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HEAT TRANSMISSION THROUGH BUILDING MATERIALS

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PREFACE

The data presented in this bulletin are the result of research work in the field of heat transmission, conducted in the Engineering Experiment Station at the University of Minnesota. The major part was carried out in co-operation with the American Society of Heating and Ventilating Engineers. Parts of the results have been published in the *Journal* and in the *Transactions of the American Society of Heating and Ventilating Engineers*, as follows:

Heat Transmission Research, F. B. Rowley, F. A. Morris, and A. B. Algren. *Journal, A. S. H. and V. E.*, July, 1928, Vol. 34, No. 7; also, *Transactions, A. S. H. and V. E.*, Vol. 34, 1928, pp. 439 to 474, inclusive.

Over-all Heat Transmission Coefficients Obtained by Tests and by Calculation, F. B. Rowley, A. B. Algren, and J. L. Blackshaw. *Journal, A. S. H. and V. E.*, May, 1929, Vol. 35, No. 5; also, *Transactions, A. S. H. and V. E.*, Vol. 35, 1929, pp. 443 to 456.

Thermal Resistance of Air Spaces, F. B. Rowley and A. B. Algren. *Journal, A. S. H. and V. E.*, January, 1929, Vol. 35, No. 1, pp. 17 to 26; also, *Transactions, A. S. H. and V. E.*, Vol. 35, 1929, pp. 165 to 181.

Effects of Air Velocities on Surface Coefficients, F. B. Rowley, A. B. Algren, and J. L. Blackshaw. *Journal, A. S. H. and V. E.*, Vol. 1, No. 8, December, 1929, pp. 673 to 676.

Surface Conductances As Affected by Air Velocity, Temperature, and Character of Surface, F. B. Rowley, A. B. Algren, and J. L. Blackshaw. *Journal, A. S. H. and V. E.*, Vol. 2, No. 6, June, 1930, pp. 501 to 508.

Surface Coefficients As Affected by Direction of Wind, F. B. Rowley and William A. Eckley. *Journal, A. S. H. and V. E.*, October, 1931, Vol. 3, No. 10, pp. 870 to 874.

Thermal Properties of Building Materials, F. B. Rowley and A. B. Algren. *Journal, A. S. H. and V. E.*, May, 1932, pp. 363 to 369, inclusive.

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HEAT TRANSMISSION THROUGH BUILDING MATERIALS

INTRODUCTION

The study of heat transmission through insulating materials and building construction has been in progress at the Engineering Experiment Station, University of Minnesota, for several years. At first, the problem was that of developing an apparatus for determining overall heat transmission coefficients of built-up wall structures. For this purpose, a guarded hot box apparatus was devised, and a series of tests were run on certain insulating materials and built-up wall sections which were described in Bulletin No. 3 of the Engineering Experiment Station, "Transmission of Heat through Building Materials," 1923. These and subsequent tests led to new ideas as to the apparatus and a general broadening of the scope of the work.

At the start, the work was financed by the Engineering Experiment Station as an independent project. Later the Research Laboratory of the American Society of Heating and Ventilating Engineers became interested in the work, and, for the past five years, has financed it jointly with the University.

Since the publication of Bulletin No. 3, many revisions and changes have been made in the apparatus and in the method of conducting the tests. The hot box apparatus as described then has been revised and built in conjunction with a cold storage room, so that tests may now be made at temperature ranges from as high as 80° to 150°F. on the hot side of the wall and as low as -35°F. on the cold side. In addition to this, hot plates have been designed and built for determining the thermal conductivity of insulating materials. The results of the work have been published in part from time to time in papers which have appeared in the *Journal of the American Society of Heating and Ventilating Engineers*, in the *Journal of the American Society of Mechanical Engineers*, and in other technical papers. Some of these papers have been reprinted and distributed, altho no comprehensive report of the complete research project has been published. The object of this bulletin is to bring the more important parts together and correlate them to make a more complete report of the work than has been published before.

OBJECT OF THE WORK

It is difficult to find, in engineering, a process which has a more general application than that of the flow of heat through materials. In many cases, such as boilers, condensers, heat exchangers, and refrigerating machinery, the object is to get a rapid flow of heat through materials with as little resistance as possible. In other cases, such as cold storage work, refrigerator cars, and many types of building construction, the object is to reduce the flow of heat or, in other words, to build into the structure definite heat resistance. While the greater part of this work has been directed to a study of building construction, the same principles and results apply to cold storage and refrigerator work.

The laws governing the flow of heat through homogeneous materials or through a compound wall construction are reasonably well known. The correct application of these laws in practice has proven difficult, owing to the lack of specific knowledge covering the properties of the materials. For instance, when one comes to apply the well-known formula for heat flow through a built-up wall structure, the question arises as to the thermal conductivity of each material for the particular mean temperature at which it occurs in the wall, the outside surface resistances of the structure, and the resistance of any internal air spaces which may be built into the wall. In the past, there has been so much doubt as to these various factors that the method of arriving at accurate results by calculation has often been questioned. Without the proper coefficient to use in making these calculations, the final results, in many cases, have differed materially from tests, thus casting reflections on test methods and leaving the engineer in doubt as to how best to arrive at accurate results.

The objects of this work were :

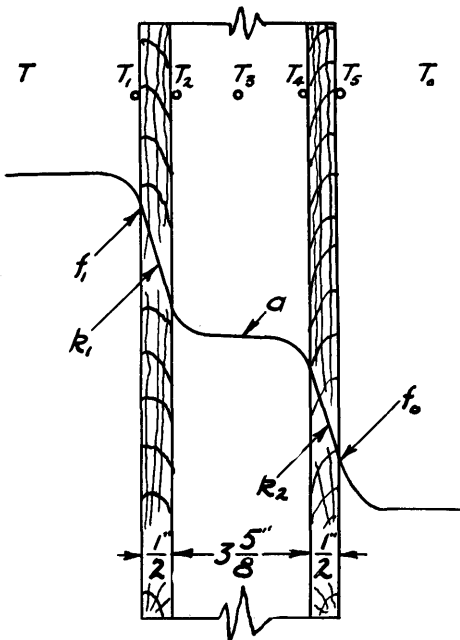
1. To develop and build reliable apparatus for determining both the thermal conductivity of insulating materials and the overall heat transmission coefficients of built-up wall constructions.
2. To determine the proper thermal coefficients for the surfaces of materials, for air space construction, and for the materials themselves for use in calculating overall heat transmission coefficients of built-up wall construction.
3. To compare the results obtained by tests and by calculations and to determine the accuracy of the overall heat transmission coefficients obtained by calculation.
4. Other objects were to determine the practicability of different

types of construction, and the effect of mean temperature, density, and moisture on the thermal conductivity of materials.

HEAT FLOW DISCUSSION

Resistance to the flow of heat is a property common to all materials. It varies with the different materials, ranging from such substances as copper, silver, and other metals on one end of the line, which are known as conductors, to those materials like wool, cork, some species of wood, on the other end of the line, which have several thousand times the resistance of some of the first group and are known as insulators. In order that heat may flow through any material, a drop in temperature is required along the path of flow. If a given amount of heat is flowing through a given path, the drop in temperature from point to point will represent the heat resistance between the points. For instance, if heat were flowing from air on one side of a homogeneous wall to air on the other side, there would necessarily be drops in temperature between the

WALL NO. 25



RESULTS OF TESTS					
	COND.	M	COND.	M	
	CONST.	T	CONST.	T	
	RUN1	DEG.	RUN2	DEG.	
U	.184	40.2	.185	40.5	
R_1	.356	60.0	.358	61.0	
R_2	.339	23.3	.341	23.2	
f_1	1.80		1.82		
f_2	1.25		1.28		
a	.979		1.01		
TEMPERATURES °F					
T	80.5		80.5		
T_1	72.3		72.3		
T_2	49.7		49.6		
T_3	42.0		41.9		
T_4	34.8		34.8		
T_5	11.8		11.7		
T_6	0		+0.05		

FIGURE 1. TEMPERATURE GRADIENT THROUGH WALL SECTION CONSTRUCTED WITH TWO 1/2-INCH INSULATING BOARDS AND ONE 3 5/8-INCH AIR SPACE

warm air and the surface of the wall, between the two surfaces of the wall, and between the surfaces of the wall and the air into which the heat was passing. If the wall were composed of more than one material with air spaces between, the total temperature drop between the air on both sides of the wall would be distributed between the various materials and air spaces and the outside surfaces proportional to their respective heat resistances.

Figure 1 represents a sectional view of a wall which was built up with 2 × 4 studs, covered on each side with a ½-inch insulating board. The heavy line passing from left to right downward through the wall represents the temperature drop, as taken by an actual test, between the air on the left side of the wall, through the material and air space,

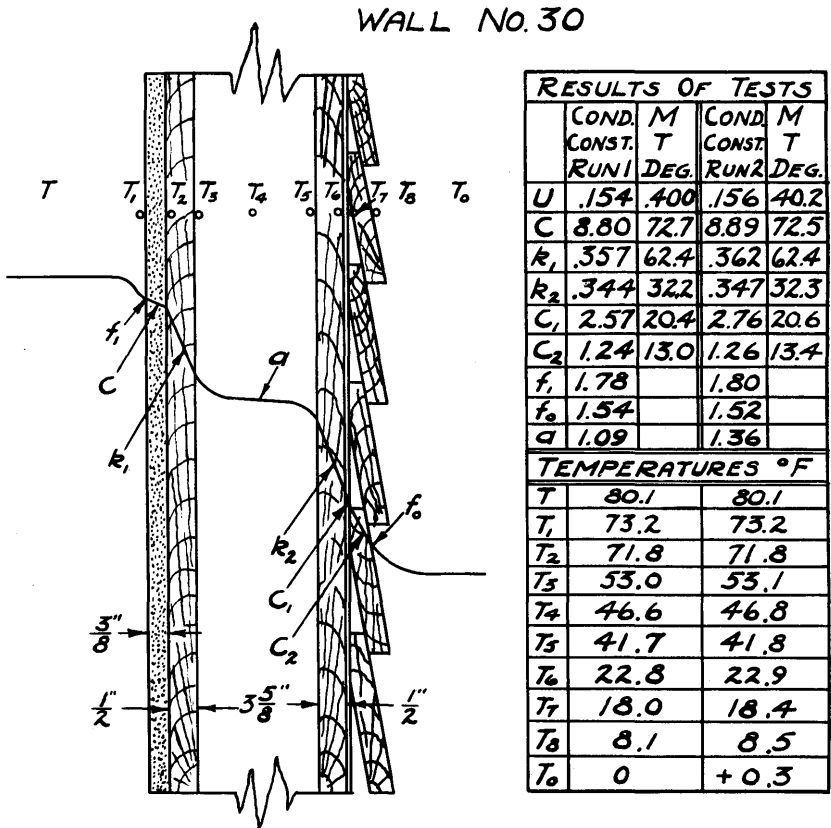


FIGURE 2. TEMPERATURE GRADIENT THROUGH WALL SECTION WITH INSULATING MATERIALS BUILT INTO EACH SURFACE

to the air on the right side. The temperatures were taken of the air on each side of the wall and at the points indicated by T_1 , T_2 , T_3 , etc., and the line was drawn to a vertical scale indicating the temperature drops.

An inspection of this figure shows that the temperature gradient line may be divided into several distinct parts, representing heat resistances which may be found in the average wall:

1. The drop between the temperature of the air near the wall and the surfaces of the wall. This drop is required to overcome the surface resistance of the wall and is common to both the inside and outside surfaces.

2. The drops in temperature from T_1 to T_2 and from T_4 to T_5 . Since the materials constituting the surfaces of the wall are homogeneous, these temperature gradients are straight lines and the drop in temperatures through each material is proportional to the heat resistance of each.

3. The temperature drop across the air space from T_2 to T_4 . This represents the total resistance of the air space or a combination of resistance to radiant and convected heat.

Figure 2 shows the temperature gradient through a frame wall, the inside finish being $\frac{3}{8}$ -inch plaster applied to a $\frac{1}{2}$ -inch insulating board, and the outside finish being $\frac{1}{2}$ -inch insulating board, building paper, and 4-inch pine siding. The temperature gradient line for this wall shows very clearly the difference in heat resistance for the various parts of the wall. In general, the heat resistance of a compound wall may be divided into three parts:

1. The outside surface resistances.

2. The internal resistances of the specific materials of which the wall is constructed.

3. The resistances of the air spaces built into the wall.

If the overall heat transmission coefficient of the wall is to be determined by test, specific knowledge of these various factors is not necessary. If, however, the heat flow through the wall is to be determined by calculation, the laws governing the flow through the component parts of the wall must be known. The problem thus divides itself into three elements, as indicated.

NOMENCLATURE AND DEFINITIONS

Due to the fact that changes have been made to meet the recent recommendations of the Committee on Heat Transmission of the National Research Council, the symbols used in this bulletin will be some-

what different from those published in previous papers. The following are the symbols and definitions used:

U = the overall coefficient of heat transmission for a complete wall. It represents the number of British thermal units transmitted through one square foot of the wall per hour per degree difference in temperature, Fahrenheit, between the air on the inside and the air on the outside of the wall.

k = the thermal conductivity of a homogeneous material. It is the amount of heat, expressed in B.t.u., transmitted through one square foot of homogeneous material one inch thick per hour per degree temperature difference between the two surfaces of the material.

C = the thermal conductance of a material and is the amount of heat expressed in B.t.u., transmitted through one square foot of material per hour per degree difference in temperature between the two surfaces. (It will be noted that C is different from k in that it represents the flow of heat through the material as built and not per one inch thick.)

f = film or surface conductance and is the amount of heat expressed in B.t.u. transmitted between the air and the surface of the material per square foot of area per degree difference in temperature between the air and the surface. To differentiate between the two surfaces, f_i is used for the inside surface and f_o for the outside surface conductance.

a = the thermal conductance of an air space. It is the amount of heat expressed in B.t.u. transmitted through an air space per hour per square foot of area per degree Fahrenheit difference in temperature.

The resistance to the heat flow through any path equals the reciprocal of its conductivity over the same path.

Thus $\frac{1}{U}$ = overall resistance from air to air.

$\frac{1}{k}$ = the internal resistance per inch of material.

$\frac{1}{C}$ = the internal resistance of the material in thickness as constructed.

$\frac{1}{f}$ = the surface or film resistance.

$\frac{1}{a}$ = air space resistance.

HEAT TRANSMISSION FORMULAE

An extended discussion of the formulae which are commonly used in heat transmission calculations is not necessary. However, since this bulletin deals with the various coefficients, the relation between them will be briefly considered. The fundamental formula by which the

overall heat transmission coefficient U is generally calculated is as follows:

$$(1) \quad U = \frac{1}{\frac{1}{f_1} + \frac{x_1}{k_1} + \frac{1}{a} + \frac{x_2}{k_2} + \frac{1}{f_0}} \quad \text{This represents a wall with air space as shown in Figure 1.}$$

In the above formula, x_1 and x_2 are the thicknesses and k_1 and k_2 are the conductivities of the two materials making up the wall structure.

While the foregoing formula represents the relation between the overall heat transmission coefficient of the wall and the coefficients of the component parts, it is less confusing to consider the relation between the resistances. Thus the overall thermal resistance is equal to the sum of the resistances of the component parts, and this holds true regardless of the structure. Thus Equation 1 might be rewritten as follows:

$$(2) \quad \frac{1}{U} = \frac{1}{f_1} + \frac{x_1}{k_1} + \frac{1}{a} + \frac{x_2}{k_2} + \frac{1}{f_0} \quad \text{in which}$$

$\frac{1}{U}$ = the thermal resistance of the complete structure.
 $\frac{1}{f}$ = the inside surface resistance
 $\frac{x_1}{k_1}$ = the resistance of the inside lining, etc.

TYPES OF TEST APPARATUS

Two general types of apparatus are used for determining the thermal conductivity of materials: The first is most commonly used for determining the thermal conductivity from surface to surface of the material and is often referred to as the hot plate apparatus. This is more specifically adapted to homogeneous materials, the surfaces of which are smooth enough to give reasonably good contact between the test plates and the material. The second type is that employed for determining the overall heat transmission coefficient from air on one side to air on the other side of the material and is particularly adapted to testing built-up wall sections or structures whose surfaces are too rough for good contact with the plate as used in the hot plate method of tests. Several individual designs of the second type have been used. A common method has been that of building a box either completely of the material to be tested or with one side constructed of the material

and the remainder of the box accurately calibrated. Another method has been to use a thermal conductivity meter placed in contact with one side of the wall to be tested. The Nicholls heat meter is undoubtedly the best known apparatus of this type. The apparatus devised and used in these tests consists of a double or guarded box arrangement which will be described later.

The fundamental difference between the two types of apparatus is that, in the hot plate method, the conductance is determined from surface to surface of the material under test, thus eliminating the surface resistances, while in the hot box method, the conductance is determined from air to air, which includes the surface resistances. The conductance from surface to surface may be obtained by the hot box method, provided that thermocouples are properly placed on the surfaces of the material under test, or the overall heat transmission coefficient may be calculated from the results obtained from the hot plate test, if the surface coefficients are known. The main objection to using the hot plate method for large wall sections is the difficulty experienced in getting contact between the plate and the surface of the wall. At present, the hot plate method is generally accepted for determining the thermal conductivity coefficients of homogeneous materials. A single method, however, of determining overall coefficients has not been so generally accepted. In any type of apparatus, the principal object is to get accurate results. This can only be done by giving special attention to temperature measurements and to the path of heat flow through the material. Special precautions must be taken to prevent heat losses from the test section and to insure that the lines of heat flow are perpendicular to the test surfaces.

HOT PLATE APPARATUS

The general design of the hot plate apparatus used in this series of tests is shown in Figures 3 to 6, inclusive. This design conforms to the generally accepted standard for this type of apparatus and differs from those previously used at Minnesota in that special precautions were taken to eliminate all paths for heat flow between heating plate and guard ring, and, also, to reduce condensation on the outside of the cooling plate.

Figure 3 shows two views, part in section, of the complete apparatus. Referring to the right-hand view, the general construction of the plate is as follows: The central or heating portion is 12 inches square, $\frac{7}{8}$ inch thick, and lined on each side with a copper plate $\frac{1}{4}$ inch thick. The copper plates are divided into two parts—an inner section 9 inches square and a band or guard ring $1\frac{1}{2}$ inches wide surrounding

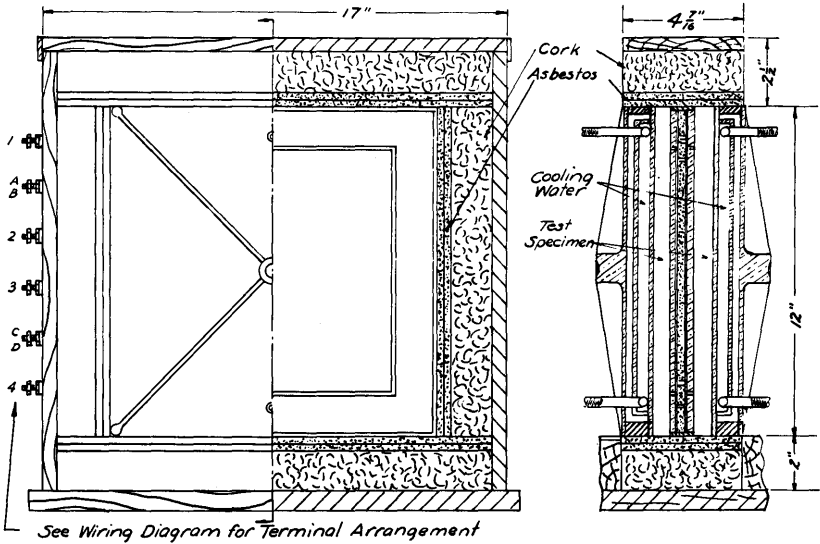


FIGURE 3. SECTIONAL VIEW OF HOT PLATE, SHOWING INSULATED GUARD

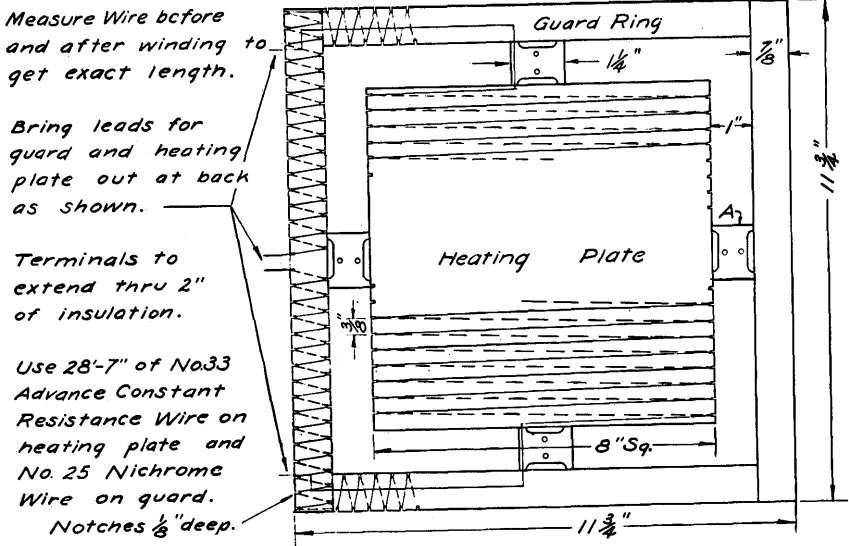


FIGURE 4. HEATING ELEMENT FOR HOT PLATE

this section. These two sections are completely separated by a $\frac{1}{8}$ -inch air gap which completely eliminates any metallic connection between the inner and outer portions of the heating plate. The inner or 9-inch section is the test section proper and the outer portion is the guard ring provided to eliminate heat losses through the edges of the material.

Heat is supplied to the plate by electric heating elements wound on $\frac{1}{4}$ -inch transite board and placed between the two $\frac{1}{4}$ -inch copper plates. The arrangements for these windings are shown in Figure 4. The heating element supplying the inner test section is completely separated from that supplying the guard ring section by a 1-inch air gap. The inner or test section of the plate is kept in line with the outer or guard section by the four insulating blocks designated by *A*. These constitute

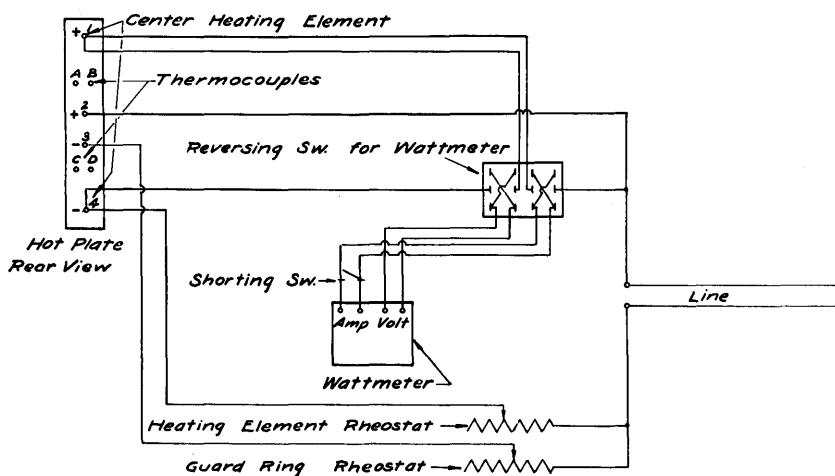


FIGURE 5. WIRING DIAGRAM FOR HOT PLATE

the only positive connection between the inner and outer portions of the heating plate. The only other paths for heat flow between these two sections are along the wires which are necessary to connect the heating elements and thermocouples to the apparatus outside of the plate.

The test specimens are placed one on each side of the heating plate and each covered by a cooling plate which is clamped sufficiently tight to hold the specimen in close contact with the surface of the heating and cooling plates. The assembled apparatus is surrounded by an insulating guard which serves as an additional precaution against heat losses from the edges of the test specimen.

The plates are provided with copper constantan thermocouples for

measuring the surface temperatures of the copper plates which are taken as the surface temperatures of the materials under test. Two of these couples are provided in each face of the test section and two in each face of the cooling plates. A differential couple is provided across the air gap between the inner and outer portions of the hot plate in order to determine when a balanced temperature has been reached.

The heating plate is supported in a frame, the top and front portions of which are removable. All of the thermocouple and electric wires are brought out through the stationary portion of the frame (Figs. 3 and 6).

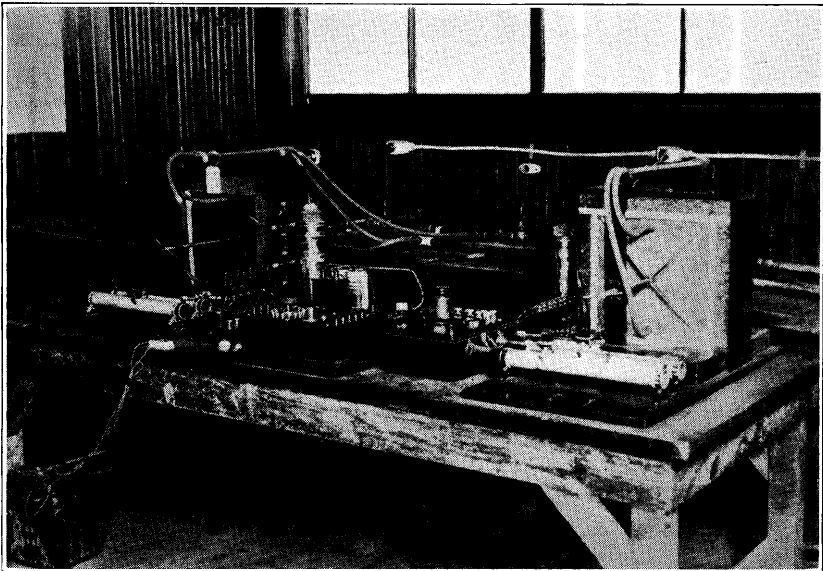
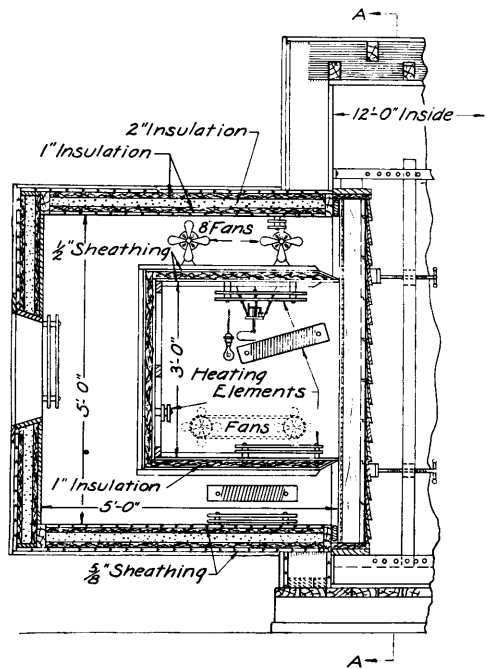


FIGURE 6. PLATES AS SET UP FOR USE

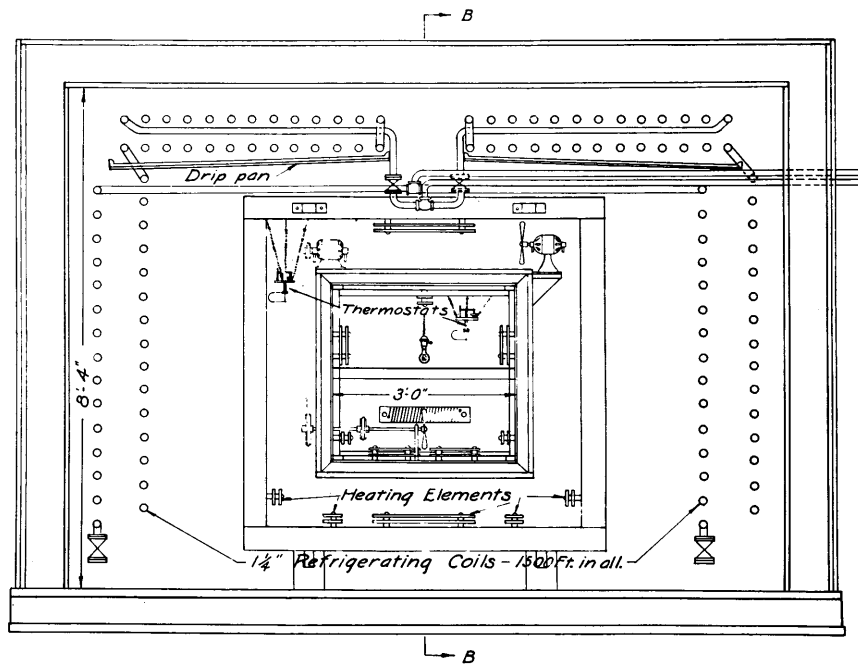
The cooling plates are provided with water-circulating channels and are protected on the outside by an air gap to prevent condensation on the outer surfaces which are in contact with the air.

HOT BOX APPARATUS

The apparatus used for determining the overall heat transmission coefficients of built-up wall sections was designed at the beginning of the test program and consists of a double box construction built into one of the side walls of the cold storage room. This construction, together with heating elements, thermocouples, and instruments, is shown



SECTION BB
 Showing Construction and Position of
 Test Box and Test Wall.
 FIGURE 7. SECTIONAL VIEW OF DOUBLE
 BOX AND WALL SECTION IN PLACE



SECTION AA
 Showing Wall Section Removed
 FIGURE 8. SECTIONAL VIEW OF COLD ROOM, LOOKING INTO OPEN
 END OF TEST BOX

by Figures 7 to 13, inclusive. Figure 7 shows a vertical cross-sectional view of the double walled test box placed in the wall of the cold storage room with a test wall in place. Figure 8 shows a vertical cross-section of the cold storage room, looking into the open end of the test boxes with the wall section removed. As shown by these two figures, both the inner and outer test boxes have one side omitted, and the boxes are so arranged that these two open faces will be in the same plane, parallel, and slightly inside of the inner surface of one of the walls of the cold room. The wall under test is placed over the open side of the two boxes and thus completely cuts off the passage of air between the inner and outer test boxes. The air temperatures of both boxes are maintained equal and at a higher level than those of the cold room. Since the air temperatures on both sides of the walls of the inner box are equal, heat supplied to this box can only pass out through the test wall into the cold room. Heat must flow in lines perpendicular to the test surface, as the area of the wall outside of the inner box is in contact with air equal in temperature to that of the inner box. Thus if the amount of heat supplied to the inner box is definitely measured and the temperatures of the air on the two sides of the test wall are measured, complete data are available for calculating the overall heat transmission coefficient for the test section. The apparatus is so designed that all air temperatures are automatically controlled and those in the test boxes may be maintained at any range up to 150°F. , while those in the cold room may run as low as -35°F. All heat to the inner and outer test boxes is supplied by electric heating elements and that to the inner box is accurately metered. Since the only purpose of the outer box is to balance the inner box temperatures and prevent heat losses other than through the test section, it is not necessary to meter the current supplying the heat for this air. The distribution of the heating elements is shown in Figures 7, 8, and 13. There are eight each for the inner and the outer boxes and the greater number of them are placed near the bottom of the boxes to give better temperature distribution. Each element is wound with resistance wire so that four different heating rates may be obtained by externally operated switches.

In addition to distributing the greater part of the heating elements in the bottom portion of the test boxes, a uniform temperature of the air from top to bottom of the test section required a slight amount of agitation. For this purpose, two 8-inch fans were installed in each box, as shown. Those for the inner box were mounted on ball bearings and driven by an external motor at 240 revolutions per minute, which was

found sufficient to maintain uniform temperature over the test surface and yet have practically a still air condition. Calibrations were made to determine the heat generated by the friction of the bearings and belt of that part of the fan installation which was inside of the inner box. This amount of heat was added to that indicated by the electric meters for each test. The fans for the outer box were driven by direct connected motors placed in the outer box space. The air temperatures to both the inner and outer boxes were controlled by thermostats (Figs. 8 and 13).

The air temperature on the cold side of the test specimen was maintained by a $7\frac{1}{2}$ -ton ammonia compression refrigerating machine and 1,500 feet of $1\frac{1}{4}$ -inch direct expansion pipe placed in the ceiling and side wall of the cold room. To get more accurate temperature control than was possible by the expansion valve alone, a small, thermostatically controlled heat unit was installed. The refrigerating machine was set to give air temperatures slightly lower than required for the test, and the heating unit was relied upon for accurate control of the air temperature.

The wall under test is held in place by four locking screws which are carried by vertical bars placed at the outside edges of the test specimen. A rubber tube is used as a gasket to form a complete seal between the test wall and the inner box, and the space between the outer box and the wall section is carefully calked to make it air-tight after a wall is in position for test. The locking screws are outside of the test section proper, and therefore do not interfere with air circulation over the test surface. Figure 11 shows a view in the cold room of a wall clamped in place and ready for test.

A diagrammatic drawing of the electric wiring for the heating elements is shown in Figure 9. The heating current is brought to the control switch and fuse block, from which point it is taken through relays to the inner and outer box heating element. These relays are placed on a switchboard outside of the test apparatus and are controlled by thermostats placed in the inner and outer boxes. Only that portion of the current used to heat the inner box is passed through the electric meter.

All temperatures are measured by 28-gage copper constantan thermocouples. A recording instrument is used during the preliminary period, while the apparatus and test specimens are brought up to constant temperature conditions, and a Leeds-Northrup Type K potentiometer is used for the test data. A diagram of the principal thermocouples in the

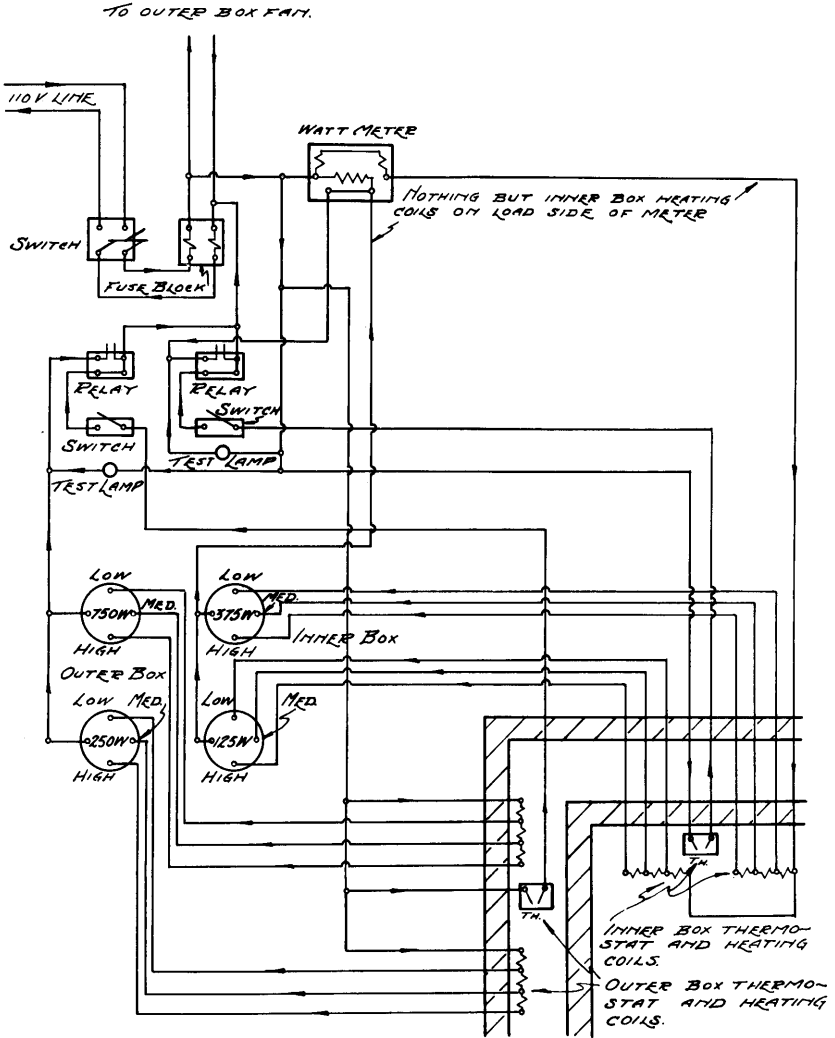
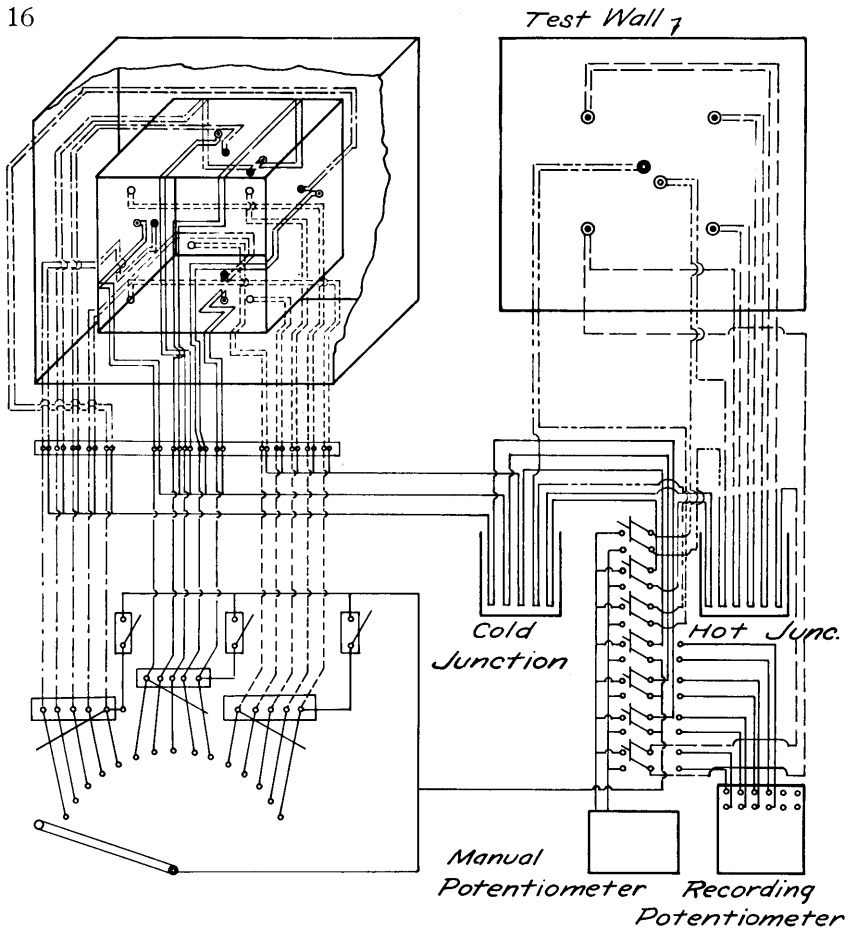


FIGURE 9. DIAGRAM OF ELECTRICAL WIRING FOR HEATING ELEMENT



KEY

- ====● Cold room thermocouple—located at center on test surface.
- ====● Cold room series thermocouple—located 6" from test surface.
- Outer box thermocouples—located 2" from outside wall of inner box.
- Inner box thermocouples—located 2" from inside wall of inner box.
- Inner box thermocouples—located 6" from test surface.
- ====● Inner box thermocouple—located at center on test surface.

FIGURE 10. DIAGRAM SHOWING ARRANGEMENT OF THERMOCOUPLES IN HOT BOX

hot box proper is shown by Figure 10. These couples are arranged as follows:

1. A group of five thermocouples used to measure the air temperature of the inner box. These couples are arranged with one for each of the five sides of the inner box, and are centrally located 2 inches from the inner surface.

2. A group of five thermocouples used to measure the air temperature between the inner and outer box. This group is arranged with one

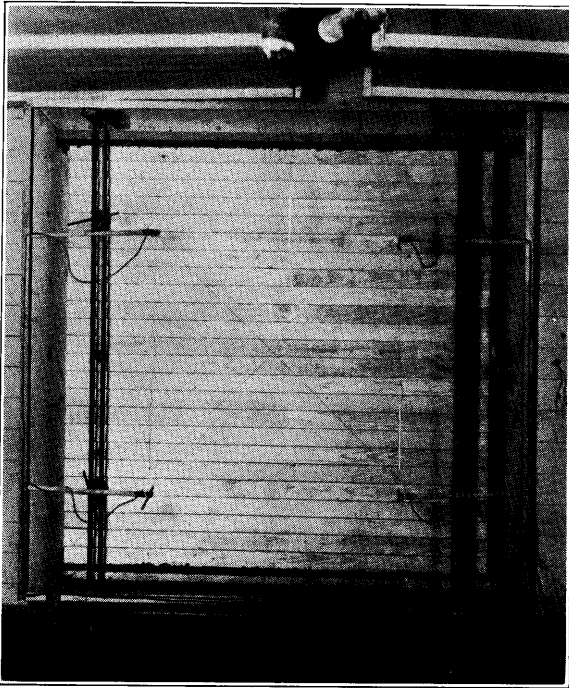


FIGURE 11. WALL SECTION IN PLACE FOR TEST

- couple for each of the five outer surfaces of the inner box, each couple is placed centrally with the side 2 inches from the outer surface.

3. A group of five thermocouples used to measure the air temperature for the inner side of the test section. These couples are uniformly distributed over the test area and are placed 6 inches inside of the test surface.

4. A group of four thermocouples used to determine the air temperatures over the outer surface of the test section. These are placed

in the cold room, distributed uniformly over the central or test section of the wall, and are 6 inches from the outer surface.

All of the above groups of couples are so arranged that temperatures may be taken for each couple individually, or the average of any group may be taken by one reading. In addition to the couples shown, there were individual couples to measure surface temperatures and the temperatures throughout various sections of the wall, depending upon the requirements of the test.

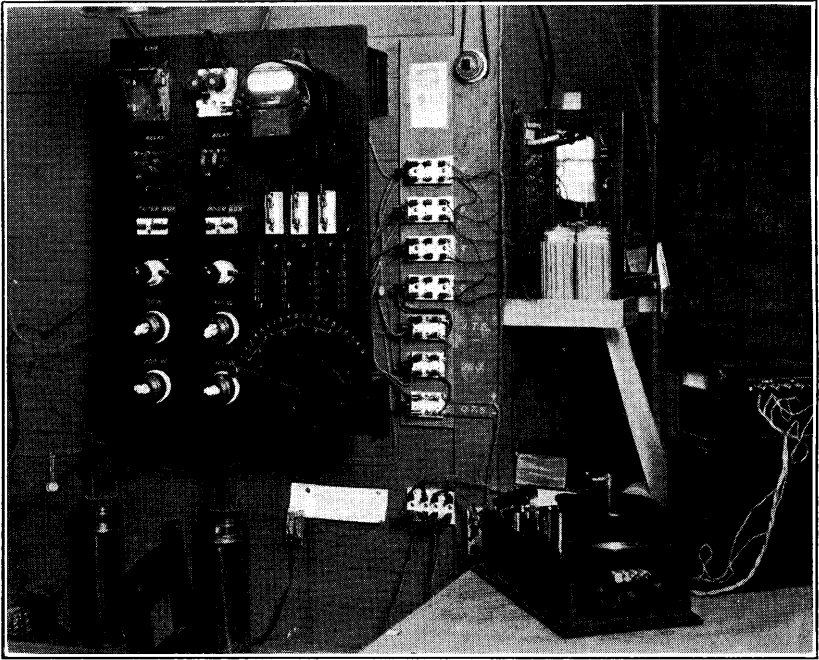


FIGURE 12. INSTRUMENT BOARD FOR HOT BOX TEST APPARATUS

All thermocouple wires and electric connections are carried out of the box to an instrument board (Fig. 12). The relays and electric controls as well as the selective switches for the majority of the thermocouples are mounted on this board. The recording potentiometer is shown at the right of the switchboard, with the Type K potentiometer and galvanometer on the table beneath.

Special test apparatus was constructed for the purpose of determining surface coefficients as described later.

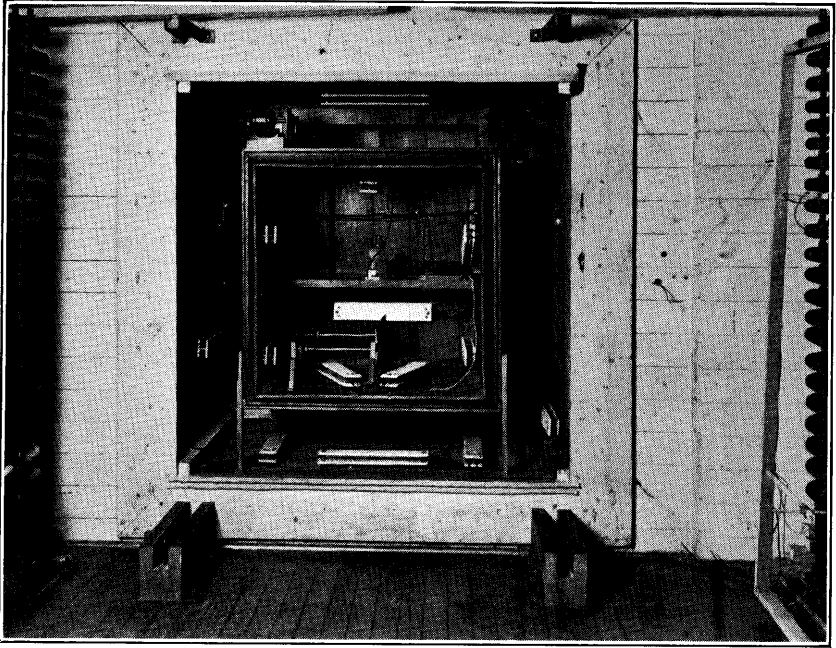


FIGURE 13. OPEN END VIEW OF HOT BOX FROM COLD ROOM

SURFACE CONDUCTANCE

The transfer of heat between air and the surface of a material is affected by several factors. Those which appear to be the most important are:

1. Air velocity.
2. Direction of air movement with reference to the surface of the material.
3. Mean temperature between the air and the surface of the material.
4. The character of the surface.

To determine the effects of these factors on the transfer of heat between air and surfaces, two series of experiments were conducted. In the first, the apparatus was arranged to give air velocities parallel to the test surface, ranging from 0 to 35 miles per hour, and with a mean temperature variation between the test surface and the air from 10° to 100° F. In this series, seven different surfaces were tested, ranging from plate glass to a rough stucco surface. In the second series of tests, the apparatus was arranged so that the angle between the wind velocity and the test surface could be varied from 0 to 90

degrees. In this series, only two surfaces were tested at a mean temperature of approximately 80°F .

In those tests made to determine the coefficients with air passing parallel to the surface, it was necessary to construct apparatus to provide the following conditions:

1. Air moving over a test surface parallel to the surface at various constant velocities.
2. Accurately controlled air temperatures.
3. Test surfaces which could be supplied with a measured amount of heat.

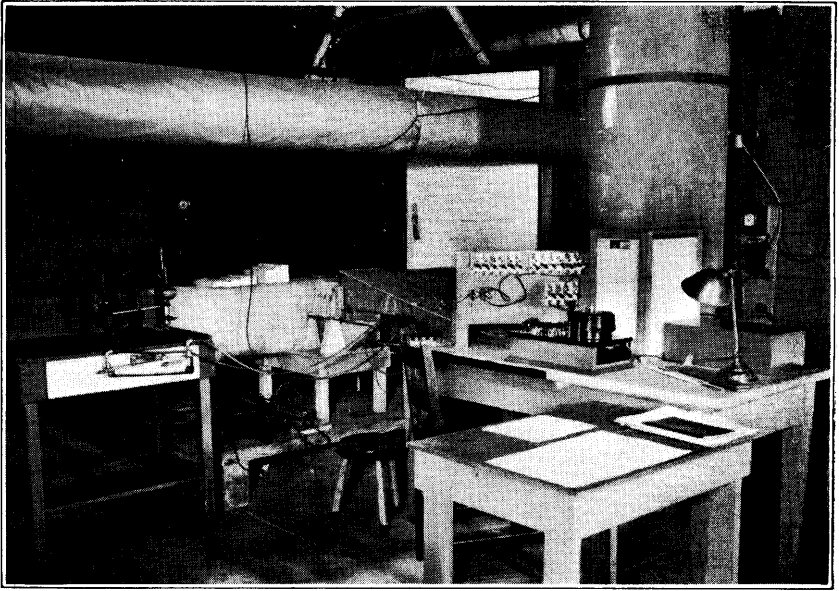


FIGURE 14. GENERAL VIEW OF SURFACE CONDUCTANCE TEST APPARATUS

4. Instruments for measuring the air velocity, the temperature of the air over the test surface, and the amount of heat flowing through the test surface.

In order to obtain these conditions, the apparatus was set up as shown in the photograph of Figure 14 and the line drawings in Figures 15 and 16. Air of the required temperature taken from the cold room by a 12-inch multi-blade fan driven by a $\frac{1}{2}$ h.p. variable speed D. C. motor, was supplied from the cold room used in connection with the hot box apparatus. The air from the fan was delivered to a straight

6 × 12-inch rectangular duct 17 feet to the test surface. After passing the test surface, the air was brought by a return bend back to the cold room. The arrangement of the test surface, together with the method of measuring the air flow and air temperatures, can best be described by referring to Figure 16, which is an enlarged section from Figure 15. As shown in this drawing, the test material was placed with the test surface flush with the inside surface of the air duct. The test material was 12 inches square and varied in thickness from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch, depending upon the type of the surface. Heat for the test surface was applied by a hot plate, the quantity being measured by passing it through

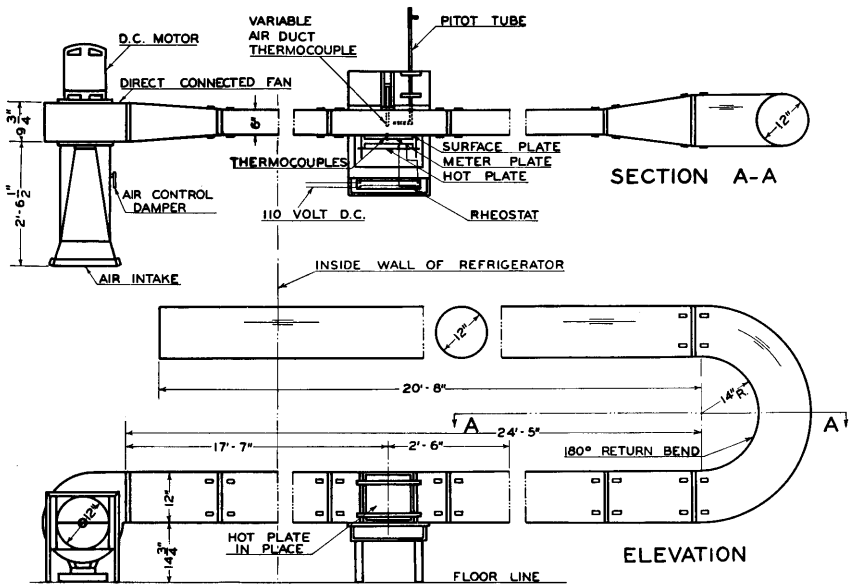


FIGURE 15. PLAN AND ELEVATION OF TEST APPARATUS FOR DETERMINING SURFACE CONDUCTANCES

a heat meter. The hot plate was electrically heated with 110-volt direct current, controlled by a rheostat.

The meter plate constructed of $\frac{1}{8}$ -inch bakelite was substantially the same as the Nicholl heat flow meter. Two parallel series of 28 pairs of 28-gage copper constantan thermocouples differentially wound on the plate were used. Of these, one series of 56 couples served to check the other series. Surface temperatures of the meter plate were also taken with three 28-gage copper constantan thermocouples on each side. The meter plate was calibrated by a standard hot plate apparatus, and read-

ings for the transmission through the plate were taken directly from the calibration curve.

The air velocities at various distances from the test surface were measured by means of a pitot tube and draft gage. For the lower velocities, the Wahlen gage was used, but for higher velocities, the inclined draft gage was found satisfactory.

The temperatures of the air passing over the test surface were measured with a 24-gage copper constantan thermocouple so arranged

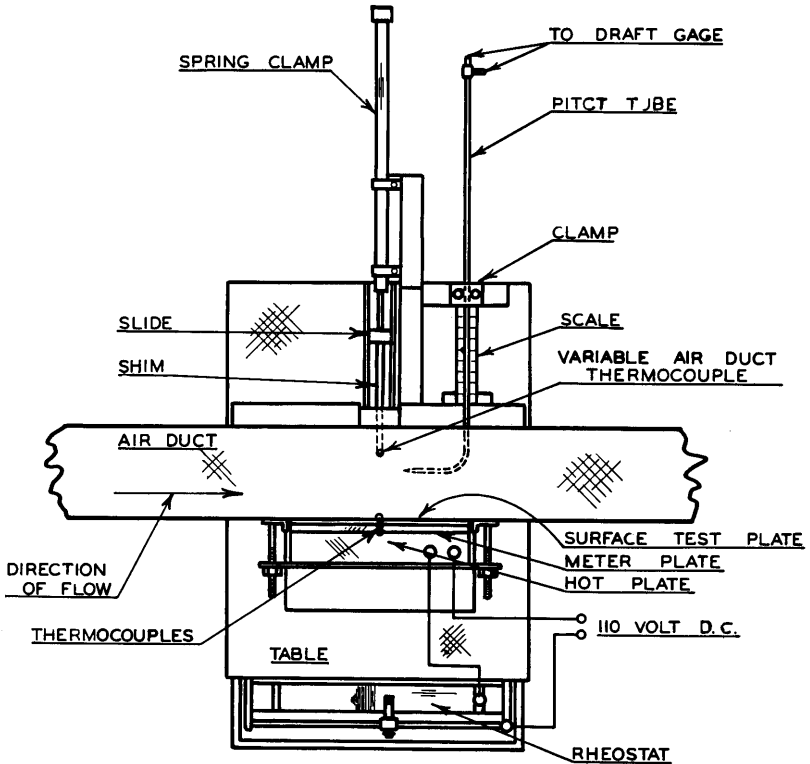


FIGURE 16. PLAN VIEW SHOWING ARRANGEMENT OF METER PLATE, TEST SPECIMEN, THERMOCOUPLE, AND PITOT TUBE IN RELATION TO AIR DUCT

that it could be moved in and out from the test surface or held at any predetermined distance. Tests made both with and without a shield between the thermocouple and the test surface showed that, at the low temperatures used, radiation had no effect on the temperatures indicated by the couple; therefore, most of the tests were made without this shield.

All thermocouple readings were read with a potentiometer, the cold junction in all cases being an ice bath.

In order to obtain average radiation conditions, the inside surface of the test duct was painted a dull gray, and all of the air pipes outside of the refrigerator room were covered with one inch of blanket insulating material. With this arrangement, the surfaces immediately around the test surface were at substantially the same temperature as the surrounding air, is a practical condition for the average wall.

Two different methods were tried for determining surface temperature:

1. The couple was imbedded in the material to bring the junction flush with the test surface.

2. The couple was rigidly attached to the surface and covered with a thin vellum paper.

When the thermocouple was imbedded in the material, the difference between the air temperature and that of the indicated surface was greater than when it was placed on the surface, and, therefore, the calculated surface coefficients were somewhat lower. This difference, however, was very small and in all of the test results reported, the thermocouple was fastened to the surface and covered with vellum paper. The surface couples were made of 28-gage copper constantan wire flattened out at the junction, thus giving a very thin couple at the point of contact.

In the assembly of the test apparatus, the test surface, together with the heat meter and the hot plate, was placed in the side of the air duct and clamped in place with specially designed clamping screws. The conditions, such as air velocity, air temperature, and surface temperature, were then selected and the apparatus was operated under these conditions for a sufficient length of time to insure uniform results. The air velocity for the test was measured at the center of the duct, because this would be the maximum air velocity over the test surface. The air temperature was measured by placing the thermocouple 1 inch from the test surface. Preliminary tests had shown that when the thermocouple was placed in contact with the test surface and gradually moved away from it, the temperature steadily dropped until the couple was about $\frac{1}{2}$ inch from the surface, after which this temperature remained uniform and equal to that of the air regardless of distance. One inch was therefore taken as a reasonable distance and was maintained throughout all tests. Data for tests were not recorded until preliminary observa-

tions taken at 15-minute intervals showed that the heat flow, room, surface, air temperatures, and air velocities were constant.

As all temperatures were taken at, or near, the center of the meter plate and test surface, and, as the meter plate and test surface were very thin, no allowance was made for end loss of heat from these plates. As an additional precaution, however, the edges of these plates were insulated with heavy layers of felt. Mean temperatures for a test were taken as the average between the air temperature and the surface temperature of the test specimen. Values of the surface conductance for a test were obtained by dividing the total heat leaving the test surface per square foot per hour by the temperature difference between the test surface and the air 1 inch away from the surface.

The value of the surface conductance for any particular surface varies with the mean temperature and the air velocity. Keeping one of these two variables constant, a series of tests was made to determine the effect of the other, and the results were plotted in the form of a curve. Several different air velocities were selected and runs were made at different mean temperatures for each air velocity.

The surfaces considered the most typical of building construction and used in the tests were glass, brick, white paint on pine, smooth plaster, clear white pine, rough plaster, concrete, and stucco. Very complete tests were made on the first three of these surfaces, four or more points being taken for each respective air velocity at different mean temperatures ranging from 0° to 100°F. It was found that these points lay practically in a straight line and when they were plotted on a large scale graph and the lines were extended, they crossed the line of zero surface conductance at absolute zero mean temperature, or, in other words, with total absence of heat, the surface conductance was zero. This was found true for all surfaces tested.

The results of the tests on the various surfaces are shown graphically in the curves of Figures 17 to 33, inclusive, and in Table I. Referring specifically to the curves of Figures 17 and 18, these results were obtained for a plate glass surface and are typical of all of the surfaces tested. In Figure 17, the points are plotted as determined from test data. The constant mean temperature lines of Figure 18 were taken directly from the group of curves on Figure 17. Other ranges of mean temperatures might have been plotted in the same manner.

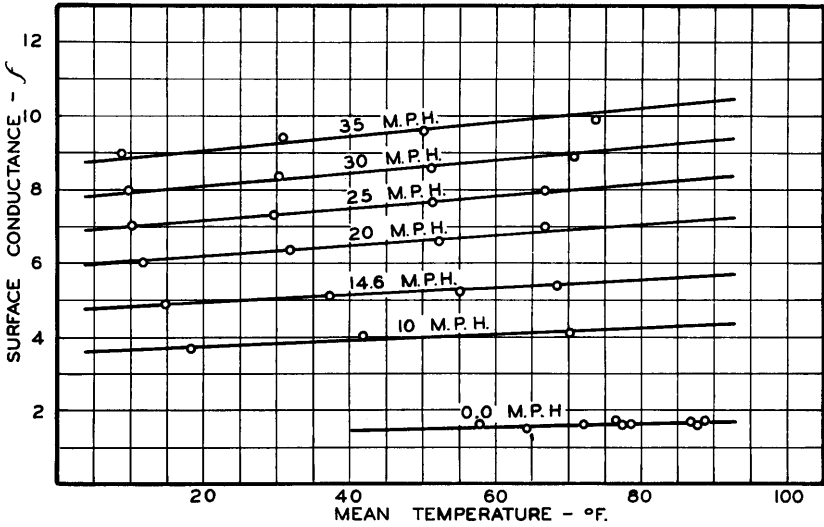


FIGURE 17. CONSTANT VELOCITY CURVES FOR GLASS SURFACE

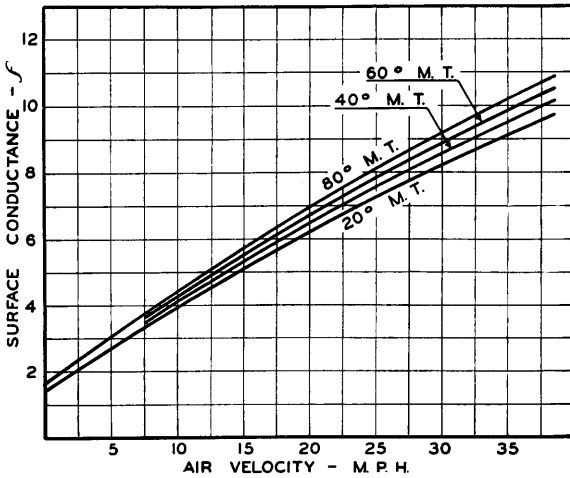


FIGURE 18. CONSTANT MEAN TEMPERATURE CURVES FOR GLASS SURFACE

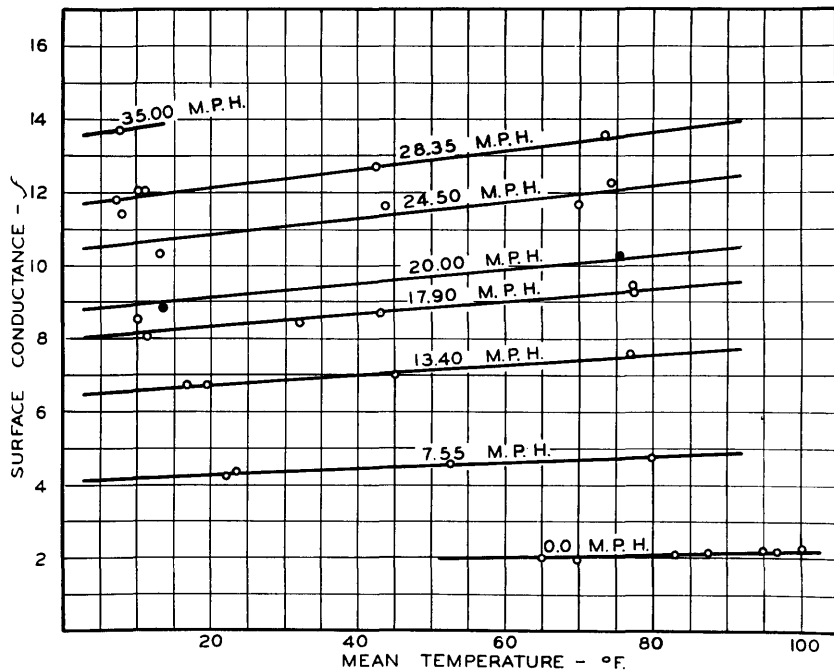


FIGURE 19. CONSTANT VELOCITY CURVES FOR BRICK SURFACE

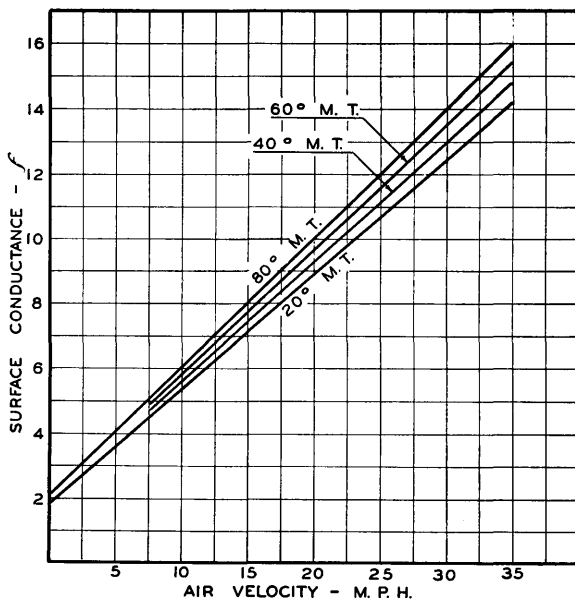


FIGURE 20. CONSTANT MEAN TEMPERATURE CURVES FOR BRICK SURFACE

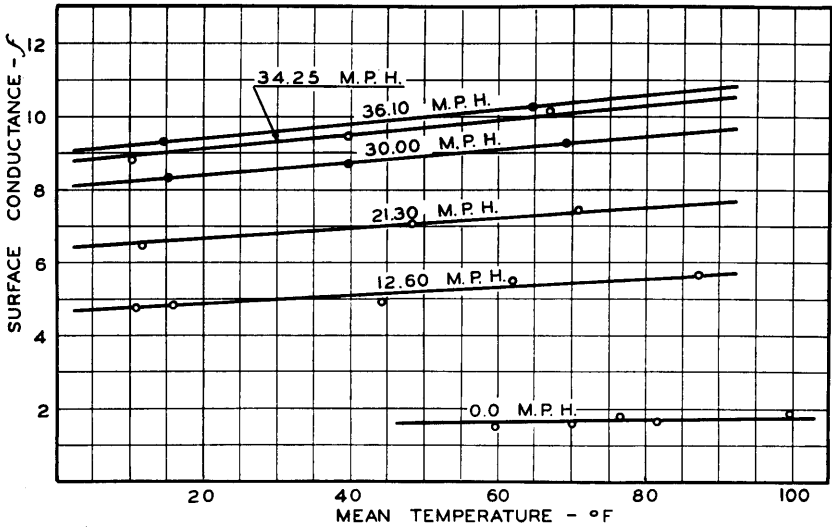


FIGURE 21. CONSTANT VELOCITY CURVES FOR WHITE PAINT SURFACE ON PINE

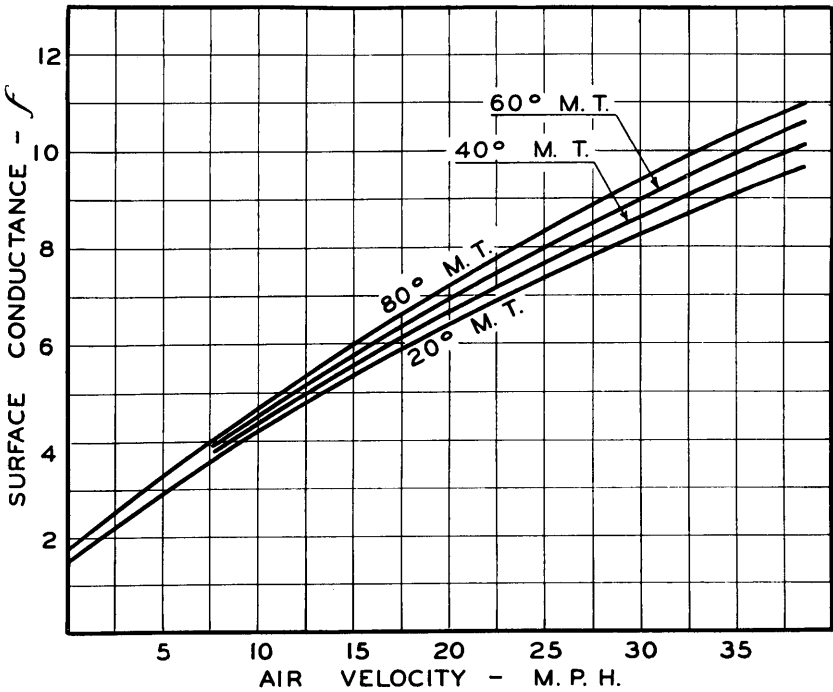


FIGURE 22. CONSTANT MEAN TEMPERATURE CURVES FOR WHITE PAINT SURFACE ON PINE

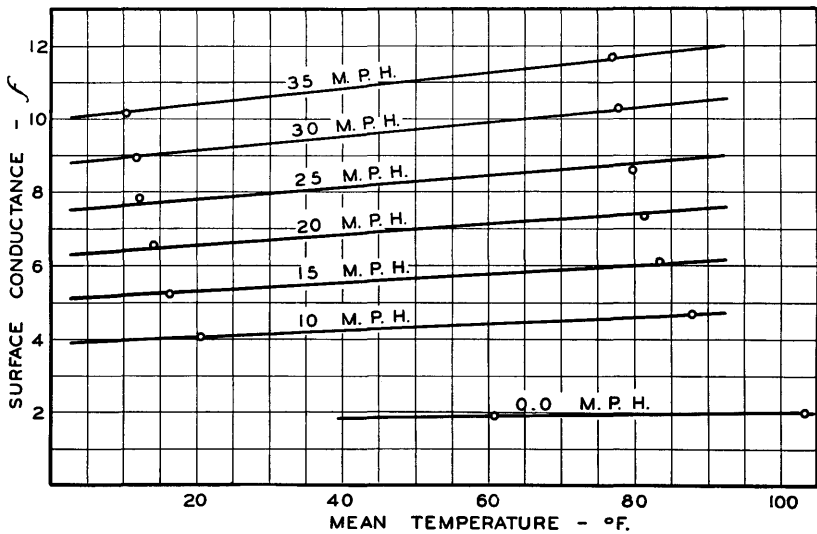


FIGURE 23. CONSTANT VELOCITY CURVES FOR SMOOTH PLASTER SURFACE

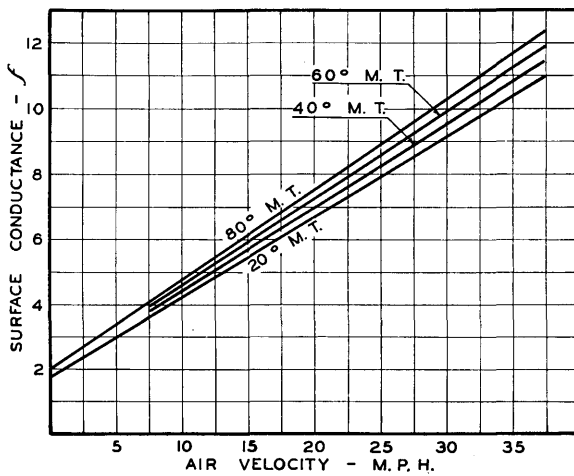


FIGURE 24. CONSTANT MEAN TEMPERATURE CURVES FOR SMOOTH PLASTER SURFACE

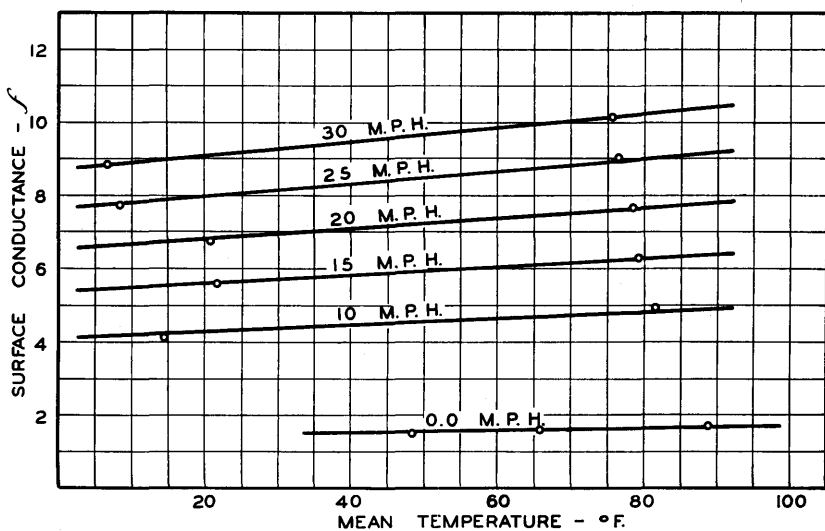


FIGURE 25. CONSTANT VELOCITY CURVES FOR CLEAR PINE SURFACE

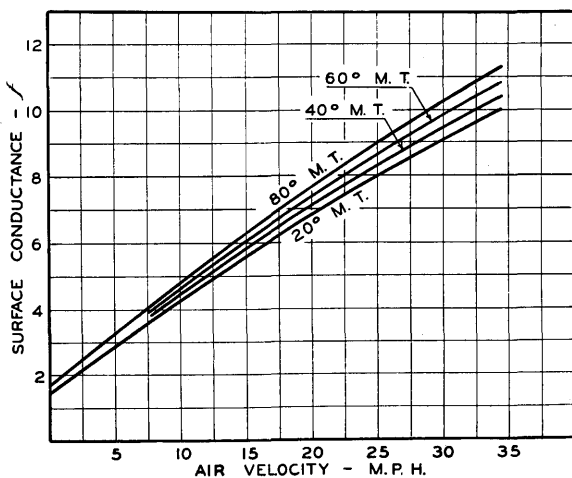


FIGURE 26. CONSTANT MEAN TEMPERATURE CURVES FOR CLEAR PINE SURFACE

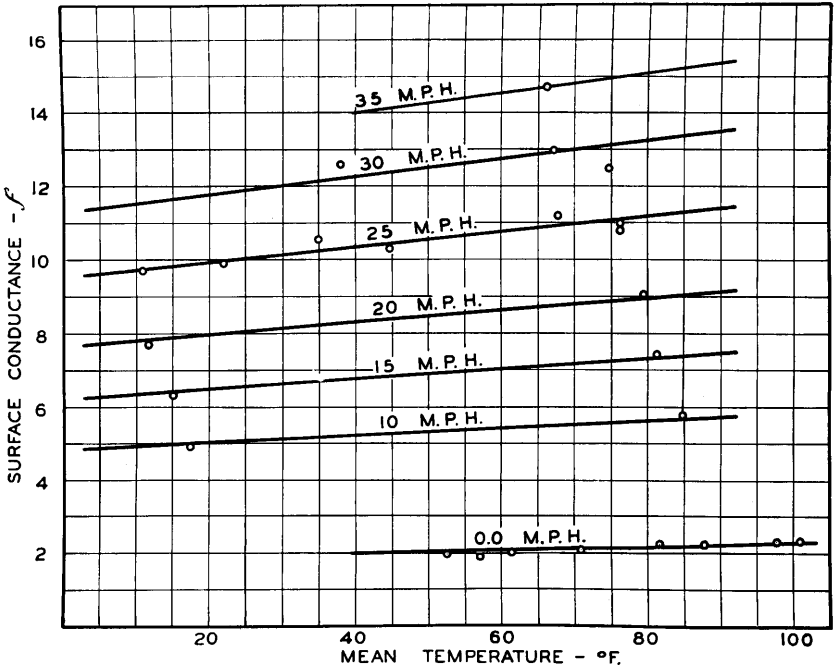


FIGURE 27. CONSTANT VELOCITY CURVES FOR CONCRETE SURFACE

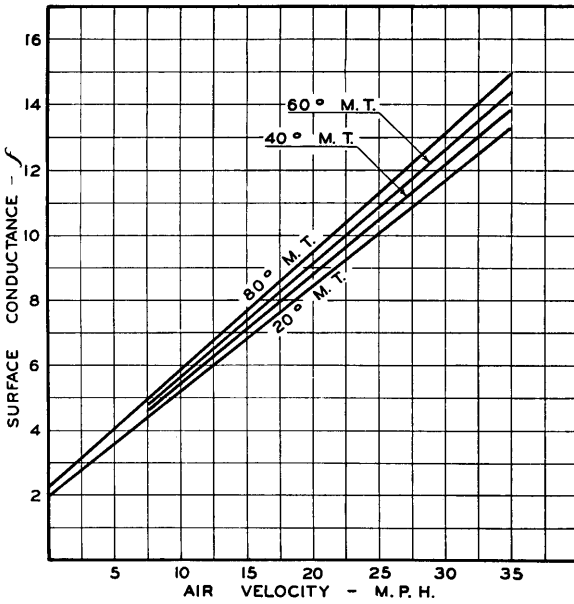


FIGURE 28. CONSTANT MEAN TEMPERATURE CURVES FOR CONCRETE SURFACE

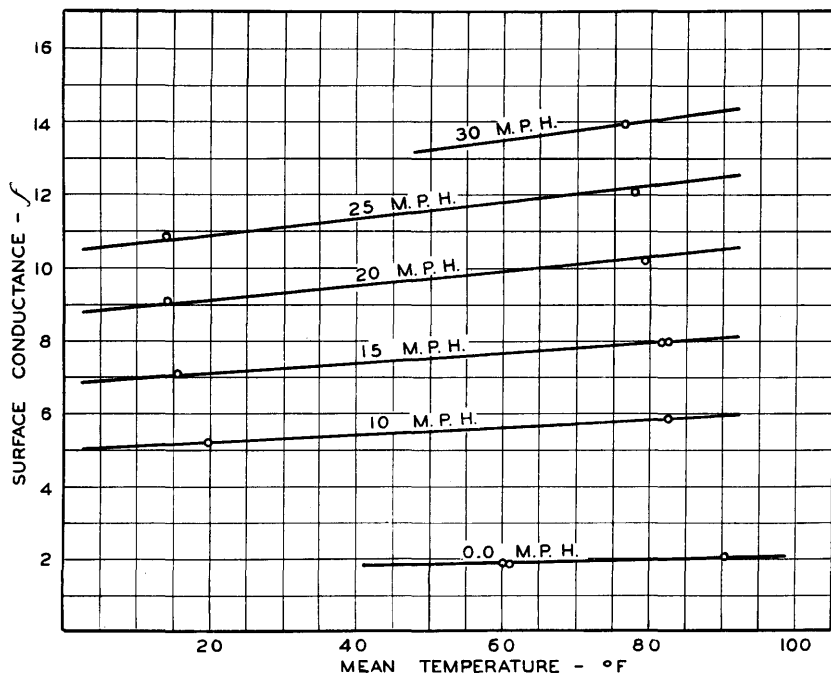


FIGURE 29. CONSTANT VELOCITY CURVES FOR ROUGH PLASTER SURFACE

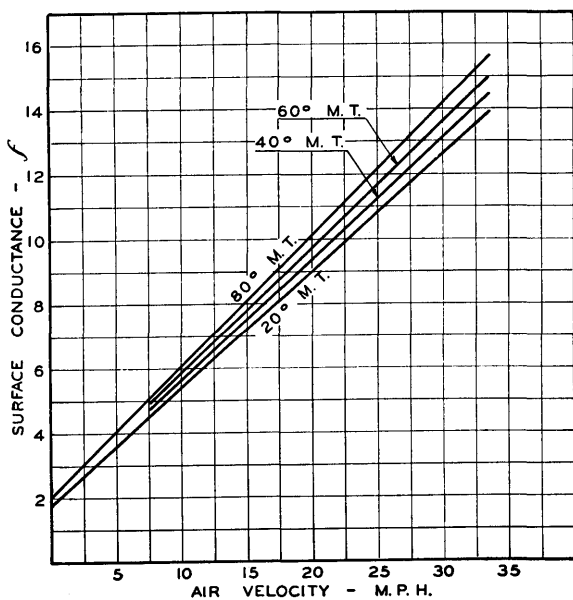


FIGURE 30. CONSTANT MEAN TEMPERATURE CURVES FOR ROUGH PLASTER SURFACE

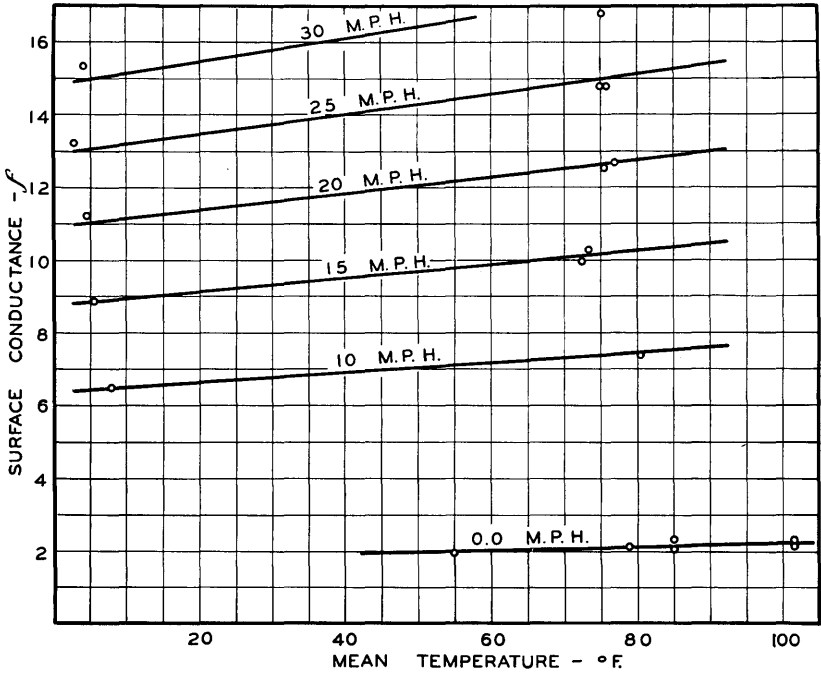


FIGURE 31. CONSTANT VELOCITY CURVES FOR STUCCO SURFACE

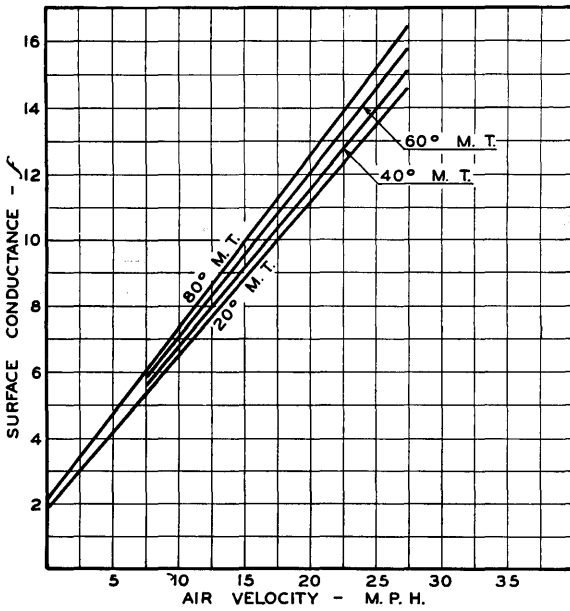


FIGURE 32. CONSTANT MEAN TEMPERATURE CURVES FOR STUCCO SURFACE

TABLE I
COEFFICIENTS OF SURFACE CONDUCTANCE, AIR FLOWING
PARALLEL TO SURFACE

SURFACE MATERIAL	MEAN TEMP. ° F.	AIR VELOCITY IN M.P.H.					
		5	10	15	20	25	30
Smooth plaster	20	2.96	4.20	5.45	6.65	7.90	9.15
	40	....	4.40	5.70	6.95	8.21	9.50
	60	....	4.60	5.94	7.22	8.58	9.90
	80	3.40	4.75	5.15	7.50	8.90	10.26
Rough plaster	20	3.55	5.40	7.20	8.96	10.80	12.60
	40	....	5.60	7.50	9.34	11.20	13.10
	60	....	5.82	7.80	9.70	11.82	13.60
	80	4.05	6.02	8.06	10.10	12.14	14.20
Concrete	20	3.55	5.20	6.80	8.41	10.04	11.65
	40	....	5.42	7.10	8.80	10.45	12.15
	60	....	5.61	7.40	9.10	10.85	12.60
	80	4.02	5.82	7.62	9.45	11.30	13.10
Stucco	20	4.18	6.50	8.80	11.16	13.42	....
	40	....	6.76	9.10	11.52	13.92	....
	60	....	7.05	9.50	12.01	14.60	....
	80	4.75	7.37	9.86	12.55	15.16	....
Glass	20	2.70	3.90	5.10	6.20	7.25	8.20
	40	....	4.15	5.30	6.45	7.57	8.55
	60	....	4.30	5.50	6.70	7.82	8.83
	80	3.10	4.45	5.70	6.95	8.10	9.20
Brick	20	2.70	5.35	7.10	8.85	10.65	12.40
	40	....	5.60	7.42	9.25	11.15	13.00
	60	....	5.80	7.70	9.60	11.60	13.50
	80	3.10	6.05	8.01	10.00	12.00	14.00
Clear white pine	20	2.83	4.21	5.55	6.80	8.00	9.05
	40	....	4.45	5.80	7.10	8.30	9.43
	60	....	4.60	6.03	7.39	8.62	9.81
	80	3.25	4.80	6.30	7.62	9.00	10.22
White paint on pine	20	2.90	4.20	5.35	6.40	7.35	8.22
	40	....	4.35	5.55	6.62	7.63	8.60
	60	....	4.50	5.75	6.90	7.98	8.96
	80	3.30	4.65	6.00	7.20	8.30	9.40

The curves shown by Figures 19 to 32, inclusive, need no specific explanation, as they are similar to the curves of Figures 17 and 18 and were obtained from materials as indicated. The curves of Figure 33 were taken from the corresponding curve sheet for each of the ma-

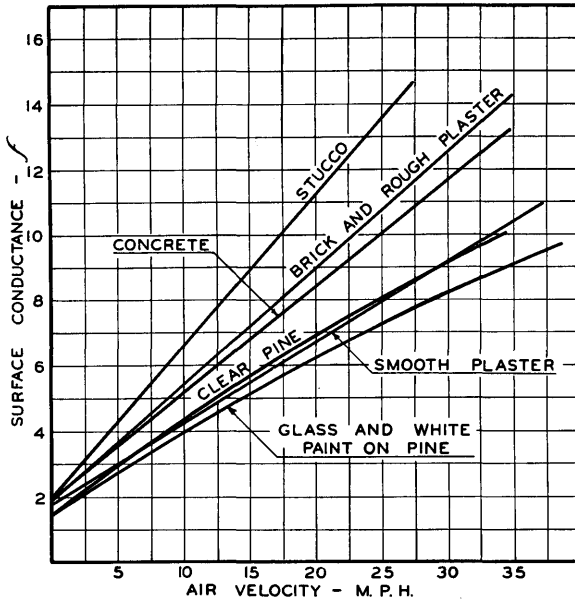


FIGURE 33. CURVES SHOWING RELATION BETWEEN SURFACE CONDUCTANCES FOR DIFFERENT SURFACES AT A MEAN TEMPERATURE OF 20° F.

materials at a mean temperature of 20°F. This group of curves shows the manner in which the surface characteristics of the material affect the heat transmission coefficients.

SURFACE CONDUCTANCE AS AFFECTED BY DIRECTION OF WIND

In practice, the wind may blow at any angle to the exposed surface of the wall, and the question arises as to the relation of the surface coefficients for the different angles of incidence between the wind and the surface. To determine this relation, test apparatus as shown in Figures 34 and 35 was set up, and a series of tests were made with wind velocities varying from 0 to 30 miles per hour and at angles to the test surface varying from 0° to 90°. The apparatus consisted essentially of a 30-inch air duct, 25 feet long, supplied with air by a variable speed

fan. The air duct was provided with a pitot tube and draft gage at a point 75 inches from the outlet end for measuring the air velocity. The test surfaces were 15 inches square and were placed with the vertical center line 12 inches in front of the outlet end of the duct. Each surface was placed on a pedestal and arranged so that it could be rotated around the vertical axis to give any desired angle of incidence between the air and the test surface. A 12-inch wing or extension wall was placed on the leading edge of the test surface to direct the wind over the surface and prevent, as much as possible, disturbing eddy currents from interfering with the test plate proper.

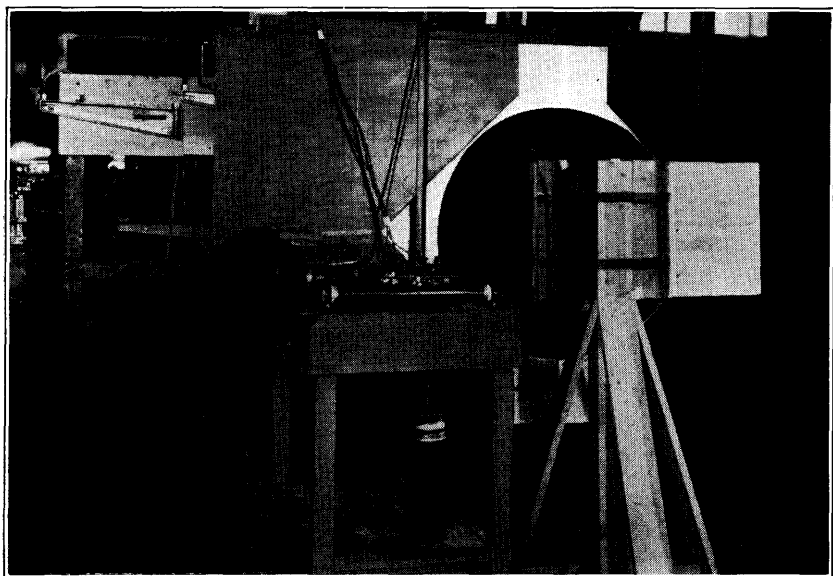


FIGURE 34. VIEW AT OUTLET END OF 30-INCH DUCT, SHOWING TEST SURFACE AND APPARATUS

The test surface was placed against a meter plate that was 12 inches square and was supplied by heat with an electrically heated plate with rheostat control. Figure 34 shows the open end of the 30-inch duct, together with the test specimen plate and the rheostat for controlling the temperatures of the test surface. Figure 35 shows a plan view of the outlet end of the air duct, together with a partial sectional view of the test surface and heat meter.

The differential temperatures of the heat meter, the surface temperatures of the test specimen, and the air temperatures were taken with

copper constantan thermocouples and a Leeds-Northrup Type K potentiometer. The surface temperatures were taken by 28-gage copper constantan thermocouples flattened out and cemented to the surface of the test specimen and covered with thin vellum paper. The air temperatures were taken by thermocouples placed $1\frac{1}{2}$ inches in front of and at the center of the test surface. The air velocities in the duct were taken with a pitot tube 75 inches from the outlet end and again by a pitot tube placed close to the test surface in order to determine the velocities parallel to the test surface, and, also, the static pressures of the air at the surface.

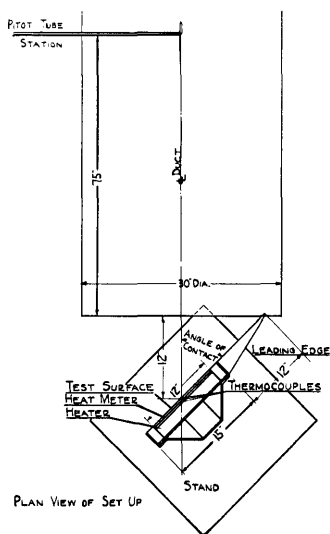


FIGURE 35. PLAN VIEW SHOWING RELATIVE POSITION OF TEST SECTION TO OUTLET END OF AIR DUCT

In the set-up as made, it was impossible to vary the air temperatures through any wide range of temperature. Since the object of the test was to find the relation between the coefficients at different wind velocities and at different angles of the wind to the test surface, a mean temperature was selected which was within the range of the apparatus, and this temperature was approximated throughout all of the tests. A temperature of 83°F . was maintained throughout most of the tests, altho, in some cases, there was a variation in either direction of as much as 5 degrees in mean temperature. This variation, however, was not sufficient to make any particular difference in the final results. The mean temperature was taken as the average temperature between the

test surface and the surrounding air, it being assumed that the surrounding objects were of the same temperature as the air.

In making the tests, plate glass and smooth pine surfaces were used. The tests were made at angles of incidence varying from 0 to 90 degrees at 15-degree intervals. For each test, the velocity of the air in the duct was varied from 0 to nearly 30 miles per hour.

The results of the tests for a glass surface are shown graphically in Figure 36, and those for pine are shown in Figure 37. By comparing the curves for parallel air flow with those for the corresponding surfaces at 80°F. mean temperature as shown on the curves of Figures 18 and 26, it will be noted that for glass the two curves are practically identical up to 20 miles per hour. Above this, the curve on Figure 18 drops off, while that from Figure 36 continues as a straight line. For the pine surface, the coefficients of the second set of tests (Fig. 37) are slightly greater than those of the first set (Fig. 26). This may be owing to a slight difference in the smoothness of the two surfaces. The fact that the glass surfaces show coefficients which are practically the same for the two different series of tests would indicate that the coefficients by either method are substantially the same so long as the mean temperatures and air velocities agree.

Figures 36 and 37 show that, as the angle between the direction of the wind and the test surface is changed, the surface coefficients are slightly changed. The reduction for all angles is reasonably the same up to a wind velocity of 15 miles per hour. Above this velocity the reduction increases with the angle.

The reduction, however, at any point is not as great as might be expected. For a 15-mile wind, the average reduction in coefficients for both the glass and pine surface is 16 per cent. It seems reasonable, therefore, to assume a reduction of 15 per cent in surface coefficients as obtained by test methods with parallel air flow when applying these to practical walls.

To show the action of the air near the test surface, readings were taken to determine the velocity parallel to the surface and the static pressure of the air for the different angles of incidence between the air stream and the surface. The results of these readings are shown in Table II. From these data, it will be observed that, as the angle of incidence is increased, the static pressure is gradually increased at the surface until, at 60 degrees, the static pressure practically equals the velocity pressure in the main duct. At 75 and 90 degrees, the static pressure slightly exceeds the velocity pressure. Further, as the angle

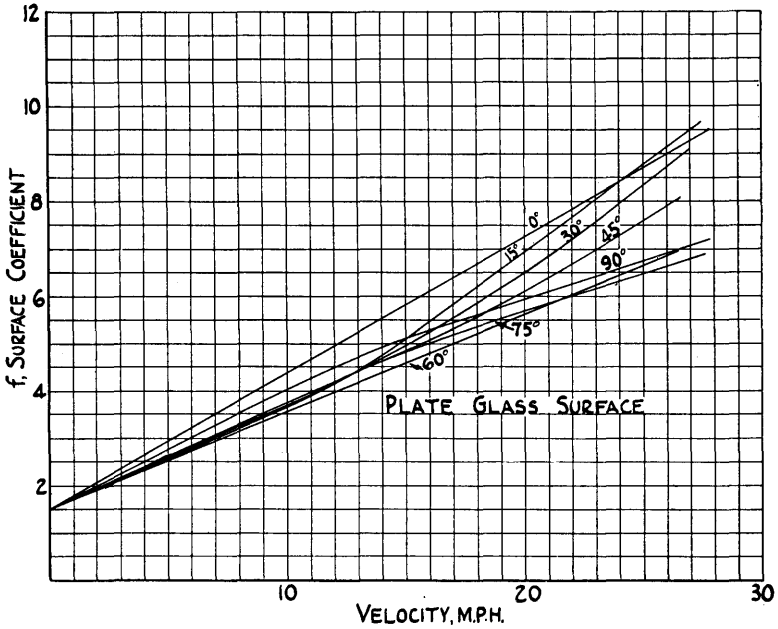


FIGURE 36. SURFACE COEFFICIENT FOR A PLATE GLASS SURFACE FOR WIND VELOCITIES VARYING FROM 0 TO 30 MILES PER HOUR AND WIND DIRECTION VARYING FROM 0° TO 90° TO TEST SURFACE

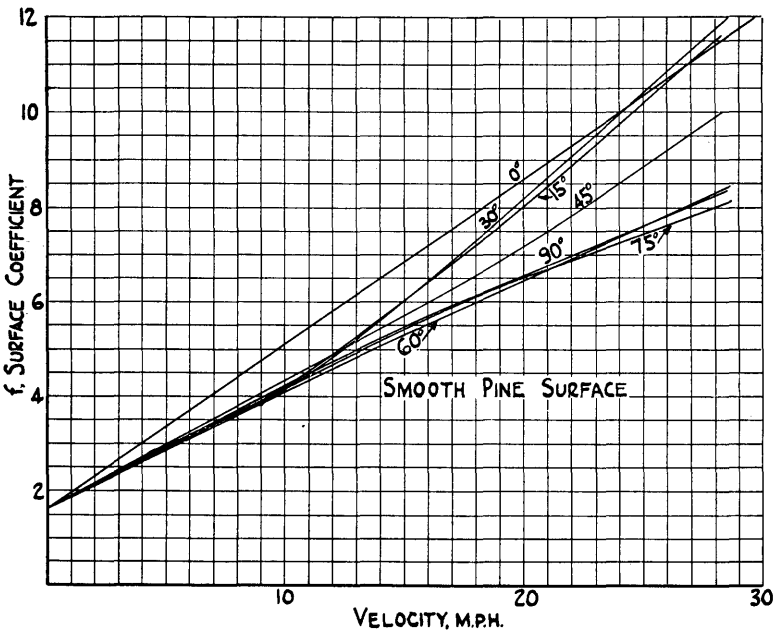


FIGURE 37. SURFACE COEFFICIENTS FOR A SMOOTH PINE SURFACE FOR A WIND VELOCITY VARYING FROM 0 TO 30 MILES PER HOUR AND A WIND DIRECTION VARYING FROM 0° TO 90° TO TEST SURFACE

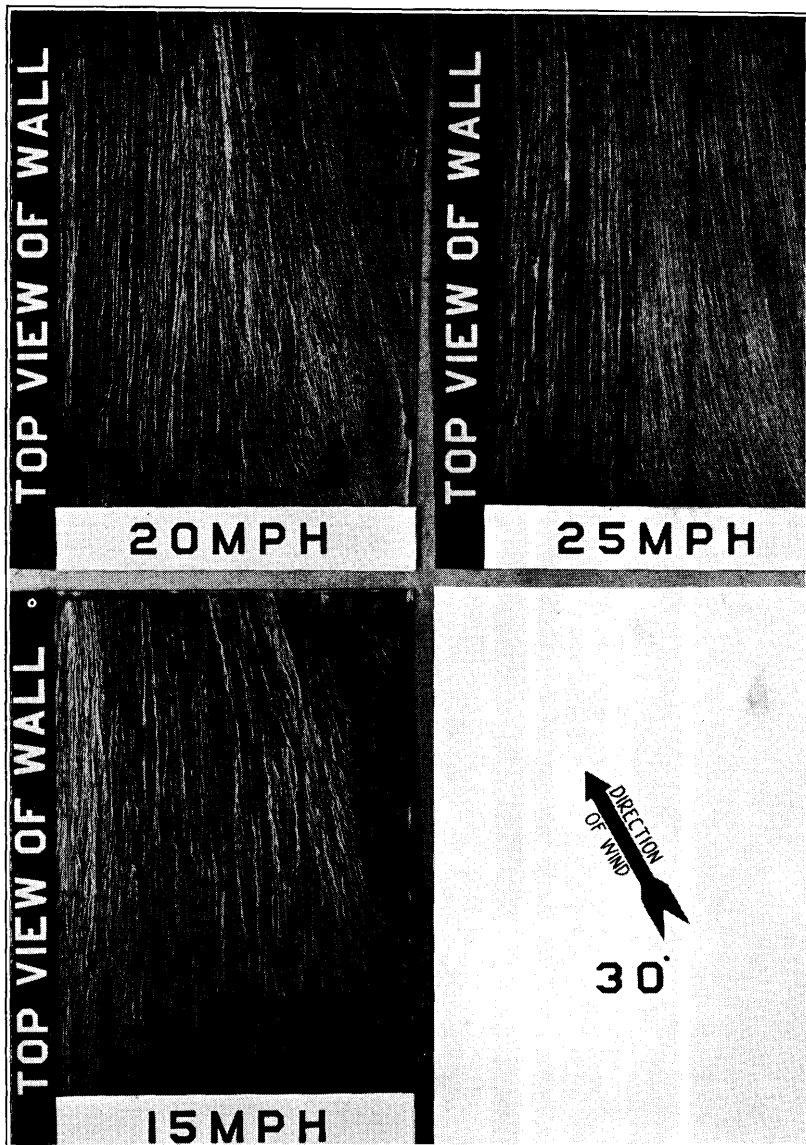


FIGURE 38. LINES SHOWING DIRECTION OF AIR CURRENT FOR A DISTANCE OF 12 INCHES FROM TEST SURFACE IN A PLANE PARALLEL TO WIND DIRECTION. ANGLE OF WIND TO TEST SURFACE, 30°

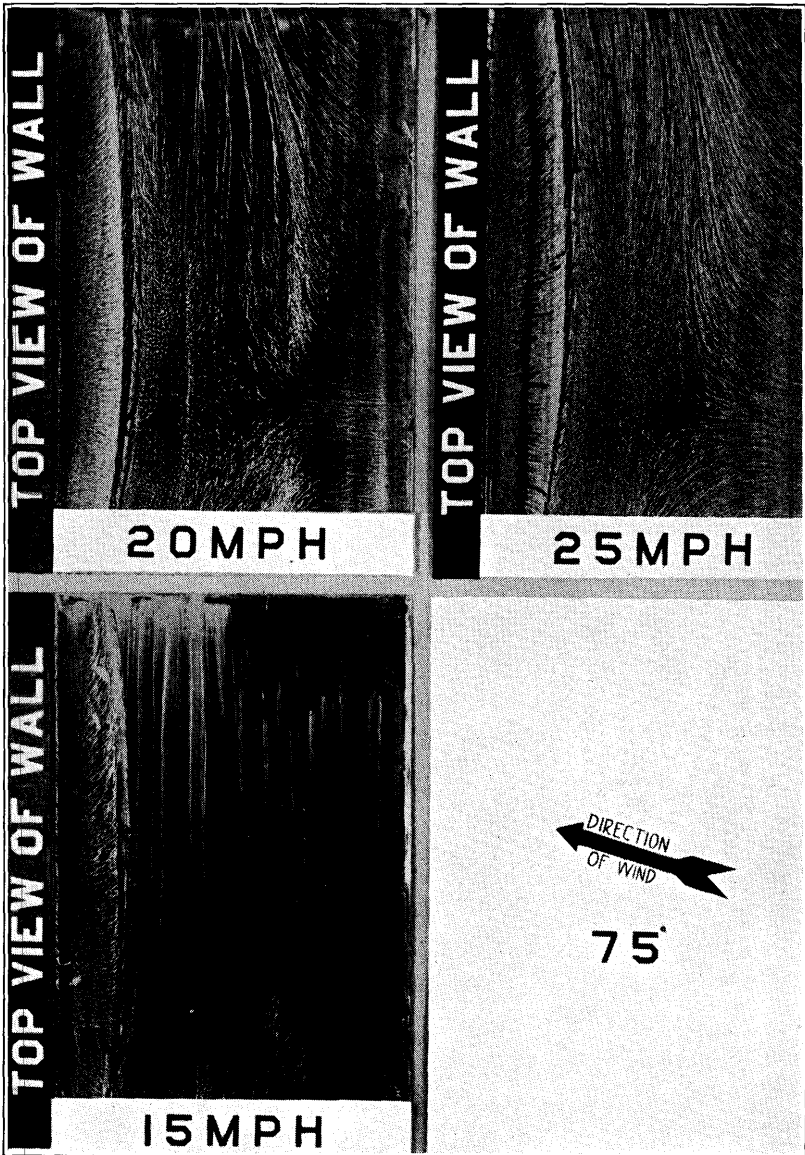


FIGURE 39. LINES SHOWING DIRECTION OF AIR CURRENT FOR A DISTANCE OF 12 INCHES FROM SURFACE IN A PLANE PARALLEL TO WIND DIRECTION, ANGLE OF WIND TO TEST SURFACE, 75°

TABLE II
AIR VELOCITY AND STATIC PRESSURE AT SURFACE FOR VARIOUS ANGLES
OF INCIDENCE OF WIND TO SURFACE

WIND VELOCITY MILES PER HR.	VELOCITY PRESSURE IN DUCT INCHES, WATER	VELOCITY PRESSURE PARALLEL TO SURFACE	WIND VELOCITY PARALLEL TO SURFACE	STATIC PRESSURE AT SURFACE INCHES, WATER
Angle of incidence = 0 degree				
10	.0465	.0420	9.50	0.000
15	.1045	.072	12.46	.004
20	.185	.170	19.12	.010
25	.290	.310	25.85	.019
Angle of incidence = 15 degrees				
10	.0465	.052	10.59	.004
15	.1045	.089	13.83	.007
20	.185	.192	20.35	.011
25	.290	.320	26.25	.016
Angle of incidence = 30 degrees				
10	.0465	.055	10.85	.016
15	.1045	.1045	15.0	.032
20	.185	.190	20.22	.054
25	.290	.308	25.75	.085
Angle of incidence = 45 degrees				
10	.0465	.0465	10.0	.030
15	.1045	.1045	15.0	.068
20	.185	.185	20.0	.120
25	.290	.306	25.67	.179
Angle of incidence = 60 degrees				
10	.0465	.032	8.3	.042
15	.1045	.064	11.74	.096
20	.185	.112	15.5	.182
25	.290	.192	20.3	.267
Angle of incidence = 75 degrees				
10	.0465	.013	5.29	.050
15	.1045	.024	7.19	.115
20	.185	.042	9.51	.195
25	.290	.076	12.8	.309
Angle of incidence = 90 degrees				
10	.0465	.002	2.07	.053
15	.1045	.004	2.94	.125
20	.185	.009	4.4	.230
25	.290	.020	6.57	.360

of incidence is increased, the velocity pressure on the surface, and, therefore, the surface velocities, are substantially the same as the velocity of the air in the duct until an angle of 45 degrees is reached, after which the surface velocity is gradually reduced until it reaches a minimum at an angle of 90 degrees. As the surface velocity is greatly reduced for the high angles of incidence, it might be assumed that the surface coefficients for these conditions should also be greatly reduced. The fact that they are not is probably owing to the corresponding increase in air pressure at the surface, which makes the contact between the air and surface more effective in removing the surface heat.

As a further study to determine the action of the air on the test surface for the various angles of incidence between the air and the surface, sheet metal plates 12×18 inches were placed perpendicular to the test wall and in the plane of the air flow. In this position, the plate did not disturb the air flow but merely separated the air as it approached the wall. A light coating of lampblack and kerosene was placed on the surface of the metal sheet and the air was blown on to the test surface for a sufficient length of time to impress or mark the direction lines of the air on the surface coating of the plate. Two of the typical plates as obtained from this test are shown in Figures 38 and 39. The lines on these plates showed very clearly the change in surface velocity conditions which took place after passing the 45-degree angle. It is very evident that, at the higher angles, the surface velocity is retarded and that the surface pressure is built up, as was indicated by the pressure gage.

While tests were made on only two surfaces, it is probable that the same characteristics would prevail for other types of surfaces. For all practical purposes the surface coefficient as obtained for air flow parallel to the surface may be used when calculating heat flow through built-up wall sections or at most a reduction of 15 per cent may be made.

CONDUCTANCE OF AIR SPACES

The thermal conductance of an air space will be affected by several factors; among these are width of air space, temperatures of surfaces, character of surfaces, the ratio of the area of the confined space to its thickness, and the position of the air space with respect to direction of heat flow. The effects due to width of space and mean temperature between surfaces should be the same for all surfaces. The surface effect will be different for different classes of material, altho, in many cases, it should be possible to group materials having similar character-

istics. The effect of ratio of surface area to thickness of air space should be more pronounced for small ratios, and it is probable that for average building construction it may be neglected. In the following experiments, the air space coefficients were determined for different widths of air spaces and different mean temperatures. Such surfaces were used as Insulite, Masonite, Flaxlinum, Celotex, Compo-board, and Gypsum Board, the last two being paper covered. The limited area of the air spaces was 9 inches square for the tests made by the hot plate method, and 36 inches square for those made by the hot box method.

In performing the tests, sheets of homogeneous material of uniform thickness were selected. Their conductances were first obtained by the hot plate method, after which two sheets of the material were separated by skeleton separators to a given distance, and the conductance of the combined sheets with the enclosed air space determined. These tests were repeated, using various mean temperatures and different widths of air spaces. As the only difference in the construction of the several test specimens was the separation of the material forming different widths of air spaces, the air space resistance was readily calculated. By this method, air space coefficients were obtained for spaces varying from .05 up to .71 inch by the hot plate method, and from .50 inch to 1.50 inches by the hot box method. The separators were built of pine strips $\frac{1}{8}$ inch wide for the hot plate tests, and $\frac{3}{4}$ inch wide for the hot box tests. Thus the area occupied by the strips was very small as compared with the air space area. For those thicknesses of air space between $\frac{1}{2}$ and $\frac{3}{4}$ inch that were tested both by the hot plate and the hot box methods, the conductances were found to check, even tho the confined area for the hot plate test was only 9 inches square as compared with a 3-foot square area for the hot box test. It is therefore probable that, for all practical building construction, the area of the confined air space is not a factor so long as there is no direct leakage of air into or out of the air space.

Heat is transmitted through an air space by radiation, conduction, and convection. Radiation depends upon the nature of the surfaces and their temperatures. It is independent of the width of the air gap. For air without motion, the heat transmitted by conduction is inversely proportional to the thickness of the air space. The amount transmitted by convection is dependent upon the temperature difference between the two sides of the air space and the freedom of the air to circulate. Thus for two surfaces, at constant temperature difference, as the air space is increased from zero, the amount of heat transmitted by radiation will

remain constant, the amount transmitted by conduction will be decreased, and the percentage transmitted by convection, increased.

As a very thin air space is increased in thickness, the gradual decrease in the heat transmitted by conduction is at first greater than the increase in the amount transmitted by convection. This ratio, however, changes until the greater part of the heat is transmitted by convection, and that transmitted by conduction becomes a negligible factor. This reasoning applies only to vertical air spaces.

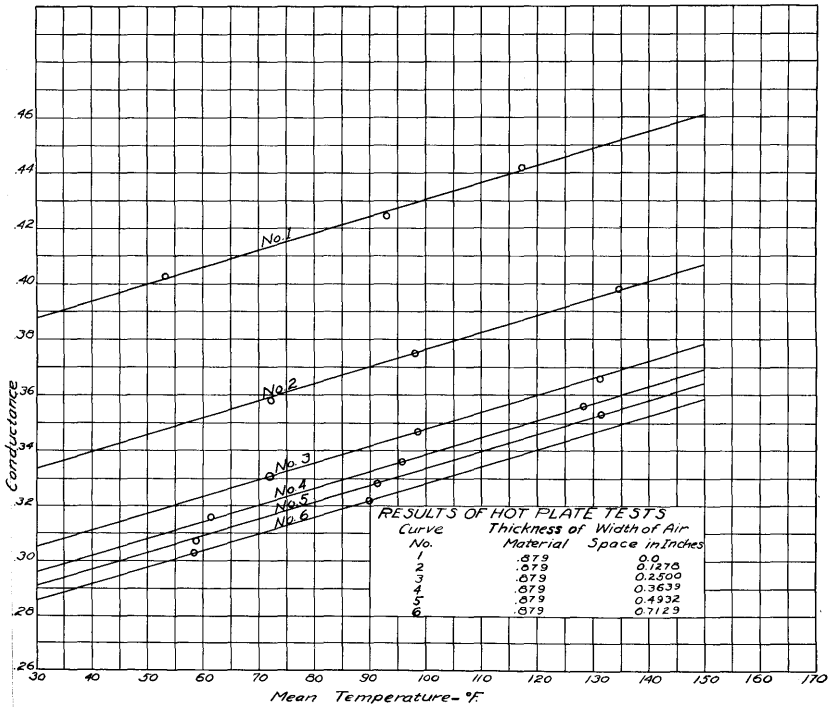


FIGURE 40. CONDUCTANCE OF TWO SHEETS OF HOMOGENEOUS MATERIAL WITH AND WITHOUT AIR SPACES

The results of the tests are shown in the curves of Figures 40 to 43, inclusive, and in Table III which was taken directly from the curves of Figures 42 and 43. The points on the curves of Figure 40 were plotted directly from experimental data. The conductance curve of Figure 41 for the air spaces was calculated from the results shown in Figure 40. Thus Curve No. 1 of Figure 41 was calculated from data taken from Curves 1 and 2 of Figure 40, etc. The curves of Figure

42 were determined for the various mean temperatures from Figure 41. For instance, vertical lines on Figure 41 representing constant mean temperatures were drawn and the points where these lines crossed Curves 1 to 6, respectively, were plotted as the constant mean temperature curve for Figure 42. These vertical lines were taken from 20° to 150° F. mean temperature at 10-degree intervals. The curves of Figure 43 represent the resistances of the air spaces and are the reciprocals of the values taken from Figure 42. In this set of curves, it

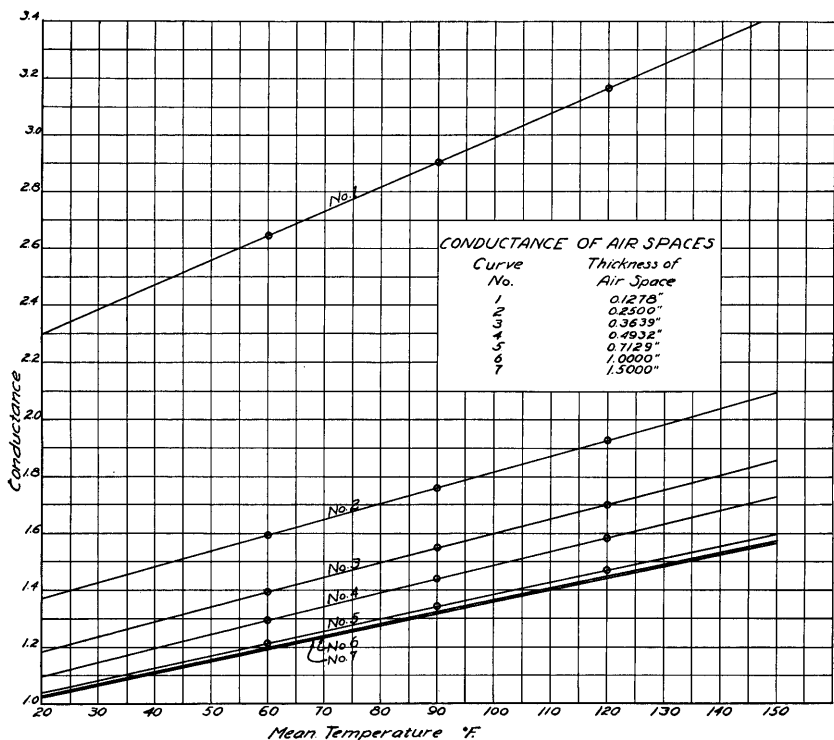


FIGURE 41. CONDUCTANCE OF AIR SPACES CALCULATED FROM DATA SHOWN IN CURVES OF FIGURE 40

was assumed that the thermal resistance of a zero air space would be zero, and all of the lines were thus drawn through the zero point, as it was impossible to get these data from Figure 42. One point, however, was determined at approximately .05-inch air space for 60° F. mean temperature and found to fall on the line passing through the zero point.

From the results of these tests, it is evident that the thermal resistance of an air space gradually increases as the thickness of the air

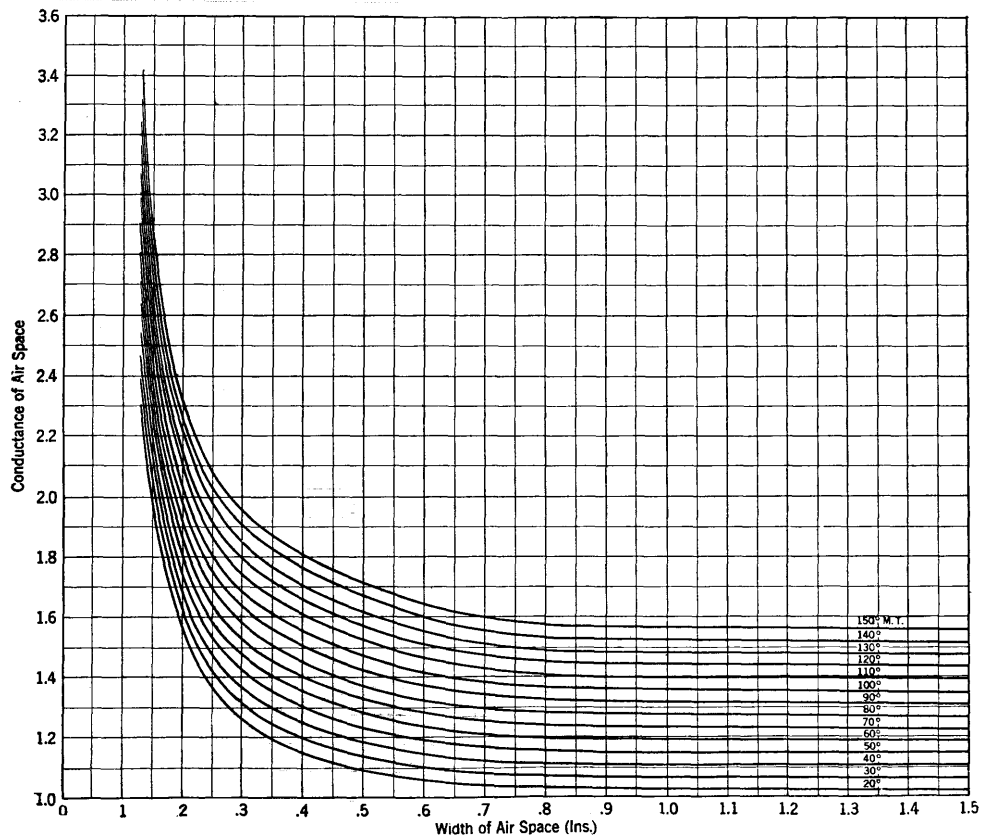


FIGURE 42. CONDUCTANCE OF AIR SPACES FOR DIFFERENT MEAN TEMPERATURES FAHRENHEIT

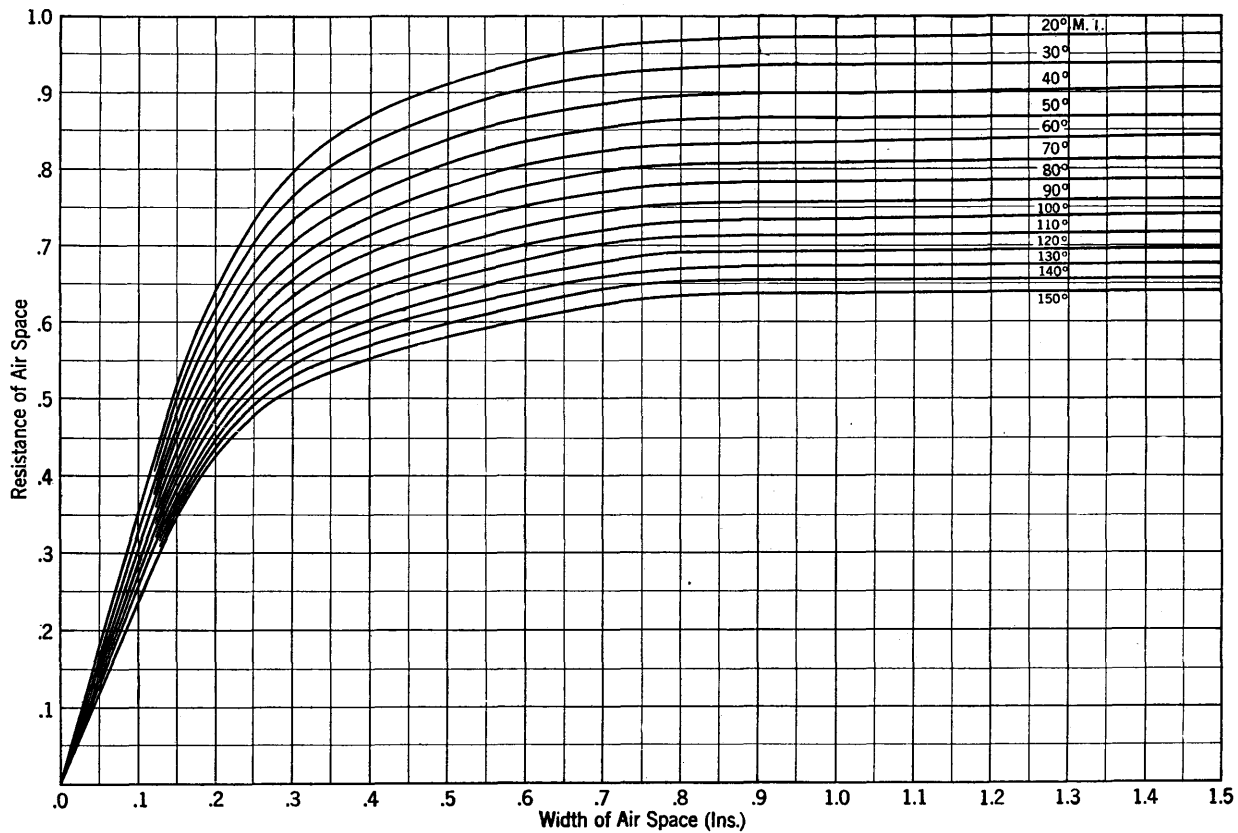


FIGURE 43. RESISTANCE OF AIR SPACES FOR DIFFERENT MEAN TEMPERATURES FAHRENHEIT

TABLE III
 CONDUCTANCES OF AIR SPACES FOR VARIOUS WIDTHS OF AIR SPACES IN INCHES

MEAN TEMP. DEG. FAHR.	.125	.250	.375	.500	.625	.750	1.000	1.250	1.500
20	2.300	1.370	1.172	1.095	1.058	1.040	1.030	1.026	1.022
30	2.381	1.425	1.223	1.141	1.100	1.080	1.070	1.067	1.065
40	2.469	1.480	1.275	1.186	1.142	1.120	1.112	1.108	1.105
50	2.564	1.535	1.330	1.235	1.188	1.162	1.152	1.150	1.149
60	2.667	1.590	1.380	1.288	1.228	1.201	1.195	1.191	1.188
70	2.747	1.648	1.427	1.332	1.275	1.248	1.240	1.234	1.228
80	2.833	1.702	1.482	1.375	1.315	1.288	1.280	1.275	1.270
90	2.915	1.757	1.532	1.427	1.365	1.339	1.320	1.315	1.310
100	3.003	1.813	1.585	1.478	1.408	1.378	1.362	1.356	1.350
110	3.086	1.870	1.638	1.528	1.454	1.420	1.402	1.397	1.392
120	3.175	1.928	1.688	1.572	1.501	1.460	1.445	1.440	1.435
130	3.268	1.980	1.740	1.622	1.545	1.500	1.485	1.480	1.475
140	3.356	2.035	1.796	1.675	1.590	1.540	1.530	1.525	1.519
150	3.448	2.090	1.840	1.718	1.633	1.586	1.569	1.564	1.559

space is increased, until a thickness of approximately .8 inch is reached. After this, the resistance of the air space remains practically constant, regardless of its thickness. While these curves show thicknesses of only 1½ inches as a maximum, other tests were conducted with air spaces 3½ inches thick and found to bear out the conclusion of uniform resistance after a thickness of approximately .8 inch.

RESULTS OF TESTS ON WALLS BY HOT BOX METHOD

Different types of wall sections have been built up and tested by the hot box method to determine the overall coefficient of thermal conductivity. About eighty of these tests are reported here. This group includes frame, brick, tile, stone, concrete, cinder block, and several specially constructed walls. Both insulated and uninsulated walls were tested, and the thickness, in some cases, ran as high as 12 inches.

As many of these walls were built up with mortar or were given a plaster finish on the inside surface, it was necessary to build them and

TABLE IV
TYPICAL LOG. OF TEST DATA

WALL 33F MARCH 27, 1929 RUN 536 - PAGE 2				HOT BOX READINGS					COLD ROOM READINGS				
READ. NO.	TIME	METER	WATTS	A	B	T	ITS		OTS		C		
				AIR TEMP INNER BOX	AIR TEMP OUTER BOX	AIR TEMP INNER BOX	TEMPERATURE BOX-CENTER TEST SURFACE	TEMPERATURE COLD ROOM CENTER TEST SURFACE	AIR TEMPERATURE COLD ROOM SERIES				
				GROUP	GROUP	GROUP	ITS-1	ITS-2	OTS-1	OTS-2	6" FROG WALL		
33	10:33:52	1039.20	7.75	1.032	1.051	1.026	797	800	-400	-413	-2.574	-645	
34	10:43			1.051	1.050	1.025	796	800	-410	-410	-2.601	-650	
35	11:00			1.053	1.032	1.023	797	801	-405	-415	-2.596	-649	
36	11:15			1.053	1.033	1.022	796	801	-408	-416	-2.631	-650	
37	11:41:07	1047.30	8.10	1.053	1.051	1.023	799	804	-408	-416	-2.570	-648	
38	11:45			1.053	1.051	1.023	799	804	-412	-426	-2.563	-646	
39	12:00			1.053	1.051	1.024	797	802	-421	-428	-2.593	-648	
40	12:15			1.052	1.050	1.024	797	803	-422	-427	-2.602	-651	
41	12:30			1.052	1.029	1.022	797	802	-422	-425	-2.590	-647	
62	12:44:47	1054.85	7.55	1.052	1.052	1.024	797	801	-421	-421	-2.574	-643	
43	1:00			1.051	1.050	1.026	798	803	-410	-415	-2.576	-644	
44	1:15			1.052	1.051	1.024	797	803	-412	-405	-2.568	-642	
45	1:30			1.051	1.053	1.024	798	802	-401	-410	-2.584	-646	
46	1:50:11	1062.70	7.85	1.051	1.053	1.025	797	803	-405	-425	-2.603	-651	
47	2:00			1.052	1.052	1.024	798	802	-421	-412	-2.596	-649	
48	2:15			1.052	1.052	1.025	798	803	-404	-418	-2.626	-657	
49	2:30			1.051	1.052	1.027	799	804	-420	-430	-2.651	-663	
70	2:48:25	1069.75	6.95	1.051	1.051	1.024	798	802	-424	-427	-2.638	-659	
71	3:00			1.051	1.051	1.022	798	802	-421	-428	-2.632	-659	
72	3:15			1.051	1.051	1.020	797	803	-425	-419	-2.625	-656	
73	3:30			1.052	1.053	1.025	799	804	-429	-418	-2.601	-650	
74	4:00			1.051	1.052	1.026	798	805	-424	-416	-2.535	-654	
75	4:15			1.051	1.052	1.024	798	804	-415	-415	-2.574	-646	
76	4:31:17	1082.10	12.48	1.052	1.052	1.026	798	803	-415	-430	-2.576	-643	
77	4:45			1.051	1.052	1.026	797	803	-408	-420	-2.568	-642	
78	5:00			1.052	1.052	1.023	797	803	-410	-415	-2.595	-649	
79	5:15			1.051	1.051	1.023	797	804	-413	-405	-2.532	-638	
80	5:35:38	1089.55	7.45	1.051	1.052	1.023	798	805	-395	-400	-2.572	-643	
81	5:45			1.054	1.054	1.023	798	804	-390	-406	-2.595	-649	
82	6:00			1.053	1.053	1.022	799	805	-396	-402	-2.583	-646	
83	6:15			1.052	1.052	1.023	802	807	-393	-398	-2.572	-643	
84	6:30			1.052	1.051	1.023	801	806	-392	-398	-2.555	-639	
85	6:49:10	1098.20	8.65	1.052	1.053	1.023	802	806	-395	-395	-2.556	-639	
RUL 822				59.00	Ave 1.052	Ave 1.052	Ave 1.024	Ave 798	Ave 803	Ave 411	Ave 415	AVERAGE	647
				79.31*	79.30*	79.10*	69.05*		11.35*			+40*	

TIME - START 6:49:10
END 10:32:52
TOTAL 3.872

METER - START 1039.20
END 1098.20
DIFF. 59.00

Box Core = 290 x 45 x 272 x .01 = 1.09

$U = \frac{(2900 \times 250) + (36 \times 272)}{78.91 \times 9 \times 2.72}$ = 1.109

$U = .2170$ M.T. = 39.85"

$C = \frac{1268.906}{57.70 \times 74.4 \times 8} = 2.96$

$f = \frac{1268.906}{10.26 \times 74.4 \times 8} = 1.661$ M.T. = 74.10"

$C = \frac{1268.906}{10.95 \times 74.4 \times 8} = 1.557$ M.T. = 5.87"

allow them to season a sufficient length of time to thoroly dry out the moisture. In several cases, walls were allowed to stand over for a period of a year in order to determine whether or not any changes had taken place in the conductivity coefficients.

Before taking test data, it was found necessary to place the wall in the test apparatus, adjust the air temperatures, and make an extended preliminary run in order to insure a uniform temperature gradient through the wall and uniform results. The preliminary period necessary depended upon the conductivity and heat capacity of the wall. In heavy masonry construction, it was found necessary, in some cases, to run the apparatus under constant conditions for 48 hours before test data were taken. After conditions were adjusted, all readings were taken at 15-minute intervals, and the test was continued until uniform results were assured. The average test was of 8 hours duration. Table IV shows the test data as taken for Wall 53F, Test 556.

The description of the walls as tested and the details of construction are given in Tables V and VI and Figures 44 to 60, inclusive. Each wall is designated by a number which is followed throughout the description and test results. The complete details of construction of each wall may be obtained by referring to Table V and the corresponding drawing of the wall. In cases where insulating materials were used in the wall construction, they were designated by a letter. The thickness and location of the insulating materials are shown in Table V, while the description and insulating qualities are shown in Table VI. Due to the fact that many insulating materials of different trade names have similar characteristics and will give comparable results when placed in the wall in the same manner, and also in order to avoid the use of trade names, these materials were designated by letters.

In all cases where building paper was used in the walls, it was known as No. 2 Building Felt, with an average weight of 44 to 55 pounds per roll of 324 square feet.

To get a complete description of any wall, it is necessary to refer to the figure showing that wall and to Table V. If insulating material has been used in its construction, it is also necessary to refer to Table VI to get the thickness of the insulating material and its insulating value. In several cases, the same figure applies to more than one wall number. In case the walls are of identical construction, the average value of U is given. If, however, the walls are of different construction, such as thickness of insulating material (Table VI), the heat transmission coefficients are given for each wall.

TABLE V
DESCRIPTION OF WALLS AS TESTED

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
7	44	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	None
7A	44	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	None
8	44	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	None
8A	44	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	None
8B	48	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Two thicknesses of $\frac{1}{8}$ -inch corrugated paper spaced between studs to divide air space into 3 equal parts
9	46	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation D, flanged midway in air space between studding
10	44	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Insulation A Building paper 4-inch pine lap siding	None
11	44	Wood frame	$\frac{3}{8}$ -inch plaster Insulation A	Insulation A Building paper 4-inch pine lap siding	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
12	45	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation F, $\frac{3}{8}$ -inch thick, flanged midway in air space between studding
15	45	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation G, $\frac{1}{4}$ -inch thick, flanged midway in air space between studding
16	45	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation F, $\frac{5}{8}$ -inch thick, nailed on studding under sheathing
17	49	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation K poured between studding, $3\frac{1}{2}$ inches thick
18	49	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper Metal lath Stucco	Insulation K poured between studding, $3\frac{1}{2}$ inches thick
19	46	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation D placed between studs against sheathing
21	53	8-inch 3-cell tile	$\frac{3}{8}$ -inch plaster Insulation A 1-inch furring strips	$\frac{3}{4}$ -inch stucco on surface of tile	None
22	53	8-inch 3-cell tile	$\frac{1}{2}$ -inch plaster on surface of tile	$\frac{3}{4}$ -inch stucco on surface of tile	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
23	51	Special	Insulation C	Insulation C	None
24	53	8-inch 3-cell tile	3/8-inch plaster 3/8-inch wood lath 1-inch furring strips	3/4-inch stucco on surface of tile	None
25	51	Special	Insulation A	Insulation A	None
26	48	Wood frame	3/8-inch plaster Insulation C	Insulation C Building paper 4-inch pine lap siding	None
27	51	Wood frame	Insulation A	Insulation A Building paper 4-inch pine lap siding	None
28	48	Wood frame	3/8-inch plaster 3/8-inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Two thicknesses water-proofed roofing felt spaced between studs to divide air space into 3 equal parts
29	48	Wood frame	3/8-inch plaster 3/8-inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Two thicknesses water-proofed roofing felt nailed to each side of studs bowed in at center 1 1/4 inches
30	44	Wood frame	3/8-inch plaster Insulation A	Insulation A Building paper 4-inch pine lap siding	None
31	51	Wood frame	3/8-inch plaster Insulation A, .7 inch thick	Insulation A, .7 inch thick 4-inch pine lap siding	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
32	46	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation D flanged midway in air space, between studding
33	49	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation J, 1.11-inches thick back against sheathing, blown in place
34	47	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation A with one surface papered, flanged midway in air space between studding
35	45	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation F, $\frac{5}{8}$ -inch thick, flanged midway in air space between studding
36	46	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation D papered surfaces, flanged midway in air space between studding
37	59	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper Face brick with three 1-inch holes in each brick	Insulation J, 1.11 inches thick, back against sheathing, blown in place
40B	45	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation F, 1 inch thick, flanged midway in air space between studding
41	47	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation H nailed on studding under sheathing

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
42	59	Brick	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	$1\frac{5}{8} \times 1\frac{5}{8}$ -inch furring strip Common clay brick $\frac{3}{4}$ -inch air space Face brick	Insulation J, .814 inch thick, against common clay brick, blown in place
47	52	Special, two $\frac{3}{8}$ -inch panels with 1-inch air space	$\frac{3}{8}$ -inch Gypsum Board, both surfaces covered with paper	$\frac{3}{8}$ -inch Gypsum Board, both surfaces covered with paper	None
50	59	Brick	One tier of common yellow clay brick	One tier of common yellow clay brick	None
51	58	Brick	One tier of common yellow clay brick	One tier of common yellow clay brick	None
52	58	Brick	One tier of common yellow clay brick	One tier of red clay brick	None
53A	44	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	None
53B	47	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation D flanged midway in air space between studding
53C	47	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation D flanged midway in air space between studding with 1 inch of insulation removed from top and bottom

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
53D	47	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation F flanged midway in air space between studding
53E	47	Wood frame	$\frac{3}{8}$ -inch gypsum with paper covered surfaces	Fir sheathing Building paper 4-inch pine lap siding	Insulation F flanged midway in air space between studding with 1 inch insulation removed from top and bottom
53F	44	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	None
54	52	Special	4-inch pine lap siding Building paper Fir sheathing	Fir sheathing Building paper 4-inch pine lap siding	None
55	59	Concrete, 5.95 inches thick	Concrete	Concrete	None
56	52	Special	$\frac{3}{4}$ -inch stucco Metal lath Building paper Fir sheathing	$\frac{3}{4}$ -inch stucco Metal lath Building paper Fir sheathing	None
57	52	Special	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	None
57B	52	Special	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	None
59	53	8-inch clay tile	Tile	Tile	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
60	54	8-inch clay tile	Tile	Tile	½-inch flexible insulation strips and pads in mortar joints
61	55	8-inch clay tile	¾-inch plaster on surface of tile	Tile	½-inch flexible insulation strips and pads in mortar joints
61A	54	8-inch clay tile	Tile	Tile	½-inch flexible insulation strips and pads in mortar joints
62	55	12-inch clay tile	Tile	Tile	None
63	54	8-inch clay tile	Tile	Tile	None
64	54	8-inch clay tile	Tile	Tile	None
65	55	8-inch clay tile	¾-inch plaster on surface of tile	⅝-inch stucco on surface of tile	½-inch flexible insulation strips and pads in mortar joints
66	54	8-inch clay tile	Tile (solid mortar joint)	Tile (solid mortar joint)	None
67	55	8-inch clay tile	Tile (solid mortar joint)	Tile (solid mortar joint)	None
68	59	Concrete 6 inches thick	Concrete	Concrete	None
69	59	Concrete 6 inches thick	Concrete	Concrete	None
70	57	8-inch cinder block	Cinder block	Cinder block	None
71	58	8-inch concrete block	Concrete block	Concrete block	None
72	58	8-inch concrete block	Concrete block	Concrete block	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
73	58	12-inch concrete block	Concrete block	Concrete block	None
74	58	12-inch concrete block	Concrete block	Concrete block	None
75	57	Rubble stone, 8.22 inches thick	Rubble stone	Rubble stone	None
76	57	Rubble stone, 8.03 inches thick	Rubble stone	Rubble stone	None
77	49	Wood frame	$\frac{3}{8}$ -inch plaster $\frac{3}{8}$ -inch wood lath	Fir sheathing Building paper 4-inch pine lap siding	Insulation I, 2.78 inches thick, placed back against sheathing, hand-packed in place
78	60	Special, $\frac{3}{8}$ -inch Gypsum Board	Surface covered with paper	Surface covered with paper	None
78B	60	Special, $\frac{3}{8}$ -inch Gypsum Board	Surface covered with aluminum foil	Surface covered with aluminum foil	None
79	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with paper	All surfaces covered with paper	None
79A	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with aluminum bronze	All surfaces covered with aluminum bronze	None

TABLE V—Continued

WALL NO.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
79B	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with gold bronze	All surfaces covered with gold bronze	None
80	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with paper	All surfaces covered with paper	None
80A	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with aluminum foil	All surfaces covered with aluminum foil	None
81	56	4-inch 3-cell gypsum partition tile	Plain gypsum surface	Plain gypsum surface	None
82	57	3-inch 4-cell gypsum partition tile	Plain gypsum surface	Plain gypsum surface	None
83	57	3-inch solid gypsum partition tile	Plain gypsum surface	Plain gypsum surface	None
85	60	Special, three $\frac{3}{8}$ -inch Gypsum Boards, two 1-inch air spaces	All surfaces covered with paper	All surfaces covered with paper	None
86	50	Wood frame	$\frac{3}{8}$ -inch plaster Insulation A	Fir sheathing Building paper 4-inch pine lap siding	None

TABLE V—Continued

WALL No.	FIGURE SHOWING CONSTRUCTION	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	ADDITIONAL INSULATION
87	50	Wood frame	$\frac{3}{8}$ -inch plaster Insulation C	Fir sheathing Building paper 4-inch pine lap siding	None
88	50	Wood frame	$\frac{3}{8}$ -inch plaster Insulation B	Fir sheathing Building paper 4-inch pine lap siding	None
89	50	Wood frame	$\frac{3}{8}$ -inch plaster Insulation E	Fir sheathing Building paper 4-inch pine lap siding	None
90	56	8-inch clay tile	Tile	Tile	None
91	56	8-inch clay tile	Tile	Tile	None
92	56	8-inch clay tile	Tile	Tile	None

TABLE VI
DESCRIPTION OF INSULATING MATERIALS USED IN WALL CONSTRUCTION WITH CONDUCTIVITIES BY HOT PLATE METHOD

MARK DESIGNATING MATERIAL	DESCRIPTION OF MATERIAL	TESTED	AVERAGE THICKNESS	AVERAGE DENSITY	M. T.	CONDUCTIVITY
			Inches	Lb./Cu. Ft.		
A	Rigid wood fiber board	Dry	.500	16.12	75.06	.343
B	Rigid wood fiber board	Dry	.486	16.99	74.9	.373
C	Rigid cereal fiber board	Dry	.450	15.59	74.75	.348
D	Semi-rigid flax fiber board	Dry	.553	13.17	61.9	.312
		Dry	.500	12.76	75.6	.317
E	Semi-rigid flax fiber board with heavy waterproofed asphalt, paper, and metal lath on one side					
F	Felted wood fiber between 2 layers of heavy waterproofed paper	Dry	.496	4.39	77.3	.254
		As received	.497	3.65	76.8	.264
G	Hair felted and stitched between 2 layers of heavy waterproofed paper					
		As received	.269	9.72	66.9	.250
H	Ell grass felted and stitched between 2 layers of heavy waterproofed paper					
		As received	.413	8.38	75.7	.275
I	Limestone melted and blown into a fibrous form		2.78			
J	Shredded paper with bounding solution sprayed on wall	As received	1.110	5.78	61.6	.283
			.814			
K	Cellular gypsum material poured into place	Dry	3.500	10.90	69.78	.447
		As received	3.500	11.05	72.50	.482

A summary of test results for all walls is given in Table VII. In this table, two values for the overall coefficients U are given:

1. That obtained by the test.
2. A coefficient corrected for a 15-mile wind velocity over the outside surface of the wall. In making this correction, an average outside surface coefficient of 1.65 was taken as that obtained by test. This was the average for all tests which were made under the same conditions of air velocity over cold surfaces. The average was used on account of the difficulty in obtaining accurate surface coefficients on such surfaces as stucco, lap siding, etc. The corrected coefficient for a 15-mile wind was taken from the curves of Figure 33. These values were reduced 15 per cent to get average conditions for all angles between direction of wind and test surface.

In many cases, several tests were run on the same wall, using different mean temperatures of the air on the two sides of the wall. In such tests the results at 40°F. mean temperature are reported as the value of U , which is given in Table VII and with the figure showing the construction of the wall.

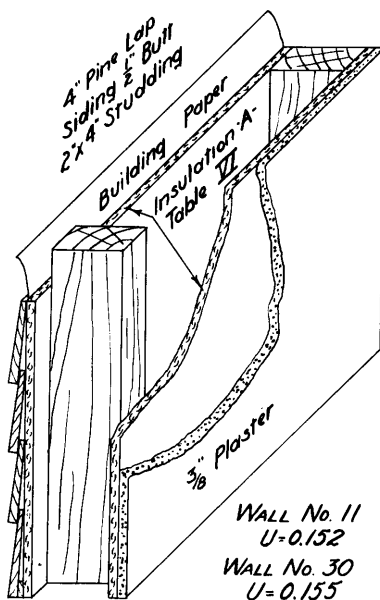
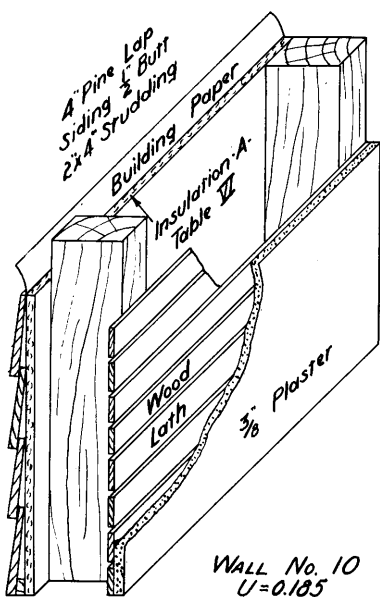
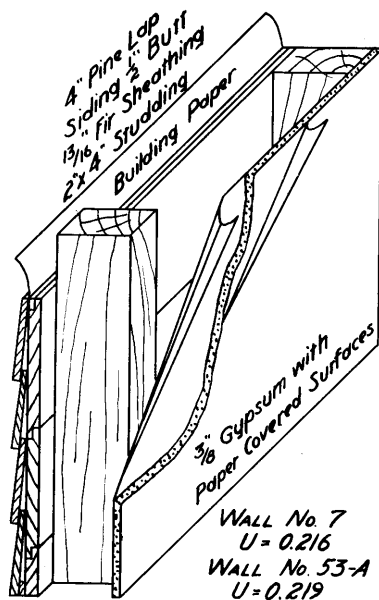
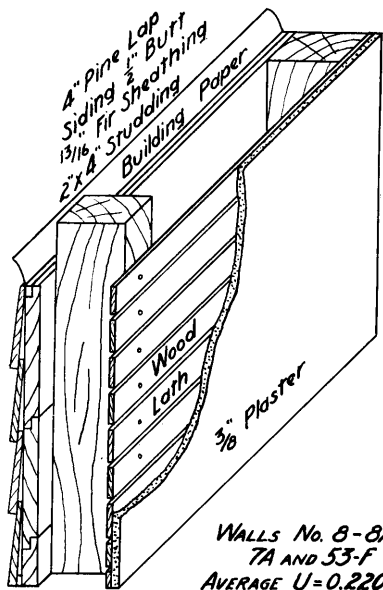
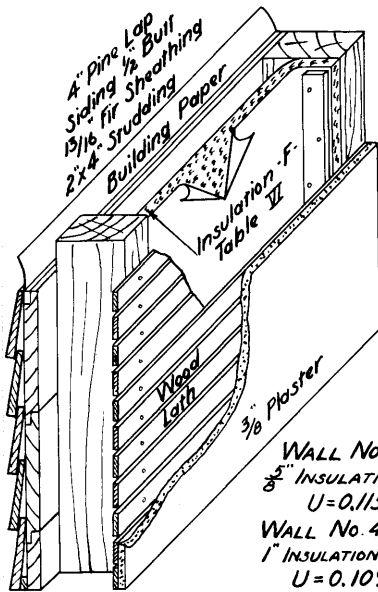
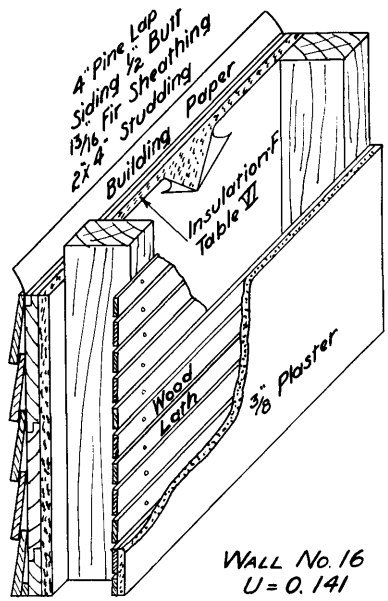


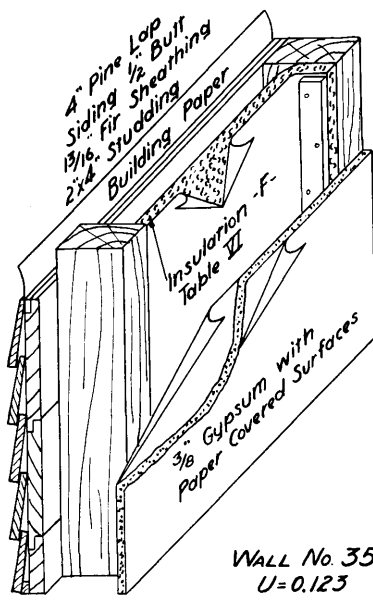
FIGURE 44. SECTIONAL VIEWS OF TEST WALLS



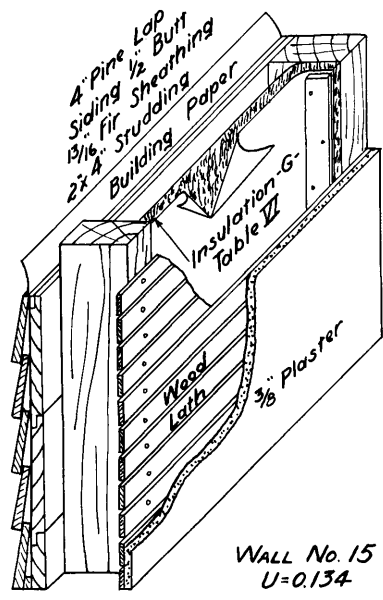
WALL No. 12
3/8" INSULATION
U=0.115
WALL No. 40-B
1" INSULATION
U=0.109



WALL No. 16
U=0.141



WALL No. 35
U=0.123



WALL No. 15
U=0.134

FIGURE 45. SECTIONAL VIEWS OF TEST WALLS

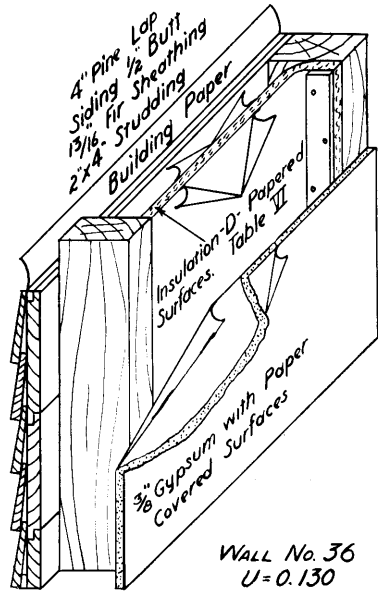
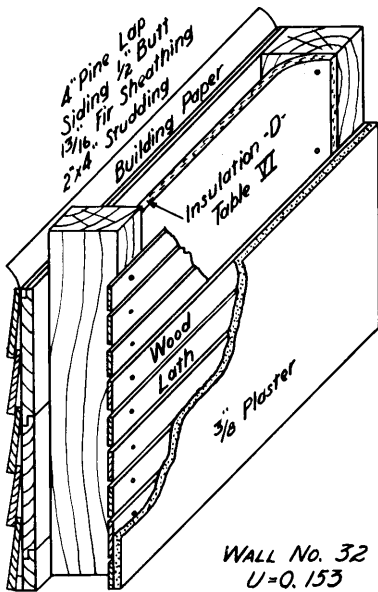
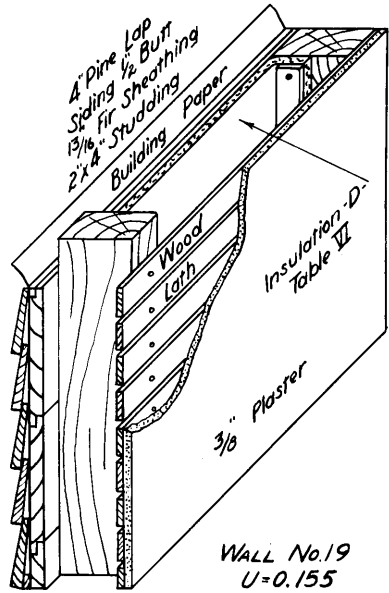
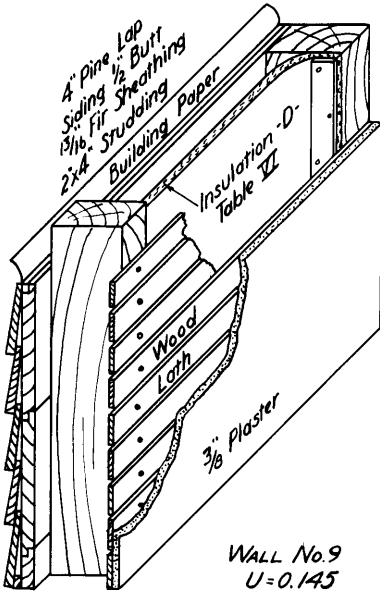


FIGURE 46. SECTIONAL VIEWS OF TEST WALLS

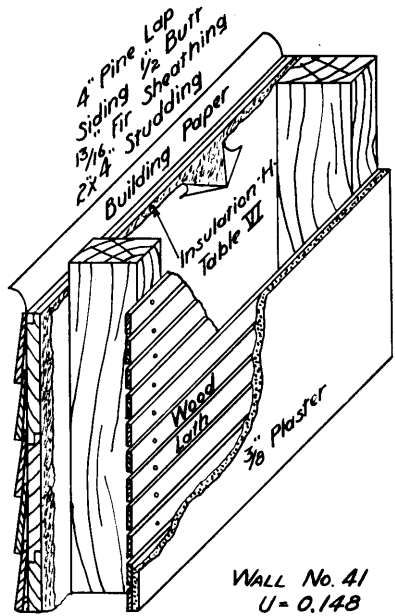
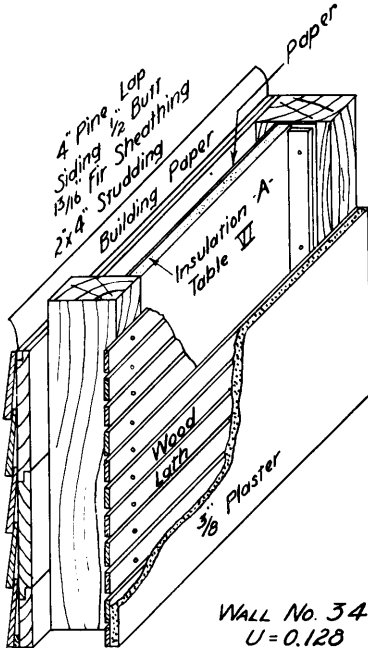
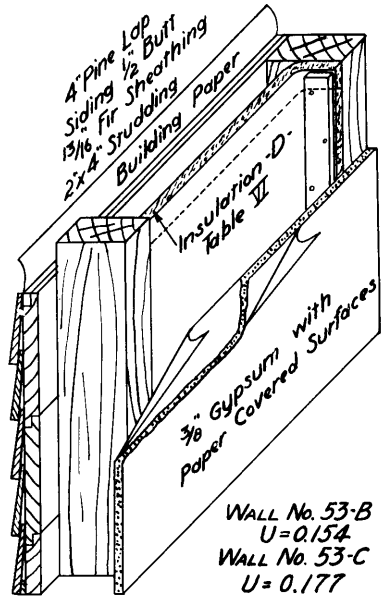
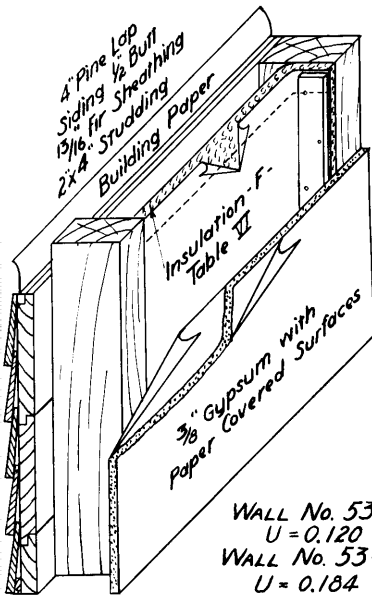


FIGURE 47. SECTIONAL VIEWS OF TEST WALLS

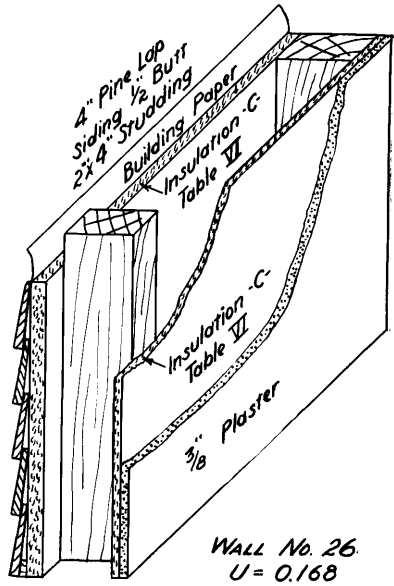
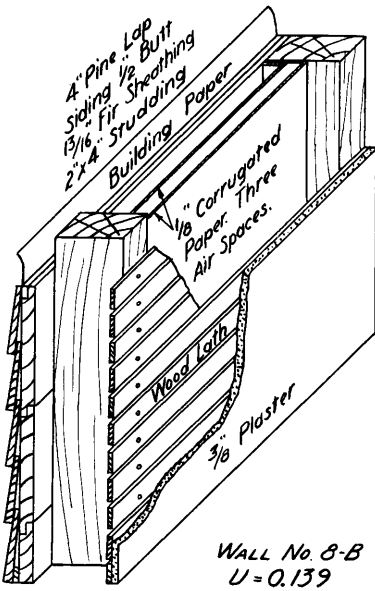
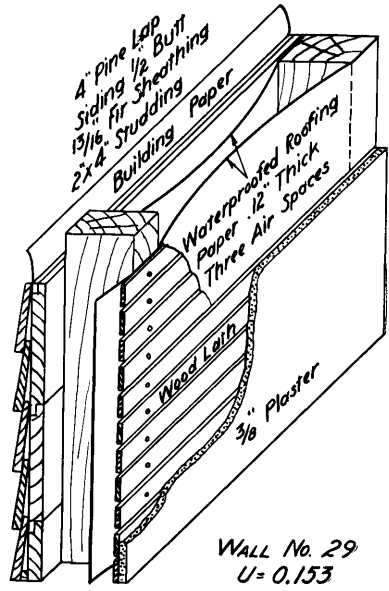
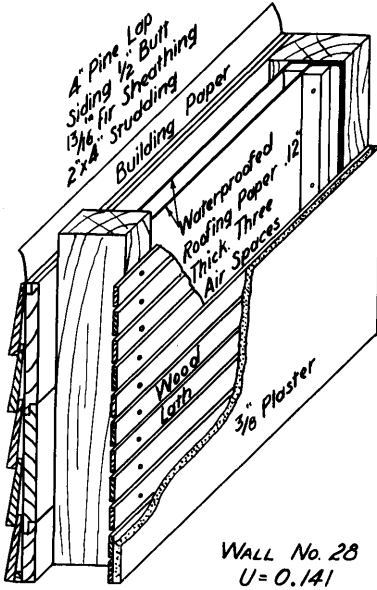


FIGURE 48. SECTIONAL VIEWS OF TEST WALLS

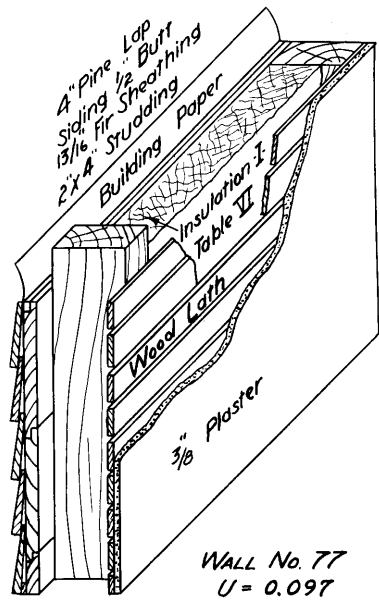
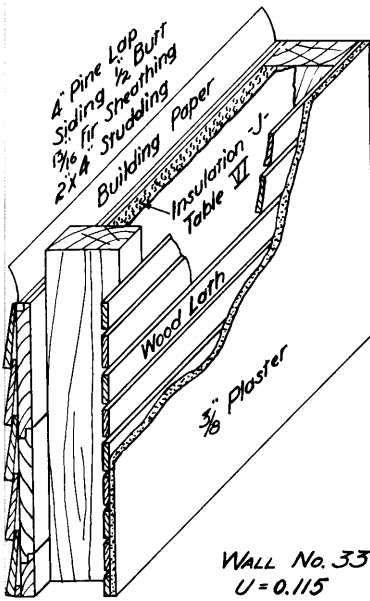
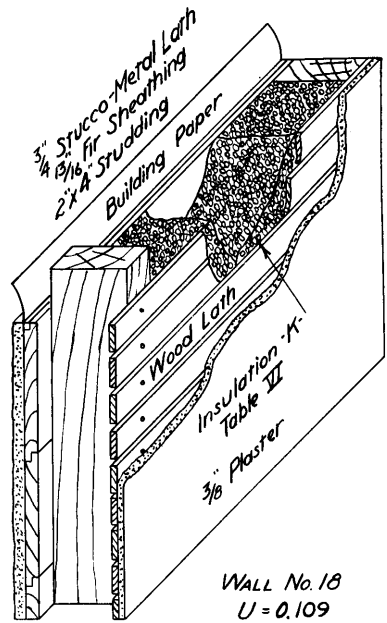
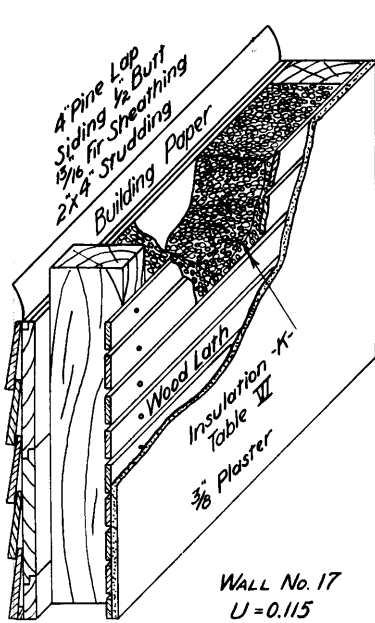


FIGURE 49. SECTIONAL VIEWS OF TEST WALLS

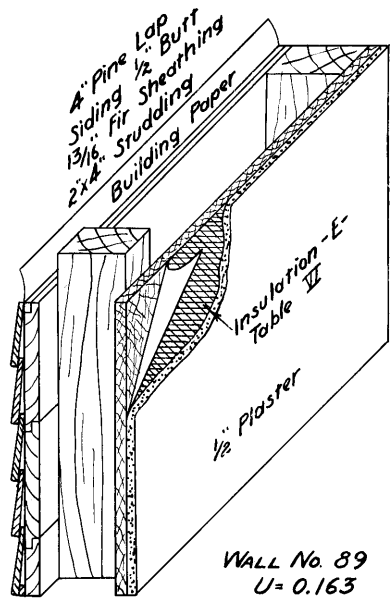
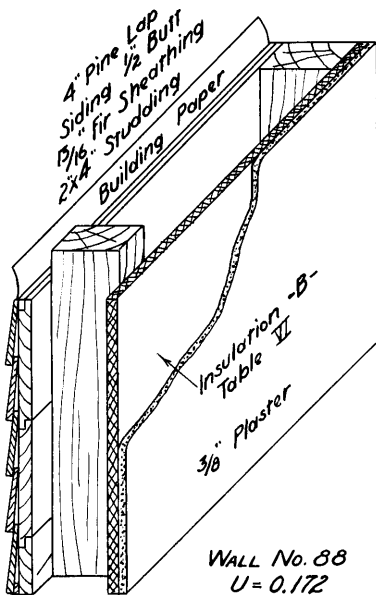
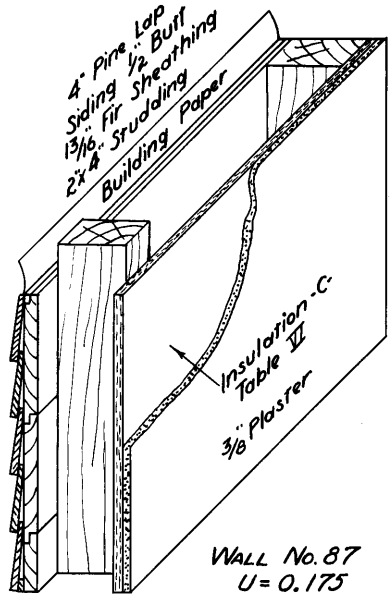
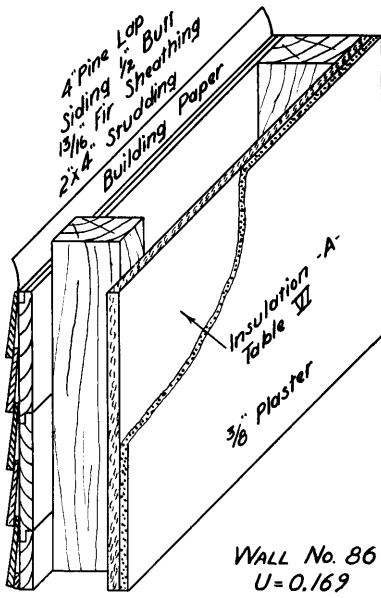


FIGURE 50. SECTIONAL VIEWS OF TEST WALLS

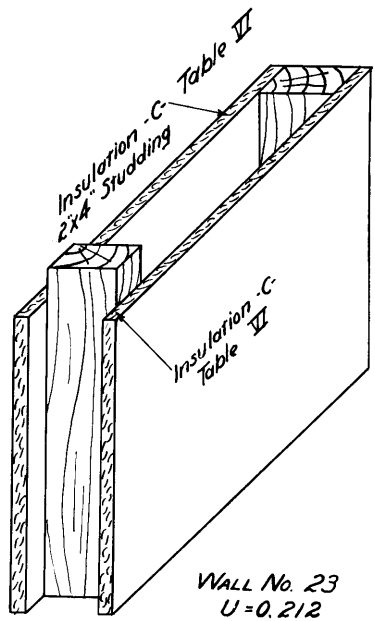
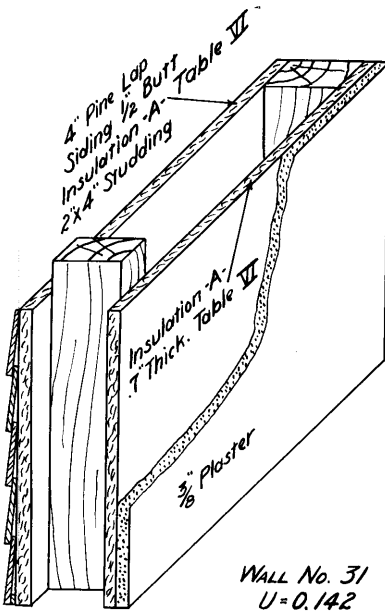
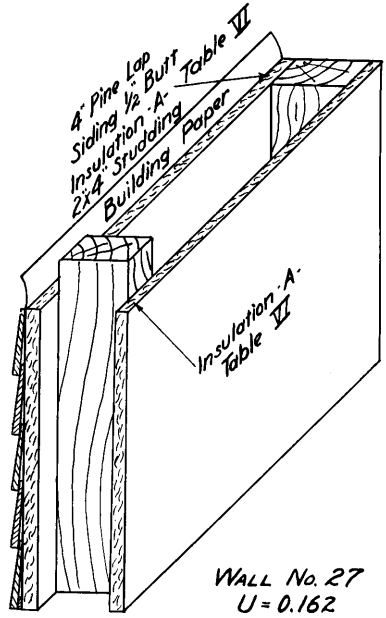
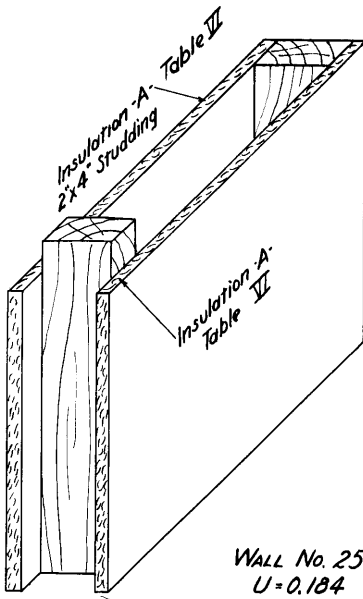


FIGURE 51. SECTIONAL VIEWS OF TEST WALLS

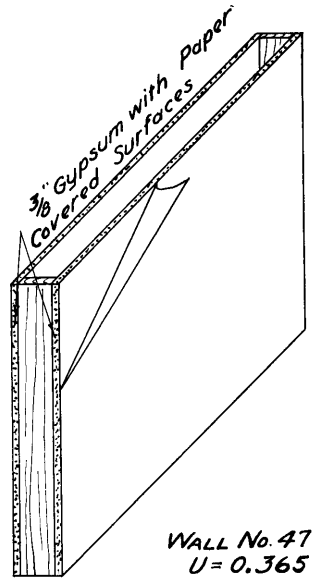
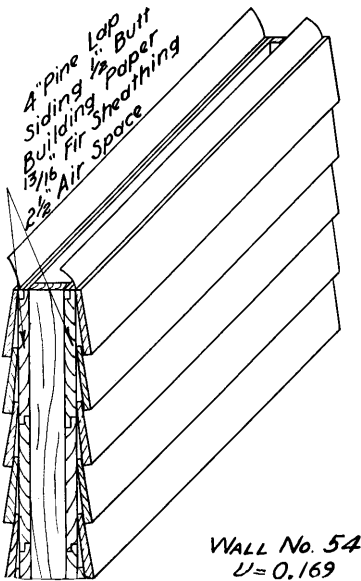
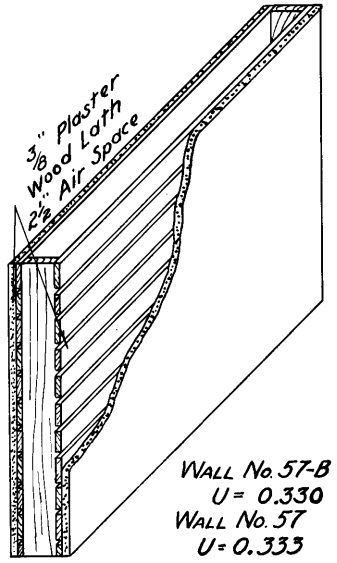
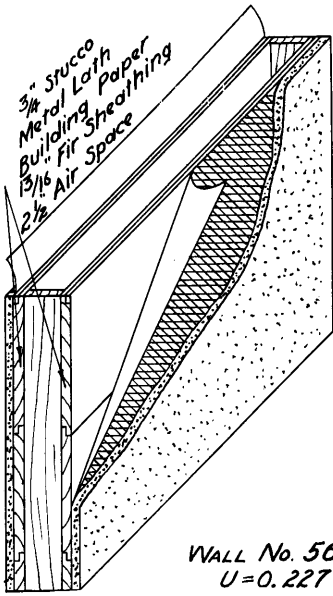


FIGURE 52. SECTIONAL VIEWS OF TEST WALLS

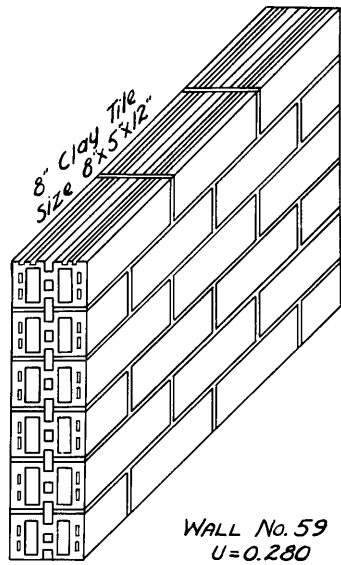
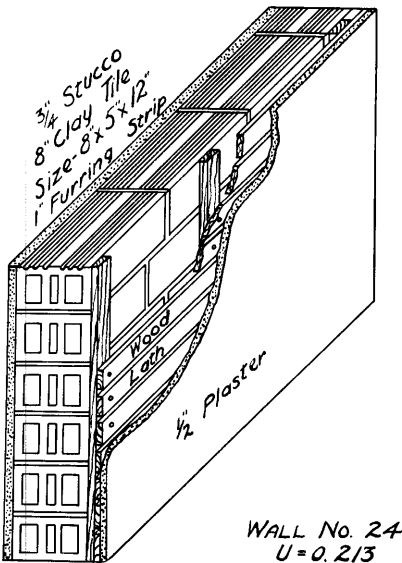
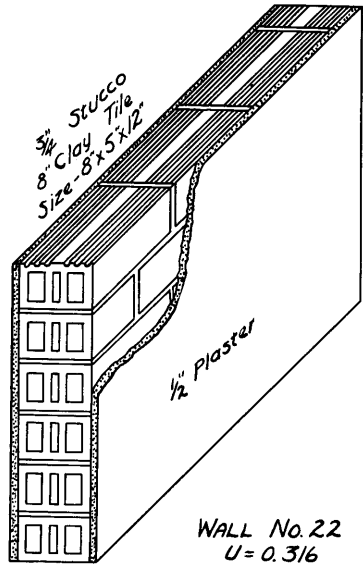
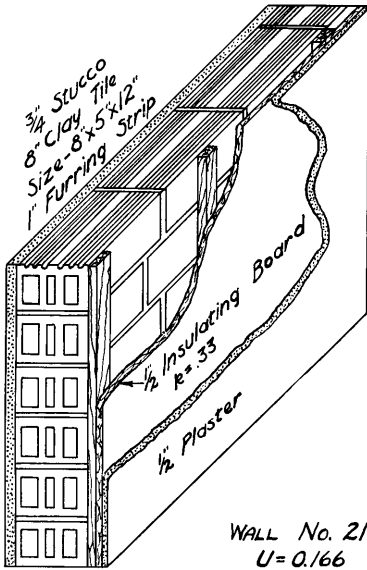
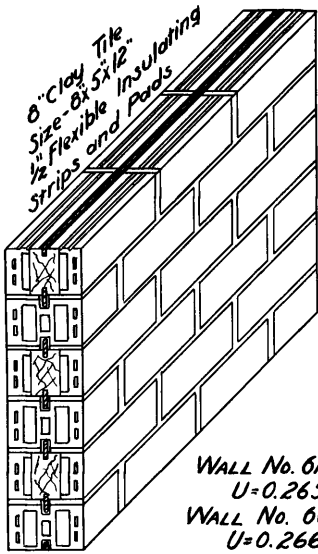
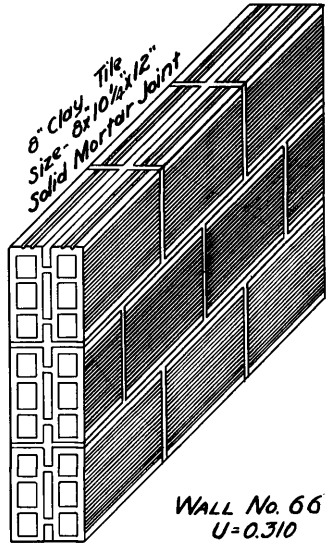


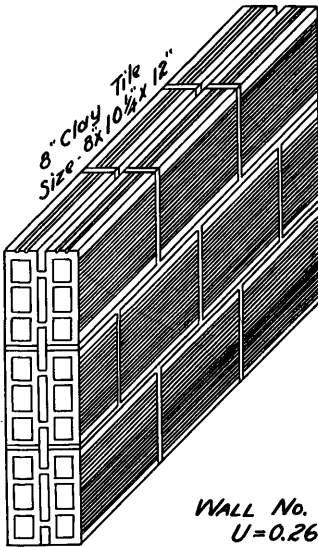
FIGURE 53. SECTIONAL VIEWS OF TEST WALLS



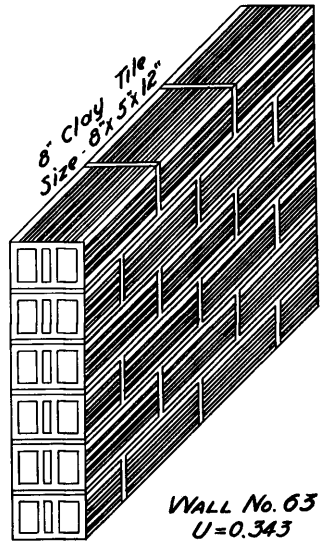
WALL No. 61-A
 $U=0.265$
 WALL No. 60
 $U=0.266$



WALL No. 66
 $U=0.310$

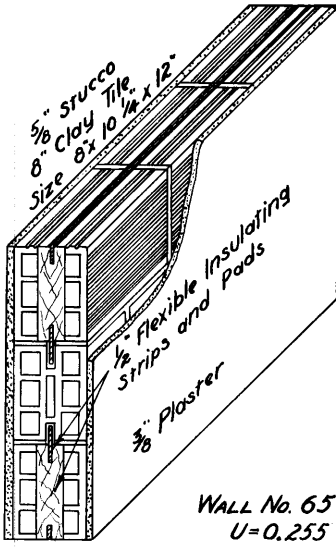


WALL No. 64
 $U=0.265$

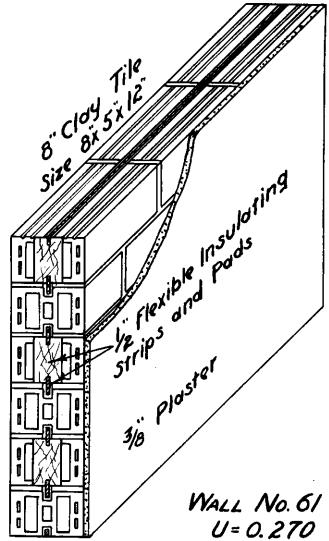


WALL No. 63
 $U=0.343$

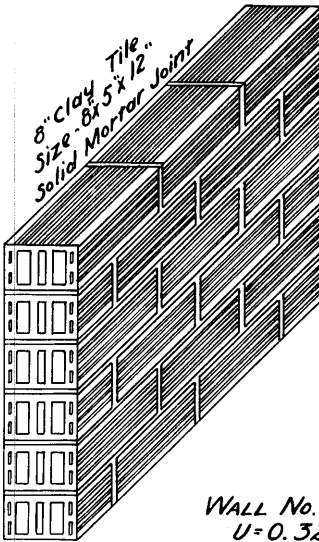
FIGURE 54. SECTIONAL VIEWS OF TEST WALLS



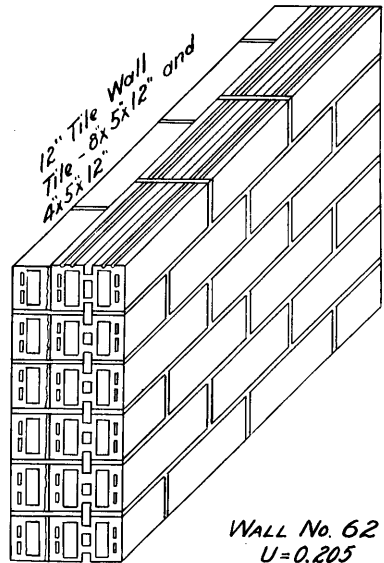
WALL No. 65
U = 0.255



WALL No. 61
U = 0.270

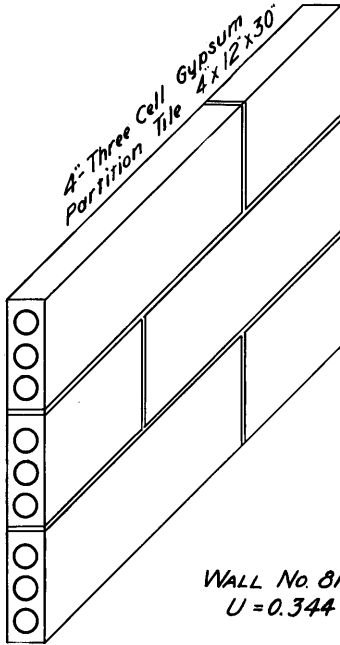


WALL No. 67
U = 0.320

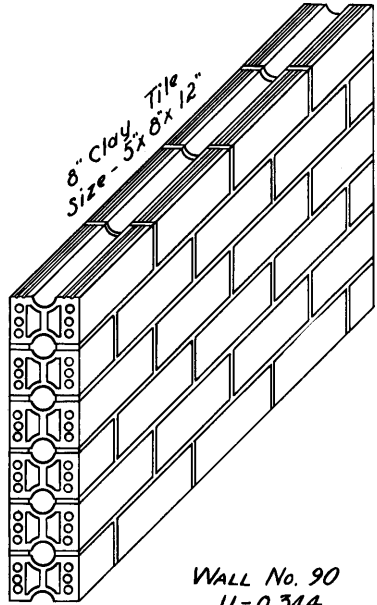


WALL No. 62
U = 0.205

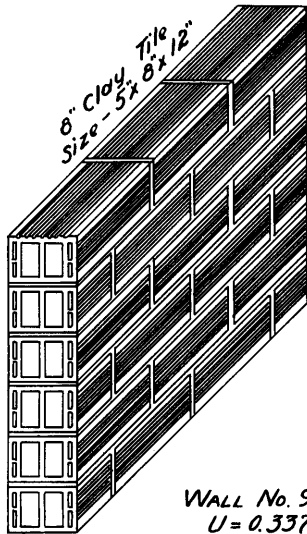
FIGURE 55. SECTIONAL VIEWS OF TEST WALLS



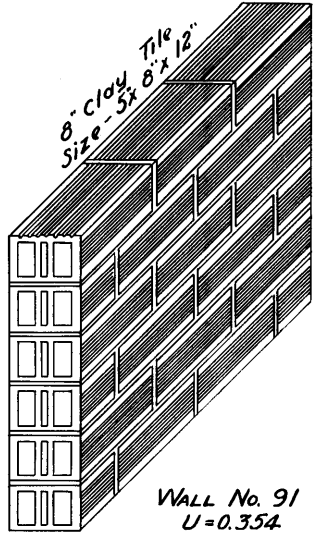
WALL No. 81
 $U = 0.344$



WALL No. 90
 $U = 0.344$

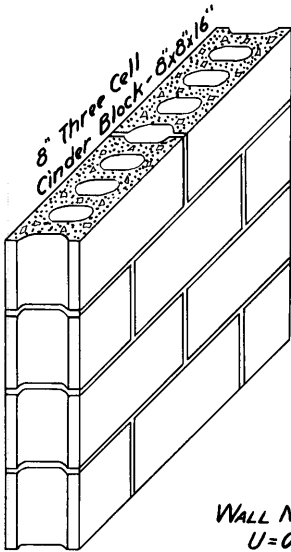


WALL No. 92
 $U = 0.337$

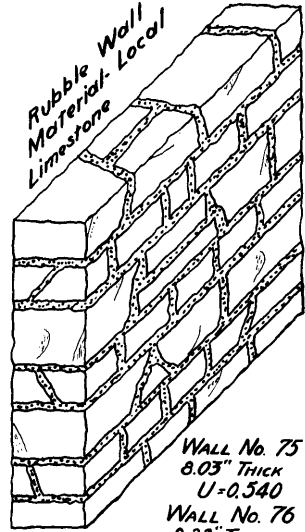


WALL No. 91
 $U = 0.354$

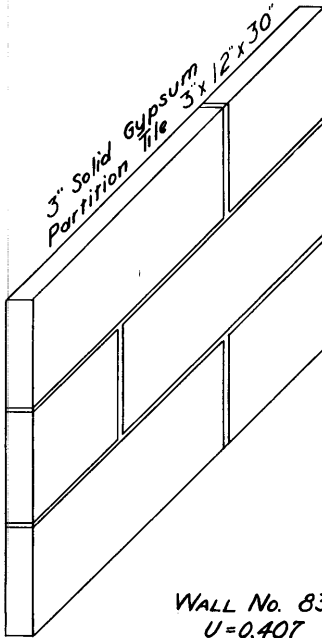
FIGURE 56. SECTIONAL VIEWS OF TEST WALLS



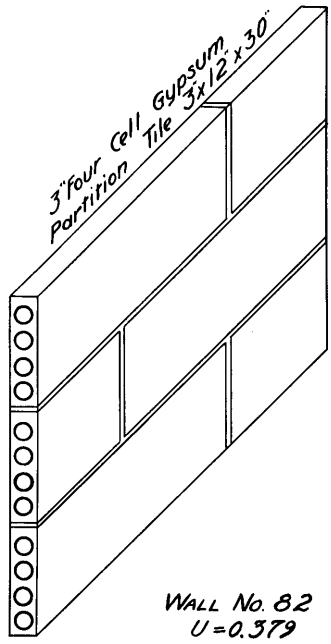
WALL No. 70
U=0.355



WALL No. 75
8.03" THICK
U=0.540
WALL No. 76
8.22" THICK
U=0.553

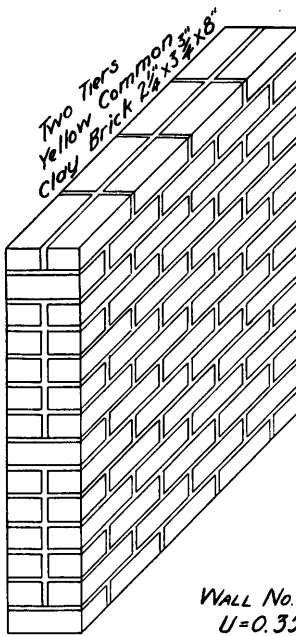


WALL No. 83
U=0.407

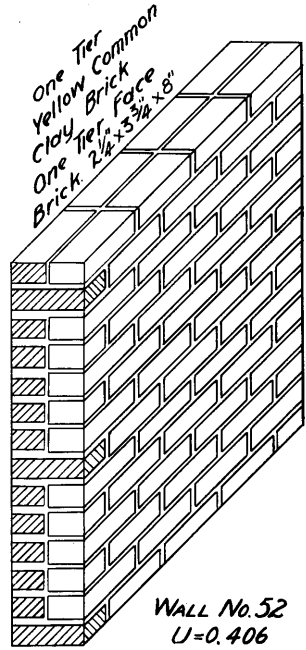


WALL No. 82
U=0.379

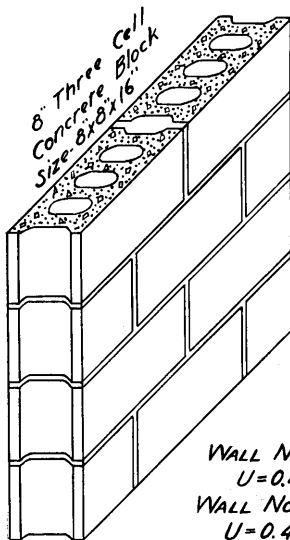
FIGURE 57. SECTIONAL VIEWS OF TEST WALLS



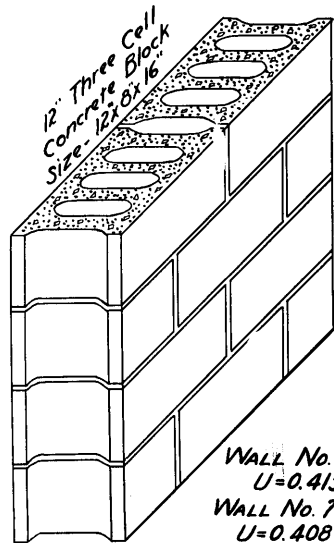
WALL No. 51
U=0.355



WALL No. 52
U=0.406



WALL No. 72
U=0.436
WALL No. 71
U=0.458



WALL No. 74
U=0.413
WALL No. 73
U=0.408

FIGURE 58. SECTIONAL VIEWS OF TEST WALLS

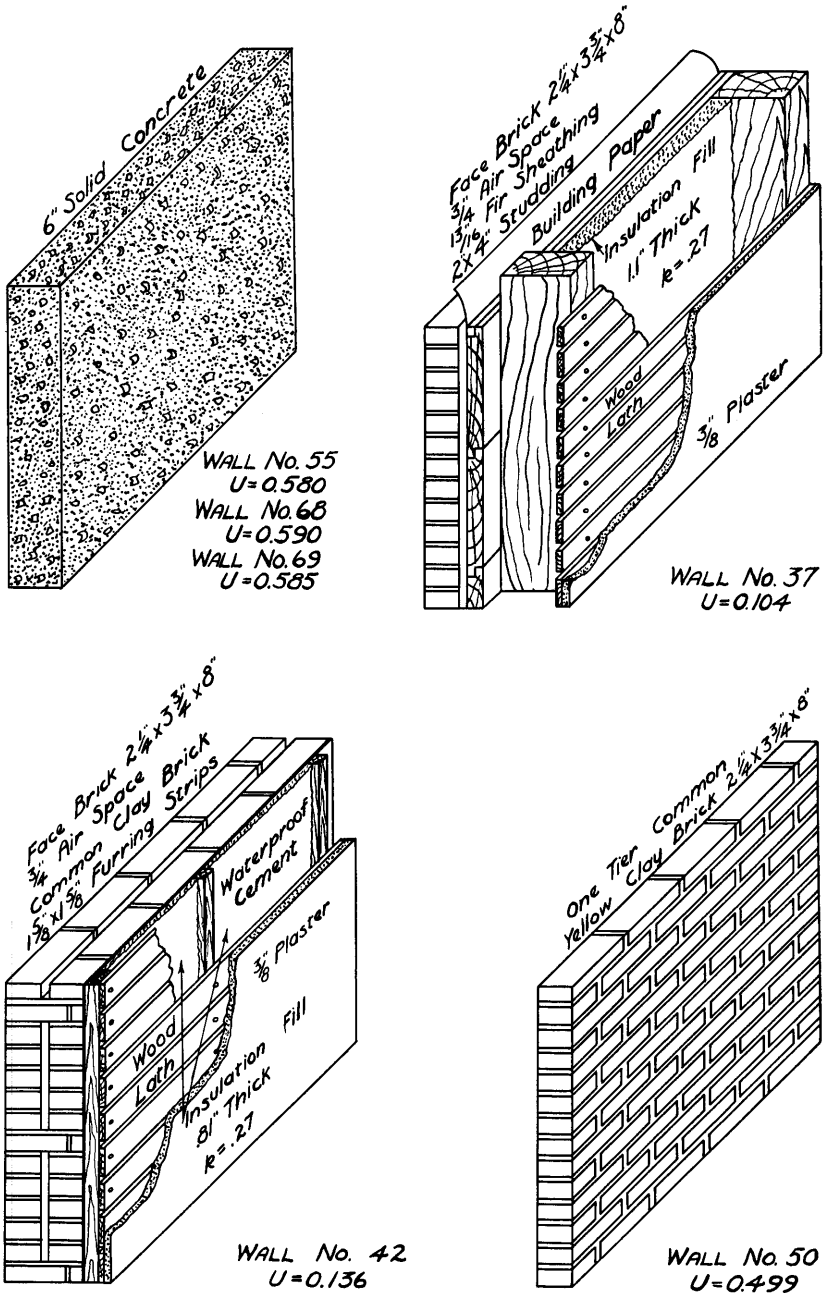


FIGURE 59. SECTIONAL VIEWS OF TEST WALLS

TABLE VII
SUMMARY OF RESULTS OF TESTS ON WALL CONSTRUCTION BY THE HOT BOX METHOD

DATE OF TEST	WALL No.	TEST No.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION U	
			High Side	Low Side	Mean Temp.	Inside, f_i	Outside, f_o	By Test	Corrected to 15-Mile Wind Velocity
12/22/27	7	401	80.7	-0.05	40.35	1.619	2.094	.216	.236
12/23/27	7	402	80.8	-0.10	40.35	1.619	2.081	.216	.236
1/24/28	7A	418	80.45	0.1	40.27	1.748	1.803	.211	.231
1/25/28	7A	419	80.5	0.4	40.45	1.769	1.732	.209	.228
12/19/27	8	400	81.2	-0.35	40.4	1.721	2.057	.226	.249
10/12/28	8A	496	79.87	0.0	39.93	1.503	1.726	.229	.252
10/16/28	8A	497	80.39	0.0	40.2	1.826	1.703	.222	.244
10/17/28	8A	498	80.33	0.02	40.17	1.866	1.802	.228	.251
12/7/28	8B	518	80.28	-0.41	39.93	1.584	1.455	.139	.147
4/10/28	9	452	80.1	0.0	40.05	1.647	1.856	.146	.154
4/11/28	9	453	80.1	0.0	40.05	1.629	1.780	.144	.152
12/28/27	10	403	80.4	-0.20	40.05	1.671	1.906	.184	.198
12/29/27	10	404	80.4	-0.30	40.0	1.665	1.918	.187	.202
1/6/28	11	409	80.4	-0.10	40.15	1.736	2.515	.153	.163
1/9/28	11	410	80.4	0.0	40.2	1.795	2.442	.152	.162
12/30/27	12	405	80.4	0.0	40.2	1.690	1.739	.113	.118
12/31/27	12	406	80.35	-0.1	40.2	1.650	1.811	.115	.120
1/26/28	12	420	80.5	-0.05	40.25	1.745	1.762	.117	.123
1/12/28	15	413	80.25	-0.15	40.0	1.750	2.595	.134	.141
1/13/28	15	414	80.2	-0.05	40.07	1.784	2.933	.133	.140
1/18/28	16	415	80.5	0.0	40.25	1.776	1.993	.141	.149
1/19/28	16	416	80.5	-0.05	40.25	1.747	1.943	.141	.149
1/20/28	16	417	80.5	-0.15	40.15	1.786	1.719	.142	.150
3/14/28	17	442	80.55	-0.20	40.15	1.754	1.490	.116	.121

TABLE VII—Continued

DATE OF TEST	WALL NO.	TEST NO.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION U	
			High Side	Low Side	Mean Temp.	Inside, f_i	Outside, f_o	By Test	Corrected to 15-Mile Wind Velocity
3/16/28	17	443	80.65	0.1	40.3	1.827	1.399	.115	.120
5/12/28	18	466	80.7	-0.05	40.37	1.808	1.395	.110	.116
5/13/28	18	467	80.7	2.6	41.65	1.809	1.394	.109	.115
7/10/28	18	478	80.25	-0.10	40.07	1.786	1.469	.108	.114
2/3/28	19	425	80.55	-0.2	40.15	1.625	1.825	.156	.166
2/8/28	19	426	80.8	0.9	40.9	1.639	1.835	.154	.165
2/17/28	21	431	80.5	0.0	40.2	1.844	1.403	.167	.181
2/21/28	21	432	80.6	0.0	40.3	1.830	1.629	.166	.180
3/21/28	22	445	80.05	0.05	40.1	2.007	2.188	.318	.375
3/22/28	22	446	80.2	0.0	40.1	1.981	2.168	.314	.369
2/28/28	23	434	80.5	0.3	40.35	1.753	1.684	.212	.232
2/29/28	23	435	80.45	0.05	40.3	1.737	1.637	.213	.233
3/28/28	24	448	80.2	-0.05	40.1	1.781	1.651	.212	.232
3/29/28	24	449	80.2	0.0	40.1	1.789	1.847	.214	.234
3/8/28	25	439	80.5	0.0	40.25	1.803	1.253	.184	.198
3/9/28	25	440	80.5	0.05	40.28	1.819	1.280	.185	.199
4/13/28	26	454	80.15	0.0	40.07	1.648	1.476	.168	.180
4/14/28	26	455	80.2	0.0	40.1	1.649	1.470	.169	.181
4/3/28	27	450	80.05	-0.05	40.0	1.921	1.387	.162	.173
4/4/28	27	451	80.05	-0.05	40.0	1.887	1.629	.163	.174
4/17/28	28	456	80.3	0.0	40.15	1.720	1.419	.141	.149
4/18/28	28	457	80.15	0.0	40.07	1.761	1.403	.142	.150
4/20/28	29	458	80.2	0.05	40.13	1.758	1.609	.154	.165
4/24/28	29	459	80.2	0.0	40.1	1.773	1.579	.153	.164
5/1/28	30	462	80.1	0.0	40.5	1.785	1.542	.154	.165

TABLE VII—Continued

DATE OF TEST	WALL No.	TEST No.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION <i>U</i>	
			High Side	Low Side	Mean Temp.	Inside, f_i	Outside, f_o	By Test	Corrected to 15-Mile Wind Velocity
5/2/28	30	463	80.1	0.3	40.2	1.803	1.518	.156	.166
4/26/28	31	460	80.15	0.0	40.07	1.649	1.517	.142	.150
4/27/28	31	461	80.05	0.0	40.02	1.684	1.527	.143	.151
5/24/28	32	468	81.2	0.6	40.9	1.765	1.715	.153	.164
5/25/28	32	469	81.4	0.35	40.87	1.700	1.643	.151	.161
11/27/28	32	513	79.85	-0.08	39.89	1.798	1.614	.154	.165
6/6/28	33	470	80.25	0.0	40.12	1.867	1.387	.117	.123
6/7/28	33	471	80.25	0.0	40.12	1.794	1.307	.114	.119
6/8/28	33	472	80.2	0.0	40.1	1.778	1.422	.115	.120
6/21/28	34	473	80.25	0.3	40.27	1.664	2.110	.128	.135
6/22/28	34	474	80.3	-0.05	40.12	1.645	2.116	.129	.136
6/26/28	35	475	80.25	2.6	42.57	1.794	1.540	.123	.129
7/3/28	36	476	80.25	2.6	41.42	1.815	1.171	.130	.137
7/6/28	36	477	80.25	0.0	40.12	1.768	1.349	.131	.138
9/1/28	37	487	80.3	-0.15	40.07	1.675	.859	.101	.106
9/27/28	37	488	80.25	-0.35	39.95	1.819	.914	.107	.113
10/2/28	37	490	80.37	-0.23	40.07	1.834	.720	.099	.104
11/23/28	37	512	81.48	-1.0	40.24	1.855	1.291	.106	.111
10/19/28	40B	499	80.13	-0.02	40.05	1.639	1.583	.109	.114
10/23/28	40B	500	80.14	0.02	40.08	1.641	1.599	.109	.114
3/26/29	40B	555	79.27	0.24	39.75	1.829	1.379	.109	.114
12/20/28	41	523	79.86	0.97	40.41	1.931	1.619	.148	.157
12/21/28	41	524	79.89	-0.37	39.76	1.956	1.785	.148	.157
10/30/28	42	502	80.37	0.00	40.18	1.658	1.235	.135	.144
10/30/28	42	502A	80.39	0.00	40.19	1.678	1.465	.138	.147
12/4/28	47	516	80.26	-0.03	40.11	1.667	1.448	.365	.427

TABLE VII—Continued

DATE OF TEST	WALL NO.	TEST NO.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION <i>U</i>	
			High Side	Low Side	Mean Temp.	Inside, f_i	Outside, f_o	By Test	Corrected to 15-Mile Wind Velocity
12/27/28	50	525	79.81	-0.57	39.62	1.680	1.567	.499	.640
2/5/29	50	541	80.46	-0.29	40.08	1.662	1.624	.499	.640
1/29/29	51	539	80.67	-0.38	40.14	1.690	1.548	.357	.425
4/23/29	51	566	80.59	-0.37	40.11	1.714	1.591	.354	.422
2/1/29	52	540	80.39	-0.32	40.03	1.808	1.571	.412	.504
4/18/29	52	565	80.66	-0.57	40.04	1.841	1.619	.401	.487
1/2/29	53A	527	79.57	0.69	40.13	1.685	1.671	.223	.245
1/7/29	53A	530	80.47	-0.63	39.92	1.561	1.588	.217	.238
1/8/29	53A	531	80.50	-0.82	39.84	1.553	1.644	.219	.240
1/12/29	53B	533	80.31	-0.69	39.81	1.781	1.574	.155	.166
1/15/29	53B	534	80.15	0.05	40.10	1.761	1.579	.153	.164
1/18/29	53C	535	80.25	-0.04	40.10	1.586	1.528	.177	.190
1/21/29	53D	536	80.10	-0.03	40.03	1.650	1.525	.120	.126
1/23/29	53E	537	79.60	-0.17	39.72	1.646	1.580	.184	.198
3/27/29	53F	556	79.31	0.40	39.85	1.669	1.564	.217	.235
1/10/29	54	532	80.33	-0.51	39.91	1.625	1.524	.171	.183
4/30/29	54	568	80.79	-0.98	39.90	1.716	1.526	.168	.180
1/25/29	55	538	80.81	-0.48	40.17	1.646	1.668	.588	.792
4/26/29	55	567	80.90	-1.07	39.91	1.646	1.625	.572	.762
11/5/29	55	583	80.27	-0.02	40.12	1.665	1.605	.579	.776
9/23/30	55	597	79.5	0.40	39.95	2.615	1.721	.582	.780
2/7/29	56	542	79.79	-0.04	39.88	1.768	1.486	.227	.254
2/8/29	56	543	79.81	0.0	39.90	1.777	1.493	.227	.254
2/14/29	57	544	79.73	-0.16	39.78	1.700	1.585	.331	.381
2/15/29	57	545	79.74	0.05	39.89	1.716	1.677	.335	.387
5/10/29	57B	573	79.47	-0.33	39.57	1.649	1.511	.330	.380

TABLE VII—Continued

DATE OF TEST	WALL No.	TEST No.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION U	
			High Side	Low Side	Mean Temp.	Inside, f_i	Outside, f_o	By Test	Corrected to 15-Mile
									Wind Velocity
6/18/29	59	575	80.94	-0.90	40.02	1.747	1.505	.280	.319
6/20/29	60	576	81.24	-1.08	40.08	1.831	1.474	.266	.301
6/22/29	61	577	79.93	0.02	39.98	1.602	1.561	.270	.306
7/9/29	61A	582	79.98	0.13	40.05	1.777	1.480	.265	.300
6/27/29	62	579	79.92	0.01	39.96	1.815	1.884	.205	.226
7/2/29	63	580	79.93	0.22	40.07	1.726	1.800	.343	.403
6/25/29	64	578	79.94	0.14	40.04	1.708	1.318	.265	.299
7/6/29	65	581	79.99	0.13	40.06	1.733	1.528	.255	.290
5/24/30	66	589	80.30	-0.05	40.12	1.711	1.627	.310	.360
5/27/30	67	590	80.40	-0.15	40.12	1.732	1.654	.320	.372
10/2/30	68	599	79.81	0.05	39.93	1.803	2.247	.590	.795
9/26/30	69	598	79.89	0.09	39.99	1.924	1.655	.585	.785
6/10/30	70	594	80.09	0.10	40.09	1.544	1.981	.358	.425
10/9/30	70	601	79.80	0.20	40.00	1.618	1.618	.353	.418
6/13/30	71	595	80.10	0.15	40.12	1.594	1.605	.460	.576
10/7/30	71	600	79.85	0.10	39.97	1.662	1.559	.457	.571
6/6/30	72	593	80.07	0.0	40.04	1.571	1.575	.436	.540
6/3/30	73	592	79.85	0.35	40.10	1.632	1.648	.408	.497
6/18/30	74	596	80.08	0.33	40.20	1.604	1.895	.413	.504
1/20/31	75	627	79.98	0.13	40.05	1.623	1.477	.540	.707
1/14/31	76	626	79.90	0.04	39.97	1.622	1.529	.553	.729
5/29/30	77	591	79.90	0.10	40.00	1.428	1.789	.097	.101
10/15/30	78	602	79.82	0.52	40.17	1.954	1.616	.691	...
2/5/31	78B	631	80.22	-0.43	39.89	1.246	0.923	.460	...
10/27/30	79	606	78.89	-0.04	39.42	1.761	1.588	.264	...
10/30/30	79A	608	80.16	-0.08	40.04	1.280	1.164	.169	...

TABLE VII—Continued

DATE OF TEST	WALL NO.	TEST NO.	AIR TEMPERATURES, DEG. F.			SURFACE CONSTANTS		COEFFICIENT OF TRANSMISSION <i>U</i>	
			High Side	Low Side	Mean Temp.	Inside, f_1	Outside, f_0	By Test	Corrected to 15-Mile Wind Velocity
11/10/30	79B	610	80.12	0.06	40.09	1.230	1.467	.175	...
11/18/30	79B	611	79.97	0.02	39.99	1.252	1.291	.171	...
10/28/30	80	607	79.87	-0.27	39.80	1.746	1.407	.257	...
5/26/31	80A	661	81.00	2.08	41.54	0.814	1.757	.130	...
1/6/31	81	624	79.06	-0.20	39.43	1.671	1.542	.344	.405
1/8/31	82	625	80.02	0.0	40.01	1.701	1.429	.379	.454
11/25/30	83	613	79.60	0.07	39.83	1.726	1.623	.407	.495
3/18/31	85	641	75.14	-0.06	37.54	1.512	1.298	.235	...
4/1/31	86	646	80.73	-0.06	40.34	1.519	1.390	.169	.181
4/9/31	87	649	80.80	-0.10	40.35	1.519	1.130	.175	.188
4/7/31	88	648	80.86	-0.02	40.42	1.572	1.347	.172	.185
4/6/31	89	647	80.74	-0.16	40.29	1.519	1.367	.163	.174
4/13/31	90	650	80.38	-0.17	40.10	1.661	1.533	.344	.405
4/16/31	91	651	80.27	-0.01	40.13	1.719	1.532	.354	.418
4/20/31	92	652	80.31	0.19	40.25	1.760	1.575	.337	.396

NOTE.—Average surface conductance (f_0) for walls as tested = 1.633.

Surface conductance (f_0) for pine surface for outside wind exposure of 15 miles per hour = 4.75.

Surface conductance (f_0) for stucco surface for outside wind exposure of 15 miles per hour = 7.50.

Surface conductance (f_0) for brick surface for outside wind exposure of 15 miles per hour = 6.10.

Surface conductance (f_0) for concrete, tile, cinder block, and rubble stone surfaces for outside wind exposure of 15 miles per hour = 5.78.

Surface conductance (f_0) for plaster surface for outside wind exposure of 15 miles per hour = 4.68.

VARIATIONS IN WALL CONSTRUCTION

Even tho two walls are built in the laboratory under rather careful supervision and after the same specifications, some variation in the materials and construction is to be expected. In several instances, duplicate walls were constructed and tested. In some the materials were selected from different lots and the walls were built at different times. Some examples with the variations found are as follows :

1. Walls 7A, 8, 8A, and 53F (Fig. 44) :

These walls were of frame construction with lath and plaster on the inside, and wood sheathing, building paper, and lap siding on the outside, surface. The coefficients for these walls varied from .209 to .229, a difference of approximately 9 per cent. This variation might be accounted for partially by the difference in conductivity of the lath and plaster as applied to the different walls, but mostly to the difference in conductivity of the sheathing and siding used in the outside construction. There is considerable variation, depending upon the density, moisture content, and cell structure, in the conductivity of wood, even for the same species.

2. Walls 7 and 53A (Fig. 44) :

These walls were of frame construction similar to the first group, with the exception that Gypsum Boards were used on the inside surface instead of lath and plaster. In this case, the variation in the coefficients was from .216 to .218, showing a very close agreement between the two walls.

3. Walls 11 and 30 (Fig. 44) :

In these walls, a rather uniform quality of insulating board was used as outside sheathing and as a plaster base. The results for the overall coefficients of conductivity range from .152 to .155—a very close agreement.

4. Walls 57 and 57B (Fig. 52) :

Tests of these walls gave coefficients of .330 and .333, respectively.

5. Walls 75 and 76 (Fig. 57) :

These walls were built of limestone approximately 8 inches thick, and gave coefficients of .540 and .553—a variation of 2.4 per cent.

6. Walls 71 and 72 (Fig. 58) :

These walls were built of 8-inch three-cell concrete blocks, the blocks being of the same construction but purchased from different manufacturers. The coefficients for these walls were .436 and .458.

In practice, walls constructed after the same specifications might show variations in conductivity coefficients even greater than those noted. This would be due partly to the differences in materials and partly to workmanship. Where materials of uniform construction are used and the walls are built by the same workman with reasonable care, it is

possible to get very close agreement between the coefficients of conductivity. If, however, materials with large variations in thermal properties are used, or, if the walls are poorly constructed, the thermal properties of the finished walls may not agree with those shown by tests on laboratory samples.

FRAME WALLS

A great variety of walls comes under the head of Frame Construction. These walls may vary greatly as to the inside and outside surface finish, and, also, as to the treatment of air space between the studs. All those which have been tested in this group have been built up of $2'' \times 4''$ studdings placed 16 inches on center. Providing the air space between these studs had had the same treatment and the surfaces of the walls had been of the same construction, the results would have been substantially the same if 2×6 studdings placed 16 inches on center had been used.

The walls shown in Figures 44, 50, and 51 show typical construction for frame walls without insulating material between the studs. A study of the results of tests on these walls will show that the insulating value of the wall is progressively increased as better insulating materials are used for outside sheathing or plaster base.

The walls shown in Figures 45, 46, 47, 48, and 49 show different exterior construction with various applications of flexible insulating materials between the studs. In these walls, the insulating material is applied as an additional insulation and does not add to the structural value of the wall as did the insulating materials of the previous group. A study of these walls will show that the method of application of the insulating material, as well as its insulating value, has an appreciable effect upon the overall heat transmission coefficient of the wall.

INSULATING VALUE OF MATERIALS AS AFFECTED BY THEIR APPLICATION

Consider specifically Walls 12 and 16 of Figure 45. Each of these walls is constructed of the same material and, in addition to the structural material in the wall, has a flexible insulation added. This insulation is covered with paper and is, therefore, impervious to air passage. In Wall 12, the insulation is flanged between the studs and sealed at the top and bottom. In Wall 16, it has been nailed to the outside of the studs underneath the sheathing. The coefficients for these walls are .115 and .141, respectively, showing a considerable advantage for the wall with the material flanged between the studs. This point is

often overlooked in the construction of a wall. It is cheaper to nail the material on the studding underneath the sheathing; but the results are not as satisfactory. This difference may not be as great for materials that are not impervious to the passage of air. For instance, Walls 19 and 9 of Figure 46 are constructed of the same materials, the insulating material being very porous in construction. In this case, the wall in which the insulating material has been placed up against the sheathing gives a better result than the wall in which the insulating material was flanged midway in the space between the studs. This is due to the fact that the insulating material is porous, and the passage of air between the two air spaces of Wall 19 breaks down the effectiveness of the insulation, or, in other words, heat is transferred from one air space to the other by convected air currents.

If an insulating material is applied between the studs of a frame wall in such a way as to divide the air space into two parts, each at least an inch or more thick, the insulating value of the air space has been doubled. To realize this additional insulation due to the air spaces, care must be taken to prevent the passage of air from one space to the other. This air may filter through the materials or it may pass around them at top and bottom if they are not properly sealed.

In order to determine the comparative values of good and poor construction when the insulating material is placed midway between the studs, Walls 53D, 53E, 53B, and 53C of Figure 47 were constructed and tested. In Walls 53D and 53E, the same materials were used, the only difference was that the insulating material placed between the studs was carefully sealed at the top and bottom for Wall 53D, whereas for 53E it was cut off at the top and bottom for a distance of 1 inch to allow free passage of air between the two air spaces and to represent what might be considered very poor construction. The transmission coefficients for these walls were .12 and .184, respectively, or an increase of over 50 per cent in the heat transmission for the wall in which the insulation was not sealed at top and bottom. When the insulation is not sealed, the warm air passes up on the inside of the wall, over the opening at the top of the insulation, and down on the outside, thus carrying the heat from the warm air space to the cold air space by convection currents and eliminating the effect of the insulation.

In Walls 53B and 53C, the same insulating materials were used, that of 53C being cut off at the top and bottom in order to allow free air passage. In this case, the insulating material was of a porous nature, and, as will be noted, the effect of cutting the top and bottom was not

as great as in the previous case. The coefficients of conductivity were .154 and .177, respectively. Wall 53B is of the same construction as Wall 19, Figure 46, except that sheet rock was substituted for lath and plaster. The coefficients are .154 and .155, respectively.

Walls 28, 29, and 8B of Figure 48 show the effect of dividing the air space between the studs into three parts by comparatively thin materials. In these walls, the additional insulation is due almost entirely to the sealed air spaces. It is essential that these be properly sealed.

Walls 28 and 29 were constructed of exactly the same materials. In Wall 28, the insulating material is flanged between the studs and the air spaces are of uniform thickness throughout, while in Wall 29 the material is nailed to the surface of the studs underneath the sheathing and the lath, making the air spaces near the studs unevenly divided. Previous tests have shown that air spaces of less than about $\frac{3}{4}$ inch do not give the full insulating value. The coefficients for Walls 28 and 29 are .142 and .153, respectively. The better value for the first wall is due to the more efficient arrangement of air spaces.

FILL INSULATIONS

The four walls of Figure 49 show different types of fill insulation as placed between the studs. The value of such insulation depends upon its thermal conductivity and the thickness used. It usually does not have structural value.

CLAY TILE WALLS, TEST RESULTS

Figures 53, 54, 55, and 56 show a group of fifteen clay tile walls. Fourteen of these walls are 8 inches thick, are built with tile of different cell structure, and are treated differently as to joints and surface finish. The range in values of the conductivity coefficient U for the unfinished walls is from .354 for Wall 91 (Fig. 56) to .265 for Wall 64 (Fig. 54).

Walls 63 and 91 are built of a common type of three-cell tile, the construction being similar altho the tile was obtained from different manufacturers. The coefficients for these walls are .343 and .354, respectively, which may be taken as reasonable averages for this type of construction.

In Walls 92 and 67 the air cells have been broken up in such a manner as to give substantially four cells for Wall 92 and five cells for Wall 67. The coefficients of conductivity are .337 and .320, respectively, indicating that, as the air cells are broken up into greater numbers, the conductivity of the finished wall is decreased.

In each of the four walls, Nos. 63, 91, 92, and 67, there is a direct path for the flow of heat through the top and bottom surfaces of the

individual tile. In other words, there is a direct line of low heat-resisting material through which heat may flow from the hot to the cold surface of the wall. As a direct contrast to this, consider Wall 64 in which the air spaces are staggered, giving a longer path through the material for the flow of heat from surface to surface. In this case the coefficient U is .265—a material reduction over the other type. Wall 66 was built of the same tile as Wall 64, but the joints were filled solid with mortar. The coefficient was increased to .31 as compared with .265 when the joints were not filled. Wall 65 was built of the same tile as Wall 64, but, for Wall 65, insulating strips were placed horizontally in the open air spaces at the joints, and insulating pads were placed at the end of each tile (Fig. 55). These insulating pads and strips gave slightly better insulation than the air space and prevented any mortar from getting into the joints, and, as shown from the results, reduced the coefficient to .255 as compared with .265 without the strips. This reduction, however, may have been partly due to the surface finish on the wall.

Walls 59, 60, and 61A were built of the same tile, the difference being that Walls 60 and 61A have insulating strips placed in the joints, filling the central air space between the tile, and, also, insulating pads at the end of the tile. In these walls, the insulating strips reduced the coefficient from .28 to .265. Wall 61 was of the same construction as Walls 60 and 61A, with the exception that $\frac{3}{8}$ -inch plaster was applied to the inner surface of Wall 61. In this case, the coefficient was .27 as compared with .265 without the plaster. This increase may have been due to some slight difference in surface coefficients or to a difference in construction which can always be expected in walls of this type.

Wall 62 was built of the same tile as Wall 59, the difference being that it was built 12 inches wide, using $1\frac{1}{2}$ thicknesses of the tile. If, for these walls, the surface coefficients are deducted, it is found that the conductances are proportional to the thicknesses.

In general, the efficiency of a tile wall is increased by breaking up the air spaces and by eliminating any direct paths or tile connections between the two surfaces of the wall. The greatest improvement seems to be possible by breaking up the direct path for heat flow.

The effect of different surface finishes on the tile walls is shown by Walls 21, 22, and 24 of Figure 53. In these walls the same tile was used, the exterior finish in each case being $\frac{3}{4}$ -inch stucco and the interior, $\frac{1}{2}$ -inch plaster applied directly to the tile for Wall No. 22; applied to wood lath furred out for Wall No. 24, and to $\frac{1}{2}$ -inch insulating board furred out for Wall No. 21. Wood lath on 1-inch furring strips reduces the coefficient from .316 to .213, while $\frac{1}{2}$ -inch insulating board A on 1-inch furring strips reduces it to .167.

CONCRETE WALLS, TEST RESULTS

Of the concrete walls, Nos. 55, 68, and 69 (Fig. 59) were of monolithic construction, Nos. 71 and 72 (Fig. 58) were built of 8-inch three-cell concrete blocks, and Nos. 73 and 74 (Fig. 58) were built of 12-inch three-cell concrete blocks. Referring to the first three, No. 55 was built of a 1:2:4 mix and Nos. 68 and 69 were built of a 1:2½:4 mix. Wall 68 and Wall 69 were mixed with water to give a 6- and a 3-inch slump, respectively. In all cases, No. 4 sand, that is, 95 per cent passing No. 4 sieve, was used, and the gravel was graded from 1½ inches to ¼ inch. The results of these three tests were so close as to indicate that the slump tests had nothing to do with the thermal conductivity of the material. If, for the average result of .585, surface coefficients of 1.65 be deducted, the conductivity coefficient per inch of concrete is found to be 12. This is somewhat higher than has ordinarily been taken for concrete, but checks very favorably with other recent test results.

The two 8-inch concrete block walls, Nos. 71 and 72, were built of blocks of the same dimensions but were purchased from different manufacturers. The variation, from .436 to .458, in these test results may be accounted for partly by the possible difference in the amount of mortar placed in the joints, by a difference in the aggregate used, and, possibly, to experimental differences. The 12-inch concrete block walls 74 and 73 were likewise built from blocks of the same dimensions but purchased from different manufacturers. In this case, the test results, .408 and .413, show a very close agreement.

Wall 70 was built from 8-inch three-cell cinder-concrete blocks purchased on the open market. In these blocks, the aggregate was made completely of cinders, and the density was found to be 105 pounds per cubic foot. There is naturally a variation in cinders, and any one test cannot be considered as a standard. However, the coefficient of .355 as compared with that of .447 for walls of the same type of concrete block indicates a considerable reduction in heat transmission for cinder-concrete.

BRICK WALLS, TEST RESULTS

In Figures 58 and 59, five brick walls are shown which are constructed either entirely of brick or of brick in combination with other materials. Walls 50 and 51 are both constructed of common yellow bricks, $8 \times 3\frac{3}{4} \times 2\frac{1}{2}$ inches in dimension. Wall 50 is a single row and Wall 51 a double row of brick. If for these walls the inside and outside coefficient of conductivity be taken as 1.65, the thermal conductivity $k = 5.0$. Wall 52 is an 8-inch wall composed of one layer

of 4-inch common yellow brick and one layer of pressed face brick. The coefficient U in this case is .406 as compared with .356 for the same thickness of wall built entirely of common brick, indicating that the surface brick has a much higher coefficient of conductivity than the common yellow clay brick. Wall 37 shows an insulated frame wall with a brick veneer finish and Wall 42 shows an 8-inch brick wall with insulating material, furring lath, and plaster on the inside.

GYPHUM PARTITION TILE WALLS, TEST RESULTS

Walls No. 81 of Figure 56 and Nos. 82 and 83 of Figure 57 were built of different thicknesses of gypsum partition tile as shown. By comparing the results for Walls 82 and 83, it is found that the cylindrical openings through the tile reduce the conductivity coefficient for the 3-inch wall from .407 to .379, or, in other words, these openings introduce a heat resistance into the wall equal to .18. If for Wall 83 the average inside and outside surface coefficients are taken to be 1.65, the thermal conductivity per inch of material is found to be 2.5.

RUBBLE WALLS, TEST RESULTS

Walls 75 and 76 were built of limestone and were approximately 8 inches thick. The conductivities were .54 and .553, respectively, a variation well within experimental limits for walls of this type. If the average coefficient is used and the surface coefficients are taken as 1.65 for both inside and outside surfaces, the thermal conductivity k for the wall is found to be 12.5, or slightly higher than that found for concrete walls. It is probable, however, that the surface coefficients may be somewhat higher than the average of 1.65, due to the uneven character of the surfaces.

CONDUCTIVITY OF HOMOGENEOUS INSULATING MATERIALS

The thermal conductivity of homogeneous insulating materials is affected by several factors. Those which should be particularly noted in making comparisons are:

1. Percentage of moisture in the material.
2. Mean temperature at which conductivity coefficient was determined.
3. Density of the material.

Most fiber insulating materials will absorb moisture from the atmosphere, an average being from 6 to 10 per cent by weight, depending upon the nature of the material and the condition of the atmosphere. The amount of moisture present has a direct bearing upon the conductivity, increasing the coefficient directly as the percentage of moisture is increased. In order that test results may be comparable, materials should

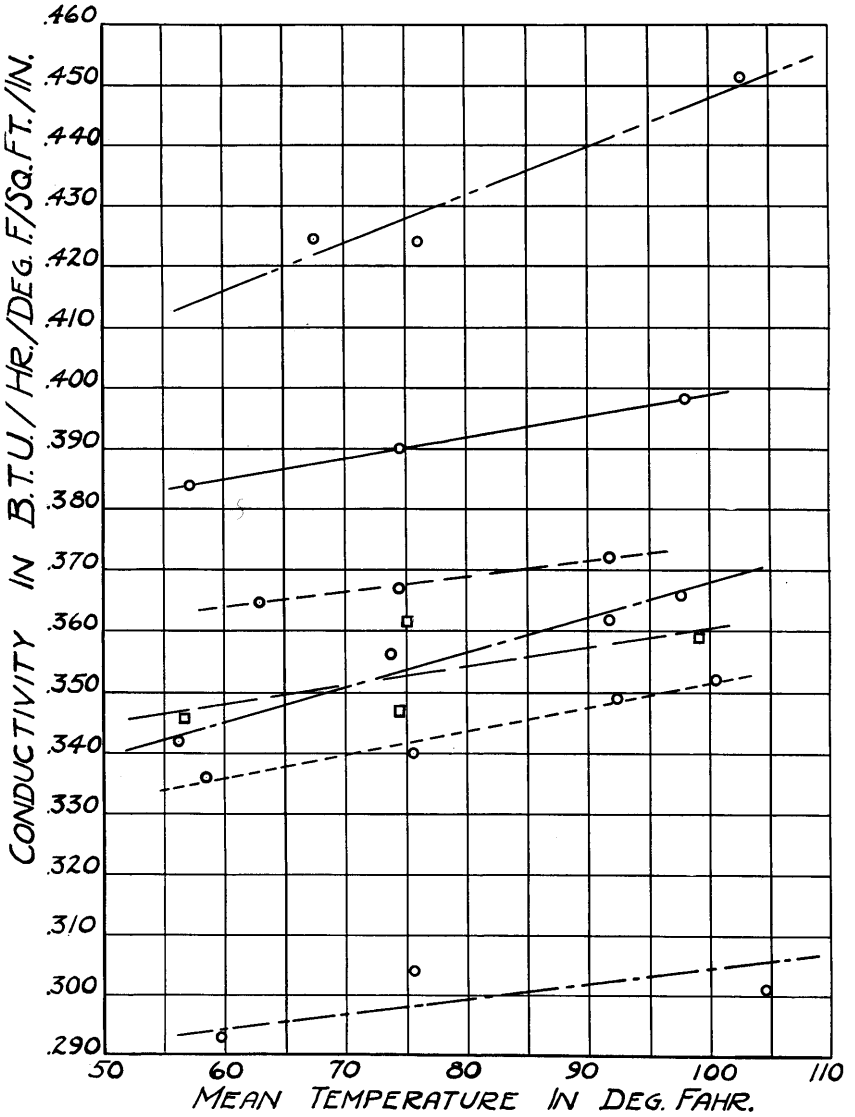


FIGURE 60. RELATION BETWEEN CONDUCTIVITY AND MEAN TEMPERATURE FOR VARIOUS INSULATING BOARDS

either be tested on a bone-dry basis or else subjected to the same atmospheric condition for a sufficient length of time prior to the test to give stable moisture content. In this case, the amount of moisture absorbed and the condition of the atmosphere should be reported. The materials reported in Table VI were tested under atmospheric conditions which were substantially the same as those under which the materials were used in the walls. The results of these tests, therefore, represent the actual insulating value of the materials as used in the different walls.

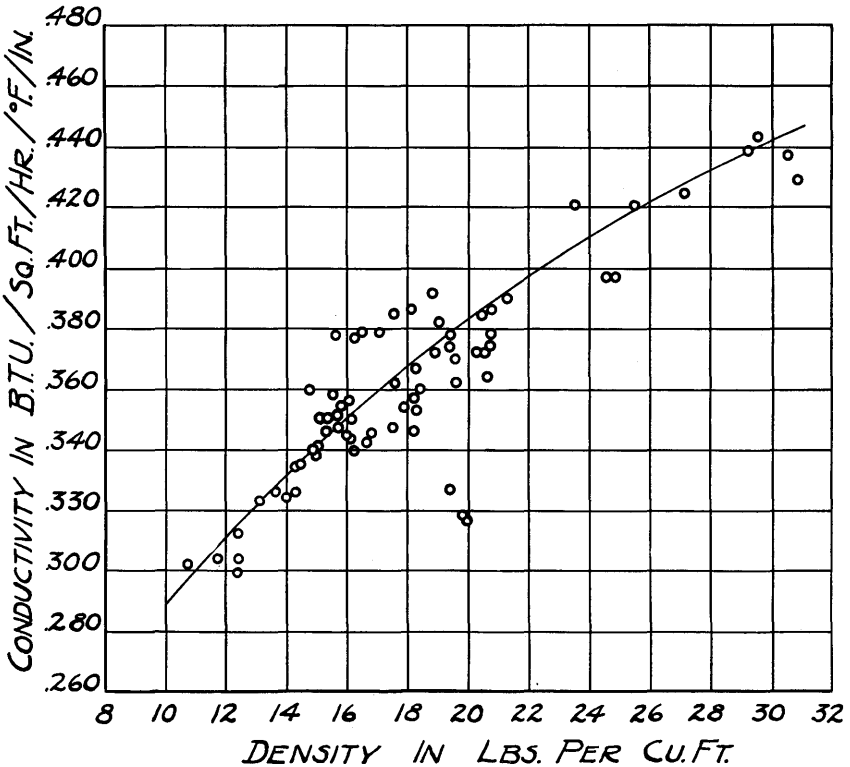


FIGURE 61. RELATION BETWEEN CONDUCTIVITY AND DENSITY FOR A GROUP OF DIFFERENT TYPES OF FIBER INSULATING BOARDS

The thermal conductivity of an insulating material varies directly with the mean temperature. The increase in conductivity for several different fiber insulating materials is shown in the curves of Figure 60. While the increase in conductivity with that in mean temperature is not the same for all of these materials, an average increase of .01 may be taken for each 30°F. increase in mean temperature, providing definite data are not available for the specific material.

In general, conductivity of fibrous insulating materials varies directly with density. For the same material with all other conditions equal, this variation is usually a straight line. Other factors, such as moisture, arrangement and character of the fiber, etc., may have a greater effect than density. The points shown on the curve of Figure 61 represent test results for a group of insulating boards made from the same type of fibrous materials but of different densities. In general, a line may be drawn through the entire group, representing the average density-conductivity variation. However, some points widely scattered from this line, indicate that, for these materials, other qualities than density affect the conductivity.

EFFECT OF MEAN TEMPERATURE ON COEFFICIENTS OF TRANSMISSION THROUGH BUILT-UP WALL SECTIONS

Several wall sections were tested by the hot box method at mean temperatures ranging from 32°F. to 108°F. The results are given in Table VIII and in the curves of Figure 62. As shown in the curves for these walls, the test points for each wall fall substantially on a straight line and give variations for mean temperatures which are practically the same for all of the walls tested, with the exception of Wall 80A, the surfaces of which were covered with aluminum foil.

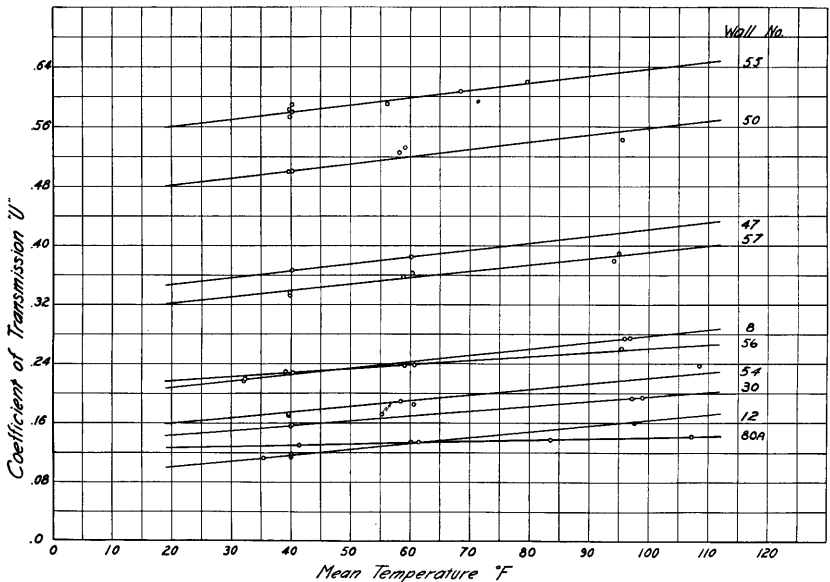


FIGURE 62. RELATION BETWEEN COEFFICIENT OF TRANSMISSION U AND MEAN TEMPERATURE FOR VARIOUS TYPES OF WALL CONSTRUCTION

TABLE VIII
RESULTS OF TESTS MADE TO DETERMINE THE EFFECT OF MEAN
TEMPERATURE ON THE COEFFICIENT OF TRANS-
MISSION U FOR WALL SECTIONS

WALL No.	TEST No.	AIR TEMP. HIGH SIDE, DEG. F.	AIR TEMP. LOW SIDE, DEG. F.	MEAN TEMP., DEG. F.	COEFFI- CIENT U
8	367	72.0	-7.6	32.2	.217
8	374	72.2	-7.4	32.4	.218
8	400	81.2	-0.35	40.4	.226
8	376	119.5	2.4	60.9	.238
8	374A	119.5	72.7	96.1	.274
8	375	119.5	74.4	96.9	.274
12	421	80.6	-9.1	35.7	.112
12	405	80.4	0.0	40.2	.113
12	406	80.35	-0.1	40.2	.115
12	420	80.5	-0.05	40.2	.117
12	423	123.8	-0.3	61.7	.133
12	424	123.8	71.7	97.7	.160
30	462	80.1	0.0	40.0	.154
30	463	80.1	0.3	40.2	.156
30	464	123.75	71.1	97.4	.193
30	465	123.75	74.5	99.1	.194
47	516	80.26	-0.03	40.1	.365
47	517	80.35	39.9	60.1	.383
50	525	79.81	-0.57	39.6	.499
50	541	80.46	-0.29	40.1	.499
50	551	117.60	-1.30	58.1	.525
50	550	117.55	0.75	59.1	.531
50	549	117.45	73.60	95.5	.542
54	532	80.33	-0.51	39.9	.171
54	568	80.79	-0.98	39.9	.168
54	560	79.00	31.80	55.4	.171
54	554	117.15	-0.20	58.5	.188
54	569	108.85	12.80	60.8	.184
54	570	147.10	70.15	108.6	.238
55	567	80.90	-1.07	39.9	.572
55	597	79.5	0.4	39.9	.582
55	583	80.27	-0.02	40.1	.579
55	538	80.81	-0.48	40.2	.588
55	653	94.95	17.50	56.2	.590
55	657	124.63	12.1	68.4	.607
55	656	124.75	34.60	79.7	.619
56	542	79.79	-0.04	39.88	.227
56	543	79.81	0.0	39.90	.227
56	548	117.65	-0.50	58.57	.238
56	552	117.45	73.50	95.48	.262

TABLE VIII—*Continued*

WALL No.	TEST No.	AIR TEMP. HIGH SIDE, DEG. F.	AIR TEMP. LOW SIDE, DEG. F.	MEAN TEMP., DEG. F.	COEFFI- CIENT <i>U</i>
57	544	79.73	-0.16	39.8	.331
57	545	79.74	0.05	39.9	.335
57	553	117.3	0.52	58.9	.357
57	557	121.2	-0.43	60.4	.362
57	546	117.5	71.4	94.4	.379
57	558	120.75	69.35	95.0	.389
57B	573	79.47	-0.33	39.57	.330
57B	572	115.55	19.05	67.30	.351
57B	571	147.15	75.05	111.10	.418
80A	661	81.00	2.08	41.5	.130
80A	664	99.74	20.02	60.0	.134
80A	665	121.31	45.80	83.6	.138
80A	663	133.72	81.13	107.4	.141
85	634	65.16	-15.89	24.63	.232
85	641	75.14	-0.06	37.54	.235
85	638	97.16	9.76	53.46	.279
85	637	97.07	40.60	68.83	.285
85	639	134.95	40.41	87.68	.347

EFFECT OF CHARACTER OF SURFACE ON HEAT TRANSMISSION

While most building materials have surfaces which show similar characteristics as far as the transmission of heat is concerned, it is a well-known fact that such surfaces as aluminum bronze, gold bronze, aluminum foil, or, in fact, any metallic, highly polished surface, present a greater resistance to heat transmission than the surface of the average building material. For these surfaces, the greater heat resistance is due primarily to the lower coefficient of heat transmission by radiation.

In order to show the effect of a few of these surfaces, Walls 78, 78B, 79, 79A, 79B, 80, and 80A of Figure 63, were built up and tested. These walls were constructed of $\frac{3}{8}$ -inch Gypsum Board both with and without air spaces and with different surface treatment. Walls 78 and 78B were built of a single $\frac{3}{8}$ -inch thick panel of gypsum, the difference being that for Wall 78 the surfaces were covered with paper, whereas for Wall 78B, the surfaces were covered with a thin aluminum foil. In this case, the reduction in overall heat transmission coefficient *U* was from .691 for the paper-covered surfaces to .460 for the aluminum foil-covered surfaces.

The remaining walls were built with $\frac{3}{8}$ -inch Gypsum Board panels, using three panels for each wall spaced so as to give two 1-inch air

spaces. Walls 79 and 80 had their surfaces covered with paper and gave coefficients $U = .264$ and $.257$, respectively, or an average of approximately $.26$. For Wall 79A, the surfaces both inside and out were coated with an aluminum bronze paint. In this case, the coefficient was

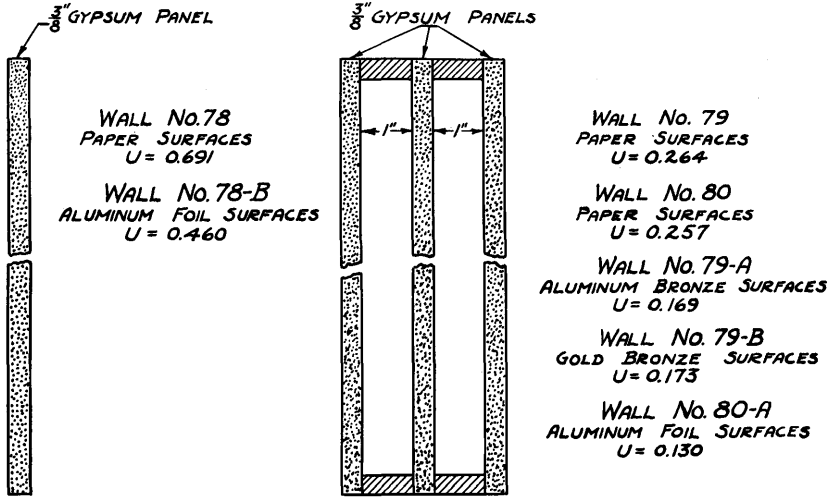


FIGURE 63. WALLS CONSTRUCTED TO SHOW THE EFFECT OF DIFFERENT SURFACE FINISHES ON HEAT TRANSMISSION

reduced to $.169$. For Wall 79B, the surfaces of the material were covered with a gold bronze paint and the coefficient was reduced to $.173$, substantially the same as when the aluminum bronze surfaces were used in Wall 79A. For Wall 80A, the surfaces of the material were covered with a thin aluminum foil and the overall coefficient U was reduced to $.13$ or approximately one half of that for the wall in which the surfaces were covered with paper. These coefficients show that a very material difference in the coefficients may be obtained by the proper treatment of the surfaces.

OVERALL HEAT TRANSMISSION COEFFICIENTS BY TESTS AND BY CALCULATION

It would be obviously impossible to build up all of the different combinations of materials and make tests to determine the overall heat transmission coefficients, altho it is usually the overall heat transmission coefficient of some specific combination of materials with air spaces that is required by the engineer. The relation between the overall heat transmission coefficient U and the coefficient for the individual materials,

surfaces, and air spaces within the walls is definitely expressed by the fundamental equation for heat transmission shown on page 7. If the individual coefficients are known and substituted in this formula, the calculated results should check with the test results. In the past, there have been many failures to get any reasonable agreement between coefficients as obtained by the two different methods. These failures have reflected discredit both on the test methods and upon the accuracy of the calculated results.

Since the fundamental formula is theoretically correct, failure for the coefficients to agree must either be attributed to unreliable test methods or else to a misunderstanding of the proper coefficients to be substituted in the formula. These coefficients are variable, depending upon several factors, and the same numerical values cannot be used to cover all cases. Thus the coefficient of conductivity for an air space varies with the widths of the air space, with the type of boundary surfaces, and with the mean temperature at which the air space occurs in the wall. An air space $\frac{1}{4}$ inch in width would have a different coefficient than an air space 1 inch in width, or an air space used near the inside surface of an ordinary house wall where the mean temperature across the air space might be 66° F. would have a higher coefficient than a similar air space used on the outside of the wall where the mean temperature might be 0° F. Likewise, the coefficient of conductivity of an insulating material would be different for the two sides of a wall on account of the difference in mean temperature. It is true that these variations are often small and may be neglected in practical calculations, but, if an agreement is expected between the calculated and test results, the proper coefficients for the individual parts of the wall must be carefully selected.

As a check between the calculated and test results, a group of 19 walls was selected from those which were tested by the hot box method. These walls were analyzed; the conductivity coefficients for the various materials, air spaces, and surfaces were determined for the proper mean temperature and for the conditions under which they occurred in the walls tested, and, from these coefficients, the overall heat transmission coefficients were calculated and compared with the test results.

The group of walls selected is given in Table IX. The insulating materials, together with their properties, and the conductivity coefficients for the mean temperature at which they were found in the walls are given in Table X and the surface coefficients as used in the calculations, in Table XI. Table XII gives the conductances of specific combinations of materials found in several walls. The air space coeffi-

TABLE IX
DESCRIPTION OF WALLS TESTED AND CALCULATED

WALL NO.	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	INSULATION	AIR SPACE
8	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	None	One $3\frac{1}{2}$ -inch air space
8A*	Frame Same as 8	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	None	One $3\frac{1}{2}$ -inch air space
8B†‡	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Two thicknesses of insulation M applied between studding to divide air space into three parts.	Two $1\frac{1}{8}$ -inch air spaces One $\frac{7}{8}$ -inch air space
10	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	Insulating board A Building paper 4-inch pine lap siding	None	One $3\frac{1}{2}$ -inch air space
11	Frame	Insulating board A $\frac{3}{8}$ -inch plaster	Insulating board A Building paper 4-inch pine lap siding	None	One $3\frac{1}{2}$ -inch air space
12†	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Insulation F flanged midway in air space between studding	Two $1\frac{1}{2}$ -inch air spaces
15†§	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Insulation G flanged midway in air space between studding	Two $1\frac{3}{8}$ -inch air spaces

For footnotes, see page 101.

TABLE IX—Continued

WALL NO.	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	INSULATION	AIR SPACE
16	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Insulation F nailed on studding under sheathing	One $3\frac{1}{2}$ -inch air space
19	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Insulation D placed back against sheathing	One $3\frac{1}{2}$ -inch air space
23	Frame	Insulating board C nailed to studding	Insulating board C nailed to studding	None	One $3\frac{1}{2}$ -inch air space
26¶	Frame	Insulation C $\frac{3}{8}$ -inch plaster	Insulation C, building paper 4-inch pine lap siding	None	One $3\frac{1}{2}$ -inch air space
28†	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Two thicknesses of insulation L spaced between studding to divide air space into three equal parts.	Three 1.08-inch air spaces
33	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	1.11 inches of insulation J applied between studding directly to sheathing	One 2.4-inch aid space
34†||	Frame	$\frac{3}{8}$ -inch wood lath $\frac{3}{8}$ -inch plaster	$\frac{3}{4}$ -inch fir sheathing, building paper 4-inch pine lap siding	Insulation A, with heavy craft paper on cold side, placed midway between studding	Two $1\frac{1}{2}$ -inch air spaces

TABLE IX—Continued

WALL NO.	TYPE OF WALL	INSIDE CONSTRUCTION	OUTSIDE CONSTRUCTION	INSULATION	AIR SPACE
36†	Frame	3/8-inch gypsum Papered on each side	3/4-inch fir sheathing, build- ing paper 4-inch pine lap siding	Insulation D, covered on both sides with light craft paper	Two 1 3/8-inch air spaces
37**	Frame with brick veneer	3/8-inch wood lath 3/8-inch plaster	Face brick	Insulation J, 1.11 inches thick, applied between studding directly to sheathing	One 3/4-inch air space between brick and paper in addition to air space of Wall 33
42††	8-inch brick	3/8-inch wood lath 3/8-inch plaster	4-inch face brick backed with 4-inch common brick	Insulation J, .814 inch thick, applied to inner surface of brick between 1 5/8-inch furring strips	One .5-inch air space between insulation and lath One .6-inch air space between inner and outer courses of brick
53D†	Frame	3/8-inch gypsum Papered on each side	3/4-inch fir sheathing, build- ing paper 4-inch pine lap siding	Insulation F flanged be- tween studding	Two 1 3/8-inch air spaces
53F	Frame	3/8-inch wood lath 3/8-inch plaster	3/4-inch fir sheathing, build- ing paper 4-inch pine lap siding	None	One 3 1/2-inch air space

* Test area of wall was blocked off to prevent convection currents.

† 40° was taken as the average mean temperature for the air spaces.

‡ A paper board header was used in air space at three-foot intervals.

§ The application of the insulating material causes air spaces to be formed between the craft paper and hairfelt. These spaces cover about 65 per cent of the area and average 0.6 inch thick.

¶ Wall 26 was made up by adding surface finishes to Wall 23.

|| Air space between insulating board and craft paper averaged 0.2 inch.

** The siding was removed from Wall 33. A 4-inch face brick was then added, leaving a 3/4-inch air space between brick and sheathing. The conductivity for the brick was taken from a test on a 4-inch clay brick wall.

†† The inner surface of brick was covered with two coats of waterproof cement before the insulation was applied.

TABLE X
DESCRIPTION OF INSULATION USED IN THE WALLS GIVEN IN TABLE IX

MARK DESIGNATING MATERIAL	DESCRIPTION OF MATERIAL	WALL IN WHICH USED	THICKNESS AS USED, INCHES	DENSITY LB. PER CU. FT.	CONDUCTIVITY K	MEAN TEMP., DEG. F.
A	Wood fiber board	10 outside	0.520	15.2	0.315	30.0
		11 inside	0.526	14.4	0.330	62.0
		11 outside	0.527	15.1	0.315	30.0
		34	0.526	15.0	0.318	40.0
C	A cereal fiber board	23 inside	0.48	14.4	0.362	62.0
		23 outside	0.47	14.8	0.340	22.0
		26 inside	0.48	14.4	0.362	62.0
		26 outside	0.47	14.8	0.342	30.0
D	Semi-rigid board	19	0.580	13.3	0.297	35.0
		36	0.660		0.300	40.0
F	Felted wood fiber between two layers of craft paper	12	0.750	4.8	0.253	40.0
		16	0.625	4.8	0.250	35.0
		53D	0.750	4.8	0.253	40.0
G	Animal hair lined on one side with tar paper and on the other with heavy craft paper	15	0.36	9.7	0.238	40.0
J	A ground waste paper pulp held together with a binder and applied by air gun	33 outside	1.11	5.78	0.272	35.0
		37 outside	1.11	5.78	0.272	35.0
		42	0.814	5.78	0.283	60.0
L	Paper felt treated on the surfaces with creosote for waterproofing	28	0.119	34.4	0.470	40.0
M	Corrugated paper board	8B	0.209	11.7	0.374	40.0

TABLE XI
 SURFACE COEFFICIENTS USED FOR CALCULATING THE OVERALL TRANSMISSION COEFFICIENTS OF WALLS GIVEN IN TABLE IX

SURFACE	MEAN TEMPERATURE	F ₁	F ₀
Plaster	77	1.8	..
Sheet rock	75	1.7	..
Stucco	5	..	1.5
Siding	5	..	1.6

TABLE XII
 CONDUCTANCE OF SPECIFIC COMBINATIONS OF MATERIAL USED FOR CALCULATING THE OVERALL TRANSMISSION COEFFICIENTS OF WALLS GIVEN IN TABLE IX

MATERIALS	MEAN TEMPERATURE	CONDUCTANCE
3/8-inch lath and 3/8-inch plaster	70	2.50
Fir sheathing, building paper, and pine lap siding..	20	0.50
Fir sheathing, building paper, and stucco	20	0.82
Fir sheathing and building paper	30	0.706
Building paper and 4-inch pine lap siding	15.5	0.854
Conductance of 3/8-inch plaster	73	88

TABLE XIII
COEFFICIENTS USED FOR CALCULATING THE OVERALL TRANSMISSION COEFFICIENTS OF WALLS GIVEN IN TABLE IX

WALL No.	F ₁	MEAN TEMP. DEG. F.	F ₀	MEAN TEMP. DEG. F.	CONDUCTANCE INNER CONSTRUCTION	MEAN TEMP. DEG. F.	CONDUCTANCE OUTER CONSTRUCTION	MEAN TEMP. DEG. F.	CONDUCTIVITY. INSULATION	MEAN TEMP. DEG. F.	CONDUCTANCE OF AIR SPACE	MEAN TEMP. DEG. F.
8	1.8	77	1.6	5.0	2.50	70	0.50	20.0	None		1.14	48.0
8A	1.8	77	1.6	5.0	2.50	70	0.50	20.0	None		1.14	48.0
8B	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.374	40.0	*(3) 1.10	40.0
10	1.8	77	1.6	5.0	2.50	70	0.354	26.0	0.315	30.0	1.14	48.0
11	1.8	77	1.6	5.0	0.587	63	0.354	26.0	0.330 Inside	62.0	1.10	40.0
									0.315 Outside	30.0		
12	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.253	40.0	(2) 1.10	40.0
15	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.238	40.0	(2) 1.10	40.0
16	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.250	35.0	1.14	48.0
19	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.297	35.0	1.14	48.0
23	1.7	77	1.6	5.0	0.753	62	0.723	22.0	0.362 Inside	62.0	1.10	40.0
									0.340 Outside	22.0		
26	1.8	77	1.6	5.0	0.696	63	0.392	26.0	0.362 Inside	62.0	1.10	40.0
									0.342 Outside	30.0		
28	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.470	40.0	(3) 1.10	40.0
33	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.272	35.0	1.14	48.0
34	1.8	77	1.6	5.0	2.50	70	0.50	20.0	0.318	40.0	(2) 1.10	40.0
											(1) 1.62	37.0
36	1.7	75	1.6	5.0	3.30	70	0.50	20.0	0.300	40.0	(2) 1.10	40.0
37	1.8	77	1.6	5.0	2.50	70	(4-inch brick 1.24)	19.0	See Wall 33		1.14	48.0
											1.04	20.0
42	1.8	77	1.6	5.0	2.50	70	(4-inch brick 1.24)	19.0	0.283	60.0	(1) 1.32	68.0
											(1) 1.10	30.0
53D	1.7	75	1.6	5.0	3.30	70	0.50	20.0	0.253	40.0	(2) 1.10	40.0
53F	1.8	77	1.6	5.0	2.50	70	0.50	20.0	None		1.14	48.0

* Numbers in parentheses indicate number of air spaces.

TABLE XIV
RELATION BETWEEN CALCULATED AND TEST RESULTS

WALL No.	CALCULATED VALUE OF U AT 40 DEG. F., MEAN TEMP.	HOT BOX VALUE OF U AT 40 DEG. F., MEAN TEMP.	PER CENT VARIATION BASED ON TEST RESULTS
8.....	0.224	0.226	0.88
8A	0.224	0.225	0.45
8B	0.134	0.139	3.59
10.....	0.189	0.186	1.61
11.....	0.151	0.153	1.31
12.....	0.119	0.115	3.48
15.....	0.134	0.134	0.0
16.....	0.144	0.141	2.13
19.....	0.155	0.155	0.0
23.....	0.207	0.212	2.36
26.....	0.165	0.168	1.79
28.....	0.146	0.142	2.82
33.....	0.117	0.116	0.86
34.....	0.131	0.129	1.55
36.....	0.133	0.130	2.31
37.....	0.103	0.106	2.83
42.....	0.136	0.137	0.73
53D	0.120	0.120	0.0
53F	0.224	0.217	3.22

coefficients were taken directly from the curves of Figure 42. Table XIII gives the coefficients used throughout the various walls, and the variations between the overall heat transmission coefficients as obtained by calculation and by test are shown in Table XIV.

The coefficients in these calculations were carefully selected to match the mean temperatures and particular conditions at which the materials occurred in the walls. The insulating materials were tested by the hot plate method and the results interpolated for the proper mean temperature. The surface coefficients were selected from test results by the hot box method, and therefore corresponded to those for the tests. The conductances for certain combinations as given in Table XII were determined by building up these combinations and testing them by the hot box. Thus the coefficient of such a combination of materials as building paper and 4-inch pine lap siding (Wall 54, Fig. 52), would be very difficult to obtain by the hot plate method or to select for accurate calculations without an actual test. In practice, it might not be necessary to resort to such refinement, but the objects of these calculations and tests were to determine the agreement between tests and calculated results. The variations as recorded in Table XIV are very small and within much closer limits than could be expected in practical work. It would not only be impractical to go to such refinement in selecting the coefficients, but variations in construction would show up much greater differences in coefficients even for walls built after the same specifications. For practical purposes, however, it is possible to use calculated results with reasonable certainty, but in making the calculations care should be used in selecting the proper coefficients.