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Discussion of Heat Flow Meter Apparatus and Transfer Standards Used for Error Analysis

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RÉSUMÉ

Le besoin de mesurer la résistance thermique d'échantillons épais (100 à 180 mm) d'isolant thermique à faible densité et la modification subséquente des normes d'essai de l'ASTM ont rendu plus pressante la nécessité d'évaluer la précision que permet d'obtenir le fluxmètre thermique. Cette évaluation se fait habituellement au moyen de normes de transfert établies sur une plaque chaude gardée. La Division des recherches en bâtiment du Conseil national de recherches du Canada (DRB/CNRC) a mis au point une banque de normes de transfert et d'échantillons calibrés qui sert à vérifier les procédures d'essai du fluxmètre thermique et la marge d'erreur de l'appareil. Ce document traite de la calibration et de l'utilisation du fluxmètre thermique, et il décrit les normes [illegible] mises au point

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Discussion of Heat Flow Meter Apparatus and Transfer Standards Used for Error Analysis

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ABSTRACT: The need for thermal resistance measurements on thick specimens (100 to 180 mm) of low-density thermal insulation and subsequent changes in ASTM test standards have increased the need for the evaluation of precision and accuracy attainable with the heat flow meter (HFM) apparatus. Such an evaluation is usually performed with transfer standards established on a guarded hot plate. The Division of Building Research of the National Research Council of Canada (DBR/NRCC) has developed a transfer standard and calibrated specimen bank to be used in verifying HMF test procedures and instrument error evaluation. This paper discusses such calibration and the use of the HFM apparatus and reviews the transfer standards developed at NRCC.

KEY WORDS: thermal resistance, thermal conductivity, heat flow measurements, heat flow transducers, heat flow apparatus, heat flow meter

For the past several years the only Canadian laboratory performing thermal conductivity (thermal resistance) tests on insulating materials for official evaluation and acceptance programs has been that of the Division of Building Research of the National Research Council of Canada (DBR/NRCC). It has been also responsible for developing expertise in thermal conductivity testing.

Rapid developments in thermal insulating materials and advancement in laboratory instrumentation has forced DBR/NRCC to review its role. Technology transfer, enhancement of the capability of industrial laboratories to perform reliable and precise measurements, has been deemed more important than the maintenance of one, highly specialized, national testing facility.

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This paper reviews recent developments and, in particular, information developed at DBR/NRCC related to:

1. Determination of uncertainty in thermal resistance testing, using transfer standard specimens developed at DBR/NRCC.
2. Determination of the technical expertise or proficiency of laboratory staff, using calibrated specimens developed at DBR.

The term "transfer standard" is used to describe an insulation specimen with an established mean R-value and an uncertainty estimate of its thermal resistance. The term "calibrated specimen" is used to describe a specimen that is sent to a laboratory for a proficiency check. The laboratory must determine the thermal resistance of the specimen, and the result is then compared, by the certifying agency, with the characteristic obtained by the standard laboratory, in this case, DBR/NRCC.

The two apparatuses in most common use for laboratory determination of thermal resistance are the guarded hot plate (GHP) and the heat flow meter (HFM). At DBR/NRCC the GHP apparatus is used to develop transfer standards and calibrated insulation specimens; the HFM apparatus is used for routine thermal conductivity testing. It is also used by most independent commercial testing laboratories and by the research and development and quality control laboratories of manufacturers of thermal insulating material.

In this discussion a HFM apparatus means an instrument for laboratory determination of thermal resistance that employs one or more heat flow transducers. Although similar comparative methods have existed for approximately 100 years, it is only recently that the range of testing conditions in which the HFM method is utilized has exceeded that of other laboratory techniques. Broadening the range of HFM apparatus applications, however, has introduced new problems.

Historic Background[2]

Between 1870 and 1878 Péclet proposed three different methods of determining thermal conductivity: sphere, pipe section, and a vertical slab. At about the same time, in 1872, Forbes introduced a slab method for determining negative temperatures in which he measured the thickness of the ice layer formed on one surface of the specimen while the other side was exposed to a freezing mixture. In 1881 Christiansen built a comparative instrument that later was developed into a HFM apparatus. It contained three relatively thick copper plates with carefully drilled holes for thermometers. Two specimens,

[2]Two Russian books, namely: B. S. Pietuchow, *Optnoje Izuczenije Procesow Tieplopieriedaczi (Experimental Study of Heat Transfer Processes)*, Gosenergoizdat, 1952, and D. N. Timrot, *Opriedielenije Tieploprowodnosti Stroitielnych Materialow (Determination of Thermal Conductivity of Building Materials)* Gosenergoizdat, 1932, provide a detailed review of the historic background for this area of testing.

one with known thermal conductivity and another for which thermal conductivity was to be measured, were placed between the plates. Christiansen proposed a formula

$$\lambda = \lambda_0 \frac{L\,(T_3 - T_2)}{L_0\,(T_2 - T_1)}$$

where

λ, L = thermal conductivity, thickness of the specimen,
λ_0, L_0 = same as above, for the reference material, and
T_3, T_2, T_1 = temperatures of copper plates, starting from the hot plate.

Over the years the slab apparatus has been developed into a GHP through the efforts of many research workers, for example, Lees in 1892, Lees and Chorlton in 1896, Niven in 1906, Nusselt and Groeber in 1911, and Pönsgen in 1912 who introduced guarding heaters surrounding the main heater.

The concept of a heat flow transducer was used in Germany by Hencky in 1919 and by Schmidt in 1923 for field work, particularly on industrial insulations. While Hencky added a layer with thermal resistance comparable to that being measured, Schmidt's transducer had a small thermal resistance and was provided with compensating rubber strips of approximately the same resistance as the transducer. Depending on the nature of the substrate and the edge loss error, the number of compensating (guarding) strips could be increased (for example, to five if the heat flow transducer was placed on the metal surface).

It may be surprising that 60 years later the same technique is used, with the same magnitude of error. The explanation is simple: the physical principles involved remain practically unchanged, but understanding of the measurement uncertainties has improved significantly. Progress in such measurements is therefore not so much in the development of more precise instruments as in enlarging the range of materials and testing conditions for a given level of precision and accuracy. HFM apparatus developments are very characteristic in this respect. With the abundance of inexpensive electronic components it is possible to build today an apparatus that can yield results several times faster than a GHP apparatus can, one moreover that permits testing under conditions in which the GHP would yield excessive errors.

Advantages and Drawbacks of the HFM Method

The HFM method is not an absolute one and requires calibration with specimens having both mean thermal resistance and the uncertainty range of this value determined by an absolute method, for example, by the GHP method. In an earlier paper [*1*] that compared various calibration techniques for the HFM the authors concluded that the preferred technique is to use

transfer standards. As errors in measurement vary with thickness, mean temperature, and often even with temperature gradient across the specimen, one must either calibrate the HFM apparatus with the same type of specimen under the same testing conditions for which the apparatus will be used or perform a complex error verification to establish how different test conditions affect the uncertainty of HFM results.

If the HFM apparatus is to be used for quality control in the manufacture of thermal insulation, the calibration should be performed using a transfer standard of the same material as that manufactured. If it is to be used in a broad range of testing conditions, the same approach, that is, use of transfer standards, would require that GHP tests be performed on a variety of materials and under a variety of testing conditions. However, there may be significantly larger errors in GHP measurement results.

Another paper [*2*] discussing errors associated with GHP measurements dealt only with errors in the basic measurement characteristics of the equipment; the effect of the characteristics of the material under test was not discussed. Precision of the GHP apparatus was shown to be strongly dependent on the uniformity of heat flow across the gap between the metering and guard ring areas and "zero balance" of the system. It was also shown that only homogeneous, thin, uniform, "ideal" specimens could be used for experimental determination of the uncertainties in GHP testing.

Errors associated with the GHP apparatus arise from uncertainties in basic electrical (power and temperature) and thickness measurements and from deviation from one-dimensional heat flow [*3,4*]. The errors in basic measurements are characteristic of the equipment used; for example, for a 600 by 600-mm GHP apparatus at DBR/NRCC the repeatability precision of 0.2% and accuracy of 1.2% were determined at the 90% probability level. The errors resulting from multidimensional heat flow, that is, unbalance and edge loss error, depend on the nature of the material as well as on the equipment used and can be easily larger.

It is therefore important to remember that while the GHP method yields high precision and accuracy under well-defined conditions of unidirectional heat flow, this may not be the case for thick, low-density thermal insulations with a significant fraction of radiative heat transfer or for layered specimens with a high conductivity facing material.

Restrictions in the use of the GHP method relate to combinations of specimen thickness and testing conditions, where a lateral flow occurs over the air gap between main and guard ring heaters and in the specimen. Although a proper design of GHP apparatus may enlarge the range of testing conditions and material selection, its precision is reduced for thick specimens of thermal insulation faced with high-conductivity skins or membranes, layered and highly nonisotropic materials, or low-density materials in which a significant fraction of heat transfer is by radiation. In such cases the HFM apparatus may be used to better advantage than the GHP apparatus.

All these considerations limit the choice of specimen thickness and the materials and testing conditions that can be used for calibration and verification of HFM apparatus. If thicker transfer standards are needed, they must consist of two or more layers, each tested separately.

Principles of HFM Calibration

Bomberg and Solvason [2] have compared two methods of calibration. The first involves the use of calibrated specimens whose thermal resistance has been determined previously in the GHP. The heat flux in the HFM apparatus may be then inferred from the temperature difference across the specimen. This method is referred to as calibration of the HFM apparatus. In the second method, referred to as calibration of the heat flow transducer, the transducer and a dummy sample are placed between the plates of the one-sided GHP apparatus. The heat flux through the metering area of the transducer is assumed to be the same as that for the GHP measurement.

Both methods have advantages and disadvantages. In the calibration of the transducer, heat flow rate is measured directly and does not depend on a reference specimen. Accuracy depends, however, on the assumption that the heat flux through the dummy specimen and the transducer is strickly one-dimensional.

Two transducer types were examined: cork core [5], called ARM, and commercially available transducers [6] called SG heat flow meters. The 300-mm square transducers (ARM 1 and ARM 2) were built on a 6.3-mm core of Armstrong cork (No. 975), average density 496 kg/m^3, following the construction method described by Zabawsky [7]. Nine pairs of Chromel-Constantan thermocouple junctions were installed to provide a central 150 by 150-mm metering area. The total thickness of the transducer, including cork cover sheets, copper, and Mylar films, is about 8.4 mm. The surfaces were covered with the same black Nextel paint as was used on the SG heat flow meters, yielding the same emittance.

Table 1 gives the results of the calibration of ARM type transducers with high-density glass fiber and polystyrene transfer standards. Table 2 shows the

TABLE 1—*Calibration coefficients and confidence intervals as described by three standard deviations for ARM transducers (10 measurements).*

Calibration Procedure and Specimens	ARM 1, Hot Side		ARM 2, Cold Side	
	C_1 at 35°C, 3 σ		C_2 at 13°C, 3 σ	
Double HFM apparatus heat flux from high-density glass fiber and polystyrene transfer standards	25.03	0.30	24.69	0.48

TABLE 2—*Calibration coefficient of ARM 1 and ARM 2 heat flow meters as affected by change of layer adjacent to surfaces (heat flux determined from GHP apparatus).*

Test No.	Code	Materials in Contact with HFM	Heat Flux, W/m²	ARM 1		ARM 2	
				t_m, °C	C_1, W/m² mV	t_m, °C	C_2, W/m² mV
1	345-81	hot and cold plate of GHP	219.9	24.1	27.76	24.3	27.07
2	345-85	Hot plate, 12-mm RTV rubber	77.4	26.6	27.70	26.6	27.11
3	345-87	3-mm cork, 12-mm RTV rubber	56.6	24.6	26.20	24.7	25.72

calibration coefficient for the same transducers inserted in the square 300-mm GHP apparatus:

ARM transducer alone, Test 1,
ARM transducer in series with 12-mm RTV rubber, Test 2,
ARM transducer between 3-mm cork and 12-mm RTB rubber, Test 3.

The thermal properties of the layer adjacent to the transducer surface, as shown in Table 2, have a large effect on the apparent calibration coefficient, indicating a significant lateral component of heat flow.

Thus, one should calibrate the HFM apparatus using transfer standards, not the transducer alone. The transfer standards should be tested in the GHP apparatus under conditions identical to those used during HFM calibration and should cover the range of test conditions for which the HFM apparatus is intended. Most errors in calibration are, however, inversely proportional to the heat flux, suggesting that the HFM should be calibrated using thin transfer standards and high heat fluxes. This calibration would be valid for the low heat flux associated with testing thick specimens only if the output of the thermopile were proportional to the heat flux through it under all test conditions.

Figure 1 shows that this is not always the case even for thin specimens. It gives an example of a calibration performed on a heat flow transducer, using 26-mm thick specimens of three different materials:

low-density glass fiber (LDGF), tested with spacers,
LDGF specimens, tested with wooden frames,
high-density glass fiber (HDGF) specimens.

Figure 1 also indicates that the calibration coefficient obtained for each calibration specimen is different (with probability higher than 95%). There is a difference in the slope of the temperature dependence of the calibration for LDGF and HDGF specimens. In the temperature range 28 to 32°C the cali-

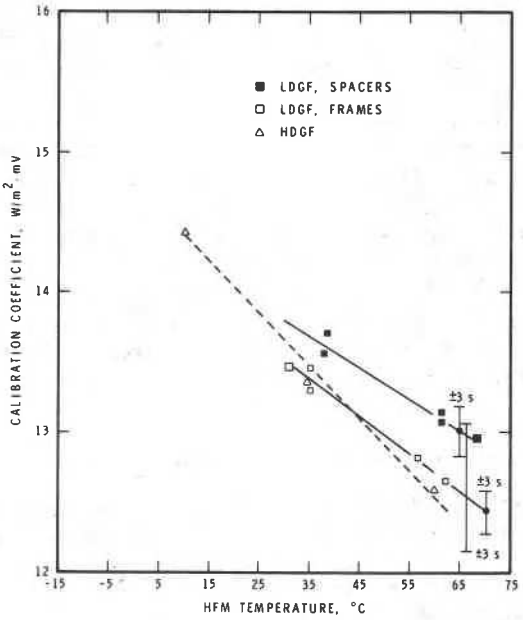

FIG. 1—*Calibration of HFM with 26-mm thick LDGF and HDGF specimens.*

bration coefficient, using LDGF, appears to be the same as that for specimens of HDGF. With extreme temperatures the differences are larger.

As the precision of an HFM calibration using LDGF specimens is as good as that for the high-density standard reference material, it should be possible to obtain the same precision over a larger range of specimen thicknesses or temperatures. This issue has been discussed elsewhere [*8,9*]. Although calibration of the HFM apparatus in the same range of conditions as will be used in testing identical material (or similar) may constitute a practical solution, a design that will ensure the same calibration coefficient for various materials and testing conditions appears to be a more satisfactory approach.

The response of the heat flow transducer to the properties of the tested specimen may be affected by nonuniformity of the transducer core, which may have low resistance paths through the thermopile junctions. Output will be slightly higher if high conductivity material contacts the surface in the area of the thermopile junctions. This effect can be eliminated by facing the transducer core with a high conductivity layer such as a few metal plates, separated with air gaps, to provide an isothermal surface adjacent to the specimen without increasing the lateral heat flow component at the metering area. Alterna-

tively, the HFM plate can be faced with a layer of low conductivity material such as 1.5 or 2-mm cork. This allows the temperature of the surface adjacent to the specimen to vary, depending on the nature of the contact resistances with the specimen. In both cases the thermal regime at the transducer surface will be always the same, regardless of the properties of the specimen. Two HFM instruments based on these considerations were built at NRCC [*1*].

Other transducer constructions were also tried, for example, dividing the metering field into a number of smaller, separately recorded areas to assess the errors caused by nonuniformity of either the specimen or the transducer itself. In calibrating the apparatus under a given set of testing conditions one has to examine the effect of a specific change in testing conditions on the overall accuracy of thermal resistance testing. This kind of activity is called verification of HFM uncertainties. Different types of transfer standards are required for this purpose.

Transfer Standards for HFM's Error Verification

The following materials were used at DBR/NRCC to establish sets of transfer standards based on uniformity, stability, and handling qualities:

1. Expanded polystyrene with density not less than 18 kg/m^3.
2. Air-filled extruded polystyrene.
3. Medium- and high-density glass fiber insulation (Standard Reference Material No. 1450 from National Bureau of Standard [*10*].
4. Thin (nonconvective) air layers with or without reflective surfaces.
5. Thin layers of glass fiber insulation with a density between 7 and 10 kg/m^3.

A transfer standard is established as follows. A pair of specimens matched in both thermal resistance and density are tested at least nine times in the GHP apparatus. Five of the tests are performed with a mean temperature in the range 20 to 28°C, and four are performed at the extreme ends of the test range, for example, a mean temperature between 0 and 10°C and one between 40 and 50°C. If the standard deviation calculated for these test series is less than 0.5% and a substantial amount of information exists on the same lot (batch) of the material from which the specimens were selected, this pair of specimens will be called transfer standards. If, however, either the standard deviation is higher than 0.5% or there are no other test results on the same lot of the material, the specimens will be called calibrated specimens. They can be used for comparison purposes such as verification of the HFM apparatus errors. However, they are not recommended for calibration of the HFM apparatus. The following sections describe examples of a transfer standard; for other examples see Ref *8*.

Glass Fiber Transfer Standard for Calibration of 300-mm HFM Apparatus

Two specimens, coded 357-154-A and 357-154-B, were prepared from a 1.2 by 2.4 m by 25-mm sheet of glass fiberboard produced by Johns-Manville for the National Bureau of Standards, Washington, D.C., in 1978. Specimens were cut and placed in frames in June 1980.

Density, Specimen A = 56.1 kg/m^3 (3.50 lb/ft^3)
Density, Specimen B = 56.5 kg/m^3 (3.53 lb/ft^3)
Mean = 56.3 kg/m^3 (3.51 lb/ft^3).

Table 3 gives the values of thermal resistance measured in the GHP apparatus, with corresponding values of mean specimen temperature, thickness, and thermal conductivity.

Thickness measured in the GHP apparatus is allowed to differ $\pm 0.2\%$ from the specimen thickness determined outside the apparatus. If it differs by more than 0.2%, the test results are excluded. For a difference of less than 0.1% the measured thermal resistance value is used; for a difference between 0.1% and 0.2% a correction is applied.

The following relation was obtained from a regression analysis of the test results

$$R = 0.8883 - 0.00295T \qquad 0 \leqslant T \leqslant 50°C \tag{1}$$

where

R = thermal resistance, m^2 K/W and
T = mean specimen temperature, °C.

The mean standard deviation between measured R, recalculated to reference thickness, and the R-values calculated from Eq 1 is $s = 0.2\%$. An error of ± 0.4, therefore, can be estimated on a 90% probability level by using two standard deviations.

Use of Expanded Polystyrene for Transfer Standards

Three groups of specimens cut from a special run of expanded polystyrene were examined. Spatial variability in density and in associated thermal conductivity was found to be too large in materials with density less than 18 kg/m^3. Two other series of specimens from materials with a density range of 18 to 24 kg/m^3 (1.1 to 1.5 lb/ft^3) showed satisfactory results. Table 4 shows thermal conductivity values as a function of specimen density measured at a mean temperature of 24°C. Using a linear regression for thermal conductivity as a function of density and comparing this with the measured values, there is a $\pm 1.0\%$ uncertainty range for a probability of 95%, that is, precision com-

TABLE 3—*Thermal resistance of 357-154A/B medium-density glass fiber specimens (GHP tests), specimens dried prior to testing.*[a]

Date	Measurements			
	Mean Temperature, °C	Thermal Resistance, m^2 K/W	Thickness, mm	Thermal Conductivity, W/m K
800716	−0.69	0.8882	25.99	0.02926
800718	12.40	0.8510	25.99	0.03054
800910	23.96	0.8184	25.97	0.03174
800912	22.21	0.8205	25.97	0.03165
800917	25.97	0.8114	25.97	0.03200
800918	28.04	0.8045	25.97	0.03228
800922	35.92	0.7828	25.97	0.03318
800929	47.44	0.7509	25.97	0.03458
801001	0.19	0.8933	25.97	0.02907
801003	12.44	0.8514	25.97	0.03050
801006	23.28	0.8165	25.97	0.03181
801027	20.14	0.8282	25.99	0.03138
801028	23.72	0.8185	25.99	0.03176

[a]Reference thickness, $L = 25.97$ mm.

TABLE 4—*Thermal conductivity and density of polystyrene specimens tested on 600-mm square heat flow meter apparatus at 24°C.*

Specimen Code	Density, ρ kg/m^3	Measured λ, W/m K
1	21.6	0.0375
2	18.1	0.0405
3	22.7	0.0365
4	24.0	0.0352
5	19.2	0.0399
6	22.6	0.0370
7	23.0	0.0365
8	22.3	0.0373
9	22.2	0.0371

parable with that obtained on high-density glass fiber transfer standards. Temperature dependence for three sets of transfer standards prepared for the same lot of material is shown in Table 5. The agreement is good.

Use of Layered, Low-Density Glass Fiber Specimens as Transfer Standards

The following technique was used at DBR/NRCC to fabricate low-density transfer standards ranging in thickness from 50 to 200 mm. Using a light

TABLE 5—*Thermal resistance as a function of temperature for three sets of transfer standards and calibrated specimens prepared from the same batch of 18.4 kg/m³ density expanded polystyrene.*

Specimen Code	Temperature Dependence, R (m^2 K/W) versus T_m (°C)
365-146	$R = 2.792\ (1 \text{ to } 0.00330\ T_m)$
372-173	$R = 2.773\ (1 \text{ to } 0.00318\ T_m)$
372-2	$R = 1.343\ (1 \text{ to } 0.00335\ T_m)$

table [*11*], 30 specimens were selected whose density varied between 7.2 and 10.0 kg/m³. To reduce the number of tests required to establish their thermal characteristics two specimens separated by one paper layer (septum) to intercept radiative heat transfer were tested. Nine pairs were finally selected [*8*].

Thermal conductivity tests on glass fiber multilayer specimens with and without paper septa were useful in examining the effect of specimen thickness [*12, 13*] on apparent thermal conductivity and HFM apparatus errors related to increasing specimen thickness [*8, 9*]. Although thick, uniform, calibrated specimens are developed in a manner identical to that used for transfer standards (see description of the glass fiber transfer standard in the previous section), the development of layered, calibrated specimens is far more difficult. The thermal resistance of these specimens is determined for standard conditions (24°C mean) only. To determine such values DBR/NRCC uses GHP and HFM measurements as well as computer calculations.

Proficiency Testing

In contrast to transfer standards, which are loaned by DBR/NRCC together with certificates stating both the mean value and the uncertainty in thermal resistance over a given temperature range, calibrated specimens for proficiency testing are made available without any information on their thermal resistance. Each laboratory must decide on a testing procedure for determining the thermal resistance of the calibrated specimens; it knows only that different results may be obtained with different testing conditions.

There are two kinds of proficiency tests: those performed at standard conditions of mean temperature 24 ± 1°C and temperature difference of 22 ± 2°C; and those performed over a range of mean temperatures between 0 and 50°C. Although some requirements for the two cases will be different, the same specimens are used. Those for proficiency testing will include homogeneous transfer standards and the layered, calibrated specimens specially constructed for the purpose of proficiency testing.

Use of Layered Specimens

At DBR/NRCC the following were built and developed as calibrated, layered specimens for proficiency testing:

1. 180 to 190-mm thick, uniform, layered polystyrene (type 2),
2. 150 to 180-mm thick, uniform, layered, low-density glass fiber,
3. 90 to 120-mm thick, cellular plastic specimens covered on one surface with medium conductive, uneven, metal reinforced bonding cement surface.

Table 6 shows thermal resistance of one pair of layered specimens as tested on HFM and GHP apparatus.

Proposed Requirements for Standard Test Conditions

1. The laboratory should perform, in sequence, a minimum of eight tests on one pair of transfer standards: Specimen A alone; Specimen B alone; Specimens A and B together, with a paper septum between. The mean thermal conductivity should be within 2.0% of the mean value determined in the GHP apparatus at DBR/NRCC, and the standard deviation of thermal resistance determined in this test series should not exceed 1.0% (that is, twice that allowed for transfer standards at DBR/NRCC).
2. Three coded, layered, calibrated specimens should be tested. The mean test results should not differ more than 3% from the mean determined at NRCC, and none of the separate test results should differ more than 5% from the mean value determined by NRCC.

Proposed Requirements for Testing over a Temperature Range

1. The laboratory should perform a minimum of nine tests on each pair of transfer standards, five with mean temperature in the range 20 to 28°C, and

TABLE 6—*Apparent thermal resistance of 90-mm thick polystyrene specimen covered on one side with bonding cement reinforced by expanded metal lath to increase lateral conduction of surface layer.*

Equipment Type	Test Code	Heat Flux Measured on Side Contacting		Placement of Stucco
		Stucco	Polystyrene	
GHP	380-30		100.0	cold side
GHP	380-29	94.3		hot side
HFM	380-24	95.3	99.5	hot side
HFM	380-14	93.2	98.1	hot side
HFM	380-25	96.2	100.1	cold side
HFM	380-15	96.0	101.1	cold side
HFM mean value	...	95.2	100.3	...

four at the extreme ends of the test range, for example, between 0 and 10°C and between 40 and 50°C. Thermal conductivity should be within the following limits:

(*a*) Mean of three or more tests at 24 ± 2°C should be within 2.0% of the NRCC determined value.

(*b*) Mean of two or more tests at other temperature should not differ by more than 2.5%.

2. Three layered, calibrated specimens should be tested at 24 ± 1°C. The requirements are the same as for point 2, Standard Test Conditions.

3. Lateral heat flow tests with three different ambient air temperatures should also be performed [*8*].

Closing Remarks

The transfer standards and calibrated specimens must be returned to DBR/NRCC. In addition, the laboratory applying for accreditation should develop its own reference specimen. It may be one specimen or a pair of identical specimens (material may be supplied by NRCC). The verification tests will be performed at DBR/NRCC and the specimens then returned to the accredited laboratory. Control charts must be established by that laboratory and adjusted during subsequent testing of the reference specimen [*9*]. The reference specimen must be retested by the accredited laboratory periodically and not more than 30 days before the test to be reported.

Cooperative projects performed by DBR/NRCC and by testing and industrial laboratories have proved that HFM apparatuses may be recalibrated quite easily to meet the proposed requirements.

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