr.	20.82	20.58
Value of K	.2641	.2630
Average for wall	.264	

DISCUSSION OF RESULTS OF WALL TESTS

In order to show the comparison of insulated and non-insulated walls the following tabulations were made:

	Wall Number	
	2	8
Outside surface	6-inch D&M fencing, building paper, and drop siding	3/8-inch magnesite stucco on byrkette sheathing with building paper
Inside surface	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Value of K	.237	.264

The transmission constant, K, shows a reduction in heat loss of 10.1 per cent by using the lap siding and 6-inch D & M fencing instead of stucco and byrkette sheathing. The inner surfaces of the two walls are of the same construction.

	Wall Number	
	3	8
Outside surface ..	3/8-inch magnesite stucco on insulation plaster base	3/8-inch magnesite stucco on byrkette sheathing with building paper
Inside surface ...	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Value of K	.219	.264

The only difference between these two walls is that in Wall 3 an insulation plaster base has been substituted for the byrkette sheathing and building paper giving a reduction in the heat transmission constant of 16.8 per cent.

	Wall Number	
	2	4
Outside surface ..	6-inch D&M fencing, building paper, and lap siding	6-inch D&M fencing, building paper, and lap siding
Inside surface ...	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Insulation between studding	None	One layer 1/2-inch thick
Value of K	.237	.175

Walls 2 and 4 are identical, with the exception that in Wall 4 one layer of one-half inch insulation has been applied between the studding, giving a reduction of heat transmission constant of 26.2 per cent.

	Wall Number	
	3	7
Outside surface ..	3/8-inch magnesite stucco on an insulation base	3/8-inch magnesite stucco on an insulation base
Inside surface ...	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Insulation between studding	None	One layer 1/2-inch thick
Value of K	.219	.158

Walls 3 and 7 are identical, with the exception that one-half inch insulation has been applied between the studding of Wall 7, giving a reduction in heat transmission constant of 27.7 per cent.

	Wall Number	
	4	5
Outside surface ..	6-inch D&M fencing, building paper, and lap siding	6-inch D&M fencing, building paper, and lap siding
Inside surface ...	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Insulation between studding	One layer 1/2-inch thick	Two layers 1/2-inch thick
Value of K	.175	.133

These walls are the same with the exception that in Wall 5 two layers of insulation have been applied in place of one, giving a reduction of heat transmission constant of 23.7 per cent.

	Wall Number	
	5	6
Outside surface ..	6-inch D&M fencing, building paper, and lap siding	Building paper, byrkette sheathing, and 3/8-inch stucco
Inside surface ...	3/8-inch wood fibre plaster on wood lath	3/8-inch wood fibre plaster on wood lath
Insulation between studding	Two layers 1/2-inch thick	Two layers 1/2-inch thick
Value of K	.133	.144

The only difference in these walls is in the outside surface construction showing the lap siding with sheathing to give 7.44 per cent less heat transmission than the byrkette sheathing and stucco.

	Wall Number	
	1	8
Outside surface ..	1/2-inch magnesite stucco on metal lath with back plaster	3/8-inch magnesite stucco on byrkette sheathing with building paper
Inside surface ...	1/2-inch wood fibre plaster on metal lath	3/8-inch wood fibre plaster on wood lath
Value of K	.401	.264

This shows a reduction of 34 per cent by using building paper and byrkette sheathing in place of metal lath and back plaster without insulation. Wall 1 was used as an example of uninsulated construction altho the addition of insulating material is recommended in practice.

These results show conclusively the value of insulating material as applied to wall construction. No absolute figure can be given as the maximum heat transmission constant which should be allowable in construction of this type, but from the results of these tests it should not be greater than .2 if the wall is to be considered well insulated. The most effective way of applying the insulation depends upon the type of construction allowable. The comparison of Walls 2 and 4 and Walls 3 and 7 shows that insulation applied between the studding is very effective. In cases where a plaster base insulation is permitted in place of sheathing it gives a comparatively well-insulated wall, as shown by comparing Walls 2 and 3 and also serves as a substitute for the sheathing and building paper. While these results are interpreted only in the light of heat which is saved in the cold weather, there is also the added advantage that a well-insulated wall keeps the building much cooler in hot weather—a fact which cannot be measured so much in dollars and cents or coal saved as in comfort.

These walls were all tested in still air. Under high wind velocities the heat transmission constant would be larger, but the per cent of increase would be much greater for the non-insulated walls than for the insulated walls due partially to the fact that the non-insulated walls would permit greater air leakage and also to the fact that the surface resistance of a non-insulated wall is a greater per cent of the total resistance than it is for an insulated wall.

APPLICATION TO A SMALL HOUSE

House selected.—In order to show the practical value of insulated walls when applied to house construction, plans were selected of a two-story house, 28x30 feet foundation, and the heat losses calculated for this house using the constants for insulated and non-insulated walls. These plans were obtained through the courtesy of the Architects Small House Service Bureau, Minneapolis. The plans and elevations are shown in Figures 40 to 45 inclusive.

Transmission constants used.—In calculating the heat loss, it was assumed that storm sash was used in all cases giving a transmission constant for the glass of .45. The air change was assumed to be one volume per hour for all cases.

In determining the heat losses through the ceilings the second story ceiling only was considered. This ceiling, together with the roof, was taken as a compound wall with an air space between. The insulation was assumed to be one inch thick and placed between the attic floor and the second floor ceiling. The heat transmission constants assumed were as follows: roof in all cases .40, second story ceiling .26, insulation in ceiling .24. This gave for non-insulated ceilings a constant as follows:

$$K = \frac{1}{\frac{1}{.26} + \frac{1}{.40}} = .158$$

Insulated ceilings:

$$K = \frac{1}{\frac{1}{.26} + \frac{1}{.40} + \frac{1}{.24}} = .095$$

The first constant was used for the ceilings with the non-insulated walls and the second was used for the insulated walls.

Conditions assumed for determining heat losses.—The total heat loss and the square feet of radiation were figured for the building using each wall. The heat loss through the windows and the infiltration loss were assumed to be the same in all cases altho the infiltration loss would be less with insulated walls. In determining the square feet of radiation required an outside temperature of 20° below zero was assumed, the room temperature being 70° F. It was assumed that two-column, 38-inch, hot water radiators were used with average temperature of 170° F. in the radiator.

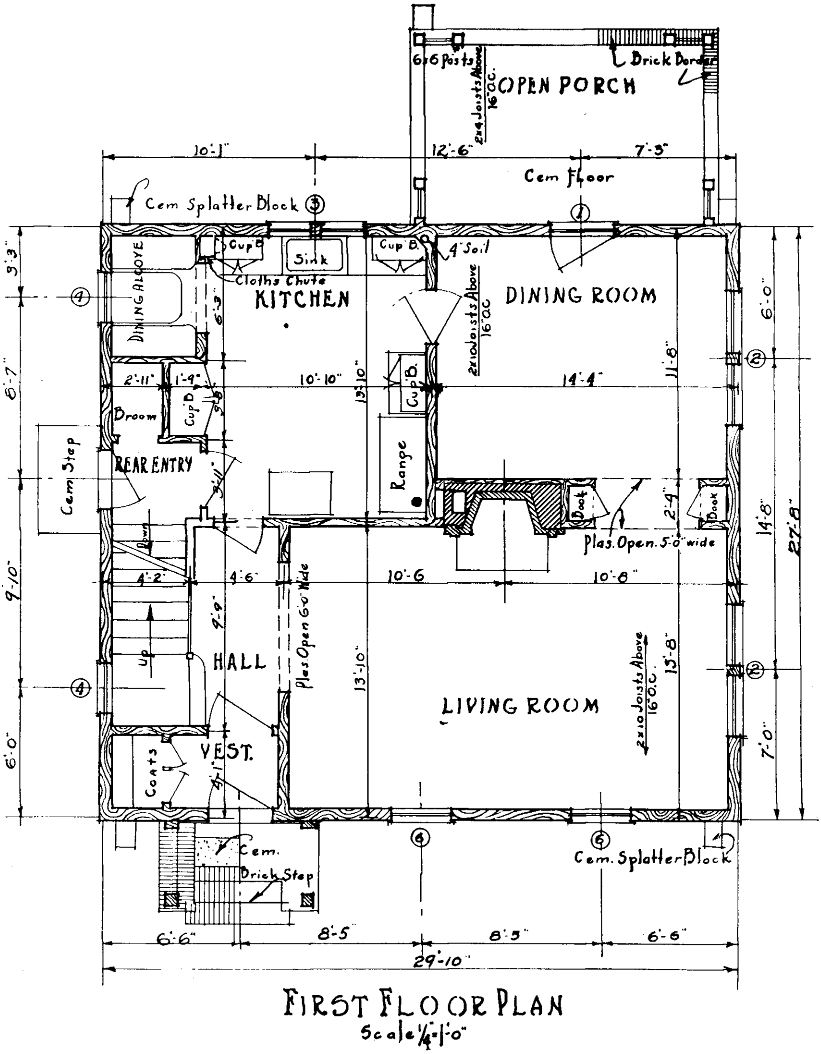


FIGURE 40. FIRST FLOOR PLAN

In determining the total heat loss for the season a heating season of 210 days was taken with an average temperature difference between the inside and the outside of the building of 32° F. The total coal consumption for the season was based on the assumption that 8000 B.t.u. per ton of hard coal would be converted into useful heat for the house by the heating plant. These figures might vary somewhat from year to year, but serve to give comparative results for the walls figured.

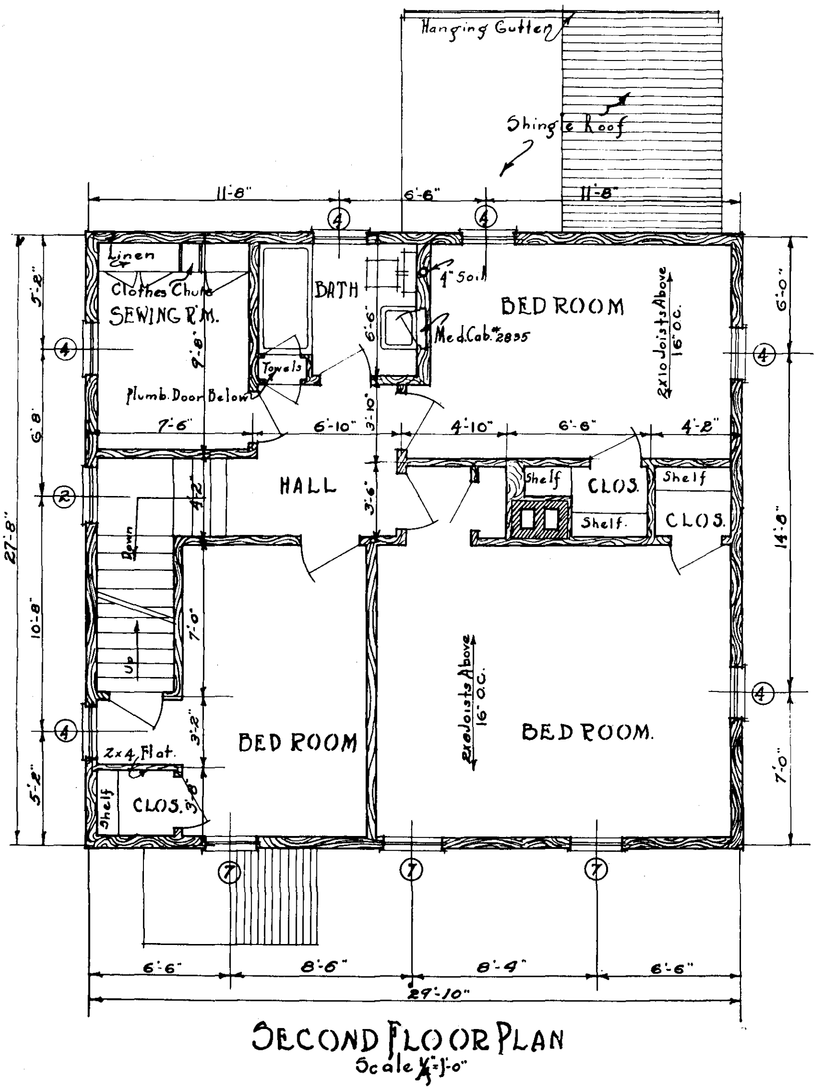


FIGURE 41. SECOND FLOOR PLAN

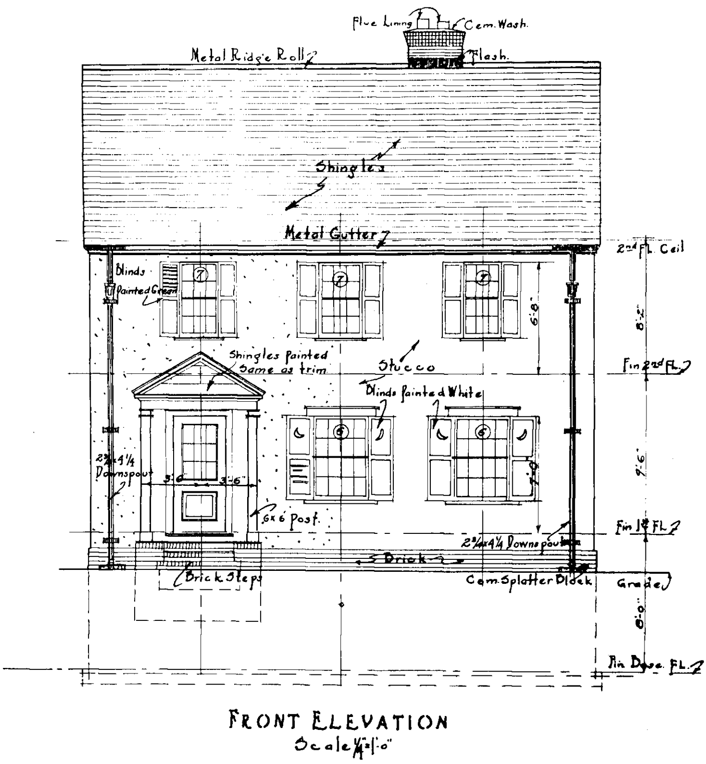


FIGURE 42. FRONT ELEVATION

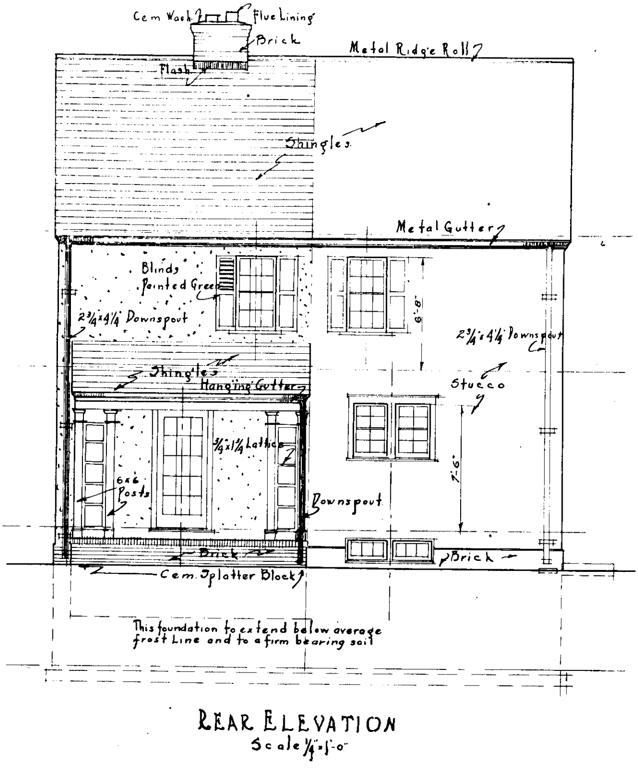


FIGURE 43. REAR ELEVATION

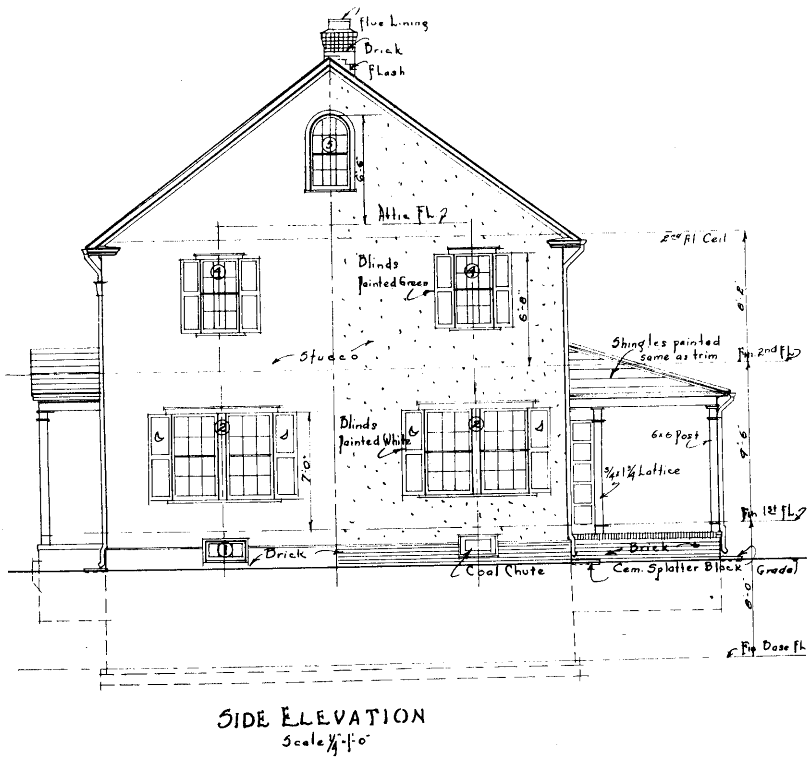


FIGURE 44. RIGHT ELEVATION

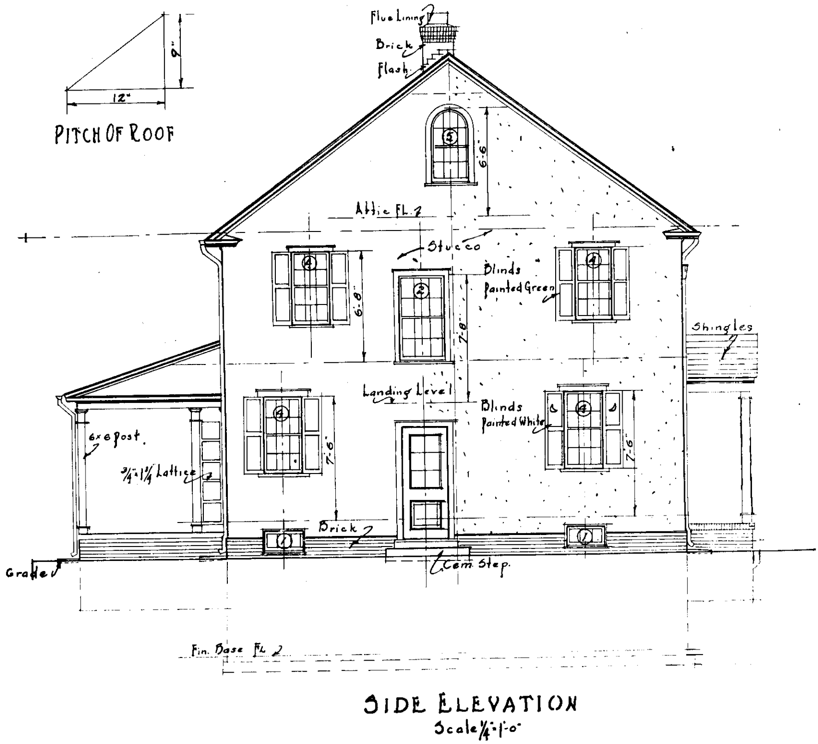


FIGURE 45. LEFT ELEVATION

METHOD OF CALCULATING HEAT LOSSES

Let H = total heat in B.t.u.
W = wall surface in square feet.
G = glass surface in square feet.
C = ceiling surface in square feet.
V = volume of air in cubic feet.
N = air infiltration changes per hour.
t_1 = room temperature.
t_0 = outside temperature.
K_w = heat transmission constant for wall.
K_g = heat transmission constant for glass.
H_w = heat in B.t.u. transmitted through wall per hour.
$= K_w W (t_1 - t_0)$.
H_g = heat in B.t.u. transmitted through glass per hour.
$= K_g G (t_1 - t_0)$.
H_a = heat in B.t.u. lost by infiltration per hour.
$= .02 V N (t_1 - t_0)$.
$H = H_w + H_g + H_a$.

Radiation for living room uninsulated wall

W = 233 square feet of wall surface.
G = 60 square feet of glass surface.
V = 2380 cubic feet.
$N = 1$
$K_w = 0.401$
$K_g = .45$
$t_1 = 70°$ F.
$t_0 = 20°$ F.

$H_w = K_w W (t_1 - t_0) = 0.401 \times 233 \times 90 =$	8410
$H_g = K_g G (t_1 - t_0) = 0.45 \times 60 \times 90 =$	2430
$H_a = .02 VN (t_1 - t_0) = 0.02 \times 2380 \times 1 \times 90 =$	4290
Total B.t.u. per hour =	15.130
Add 15 per cent for N-W Exposure =	2,269
	17,399

$$\text{Radiation required*} = \frac{17399}{1.65 \times 100°} = 105 \text{ square feet}$$

* Assume 38-inch, 2-column radiators; transmission constant, 1.65; water temperature, 170° F.; room temperature, 70° F.

TABLE I

COMPUTED RESULTS FOR HOUSE, USING VARIOUS WALLS

W = 1982 sq. ft. wall surface total C = 783 sq. ft. ceiling surface total.
G = 333 sq. ft. glass surface total V = 13,010 cu. ft. volume total.

	Wall Number							
	1	2	3	4	5	6	7	8
K_w wall constant	.401	.2368	.2191	.1747	.1332	.1439	.1583	.2635
K_g glass constant	.45	.45	.45	.45	.45	.45	.45	.45
K_c ceiling constant	.158	.158	.095	.095	.095	.095	.095	.158
H_w heat lost through wall, per hour	71,530	42,240	39,082	31,163	23,760	25,663	28,237	47,003
H_g heat lost through glass, per hour	13,486	13,486	13,486	13,486	13,486	13,486	13,486	13,486
H_c heat lost through ceiling, per hour	11,134	11,134	6,695	6 695	6,695	6,695	6,695	11,134
H_v heat lost by infiltration, per hour	23,418	23,418	23,418	23,418	23,418	23,418	23 418	23,418
Total calculated loss per hour B.t.u.	119,568	90,278	82,681	74.762	67,359	69,262	71,836	95,041
Assume 10% additional for average exposure	11,956	9,027	8,268	7.476	6,926	6,926	7,183	9 504
Total loss per hour B.t.u.	131;524	99,305	90,949	82.238	74,095	76,188	79.019	104,545
Total radiation required sq. ft.	797	602	551	498	449	461	479	632
Average coal burned per season, tons	14.7	11.1	10.1	9.2	8.3	8.5	8.8	11.7

Note: The maximum heat loss per hour was calculated for an outside temperature of —20° F. and a room temperature of 70° F. The heat loss for the heating season was calculated for a season of 210 days and a temperature difference of 32° F

SUMMARY

This work has been confined to the insulating properties of building materials and while the work and discussion have been along the lines of preventing heat losses from buildings in cold weather, there are also advantages to be gained in warm weather. A well-insulated building is much cooler and more comfortable in warm weather than one which is not insulated, altho the direct saving cannot be so readily calculated. No work has been attempted to determine the structural properties of the materials but it is recognized that several of the materials tested add greatly to the strength of the building. Some of the materials which may be used as a plaster base may be substituted for the sheathing as generally used and when so substituted a well-insulated wall is obtained at a reduced expense. If sheathing is required and but one thickness of insulation is to be used, the latter should be placed between the studding as this divides the air space. In all cases of house construction some insulation should be used the amount depending upon the composition of the wall. The average insulating material as now used is one-half inch thick and may be expected to give a value of K of approximately .4 when tested by the hot box method.

In the following tabulations the results of the several tests on insulating materials and wall sections are summarized. In cases where several samples of the same commercial stock were tested the values under the headings of thickness, weight, and value of K are the limits in values for all samples tested. The summary does not include the tests on combinations of two, three, and four layers of the same material.

TABLE II

SUMMARY OF TESTS ON INSULATING MATERIALS

Material	Appfoximate Description	Date of Test	Measured Thickness Inches	Wt. per 100 Sq. Ft., Lbs.	Value of K
A—(Figure 17)	Felted flax straw fibre............	April, 1922	37/64 to 39/64	53.6 to 57.3	.352 to .388
A—(Figure 17)	Felted flax straw fibre............	Nov., 1921	1 3/64 to 1 4/64	121.8 to 122.5	.25 to .24
B—(Figure 18)	Wood pulp board, plaster base....	Oct., 1921	35/64	66.6	.39 to .396
C—(Figure 19)	Sugar cane fibre board, firmly pressed, plaster base	Dec., 1921	30/64 to 32/64	49.4 to 70.8	.439 to .472
D—(Figure 20)	Sugar cane fibre board, insulation base	April, 1922	38/64 to 39/64	52.1 to 61.0	.353 to .378
E—(Figure 21)	Rye straw board	April, 1922	37/64	63.2	.386
F—(Figure 22)	Hair stitched between two layers of paper	Oct., 1921	7/16	39.6	.412
G—(Figure 23)	Paper pulp board keyed for plaster, with grooves ¼ in. deep....	Dec., 1921	37/64	83.9	.496
H—(Figure 24)	Beveled lath mounted on chemically treated cardboard	May, 1922	.....	94.6	.669
I —(Figure 25)	Plaster and paper in alternate layers, total thickness approximately 5/16 inch	May, 1922	22/64	190.	.796
J —(Figure 26)	Flax straw fibre stitched between layers of craft paper..........	May, 1923	1/2 to 11/16	27.2 to 30.4	.33 to .25
K—(Figure 27)	Sea grass loosely matted, stitched between layers of craft paper..	June, 1922	1/2	20.0	.349
T—(Figure 30)	Flax and cereal straw fibre board	May, 1923	33/64 to 40/64	60.0 to 74.0	.46 to .356
U—(Figure 30a)	Wood fibre between two layers of craft paper	July, 1923	1/2	21.8	.322
N—	Black building paper	May, 1922	.017	8.2	1.01
O—	Red resin building paper.........	May, 1922	.02	7.2	.84

TABLE III

SUMMARY OF TESTS OF PLASTER BASE INSULATING MATERIALS WITH PLASTER APPLIED

Material	Approximate Description	Value of K
P	Material G covered with 3/8 inch wood fibre	.491
Q	Material B covered on one side with 3/8 inch wood fibre plaster..	.380
R	Material M, Fig. 29, covered on one side with 3/8 inch wood fibre plaster	.311
S	Material C covered on one side with 3/8 inch wood fibre plaster..	.428

TABLE IV

SUMMARY OF TESTS ON WALL SECTIONS

Wall No.	Outside Surface	Inside Surface	Insulation between Studding	Value of K
1.	1/2 inch magnesite stucco on metal lath with 3/4 inch back plaster.	1/2 inch wood fibre plaster on metal lath.	None	.401
2.	Sheathing, building paper, and lap siding.	3/8 inch wood fibre plaster on wood lath.	None	.237
3.	3/8 inch magnesite stucco on an insulation base.	3/8 inch wood fibre plaster on wood lath.	None	.219
4.	Sheathing, building paper, and lap siding.	3/8 inch wood fibre plaster on wood lath.	One layer 1/2 inch thick.	.175
5.	Sheathing, building paper, and lap siding.	3/8 inch wood fibre plaster on wood lath.	Two layers 1/2 in. thick	.133
6.	Building paper, byrkette sheathing, 3/8 inch magnesite stucco.	3/8 inch wood fibre plaster on wood lath.	Two layers 1/2 in. insulation.	.144
7.	Keyboard 3/8 inch magnesite stucco.	3/8 inch wood fibre plaster on wood lath.	One layer 1/2 inch thick.	.158
8.	Building paper, byrkette sheathing, 3/8 inch magnesite stucco.	3/8 inch wood fibre plaster on wood lath.	None	.264