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Thermal Conductivity of Fibrous Glass Board by Guarded Hot Plates and Heat Flow Meters: An International Round-Robin

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In the early 1980s, an international round-robin was held in which the apparent thermal conductivity of specimens of fibrous glass insulation board was measured by users of guarded hot plates (GHPs) and heat-flow meters (HFMs). The round-robin was performed over a period of several years by laboratories in Europe, North America, Australia, and the Far East. Participants in this round-robin were organized into 12 "loops," 8 for participants with GHPs and 4 for those with HFMs. Each loop included laboratories located in the same region of the world and sharing the same set of specimens. In an attempt to obtain insight into the accuracy of the measurements, participants were also asked to measure the thermal conductivity of a layer of air. The data submitted in this round-robin are exhibited and analyzed. The overall agreement of individual measurements with a least-squares fitted curve, as measured by one standard deviation σ, was $\sigma = 2.4\%$ for GHPs and $\sigma = 2.7\%$ for HFMs. Suggestions are made for conducting future round-robins of this type.

KEY WORDS: fibrous glass; guarded hot plate; heat flow meter; thermal conductivity; thermal insulation.

1. INTRODUCTION

In October of 1978, under the auspices of the International Organization for Standardization (ISO), a round-robin test program was organized. This round-robin would involve users of guarded hot plates (GHPs) and, optionally, heat-flow meters (HFMs), measuring apparent thermal conductivity.[2] The purpose was to determine the current worldwide state of the art

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[2] Because heat may often be transported through thermal insulation by both radiative and conductive processes, such a thermal insulation does not have a true thermal conductivity and one should therefore speak of "apparent" conductivity. However, for brevity, in the rest of the text the term "apparent" is dropped.

in GHP and HFM measurement technology, prior to development of ISO standards, and to create uniformity in (GHP and HFM) test methods for measuring the thermal conductivity of thermal insulation specimens.

Because of logistical problems, the same set of test specimens was not distributed to all participants, for each participant was able to accommodate only a specific size of specimens. Instead, the round-robin was actually an intercomparison of measurements on samples from the same lot of material. Specimens were distributed among participants in each of 12 small and localized, round-robin groups, called "loops." Because all the specimens came from the same lot, it is assumed that their conductivities agree within less than the standard deviation of the global round-robin measurements.

The actual participants in the round-robin are identified in Table AI in the Appendix. Within each loop the laboratory requiring the largest specimen size was given the loop specimen first. After each laboratory finished, the specimen was circulated to the next laboratory in order of size needed. Each laboratory trimmed the received specimen to the proper size for its own test apparatus.

Operational considerations included the directive that thermal conductivity would be measured at two specified mean temperatures; a third measurement would be performed at a temperature selected by the laboratory.

2. MEASUREMENTS

2.1. Test Specimens

ISO working group WG-6 had selected semirigid high-density fibrous glass insulation board with phenolic binder as the test material. The density was approximately $164\,\mathrm{kg \cdot m^{-3}}$ ($10.2\,\mathrm{lb_m \cdot ft^{-3}}$). From a single lot of material, the manufacturer supplied boards 1220 mm (48 in.) square and 25.4 mm (1 in.) thick to the convener at NBS, where the test specimens were prepared and distributed to participants. Other portions of this material also became the thermal-conductivity standard reference material NBS SRM 1450b. The actual specimens were distributed in sizes ranging from squares with an edge dimension of 1220 mm down to disks 180 mm in diameter.

As a means of giving some information on the accuracy of measurements by participant, each laboratory was invited to measure also the thermal conductivity of an inexpensive and universally available "standard reference material": air. This "standard" was to be an enclosed air gap using the same apparatus (GHP or HIM) that was used to measure the conductivity of the fibrous glass board.

2.2. Test Procedures

Before measuring the thermal conductivity, each laboratory was to dry its test specimen(s) to constant mass in an oven maintaining a temperature of 103°C. Then the length, width, and thickness were to be measured and combined with the (dry) mass to determine the total "dry" test density. The density of the metered section alone, which would be more representative of the measured conductivity, was not measured. Due to possible inhomogeneities in the specimen (pair), the density of a specimen may have shifted slightly as the specimen was passed on to each following participant and cut down to smaller sizes to accommodate smaller apparatuses. The dimensions and bulk densities of each specimen were to be reported in SI units on the data-entry form appropriate to each measuring apparatus. Because two specimens were measured in the guarded hot plate apparatus, two values of density were reported for each corresponding laboratory's specimens.

Participants measuring the thermal conductivity of the fibrous glass specimens with guarded hot plates were asked to measure the conductivities at mean specimen temperatures of 283 and 297 K (approximately 10 and 24°C) add at a third temperature within the range from 273 to 313 K (0 to 40°C). As is conventional, the mean temperatures reported are arithmetic means of the hot-side and cool-side temperatures actually used. The conductivity in HFMs was to be measured on a single specimen at 23.9°C (291 K).

Originally the conductivity of an enclosed air gap 6 mm thick was to be measured at a mean temperature of 23.9°C (291 K) and with a temperature difference of 28 K. Somehow a thickness value of 25 mm, rather than 6 mm, was introduced into the instructions communicated to the participants.

3. INPUT OF DATA BY PARTICIPANTS

Participants were requested to record their measurements on standard data-entry forms supplied by the convenor. The data forms requested the entry (in SI units) of raw data: oven-dried mass (g), specimen dimensions (mm), total specimen density[3] ($kg \cdot m^{-3}$), mean specimen temperature, temperatures of each plate, temperature difference ΔT across the specimen,

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[3] This "total" density, total mass divided by total specimen area, is not necessarily equal to the density of the central metered area. Also, the specimens within a regional loop were sent to laboratories in order of decreasing size of measurement apparatus, and so total densities of the specimens may have varied as the specimens were reduced in size.

and ambient temperature (all in K), thickness of the specimen as tested (m), ambient relative humidity (%), metering area $A(\mathrm{m}^2)$ and power input Q (W) to the metering heater, and emissivities of hot and cold plates. From the raw data the participant was asked to calculate the thermal resistance $R_{\mathrm{th}} = A\,\Delta T/Q(\mathrm{m}^2 \cdot \mathrm{K} \cdot \mathrm{W}^{-1})$, the thermal conductance $C_{\mathrm{th}} = Q/(A\,\Delta T) = 1/R_{\mathrm{th}}(\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \mathrm{K}^{-1})$, and then the thermal conductivity $\lambda = (Q_{\mathrm{th}}/A)/(\Delta T/\Delta X) = C_{\mathrm{th}}\,\Delta X(\mathrm{W} \cdot \mathrm{m}^{-1} \cdot \mathrm{K}^{-1})$. The steps in the calculations just outlined here requested the participants to follow a logical order from the raw data to a final calculation of conductivity.

To analyze the round-robin data, we used spreadsheet templates for recording the data in formats very similar to those originally used by the participants to submit their data. Minor changes were made in the formats for ease of data entry and analysis by computer, but all the original data were faithfully preserved. The purpose of this part of the analysis was to allow the data to be regrouped for various useful comparisons, as desired.

4. ANALYSIS OF RETURNED DATA

Several important factors were assessed while entering the returned data into the spreadsheet templates for analysis. First, each data sheet was carefully examined for internal consistency among the reported values. Calculated values, such as density, thermal resistance, and thermal conductivity, derived from the data submitted by each participant, were checked for accuracy by recalculation. In this stage several types of questionable data were found.

A few data were obviously in error, but it was apparent in most cases that simple errors in transcription had probably occurred. We assumed that this was the source of the discrepancy, and corrected such data.

Two serious types of error occurred, when (a) the values of thermal resistance, conductance, and conductivity were internally inconsistent or (b) the raw data were incomplete (lacking the value of heater power used, for example). In the latter case no test of internal consistency could be performed. In these two cases the values of thermal resistance, conductance, and conductivity were *listed as submitted by the participant*. Only small benefits of the doubt were given to the submitted data.

4.1. Outliers

If the purpose of a given set of conductivity measurements were to determine the thermal properties of a material, then it would be proper to test for the presence of outliers according to accepted statistical guidelines.

However, the purpose of this set of measurements was not to establish the thermal properties of fibrous glass board but, rather, to compare the results of measurements by different laboratories around the world so that each laboratory can evaluate its measurement apparatus and technique. Thus the concept of "outliers" has no application to this present case. No "outliers" have been excluded from presentation in this work.

5. PRESENTATION OF DATA

Space here does not allow a complete discussion of either the purposes of this round-robin or suggestions for a successor round-robin. Presentation of the complete set of data and its treatment is also not possible here. A complete report is being published as NIST Technical Note 1381 [1], limited quantities of which are available from the author.

Here, abbreviated sets of data are presented for the complete population of participants and identified according to three individual major groupings. The first grouping, "Asia," actually includes participants in Africa, Asia, and Australia, but these laboratories are grouped together under one title for convenience and reflecting their participation in a common loop. The second group is Europe, and the third is North America.

5.1. Thermal Conductivity of Fibrous Glass Board

5.1.1. *Measurements with Guarded Hot Plates*

The complete GHP data set for thermal conductivity as a function of temperature is plotted in Fig. 1. The solid curve is a least-squares fit to all the data; however, solely for the purpose of performing this fit, the three highest data points (asterisks) were excluded. The function fitted was of the form

$$\lambda = A_0 + A_1 D + A_2 T + A_3 T^3 \tag{1}$$

where λ is thermal conductivity in $\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$, D is density in $\mathrm{kg \cdot m^{-3}}$, and T is mean specimen temperature in K. The physical justification of this representation is that the conductivities of both the gas and the solid vary approximately linearly with temperature, but the solid fibers in low-density insulation should also contribute a term to the conductivity directly proportional to the density; finally, any radiative transport should contribute the term in T^3. The least-squares values found for the coefficients in Eq. (1) were

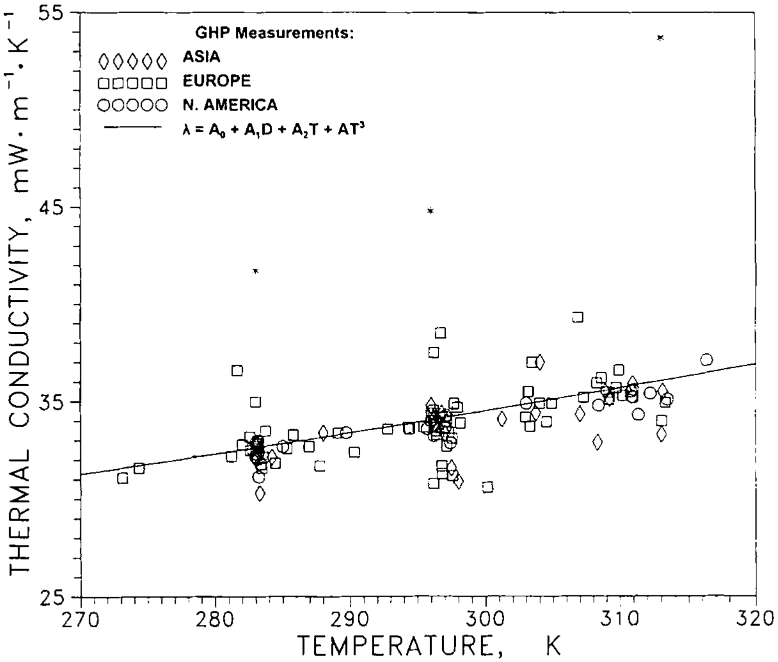

Fig. 1. Measurements with guarded hot plates (GHPs) of thermal conductivity of fibrous glass board specimens as a function of temperature, for all participants (Asia—Asia, Africa, and Australia; Europe; and North America). The solid line is Eq. (1), a least-squares fit to all the data except the three highest-conductivity data points (asterisks).

$$A_0 = 9.578 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$$

$$A_1 = 0.0265 \text{ mW} \cdot \text{m}^2 \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$$

$$A_2 = 0.0457 \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-2}$$

$$A_3 = 2.552 \times 10^{-7} \text{ mW} \cdot \text{m}^{-1} \cdot \text{K}^{-4}$$

The deviations of the GHP data from the fitted curve in Fig. 1 are plotted in Fig. 2. In order to show the value of each deviation more precisely, the data showing the three largest deviations (data represented by asterisks in Fig. 1) are not included in Fig. 2. The relative standard deviation of the data from the fitted curve is 2.4%. In Fig. 2, the two parallel solid lines, one above and one below the central zero-deviation line, are separated from the central line by one standard deviation (2.4%).

Statistically, lines lying above and below the central zero-deviation line and separated from it by two standard deviations (±4.8%, or about

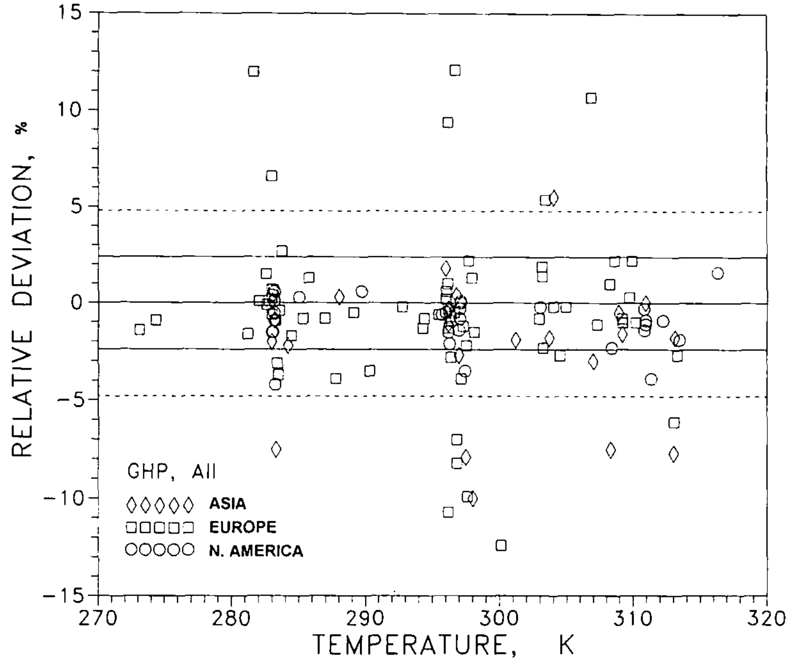

Fig. 2. Deviations of GHP data in Fig. 1 from the fitted curve, Eq. (1), for all participants. The mean density of each individual specimen pair was used in Eq. (1) to compute each deviation. To allow precise examination of deviations, the deviations for the three highest-conductivity points (asterisks in Fig. 1) are not shown here. The two parallel solid lines, one above and one below the central zero-deviation line, are separated from the central line by one standard deviation (2.4%). The two parallel dashed lines are separated from the central line by two standard deviations (4.8%).

1.65 conductivity units at 300 K) should include about 95%of the data in the complete set, if the data are normally distributed. The two parallel dashed lines in Fig. 2 are separated from the central line by two standard deviations (4.8%). Clearly the data are not normally distributed about the fitted curve, as there are about 22 data points (19 of which are shown in Fig. 2) that deviate from the fitted curve by more than 5%, of a total population of 124 points.

5.1.2. *Measurements with Heat Flow Meters*

Figure 3 shows the complete data set for conductivity as a function of specimen density for participants using HFMs. The solid curve is the least-squares fit to all the GHP data, Eq. (1), calculated for an assumed mean specimen temperature of 297 K. The mean specimen temperature for the five "Asian" participants' data displayed here was 297.4 K, that for the 15

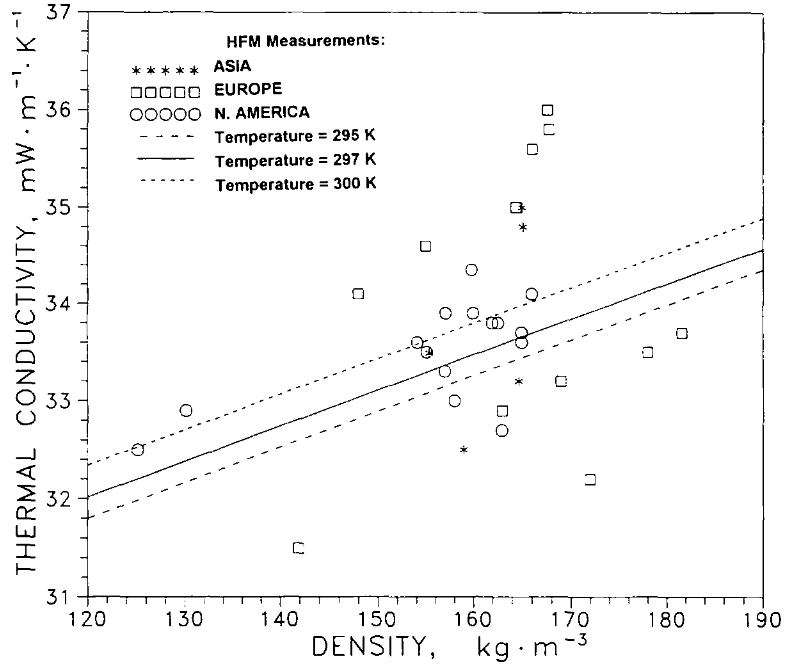

Fig. 3. Measurements with heat flow meters (HFMs) of thermal conductivity of fibrous glass board specimens as a function of temperature, for all participants (Asia—Asia, Africa, and Australia; Europe; and North America). The solid line is Eq. (1), a least-squares fit, calculated for an assumed mean specimen temperature of 297 K. The mean specimen temperature for the five Asian participants' data displayed here was 297.4 K, that for the 15 European participants' data was 297.9 K, and that for the 21 North American participants' data was 297.6 K. Plots of Eq. (1) for mean specimen temperatures of 295 and 300 K are shown for comparison, to illustrate the effect of mean specimen temperature.

European participants' data was 297.9 K, and that for the 21 North American participants' data was 297.6 K. The global mean specimen temperature for all 41 participants is 297.7 K. Plots of Eq. (1) (dashed lines) for mean specimen temperatures of 295 and 300 K are almost equally separated from the mean temperature of measurement, 297.7 K. These are shown for comparison, to illustrate the effect of the mean specimen temperature on the submitted data.

Figure 4 plots deviations of HFM data in Fig. 3 from the fitted curve, Eq. (1), for all participants. The mean density of each individual specimen pair was used in Eq. (1) to compute each deviation. The standard deviation from the curve for the "Asia" data is 2.7%(for all 26 data points; the mean deviation for 23 points left after excluding the 3 highest-conductivity points

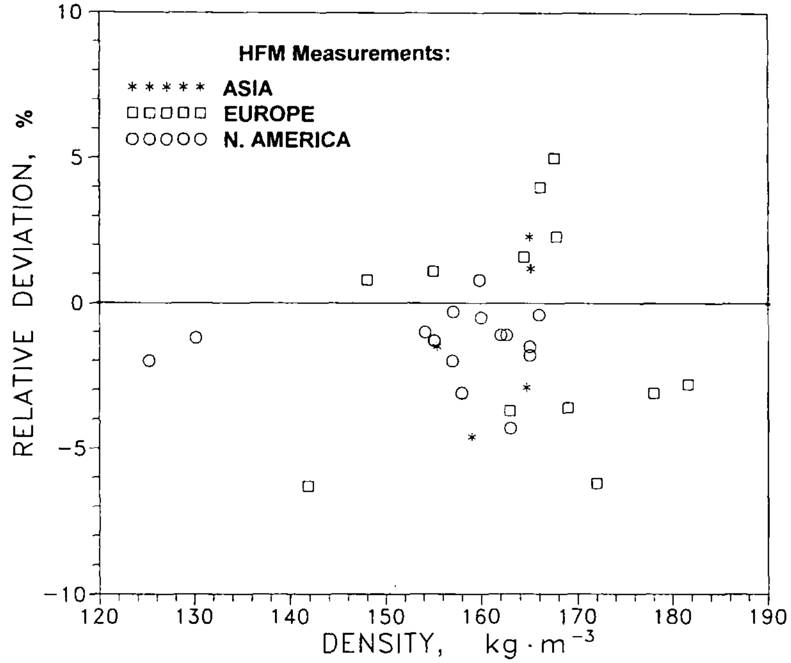

Fig. 4. Deviations of HFM data in Fig. 3 from the fitted curve, Eq. (1), for all participants. The mean density of each individual specimen pair was used in Eq. (1) to compute each deviation. Open circles and squares and asterisks have the same meaning as in Fig. 3.

for "Asia" is −1.9%), the standard deviation for the European data is −0.6%, and that for North American data is −1.0%.

5.1.3. *Thermal Conductivity of a Layer of Air*

The second type of specimen requested to be tested in the round-robin was a layer of air approximately 25 mm thick, either on GHP or on HFM apparatuses. Some laboratories did not perform this measurement. The participants were not directed to correct their data for the (appreciable) effects of radiative transfer that could have been present in their apparatuses, between the plates bounding the air layer. No participants indicated that they did so. Thus the measurements here probably include the combined effects of conductive and radiative transfer, and can be compared only qualitatively with accepted values for the conductivity of air.

Table I lists the conductivity data obtained from laboratories that measured the thermal conductivity of the air layer in a GHP apparatus. Table II lists the data obtained from laboratories that measured the air layer with a HFM apparatus.

Table I. Thermal Conductivity λ of a Layer of Air as Measured with a GHP Apparatus[a]

Plate emittance		Heat flow direction	T_{mean} (K)	λ $(\mathrm{mW\cdot m^{-1}\cdot K^{-1}})$	Temperature difference (K)
Top	Bottom				
			Asia		
0.35	0.35	NR	297	119.6	27.9
0.8	0.9	H	299.0	123	31.4
0.41	0.41	V	296.9	127.5	28
NR	NR	V	297.5	132	28.9
0.85	0.95	H	306.6	143.4	17.2
0.8	0.8	H	296.9	148	28
0.88	0.88	V	297.0	174.5	28.1
			Europe		
NR	NR	V	297	32	10
0.15	0.15	V	297	72	28
0.64	0.64	V	296.6	86.1	9.86
NR	NR	V	297.7	167	20.8
NR	NR	V	297.33	168.33	24.39
0.9	0.9	V	290.97	168.9	16.20
0.9	0.9	V	296	170	27.3
NR	NR	V	297.02	171.5	28.00
NR	NR	V	297.7	173	26.3
0.82	0.82	V	297.08	174.0	28.42
0.9	0.9	V	297	177.5	28.0
0.92	0.92	V	297.1	178	28.1
0.9	0.9	V	300.4	181	3.9
0.95	0.95	V	296.93	184.8	28.08
0.9	0.9	Vdn	296.96	191	28.03
0.9	0.9	V	296.95	204	23.20
			North America		
0.8	0.8	H	297	141.4	27.78
0.9	0.9	H	297.05	152.8	27.78
0.89	0.89	V	297	170	27.8
0.95	0.95	V	297.19	175.9	12.038
0.86	0.86	H	296.8	180	19.4
0.9	0.9	H	295	187	22.9
0.89	0.89	H	296.16	191.3	27.86
0.96	0.96	V	297	191.8	28.3

[a] The data have been sorted in order of increasing thermal conductivity to conceal the identity of the submitting laboratory. NR, not reported; H and V, horizontal and vertical heat flow; Vdn, vertically downward heat flow.

Table II. Thermal Conductivity λ of a Layer of Air as Measured with a HFM Apparatus[a]

Plate emittance		Heat flow direction	T_{mean} (K)	λ ($\text{mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$)	Temperature difference (K)
Top	Bottom				
			Asia		
0.8	0.8	Vdn	301.9	87.78	24.2
NR	NR	Vdn	297.1	117	27.8
NR	NR	Vdn	302.2	172	19.5
			Europe		
NR	NR	Vdn	297.04	142	28.07
NR	NR	Vdn	294.8	144.3	3.30
NR	NR	Vdn	297.1	147	27.8
0.9	0.8	Vdn	297.05	151	37.2
0.85	0.85	Vdn	297.15	156	27.2
Black	Black	Vup	298	205	27.8
NR	NR	Vup	298.09	207	25.00
			North America		
0.9	0.9	H	297	77.8	22.2
0.86	0.86	Vdn	297.1	152	27.6
0.94	0.94	Vup	297.03	184.4	16.74

[a] The data have been sorted in order of increasing thermal conductivity to conceal the identity of the submitting laboratory. NR, not reported; H, horizontal heat flow; Vdn, vertically downward heat flow; Vup, vertically upward heat flow.

The measured values for the thermal conductivity of the air layer versus temperature as measured on both GHPs and HFMs are plotted in Fig. 5. Only one point (lowest open square: 32 $\text{mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ at 297 K), for a measurement with a GHP, is near the value of the conductivity of air (about 26 $\text{mW} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$) at 300 K. However, in the absence of information submitted by this participant about whether the total heat transfer was corrected for the effects of radiative transfer, even this point cannot be assumed necessarily to represent a valid measurement of the conductivity of air.

All the measured values obtained with heat flow meters lie far above the value of the conductivity of air at 297 K and do not represent a measurement of the true conductivity of air. The significance of these data is discussed in the next section.

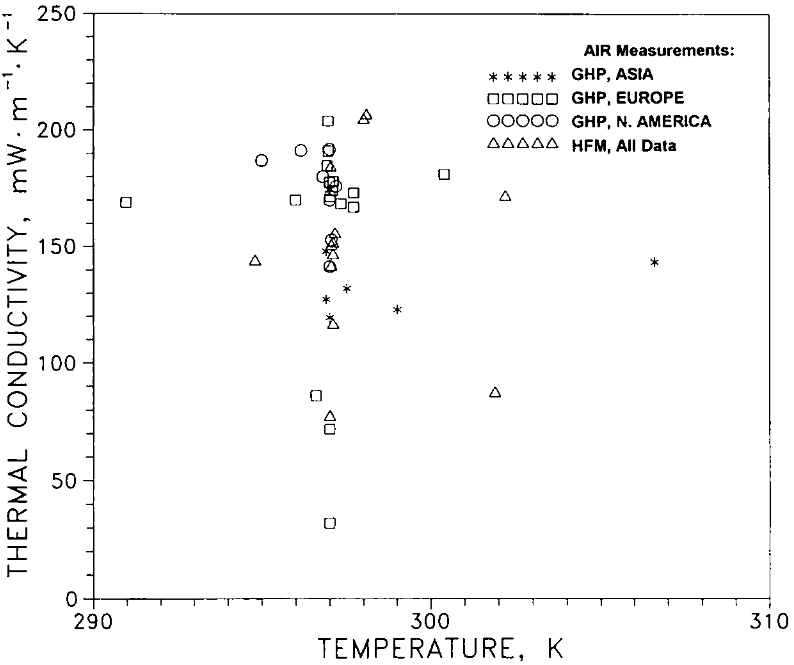

Fig. 5. Measurements with GHPs and HFMs of the thermal conductivity as a function of temperature of an air layer 25 mm thick by all participants (GHPs—asterisks, "Asia;" squares, Europe: circles, North America; HFMs—triangles, all participants).

6. FUTURE ROUND-ROBIN STUDIES: DISCUSSION AND RECOMMENDATIONS

6.1. Measurement of the Effective Thermal Conductivity of a Still Layer of Air

Asking the participants to measure the conductivity of air was an excellent idea, as it offered the potential of using the air "specimen" as an in-house "standard reference material" freely and inexpensively accessible to all participants. However, judging from the very wide scatter in data for the conductivity of air, it appears that almost all participants did not understand how to perform this measurement.

Measuring the conductivity of air, although not difficult when correctly done, is, on the other hand, not a trivial exercise. Because of the great difficulty apparently encountered by the participants in measuring the conductivity of air for this round-robin, the procedures to be followed (several small thicknesses) in measuring the conductivity of air in any future round-robin program will have to be carefully spelled out in the next round-robin protocol. A paper by Jaouen and Klarsfeld [2] clearly describes a straightforward procedure for obtaining both the plate emittance and the thermal conductivity of air in either a GHP or an HFM apparatus.

The important feature in performing this measurement is that the conductivities of at least two or three layers of air of different thicknesses should be measured. To promote stable stratification of the air layer, the flow of heat should be downward only, and the thickness of each layer should be of the order of only a few millimeters, to guard against the occurrence of convective heat transfer. This can be accomplished by the use of a set of two plastic (poorly thermally conducting) annular rings in the guard region of the specimen. If one ring is, say, 3 mm thick and the other, twice as thick (6 mm), then the conductivity of air may be measured at three thicknesses: 3, 6, and (stacking the two rings together) 9 mm. The exact thicknesses are of course subject to choice but should be fairly uniformly spaced.

By measuring the heat transfer through the air layers at different thicknesses, one can obtain a line whose slope and intercept contain information from which both the plate emittance and the conductivity of air may be readily obtained. The use of at least three thicknesses allows a line to be fitted by linear least-squares, with consequent partial averaging-out of the contributions from random experimental errors. This test offers the benefit of providing not only a test of the ability to measure the thermal conductivity of a "standard material" (still, nonconvecting) air, but also an estimate of the plate emittance in the apparatus.

In retrospect, it seems clear that the choice of a thickness for the air layer of 25 mm, rather than 6 mm, was unfortunate. This thickness is too large to ensure accurate measurements of the thermal conductivity of a (fluid) gas. Also, in order to stratify the air layer and minimize the possibility of convective heat transfer, the conductivity should have been measured for only a single layer of air, with the top boundary (hot plate) at a greater temperature than that of the bottom boundary (cold plate). For guarded hot plates this involves operation in a "one-sided" mode, a procedure with which many or most participants may not have been familiar. For both apparatuses care must be taken to set up a thermally stratified, stable (nonconvective) layer of air for measurement.

The data for the air measurements do not prove, but are consistent with, the possibility that (a) convective effects permitted by the large thickness and (b) effects of unknown but variable plate emittances had a strong influence on the total heat transfer. The participants did not have the procedure outlined by Jaoten and Klarsfeld available to them. As a result, total heat transfer, not simply thermal conductivity, was the actual physical variable actually measured by both types of apparatus in the round-robin.

6.2. Reporting of Data by Participants

The two data sheets sent to participants for submitting their conductivity results were quite detailed. One form asked for information on the preparation of the specimens for the measurements. The second asked for all the experimental data as input.

Both the input and the output data formed somewhat redundant sets of data. For example, in the set of input data, *either* the set of both surface temperatures *or* the set of mean temperature and temperature difference suffices to calculate the output quantities needed. However, asking for *both* sets of temperature values provided a valuable tool for checking for internal consistency of the input data. Similarly, asking for heat flux, thermal conductance, thermal resistance, and thermal conductivity provided redundancy for checking for internal consistency of the output data by the author.

At the cost of additional labor, the redundancy of input and output data allowed, in a few cases, some minor errors to be corrected in both input and output and the appearance of error, where none really existed, to be avoided. The use of redundancy in the submitted information therefore turned out to be a resource of some significant value in identifying where problems exist. On a related topic, in some cases the data were not submitted in the units (SI) requested.

6.3. Criteria for Measurements

From the above results it is evident that organizers of any future round robin must ensure that a clear set of criteria is established for conducting the measurements of thermal conductivity. Whether the use of either national or ISO standards is to be left to the choice of the participant or specified by the planning committee must be decided upon in advance in order to promote uniformity of measuring conditions among a community of worldwide participants. If only one standard is to be adhered to (or a few uniform, widely accepted standards such as ASTM and/or ISO), care should be taken to ensure that all participants have access to the relevant measurement standards. It should be clearly stated that only data in SI units will be accepted into the round robin.

Deciding on the ambient conditions to be established or permitted is complicated of course by the fact that in any worldwide round-robin or intercomparison, ambient conditions can vary widely with geographic location, as well as with seasons of the year.

In particular, such important parameters as the mean temperature of measurement, the temperature difference, the measured thickness, the range of ambient temperature, the pressure and humidity permitted or established in the laboratory during the measurement, and the order in which data points are to be measured must all be carefully considered. Some conditions (general laboratory ambient) may of necessity have to be left to the participant to decide upon, while other, more critical conditions (such as specimen conditioning for measurement of density and thermal conductivity) may have to be specified as mandatory. Care must be taken in specifying in advance the ambient conditions for measurement of related parameters such as density and thickness.

6.4. Statistical Considerations

Repeating measurements after attaining the highest or lowest mean temperature should, if permitted, also be clearly described. In any case it should be made clear what number of conductivity measurements are to be performed by each participant and that only those submitting this exact number of measurements will have their data accepted into the intercomparison. It is very important to have a uniformly sized set of data from each participant, for uniform statistical weighting of data among the total population of participants. The analyst cannot supply missing data, nor should the analyst be the judge of which data not to accept, when an excess is submitted.

APPENDIX

Table AI. Round-Robin Participants[a]

Guarded hot plates		
Loops 1 and 2 (U.S.A. and Canada)		
D. J. McCaa	CertainTeed Corp.	Blue Bell, PA
R. P. Tye	Dynatech R/D Company	Cambridge, MA
R. G. Miller	Jim Walter Research Corp.	St. Petersburg, FL
R. M. Lander	Lander Thermal Conductivity Laboratory	Minneapolis, MN
B. Rennex	National Bureau of Standards	Gaithersburg, MD
M. K. Kumaran	National Research Council of Canada	Ottawa, Ontario
P. Wenning	Ontario Research Foundation	Mississauga, Ontario
R. Adams	Owens-Corning Fiberglas Corp.	Granville, OH

[a] In each category, entries are alphabetic, by organization.

Table AI. *(Continued)*

Guarded hot plates		
Loops 4 and 5 (Asia and Australia)		
V. V. Varma	Central Building Research Institute	Roorkee, India
X. Zhang	Chinese Academy of Preventive Medicine	Beijing, China
D. Jolly	CSIRO (Div Appl. Phys.)	Adelaide, Australia
S-h. Cao	Henan Research Institute of Building Materials	Henan, China
V. P. Wasan	National Physical Laboratory	New Delhi, India
Y. Takita	NICHIAS Corp. Research Centre	Yokohama, Japan
S. K. Sharma	Projects & Development India Ltd.	Bihar, India
S. Fujii	Testing Center for Construction Materials	Inari Soka-shi, Japan
Li-z. Han	Tsinghua University	Beijing, China
Loops 7, 8, 10, and 11 (Europe)		
A. Grelat	CEBTP	Paris, France
T. Zimmerli	EMPA	St. Gallen, Switzerland
J. Achtziger	Forschungsinstitut für Wärmeschutz	Grafelfing, Germany
N. König	Fraunhofer Institut für Bauphysik	Stüttgart, Germany
M. M. Riley	Fulmer Yarsley Ltd.	Redhill, Surrey, England
J. Murray	Institute for Industrial Research Standards	Dublin, Ireland
W. Ploński	Instytut Techniki Budowlanej	Warsaw, Poland
D. Zerbi	Istituto di Ricerche E Collaudi M. Masini	Milan, Italy
G. Venuti	Laboratoire National d'Essais	Paris, France
A. Cavaleiro e Silva	Laboratório Nacional de Engenharia Civil	Lisbon, Portugal
J. M. Corsan	National Physical Laboratory	Teddington, England
A. Tveit	Norwegian Building Research Institute	Trondheim, Norway
Ch. Beerten	Pittsburg Corning Europe N.V. (Brussels)	Tessenderlo, Belgium
G. Ruscica	Politecnico di Torino	Torino, Italy
H. Marouda	Public Works Research Center	Athens, Greece
G. Weissbach	Staatliches Materialprüfungsamt	Dortmund, Germany
E. Kokko	Technical Research Centre of Finland	Espoo, Finland
N. Svenningsen	Teknologisk Institut Varme- og installationsteknik	Tastrup, Denmark
W. Millard	Thermalite Limited	West Midlands, Eng.
C. Pisoni	Universita di Genova	Genoa, Italy
Heat flow meters: Loop 3 (U.S.A.)		
D. J. McCaa	CertainTeed Corp.	Blue Bell, PA
R. Tye	Dynatech R/D Company	Cambridge, MA
R. L. Hauser	Hauser Laboratories	Boulder, CO
R. G. Miller	Jim Walter Research Corp.	St. Petersburg, FL
R. L. Troyer	Johns-Manville R/D Center	Denver, CO
B. Rennex	National Bureau of Standards	Gaithersburg, MD
R. Adams	Owens-Corning Fiberglas Corp.	Granville, OH

Table AI. *(Continued)*

	Heat flow meters	
	Loop 6 (Africa, Asia)	
X. Zhang	Chinese Academy of Preventive Medicine	Beijing, China
L. F. O'Brien	CSIRO (Div. Bldg. Res.)	Victoria, Australia
Y. Takita	NICHIAS Corporation	Yokohama, Japan
J. MacCurtain	South African Bureau of Standards	Pretoria, S. Africa
Shen Tianxing	Tianjin University	Tianjin, China
	Loops 9 and 12 (Europe)	
F. Fischer	BASF Aktiengesellschaft	Ludwigshafen, Germany
A. Grelat	CEBTP	Paris, France
M. M. Riley	Fulmer Yarsley Ltd.	Redhill, Surrey, England
G. Pagliarini	Instituto di Fisica Tecnica	Bologna, Italy
A. Tveit	Norwegian Building Research Institute	Trondheim, Norway
W. den Hoed	Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek	Delft, Netherlands
A. J. Aindow	Pilkington Insulation Ltd.	St. Helens, Merseyside, England
S. Tesseris	Public Works Research Center	Athens, Greece
B. Jonsson	Swedish National Testing Institute	Boras, Sweden
F. De Ponte	University of Padova	Padua, Italy

[a] In each category, entries are alphabetic, by organization.

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