NATIONAL BUREAU OF STANDARDS REPORT

3980

THERMAL CONDUCTANCES OF SIX INFRA INSULATIONS IN CLOSED AIR SPACES FOR VARIOUS DIRECTIONS OF HEAT FLOW

by

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THERMAL CONDUCTANCES OF SIX INFRA INSULATIONS IN CLOSED AIR SPACES FOR VARIOUS DIRECTIONS OF HEAT FLOW

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to

Civil Aeronautics Administration
Department of Commerce

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I INTRODUCTION

The thermal insulating value of a wall, floor or ceiling construction incorporating closed air spaces, such as those formed by studs or joists, can be considerably increased by the use of a reflective insulation installed in the spaces. This report presents data as to the thermal conductance between the inner surfaces of the two faces of a test panel having nominal 2x6 inch framing spaced 16 inches on centers, with the original air space (a) uninsulated (b) insulated with five differenct types (Type 4S, 4PS, 4PX, 6PK, and 6PS) of Infra Accordion insulation (c) insulated with Infra Retardive (flat) insulation to form three reflective air spaces of equal thickness. The results were obtained in a rotatable guarded hot-box heat transfer apparatus, and include the effect of the wood framing members. The conductances were determined in most cases for five orientations of the test panel, from horizontal with heat flow downward to horizontal with heat flow upward.

The measurements were made at the request of the Civil Aeronautics Administration of the Department of Commerce.

II DESCRIPTION OF INSULATIONS, TEST PANEL, AND TEST METHOD

Measurements were made of the thermal conductance between the inner faces of a test panel, with various orientations of the panel, and with the panel spaces (a) uninsulated (b) insulated with five different types of Infra Accordion Insulation, made by Infra Insulation, Inc., New York, N. Y., and designated by the manufacturer as Types 4S, 4PS, 4PX, 6PK and 6PS and (c) insulated with two sheets of Infra Retardive (flat) aluminum foil forming three air spaces of equal thickness. In addition, preliminary tests were made on a "check panel" of 1 1/4-inch plywood to compare results obtained in the test apparatus with those obtained by means of a guarded hot plate thermal conductivity apparatus.

The several Infra Insulations were designed for application between framing members spaced 16 inches on centers. Figure 1(a) shows the construction of the

5.5x8 ft test panel, the faces of which were 19-gage galvanized sheet steel painted on all surfaces with a flat white paint having a total emissivity at ordinary temperatures of approximately 0.9. The faces were screwed to the nominal 2x6 inch framing members over stud-width felt strips. The metering or test area of the panel was the central rectangle 32 inches wide (two framing spaces) and 60 inches high; the surrounding area of the panel served as a thermal guard for the metering area. The metal sheet covering the test area on each face was separated from the surrounding sheet metal by a 1/8-inch gap to minimize lateral heat flow; ten thermocouples were permanently soldered to each sheet, at the centers of the ten 16x12-inch rectangles into which its area could be divided, for measuring its temperature during a test.

The several reflective insulation applications tested are shown in Figures 1(b) to 1(g). Each figure shows the construction or design of the insulation, and particulars as to its dimensions and application in the test panel. Each of the several insulations was installed in the test panel by a representative of the manufacturer; all spaces in the panel were insulated as similarly as possible. The accordion insulations were fastened in place by means of staples in two rows about 1/2 inch apart, staples in each row being spaced 1 1/2 to 1 3/4 inches on centers. The Retardive insulation (Fig.1(e)) was fastened by means of staples spaced 1 1/2 inches on centers, driven through a reinforcing cardboard strip.

In all cases, the flat (stapling flange) side of the insulation was toward the warm side, and the peak side toward the cold side. For the accordion insulations, the flat side aluminum foil was 0.0009-inch thick, the peak-side (or other) foil 0.0007-inch thick, and the accordion-folded blue paper 0.005 inch thick, approximately. The Retardive aluminum foil was 0.0015 inch thick. All of the aluminum foils had bright clean surfaces, both before and after the tests.

Because the ends of the several accordion types of insulation had to be folded for stapling at the end of the framing spaces, some thinning of the insulation thickness at the ends occurred. The decrease in thickness was slight except for Type 6PS, for which it was about one inch at points a few inches from the ends.

Examination of the installed insulations after each was tested indicated that little or no sagging or movement of the exterior foils of the insulation occurred when the panel was turned from one horizontal position to the other, except in the case of Type 6PK, the peak foil of which deflected downward about one inch in the center when the peak side was downward.

It will be noted that with Type 4S insulation (Fig. 1(b)), a gap of triangular cross section existed between the framing member and the flank of the insulation on the peak side. The other types of accordion insulation (Figs. 1(c) to 1(g)) were designed to have the peak flank in close contact with the framing member. This was found to be the case for all of these types, the gap being substantially closed except for Type 6PK. In this case, a gap of about 1/4 inch width at the peak existed for a distance of about 3 ft along one flank side of one of the metering area framing spaces. This may have been partly due to the fact that the distance between the sides of two framing members in the test panel was 14 11/16 inches instead of the nominal 14 3/8 inches. This spacing was adjusted to 14 7/16 inches for the tests of the Types 4PS, 4PX, and 6PS insulations, for which flank contact was important.

The tests were made in a rotatable guarded hot-box heat transfer apparatus which is wholly mounted on horizontal trunnions to allow the entire apparatus to be rotated for positioning the plane of the panel at any angle up to 90 degrees from the vertical in either direction.

The hot-box apparatus conforms substantially to the requirements of ASTM 236-54T, "Method of Test for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot-Box", except for the additional feature of rotatability on trunnions.

The test panel was tightly held and sealed by gaskets between the "cold box" and the "guard box", the latter containing a "metering box" tightly pressed and sealed by gaskets against the central area of the panel 32 inches wide and 60 inches high. The cold box was held at a constant temperature of about 0°F by a refrigerating coil, and the metering and guard boxes were

heated electrically to a constant temperature of about 70°F or more. All electrical input to the metering box was measured by a calibrated integrating watt-hour meter; the guard box was automatically maintained by a sensitive differential thermostat at the same temperature as the metering box to minimize heat flow between them. A sensitive compound thermocouple indicated the magnitude of any unbalance, to compensate for which a small adjustment was applied to the measured power input to the metering box. Air temperatures were measured by means of thermocouples at ten points three inches from the panel surface on each side. The air in the boxes was circulated gently by fans (at about 40 fpm on the warm side and 90 fpm on the cold side) in a direction to assist natural convection on the faces of the panel.

Each test was begun after a state of steady temperature conditions had been reached and held for several hours; the average data-taking period was about 20 hours for each test. During this period, all observed air and surface temperatures were constant to within 0.6 degree F or less. All thermocouple data used for calculations were read by means of a semi-precision manually-operated potentiometer. A sensitive temperature-recorder was used to record six selected temperatures continuously for information as to the constancy of conditions between manual readings.

Most of the tests were made with the air at about 70°F on the warmer side and 0°F on the colder side, except for those with heat flow downward and the tests made with Infra Retardive forming three reflective air spaces. In the two latter cases the air temperature on the warm side was raised because the metering box fan power input alone was slightly more than the heat required for a 70 degree temperature difference across the panel.

The thermal conductance of the insulated space was calculated from the net measured heat input to the metering box divided by the area of the metering section of the panel (13.33 ft^2) and by the average temperature difference observed between the surfaces of the metal faces which covered the stud spaces.

As a preliminary to these tests, tests were made in three orientations on a "check panel" of plywood, 5.5 ft x8 ft x 1 1/4 inches in size, to compare the results obtained in the guarded hot box apparatus with those obtained on a specimen of the same plywood tested in an 8-inch guarded hot plate thermal conductivity apparatus. The hot plate result, at approximately the same moisture content and mean temperature as existed during the hot box tests, indicated a thermal conductivity of 0.80 Btu/hr ft^2 (deg F/inch), corresponding to a thermal conductance for the 1 1/4 inch panel of 0.64 Btu/hr ft^2 (deg F), as compared to the average conductance of 0.65 obtained in the three hot box tests. Since the difference would be accounted for by a change of one percent in the moisture content of the plywood, the two results are considered satisfactorily concordant.

III TEST RESULTS

The data and calculated results for all of the tests are summarized in Table 1. The thermal conductances for the several Infra Insulation applications are shown graphically in Figure 2. Included in Table 1 and Figure 2 for purposes of comparison are similar data on Type 4K and Type 6S Infra Insulations obtained in tests conducted in 1949 and 1950 respectively. These two insulations resembled Type 4S (Fig.1(b)) in that the flank of the insulation on the peak side did not hug the side of the framing member.

In Table 1 and in Figure 2, the thermal conductance referred to is that between the inner or facing surfaces of the faces of the test panel. This conductance includes the effect of the nominal 2x6 inch framing members, which occupied approximately the same proportion of the test area as is ordinarily occupied in practice by framing members spaced 16 inches on centers. The effect of the framing members is slight in most cases since their conductance is estimated to be about 0.14 Btu/hr ft^2 (deg F).

IV DISCUSSION OF RESULTS

The test values of the thermal conductance of the empty test panel, as recorded in Table 1, are in close agreement with corresponding values calculated on the basis of the convection data given in the paper "The Thermal Insulating Value of Airspaces" (Housing Research Paper No. 32, Government Printing Office), for the cases of heat flow horizontal and heat flow upward. In the case of heat flow downward, the test conductance is 9 percent lower than the calculated value. The calculations were based on an assumed total emissivity of 0.90 for the inner panel surfaces, and include the effect of radiation to and from the framing members considered as "refractory surfaces" (See "Heat Transmission" by W. H. McAdams, 3rd edition, pp. 69-76, 1954, McGraw-Hill Book Co., Inc., New York, N.Y.).

The thermal conductances obtained for the test panel with three reflective spaces of equal thickness formed by two sheets of Retardive insulation (Fig.1(e)) are from 1.8 percent (heat flow direction 45° upward) to 6.8 percent (heat flow vertically downward) greater than corresponding values calculated using the data and procedure given in Housing Research Paper No. 32.

In view of the uncertainties involved in the calculations in allowing for the effect of the framing members, and the small conductance for heat flow downward, the test and calculated conductances are in good agreement.

Considering the results shown graphically in Figure 2, it may be noted that for the insulations which had conductances approximately equal to the value for three reflective plane air spaces for heat flow horizontal, the conductances are smaller for heat flow upward, and larger for heat flow downward, than they are for the three reflective plane air spaces. Their relatively decreased conductance for heat flow upward is believed to be due to the interference of the accordion-folded blue paper with convection currents between the aluminum foils. Since convection is the predominant mode of heat transfer for heat flow upward, such interference is of major importance in reducing the conductance for this condition. For heat flow vertically downward, these insulations have approximately the same conductance (0.082 to 0.093), a result which would be expected if convection were reduced to a quite small magnitude. The fact that the conductances for heat flow vertically downward are definitely greater than that for the three reflective spaces is believed to be due in part to metallic conduction of heat from the warmer aluminum foil to the cooler foil via the folded edges of the insulation where the foils lie in close thermal contact. An estimate of the thermal conduction by this path yielded a value equivalent to about 0.02 conductance units for the Type 4PX insulation, which is approximately the amount by which the insulation conductances exceed the value for the three reflective air spaces formed by two sheets of foil not in thermal contact at the framing member.

The effect of closing the gap between the peak-side flank of the insulation and the framing member is very considerable, as shown by comparison of results for Types 4S with those for 4PS and 4PX, and those for Type 6S with those for 6PK and 6PS. The effect of the gap is of course most marked for orientations where convection in the outer air spaces is important; for heat flow vertically downward, stratification of the air inhibits the effect of the gap, and all of the insulations tend to yield about the same conductance.

The differences in conductance for Types 6PK and 6PS (apart from the probably smaller effect of the small flank gap of the 6PK insulation, previously mentioned) appear to be due to the greater thickness of the 6 PS insulation, and to the separation between the peak side foil and the blue paper of the Type 6PS design. The downward deflection of the peak-side foil of the 6PK insulation when it was underneath, as mentioned previously, would cause it to simulate the Type 6PS insulation for vertically downward heat flow, as the results indicate was the case.

In considering the closed-air-space conductances obtained with the various insulations in these tests, it is important to appreciate the fact that the insulations were carefully installed under laboratory conditions. That is, the edges and ends were stapled tightly to the framing members, there were no perforations or tears in the foil membranes, and care was taken (working only on the stapling side of the test panel) to assure good contact between the peak-side flanks of the insulation and the framing members in the cases of the insulations designed to have no flank gap.

The question may arise as to the conductances of these insulations in closed air spaces formed by framing of other dimensions, such as 2x4 studs, or 2x8 or 2x10 joists or rafters. The effect of changing the thicknesses of the outer air spaces as a result of changing the framing dimension depends chiefly on the change in the convection-conduction coefficient (h_c) of the air space with thickness. Data on this variation are given in Housing Research Paper No. 32. Reference to this data indicates that for an air space in a vertical orientation, with heat flow horizontal, little change in overall conductance would occur for air spaces with framing between 4 and 10 inches in nominal size. A similar approximate conclusion is reached for the cases of heat flow upward or downward at a 45 degree angle. In the case of heat flow vertically upward, the change in conductance of the test panel due to use of 2x10 joists is estimated to be a decrease of not more than 6 percent. For heat flow downward, it is estimated that changing the joists of the test panel from nominal 2x6 to nominal 2x10 framing would result in a decrease of about one third in the conductance between the inner faces of the panel.

TABLE I

SUMMARY OF TEST DATA AND RESULTS

Type of Insulation	Direction of Heat Flow	Duration of Test, Hours.	Avg. Power Input, Watts	Warm Surface Temp., °F	Cold Surface Temp., °F	Tem. Diff. Surface to Surface Deg F	Test Conductance* Btu/hr ft^2 Deg F
Plywood	Upward	24	104.5	53.3	13.2	40.1	0.656
Calibration	Horizontal	23	102.1	52.8	13.5	39.3	0.653
Panel	Downward	26	93.0	48.6	11.9	36.7	0.638
Empty	Upward	22	123.7	50.3	16.5	33.8	0.919
Test	Horizontal	21	111.1	50.5	16.7	33.8	0.826
Panel	Downward	21	83.4	51.4	11.9	39.5	0.531
Infra Type 4K (1949)	Upward	23	43.2	64.9	6.4	58.5	0.189
	45 deg upward	24	40.4	65.6	5.6	60.0	0.172
	Horizontal	24	34.7	63.7	5.0	58.7	0.151
	45 deg downward	22	32.7	67.2	4.1	63.1	0.133
	Downward	22	27.3	75.7	3.5	72.2	0.097
Infra Type 4S	Upward	20	42.6	65.2	5.1	60.1	0.178
	Horizontal	23	36.9	64.4	1.7	62.7	0.148
	Downward	20	23.9	71.4	2.4	69.0	0.087
Infra Type 4PS	Upward	20	39.1	65.6	4.6	61.0	0.161
	45 deg upward	19	35.5	65.0	4.1	60.9	0.146
	Horizontal	24	31.9	65.7	4.4	61.3	0.131
	45 deg downward	20	27.7	65.9	3.2	62.7	0.111
	Downward	23	23.7	75.0	2.2	72.8	0.082
Infra Type 4PX	Upward	24	38.4	65.5	5.0	60.5	0.160
	45 deg upward	19	35.1	65.4	4.4	61.0	0.145
	Horizontal	25	31.0	65.6	4.4	61.2	0.127
	45 deg downward	20	30.6	71.3	3.9	67.4	0.114
	Downward	21	24.0	75.2	2.1	73.1	0.082

TABLE 1 (Continued)

Type of Insulation	Direction of Heat Flow	Duration of Test, Hours.	Avg. Power Input, Watts	Warm Surface Temp., °F	Cold Surface Temp., °F	Temp.Diff. Surface to Surface Deg F	Test Conductance* Btu/hr ft^2 Deg F
Three Plane	Upward	23	41.8	69.9	7.0	62.9	0.167
Reflective	45 deg upward	14	37.3	70.1	5.4	64.7	0.145
Air Spaces	Horizontal	27	32.9	70.7	5.2	65.5	0.126
Infra Retardive	45 deg downward	26	26.6	72.1	3.8	68.3	0.098
	Downward	34	24.2	94.2	3.4	90.8	0.067
Infra Type 6S (1950)	Upward	45	36.1	65.3	6.4	58.9	0.154
	45 deg upward	18	34.0	65.4	5.8	59.6	0.143
	Horizontal	24	31.7	65.2	5.1	60.1	0.132
	45 deg downward	24	30.0	67.6	5.0	62.6	0.120
	Downward	17	25.6	72.4	3.6	68.8	0.093
Infra Type 6PK	Upward	22	35.8	67.6	4.9	62.7	0.144
	45 deg upward	19	34.3	67.6	4.4	63.2	0.136
	Horizontal	20	32.0	67.9	4.5	63.4	0.127
	45 deg downward	19	28.7	69.0	4.2	64.8	0.111
	Downward	24	24.0	73.8	3.0	70.8	0.085
Infra Type 6PS	Upward	20	32.1	66.6	3.9	62.7	0.129
	45 deg upward	19	30.4	67.1	3.4	63.7	0.120
	Horizontal	27	27.6	67.3	3.3	64.0	0.108
	45 deg downward	19	28.3	74.0	3.0	71.0	0.100
	Downward	24	31.3	98.6	3.5	95.1	0.083

*Thermal conductance of panel, including wood framing, between the inner surfaces of the faces applied to the framing.

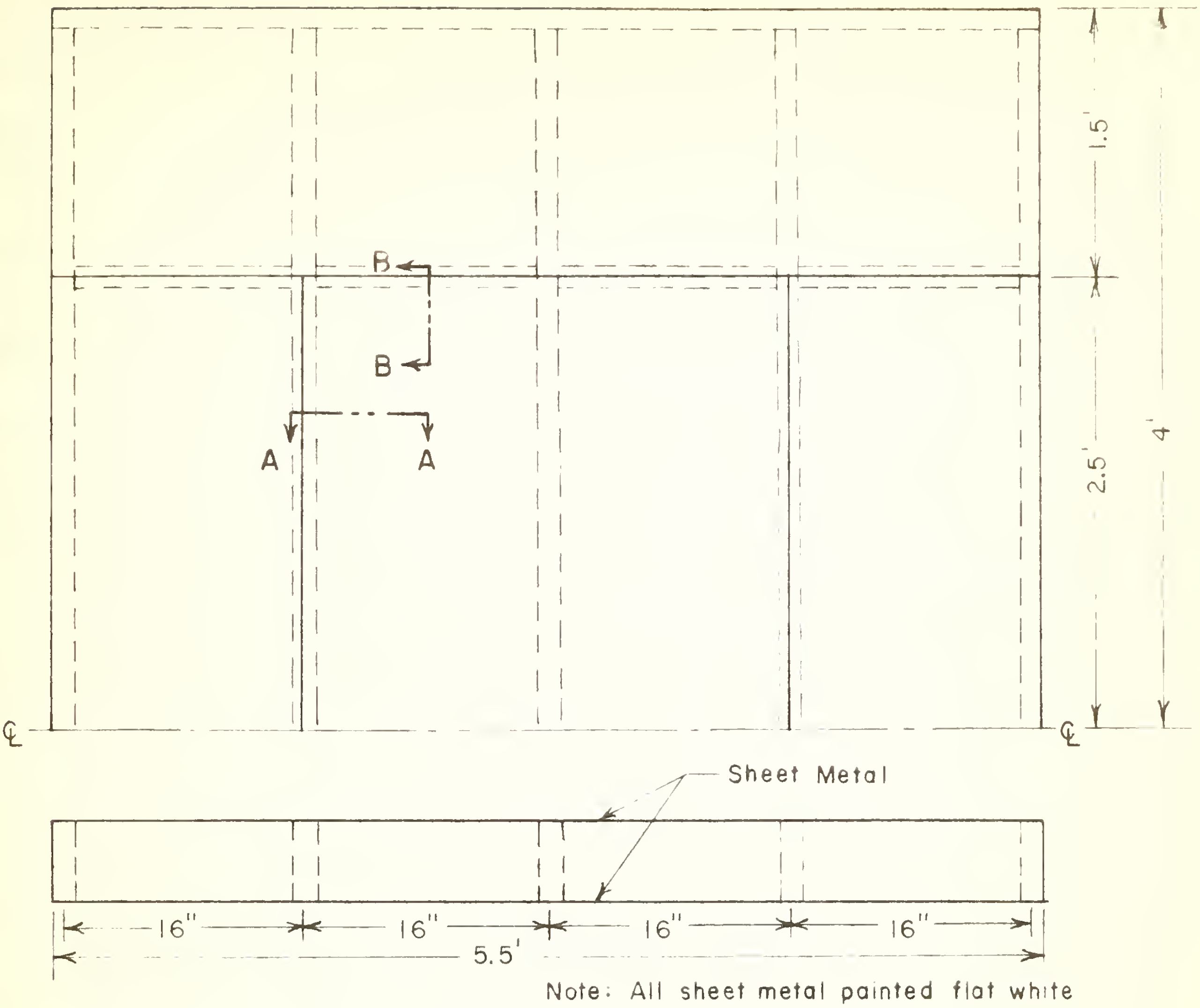

Figure 1 (a) TEST PANEL (Upper Half)

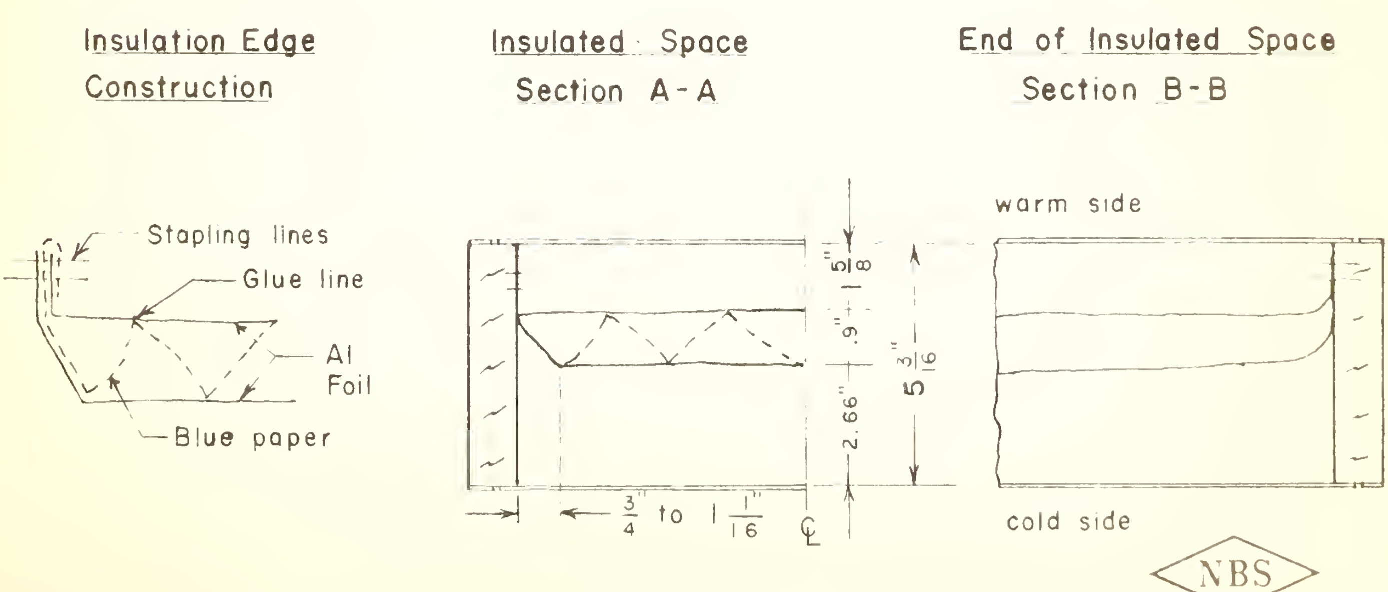

Figure 1 (b) INFRA TYPE 4 S

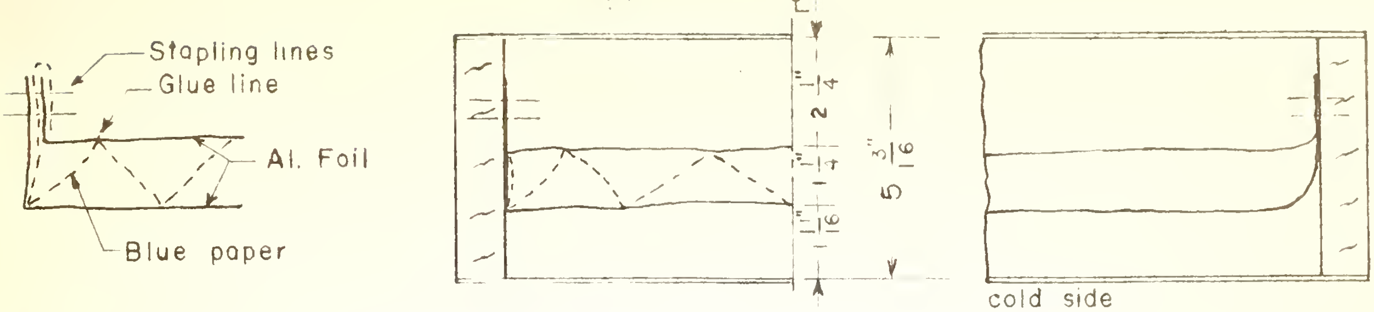

Fig. I (c) INFRA TYPE 4 PS

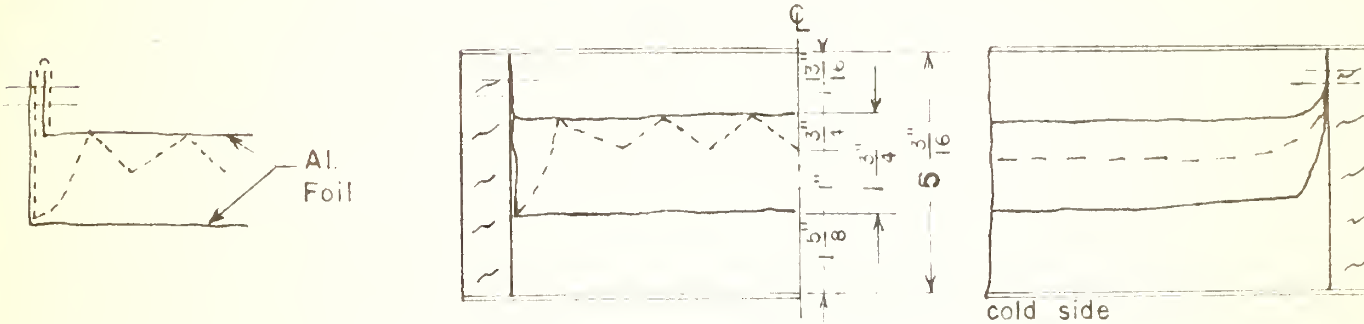

Fig. I (d) INFRA TYPE 4 PX

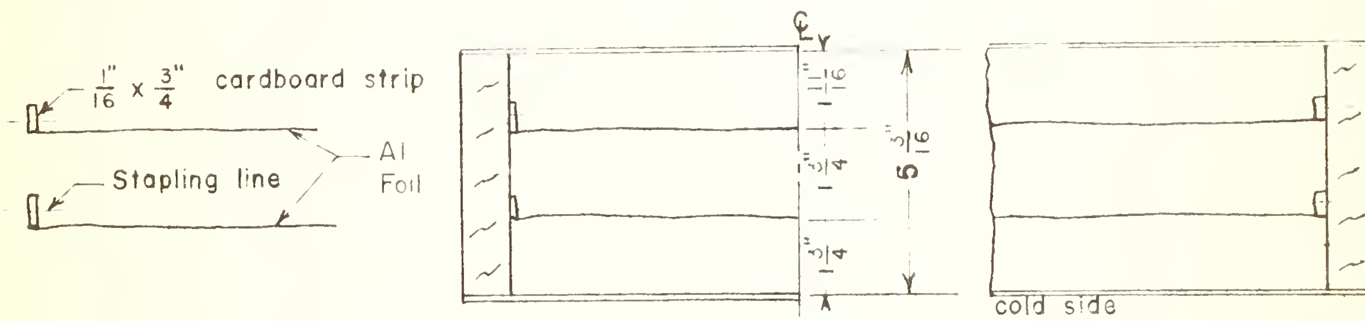

Fig. I (e) INFRA TYPE Retardive (3 Refl. spaces)

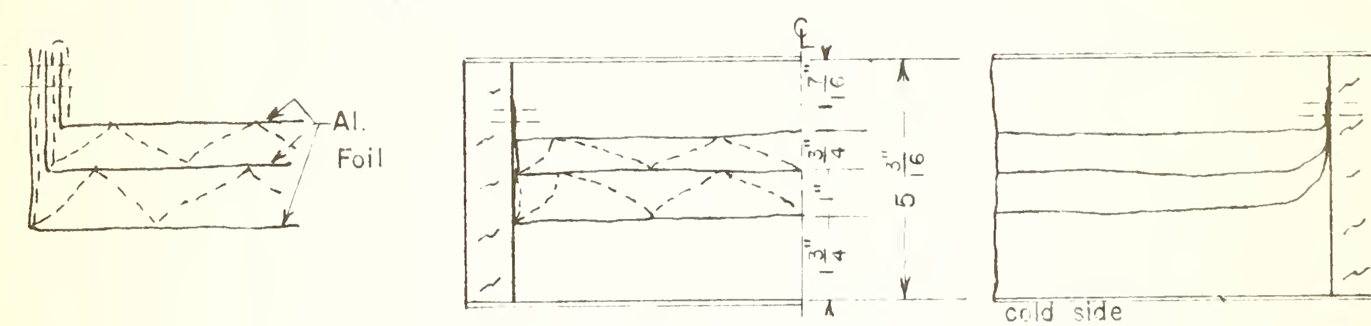

Fig I (f) INFRA TYPE 6 PK

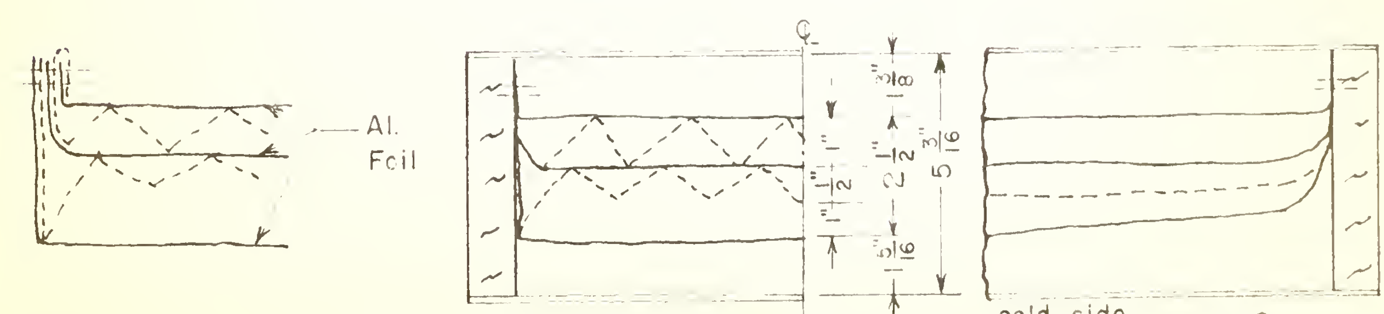

Fig I (g) INFRA TYPE 6 PS

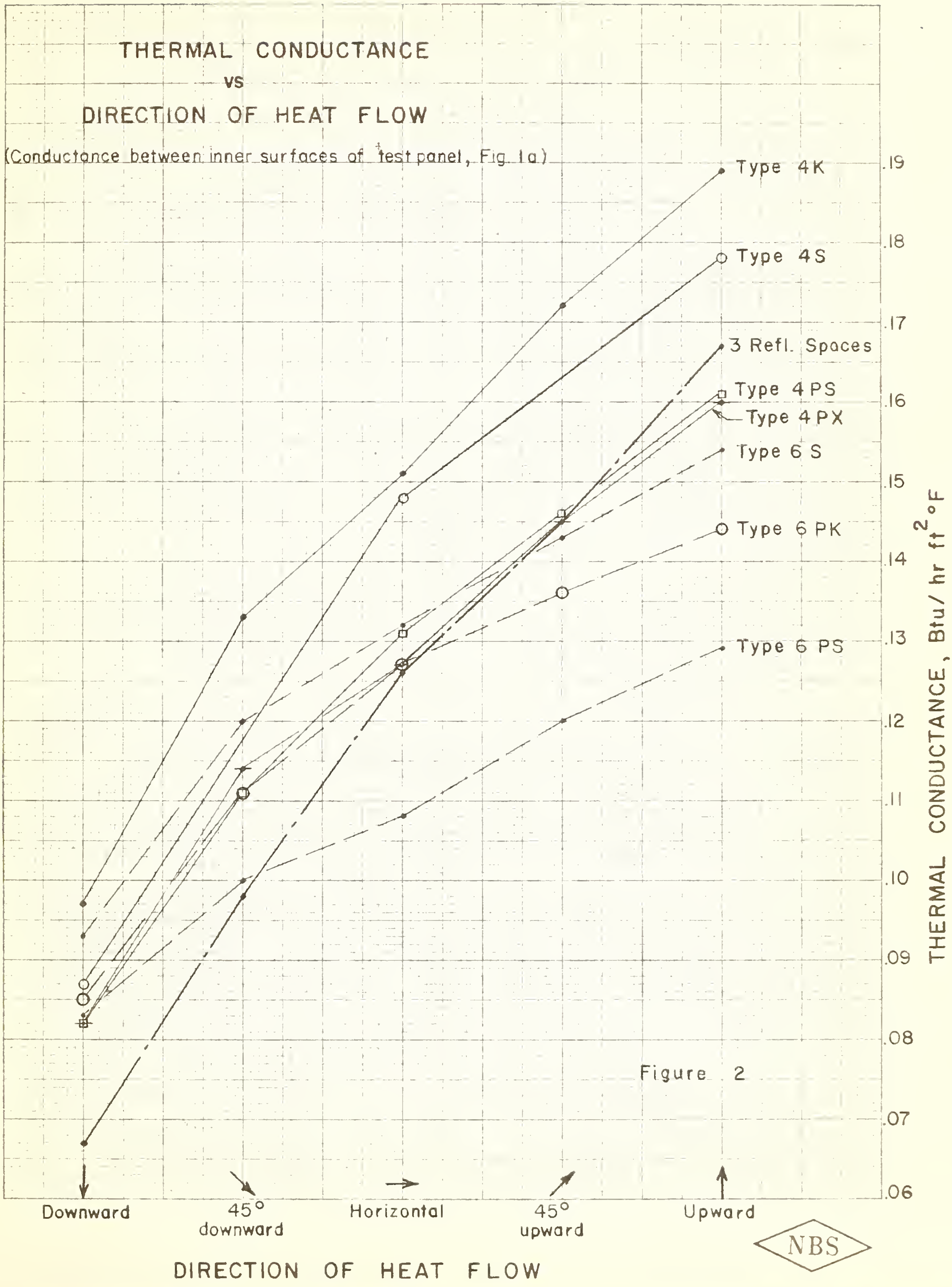
THERMAL CONDUCTANCE
vs
DIRECTION OF HEAT FLOW
(Conductance between inner surfaces of test panel, Fig. 1a)
Type 4K
Type 4S
3 Refl. Spaces
Type 4 PS
Type 4 PX
Type 6 S
Type 6 PK
Type 6 PS
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
THERMAL CONDUCTANCE, Btu/ hr ft² °F
Downward
45° downward
Horizontal
45° upward
Upward
DIRECTION OF HEAT FLOW

Figure 2

NBS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

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Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

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