Designation: C 1667 – 07

Standard Test Method for Using Heat Flow Meter Apparatus to Measure the Center-of-Panel Thermal Resistivity of Vacuum Panels[1]

This standard is issued under the fixed designation C 1667; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of steady-state thermal transmission through the center of a flat rectangular vacuum insulation panel using a heat flow meter apparatus.

1.2 Total heat transfer through the non-homogenous geometry of a vacuum insulation panel requires the determination of several factors, as discussed in Specification C 1484. One of those factors is the center-of-panel thermal resistivity. The center-of-panel thermal resistivity is an approximation of the thermal resistivity of the core evacuated region.

1.3 This test method is based upon the technology of Test Method C 518 but includes modifications for vacuum panel applications as outlined in this test method.[2]

1.4 This test method shall be used in conjunction with Practice C 1045 and Practice C 1058.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only. Either SI or inch-pound units are acceptable in the report, unless otherwise specified.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 168 Terminology Relating to Thermal Insulation
C 518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C 740 Practice for Evacuated Reflective Insulation In Cryogenic Service
C 1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions
C 1058 Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation
C 1484 Specification for Vacuum Insulation Panels

3. Terminology

3.1 *Definitions*—Terminology C 168 applies to terms used in this specification.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *center-of-panel*—the location at the center of the largest planar surface of the panel, equidistant from each pair of opposite edges of that surface.

3.2.2 *center-of-panel apparent thermal resistivity*—the thermal performance of vacuum panels includes an edge effect due to heat flow through the barrier material and this shunting of heat around the evacuated volume of the panel becomes more prevalent with greater barrier thermal conductivity, as shown in Fig. 1. For panels larger than a minimum size (as described in Annex A1), the center-of-panel apparent thermal resistivity is a close approximation of the intrinsic core thermal resistivity of the vacuum insulation panel. The effective thermal performance of a panel will vary with the size and shape of the panel.

3.2.2.1 *Discussion*—Thermal resistivity, the reciprocal of apparent thermal conductivity, is used when discussing the center-of-panel thermal behavior.

3.2.3 *core*—the material placed within the evacuated volume of a vacuum insulation panel. This material may perform any or all of the following functions: prevent panel collapse due to atmospheric pressure, reduce radiation heat transfer, and reduce gas-phase conduction. The apparent thermal conductivity of the core, or λ_{core}, is defined as the apparent thermal conductivity of the core material under the same vacuum that would occur within a panel, but without the barrier material. This is the apparent thermal conductivity that would be measured in a vacuum chamber without the barrier material.

3.2.4 *effective panel thermal resistance (effective panel R-value)*—this value reflects the total panel resistance to heat flow, considering heat flow through the evacuated region and through the barrier material. Depending on the thermal conductivity of the barrier material and the size of the panel, the effective thermal resistance may be significantly less than the product of the center-of-panel apparent thermal resistivity and

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[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] All references to particular sections of Test Method C 518 within this document refer to the 2004 edition of Test Method C 518.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

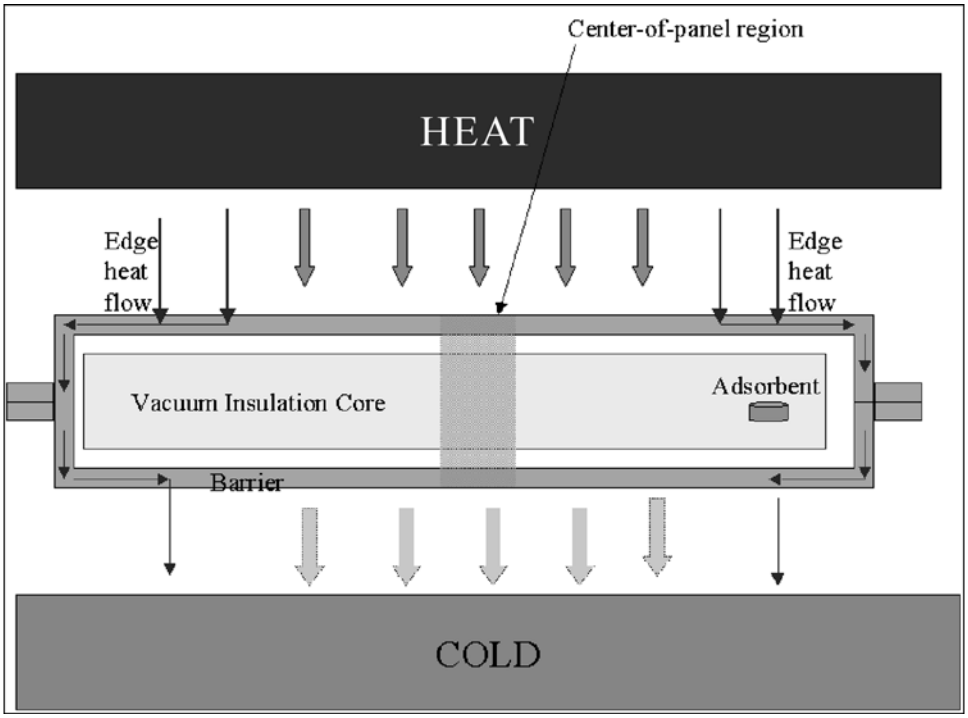

FIG. 1 Side View of a Vacuum Insulation Panel Showing Edge Heat Flow and the Center-of-Panel Region

the panel thickness. The effective thermal resistance is based on the edge-to-edge area covered by the vacuum insulation panel, that is, the entire panel. The effective thermal resistance will also vary with the panel mean temperature.

3.2.4.1 *Discussion*—Thermal resistance, the reciprocal of thermal conductance, is used when discussing the effective thermal performance of the panel. This value includes the effect of the actual panel dimensions, including the panel thickness.

3.2.5 *evacuated or vacuum insulations*—insulation systems whose gas phase thermal conductivity portion of the overall apparent thermal conductivity has been significantly reduced by reduction of the internal gas pressure. The level of vacuum will depend on properties of the composite panel materials, and the desired effective panel thermal resistance.[4]

3.2.6 *panel barrier*—the material that envelops the evacuated volume and is used to separate the evacuated volume from the environment and to provide a long term barrier to gas and vapor diffusion.

3.2.7 *seal*—any joint between two pieces of barrier material.

3.3 *Symbols and Units*:

$A_{barrier}$ = area of the barrier perpendicular to the largest panel faces, m^2

A_{core} = area of the largest panel face covering the core material, m^2

C = calibration standard conductance, W/m^2-K

E = heat flux transducer output, V

L_{panel} = panel thickness, m

$L_{calibration\ standard}$ = thickness of a single layer of the calibration standard material, m

$L_{calibration\ standard,\ target}$ = target total thickness of the calibration standard material, m

q = heat flux through the panel, W/m^2

$Q_{barrier}$ = heat flow through the barrier material, W

$Q_{center\text{-}of\text{-}panel}$ = estimated heat flow at the transducer (as calculated by the model), W

Q_{core} = heat flow through the core region, W

$R_{calibration\ standard}$ = thermal resistivity of the calibration standard, m-K/W

$R_{center\text{-}of\text{-}panel}$ = center of panel thermal resistivity, m-K/W

S = calibration factor, $(W/m^2)/V$

T_c = specimen cold surface temperature, K

T_h = specimen hot surface temperature, K

$t_{barrier}$ = thickness of the barrier material, m

W_1, W_2 = panel width, panel length, m

u_c = combined standard uncertainty

u_n = uncertainty component, for example, standard uncertainty for the measurement

Z_{edge} = an approximate estimate of the ratio of the heat flow through the barrier material to the heat flow through the core material, dimensionless

$\lambda_{barrier}$ = thermal conductivity of the barrier material, W/m-K

λ_{core} = apparent thermal conductivity of the core region, W/m-K

4. Summary of Test Method

4.1 This test method describes a modified application of Test Method C 518 to evacuated panels. These panels fall outside the scope of Test Method C 518, both in their non-homogeneity and in the current lack of specimens having an

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[4] For further discussion on heat flow mechanisms in evacuated insulations, see Practice C 740 on Evacuated Reflective Insulation in Cryogenic Service.

accepted reference value that are of similar size and have the necessary thermal characteristics. Therefore, modifications are necessary in the areas of apparatus calibration, plate separation, test procedures, precision and bias, and reporting.

NOTE 1—Primary calibration standards, using vacuum panels, have not been prepared for this class of products due to uncertainties about their long-term stability characteristics.

5. Significance and Use

5.1 Heat flow meter apparatus are being used to measure the center-of-panel portion of a vacuum insulation panel, which typically has a very high value of thermal resistivity [that is, equal to or greater than 90 m-K/W (12.5 h-ft^2-°F/Btu-in.)]. As described in Specification C 1484, the center-of-panel thermal resistivity is used, along with the panel geometry and barrier material thermal conductivity, to determine the effective thermal resistance of the evacuated panel.

5.2 Using a heat flow meter apparatus to measure the thermal resistivity of non-homogenous and high thermal resistance specimens is a non-standard application of the equipment, and shall only be performed by qualified personnel with understanding of heat transfer and error propagation. Familiarity with the configuration of both the apparatus and the vacuum panel is necessary.

5.3 The center-of-panel thermal transmission properties of evacuated panels vary due to the composition of the materials of construction, mean temperature and temperature difference, and the prior history. The selection of representative values for the thermal transmission properties of an evacuated panel for a particular application must be based on a consideration of these factors and will not apply necessarily without modification to all service conditions.

6. Apparatus

6.1 Follow Test Method C 518, Section 5 except use Section 8 of this test method for calibration.

7. Specimen Preparation

7.1 Vacuum insulation panels are typically rigid and the shape cannot be modified for testing purposes. However, to obtain representative thermal values for the panel, the two primary surfaces must be parallel and have limited surface irregularities.

7.2 If none of the standard product sizes are appropriate for the heat flow meter apparatus used in this test, then representative test specimens must be produced so that they accurately represent both the same average performance as the production product and the same typical product variability.

7.3 The specimens shall be of the same thickness as the average thickness to be applied in use.

7.4 The minimum panel size for this test is determined by the size of the heat flux transducer in the heat flow meter apparatus, the overall maximum specimen size limit for the apparatus, the thermal conductivity of the barrier, the thickness of the barrier, and the thermal conductivity of the core. Annex A1 contains a procedure to estimate the minimum acceptable panel size.

7.4.1 Preferably, specimens shall be of such size as to fully cover the plate assembly surfaces, with an allowance of up to 6 mm on each side to allow room for panel seals.

7.4.2 If the width or length, or both, of the specimen are smaller than the apparatus compartment, surround the specimen with high thermal resistance insulation. This surrounding material will reduce edge heat transfer and prevent air circulation around the specimen.

7.5 For panels with smooth parallel surfaces, the specimen thickness is represented by the plate separation.

7.6 For panels with irregular surfaces, to insure thermal contact with the apparatus surfaces, it is necessary to:

7.6.1 Measure the panel thickness with an accuracy of ±0.05 mm (0.002 in.) in at least five locations distributed over the surface of the panel and use the average of the local values. Care shall be taken so that the contact between the caliper jaws or the length meter's pressure foot does not damage the specimen surface.

7.6.2 Record the output of one thermocouple placed on the center of the top and one thermocouple placed on the center of the bottom of the panel. The temperatures recorded by the thermocouples, not the hot and cold plate temperatures, shall be used to calculate the center-of-panel apparent thermal resistivity.

7.6.3 Place one sheet (approximately 3 mm thick) of an elastomeric or soft foam rubber between each side of the panel and the corresponding apparatus plate. This sheet will improve contact between the controlled temperature plates and prevent air circulation between the panel and the plates.

8. Calibration

8.1 The apparatus shall be calibrated according to Test Method C 518 sections 6.1 to 6.5.

8.2 Specimens having an accepted reference value with physical and thermal characteristics similar to vacuum panels are not yet available. The linearity of the heat flux transducers at very low levels of heat flux must be verified using another method. The apparatus calibration must include the addition of at least one of the modified calibration procedures described in 8.5 and 8.6, that is Modified Calibration Procedure A or B. As described in 8.7, the two modified procedures can be combined if necessary to meet uncertainty goals. Although each method magnifies an element of experimental error (as discussed below), it is necessary to augment the standard Test Method C 518 calibration for this particular application.

8.3 It is not intended that the heat flow meter apparatus calibration be altered based on the results of these supplementary procedures. Rather the results will be used by qualified personnel (as described in 5.2) to determine whether a particular heat flow meter apparatus will give meaningful results for a vacuum panel application, and if so, to provide guidance on interpreting and applying the Test Method C 518 test results.

NOTE 2—Just as with the standard calibration technique, the supplementary calibration need not be repeated for every test if the equipment has been stable over a significant period of time. See Test Method C 518 section 4.5.1.

NOTE 3—The heat flow meter apparatus may take a long time to reach a true steady-state condition for low conductance specimens, as described in Test Method C 518 section 7.7.3.

8.4 In order to evaluate the linearity of the heat flux transducers at the reduced levels of heat flux that will occur with the vacuum insulation panels, a target heat flux is calculated from Eq 1, using the best information available about the center-of-panel thermal resistivity, the panel thickness, and the temperature difference of interest.

$$q_{target} = \frac{(T_h - T_c)}{R_{center\ of\ panel,\ estimated} \times L_{panel}} \tag{1}$$

8.5 *Modified Calibration Procedure A*—Make a series of test measurements using multiple thicknesses of the calibration standard, with a radiation-blocking septum between the layers. Calculate a target thickness for the heat flux level of interest using Eq 2, recognizing that the actual thickness will be an even multiple of the thickness of a single layer or the sum of the available calibration standard thicknesses.

$$L_{calibration\ standard,\ target} = \frac{(T_h - T_c)}{R_{calibration\ standard} \times q_{target}} \tag{2}$$

NOTE 4—The use of radiation-blocking septums in this procedure is not meant to imply that radiation is not a significant heat transfer mechanism within a vacuum panel. Rather, the septums are used to allow the addition of previously measured conductances for each individual layer of the calibration standards. Brown Kraft paper has been used for this purpose.

8.5.1 As described in Test Method C 518 section A1.8.2, for each stack, a first approximation is that the total thermal resistance is the sum of the individual thermal resistances.

8.5.2 All of these measurements shall be made at the same mean temperature and temperature difference that will be used for the vacuum insulation panel specimen measurement.

NOTE 5—Care must be observed in making the required measurements. Due to the low heat flux rate of the insulation stack and its thermal heat capacity, the test time parameters for determining the steady state will be significantly longer than normal testing. See 9.2.2.

8.5.3 For each heat flux transducer, calculate the calibration factor, S from Eq 3, at each heat flux level.

$$S = \frac{(T_h - T_c)}{E \times \sum_{Layers} \frac{1}{C}} \tag{3}$$

8.5.4 For each heat flux transducer, evaluate the variation in S as a function of heat flux. Determine whether the variation is acceptable and include this value as an element of the measurement uncertainty in the reported error analysis.

NOTE 6—Any change in the calibration factor for increased thickness reflects not only the effect of the reduced heat flux magnitude (which will be pertinent to the vacuum panel measurement), but also the effect of increased lateral heat losses or gains caused by the increased edge area (which may not be pertinent for this application). The lateral heat losses can be minimized by keeping the mean test temperature equal to the temperature of the local environment.

8.6 *Modified Calibration Procedure B*—Make a series of test measurements with small temperature differences using a single calibration standard. Calculate the target temperature difference as shown in Eq 4.

$$(T_h - T_c)_{target} = R_{calibration\ standard} \times q_{target} \times L_{calibration\ standard} \tag{4}$$

8.6.1 Holding the mean temperature constant, adjust the plate temperatures as necessary to reduce the temperature difference across the calibration specimen.

8.6.2 For each heat flux transducer, calculate the calibration factor, S from Eq 3, at each heat flux level. For each heat flux transducer, evaluate the variation in S as a function of heat flux. Determine whether the variation is acceptable and include this value as an element of the measurement uncertainty in the reported error analysis.

8.6.3 For each heat flux transducer, the calibration factor S is a function of plate temperature. The user shall include the variation of S with temperature in the error analysis unless this variability has already been included in the calibration factor.

NOTE 7—At smaller temperature differences, the effect of the imprecision of the plate temperature measurements on the final result will be greater.

8.7 If neither Modified Calibration Procedure A or B are sufficient to reduce the experimental heat flux to the desired levels within an acceptable uncertainty, it will be necessary to combine them, that is, to use multiple calibration specimens with a reduced temperature difference.

8.7.1 Edge effect errors will be magnified with the stacked specimen method, compared to a single calibration thickness. Smaller temperature differences will magnify the impact of the imprecision of the temperature measurements on the final result. An error analysis of the specific apparatus shall be used as a guide to select the best combination of calibration standard thickness and temperature difference to reduce the calibration uncertainty.

9. Procedure

9.1 This test method shall only be performed by qualified personnel with experience in heat transfer analysis and experimental error propagation. To ensure accurate measurement, the operator shall be instructed fully in the operation of the equipment and must have detailed familiarity with the configuration of both the apparatus and the vacuum panel.

9.2 Follow Test Method C 518 section 7.6 with the following modifications.

9.2.1 Radiation will be an important heat transfer mechanism within a vacuum panel, so select the plate temperatures to match the expected use temperatures. When possible, use the product standard rating conditions or follow Test Method C 518 section 7.7.1 and Practice C 1058.

9.2.2 These low thermal conductivity specimens usually require a longer settling time than more conductive materials. At least 10 successive observations must yield values of thermal conductivity that fall within 2 % of the mean value for these 10 readings. If the 10 readings show a monotonic variation then equilibrium has not been attained.

10. Calculations

10.1 Calculate the center-of-panel apparent thermal resistivity using the panel thickness, the temperature difference across the panel, and the heat flux through the panel as described in Practice C 1045.

10.1.1 The heat flux, q, is the average of the heat fluxes from the hot and cold plates.

10.1.2 If the panel is in direct contact with the apparatus plates, as described in 7.5, then the temperature difference is the difference between the two plate temperatures and the panel thickness, L_{panel}, is the plate separation.

10.1.3 If the panel is not in direct contact with the apparatus plates, as described in 7.6, then the temperature difference is the difference between the temperatures reported by the two thermocouples attached to the panel, and the panel thickness, L_{panel}, is the average of the five measurements from 7.6.1.

11. Report

11.1 For each test, report the following information:

11.1.1 Identify the report with a unique numbering system to allow traceability back to the individual measurements taken during the test performed.

11.1.2 Identify the material and give a physical description.

11.1.3 Provide a brief conditioning history of the specimen, if known.

11.1.4 Thickness of the specimen as received and as tested, m.

11.1.5 Method and environment used for conditioning, if used.

11.1.6 Mean temperature of the test, K.

11.1.7 Heat flux through the specimen, W/m^2.

11.1.8 Thermal resistivity of the center-of-panel, m·K/W.

NOTE 8—The thermal resistance of the non-homogenous panel is not available from this procedure.

11.1.9 Duration of the measurement portion of the test, h.

11.1.10 Date of test.

11.1.11 Description of calibration test results from Section 8, including the date of the last heat flux transducer calibration, and the type or types of calibration materials used.

11.1.12 Estimated or calculated uncertainty in reported values.

11.1.13 List exceptions to the standard, if any.

11.1.14 The name of the operator performing the tests and the data analyst preparing the test report.

12. Precision and Bias

12.1 An interlaboratory comparison of the center-of-panel thermal conductivity of powder-filled evacuated insulation panels was conducted in the early 1990s. The heat flux meter apparatus used varied in maximum specimen size and transducer size. All of the apparatus used a single heat flux transducer. Also, three participants used equipment that, unlike today's apparatus, did not measure the temperatures of the bounding plates directly and the plates were not constructed of high-conductivity rigid metal. In this interlaboratory comparison, measurements on the larger-sized panels by six laboratories produced a two standard deviation (2σ) of 7.4 % about the mean. When the results for the smaller panels [down to 15×15 cm (6×6 in.)] are included the 2σ increases to 12.9 % about the mean.[5]

12.2 An interlaboratory comparison of the center-of-panel conductivity was initiated in 2000 using apparatus that, with the exception of one participant, met the requirements of Test Method C 518. This interlaboratory study was designed to evaluate reproducibility, but did not address repeatability. The participants were not required to report their calibration procedures or the number of heat flux transducers present within the apparatus, but did report the transducer size and the method used to measure the test specimen thickness. Two vacuum insulation panel types were used, one with a more conductive barrier material than the other, to determine the effects of edge heat flow on the center-of-panel measurement. All the test specimens were the same size and contained the same core material and were evacuated to the same initial pressure. The measurements took place over a twenty-month period. The influence of panel aging, barrier heat transfer, and panel thickness measurement techniques were all noted in the data analysis. Considering all measurements made with the smaller transducer sizes [≤10×10 cm (4×4 in.)] typical of recently manufactured 30×30 cm (12×12 in.) Test Method C 518 apparatus, the data produced a two standard deviation (2σ) of 13.4 %, which would place a 95 % confidence interval for the center-of-panel resistance for the six specimens between RSI 4.2 and 5.6 m^2·K/W (R 24 and R 32 h·ft^2·°F /Btu). Considering only the data taken during the first four months (four laboratories), the data show 2σ of 10.6 %. The data for the thickness measurement (the thermal resistance is directly proportional to the measured thickness) showed 2σ of 9.4 %, explaining much of the variation in the measured thermal resistance values. The measurements based on plate separation were much more consistent than those based on separate measurements over the surface of the panel.[6]

12.3 The task group will organize a future interlaboratory study to address the issues of repeatability and the calibration procedures contained within this test method.

12.4 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring the thermal resistivity of the center-of-panel of a vacuum insulation specimen because no material having an accepted reference value is available.

13. Measurement Uncertainty

13.1 Evaluate the uncertainty for the calibration results using current international guidelines.[7]

13.1.1 Determine the combined standard uncertainty using Eq 5, where the uncertainty components include the standard uncertainty of the calibration regression coefficient, the standard uncertainty for replicate measurements, and the standard uncertainty for the measurement.

$$u_c = \sqrt{\sum u_n^2} \tag{5}$$

13.1.2 The measurement uncertainty includes the standard uncertainty of the test method used for calibration and the

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[5] Graves, R. S. and Kollie, T. G., "Interlaboratory Comparison Measurements of the Thermal Conductivity of Powder-Filled Evacuated Panel Superinsulation," *Thermal Conductivity 22*, Editor Timothy W. Tong, Technomic Publishing Co., Lancaster, PA 1994, pp. 435-446.

[6] Stovall, T. K. and Brzezinski, A., "Vacuum Insulation Round Robin to Compare Different Methods of Determining Effective Vacuum Insulation Panel Thermal Resistance," *Insulation Materials: Testing and Applications, 4th Volume, STP 1426*, A. O. Desjarlais and R. R. Zarr, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2002, pp. 314-325.

[7] ANSI, "U.S. Guide to the Expression of Uncertainty in Measurement," ANSI/NCSL Z540-2-1997, 1997.

standard uncertainty of any auxiliary measurement equipment, for example, the voltmeter used to measure the DC output signal of the heat flux transducer(s).

13.1.3 The uncertainty of the heat flux and the heat flux transducer output must be determined along with the departure from unidirectional heat flow.

13.2 Evaluate the uncertainty for the test method results using current international guidelines.[7]

13.2.1 Determine the combined standard uncertainty using Eq 5, where the uncertainty components include the standard uncertainty for replicate measurements, and the standard uncertainty for the measurement, among other uncertainty sources.

13.2.2 The measurement uncertainty includes the standard uncertainty of the test method, the standard combined uncertainty of the calibration and the standard uncertainty of any auxiliary measurement equipment, for example any thermocouples used to measure test specimen surface temperatures.

14. Keywords

14.1 effective thermal resistance (effective R-value); thermal conductivity; thermal resistance; vacuum insulation panel

ANNEX

(Mandatory Information)

A1. CALCULATIONS TO DETERMINE THE MINIMUM PANEL SIZE REQUIRED FOR A VALID CENTER-OF-PANEL THERMAL RESISTIVITY MEASUREMENT

A1.1 For a panel with an unknown core conductivity, it is necessary to determine the minimum panel size using an iterative procedure considering the size of the heat flux transducers, the size of the vacuum insulation panel, and the properties of the core region and barrier material.

A1.1.1 Measure the center-of-panel conductivity and use this measured value as an estimate of the apparent core conductivity (λ_{core}) to calculate Q_{core} as shown in Eq A1.1-A1.3. The thermal conductivity of the barrier material ($\lambda_{barrier}$) must be known or estimated. Calculate Z_{edge} using equations Eq A1.3-A1.5.

$$A_{core} = W_1 \times W_2 \tag{A1.1}$$

$$A_{barrier} = 2 \times (W_1 + W_2) \times t_{barrier} \tag{A1.2}$$

$$Q_{core} = \frac{\lambda_{core} \times A_{core} \times (T_h - T_c)}{L_{panel}} \tag{A1.3}$$

$$Q_{barrier} = \frac{\lambda_{barrier} \times A_{barrier} \times (T_h - T_c)}{L_{panel}} \tag{A1.4}$$

$$Z_{edge} = \frac{Q_{barrier}}{Q_{core}} \tag{A1.5}$$

A1.1.2 Calculate the ratio of the panel width to the heat flux transducer width. Using this variable, check Fig. A1.1 to determine if the panel was large enough. If the value of $Q_{center\text{-}of\text{-}panel}/Q_{core}$ is greater than 1.05, then the panel is too small for the selected apparatus. For a panel less than three times wider than the transducer, the model results are highly variable and thus such arrangements are not recommended.

NOTE A1.1—A full description of the heat transfer model represented by Eq A1.1-A1.5 and Fig. A1.1 is given in Appendix X2.

A1.2 If it is not possible to test a panel large enough to satisfy the accuracy requirement, either because the panels are too small or because the barrier material is too conductive, then this test method shall not be used.

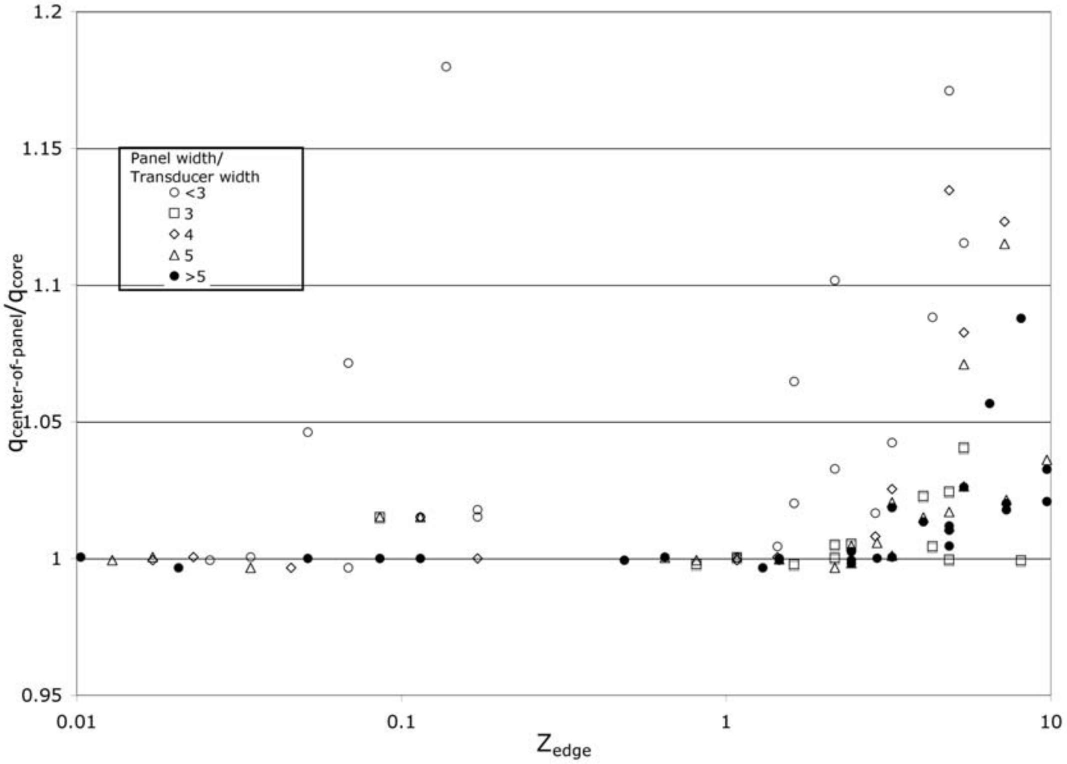

FIG. A1.1 Effect of Panel Construction on Measurement Requirements Based on the Parametric Analysis Summarized in Table X2.1

APPENDIXES

(Nonmandatory Information)

X1. HISTORY OF THE TEST METHOD

X1.1 Vacuum insulation systems have long been used for cryogenic applications. These systems have historically consisted of multi-layer evacuated jackets with active vacuum systems. In the early 1990s, sealed evacuated panels became commercially available. These panels were filled with either fibrous material or silica and had either metal or plastic barriers. The continuing design evolution includes open-celled foam and advanced powder fillers, specialty multi-layer films, and the inclusion of new adsorbent systems. In order to help potential users understand the performance of these panels, a task group was formed in 1995 to create an ASTM material specification. The first version of Specification C 1484 was the result of these efforts. Due to the complexity of this nonhomogenous insulation form, Specification C 1484 included testing advice. This test method represents the first step in separating test methods unique to evacuated insulation panels from the material standard.

X2. A SIMPLIFIED HEAT TRANSFER MODEL USED TO GENERATE FIG. A1.1

X2.1 A simplified thermal model of a vacuum insulated panel can be constructed by considering two parallel and independent heat flow paths operating across the same temperature difference, Q_{core} and $Q_{barrier}$.

NOTE X2.1—This simplified model is a useful tool in characterizing the panel, but should never be used to calculate the heat transfer through the panel.

X2.2 The first heat flow path is through the core of the panel and can be characterized by the width, length, thickness, and the thermal conductivity of the core volume (λ_{core}).

X2.3 The second heat flow path is through the barrier and can be characterized by the thickness and thermal conductivity of the barrier, and the width, length, and thickness of the panel.

X2.4 The ratio of these two simplified heat flows, Z_{edge}, gives an indication of the relative importance of the heat flow through the panel's barrier. For a sufficiently large panel, the flow through the panel's barrier will be relatively small and thermal conductivity measurements made at the center of the panel will represent the conductivity of the panel's core region within an adequate margin of error.

X2.5 To determine the size of a "sufficiently large" panel, a finite difference heat transfer model of a vacuum insulation panel was run for a variety of panel parameters. The parameters that were varied are shown in Table X2.1 and the results are presented in Fig. A1.1. This figure was produced to show the relationship between measured center-of-panel heat flux and the heat flux that would be measured if the core of the panel were present without any edge effects. The panel was assumed to be square and the sensor was assumed to be located in the center of the panel.

X2.6 Fig. A1.1 shows the ratio of the two theoretical heat flows (that is, Z_{edge}) from the simplified model on the x-axis. A small Z_{edge} means that there is much less heat flowing through the barrier material than through the core region of the panel. On the y-axis is the center-of-panel heat flux ratio, that is, the flux through the heat flux transducer area as calculated by the finite difference model ($q_{center\text{-}of\text{-}panel}$) divided by the ideal flux through the core region in the absence of any edge effects (q_{core}). The different symbols on this figure define the size of the panel relative to the size of the heat flux transducer. As can be seen in this figure, for a sufficiently large panel, the center-of-panel measurement is within 5 % of the core value, that is, $q_{center\text{-}of\text{-}panel}/q_{core}$ is less than 1.05.

TABLE X2.1 Parametric Evaluation of the Effect of Panel Size on Adequacy of Center-of-Panel Thermal Conductivity Measurements

Barrier thermal conductivity:	0.247 to 233 W/m-K (1.72 to 1615 Btu-in./h-ft^2-°F)
Barrier thickness:	0.003 to 0.08 cm (0.001 to 0.03 in.)
Core region thermal conductivity:	0.0035 to 0.0095 W/m-K (0.025 to 0.067 Btu-in./h-ft^2-°F)
Panel width:	15 to 100 cm (6 to 40 in.)
Sensor width:	7.6 to 20 cm (3 to 8 in.)