THE THERMAL CONDUCTIVITY PROPERTIES OF MASONRY MATERIALS NATIVE TO SOUTHERN ARIZONA

by

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INTRODUCTION

The flow of heat through homes and buildings for heating and cooling purposes is of primary importance in the Southwest. Cooling is the most important one of the two. The temperature differential through which the heat flows should be from about 105°F on the hot surface to about 80°F on the cool side. The thickness of the material, for purposes of comparison, should be compared on the basis of the same thickness, preferably of a thickness widely used in construction. The standard of comparison for surface area is the square foot perpendicular to the direction of heat flow.

In choosing the temperature difference it must be realized that one is assuming a steady state condition, this actual condition being very rarely found. But, as most of the heat transfer conditions met are of the unsteady state, the overall result is but an approximation. This approximation is as accurate as the original assumptions of the variables.

In the summer the highest outside wall surface temperature reaches about 150°F due to direct and reflected sun radiation. This condition does not usually last for a period of more than three hours. Also the direct sunlight is only on the southern and western walls of the house, the eastern wall being subjected to the suns rays earlier in the day.

The value of the temperature taken for use in the conduction formulae found in heating and cooling books is 105°F.

In this discussion the thickness of the material shall be eight inches, the size of building material most commonly used by builders in this area. Attention must be called to the fact that the overall coefficient of heat transfer is not a linear one as a function of wall thickness. Certain portions of the equations are constants for all materials regardless of the thickness and other portions may or may not be linear depending upon the material used.

The amount of heat transferred through a material is dependent upon the temperature difference across the material, the thickness of the material, the total area of the material subject to the heat flow, and a number characteristic of each material.

$$q = k\,A\,\frac{dt}{dx}$$

Where:

q is the heat transferred in BTU/hr./sq.ft.

k is the thermal conductivity in BTU/hr./sq.ft.in/$^\circ$F

A is the area in sq. ft.

dt/dx is the temperature difference in $^\circ$F. across the thickness divided by the thickness in inches.

For non-homogeneous materials, such as building blocks, the constant is called the C factor, the k factors being for homogeneous materials only.

$$q = C\ A\ dt$$

Where:

q is the heat transferred in BTU/hr./sq. ft.
C is the thermal conductance in BTU/hr./sq. ft./^{o}F.
A is the area in sq. ft.
dt is the temperature difference across the material in ^{o}F.

For heat to flow a temperature difference must exist. This could be compared to electricity flowing in an electrical circuit. In this case the q would be equivalent to the current flowing, dt to the voltage differential, and the resistance, R, of the electrical circuit would be equivalent to the thermal resistance, R. 1/R would be equal to 1/C or $\frac{1}{dx/k}$.

Chapter 1

TYPES OF CALORIMETERS

There are various methods for the determination of the thermal conductivity characteristics of materials. The Boiling Liquid Type of Calorimeter has five sides of the hot plate insulated with a known material of definite thickness[1]. The sixth side is the unknown material. The temperature drop across the unknown is measured with thermocouples on the hot side and a thermometer on the cold side, the thermometer being in a liquid of constant boiling point. The vapor boiled off is condensed and fed back to the cold plate. This type of device is used to test smaller specimens, but can be used for any size. A liquid that has a boiling point near the nominal room temperature should be used to arrive at a useable value for the thermal resistance of the wall. The equation for the determination of the thermal resistance is set up having the variable parameters of the temperature of the hot plate or the heating surface, the thickness of the material being tested, and the ambient room temperature.

Another type of Calorimeter is the A.S.H.V.E. Hot Box, used to determine the overall U factor of a wall[2].

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[1] Watson, T.W., U.S. Department of Commerce, Letter of May 22, 1951.

[2] Severns and Fellows, Heating, Ventilating and Air Conditioning Fundamentals (New York, John Wiley, 1950), P.79.

It is constructed of two boxes, one a three foot cube, and the other five by five by four feet, both having the same side open. This side is attached to the wall to be tested. The boxes are so arranged that the space between them is everywhere equal. The inner box is the test section and the outer one the guard box. Electric heating elements and fans circulate the air in the boxes. The factor obtained is the actual U factor, based upon the standard of still air on the inside of the wall, or the cool side, and fifteen mile an hour air on the hot side of the wall. To perform this test an actual wall of the material to be tested must be built.

An interesting innovation of this method is what could be termed a "Cold Box", wherein cooling coils are used instead of heating coils. This would place the U factor obtained in the low temperature range, giving a lower factor than the value which should be used for conditions here in Southern Arizona.

The Guarded Hot Plate Calorimeter, which was used in this series of tests will be discussed in the following chapter.

Chapter 2

TEST APPARATUS

Cold Plates

The guard ring, hot plate calorimeter is the type approved and used by the Bureau of Standards for thermal conductivity tests of various materials[3]. This type is also widely used by various companies for tests of their products.

The apparatus consists of two cold plates held at the same constant temperature by circulating cold tap water. The cold plates were made from cored cast aluminum plates, which had been machined flat on one side. The baffles cast in them were to insure even cooling and turbulence for good heat transfer, plate to water, see Fig. (1).

Hot Plate

The core upon which the heaters were wound was of 3/16" Special Heater Transite and was made in three pieces; the center, the guard, and the outer guard.

The center is 11-7/8" square.

The inner guard is 12-1/8" square inside and 16" square outside.

The outer guard is 16-1/4" square inside and 18" square outside.

The main heater was wound with Nichrome V Ribbon #37,

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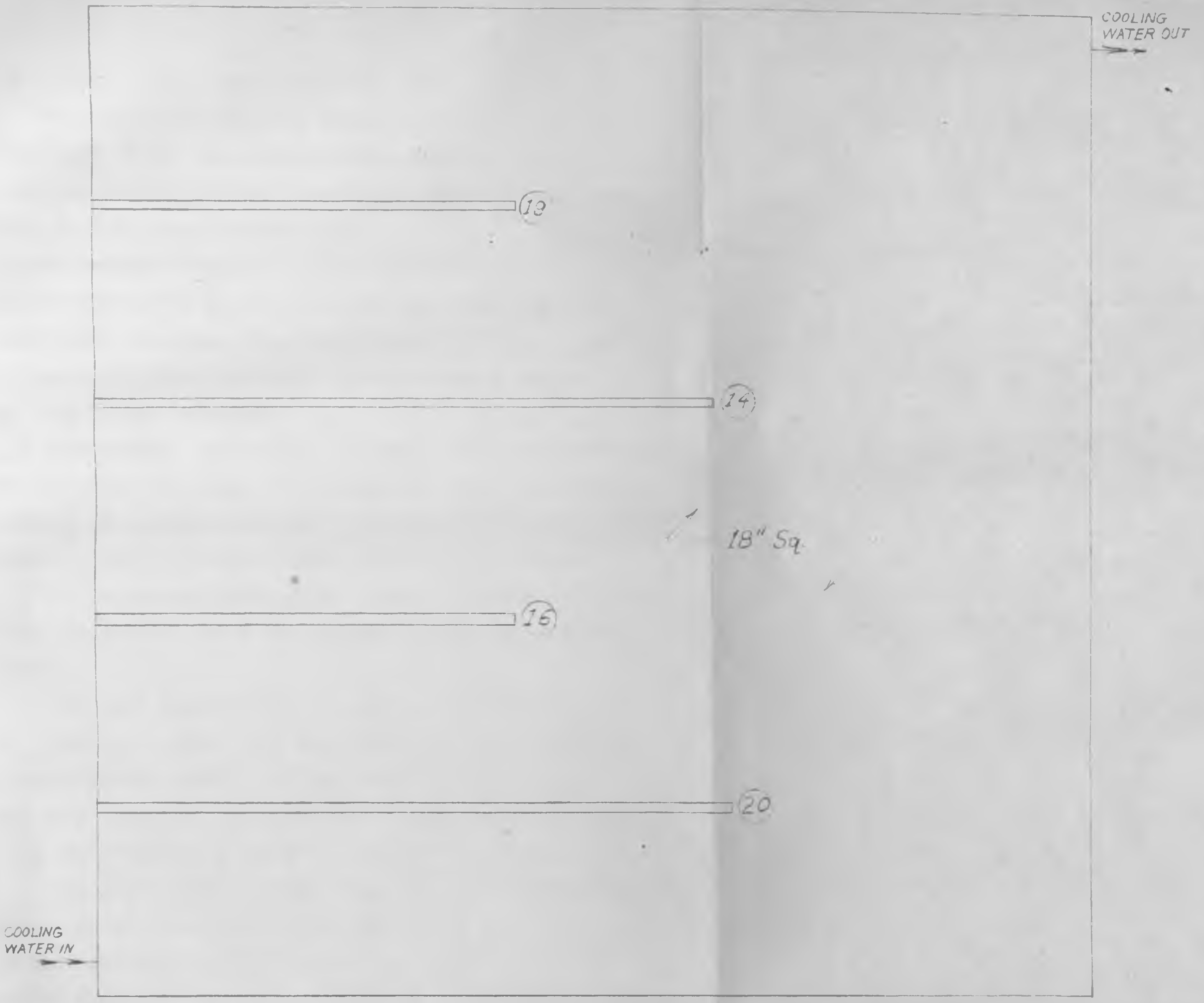
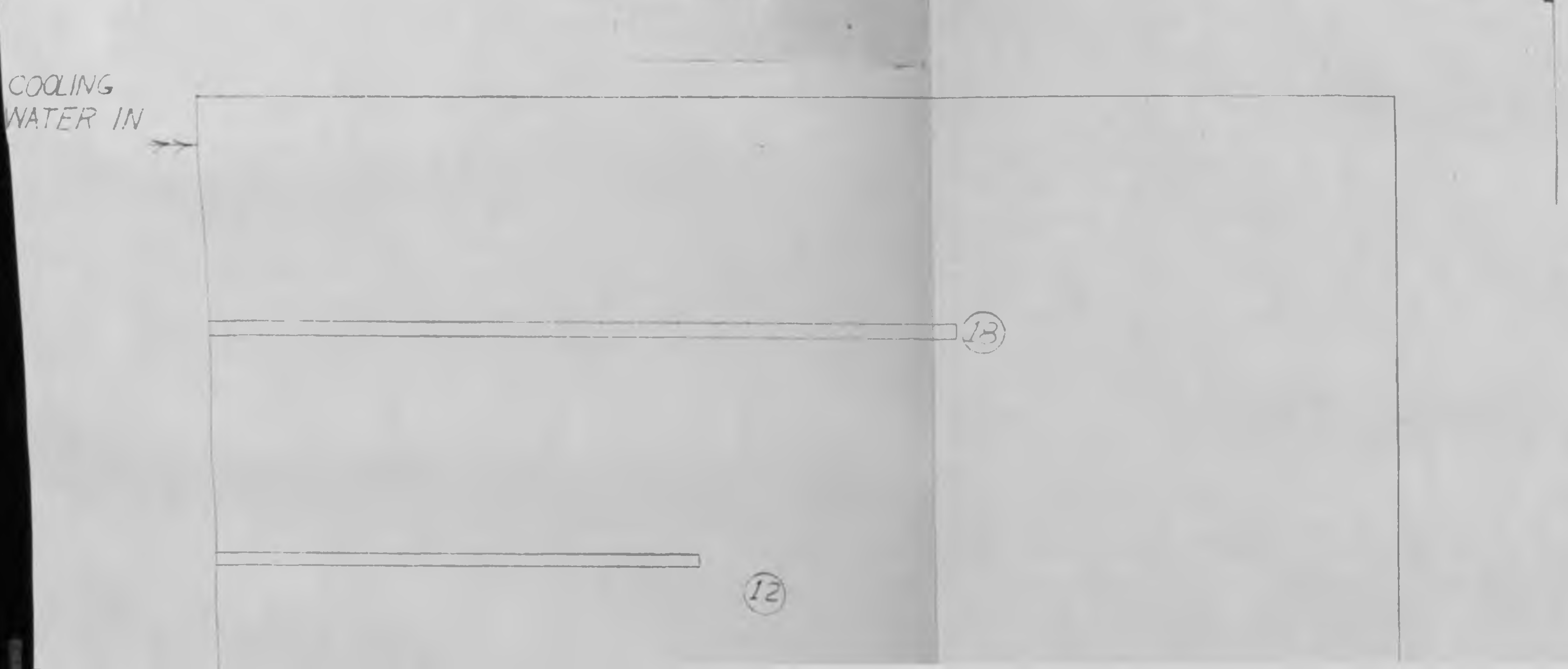
[3] "Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate", A.S.T.M. C177-45, adopted 1945.



COLD PLATE, TOP
PLAN VIEW

FIG. 1a



B & S gauge (0.0045" thick) and 1/8" wide.

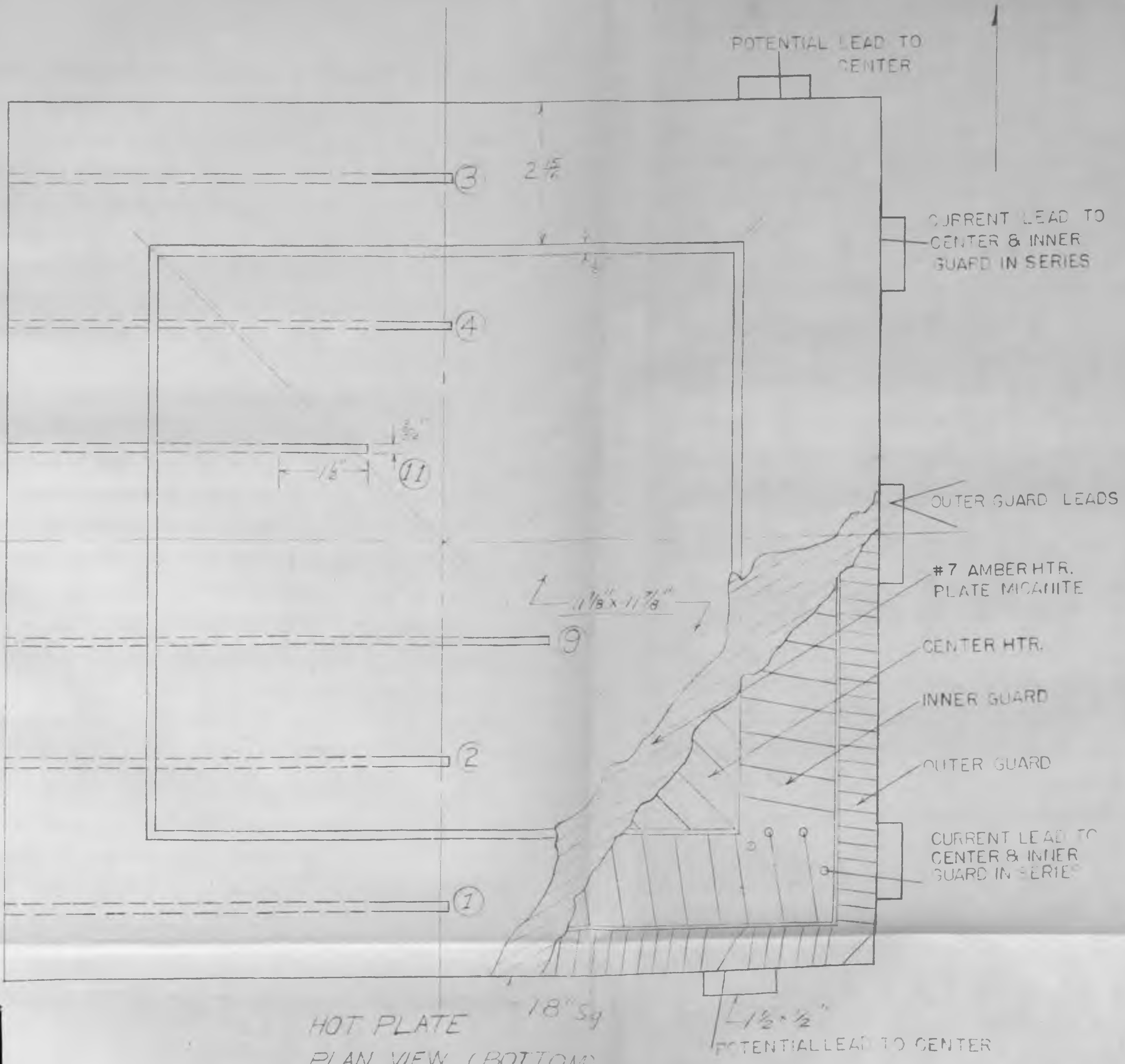
The inner guard was also wound with #37 B & S Nichrome Ribbon 1/8" wide, the spacing between windings measured along the edge of the core being 2/3". The outer guard was wound with #33 B & S Nichrome Ribbon 1/16" wide, the spacing between windings being 1/3". Note that spacings were left in the outer guard winding for leads from the center and inner guard, see Fig. (2). These leads were then fastened to insulated blocks attached to the protruding lugs on one side of the hot plate.

Shallow hack saw cuts at the points where the windings passed around the edges of the Transite served to facilitate winding, to hold the windings in place, and to minimize the danger of short circuits between the various elements.

The center was wound first. About six inches of ribbon were left at each end of the winding to serve as potential leads.

The inner guard winding was started at the upper right hand corner, and the right hand edge was wound, leaving an inch or two for welding to the lower right hand corner. It was then completed, leaving another short length at the top right hand corner for welding to the center winding.

The ends of the inner guard left for welding are now welded to the ends of the center winding at the inner edge of the inner guard. This puts the inner guard and center in series with potential leads attached to the two ends of the



HOT PLATE
PLAN VIEW (BOTTOM)

FIG. 2

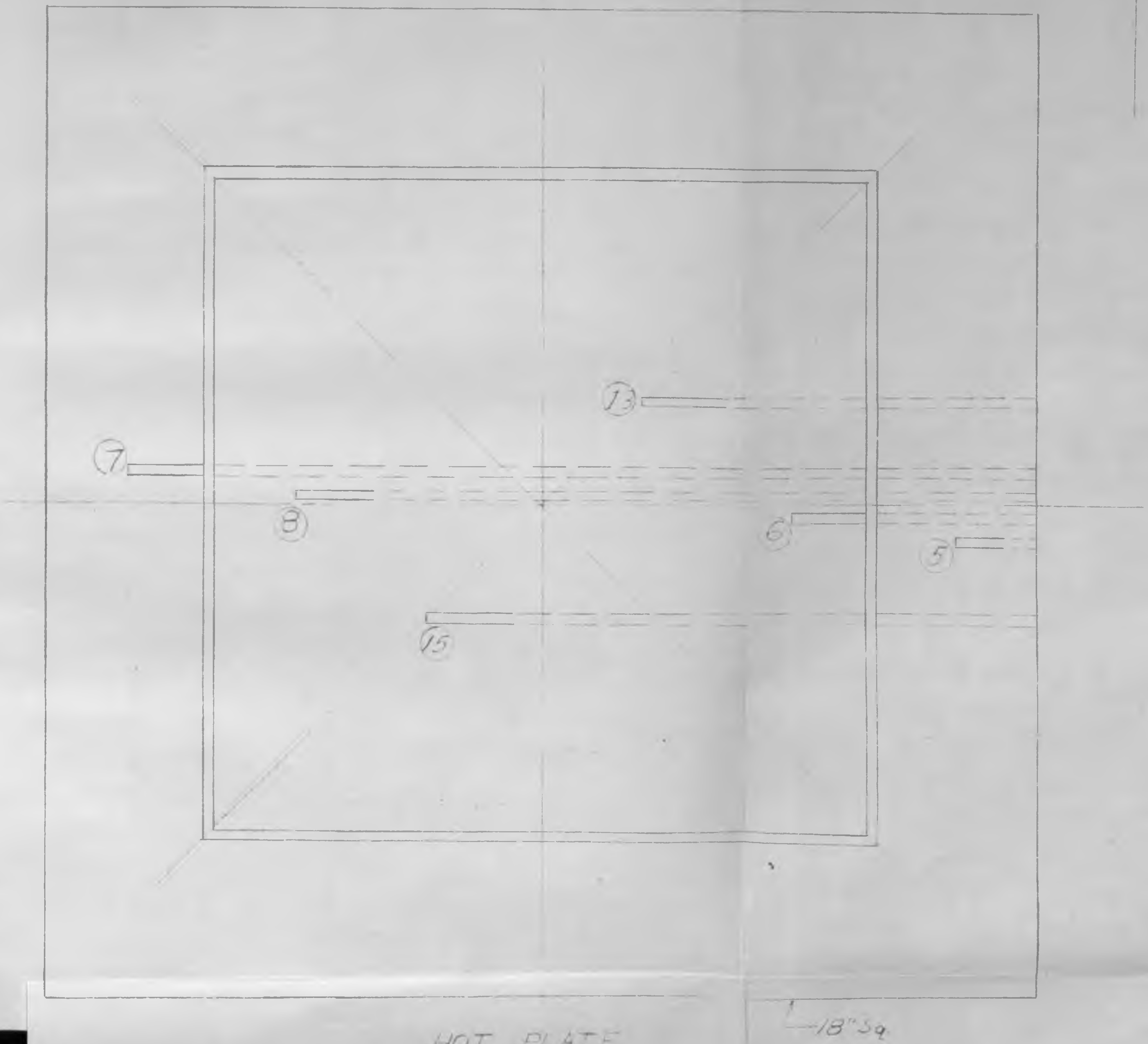
center winding so that the power to the center winding alone may be measured with a wattmeter.

The outer guard was then wound and the heater was assembled between two sheets of #7 Amber Heater Plate Micanite, 18" square and 0.015" thick, and the whole assembly was placed between two aluminum sheets cut into center and guard ring as shown in the drawing. Number 6-32 stainless steel flat headed screws were passed through the assembly and threaded into one of the aluminum hot plates so as to hold the heater assembly together. The only thermal connection between the center and the guard ring is thus the 0.015" thick Micanite, see Fig. (4).

Thermocouple Wiring System

Copper-constantan junctions were installed in the grooves as shown in Figs. (3) and (1), and the leads to each were brought out to a terminal board so that each could be read individually against a copper-constantan cold junction maintained at the temperature of melting ice. In use these may be read separately, in series, in series differential, or in parallel, depending on the manner in which they were connected at the terminal board. Except when read individually, it was necessary that the junctions be electrically insulated from the metal plates.

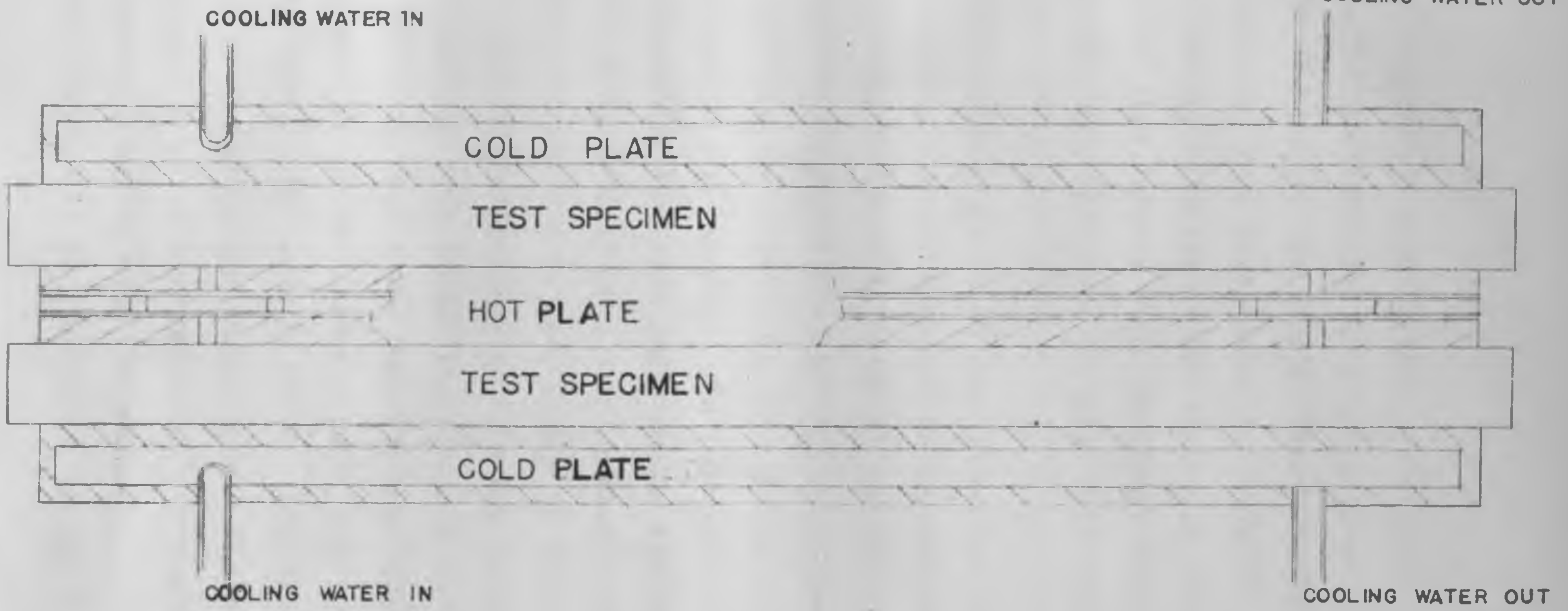
The width of the thermocouple grooves was dependent upon the size thermocouple wire used. In this apparatus # 18 B & S gauge wire with fiber glass insulation was used.



Dimentions as before

HOT PLATE
PLAN VIEW (TOP)

FIG. 3



CROSS SECTION - TEST APPARATUS

FIG. 4

This wire required a 3/32" groove. A suitable cement for cementing the thermocouples into the grooves of the hot plate and cold plates was Glyptal Clear Varnish, as it does not decompose up to a temperature of 800°F.

The thermocouple beads were carefully placed so that they did not make contact with the plates and in such a position that they were in the plane of the surface of the plates.

Thermocouples #1 to #8 were connected in series-differential to indicate any difference in temperature between center and edge as shown in Figs. (2) and (3). Thermocouples #9 to #16 were also connected in series-differential and were used to indicate the temperature difference between hot and cold surfaces of the samples. The four remaining cold surface junctions were read individually against the iced cold junction to indicate the cold surface temperature. The differential thermocouples were placed in the plates so that they were directly above one another to indicate the exact temperature drop across the specimen at that point.

It should be here noted that the lead wire must be of the same material as the thermocouples, especially the hot plate lead wires. The welding of the thermocouples to the lead wire produces two more thermocouples in the circuit if the lead wire is of another material. If these other thermocouples are in a region near the hot plate, enforcing and/or suppressing emf's will be generated, thereby introducing considerable error in the readings. The thermocouple lead wire need not be of the same length because as the circuit was balanced with the potientiometer, when read, the current in the thermocouple circuit was brought to nearly zero and therefore the IR drops in the wire was also brought to nearly zero.

Considerable trouble was caused with this type of hookup when the thermocouples were placed in series differential to read the average temperature drop across the specimens. This was due to the fact that all of the thermocouples must at all times be electrically insulated from each other. Being mounted in aluminum plates increased this difficulty along with the abrasion the thermocouples and the insulating material were subjected to during changes in the test specimens.

Due to this difficulty the thermocouples were read separately and then mathematically averaged for the final results.

The cold junction thermocouple was put in an ice water solution which is at 32^{o}F., and the other thermocouples' emfs read as emfs above the 32^{o}F. temperature emf. This was done by putting the cold junction so as to buck or reduce the other emfs. Using the cold junction of an ice water solution allowed a greater range of temperatures than taking a room temperature junction. Also the ice junction temperature was definitely known whereas the room temperature may have easily changed a degree or two during the taking of one set of data.

Electrical Wiring

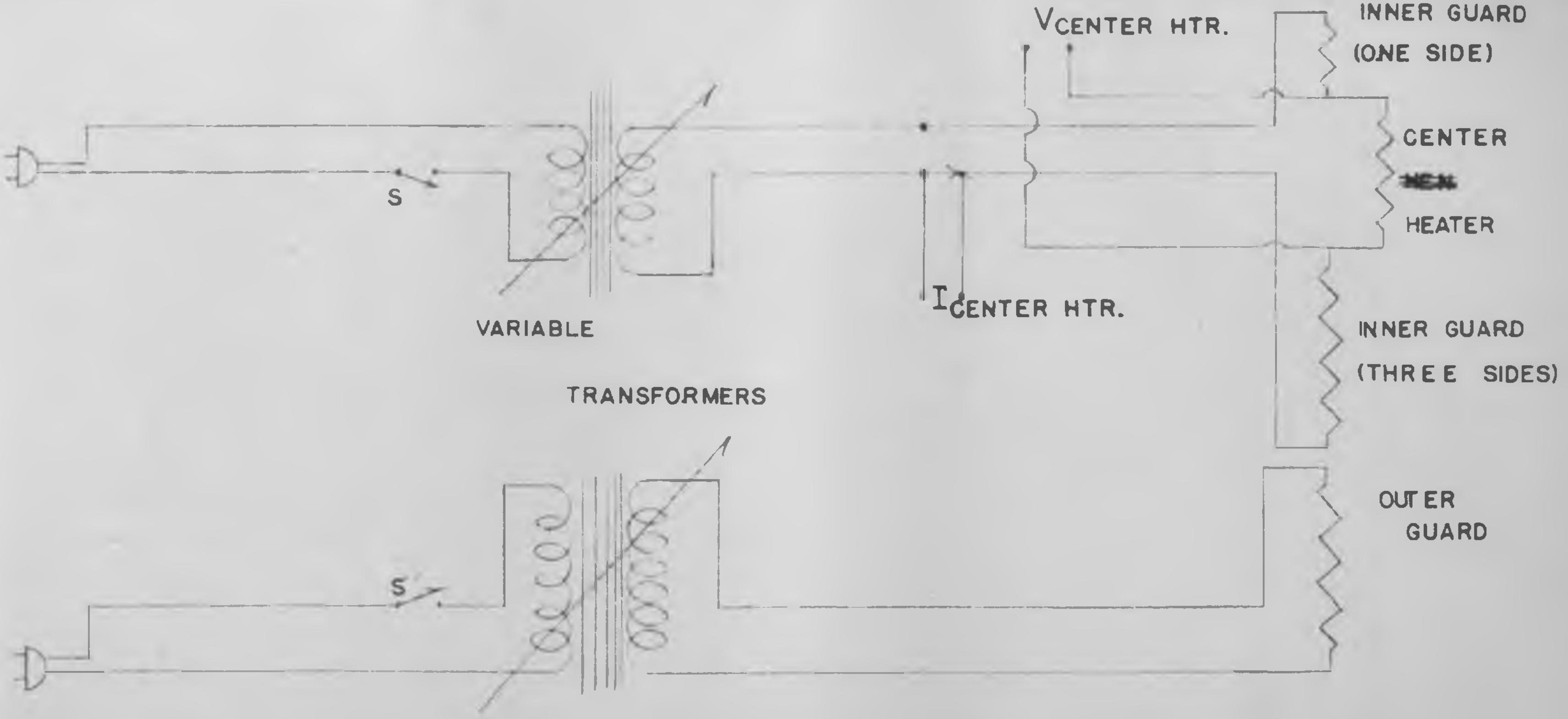
The wiring, internal to the hot plate, was done as indicated in the discussion previously. The lead wire was then brought to the terminals of the test board as indicated in the wiring diagram, Fig. (5), and the test board, Fig. (6). Care was taken that the lead wire did not run parallel to the thermocouple lead wire when it was within one foot of it. This would cause induced voltages in the thermocouple leads which would destroy the accuracy of the readings. This layout was accomplished by laying the wire along the bottom rear of the test box and approaching the test apparatus from the rear right. The thermocouple leads went diagonally up to the left front of the left side to the terminal board as indicated in Fig. (8).

To the test terminals, $V_{cent.\ htr.}$, and $I_{cent.\ htr.}$ were attached the wattmeter and voltmeter to read the wattage input to the center heater, Figs. (6) and (7). The voltage was read before and after the wattmeter was in the circuit and the read wattage corrected to the true value according to the formula:

$$W_t = W_r \frac{(V_1)^2}{(V_2)^2} - \frac{(V_2)^2}{R}$$

Where:

W_t is the true wattage input.
W_r is the read wattage.
V_2 is the voltage with wattmeter in the circuit.
V_1 is the voltage without wattmeter in the circuit.
R is the voltage coil resistance of the wattmeter.



WIRING DIAGRAM

FIG. 5

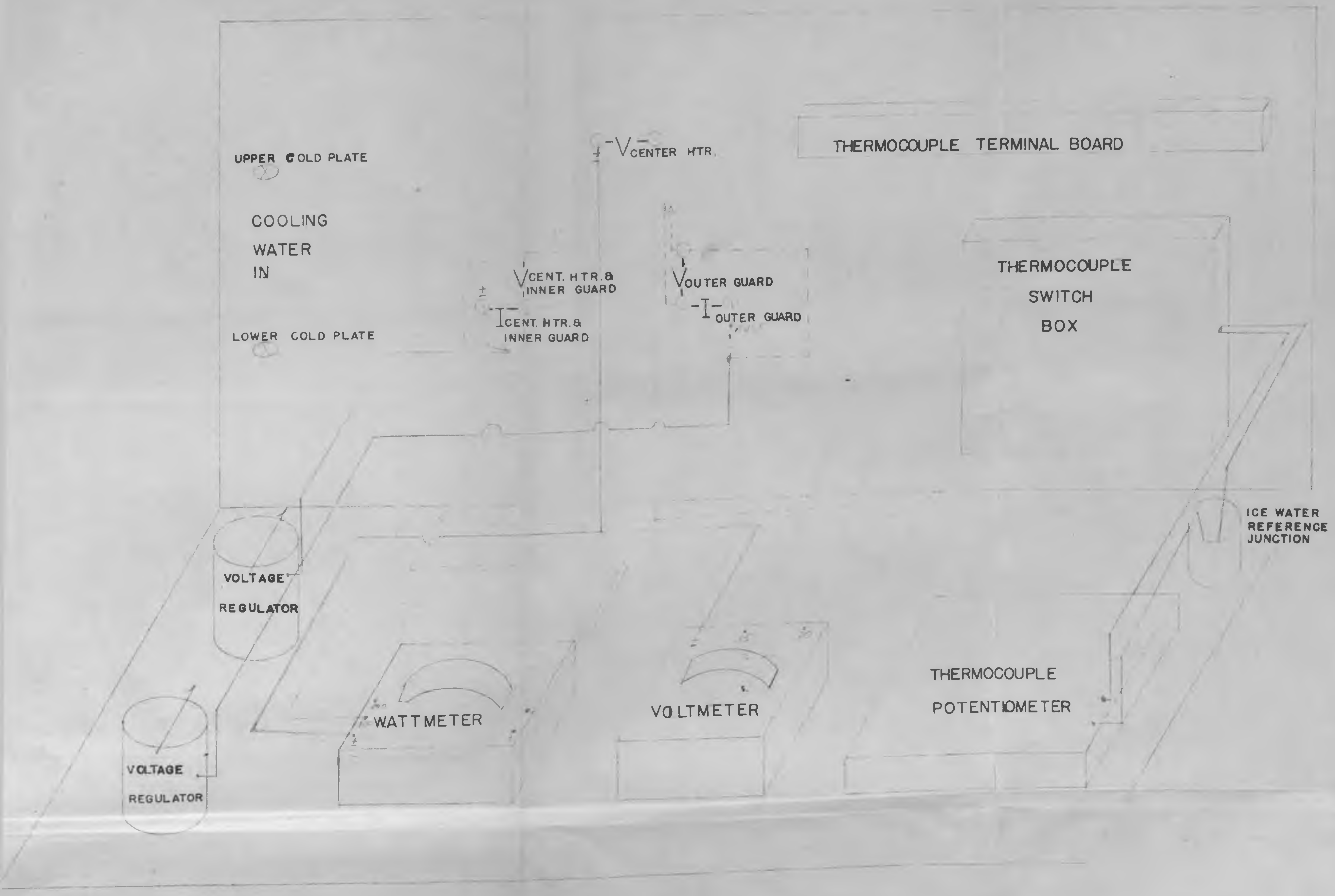

UPPER COLD PLATE
COOLING
WATER
IN
LOWER COLD PLATE
$V_{CENTER\ HTR.}$
$V_{CENT.\ HTR.\ \&\ INNER\ GUARD}$
$I_{CENT.\ HTR.\ \&\ INNER\ GUARD}$
$V_{OUTER\ GUARD}$
$I_{OUTER\ GUARD}$
THERMOCOUPLE TERMINAL BOARD
THERMOCOUPLE
SWITCH
BOX
ICE WATER
REFERENCE
JUNCTION
VOLTAGE
REGULATOR
VOLTAGE
REGULATOR
WATTMETER
VOLTMETER
THERMOCOUPLE
POTENTIOMETER

FIG. 6

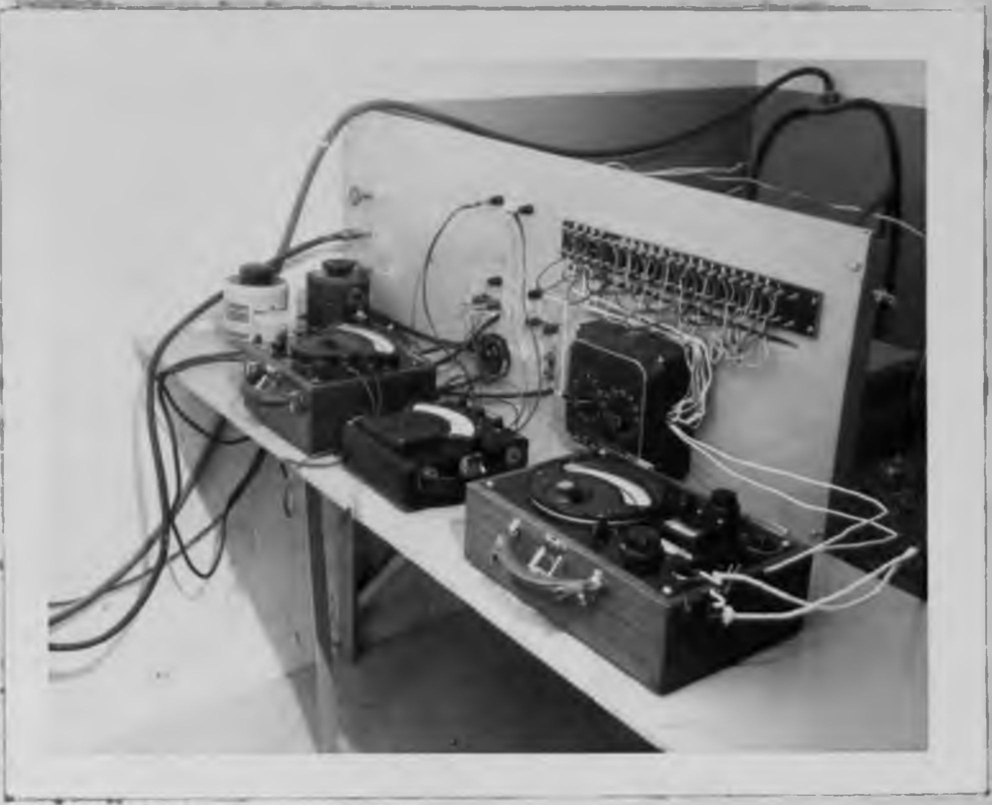


FIG. 7a

FIG 7b

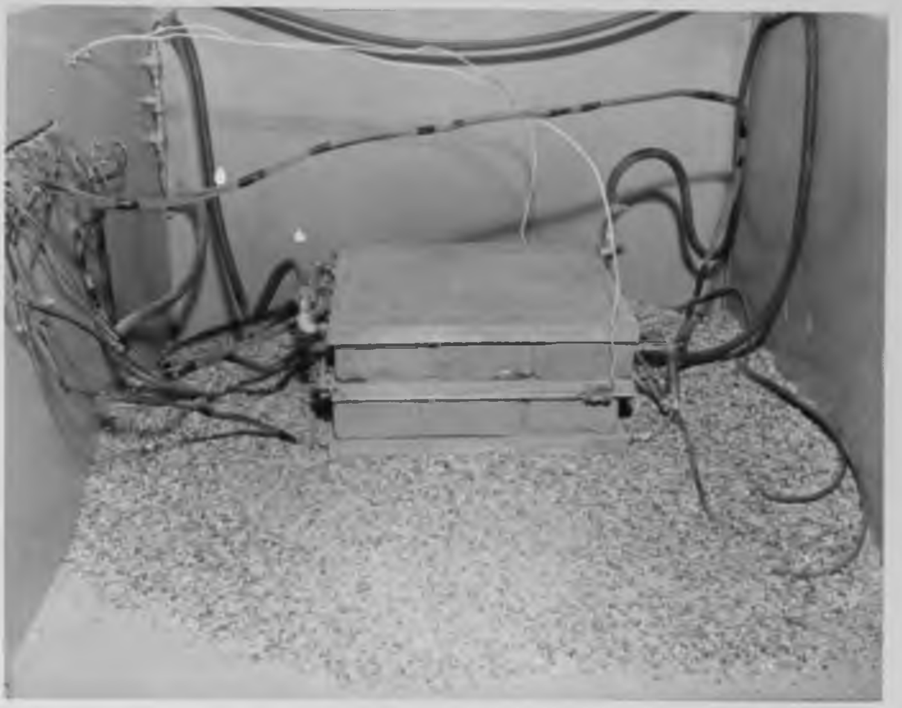


FIG. 8

FIG. 9

The voltage drop due to the voltmeter was considered neglectible.

Two variable voltage transformers raised or lowered the line voltage to the desired level for the tests. The outer guard was in parallel to the center heater and inner guard so that it could be adjusted separately to balance the temperatures.

The test box is 4' square by 4' high, one side being removable for access to the test apparatus to facilitate changing specimens and for repairs. The entire test apparatus was surrounded by a loose fill insulation, expanded vermiculite being used, to reduce the heat losses and to make the apparatus insensitive to changes in room temperature, see Fig. (9). This made it much easier to reach equilibrum conditions.

When equilibrum conditions were reached, the temperature difference, center to edge of the hot plate was approximately equal to zero. Thus, no heat flowed outward from the one square foot test section, all the heat from it flowed upward and downward through the test specimens. When the center to edge differential equaled zero, and the hot to cold plate differential did not change for a period of four hours, readings being taken at least five times during this period, then equilibrum conditions had been reached.

A series of points were run at various temperature differences so that a graph could be plotted of $T_{\text{hot plate}}$ vs. K or T_h vs. C. This was done as the curve produced may have been non-linear and also non-vertical. This then, must be considered when the overall adverage K or C is calculated.

Chapter 3

LIMITATIONS AND EXTENSIONS OF THE TEST APPARATUS

This type of test apparatus was used to determine the K factor of specimens which were flat with excellent results. The thickness of each specimen should not exceed 2" for best results. The thickness may be increased up to 3" or 4" without greatly effecting the accuracy, in those cases the outer guard ring was run about 5°F. higher than the center to counteract the added edge losses from the material.

Another test apparatus of this type could be constructed having the same 12" sq. test area but with a 6" outer guard making the overall dimensions 24" sq. instead of 18" sq. This would increase the allowable thickness up to about 4", with accurate results up to about 6"[4]. A better average insulation factor is obtained by using two specimens per test than by using only one. The main disadvantage is that the apparatus is square. One being round would have given a better guard ring, as heat does not flow in a square pattern, but a round one in each plane. This could be compensated for in the physical pattern in which the heating wire was wound.

In testing the 8" building block, it was realized that

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[4] *Ibid.*, p. 309.

the apparatus was never built with this type of test in mind, nor was it designed for such a test. This was an extension of the apparatus, but comparison of the calculated test with those of the A.S.H.V.E. "Hot Box" test for constructed walls showed that the error is about 5 to 8 percent high[5]. Running this type of test necessitated that the guard ring be kept about 15°F. hotter than the center heater. Tests could be run to determine exactly how much higher the temperature of the outer guard ring must have been relative to the center heater to give accurate results for the C factor. The great advantage was that a wall need not be constructed, and the bulky "hot box" used. In the determination of the overall heat transfer coefficient, the U factor, average values for mortar were used to calculate the U factor.

The method of laying brick varies considerably, i.e. the amount of mortar used in joints in each structure. This in itself varies the actual U factor, thus either of the test methods for C factors are an approximation.

To check the accuracy of our apparatus a check run was made from identical pieces of Thermoasbestos tested by Johns-Manville. Their range of temperatures varied from

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[5] M.D. Moeller, Superintendent, Superlite Corp., Letter of December 28, 1955.

110°F. to 200°F., the cold plate at about 80°F.[6].

The points tested were within 1/2 of 1 percent of being on their curve. This would be considered very close correlation.

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[6] J.D. Verschoor, Johns-Manville Research Center, Letter of August 2, 1955.

Chapter 4

RESULTS OF THE TESTS OF HOMOGENEOUS MATERIALS

The data for the K factor tests is presented in Appendix 2, and table 1.

Kaseyllite, a mineral found in Southern California, showed a surprisingly low K factor of 1.88. A brick cut from this material would make a good insulator. If it were crushed and cast as a sand into building blocks, the C factor should be rather low. The curve of T_h vs. K showed this material to be a linear function of temperature, the curve being non-vertical. To find an average K the temperature range used was from 100°F. to 180°F.

A construction material becoming popular for homes in Southern Arizona at the present time is burned adobe. The brick used in Tucson comes from either Hermosillo or Nogales, Mexico. Due to the poor control used in its firing, the physical properties vary widely. The Nogales brick had an average K factor of 2.98, yielding an overall U of 0.326, using $1\frac{1}{4}$" mortar joints. Hermosillo brick had a K factor of 3.35, and a U factor of 0.333. A useable average K and U factor for all burned adobe would be 3.20 and 0.33 respectively. The curve of T_h vs. K for the Nogales brick is an almost vertical straight line as indicated in Appendix 2. Thus the K factor did not vary greatly with temperature, but remained relatively constant. The range of temperatures used to establish an average K factor was from 180°F. to 100°F.

With a K factor which varies from 4.37 to 2.84, natural adobe is an insulation with a wide variation of composition which effects the physical properties of the block. To keep out the vermin usually found in natural adobe, it is plastered inside and out. This would lower the overall U factor from 0.35 for unplastered to 0.26 for a wall with stucco exterior and a plaster interior[7]. The reason an adobe house is cool in the summer is that the walls are usually at least 12" thick. The thermal delay time, or the time the heat takes to pass through the house would be about 4 to 6 hours or more[8]. Therefore the house is cool during the day, but begins to heat up inside during the evening, causing the dwellers to sleep outside, as is usually the case.

Three colors of Arizona Sandstone were tested, rust, buff, and white. The white sandstone was the most dense of the three, the rust being the lightest. The rust sandstone had the lowest K factor, that being 3.53, buff having a K factor of 5.57, white being 6.13. The respective U values are 0.346, 0.462, and 0.497 for an eight inch wall.

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[7] Servel, Inc., Servel "All-year" Air Conditioning Application Engineering Data, Table 3--Commercial Types.

[8] Severns, Heating, pp. 542-544.

Chapter 5

RESULTS OF THE TESTS OF THE NON-HOMOGENEOUS MATERIALS

Being a partially fused silicon oxide, pumice tended to be a material without much strength, but with very good insulating properties. If a pumice is found that is harder than the usual material, a strong, lightweight insulating block can be made. In most cases extra cement must be added to bring the overall strength of the block up to standard. Usually a percentage of the dry mix is made up of sand, thus improving the strength, but decreasing the insulation properties. The normal pumice block, the 8" one, has a C factor of 0.545 and a U of 0.384.

For increased strength properties to meet the F.H.A. specifications, a special pumice block consisting of the same exterior size with a smaller hole size is being produced. This block is called the F.H.A. Special. Due to the increased amount of pumice present and the smaller holes, causing smaller convection currents inside the wall, the C and U factors were reduced to 0.462 and 0.319 respectively.

If the normal pumice block holes were to be filled with raw pumice after construction of the wall, the overall U factor would be reduced to about 0.2, because the pumice in its natural state is an excellent insulation material.

In almost all cases the percentage by volume of sand to lightweight insulation material is 10% to 90%. In the

Tucson area a volcanic scoria block is being produced, the cinders coming from near Benson. Volcanic scoria is also basically a fused sand. Impurities cause the color to vary from gray to black, red, or rust. The color of the cinders from near Benson are of a dark grayish color. The C and U factors are 0.510 and 0.374. This was a little lower than that of the normal pumice block, but not as low as the F.H.A. Special.

In Phoenix, blocks are produced from a volcanic scoria obtained near Williams, Ariz. This material has a rust color, indicating the presence of iron oxides. This should raise the overall conducting properties of the scoria, and also make it slightly weaker than the gray or black scoria. This decrease in structural strength may easily be compensated for by the addition of more cement in the mixture. Its C and U factors are 0.554 and 0.407. This is higher by about 15% than the other lightweight blocks, probably due to the iron oxides present in the scoria.

TABLE I

THERMAL CONDUCTIVITY PROPERTIES OF SOME MASONRY BUILDING MATERIALS NATIVE TO ARIZONA

Building Material	Geographical Origin of Aggregate	Conductivity (K) (Btu/sq ft-°F-in-hr)	Conductance (C) (Btu/sq ft-°F-hr)	Recommended Coef. for Design Purposes K (as before)	Recommended Coef. for Design Purposes U (same as for (C))
Adobe Brick					
Natural	Papago Indian Res.	4.37		3.6	0.35
"	Tucson	2.84			
" (Stuccoed & plastered)					0.26
Burned	Nogales, Son., Mex.	2.98			
"	Hermosillo, Son., Mex.	3.35		3.2	0.33
Pumice Block					
Regular	New Mexico		0.545		0.40
Special (Heavier)	" "		0.462		
Cinder Block					
Volcanic Scoria	Williams, Ariz.		0.55		
" "	Benson, Ariz.		0.49		0.39
Holes filled with loose insulation					0.20
Sandstones					
White	N.E. Ariz.	6.13		6.2	0.50
Buff		5.57		5.6	0.46
Red		3.53		3.6	0.35
Miscellaneous					
Kaseyllite	Southern California	1.88		1.9	
Red Brick (Plastered)					0.35

CONCLUSIONS

Thermal conductivity is only one of the many properties which must be taken into account when considering a building material for a given project, i.e. structural strength, density, moisture and vermin resistance, color, etc.

In general, Table 1 shows that there is not a great deal of difference in the thermal conductivity properties of the light weight construction materials, all being analyzed on the basis of an equivalent 8" wall. The average value is about 0.39 for U. The F.H.A. Special and the burned adobe factors are about 0.32.

A value for the U factor below those mentioned can be obtained by filling the holes in the block with a loose insulation fill after the wall is built. This should reduce the U factor to about 0.23 for the scoria blocks.

The extensive use of non-weatherstripped steel casement windows and loosely fitted doors throughout the Southwest introduces an infiltration air heat load of such magnitude as to nullify the somewhat questionable benefits to be derived from the selection of one building material over another.

We may therefore conclude from the foregoing discussion that aesthetic appeal and cost alone need be the determining factors in the selection of one of our common southwestern building materials for a given construction project.

APPENDIX I

GENERAL FORMULA FOR THE HEAT TRANSFER COEFFICIENT OF 4" X 8" BLOCK

Total area = 144 sq.in. = 1 sq.ft.

Brick and Mortar Area = 4" x 16" =64 sq.in.

$$\frac{144}{64} = 2\frac{1}{4} \quad (\text{4x16 sections/sq.ft.})$$

$$\text{Brick Area} = 3\tfrac{5}{8} \times 15\tfrac{5}{8} \times 2\tfrac{1}{4} = 127.4 \text{ sq.in.}$$

$$\text{Mortar Area} = (\tfrac{3}{8} \times 16 + \tfrac{3}{8} \times 3\tfrac{5}{8})2 = \underline{16.4} \text{ sq.in.}$$

$$144.0 \text{ sq.in.}$$

THERMAL RESISTANCES

Of Block:

$$R_b = \frac{1}{h_i} + \frac{1}{h_o} + \frac{1}{C_b} = \frac{1}{6.0} + \frac{1}{1.65} + \frac{1}{C_b}$$

$$R_b = 0.167 + 0.605 + \frac{1}{C_b} = 0.772 + \frac{1}{C_b}$$

Of Mortar:

$$R_m = \frac{1}{h_i} + \frac{1}{h_o} + \frac{x}{K_m} + \frac{1}{k_a} = \frac{1}{6.0} + \frac{1}{1.65} + \frac{2.5}{12} + \frac{1}{1.37}$$

$$R_m = 0.167 + 0.605 + 0.208 + 0.750 = 1.730$$

$$R_o = R_m \text{ (Mortar Area/sq.ft.)} + R_b \text{ (Block Area/sq.ft.)}$$

$$R_o = 1.73\left(\frac{16.6}{144}\right) + \left(0.772 + \frac{1}{C_b}\right)\left(\frac{127.4}{144}\right) = 0.1995 + 0.682 + \frac{0.884}{C_b}$$

$$R_o = 0.882 + \frac{0.884}{C_b}$$

$$U = \frac{1}{R} = \frac{1}{0.882 + \frac{0.884}{C_b}} = \frac{C_b}{0.882(C_b) + 0.884}$$

Where:

R is the thermal resistance of the wall.
m is the mortar.
b is the brick.
o is the overall.
C is the conductance of the material in question.
h is the air film coefficient.
i concerns the inside of the wall.
o concerns the outside of the wall.
x is the thickness in inches of the material in question.
K is the thermal conductivity of the material in question.
k_a is the dead air space resistance in the block.

APPENDIX II

DATA AND GRAPHS OF ALL MATERIALS TESTED

(See following pages)

EQUATIONS:

(a)
$$K = \frac{q\ d}{2A(T_h - T_c)} = \frac{3.415 W_t\ d}{2A(T_h - T_c)} = \frac{1.71\ W_t\ d}{(T_h - T_c)}$$

(b)
$$C = \frac{1.71\ W_t}{(T_h - T_c)}$$

Where:

A is the area of the test specimen in sq. ft. and is equal to 1.0.

q is the heat flow in B.T.U./hr. and equals 3.415 W_t.

d is the average thickness of the test specimen.

W_t is the true wattage input to the center heater of the guarded hot plate

T_h is the average hot plate skin temperature (°F.).

T_c is the average cold plate skin temperature (°F.).

K is the thermal conductivity in B.T.U./hr./sq.ft./°F./inch of thickness of the material

C is the thermal conductance in B.T.U./hr./sq.ft./°F.

U is the over-all coefficient of heat transfer having the same units as C.

THERMAL CONDUCTIVITY OF KASEYLLITE

(Kasey No. 17, claim, Calif.)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	K
1.	181.0	81.0	27.20	26.10	25.52	1.902
2.	163.0	79.4	25.40	24.34	21.94	1.965
3.	149.9	80.6	23.49	22.70	18.88	2.000
4.	125.1	79.9	18.20	17.58	11.26	1.833
5.	101.6	79.5	12.71	11.25	4.63	1.838
					Average K	1.88

U = 0.199

d = $4\frac{1}{16}$"

GENERAL DATA:

Partial Chemical Analysis:

SiO_2	67.66%
Al_2O_3	15.47%
CaO	.30%
MgO	.30%
Fe_2O_3	1.40% (Magnetite mostly)
Na_2O	Being determined
K_2O	Being determined

Density (as received) = 82.4 lb./cu.ft.

THERMAL CONDUCTIVITY OF BURNED ADOBE BRICK

(From Nogales, Sonora, Mexico)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	K
1.	176.1	79.9	48.80	48.55	62.50	3.01
2.	150.8	79.9	41.63	41.35	45.11	2.94
3.	135.9	80.0	36.30	36.10	35.50	2.93
4.	112.1	79.9	23.87	23.03	19.40	3.04
				Average K		2.98

U = 0.326 (Computation based on $1\frac{1}{4}$" mortar joints and 3" x $7\frac{1}{2}$" x 16" burned adobe brick)

THERMAL CONDUCTIVITY OF BURNED ADOBE BRICK

(From Hermosillo, Sonora, Mexico)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	K
1.	146.0	81.0	29.60	28.60	30.00	3.28
2.	127.0	80.0	25.70	24.80	22.40	3.38
3.	115.0	80.0	22.15	21.40	16.76	3.39
					Average K	3.35

U = 0.333 (Computation based on $1\frac{1}{4}$" Mortar joints and 3" x $7\frac{1}{2}$" x 16" burned adobe brick)

THERMAL CONDUCTIVITY OF NATURAL ADOBE BRICK

(From the Papago Indian Reservation, Tucson, Arizona)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	K
1.	179.0	80.0	47.30	47.20	59.50	4.13
2.	156.5	80.0	41.50	41.40	46.50	4.17
3.	136.0	80.0	35.60	35.50	35.50	4.36
4.	127.0	80.0	29.40	28.30	29.26	4.56
5.	119.5	80.0	27.10	26.15	25.00	4.62
				Average K		4.37

U = 0.413

THERMAL CONDUCTIVITY OF NATURAL ADOBE BRICK

(From the Tucson Area)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	K
1.	172.5	80.5	38.00	37.60	39.00	3.01
2.	152.5	80.0	28.80	27.80	28.06	2.87
3.	131.5	78.5	24.30	23.40	20.40	2.87
4.	110.5	78.5	18.22	17.78	11.44	2.59
					Average K	2.84

$U = 2.96$

THERMAL CONDUCTIVITY OF NAVAJO SANDSTONES

(ARIZONA FLAGSTONES)

(From the Navajo Reservation, N.E. Arizona)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	d	K	U
				WHITE				
1.	91.5	79.5	27.70	26.70	26.50	1.53	6.13	0.497
				BUFF				
1.	101.0	81.0	29.30	28.20	29.40	2.08	5.57	0.462
				RED				
1.	93.0	80.0	29.00	28.00	29.00	0.87	3.53	0.346

THERMAL CONDUCTANCE OF 8 INCH PUMICE BLOCK

(Pumice Mineral from N.W. New Mexico)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	C
1.	265.4	81.6	46.70	45.50	57.20	0.556
2.	215.7	80.0	39.10	38.00	40.00	0.529
3.	179.3	79.9	33.50	32.40	30.00	0.544
4.	166.6	79.9	27.83	26.84	26.23	0.548
5.	142.4	80.1	23.51	22.62	18.88	0.552
6.	115.8	79.0	17.94	15.56	9.27	0.539
				Average C		0.545

U = 0.384

THERMAL CONDUCTANCE OF THE F.H.A. SPECIAL PUMICE BLOCK

(Pumice Mineral from N.W. New Mexico)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	C
1.	220.0	80.0	36.85	36.70	36.25	0.442
2.	191.6	78.6	29.15	28.10	28.68	0.461
3.	179.6	79.0	27.63	26.66	25.84	0.465
4.	168.5	78.6	25.95	25.00	22.84	0.463
5.	159.0	79.0	24.54	23.65	20.40	0.463
6.	146.0	77.0	22.60	21.80	17.40	0.458
				Average C		0.462

U = 0.319

THERMAL CONDUCTANCE OF A VOLCANIC SCORIA 8 INCH BLOCK

(From Volcanic Scoria Beds, Benson Arizona Area)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	C
1.	243.8	79.6	45.90	45.70	55.70	0.583
2.	212.8	79.5	39.40	39.20	41.30	0.532
3.	177.7	79.9	32.60	32.60	29.30	0.514
4.	154.5	79.8	24.71	23.85	20.77	0.505
5.	134.9	80.0	20.18	19.45	13.74	0.456
6.	112.0	79.8	15.64	13.86	7.03	0.468
					Average C	0.510

U = 0.374

THERMAL CONDUCTANCE OF A VOLCANIC SCORIA 8 INCH BLOCK

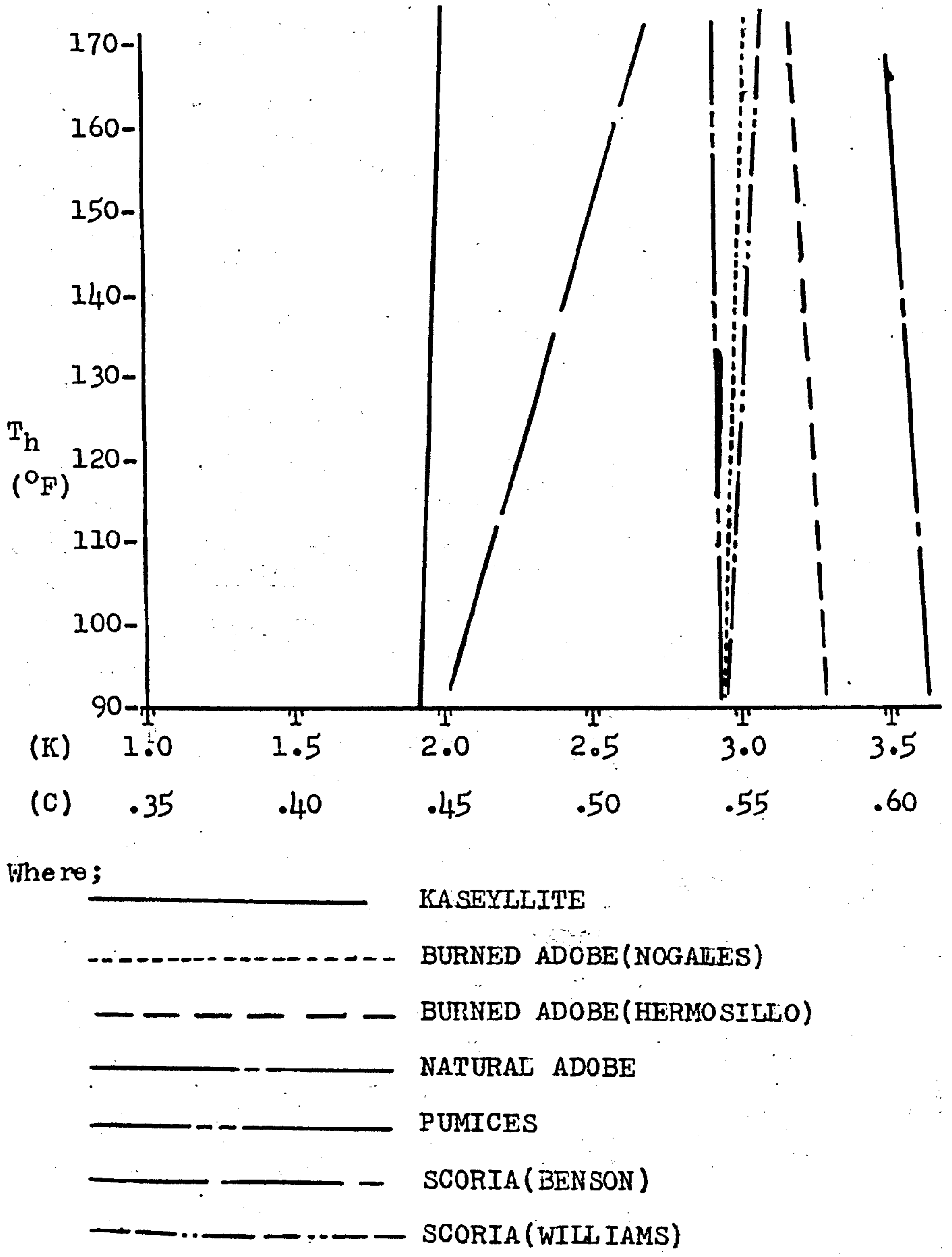
(From Volcanic Scoria Beds, Williams Arizona Area)

DATA:

Run no.	T_h	T_c	V_1	V_2	W	C
1.	176.9	78.5	29.76	28.51	29.96	0.555
2.	164.8	78.5	27.81	26.79	25.68	0.542
3.	151.1	78.4	25.44	24.57	22.12	0.553
4.	141.1	79.0	23.70	22.80	19.07	0.560
5.	127.4	78.7	21.02	20.26	14.96	0.558
				Average C		0.554

U = 0.407

HOT PLATE TEMPERATURE VS. THERMAL CONDUCTIVITY



BIBLIOGRAPHY

1. A.S.H.V.E., *Heating, Ventilation and Air Conditioning*, Vol. 25, 1947, New York.

2. Severns and Fellows, *Heating, Ventilating and Air conditioning Fundamentals*, 2nd. ed., New York (John Wiley) 1949.

3. Jordan and Priester, *Refrigeration and Air Conditioning*, New York (Prentice-Hall) 1950.

4. Servel, Inc., *Servel "All-year" Air Conditioning Application Engineering Data*, New York, 1950.

5. Jakob and Hawkins, *Elements of Heat Transfer and Insulation*, 2nd. ed., New York (John Wiley), 1950.

6. National Concrete Masonry Association, "Facts about Concrete Masonry", Chicago.

7. "Lightweight-Aggregate Concrete" *Journal of the American Concrete Institute*, May 1949.

8. P.H. Dike, *Thermoelectric Thermometry*, Philadelphia, (Leeds and Northrup Co.), 1954.

9. "An Accurate Method for the Determination of the Thermal Conductivity of Insulating Solids", A.S.M.E. Paper No. 53-A185, New York, 1953.

10. Univ. of Minnesota Engr. Experiment Station, "Effect of Surface Resistance of Thermal Conductivity by the Hot Plate Method", Technical Paper No. 40, May 1942.

11. Bradley, "The Measurement of Thermal Conductivity of Thermal Insulating Materials by Means of the Guarded Hot Plate", Journal of the A.S.R.E., Reprint from May 1943 issue of *Refrigerating Engineering*.

12. "Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate", A.S.T.M. C 177-45, Adopted 1945.

13. Marcoux and Jones, "The Thermal Conductivity of Masonry Materials Native to Arizona", Univ. of Arizona Engineering Experiment Station, T.B.P. November 1956.