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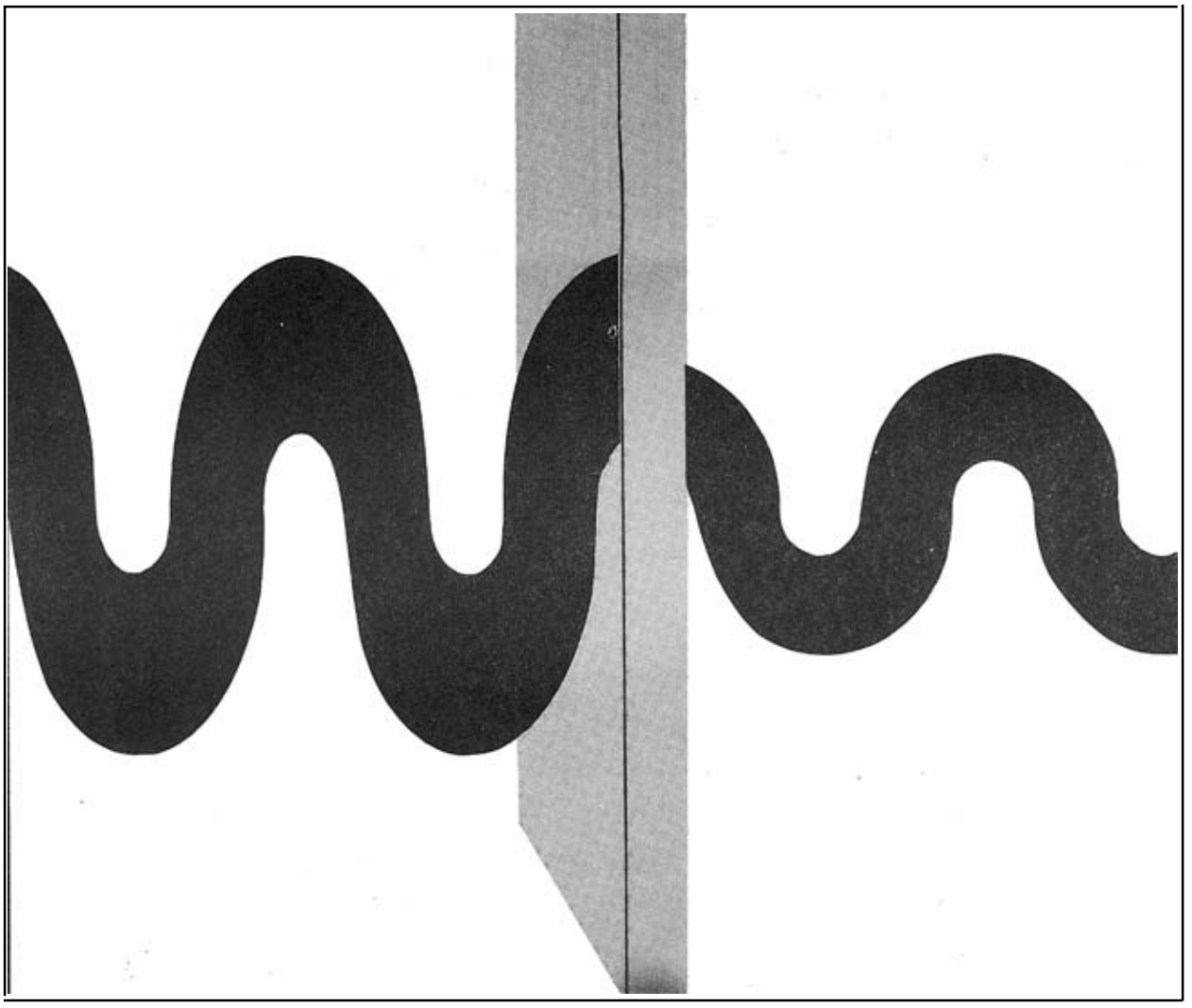
THERMAL CONDUCTIVITY OF WOOD-BASE FIBER AND PARTICLE PANEL MATERIALS



ABSTRACT

Thermal conductivity determinations of the many and changing building fiberboards and particleboards are impractical on an individual product basis. However, research reported here shows that reliable estimates of heat flow can be made on the basis of the density of a particleboard, insulation board, or hardboard.

Design curves were developed after completing evaluations of special laboratory-made fiberboards and particleboards without additives other than resin binder in the particleboards, and from values obtained for typical commercial products. The limited published values from other sources were compared with those predicted by the design curves. Results verified the validity of the values obtained in this study using Forest Products Laboratory equipment.

It is usual practice to present and calculate heat flow in buildings based on a mean temperature of 75° F. Design values of thermal conductivity at that temperature are presented for all of the common classes and kinds of insulation board, hardboard, and particleboard. Values are also presented which will permit modification of the thermal conductivity factors when conditions require other mean temperatures. Conductivity values for fiberboards should be increased or decreased 0.00053 B.t.u., inch per hour, square foot, °F., for each degree increase or decrease in mean temperature. The similar factor for particleboards is 0.00093 B.t.u., inch per hour, square foot, °F. Laboratory equipment and procedures used in this study are also fully described.

Thermal Conductivity of Wood - base Fiber and Particle Panel Materials

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INTRODUCTION

All materials offer some resistance to heat flow. Some materials are good conductors, while others are not. The importance of heat transfer varies with the application. In some instances, it is desirable that heat be contained. The interior of a house during cold weather is an example. In others, it is desirable that heat be dissipated. The heat energy developed in electrical transformers or in internal combustion engines is an example.

Heat transfer through solids is by conduction, although in many materials such as wood or thermal insulation the material is a combination of solid substance and air pockets (voids). Heat transfer through the voids is essentially by radiation; convection effects are not significant at normal temperatures. In fact, it is the many small airspaces in thermal insulations that make them inefficient conductors (good thermal insulators).

Wood and wood-base materials, then, offer resistance to heat flow because of the small air pockets in them, as well as the resistance of the wood substance itself to heat transfer. The greater the number of these small air pockets the better would be the expected conductivity factors, sofar as thermal insulation is concerned. This means that, in general, one could expect lower conductance with low-density wood-base materials than with those of high density. There should be some sort of a density-conductivity relationship. Previous work on wood has shown this to be so (3).[2] It is common practice to estimate factors for heat flow on the basis of the specific gravity of the wood (5).

The panel products industry--plywood, insulation board, hardboard, and particleboard manufacture--has shown major growth since the late

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
[2]Underlined numbers in parentheses refer to Literature Cited at the end of this report.

1940's. Products are now being manufactured that did not exist a few years ago. Many of the uses, such as in housing, require accurate estimates of heat flow. Heat-flow properties of plywood can be estimated reasonably well from values presented for solid wood. This is not so for the other panel products because they are reconstituted by breaking down wood into small components and then putting them together again. The arrangement of the small airspaces is different, as are the densities.

Heretofore, insulation boards were the only wood-base panel materials for which adequate h e at transfer values were available. The specifications for these materials all gave maximum thermal-insulating values (1, 6), since one of the major considerations was their thermal insulating quality. Even for insulating board, the information on heat flow is not adequate. New products of higher or lower density have been introduced for which heat-flow factors are not generally available.

The research reported was developed to provide more basic information on the heat-flow properties of wood-base fiber and particle panel materials. In addition, because techniques and equipment for measuring heat flow are complicated, results obtained by using Forest Products Laboratory equipment are compared with those published from other sources (4).

HEAT TRANSFER MEASUREMENT--METHODS AND UNITS

Methods

Heat-flow properties of insulation or similar materials of relatively low conductance may be determined by any one of several methods. While theoretically all of them may yield absolute values of thermal resistance and conductance, there are factors to be considered for such items as emissivity of parts of the apparatus, flanking heat loss, and contact resistance that justify the use of one procedure as a basis and referee. The guarded hotplate procedure (2) is that procedure and is the one used in this study. Figure 1 shows the Forest Products Laboratory guarded hotplate apparatus.

In addition to the apparatus shown, a refrigerating unit, with coils immersed in an insulated tank and a pump for supplying coolant to the two cold plates, was used. The two cold plates are the outside units of a pack consisting of the hotplate at the center with two identical specimens sandwiched between it and the cold plates. The hotplate, specimens, and the cold plates in the Forest Products Laboratory apparatus are 13-1/2 inches square. The hotplate is electrically heated in two sections--the central measuring section and the guarded hotplate area outside of it. The central measuring section is square with an area of 50 square inches and, thus, the two sides provide a total test area of 100 square inches, In making a determination of conductivity, the principle is to set up a steady state heat-flow condition between the hotplate and the pair of cold plates so that there is nolateral heat flow from the central measuring section to the guard-ring area, This requires that the temperature of the guard ring adjacent to the central heated area be identical to that of the central heated area.

The Forest Products Laboratory apparatus is automated to make the adjustments necessary to establish this steady state condition, Differentially connected thermocouples, located at several locations around the edge of the central section and the guard ring (actually separated a fraction of an inch and insulated from each other), are linked to a drive mechanism that adjusts the amount of heat energy being supplied to the guard ring. Further, the standard method requires that the temperature difference between the hot and cold sides of the specimens shall be at least 10°F., and for good insulators, it is recommended the temperature gradient be 40° F. or more per inch of thickness. The Forest Products Laboratory equipment has capacity to exceed that requirement and all evaluations were made with a temperature difference of 40" F. or more between the hot and cold plates. This difference is obtained by adjusting heat power supplied to the central area of the hotplate. The apparatus is calibrated with standard specimens furnished by the National Bureau of Standards.

Conductivity values vary with mean temperature. The higher the mean temperature, the higher will be the conductivity; therefore, determinations were made at three mean temperatures between about 50° F. and 130° F. so that the effect of mean temperatures could be determined.

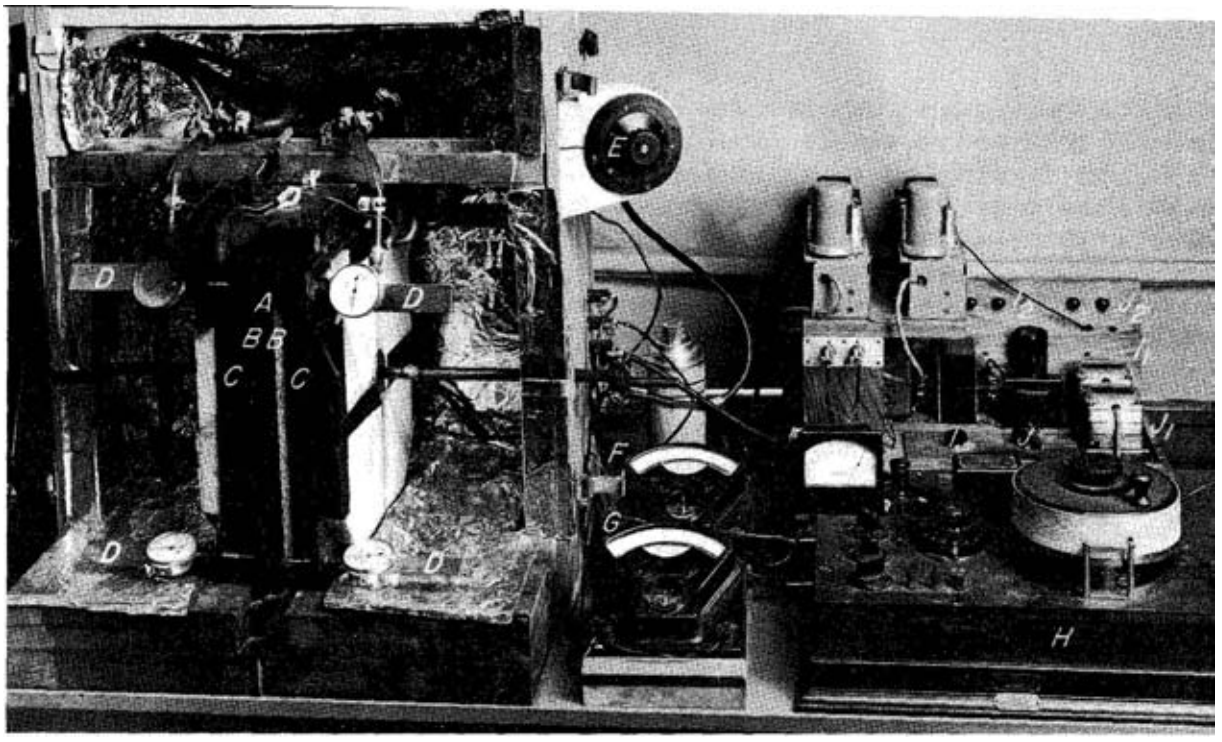

Figure 1.--Forest Products Laboratory guarded hotplate apparatus, showing: A central heated test area; B two identical test specimens; C cold plates through which coolant is circulated; D micrometer gages to control and measure thickness of specimens; E thermocouple switch; F and G microammeter and voltmeter for determining power to central heated area; H potentiometer for temperature determinations of thermocouples (copper-constantan) located on body of apparatus; I, i_j, and I_2 control, Selsyn drive, and indicator lignts for heat control of heated area of hotplate and J, J_1, and J_2 similar control, Selsyn drive, and indicator lights for guard-ring area.

(M 126 580)

Units of Measurement

Certain basic terms relating to heat flow should be clearly understood to properly interpret the results from an investigation of heat flow and, for convenience, are reviewed briefly. Thermal conductivity is the time rate of heat flow through unit thickness. It is expressed in units of heat that are transferred through unit thickness per unit of time per unit of area per unit of temperature difference. In the British system of measurements, thermal conductivity, identified universally by the symbol k, is presented algebraically in B.t.u, inch per hour, square foot, degree F. In the metric system, two sets of terms commonly are used--kilogram calorie per hour, meter, degree C., and milliwatts per centimeter, degree C. Values for building materials are frequently presented in the first set of these terms and results of scientific evaluations in the second set.

Both units are used in this report. Values of thermal conductivity are only valid when the thermal gradient from hot surface to cold surface is uniform, so that unit values may be accurately computed from the thickness of the material tested and hence, for other thicknesses of the same material, This means that the material must be essentially homogeneous in the direction the heat is flowing, but does not mean that the material must be isotropic so far as thermal properties. As in wood, they may vary considerably in the different directions. Wood 'has a decidedly different conductivity when the heat moves parallel to the grain than when moving across the grain.

A similar situation exists with the wood-base fiber and particle panel materials. The heat-flow properties are different when the heat is moving from one face to the other than when moving along or across the board. In this investigation, the heat flow was measured through the board; that is, from face to face, since in nearly all applications heat loss in that direction is the desired property.

Conductance, C, is the time rate of heat flow through a prescribed thickness of material or construction. Thus, for a homogeneous material

of unit thickness, k and C are equal. For other than unit thickness, conductance is inversely proportional to thickness. Conductance, as a measure of heat flow, has further advantages as far as nonuniform materials are concerned. A value can be presented that may be used directly in a computation of heat transfer. For example, dead airspaces in a construction or some nonuniform material such as a hollow tile or concrete block may be directly expressed. The units for conductance are B.t.u. per hour, square foot, degree F. in the British system of units, and either kilogram calories per hour, square meter, degree C., or milliwatts per square centimeter, degree C. in the metric system.

Resistance is the reciprocal of conductance and is denoted by the symbol R. In making computations of heat flow through a combination of materials, such as the wall of a building, the resistances for the individual components are added together and the reciprocal of that sum is the overall conductance of the construction, R values commonly are expressed in degree F., hour, square foot per B.t.u.; degree C., hour, square meter per kilogram calorie: or degree C., square centimeter per milliwatt.

MATERIALS INCLUDED IN STUDY

Two special sets of specimens were made for the basic part of the study. The purpose was to have a set of fibrous panels and a set of particleboards differing only in density and as free from additives as possible, so that the basic density-conductivity relationship could be established.

The special fiberboard material was made from aspen fiber in the laboratory of the Celotex Corporation, Des Plaines, Ill. Four pairs of specimens with densities of about 12, 24, 39, and 54 pounds per cubic foot were provided. The fiber was typical of that used for insulation board and hardboard manufacture.

For the particleboard specimens, it was not possible to make an additive-free board. Synthetic resin was required for producing the bond, but no other additives such as wax were introduced. The particleboards were made at the Forest Products Laboratory and, except for density and wax, could be called the "FPL Standard" board. Douglas-fir flakes, 1 inch in length and 0.015 inch thick, were bonded with 8 percent of urea-formaldehyde resin (by weight of ovendry particles). Boards were pressed for 15 minutes at 325° F. to set the resin. Nominal densities were 24, 40, 50, and 65 pounds per cubic foot.

Samples of commercial products were obtained for the second part of the study. They were used to obtain actual conductivity values for commercial products of both fiber and particle base with additional additives in them, as is the commercial practice. Products included ranged from low density, semirigid insulation board or cushioning to high density, tempered hardboard and particleboard.

The following is the identification and brief description of the commercial products included:

FIBER-BASE MATERIALS (FIBERBOARDS)

A-1, A-2, A-3	- Semirigid wood-fiber insulating board of various densities, manufactured primaily for use as cushioning.
B-1, C-1, G-1, L-1	- Regular density, sheathing-type insulation board.
B-2, F-1	- Nail-base, sheathing-type insulation board.
D-1, E-1, J-1	- Medium-density hardboard siding.
E-2	- Interiol-type insulating board
H-1	- Standard-grade hardboard.
H-2	- Service-grade hardboard.
H-3	- Tempered high-density hardboard.
K-1	- Laminated paperboard.

PARTICLE-BASE MATERIALS (PARTICLEBOARDS)

M-1	- Douglas-fir, hammer-milled greenplaner shaving, uniform gradation, urea-formaldehyde resin bonded.
N-1	- Ponderosa pine flake face, mixed softwood sliver core, urea-formaldehyde bonded.

P-1 - Ponderosa pine fine hammer-milled particle, phenolic bonded.

Q-1 - Aspen, fine attrition-mill particle, urea-formaldehyde bonded.

R-1 - Douglas-fir flake type board, urea-formaldehyde bonded.

All particleboards were of the flat-platen pressed type, since all but about 5 percent of the particleboard produced in the United States is that type. Extruded boards would have decidedly different heat-flow properties than the flat-platen pressed boards because of the predominate orientation of particles in the vertical plane.

All specimens were carefully dried at 217° ±4° F. (103° ±12° C.) to constant weight (0 percent moisture) before evaluations were made. Otherwise, it would not be possible to set up a steady-state condition in the hotplate because of moisture movement in the specimen and resulting condensation on the cold plate.

PRESENTATION AND DISCUSSION OF RESULTS

The results of the evaluations are presented in table 1 for fiber-based specimens and in table 2 for the p art i c 1 e-based specimens. In each instance, the data obtained from an evaluation were for a value of mean temperature that could not be predetermined exactly. The controls for the refrigerating unit and the hotplate were set to provide approximate conditions, As a result, values typical of those shown in figure 2 were determined for each specimen evaluated.

The values for the mean temperatures listed in tables 1 and 2 were obtained from "best-fit" straight line for the plot from the three mean temperatures actually obtained. Figure 3 presents these values for the specially manufactured fiberboard for the four mean temperatures (50°, 75°, 100°, and 125° F.) with values of thermal conductivity plotted as ordinates and corresponding specific gravity values as abscissas. Figure 4 is a similar plot of values for the specially made particleboard. Comparison of the two plots indicates that there was a definite relationship

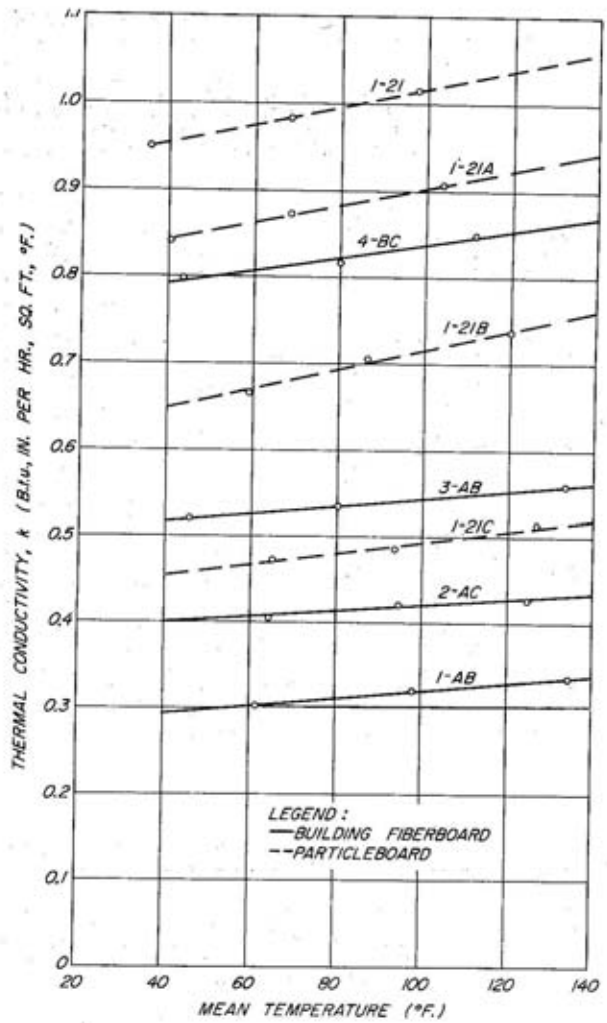

Figure 2.--Plot of thermal conductivity values obtained for various mean temperatures for the specially fabricated building fiberboards ana particleboards. (M 132 880)

for each kind of panel material. In each instance, it was possible to establish a family of curves, one for each mean, which showed how conductivity increased with density as measured by specific gravity (sometimes called bulk density in the literature) (4). Conductivity values for the same density were higher for particleboards than for the building fiberboards. The lower values for fiberboards are explained most logically by the fineness of the fibers and fiber bundles in the fiberboard as compared to the particles and the greater number of smaller airspaces.

Also noted is the fact that curves for the building fiberboards were closer together than for the particleboards. This is also shown in figure 2, where the slope of the lines for fiberboards are uniformly flatter than those for the particleboards.

Table 1.--Thermalconductivity of various building fiberboards[1]

Specimen no.	Specific gravity	Density	Thermal conductivity (k) at mean temperature of-- 50° F. (10° C.)	75° F. (24° C.)	100° F. (38° C.)	125° F. (52° C.)	10° C. (50° F.)	24° C. (75° F.)	38° C. (100° F.)	52° C. (125° F.)	10° C. (50° F.)	24° C. (75° F.)	38° C. (100° F.)	52° C. (125° F.)	Thickness as tested In.	Cm.
		Lb. per cu. ft.	B.t.u., in. per hr., sq. ft., °F.				Kg. cal. per hr., m., °C.[2]				Milliwatts per cm., °C.[2]					
SPECIAL BUILDING FIBERBOARD																
1-AB	0.187	11.7	0.30	0.31	0.32	0.33	0.037	0.038	0.040	0.041	0.43	0.45	0.46	0.48	0.52	1.32
2-AC	.380	23.7	.40	.41	.42	.43	.050	.051	.052	.053	.58	.60	.61	.62	.54	1.37
3-AB	.604	37.7	.52	.53	.54	.55	.064	.066	.067	.069	.75	.77	.78	.80	.53	1.35
4-BC	.940	58.6	.80	.82	.84	.86	.099	.101	.104	.106	1.15	1.18	1.21	1.24	.51	1.30
COMMERCIAL BUILDING FIBERBOARDS																
A-1	.026	1.6	.24	.26	.29	.31	.030	.033	.036	.039	.35	.38	.42	.45	1.12	2.85
A-2	.104	6.5	.28	.30	.31	.32	.035	.037	.038	.040	.41	.43	.44	.46	.48	1.22
A-3	.158	9.9	.27	.29	.30	.31	.034	.035	.037	.038	.40	.41	.43	.44	.77	1.96
B-1	.281	17.5	.36	.38	.39	.40	.045	.047	.048	.050	.52	.54	.56	.58	.77	1.96
B-2	.424	26.4	.46	.48	.49	.50	.058	.059	.060	.062	.67	.69	.70	.72	.51	1.30
C-1	.284	17.7	.40	.41	.42	.43	.050	.051	.052	.054	.58	.59	.61	.62	.78	1.98
D-1	.632	39.4	.63	.65	.66	.68	.078	.080	.082	.085	.91	.93	.96	.98	.42	1.07
E-1	.566	35.3	.58	.60	.61	.62	.072	.074	.075	.077	.84	.86	.87	.89	.42	1.07
E-2	.282	17.6	.38	.39	.41	.42	.047	.049	.051	.052	.55	.57	.59	.61	.49	1.24
F-1	.446	27.8	.45	.46	.47	.48	.056	.057	.059	.060	.65	.67	.68	.70	.52	1.32
G-1	.304	19.0	.38	.39	.40	.41	.048	.049	.050	.051	.55	.57	.58	.60	.51	1.30
[3]H-1	.985	61.5	.96	.97	.99	1.01	.119	.121	.123	.125	1.38	1.40	1.43	1.45	.44	1.12
[3]H-2	.916	57.2	.84	.86	.89	.91	.104	.107	.110	.113	1.21	1.24	1.28	1.31	.48	1.22
[3]H-3	.999	62.3	.94	.95	.96	.96	.117	.118	.119	.120	1.36	1.37	1.38	1.39	.41	1.04
J-1	.885	55.2	.83	.84	.85	.86	.103	.105	.106	.107	1.20	1.22	1.23	1.24	.40	1.02
[3]K-1	.494	30.8	.45	.46	.47	.49	.055	.057	.059	.060	.64	.66	.68	.70	.67	1.70
L-1	.290	18.1	.39	.40	.41	.42	.048	.050	.051	.053	.56	.58	.60	.61	.50	1.27

[1]Values are for ovendried specimens (0 pct. moisture content).
[2]Conversions made on nonrounded values; may not check to last figure.
[3]Two thicknesses bonded together for each specimen.

Table 2.--Thermalconductivity of various particleboards—!

Specimen no.	Specific gravity	Density	Thermal conductivity (k) at mean temperature of-- 50° F. (10° C.)	75° F. (24° C.)	100° F. (38° C.)	125° F. (52° C.)	10° C. (50° F.)	24° C. (75° F.)	38° C. (100° F.)	52° C. (125° F.)	10° C. (50° F.)	24° C. (75° F.)	38° C. (100° F.)	52° C. (125° F.)	Thickness as tested In.	Cm.
		Lb. per cu. ft.	B.t.u., in. per hr., sq. ft., °F.				Kg. cal. per hr., m., °C.[2]				Milliwatts per cm., °C.[2]					
SPECIAL LABORATORY PRODUCED PARTICLEBOARD																
I-21C	0.406	25.3	0.46	0.48	0.49	0.51	0.057	0.059	0.061	0.063	0.66	0.69	0.71	0.74	0.48	1.22
I-21B	.653	40.7	.66	.69	.72	.75	.082	.085	.089	.093	.95	.99	1.03	1.08	.48	1.22
I-21A	.834	52.0	.85	.88	.90	.93	.106	.109	.112	.115	1.23	1.27	1.30	1.34	.48	1.22
I-21	.980	61.2	.96	.99	1.02	1.04	.120	.123	.126	.130	1.39	1.43	1.47	1.51	.48	1.22
COMMERCIAL PARTICLEBOARD																
M-1	.633	39.5	.71	.74	.76	.79	.088	.092	.095	.098	1.03	1.06	1.10	1.13	.61	1.55
N-1	.679	42.4	.87	.89	.91	.92	.107	.110	.112	.115	1.25	1.28	1.30	1.33	.74	1.88
P-1	1.000	62.4	1.20	1.22	1.24	1.26	.149	.151	.154	.157	1.73	1.76	1.79	1.82	.52	1.32
Q-1	.478	29.8	.60	.62	.64	.67	.074	.077	.080	.083	.86	.90	.93	.96	1.46	3.71
R-1	.612	38.2	.67	.70	.73	.76	.083	.087	.090	.094	.97	1.01	1.05	1.09	.74	1.88

[1]Values are for ovendried specimens (0, pct. moisture content).
[2]Conversions made on nonrounded values; may not check to last figure.

When making estimates of thermal conductivity or heat loss in typical situations, such as in buildings, it is the general practice to use values for thermal conductivity based on a mean temperature of 75° F. In most specifications for building materials, where one of the functions is thermal insulation, limiting values are set based on that mean value. For the remainder of this presentation, values are given and comparisons made on the basis of the 75° F. mean. The conclusions drawn will be similar and valid for other mean temperatures within the range of 50° to 125° F.

In figure 5, the thermal conductivity-specific gravity curve for the special building fiberboard at 75° F. mean is plotted as the solid line. Individual results for the commercial products presented in table 1 are plotted also. Examination of these plotted values will show that with two exceptions all points fell either close to or slightly

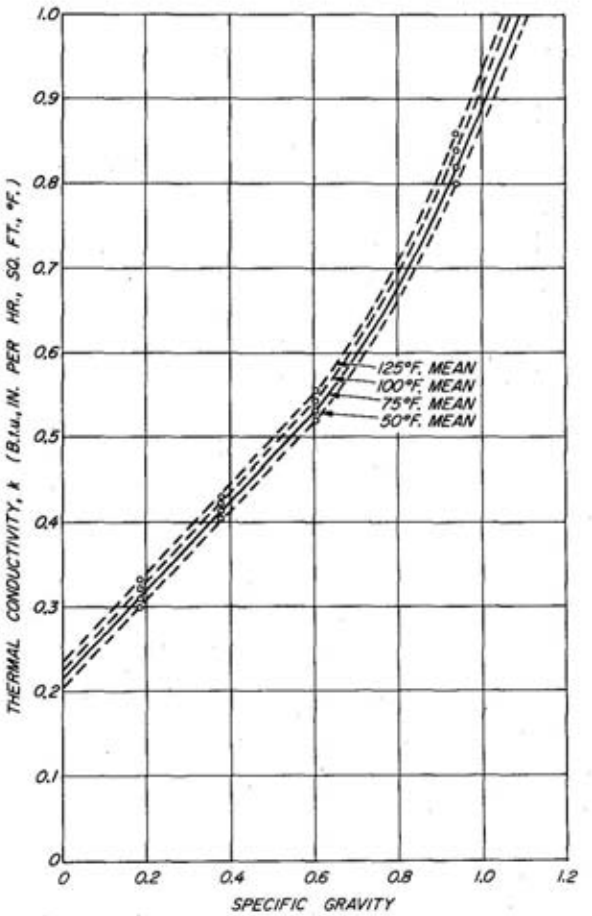

Figure 3.--Thermal conductivity-specific gravity relationship for special building fiberboard made without additives. (M 132 879)

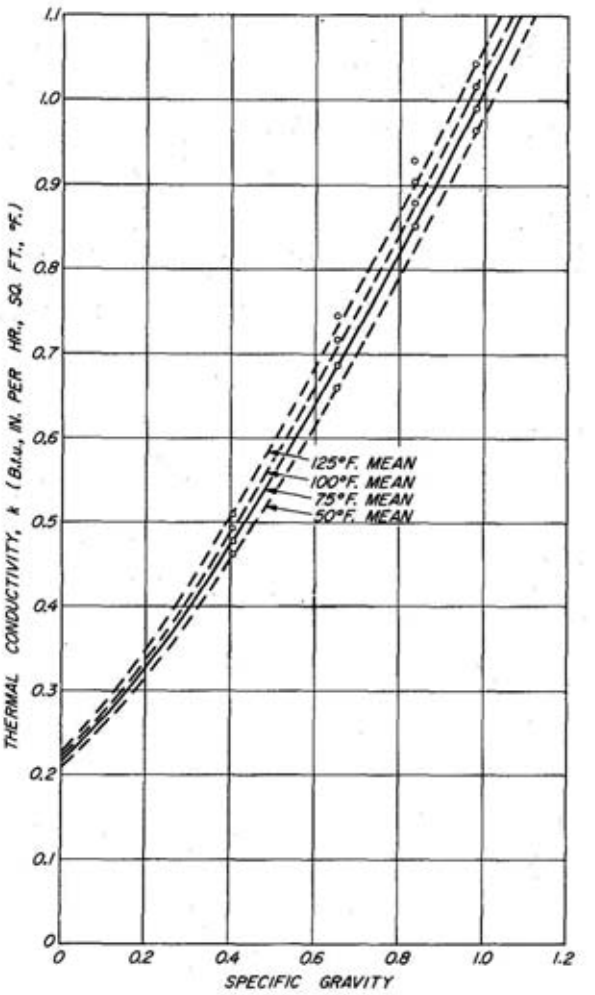

Figure 4.--Thermal conductivity-specific gravity relationship for special particleboard made with no additions but the synthetic resin binder, which was 8 percent urea resin. (M 132 878)

above the curve established from evaluation of the special building fiberboards made with no additives. T he two exceptions were medium-density hardboards specially made for use as exterior building siding. They both contained high percentages of an oleo-resinous additive for water resistance. Those two test points are identified by the numeral 1.

A new curve (shown dotted), as a suggested design curve, has been sketched on the figure parallel to but slightly higher than the basic 75° F. mean-temperature curve. It is intended to be used for design purposes in estimating thermal conductivity where the insulating factor is desired. In situations where heat dissipation is desired, the lower solid curve would provide the more conservative estimate.

Similar results for particleboards are presented in figure 6. The suggested design curve for particleboards is located further away from the basic curve than for building fiberboards. Thicker particles, hence, larger and fewer voids, at the same density could be a partial explanation; also, in most of the commercial boards, the flakes or other particles do not form as uniform layers as in the carefully made laboratory boards. Commercial specimen (N-1) was one that is usually called a three-layer board. The core was of hammer-milled particles and the faces were of flakes. That board, in the strict sense, could not be considered homogeneous in the direction of heat travel. The result of that evaluation was not substantially different than the results for the homogeneous boards, which suggests that for usual purposes estimates based on the behavior of homogeneous ones are adequate.

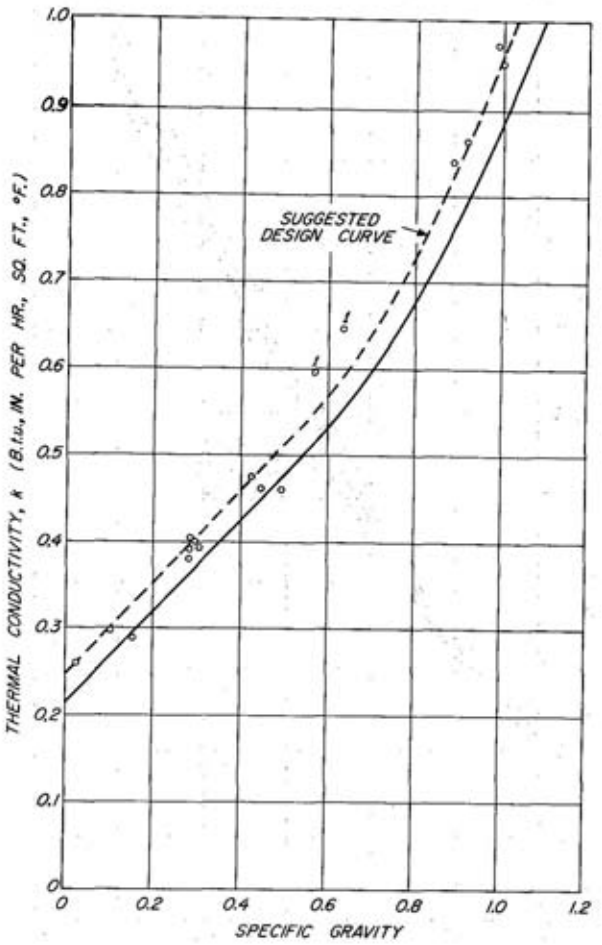

Figure 5.--Thermal conductivity-specific gravity relationship for typical building fiberboards. The two test points marked with the numeral 1 were siding products with high percentages of thermoplastic additives. (M 132 877)

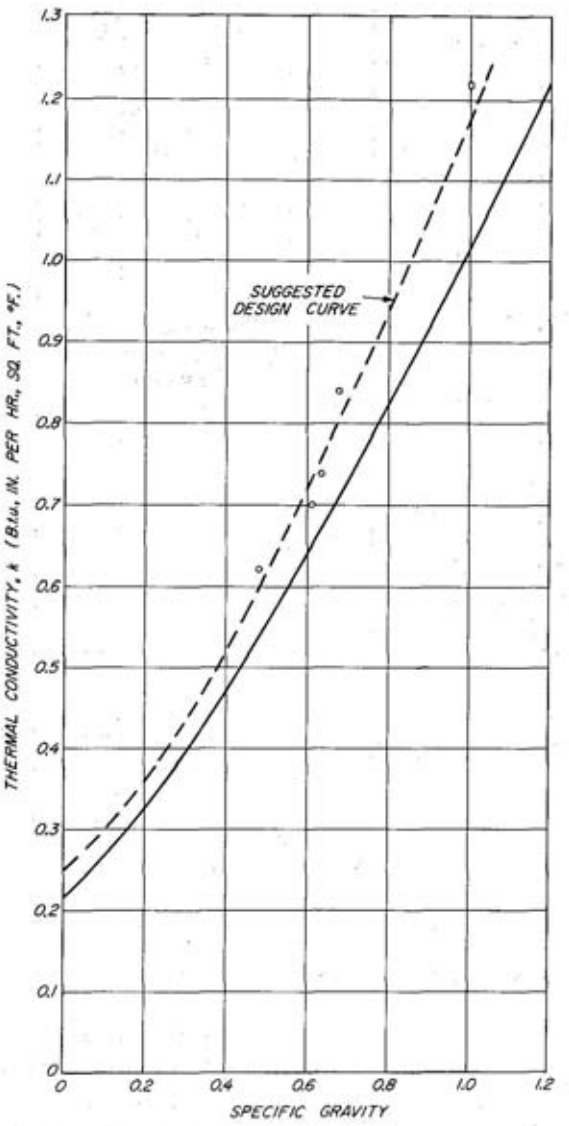

Figure 6.--Thermal conductivity-specific gravity relationship for typical commercial particleboards. (M 132 876)

COMPARISON OF FOREST PRODUCTS LABORATORY HOTPLATE RESULTS WITH OTHER PUBLISHED INFORMATION

While each of the individual pieces of apparatus available for determining conductivity may be calibrated with a standard material, there always remains the questions: Would the apparatus calibrate as well at a different density? Are the values obtained from the evaluation of a hardboard with a specific gravity of 1 as accurate as those obtained on a material with a specific gravity of 0.3? The data available and published for building fiberboards and particleboards are limited as reported by Ratcliffe (4).

Figure 7 shows how data available from other sources for building fiberboards compare when

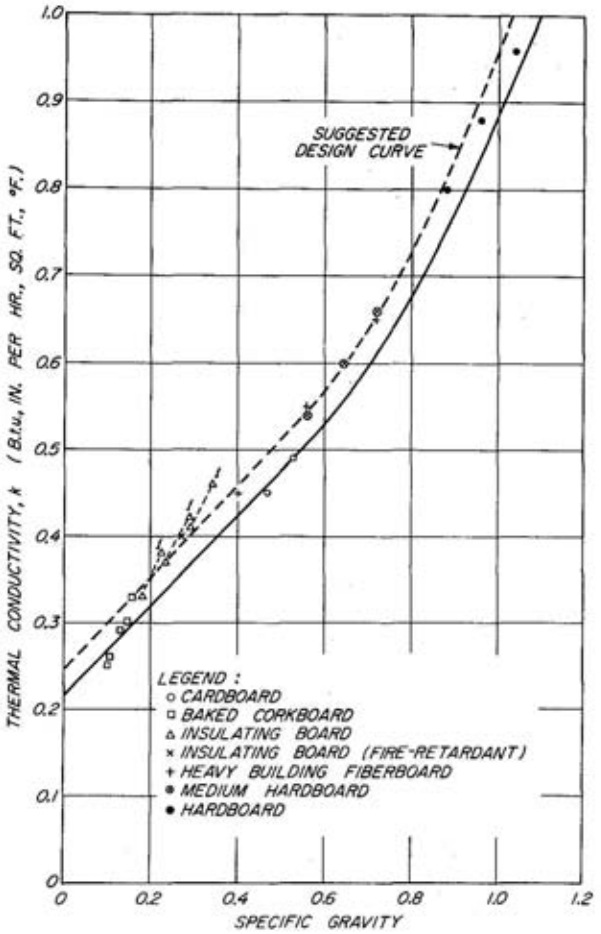

Figure 7.--Comparison of individual values of thermal conductivity (from other sources) for wood-base fiber panel materials (building fiberboards) and corresponding values indicated by suggested design curve. Points connected with a dotted line indicate that a range in values of specific gravity, thermal conductivity, or both, was shown in published values. The numeral 1 indicates a moisture content of 5 to 10 percent by weight. (M 132 875)

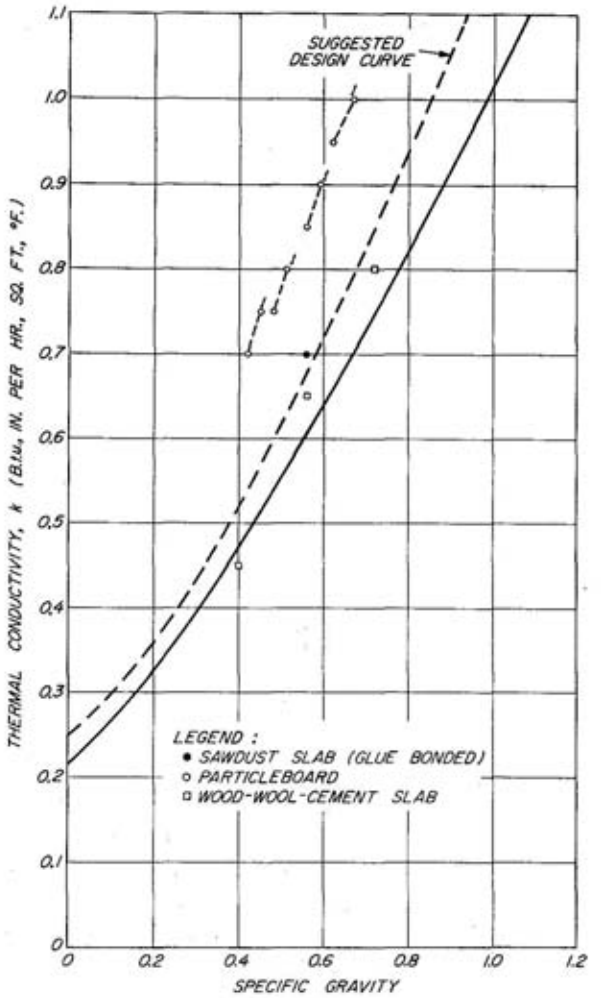

Figure 8.--Comparison of individual values of thermal conductivity (from other sources) for particleboards and corresponding values indicated by suggested design curve, Points connected with a dotted line indicate that a range in values of specific gravity, thermal conductivity, or both, was shown in the published values. The numeral 1 indicates a moisture content of 8 to 15 percent by weight. (M 132 881)

plotted on the same pair of curves given in figure 5. Figure 8 presents similar results for particleboards. Except for the results for particleboards with 8 to 15 percent moisture content, the data from other sources check very well with the results for commercial products obtained with the Forest Products Laboratory guarded hotplate. It is expected that values for particleboard with 8 to 15 percent moisture content would be substantially higher than those for ovendry material.

INTERPRETATION OF THESE RESULTS IN TERMS OF UNITED STATES COMMERCIAL PRACTICE

The validity of the results for thermal conductivity, k, presented in this report is substantiated by other published values for building fiberboards and particleboards. The conductivity-density relationship is consistent though not the

same for both building fiberboards and particleboards, with the exception of medium-density hardboard siding products that have an abnormal amount of resinous additives to make the board highly water resistant. Because of this consistency, for practical purposes in design situations where heat insulation is being measured, it appears entirely feasible to estimate thermal conductivity from density using the suggested design curves presented for each kind of material.

In the United States, commercial practice for manufacturing of various board products is fairly well established. Designvalues for those products, based on the maximum density usually observed for each class and type of board, are as follows:

Building Fiberboards

Semirigid insulation board--Maximum density 10 pounds per cubic foot, design k = 0.33 B.t.u., inch per hour, square foot, °F.

Structural insulation board.--Density 10 to 31.2 pounds per cubic foot, Within the broad classification of structural insulation board, there are several well-established use products. The more important ones, in terms of application and the suggested design values, are:

1. Interior board.--factory finished, acoustic or plain: density range 15 to 18 pounds per cubic foot, design k = 0.40.
2. Regular-density sheathing.--Maximum density about 18 pounds per cubic foot, design k = 0.40. It should be noted that it is the practice of many insulation-board manufacturers to merchandise regular density sheathing with a rated resistance that corresponds to a material having a k factor of 0.38. When this is done and the particular product has a unit conductivity factor higher than 0.38, the board is manufactured slightly thicker than nominal to provide the rated resistance.
3. Intermediate-density sheathing.--Density range 19 to 25 pounds per cubic foot, design k = 0.46.
4. Nail-base sheathing.--Density range 22 to 27 pounds per cubic foot, design k = 0.47.

Hardboard

1. Medium-density hardboard by definition is a material with a density ranging between 31.2 and 50 pounds per cubic foot. Based on the maximum density of 50 pounds per cubic foot, design k equals 0.73.
2. Special medium-density hardboard sidings with abnormal additives of resinous materials had greater thermal conductivity values than boards of the same density with normal amounts of additives. Such products are normally manufactured with a density of 40 pounds per cubic foot or less. On that basis, estimated design k equals about 0.65.
3. Service hardboard, hardboard underlayment, treated hardboard, and tempered service hardboard are all products with about the same maximum density--55 pounds per cubic foot, On that basis, design k is indicated to be 0.82.
4. Standard and tempered hardboards usually range in density from about 60 to 63 pounds per cubic foot. On that maximum density, design k is indicated to be about 1.00.

Particleboards

In the United States, standard specifications for these panel products divide them into three groups by density--low, medium, and high. On the basis of maximum density for each grouping, design thermal-conductivity factors are as follows:

Low-density particleboard.--Density less than 37 pounds per cubic foot, design k = 0.71. A popular product among low-density particleboards is a core for flush doors which has a density of about 26 pounds per cubic foot. Design k for such a product is indicated to be 0.54 B.t.u., inch per hour, square foot, °F.

Medium-density particleboard. --By classification, density is between 37 and 50 pounds per cubic foot. On the basis of the 50-pound-per-cubic-foot density, design k equals 0.94. A popular density for such uses as floor underlayment and core for hardwood plywood is about 40 pounds per cubic foot. Design k for that density is indicated to be 0.76.

High-density particleboards.--High-density particleboards are those with a density of more than 50 pounds per cubic foot, A common density is 62.5 pounds per cubic foot (specific gravity 1.0). Design thermal conductivity, k, for such a board product is indicated to be 1.18.

Design Considerations for Building Fiberboards and Particleboards With Specific Densities

Situations may exist where it is desirable to estimate the thermal conductivity of a specific insulating board, hardboard, or particleboard of a density other than the general ones given in the preceding sections, When the density is known, the following tabulation may be used as a basis for interpolation:

Density	Specific gravity	Thermal conductivity	
		Fiberboard	Particleboard
Lb. per cu. ft.		B.t.u., in. per hr., sq. ft., °F.*	B.t.u., in. per hr., sq. ft., °F.*
12.5	0.2	0.35	0.36
25.0	.4	.46	.52
37.5	.6	.57	.72
50.0	.8	.73	.94
62.5	1.0	.97	1.18

*For conversion to other units. 1 B.t.u., in. per hr., sq. ft., °F. equals 0.1240 kg. cal. per hr., m., °C., or 1.442 milliwatts per cm., °C.

THERMAL CONDUCTIVITY FACTORS AT MEAN TEMPERATURES OTHER THAN 75°F.

Thermal conductivity changes with mean temperatures as shown in figure 2. Conductivity values increase as the mean temperature increases. In figure 2, the slopes of the lines indicate the magnitude of this change. It is apparent also from figure 2 and tables 1 and 2 that the conductivity factors for fiberboards do not increase at as great a rate as those for particleboards. It is apparent also from figure 2 that the change in conductivity is not greatly dependent on density. The slope of the denser products is not consistantly steeper than for the lower density products. An analysis of results for the commercial products evaluated does not refute this observation.

It appeared practical, because of this consistency of slopes, to make an estimate of the amount of change in conductivity per degree change in mean temperature. For the 75° F. spread of mean values covered in table 1, the average change in thermal conductivity was 0.04 B.t.u., inch per hour, square foot, °F. with only four of the 21 values falling more than 0.01 away from that value. On that basis, when estimating thermal conductivity for mean temperatures other than 75° F., the factors for fiberboards should be increased or decreased by 0.04 B.t.u., inch per hour, square foot, °F. for each 75° increase or decrease in mean temperature.

A similar analysis of the data for particleboards indicates the change should be 0.07 B.t.u., inch per hour, square foot, °F. for each 75° change in mean temperature. On a "per degree" basis, this change is 0.00053 and 0.00093 B.t.u., inch per hour, square foot, "I?., respectively, for the fiberboard and particleboard.

SUMMARY AND CONCLUSIONS

The results of a comprehensive series of thermal conductivity evaluations for specially made building fiberboards and particleboards, where the only difference in each group was density, and of typical commercial products were so consistent that it appears entirely practical to estimate thermal conductivity for design purposes on the basis of density of that particular product or group of products.

Design curves were developed for thermal conductivity of each type of material based on the specific gravity (ovendry weight and volume basis). They had the following intercepts:

Building fiberboards.--For 0.2 specific gravity, a thermal conductivity k factor of 0.35 B.t.u., inch per hour, square foot, °F.; for 0.4 specific gravity, a 0.46 k factor; for 0.6 specific gravity, a 0.57 k factor; for 0.8 specific gravity, a 0.73 k factor; and for 1.0 specific gravity, a 0.97 k factor.

Particleboards.--The intercept values for particleboards were higher for each density as follows: for 0.2 specific gravity, a 0.36 k factor; for 0.4 specific gravity, a 0.52 k factor: for 0.6 specific gravity, a 0.72 k factor; for 0.8 specific gravity, a 0.94 k factor; and for 1.0 specific gravity, a 1.18 k factor.

The limited number of values published for these materials were compared with values predicted by the design curves developed. Correlation was good. On that basis and the prevailing commercial classification for various wood-base fiber and particle panel materials, the following design values are suggested for various products:

Semirigid insulation board.--k = 0.32 B.t.u., inch

per hour, square foot, °F.

Interior-quality structural insulating board.--k = 0.40

Regular density, sheathing-type structural insulating board.--k = 0.40

Inter mediate-density sheathing. --k = 0.46

Nail-base sheathing. --k = 0.47

Medium-density hardboard.--k = 0.73

Service, treated and tempered service hardboard and hardboard underlayment.--k = 0.82

Standard an d tempered high-density hardboard.--k = 1.00

Low-density particleboard.--k = 0.71

Medium-density particleboard.--k = 0.94

High-density particleboard.--k = 1.18

The previous values are based on the mean temperature of 75° F. usually considered for normal building applications. Conductivity values increase or decrease directly with mean temperatures. For building fiberboard, the indicated change in k factor per degree F. change in mean temperature was 0.00053 B.t.u. inch per hour, square foot, °F. For particleboard, the corresponding change was 0.00093, which is greater than for fiberboard.

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