Designation: C 1199 – 00

Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods[1]

1. Scope

1.1 This test method covers requirements and guidelines and specifies calibration procedures required for the measurement of the steady-state thermal transmittance of fenestration systems installed vertically in the test chamber. This test method specifies the necessary measurements to be made using measurement systems conforming to either Test Methods C 236, C 976, or C 1363 for determination of fenestration system thermal transmittance.

NOTE 1—This test method allows the testing of projecting fenestration products (that is, garden windows, skylights, and roof windows) installed vertically in a surround panel. Current research on skylights, roof windows, and projecting products hopefully will provide additional information that can be added to the next version of this test method so that skylight and roof windows can be tested horizontally or at some angle typical of a sloping roof.

1.2 This test method refers to the thermal transmittance, U, and the corresponding thermal resistance, R, of a fenestration system installed vertically in the absence of solar and air leakage effects.

NOTE 2—The methods described in this document may also be adapted for use in determining the thermal transmittance of sections of building wall, and roof and floor assemblies containing thermal anomalies, which are smaller than the hot box metering area.

1.3 This test method describes how to determine a fenestration product's (also called test specimen) thermal transmittance, U_S, at well-defined environmental conditions. The thermal transmittance, which is sometimes called the air-to-air U-factor, is also a reported test result from Test Methods C 236, C 976, and C 1363. If only the thermal transmittance is reported using this test method, the test report must also include a detailed description of the environmental conditions in the thermal chamber during the test as outlined in 10.3.

1.4 For rating purposes, this test method also describes how to calculate a standardized thermal transmittance, U_{ST}, which can be used to compare test results from laboratories with different weather side wind directions and thermal chamber configurations, and can also be used to directly compare to calculated results from current computer programs for determining the thermal transmittance of fenestration products. Although this test method specifies two methods of calculating the standardized thermal transmittance, only the standardized thermal transmittance result from one method is reported for each test. One standardized thermal transmittance calculation procedure is the Calibration Transfer Standard (CTS) method and another is the area weighting (AW) method (see 4.3 and Section 8 for further descriptions of these two methods). The area weighting method requires that the surface temperatures on both sides of the test specimen be directly measured as specified in Practice E 1423 in order to determine the surface heat transfer coefficients on the fenestration product during the test. The CTS method does not use the measured surface temperatures on the test specimen and instead utilizes the calculation of equivalent surface temperatures from calibration data to determine the test specimen surface heat transfer coefficients. The area weighting (AW) method shall be used whenever the thermal transmittance, U_S, is greater than 3.4 W/(m^2•K) {0.6 Btu/(hr•Ft ^{2}•°F)}, or when the ratio of test specimen projected surface area to wetted (that is, total heat transfer or developed) surface area on either side of the test specimen is less than 0.80. Otherwise the CTS method shall be used to standardize the thermal transmittance results.

1.5 A discussion of the terminology and underlying assumptions for measuring the thermal transmittance are included.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

1.7 *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:*

C 168 Terminology Relating to Thermal Insulating Materials[2]

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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] *Annual Book of ASTM Standards*, Vol 04.06.

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus[2]
C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[2]
C 518 Test Method for Steady-State Thermal Heat Flux Measurements and Transmission Properties by Means of the Heat Flow Meter Apparatus[2]
C 976 Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box[2]
C 1045 Practice for Calculated Thermal Transmission Properties from Steady-State Heat Flux Measurements[2]
C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[2]
C 1363 Test Method for Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus[2]
E 283 Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors[3]
E 631 Terminology of Building Constructions[3]
E 783 Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors[3]
E 1423 Practice for Determining the Steady-State Thermal Transmittance of Fenestration Systems[3]

2.2 *ISO Standards:*

ISO 8990 Thermal Insulation-Determination of Steady-State Thermal Transmission Properties—Calibrated and Guarded Hot Box[4]
ISO12567–1:2000 Thermal Insulation—Determination of Thermal Resistance of Components—Hot Box Method for Windows and Doors[4]

2.3 *Other Standards:*

NFRC 100-97 Procedure for Determining Fenestration Product Thermal U-factors[5]
BS874 Part 3, Section 3.1, 1987, British Standard Methods for Determining Thermal Insulation Properties, (Part 3, Tests for Thermal Transmittance and Conductance, Section 3.1) Guarded Hot Box Method[6]
BS874 Part 3, Section 3.2, 1990, British Standard Methods for Determining Thermal Insulation Properties, Part 3, Tests for Thermal Transmittance and Conductance, Section 3.2 Calibrated Hot Box Method[6]
ASHRAE Fundamentals Handbook, 1997[7]

3. Terminology

3.1 *Definitions*— Definitions and terms are in accordance with definitions in Terminologies E 631 and C 168, from which the following have been selected and modified to apply to fenestration systems. See Fig. 1 for temperature locations.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration transfer standard, n*— an insulation board that is faced with glazing, and instrumented with temperature sensors between the glazing and the insulation board core, which is used to calibrate the surface resistances and the surround panel (see Annex A1 for design guidelines for calibration transfer standards).

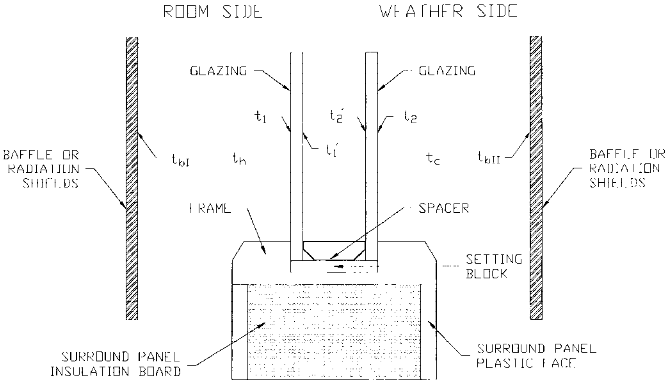

FIG. 1 Schematic Representation of Various Temperatures for Fenestration Systems

3.2.2 *overall thermal resistance, R_S, n*—the temperature difference between the environments on the two sides of a body or assembly when a unit heat flow per unit area is established through the body or assembly under steady-state conditions. It is defined as follows:

$$R_S = 1/U_S \tag{1}$$

3.2.3 *standardized thermal transmittance, U_{ST}, n*—the heat transmission in unit time through unit area of a test specimen and standardized boundary air films, induced by unit temperature difference between the environments on each side. It is calculated using the CTS method as follows:

$$1/U_{ST[CTS]} = 1/U_S + (1/h_{STh} - 1/h_h) + (1/h_{STc} - 1/h_c) \tag{2}$$

and using the area weighting (AW) method:

$$1/U_{ST[AW]} = 1/U_S + (A_S/A_h)(1/h_{STh} - 1/h_h) + (A_S/A_c)(1/h_{STc} - 1/h_c) \tag{3}$$

where h_{STh} and h_{STc} are the standardized surface heat transfer coefficients on the room side and weather side, respectively. Their numerical values are specified in 8.2.9.1.

3.2.3.1 *Discussion*—The calculation of the standardized thermal transmittance, U_{ST}, assumes that only the surface heat transfer coefficients change from the calibrated standardized values for the conditions of the test. This assumption may not be valid if the surface temperature differentials for the standardized calibration conditions are different from the surface temperature differential that existed for the fenestration product during the test procedure. Therefore, the standardized thermal transmittance should only be considered as an approximation for use in comparing with calculated thermal transmittance values with standardized surface heat transfer coefficients.

3.2.4 *surface resistance, n*—the temperature difference between an isothermal surface and its surroundings when a unit heat flow per unit area is established between the surface and the surroundings under steady-state conditions by the combined effects of convection and radiation. Subscripts *h* and *c* are used to differentiate between room side and weather side surface resistances, respectively. Surface resistances are calculated as follows:

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[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] Available from American National Standards Institute, 11 West 42 nd St., 13th Floor, New York, NY 10036.

[5] Available from National Fenestration Rating Council, 1300 Spring Street, Suite 120, Silver Spring, MD 20910.

[6] Available from British Standards Institution, British Standards House, 2 Park Street, London W1A 2BS, England.

[7] Available from ASHRAE, 1791 Tullie Circle, N.E., Atlanta, GA 30329.

$$r_h = 1/h_h \tag{4}$$

$$r_c = 1/h_c \tag{5}$$

3.2.5 *surface heat transfer coefficient, h, n*—the time rate of heat flow from a unit area of a surface to its surroundings, induced by a unit temperature difference between the surface and the environment. (This is sometimes called *surface conductance* or *film coefficient*.)

3.2.5.1 *Discussion*—Subscripts are used to differentiate between room side (1 or h) and weather side (2 or c) surface conditions (see Fig. 1). It should be recognized that due to radiation effects, the room side or weather side temperature (t_h and t_c, respectively), may differ from the respective room side or weather side baffle temperatures (t_{b1} and t_{b2}, respectively). If there is a difference of more than ±1 °C (±2.0 °F), either on the room side or weather side, the radiation effects shall be accounted for to maintain accuracy in the calculated surface heat transfer coefficients. The areas used to calculate the surface heat transfer coefficients (Eq 6 and 8) are different depending on which method of standardization is used. When the CTS Method is used to standardize the thermal transmittance, the projected area, A_S, is used to calculate the surface heat transfer coefficients, whereas when using the area weighting method, the actual "wetted or heat transfer" surface area, A_h or A_c, is used to determine the surface heat transfer coefficients.

The room side and weather side surface heat transfer coefficients are calculated as follows:

when:

$$t_h = t_{b1}\ (\pm 1\ °C), \tag{6}$$

$$h_h = Q_S/[(A_{S\ or\ h})(t_h - t_1)]$$

when:

$$t_h \neq t_{b1}\ (\pm 1°\ C), \tag{7}$$

$$h_h = (q_{r1} + q_{c1})/(t_h - t_1)$$

when:

$$t_c = t_{b2}\ (\pm 1\ °C),$$

$$h_c = Q_S/[(A_{S\ or\ c})\ (t_2 - t_c)]$$

when:

$$t_c \neq t_{b2}\ (\pm\ 1°C), \tag{8}$$

$$h_c = (q_{r2} + q_{c2})/(t_2 - t_c) \tag{9}$$

3.2.5.2 *Discussion*—When testing inhomogeneous test specimens, the test specimen surface temperatures and surface heat transfer coefficients will not be exactly the same as those obtained using the calibration transfer standard. As a consequence, the surface heat transfer coefficients obtained using the calibration transfer standard cannot be unambiguously defined and hence a test specimen conductance cannot be defined and measured. For inhomogeneous test specimens, only the thermal transmittance, U_S, can be defined and measured. It is therefore essential to calibrate with surface heat transfer coefficients on the Calibration Transfer Standard (CTS) which are as close as possible to the conventionally accepted values for building design. Likewise, it would be desirable to have a surround panel that closely duplicates the actual wall where the fenestration system would be installed. However, due to the wide variety of fenestration opening designs and constructions, this is not feasible. Furthermore, for high resistance fenestration systems installed in fenestration opening designs and constructions that are thermal bridges, the large relative amount of heat transfer through the thermal bridge will cause the relatively small amount of heat transfer through the fenestration system to have a larger than desirable error. As a result of the points stated above, the calculation of a specimen thermal conductance or resistance (surface to surface) from a measured thermal transmittance and the calculated surface heat transfer coefficients is not part of the basic measurement procedure. However, by using the CTS method or the area weighting (AW) method described in Section 8 it is possible to obtain a standardized thermal transmittance, U_{ST}, which is a rather useful tool for the evaluation and comparison of experimental results for fenestration systems with computer calculations of the thermal transmittance.

3.2.6 *surround panel (*sometimes called the *mask, mask wall,* or *homogeneous wall), n*—a homogeneous panel with an opening where the test specimen is installed (see 5.1.2 for a description of a surround panel.)

3.2.7 *test specimen, n*—the fenestration system or product being tested.

3.2.8 *test specimen thermal transmittance, U_S* (sometimes called the overall coefficient of heat transfer or air-to-air U-factor), *n*— the heat transfer in unit time through unit area of a test specimen and its boundary air films, induced by unit temperature difference between the environments on each side. It is determined as follows:

$$U_S = Q_S/[A_S \bullet (t_h - t_c)] \tag{10}$$

3.3 *Symbols*—The symbols, terms, and units used in this test method are as follows:

A_h = total heat transfer (or developed) surface area of test specimen on room side, m^2,
A_c = total heat transfer (or developed) surface area of test specimen on weather side, m^2,
A_{b1} = area of room side baffle and all other surfaces in view of the test specimen, m^2,
A_{b2} = area of weather side baffle and all other surfaces in view of the test specimen, m^2,
A_S = projected area of test specimen (same as open area in surround panel), m^2,
A_{sp} = projected area of surround panel (does not include open area in surround panel), m^2,
α = absorbtance of surface,
C_g = thermal conductance of glass or acceptable transparent plastic facing on calibration transfer standard, W/(m^2•K),

C_{sp} = thermal conductance of surround panel (surface to surface), W/(m^2•K), determined by means of Test Method C 177 and Practice C 1045, Test Method C 518 and Practice C 1045, or Test Method C 1114 and Practice C 1045,
C_{ts} = thermal conductance of calibration transfer standard, W/(m^2•K), determined by means of Test Method C 177 and Practice C 1045, Test Method C 518 and Practice C 1045, or Test Method C 1114 and Practice C 1045,
ϵ = total hemispherical emittance of surface,
F_{1b} = room side radiative factor as defined after Eq 20,
F_{2b} = weather side radiative factor as defined after Eq 25,
h_{STh} = standardized surface heat transfer coefficient, room side, (W/m^2•K),
h_{STc} = standardized surface heat transfer coefficient, weather side, (W/m^2•K),
h_h = surface heat transfer coefficient, room side, W/(m^2•K),
h_c = surface heat transfer coefficient, weather side, W/(m^2•K),
K_c = convection coefficient, W/(m^2•K$^{1.25}$),
L = length of heat flow path, m,
Q = time rate of heat flow through the total surround panel/test specimen system, W,
Q_c = time rate of convective heat flow from test specimen surface, W,
Q_{fl} = time rate of flanking loss heat flow around surround panel, W,
Q_r = time rate of net radiative heat flow from test specimen surface to the surroundings, W,
Q_S = time rate of heat flow through the test specimen, W,
Q_{sp} = rime rate of heat flow through the surround panel as determined from measured conductance C_{ts} and area weighted surround panel surface temperatures, W,
q = heat flux (time rate of heat flow through unit area), W/m^2,
q_S = heat flux through the test specimen, W/m^2,
q_{r1} = net radiative heat flux to the room side of the test specimen, W/m^2,
q_{r2} = net radiative heat flux from the weather side of the test specimen, W/m^2,
q_{c1} = convective heat flux to the room side of the test specimen, W/m^2,
q_{c2} = convective heat flux from the weather side of the test specimen, W/m^2,
ρ = reflectance of surface,
r_h = surface resistance, room side, m^2•K/W,
r_c = surface resistance, weather side, m^2•K/W,
R_S = overall thermal resistance of test specimen (air to air under test conditions), m^2•K/W,
t_{b1} = equivalent radiative baffle surface temperature, room side, K or °C,
t_{b2} = equivalent radiative baffle surface temperature, weather side, K or °C,
t_h = average temperature of room side air, °C,
t_c = average temperature of weather side air, °C,
t_1 = average area weighted temperature of test specimen room side surface, K or °C,
t_2 = average area weighted temperature of test specimen weather side surface, K or °C,
$t_{1'}$ = average area weighted temperature of room side glass/core interface of calibration transfer standard, K or °C,
$t_{2'}$ = average area weighted temperature of weather side glass/core interface of calibration transfer standard, K or °C,
U_S = thermal transmittance of test specimen (air to air under test conditions), W/(m^2•K),
U_{ST} = standardized thermal transmittance of test specimen, W/(m^2•K),
$U_{ST[AW]}$ = standardized thermal transmittance of test specimen determined using measured area weighted [AW] surface temperatures (air to air), W/(m^2•K), and
$U_{ST[CTS]}$ = standardized thermal transmittance of test specimen determined using calibration transfer standard [CTS] surface heat transfer coefficients (air to air), W/(m^2•K).

4. Significance and Use

4.1 This test method details the calibration and testing procedures and necessary additional temperature instrumentation required in applying Test Methods C 236, C 976, or C 1363 to measure the thermal transmittance of fenestration systems mounted vertically in the thermal chamber.

4.2 Since both temperature and surface heat transfer coefficient conditions affect results, use of recommended conditions will assist in reducing confusion caused by comparing results of tests performed under dissimilar conditions. Standardized test conditions for determining the thermal transmittance of fenestration systems are specified in Practice E 1423 and Section 5.3. However, this procedure can be used with other conditions for research purposes or product development.

4.3 It should be recognized that the only true experimental measurement is the thermal transmittance, U_S, value determined in Section 7. The "standardized" thermal transmittance value, U_{ST}, obtained by either the Calibration Transfer Standard (CTS) or area weighting (AW) methods described in Section 8 include adjustments to the U_S value that are made because the current computer calculation methods (NFRC 100-97) for determining the thermal transmittance are not capable of applying the actual surface heat transfer coefficients that exist on the test specimen while testing at standardized conditions. The current computer calculation methods assume that uniform standardized surface heat transfer coefficients exist on the indoor and outdoor fenestration product surfaces, which is not the case. Until such a time that the computer calculation methods are upgraded to have the actual surface heat transfer coefficients applied to the actual fenestration product geometry, the modification of the true tested thermal transmittance value, U_S, to a standardized value U_{ST}, is necessary for rating and comparison (measured with calculated) purposes.

4.3.1 It should be noted that the standardized surface heat transfer coefficients, h_h and h_s, as calibrated prior to testing a fenestration product using an appropriately sized Calibration Transfer Standard (CTS) may differ from the surface heat transfer coefficients that exist during a hot box test on a specific test specimen. Fenestration systems usually have frame and sash surfaces that introduce two- and three-dimensional convective heat transfer effects which result in variable surface heat transfer coefficients, which differ from the standardized values. As a result of this, the test specimen surface heat transfer coefficients will differ from those obtained with the non-framed, essentially flat Calibration Transfer Standard tested under the same conditions. In this standardizing procedure, it is assumed that the differences are small enough so that the calibration surface heat transfer coefficients can be used to calculate equivalent test specimen average surfaces temperatures, t_1 and t_2, in order to estimate the actual test specimen surface heat transfer coefficients. It should be recognized that this assumption will not be accurate for all fenestration products, especially for high thermal transmittance products where the surface heat transfer coefficients are a major portion of the overall thermal resistance and also for fenestration products with significant surface projections (for example, skylights, roof windows, garden windows) where the surface heat transfer coefficients are quite different from the standardized values.

4.3.2 In these situations, an attempt should be made to measure the test specimen surface temperature distributions and then calculate directly the test specimen average area weighted surfaces temperatures, t_1 and t_2. This area weighting (AW) method also has problems in that the placement of temperature sensors to get an accurate area weighting is not known, especially on high conductivity horizontal surfaces that act as heat transfer extended surfaces (that is, fins). In addition, the placement of many temperature sensors on the test specimen surfaces will affect the velocity fields in the vicinity of these surfaces which will affect the surface temperatures and surface heat transfer coefficients.

4.3.3 Guidelines for determining which standardizing procedure to follow are given in 8.2.

4.4 The thermal transmittance of a test specimen is affected by its size and three-dimensional geometry. Care must be exercised when extrapolating to product sizes smaller or larger than the test specimen. Therefore, it is recommended that fenestration systems be tested at the recommended sizes specified in Practice E 1423 or NFRC 100-97.

NOTE 3—This test method does not include procedures to determine the heat flow due to either air movement through the specimen or solar radiation effects. As a consequence, the thermal transmittance results obtained do not reflect performances that may be expected from field installations due to not accounting for solar radiation, air leakage effects, and the thermal bridge effects that may occur due to the specific design and construction of the fenestration system opening. Since there is such a wide variety of fenestration system openings in North American residential, commercial and industrial buildings, it is not feasible to select a typical surround panel construction for installing the fenestration system test specimen. This situation allows the selection of a relatively high thermal resistance surround panel which places the focus of the test on the fenestration system thermal performance alone. Therefore, it should be recognized that the thermal transmittance results obtained from this test method are for ideal laboratory conditions in a highly insulative surround panel, and should only be used for fenestration product comparisons and as input to thermal performance analyses which also include solar, air leakage, and thermal ridge effects due to the surrounding building structure. To determine air leakage for windows and doors, refer to Test Methods E 283 and E 783.

5. Calibration

5.1 *General*:

5.1.1 *Calibration requirements*—A minimum of two calibration test procedures shall be performed to determine the surround panel flanking loss and to characterize the surface heat transfer coefficients on a Calibration Transfer Standard before testing actual fenestration products. The first calibration test requires that a continuous surround panel (with the test specimen aperture filled with the same material as the rest of the surround panel) be tested at standard test conditions in order to determine the surround panel flanking heat transfer and the metering box wall heat transfer. In the second set of calibration tests, a Calibration Transfer Standard with its weather side face located 25 mm in from the weather side edge of the surround panel opening shall be mounted in the surround panel and tested at standardized conditions. The fans in the thermal chamber may have to be adjusted so that the surface heat transfer coefficients measured on both sides of the Calibration Transfer Standard are within a set tolerance of the standardized surface heat transfer coefficients (see 5.3).

5.1.2 *Surround Panel*— As explained in Notes 2 and 4, there may be a strong interaction between the heat flow in an actual surrounding wall and the frame of the fenestration system. If the surrounding wall construction contains highly conductive materials, the heat flow through the fenestration system frame could be significantly changed. Since it is not feasible to select a typical wall to use as a surround panel, it is desirable to have a relatively high-resistance surround panel to minimize this "shorting" interaction so that the heat flow through the fenestration system itself can be measured as accurately as possible. This is especially true for the highly resistive " superwindows" currently being developed.

5.1.2.1 A surround panel, consisting of a stable homogeneous thermal insulation material with a thermal conductivity at 24 °C not in excess of 0.04 W/(m•K) and having a very low gas permeance, shall be provided for mounting the test specimen (see Fig. 2). For structural integrity, the homogeneous insulation core may be sandwiched between two sheets of a support material having a very low gas (air and water vapor) permeance and stable thermal and dimensional properties. The opening in the central homogeneous insulation board core may be covered with a nonreflecting tape to minimize surface damage. The thickness of the homogeneous insulation core of the surround panel (see Fig. 2) shall be at least the maximum thickness of the test specimen (usually one part of the test specimen frame) and shall be in no circumstances less than 100 mm. The maximum thickness of the homogeneous insulation core of the surround panel should be no more than 25 mm greater than the maximum thickness of the test specimen. That is, for test specimen maximum thicknesses less than or equal to 100 mm, the surround panel core thickness should be 100 mm. For test specimen maximum thicknesses greater than 100 mm and up to 125 mm, the surround panel

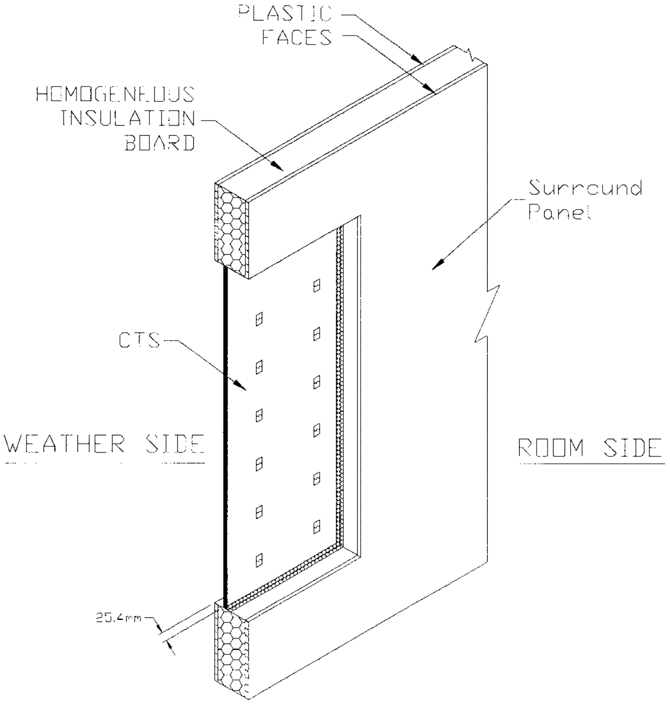

FIG. 2 Surround Panel With CTS

core thickness should be 125 mm. For test specimen maximum thicknesses greater than 125 mm and up to 150 mm, the surround panel core thickness should be 150 mm and so on for larger test specimens. Unless specifically required for test specimen mounting purposes (very high mass test specimens like patio doors or large curtain walls), no thermal anomalies (that is, thermal bridges like wood or metal) shall exist in the surround panel. In those specific situations where the surround panel is not homogeneous, a detailed drawing describing the surround panel and the thermal anomaly materials and the modified surround panel construction, along with the measured thermal conductances (using Test Methods C 177 or C 518) of all materials used shall be included with the test report. It is required that the thermal conductance (C_{sp} surface to surface including facing and core materials) of a sample of the surround panel be measured in a guarded hot place (Test Method C 177) or a heat flow meter (Test Method C 518) at a minimum of three temperatures over the range of conditions at which the surround panel will be used.

5.1.2.2 For added confidence in establishing the heat flow through the actual surround panel used in a test, it is required that it be installed in the hot box where the test specimen mounting hole(s) are completely filled with the same thickness materials (core and facers) used in constructing the homogeneous surround panel, and Test Methods C 236, C 976, or C 1363 tests at the temperature conditions above be made to determine the time rate of heat flow through a complete [without mounting hole(s)] or homogeneous surround panel. The surround panel time rate of flanking loss heat flow (Q_{FL}) should then be determined by subtracting the calculated one-dimensional surround panel time rate of heat flow [calculated by multiplying the measured surround panel thermal conductance (C_{sp}) times the total homogeneous surround panel projected surface area times the average area weighted surface temperature difference across the surround panel] from the measured time rate of heat flow through the homogeneous surround panel (see 5.2.1 and Test Method C 1363).

NOTE 4—A recommended surround panel core material is expanded polystyrene (beadboard) having a density in excess of 20 kg/m^3 which has been aged unfaced in the laboratory for a minimum of 90 days. Suitable facing materials are approximately 3 to 4 mm thick heat-resistant rigid ABS (a plastic material containing acrylonitrile, butadiene, and styrene) thermoplastic sheets with smooth or matte finish faces or similar thickness Hi-Impact Polystyrene plastic sheets (like the material used on the inside of refrigerators). The surround panel may have to have some horizontal and vertical saw cuts made in the cold side facing material to minimize the effects of differential thermal expansion between the cold and hot side faces. The thin cuts should be covered with similar emittance tape strips to provide a smooth surface to the weather and room side air flows.

5.1.3 *Calibration transfer standard*—The test facility surface heat transfer coefficients shall be calibrated using a heat flux transducer Calibration Transfer Standard constructed as described in Annex A1 and illustrated in Fig. 3a and 3b. The Calibration Transfer Standard has a core material of known characteristics traceable to primary standards such as the guarded hot plate of a national standard laboratory. The projected area of the Calibration Transfer Standard should cover the same range as the test specimen model size and tolerances as specified in Practice E 1423 or NFRC 100-97. See 5.3 for the values of the standardized surface heat transfer coefficients required for using this test method for rating purposes.

NOTE 5—It is recommended that a minimum of three Calibration Transfer Standards be used that cover the range of test specimen model sizes that a laboratory plans to test. A minimum of three Calibration Transfer Standards should be used: one approximately the smallest model size to be tested, one approximately the average model size to be tested, and one approximately the largest model size to be tested.

5.1.4 *Temperature measurements*—In addition to the air and surface area weighted temperature measurements specified in Test Methods C 236, C 976, or C 1363, the following temperature measurements are required:

5.1.4.1 *Radiating surface temperatures*—The temperature of all surfaces (baffles, surround panel opening, box surfaces, shields, etc) exchanging radiation heat transfer with the test specimen using the same area weighing criteria as specified in Test Methods C 236, C 976, or C 1363.

5.1.4.2 *Air temperatures*— The room side and weather side air stream temperatures in a horizontal plane parrallel to the surround panel surfaces shall be measured as specified in Section 6.10.3.1 of Test Method C 1363. As a minimum requirement, these should be the mean of measurements at three equidistant locations on the centerline of each glazing or test specimen surface. However, it is strongly recommended that at least nine air temperature sensors in a 3 x 3 array be used.

NOTE 6—The temperature sensor requirements given in 5.1.4, 5.1.4.1, and 5.1.4.2 are minimum requirements. Section 6.5.2 on temperature measurements requires additional temperature sensors which are dependent on the test specimen type. More temperature sensors may be used if they provide more accurate average temperature (air and surface) values.

5.1.5 *Air leakage*— For sealing procedures, see Practice E 1423.

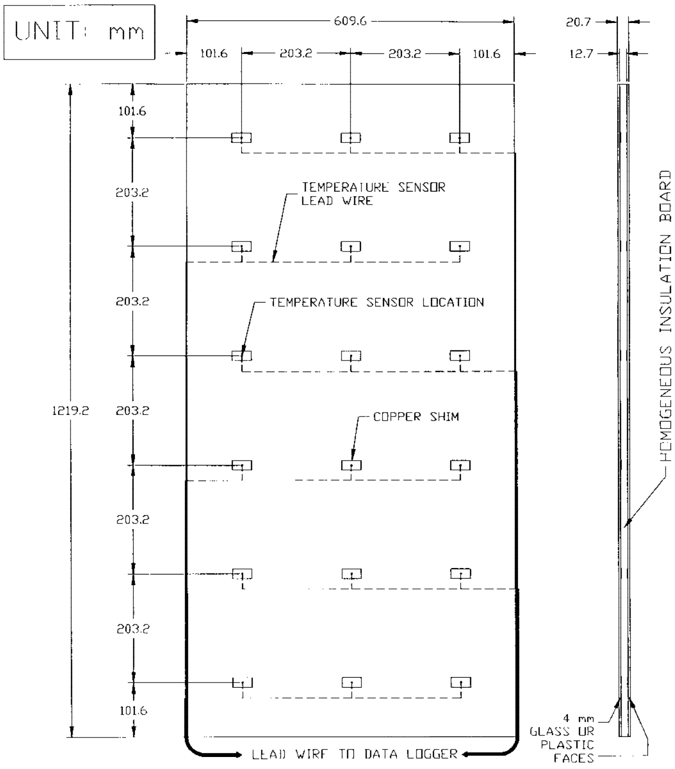

FIG. 3 (a) Example Calibration Transfer Standard Design Information

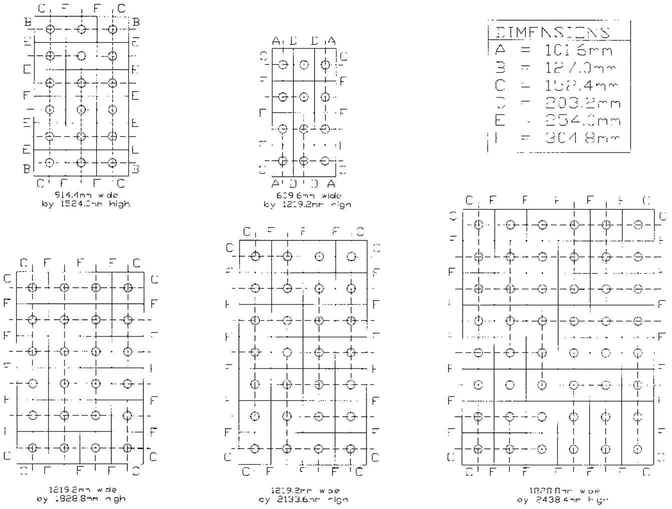

FIG. 3 (b) Minimum Temperature Sensors Array for Typical CTS

5.2 *Calibration Tests*:

5.2.1 *Flanking Loss Test Procedure*:

5.2.1.1 Install a continuous surround panel (one without the test specimen aperture cut in it) in the thermal chamber and attach temperature sensors to both sides at the density described in Test Methods C 236, C 976, or C 1363. Seal the surround panel as per section of 7.14 of Test method C 1363. The heat flow through the continuous surround panel as determined by its area, the surface temperature difference on both sides of the surround panel, and the thermal conductivity of the surround panel's materials (as determined by Test Methods C 177, C 518, or C 1114) is compared to the metered heat flow that is input into the metering chamber (after it is corrected for the heat flow through the metering chamber walls determined as per Annex A1 and Annex A2 of Test Method C 1363) to determine the surround panel flanking loss. A separate surround panel flanking loss shall be determined for each combination of materials and thicknesses of surround panels used for testing;as per Annex A3 of Test Method C 1363.

NOTE 7—It is convenient to measure the time constant of the thermal chamber and the surround panel at this time. The time constant is used to determine when a particular test has achieved steady-state conditions, and is determined using the process described in Section A5 of Test Method C 1363. A continuous surround panel (i.e., with the test specimen aperture filled with surround panel material) can be used as a conservative estimate of the time constant of most window test specimens, which have a thermal capacity and diffusivity less than an equivalent sized surround panel material. Therefore it is useful to determine the time constant of a thermal chamber and surround panel at the same time that the flanking loss is determined.

5.2.1.2 Establish, as per Test Methods C 236, C 976, or C 1363, steady-state temperature conditions for which the surround panel is to be calibrated, and record measurements of power, temperatures, and velocity.

5.2.2 *Flanking Loss Data Analysis*:

5.2.2.1 Surround panel flanking loss, Q_{FL}, is determined by performing a Test Methods C 236, C 976, or C 1363 test on a continuous surround panel (with the test specimen mounting hole completely filled with the same thickness materials used in constructing the homogeneous surround panel) at the temperature ranges expected during a test. The following equation is used to determine the surround panel flanking loss:

$$Q_{FL} = Q - Q_{sp} \tag{11}$$

where:

Q = power delivered to the metering chamber by the heaters, fans, etc., which is corrected for the heat flow through the metering box walls, W,
Q_{sp} = $C_{sp} \cdot A_{sp} \cdot (t_{sp1} - t_{sp2})$, W,
C_{sp} = conductance of surround panel, W/(m^2 • K),
A_{sp} = area of surround panel, m^2,
t_{sp1} = area weighted average room side surround panel surface temperature, °C, and
t_{sp2} = area weighted average weather side surround panel surface temperature, °C.

5.2.3 *Calibration Transfer Standard Test Procedure*:

5.2.3.1 Install the Calibration Transfer Standard with the weather side surface 25 mm (1 in.) in from the surround panel weather side surface (see Fig. 2). Seal the cracks around the perimeter of the Calibration Transfer Standard with nonmetallic tape or caulking, or both, to prevent air leakage. Each of the surface temperature thermocouples in the Calibration Transfer Standard should be individually measured, but if the thermocouples are to be electrically averaged, the thermocouple leads within an averaged group must be the same length and each averaged group must be confined to individual horizontal rows.

5.2.3.2 Establish, as per Test Method C 1363 steady-state thermal conditions for which the surround panel and Calibration Transfer Standard are to be calibrated and record measurements of power, temperature, and velocity.

5.2.4 *Calibration Transfer Standard Data Analysis*:

5.2.4.1 *Total heat flow*— The time rate of heat flow through the test assembly (surround panel and Calibration Transfer Standard), Q, is determined by the procedures specified in Test Methods C 236, C 976, or C 1363.

5.2.4.2 Calibration Transfer Standard Heat Flow, Q_s, is calculated as follows:

$$Q_S = C_{ts} \bullet A_S \ (t_{1'} - t_{2'}) \quad (12)$$

where:

C_{ts} = conductance of Calibration Transfer Standard core, W/(m^2 • K), as determined by either Test Methods C 177, C 518, or C 1114 and Practice C 1045,

A_S = area of Calibration Transfer Standard, m^2,

$t_{1'}$ = average equal area weighted temperature of room side glass/core interface of calibration standard, °C (see Fig. 1), and

$t_{2'}$ = average equal area weighted temperature of weather side glass/core interface of calibration standard, °C (see Fig. 1).

5.2.4.3 Surround panel heat flow, Q_{sp}, is then:

$$Q_{sp} = C_{sp} \bullet A_{sp} \bullet (t_{sp1} - t_{sp2}) \quad (13)$$

where:

A_{sp} = surround panel area, m^2,

$t_{sp\,1}$ = area weighted room side surround panel surface temperature, °C, and

t_{sp2} = area weighted weather side surround panel surface temperature, °C.

NOTE 8—If a mean temperature correction for the surround panel is required, conduct calibration tests at three different mean temperature conditions as required in 5.1.2.

5.2.4.4 If $t_{b1} = t_h \pm 1°C$ (±2°F) and $t_{b2} = t_c \pm 1°C$ (±2°F) see 5.2.4.6 to determine the surface heat transfer coefficients. If calculated values of the surface temperatures are to be used in the calculation procedure specified in Section 8, Calculation of Standardized Thermal Transmittance, then the calculation procedures specified in 5.2.2.5 also should be carried out to determine the convection coefficient, K_c.

5.2.4.5 If $t_{b1} > t_h$ +1°C (2°F) or $t_{b1} < t_h$ –1°C (2°F) and $t_{b2} > t_c$ +1°C (2°F) or $t_{b2} < t_c$ –1°C (2°F), after calculating t_1 and t_2 from Eq 17 and 18, respectively, see 5.2.4.7 to determine the surface heat transfer coefficients.

5.2.4.6 Surface heat transfer coefficients, h_h and h_c, when $t_{b1} = t_h \pm 1°C$ (±2°F) and $t_{b2} = t_c \pm 1°C$ (±2°F), are calculated as follows:

$$h_h = [Q_S/A_S(t_h - t_1] \quad (14)$$

where:

t_h = average room side air temperature, °C, and

t_1 = equal area weighted average room side Calibration Transfer Standard surface temperature, °C, which is calculated from the following:

$$t_1 = t_{1'} + C_{ts} \bullet (t_{1'} - t_{2'})/C_g \quad (15)$$

where:

C_g = conductance of facing on calibration transfer standard, W/(m^2•K).

NOTE 9—The conductance of the glazing layer is the thermal conductivity of the glazing material divided by the glazing layer thickness. A value of 1 W/(m•K) for the thermal conductivity of float glass is recommended if the actual value is not provided by the manufacturer. In other cases, such as laminated or plastic glazing, the glazing manufacturer should provide the measured thermal conductivity of the glazing material.

$$h_c = Q_s/(A_S \bullet (t_2 - t_c)) \quad (16)$$

where:

t_c = average weather side air temperature, °C, and

t_2 = equal area weighted average weather side calibration transfer standard surface temperature, °C, which is calculated from the following:

$$t_2 = t_{2'} - C_{ts} \bullet (t_{1'} - t_{2'})/C_g \quad (17)$$

5.2.4.7 Surface heat transfer coefficients, h_h and h_c when $t_{b1} > t_h$ +1°C (2°F) or $t_{b1} < t_h$ –1°C (2°F) and $t_{b2} > t_c$ +1°C (2°F) or $t_{b2} < t_c$ –1°C (2°F), are calculated as follows:

5.2.4.7(*1*) Room side radiative heat transfer, Q_{r1}—When the room side baffle or box wall is close to the test specimen, parallel plate radiative heat transfer can be assumed. Then:

$$q_{r1} = Q_{r1}/A_S = F_{1b} \bullet \sigma \bullet [(t_{b1}+273.16)^4 - (t_1+273.16)^4) \quad (18)$$

where:

F_{1b} = 1.0/[1/ϵ_1 + 1/ϵ_{b1}) – 1], assuming a view factor of 1.0 between infinite parallel plates,

ϵ_1 = emittance of glass Calibration Transfer Standard facing sheet (glass or plastic),

ϵ_{b1} = radiant average emittance of the baffle/shield/surround panel opening/box wall and all other surfaces in view of the test specimen,

t_{b1} = area weighted radiant average baffle/shield/box wall/surround panel opening surface temperature in view of the test specimen, °C, and

σ = Stefan-Boltzmann constant = 5.67×10^{-8}, W/(m^2•K^4).

NOTE 10—If the view factor between the test specimen surface and the baffle/shield/box wall/surround panel opening surfaces is not equal to 1.0 or if the baffle/shield/box wall/surround panel opening is not isothermal to within ±1°C (±2°F) then the radiative heat transfer calculation procedure in Annex A2 is required. Isothermal to within ±1°C (±2°F) is determined by comparing each of the individual baffle/shield/box wall/surround panel temperature measurements to the mean of all the baffle/shield/box wall/surround panel opening temperature measurements. If any of the individual baffle/shield/box wall/surround panel opening temperature measurements differ from the mean by more than ±1°C (±2°F), then the radiative heat transfer calculation procedure in Annex A2 is required. Hot box operators should recognize that the radiative calculation procedure in Annex A2 adds to the complexity of the tests being conducted. For many hot boxes, additional baffle/shield/box wall/surround panel opening and other surrounding surfaces have to have their temperatures accurately measured and recorded, and the more complex radiative heat transfer analysis specified in Annex A2 may have to be added to the data analysis. To circumvent this, hot box operators should make the necessary modifications to their facilities so that the surrounding baffle/shield/box wall/surround panel opening temperatures are isothermal to within ±1°C (±2°F) and the mean baffle/shield/box wall/surround panel opening temperature is within ±1°C (±2°F) of the respective air temperature. A simple solution for many hot box designs would be to add a large, flat baffle that is parallel to the surround panel. If a large isothermal baffle is located close enough to the surround panel so that the test specimen (or calibration transfer standard) "sees" only the baffle and the surround panel opening surfaces, the experimental data analysis does not have to include the more complex radiative heat transfer calculation procedure specified in

Annex A2. This greatly simplifies the test procedure and the experimental data analysis.

5.2.4.7(*2*) Room side convective heat transfer, Q_c:

$$Q_{c1} = Q_S - Q_{r1} \qquad (19)$$

and:

$$q_{c1} = Q_{c1}/A_s \qquad (20)$$

Also, using Eq 20, the convection constant K_c in the following equation for the convective heat transfer to the test specimen can be determined.

$$K_c = q_{c1}/(t_h - t_1)^{1.25} \qquad (21)$$

NOTE 11—The convective heat transfer calculation assumes natural convection on the room side of the Calibration Transfer Standard. To ensure that a single convection coefficient, K_c, can be used for fenestration system tests, its behavior should be investigated, using the calibration transfer standard, over the range of heat flows expected. The hot box operator may use a convective correlation different from Eq 21 if it is more appropriate for the convective heat transfer situation that exists for that operator's hot box. However, the test report should include the alternative form of Eq 21 used and the alternative value of the convection constant K_c obtained.

5.2.4.7(*3*) Room side surface heat transfer coefficient, h_h—From Eq 18 and 20:

$$h_h = (q_{r1} + q_{c1})/(t_h - t_1) \qquad (22)$$

where t_1 is calculated in accordance with Eq 15.

5.2.4.7(*4*) Weather side radiative heat transfer, Q_{r2}—When the weather side baffle or box wall is close to the test specimen, parallel plate radiative heat transfer can be assumed. Then:

$$q_{r2} = Q_{r2}/A_S = F_{2b} \cdot \sigma \cdot [(t_2+273.16)^4 - (t_{b2}+273.16)^4] \qquad (23)$$

where:

F_{2b} = $1.0/[1/\epsilon_2 + 1/\epsilon_{b2} - 1]$, assuming a view factor of 1.0 between infinite parallel plates,

ϵ_2 = emittance of Calibration Transfer Standard facing sheet (glass or plastic),

ϵ_{b2} = radiant average emittance of the baffle/shield/surround panel opening/box wall and all other surfaces in view of the test specimen,

t_{b2} = area weighted radiant average baffle/shield/box wall/surround panel opening surface temperature in view of the test specimen, °C, and

σ = Stefan-Boltzmann constant = 5.67×10^{-8}, W/(m^2•K^4).

NOTE 12—If the view factor between the test specimen surface and the baffle/shield/surround panel opening/box wall surface is not equal to 1.0 or if the baffle/shield/surround panel opening/box wall is not isothermal to within ±1°C (±2°F), then the radiative heat transfer calculation procedure in Annex A2 is required. Isothermal to within ±1°C (±2°F) is determined by comparing each of the individual baffle/shield/surround panel opening/box wall temperature measurements to the mean of all the baffle/shield/surround panel opening/box wall temperature measurements. If any of the individual baffle/shield/surround panel opening/box wall temperature measurements differ from the mean by more than ±1°C (±2°F), then the radiative heat transfer calculation procedure in Annex A2 is required.

5.2.4.7(*5*) Weather side convective heat transfer, Q_{c2}:

$$Q_{c2} = Q_S - Q_{r2} \qquad (24)$$

and

$$q_{c2} = Q_{c2}/A_S \qquad (25)$$

5.2.4.7(*6*) Weather side surface heat transfer coefficient, h_c—From Eq 23 and 25:

$$h_c = (q_{r2} + q_{c2})/(t_c - t_2) \qquad (26)$$

where t_2 is calculated in accordance with Eq 17.

5.3 *Standardized Surface Heat Transfer Coefficients*:

5.3.1 *Thermal chamber velocity adjustments*—The results from the Calibration Transfer Standard tests are used for two purposes. The primary objective is to adjust the air velocities in the room and weather side of the thermal chamber so that they produce standardized surface heat transfer coefficients, within the tolerances specified below, on both sides of each Calibration Transfer Standard used. The second objective is to determine the convection coefficient, K_c, and the weather side surface heat transfer coefficient, h_c, for use in the CTS method of calculating the standardized thermal transmittance (see 8.2.1).

5.3.2 The impinging air flow (for perpendicular and parallel air flow directions) on the Calibration Transfer Standard should be as uniform as possible. After the calibration tests have been performed, the test laboratory shall compare the surface heat transfer coefficients measured on each Calibration Transfer Standard with the standardized heat transfer coefficients specified in 5.3.3 and 5.3.4. If the surface heat transfer coefficients measured on a Calibration Transfer Standard are outside of the tolerance specified in 5.3.3 and 5.3.4, then the laboratory shall adjust the fan speeds, plenums, or thermal chamber configuration to meet the specified tolerance before running tests on fenestration products. If the surface heat transfer coefficients generated on the Calibration Transfer Standard are not within the tolerances specified in 5.3.3 and 5.3.4, then the actual Calibration Transfer Standard surface heat transfer coefficients shall be clearly identified in the test report, and only the thermal transmittance, U_S, shall be reported. The standardized thermal transmittance shall not be reported unless the surface heat transfer coefficients generated on the Calibration Transfer Standard are within the tolerance specified in 5.3.3 and 5.3.4.

5.3.3 *Room side standardized surface heat transfer coefficient*—The standardized surface heat transfer coefficient measured on the room side of each Calibration Transfer Standard shall be:

$$h_{STh} = 7.7 \text{ W/(m}^2\text{•K)} \pm 5\,\%$$
$$\text{(Allowed CTS calibration range of 7.3 to 8.0 W/(m}^2\text{•K)).} \qquad (27)$$

Since 7.0 W/(m^2•K) is the natural convection lower limit of the indoor side overall surface heat transfer coefficient, a ±5 % variation is allowed to accommodate some forced convection due to small room side air circulation fans that provide a more uniform flow distribution on the indoor side of the CTS.

NOTE 13—Using the 1997 ASHRAE Fundamentals Handbook, Fenestration Chapter 29, Table 3, the indoor side of the overall combined natural convection, radiation surface heat transfer coefficient for a 1.22 m (4 ft) high, 12.7 mm (0.5 in.) wide cavity, double glazed, low emittance glazing unit is 6.98 W/(m^2•K). For a 1.22 m (4 ft) high, 12.7 mm (0.5 in.) thick high-density expanded polystyrene (EPS) foam core Calibration Transfer Standard (CTS) with two 4 mm glass faces, the indoor side calculated overall combined natural convection, radiation surface heat transfer coefficient is 7.02 W/(m^2•K) using the same methods and equations that were used to obtain the ASHRAE Chapter 29, Table 3 results. Rounding off these two results gives a nominal standardized surface heat transfer coefficient of 7 W/(m^2•K) (1.23 Btu/(hr•ft^2•°F)), which is the natural convection lower limit for this size CTS. The room side standardized surface heat transfer coefficient has been set slightly above this level to allow a small amount of forced convection.

5.3.4 *Weather side standardized heat transfer coefficient*—The standardized surface heat transfer coefficient measured on the weather side of each Calibration Transfer Standard shall be:

$$h_{STc} = 29\ \mathrm{W/(m^2 \bullet K)} \pm 10\ \% \quad \text{(Allowed CTS calibration range of 26 to 32 W/(m}^2\text{•K)).} \tag{28}$$

Again, referring to the 1997 ASHRAE Fundamentals Handbook, Fenestration Chapter 29, the recommended design value for the weather side overall combined forced convection, radiation surface heat transfer coefficient for a nominal 24 km/h (15 mile per hour) wind speed is h_c = 29 W/(m^2•K) (5.1 Btu/(hr•ft ^{2}•°F)).

NOTE 14—Since the ASHRAE value of 29 W/(m^2•K) comes from heat transfer experiments on a 0.3 m by 0.3 m (1 ft by 1 ft) flat plate, for a larger 1.22 m (4 ft) high CTS, the forced convection heat transfer coefficient will tend to be lower due to the continued growth of the boundary layer, thus reducing the weather side overall combined forced convection, radiation surface heat transfer coefficient. The degree of this reduction depends on a number of factors, including the flow conditioning before it reaches the surface of the CTS, the initial flow direction (parallel or perpendicular), the flow regimen along the CTS surface (completely laminar or turbulent over a portion of the CTS) and the depth that the CTS is recessed in the surround panel opening. Therefore, to account for this and to also allow lower nominal weather side wind speeds to be used to adjust the weather side overall combined forced convection, radiation surface heat transfer coefficient, a ±10 % variation in the weather side standardized value is allowed.

6. Experimental Procedure

6.1 Detailed written operating procedures for each test apparatus shall be developed and shall be available to ensure that the tests are conducted in accordance with the requirements of this test method.

6.2 *Installation of Fenestration System*:

6.2.1 The fenestration system to be tested should be installed in the surround panel with a configuration that simulates the actual installation as closely as possible. That is, the complete assembly including all frame elements should be in place during the test. The surround panel requirements specified in 5.1.2 and the sealing requirements specified in 5.1.5 (for the calibration transfer standard) also apply to the test specimen. See 7.2 of Practice E 1423 for further guidance on installation.

6.3 *Test Conditions*:

6.3.1 Wherever the temperatures and standard heat transfer coefficients are not otherwise specified, 5.3 and Practice F 1423 should be used as guides for selecting the appropriate test temperature conditions.

6.4 *Stabilization and Test Times*:

6.4.1 Establish, as per 10.9 of Test Method C 1363, steady-state temperature and power conditions for which the test specimen is to be tested and record measurements of power, temperatures, and velocity at the specified test intervals.

6.5 *Recorded Test Measurements*:

6.5.1 *Power measurements*—the total net heat transfer or average power transferred through the test specimen during a measurement interval. The energy balance to determine this should account for all metering box heating and cooling, power to fans or blowers, any significant power to transducers, corrections for the metering box wall heat transfer and surround panel and test frame flanking heat transfer, any other extraneous heat flows, and corrections for the energy flow (enthalpy difference times air leakage mass flow rate) associated with any air leakage entering and leaving the metering chamber.

6.5.2 *Temperature measurements*—all measurements specified in Test Methods C 236, C 976, or C 1363. The temperature sensors used should be special limit (premium) thermocouples (24 gage may be used; 30 gage or smaller are recommended for the test specimen surface temperatures), or appropriate size thermistors or RTD's (resistance temperature detectors).

6.5.2.1 Additional temperature measurements shall be made on the surround panel wall (see 6.5.2 of Test Method C 236, 5.7 of Test Method C 976, or 6.10.2 of Test Method C 1363, for the minimum number of area weighted surround panel temperature sensors to use).

6.5.2.2 For determining the thermal transmittance, U_S, and the standardized thermal transmittance, U_{ST}, it will be necessary to make additional temperature measurements on the fenestration test specimen frame, glazing (center and near edges) and on any other surfaces (sills, muntins, etc.) in order to provide a representative area weighted value of the surface temperatures of the specimen. It must be recognized that there is such a wide range of fenestration system designs that it is not possible to specify the locations of the temperature sensors to provide a correct area weighted determination of the various surface temperatures for all configurations. See Practice E 1423 for additional guidance on the location of test specimen surface temperature sensors for different fenestration systems. The weighted heat transfer surface areas used with the frame/sash temperature measurements shall add up to the total surface area of the frame/sash in contact with the surrounding air. Also, any area weighted surface temperatures determined in this manner shall be compared with the calculated equivalent room side and weather side surface temperatures specified in 8.2.1 and 8.2.2. If a discrepancy exists, it may be due to either the temperature calculation process or the placing of the area weighted temperature sensors. The technique of area weighted temperature measurements may be necessary (see 3.1) when the frame and glazing conductances are dissimilar or the surface geometry is complicated or projects out into the weather side chamber, or both. If this is the case, excessive use of temperature sensors may cause the measured surface heat transfer coefficients, h_h and h_c to differ from the actual heat transfer coefficients, introducing further uncertainty in the results. The temperature sensors used should be special limit (premium) thermocouples (24 gage (0.02010 in., 0.5106 mm), 30 gage (0.01003 in., 0.2546 mm) or smaller are recommended for the surface temperatures), thermistors or resistance temperature detectors (RTD's), and shall be placed so as to minimize the disturbance of the air flows on the surfaces of the test specimen.

6.5.2.3 Temperature measurements should also be made in the room side and weather side air streams in the same quantity and spacing as the surface temperature sensors (see 6.5.2 of Test Method C 236, 5.7 of Test Method C 976; and 6.10.3.1 of Test Method C 1363.). This will allow for a more accurate measurement of the room side and weather side surface heat transfer coefficients.

6.5.3 *Radiation effects*—To minimize the effect of radiation-induced error on the temperature sensors, the temperatures of all surfaces exchanging radiation heat transfer with the fenestration system (test specimen or calibration transfer standard) shall be measured. This includes: (1) room side and weather side shields and baffles, (2) air distribution system components, and (3) hot box walls and portions of the surround panel that are in view of the test specimen. Any heating and cooling devices must be shielded from the surround panel/fenestration system and the surface temperature of the shield should be measured. The temperature sensors must be applied to these surfaces with tape or adhesive that has an emissivity similar to that of the surface. The air temperature sensors should either be shielded or be as small as possible so that they are not significantly affected by surfaces with which they are exchanging radiation (see 6.5.2 of Test Method C 236; 5.7 of Test Method C 976; or 6.10.3.1 of Test Method C 1363).

6.5.4 *Wind speed measurements*—The weather side wind speed shall be measured at a location that represents the free stream condition. For both perpendicular and parallel flow patterns, it is required that this location be a distance out in the air stream such that the wind speed sensor is not in the test specimen surface boundary layers or wakes. A minimum distance of 75 mm (3 in.) out from the test specimen center point is recommended. The hot box operator's experience and knowledge of the air distribution system and hot box design should be drawn upon to determine the proper location.

6.5.4.1 Mapping the velocity fields on both the room and weather sides by periodic traversing of the air flow field to determine the air velocity distribution is recommended at every calibration interval to verify that a uniform air flow is directed at or across the face of the test specimen.

6.5.4.2 On the room side, where natural convection conditions are desired, it is required to mount a velocity sensor at a location that represents the average velocity so that natural convection conditions can be verified and the room side average air velocity can be measured during the test.

6.5.4.3 The types of acceptable air speed sensors are not specified within this test method. However, an accuracy of ±5 % of the reading is required and a sensor whose signal can be converted to a digital form for automated data recording is recommended.

6.5.5 *Glazing deflection*—Glazing deflection measurements shall be reported for each test specimen as specified in Practice E 1423.

7. Calculation of Thermal Transmittance

7.1 *General Calculations*—The following shall be calculated for each test:

7.1.1 *Total heat flow, Q*—The time rate of heat input into the metering box corrected for the metering box wall heat transfer, as determined using procedures specified in Test Methods C 236, C 976, or C 1363.

7.1.2 *Surround panel heat flow*, Q_{sp},

$$Q_{sp} = C_{sp} \bullet A_{sp} \bullet (t_{sp1} - t_{sp2}) \tag{29}$$

where C_{sp} is the thermal conductance of the surround panel as specified in 5.1.2 using Test Methods C 177, C 518, or C 1114.

7.1.3 *Test specimen heat flow*, Q_S,

$$Q_S = Q - Q_{sp} - Q_{FL} \tag{30}$$

where the surround panel flanking loss, Q_{FL}, is determined as specified in 5.2.1 and 5.2.2

7.1.4 *Test specimen thermal transmittance*, U_S,

$$U_S = Q_S/[A_S \bullet (t_h - t_c)] \tag{31}$$

8. Calculation of Standardized Thermal Transmittance

8.1 The thermal transmittance results measured using this test method can be standardized for rating and comparison purposes. The standardization process attempts to determine the actual surface heat transfer coefficients on the room and weather side surfaces on the test specimen during the test, and replace them with "standard" surface heat transfer coefficients when determining the standardized thermal transmittance. The standardized thermal transmittance is useful when comparing results from different thermal chamber configurations (that is, parallel versus perpendicular weather side air flow), and when comparing test results with computer calculated thermal transmittance (U-factor) values.

8.2 The following sections offer two methods of calculating the standardized thermal transmittance. The procedure that utilizes the calculation of the equivalent surface temperatures to compute the test specimen thermal conductance (CTS method) is described in 8.2.1-8.2.3, 8.2.5, and 8.2.7, and the method that uses the area weighted surface temperature measurements to compute the standardized thermal transmittance of the test specimen (area weighting method) is described in 8.2.4, 8.2.6, and 8.2.8. The area weighting method shall be used if the measured thermal transmittance, U_S, is greater than 3.4 W/(m^2•K) (0.60 Btu/(hr•ft^2•°F)) or the ratio of the test specimen projected area to wetted (heat transfer) area on either side of the test specimen is less than 0.80. The test laboratory shall indicate in the test report which method was used to calculate the final standardized thermal transmittance.

NOTE 15—It should be noted that the surface heat transfer coefficients, h_h and h_c, determined from the appropriately sized calibration transfer standard may differ from the surface heat transfer coefficients that exist during a hot box test on a specific test specimen. Actual fenestration systems usually have frame and sash surfaces that introduce three-dimensional convective heat transfer effects in the surface heat transfer coefficients. As a result of this, the test specimen surface heat transfer coefficients will differ from those obtained with the nonframed, essentially two-dimensional calibration transfer standard tested under the same conditions. In this test method, it is either assumed that the differences are small enough so that the calibration surface heat transfer coefficients can be used to calculate equivalent test specimen average surfaces temperatures, t_1 and t_2, in order to estimate the actual test specimen surface heat transfer coefficients. It should be recognized that this assumption will not be accurate for all fenestration products, especially for high thermal transmittance products where the surface heat transfer coefficients are a major portion of the overall thermal transmittance and also for projecting fenestration products (for example, skylights, roof windows, garden windows) where the surface heat transfer coefficients are quite different from the standardized values. In these situations, an attempt should be made to measure the test specimen surface temperature distributions and then calculate directly the test specimen average surfaces temperatures, t_1 and t_2. This area weighting (AW) method also has problems in that the placement of temperature sensors to get an accurate area weighting is not known, especially on high conductivity horizontal surfaces which act as heat transfer extended surfaces (that is, fins). In addition, the placement of many temperature sensors on the test specimen surfaces will affect the velocity fields in the vicinity of these surfaces which will effect the surface temperatures and surface heat transfer coefficients. Since neither of these two methods correctly reproduces the actual thermal performance of the fenestration product, it is important that the current computer calculation models be improved so that future measured versus calculated comparisons of the thermal transmittance are made with the actual thermal transmittance, U_S:

8.2.1 *CTS method*—Equivalent room side surface temperature of test specimen, t_1, is calculated by solving the following three equations for Q_{r1}, Q_{c1} and t_1:

$$Q_S = Q_1 + Q_{c1} \tag{32}$$

$$Q_{r1} = A_h \cdot F_{1b} \cdot \sigma \cdot [(t_{b1}+273.16)^4 - (t_1+273.16)^4] \tag{33}$$

$$Q_{c1} = A_h \cdot K_c \cdot (t_h - t_1)^{1.25} \tag{34}$$

where K_c is determined during the calibration tests, and F_{1b} is calculated as shown in 5.2.4.7(*1*).

NOTE 16—One way to solve these equations is by iteration. Assume a value for t_1 in Eq 33, calculate Q_{r1}, determine Q_{c1} from Eq 32, then calculate a new t_1 from Eq 34. If this new value is different from the assumed value, then use the average of the two t_1 values in Eq 33 and repeat the calculation until the t_1 values agree to within 0.1°C.

8.2.2 *CTS method*—Equivalent weather side surface temperature, t_2,

$$t_2 = Q_S/(h_c \cdot A_c) + t_h \tag{35}$$

where h_c is determined from the procedures specified in 5.2.3.

8.2.3 *CTS method*—Room side surface conductance, h_h,

$$h_h = Q_S/[A_S \cdot (t_h - t_1)] \tag{36}$$

where t_1, the room side surface temperature, is the calculated equivalent value as determined in 8.2.1.

8.2.4 *Area weighting method*—Room side surface heat transfer coefficient, h_h:

$$h_h = Q_S/[A_h \cdot (t_h - t_1)] \tag{37}$$

where the room side surface temperature, t_1, used is the area weighted average value that was measured on the surface of the test specimen with temperature sensors.

8.2.5 *CTS method*—Weather side surface heat transfer coefficient, h_c:

$$h_c = Q_S/[A_S \cdot (t_2 - t_c)] \tag{38}$$

where t_2, the weather side surface temperature, is the calculated equivalent value as determined in 8.2.2.

8.2.6 *Area weighting method*—Weather side surface heat transfer coefficient, h_c:

$$h_c = Q_S/[A_c \cdot (t_2 - t_c)] \tag{39}$$

where the weather side surface temperature, t_2, used is the area weighted average value that was measured on the surface of the test specimen with temperature sensors.

8.2.7 *CTS method*—Test specimen standardized thermal transmittance, $U_{ST[CTS]}$,

$$U_{ST[CTS]} = 1/[1/U_S + (1/h_{STh} - 1/h_h)) + (1/h_{STc} - 1/h_c)] \tag{40}$$

where h_{STh} and h_{STc} are the standardized surface heat transfer coefficients on the room side and weather side, as defined in 8.2.9.

8.2.8 *Area weighting method*—Test specimen standardized thermal transmittance, $U_{ST[AW]}$:

$$U_{ST[AW]} = 1.0/[(1/U_S) + (A_S/A_h)(1/(h_{STh} - 1/h_h) + (A_S/A_c)(1/h_{STc} - 1/h_c)] \tag{41}$$

where h_{STh} and h_{STc} are the standardized surface heat transfer coefficients on the room side and weather side, as defined in 8.2.9.

8.2.9 *Standardized Surface Heat Transfer Coefficients*:

8.2.9.1 The nominal values of the standardized surface heat transfer coefficients as specified in 5.3.3 and 5.3.4 are:

$$h_{STh} = 7.7\ \mathrm{W/(m^2 \cdot K)}\ (1.36\ \mathrm{Btu/(h \cdot ft^2 \cdot {}^\circ F)}) \tag{42}$$

$$h_{STc} = 29\ \mathrm{W/(m^2 \cdot K)}\ (5.1\ \mathrm{Btu/(h \cdot ft^2 \cdot {}^\circ F)}) \tag{43}$$

9. Report

9.1 Report the following information:

9.1.1 All of the information specified in Test Methods C 236, Section 10; C 976, Section 11; or C 1363, Section 12. The test specimen size, design drawing(s), and a detailed description of all the test specimen components (that is, frame, glazing, hardware weather-stripping, etc.) also shall be reported. Any nonstandard test specimen size and nonstandard test conditions used shall be explained.

9.1.2 The time rate of heat flow through the total surround panel/test specimen, Q.

9.1.3 The surround panel calculated time rate of heat flow, Q_{SP}.

9.1.4 The time rate of flanking loss heat flow for the surround panel, Q_{FL}.

9.1.5 The net test specimen heat flow rate, Q_S.

9.1.6 The weather side and room side average baffle temperatures, t_{b1} and t_{b2}.

9.1.7 The test specimen room side and weather side heat transfer surface areas, A_h and A_c.

9.1.8 The surround panel area, A_{sp}.

9.1.9 The room side and weather side baffle areas, A_{b1} and A_{b2}.

9.1.10 The measured thermal transmittance, U_S.

9.1.11 If determined, the values of and the method used to determine:

9.1.11.1 The calculated room and weather side surface heat transfer coefficients, h_h and h_c.

9.1.11.2 The average test specimen room side and weather side surface temperatures, t_1 and t_2.

9.1.11.3 The calculated standardized thermal transmittance, U_{ST} (CTS or AW).

9.1.12 Also, the following information should be provided:

9.1.12.1 Diagrams documenting all surface temperature locations (baffles, surround panel, and test specimen) and the corresponding temperatures at each location.

9.1.12.2 The values of, and method used to determine, the glass deflections as required in 6.5.5.1.

9.1.13 See Test Method C 1363 for measurement uncertainties required.

9.1.14 The following statement shall be included in the test report directly after the above results are reported. "This test method does not include procedures to determine the heat flow due to either air movement through the specimen or solar radiation effects. As a consequence, the thermal transmittance results obtained do not reflect performances which may be expected from field installations due to not accounting for solar radiation, air leakage effects, and the thermal bridge effects that may occur due to the specific design and construction of the fenestration system opening. The latter can only be determined by in-situ measurements. Therefore, it should be recognized that the thermal transmittance results obtained from this test method are for ideal laboratory conditions and should only be used for fenestration product comparisons and as input to thermal performance analyses which also include solar, air leakage and thermal bridge effects."

9.1.15 If the thermal chamber is set up to test at environmental conditions that are not within the tolerances specified for the room side and weather side standardized surface heat transfer coefficients in 5.3 and the nominal ASHRAE environmental temperatures of 21°C (70°F) and –18°C (0°F), then the following additional information from Section 5 must be reported for each test specimen: the size, construction, material thermal properties, and measured thermal transmittance of the relevant Calibration Transfer Standard, the test conditions, air and surface temperatures, and surface heat transfer coefficients measured on that Calibration Transfer Standard; any calibration coefficients used in calculating the test specimen standardized thermal transmittance from the relevant calibration or Calibration Transfer Standard tests; and an explanation of any other conditions that are outside of the requirements specified in this test method.

9.2 *Uncertainty Estimation*:

9.2.1 The individual laboratory measurement uncertainty of this test method depends upon the test equipment and operating procedures, and upon the test conditions and specimen properties. For this reason, no simple quantitative statement can be made that will apply to all tests; however, in order to comply with the requirements of 9.1.13, it is necessary to estimate the uncertainty of the results for each test to be reported. Such estimates of uncertainty can be based upon an analysis using the propagation of errors theory (often called uncertainty analysis) discussed in textbooks on engineering experimentation and statistical analysis (see, for example, Schenck[8]). These uncertainty estimates can be augmented by the results of intralaboratory test comparisons, by the results of experiments designed to determine repeatability of the effect of deviations from design test conditions, and by measurements of reference specimens from appropriate standards laboratories. In general, the best overall accuracy will be obtained in an apparatus with low metering box wall heat transfer, low surround panel heat transfer, and low flanking (surround panel and surround panel frame) heat transfer relative to the test specimen heat transfer. Low metering box wall heat transfer can be achieved by using highly insulated walls subjected to small temperature differences. Low surround panel heat transfer can be achieved with highly insulated surround panels that have a small exposed surface area in relation to the metering chamber aperture area. Low surround panel and surround panel frame flanking heat transfer, in relation to metering box heat input, can be achieved by using homogeneous and highly insulated surround panels and surround panel frames with no thermal bridges. Also in general, for a particular apparatus, the uncertainty will decrease as the heat transfer through the specimen increases.

NOTE 17—As an example, an outline of the procedure for an uncertainty analysis for thermal transmittance, U_S, is as follows:

From 7.1.4, $U_S = Q_S/(A_S \bullet (t_1 - t_2))$ where the heat transfer through the specimen, Q_S, is determined from the electrical power input (heating elements and fans) to the metering box, Q_E, the heat into or out of the metering box through its walls, Q_{BW}, the heat transfer through the surround panel, Q_{sp}, and the flanking (surround panel and surround panel frame) heat transfer, Q_{FL}; such that $Q_S = Q_E \pm Q_{BW} - Q_{sp} - Q_{FL}$. (Other terms such as air cooling or air leakage also should be accounted for if they occur.)

Combining these equations, the relation for the thermal transmittance is $U_S = (Q_E \pm Q_{BW} - Q_{SP} - Q_{FL})/(A_S \bullet (t_1 - t_2))$. The individual uncertainty for each quantity in this equation must be estimated. Such estimates may be made from the knowledge of how each of these quantities is determined. This should include an uncertainty analysis of each quantity by taking the appropriate partial derivatives with respect to the variables that are used to determine that quantity until an individual instrument (temperature, power, etc.) with a known measurement uncertainty or from the results of calibration experiments designed to investigate such uncertainties are determined. Then, following the propagation of errors theory which assumes the errors to be independent, the uncertainties are combined by determining the square root of the sum of the squares of all of the contributing uncertainties. Relative uncertainties (fractional or percentage of a the variable whose uncertainty is being estimated) can also be obtained. One ad hoc estimate by Elmahdy[9] for a fenestration hot box gave an uncertainty estimate of 6 %.

10. Precision and Bias

10.1 *Interlaboratory Comparison Results*:

10.1.1 *Background*—Seven interlaboratory comparisons for this procedure have been conducted by the National Fenestration Rating Council (NFRC) from 1994 to 1998 using both guarded and calibrated hot boxes. These interlaboratory comparisons had between seven and nine laboratories participating, with some laboratories having parallel weather side air flow, and others having perpendicular weather side air flow in the thermal chamber. All of the laboratories were expected to test the specimens at the following nominal conditions:

10.1.1.1 Weather side average air temperature of –18°C,

10.1.1.2 Room side average air temperature of 21°C,

10.1.1.3 Standardized weather side surface heat transfer coefficient of 29 W/(m^2•K), and

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[8] Schenck, H., *Theory of Engineering Experimentation*, McGraw Hill, New York, NY Third Edition, 1979, p. 53.

[9] Elmahdy, A. H., "Heat Transmission and R-value of Fenestration Systems Using IRC Hot Box: Procedure and Uncertainty Analysis," *ASHRAE Transactions* 98(2): 630–637.

10.1.1.4 Standardized room side surface heat transfer coefficient of 8.3 W/(m^2•K).

10.1.2 See Table 1 for a summary of the seven interlaboratory comparison results described below.

10.1.2.1 *1994 interlaboratory comparison Number 1*—The design of the first interlaboratory comparison is described by Wise and Mathis.[10] Nine laboratories participated in this interlaboratory comparison, which was conducted between March and August 1994. Data were reported for a 182 cm × 121 cm horizontal sliding window with a non-thermally broken aluminum frame and 19 mm double glazed clear insulating glazing units filled with air.

10.1.2.2 *1994 Interlaboratory Comparison Number 2*—Seven testing laboratories participated in this interlaboratory comparison, which was conducted between July and October 1994. The test specimen in this interlaboratory comparison was a 183 cm × 122 cm Calibration Transfer Standard made from a 13.5 mm EPS core, which was faced with 3.86 mm polycarbonate. This interlaboratory comparison only requested that the test laboratories report the standardized thermal transmittance calculated by the CTS method, and thermocouples were not placed on the outside of the test specimen. In addition, the polycarbonate was scored on both sides to minimize thermal expansion.

10.1.2.3 *1995 Interlaboratory Comparison Number 3*—Eight testing laboratories participated in the third interlaboratory comparison between April and December 1995. Results were reported for a 122 cm × 183 cm double hung window with a reinforced vinyl frame, and 19 mm double glazed, argon-filled glazing units with a low-e coating of emittance 0.09 on surface number 3.

10.1.2.4 *1995 Interlaboratory Comparison Number 4*—Eight testing laboratories participated in the fourth interlaboratory comparison, which was conducted between June 1995 and August 1996. The test specimen in this interlaboratory comparison was a 183 cm × 122 cm calibration panel with 13.5 mm EPS core faced with 4.76 mm glass. This interlaboratory comparison only requested that the test laboratories report the standardized thermal transmittance calculated by the CTS method even though thermocouples were placed on the outside of the test specimen.

10.1.2.5 *1996 Interlaboratory Comparison Number 5*—Eight testing laboratories participated in the fifth interlaboratory comparison between May and November 1996. Results were reported for a 122 cm × 122 cm fixed window with an aluminum clad wood frame, which was quadruple glazed with two suspended films having a low-e coating of emittance of 0.11, and the glazing cavity was filled with krypton.

10.1.2.6 *1997 Interlaboratory Comparison Number 6*——Nine testing laboratories participated in the sixth interlaboratory comparison between March and August 1997. Results were reported for a 122 cm x 122 cm fixed window with an aluminum clad wood frame, which was dual glazed, consisting of nominal 25.4 cm thick insulating glass fabricated from two nominal 5 mm sheets of glass, nominal 16 mm air space, no inert gas fill and a reported 0.04 emittance Low "E" coating. The spacer was specified to be a dual-sealed, U-shaped rolled spacer system.

10.1.2.7 *1998 Interlaboratory Comparison Number 7*——Nine testing laboratories participated in the seventh interlaboratory comparison between March and August 1998. Results were reported for a 122 cm x 122 cm fixed window with an aluminum clad wood frame, which was dual glazed, consisting of niminal 25.4 cm thick insulating glass fabricated from two niminal 5 mm sheets of glass, nominal 16 mm air space, no inert gas fill and a reported 0.04 emittance Low "E" coating. The spacer was specified to be a dual-sealed, U-shaped rolled spacer system. Same test sample was used for the 1997 Interlaboratory Comparison Number 6.

10.1.3 *Precision*——Table 1 presents a summary of the seven above described interlaboratory comparisons. The year, test specimen, and number of laboratories participation is given, along with the following results:

U_S = average thermal transmittance, W/(m^2•K)
U_{ST} = average standardized thermal transmittance, W/(m $_2$•K)
R = reproducibility limit [for 95 % confidence limits, 2.8 times the standard deviation], W/(m^2•K)
R % = reproducibility limit percent [reproducibility limmit divided by the mean], %

10.1.4 *Bias*—— To give some idea of the bias associated with the above described interlaboratory comparisons, the calibration standard used in the comparison 2 had a calculated theoretical thermal transmittance of 1.65 W/(m^2•K), and the caliabration transfer standard used in comparison 4 had a calculated theoretical thermal transmittance of 1.75 W/(m^2•K). The calculated theoretical values have an associated uncertaincy which is not known.

TABLE 1 Summary of Interlaboratory Comparison Results

Comparison Number	Year	Test Specimen	Labs	U_S W/m^2•K	U_{ST} W/m^2•K	U_S R (W/m^2•K)	U_S R (%)	U_{ST} R (W/m^2•K)	U_{ST} R (%)
1	1994	Aluminum frame slider window	9	4.01	3.80	±0.98	24.4	±0.58	15.4
2	1994	Calibration transfer standard	7	1.69	1.65	±0.57	33.9	±0.34	20.3
3	1995	Vinyl frame double hung window	8	2.16	2.09	±0.38	17.8	±0.30	14.3
4	1995/1996	Calibration transfer standard	8	1.74	1.70	±0.22	11.7	±0.20	12.7
5	1996	Aluminum clad wood frame fixed window	8	1.47	1.43	±0.30	20.4	±0.23	16.3
6	1997	Aluminum clad wood frame fixed window	9	1.91	1.88	±0.37	19.5	±0.23	12.3
7	1998	Aluminum clad wood frame fixed window	9	1.84	1.79	±0.24	13.0	±0.16	9.0

Note: R = Reproducibility Limit W/(m^2•K), R % = Percent Reproducibility limit

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[10] Wise, D. J., Mathis, R. C., "An Assessment of Interlaboratory Repeatability in Fenestration Energy Ratings—Part 2: Interlaboratory Comparison of Test Results," *Thermal Performance of the Exterior Envelopes of Buildings VI: Conference Proceedings*, December 4-8, 1995, p. 535–540.

11. Keywords

11.1 doors; fenestration; heat; hot box; R-value; steady-state; testing; thermal transmission; U-factor; U-value; windows

ANNEXES

(Mandatory Information)

A1. CALIBRATION TRANSFER STANDARD DESIGN

A1.1 This large heat flux transducer is used in the calibration of the surface heat transfer coefficients. Fig. 3a is a schematic diagram of a calibration transfer standard which consists of a homogeneous, well characterized, core calibration material made from an insulation board that has a known thermal conductivity measured by Test Methods C 177 or C 518. A recommended calibration transfer standard core material is 12.7 mm nominal thickness expanded polystyrene (beadboard) having a density in excess of 20 kg/m^3 that has been aged unfaced in the laboratory for a minimum of 90 days. (Expanded polystyrene with a nominal density of 50 kg/m^3 and a nominal thermal conductivity of 0.033 W/(m K) has been used with success. Machining the surfaces of the expanded polystyrene to ensure flatness is also recommended.) Suitable facing materials are 3 to 6 mm tempered float glass (glass sheets of thickness 4 mm, with a nominal thermal conductivity of 1.0 W/(m K) and a nominal surface hemispherical emittance of 0.84 have been used with success) or 3 to 6 mm clear polycarbonate sheet. (It should be recognized that the surface emittance of the polycarbonate has to be precisely measured and used where appropriate in calculations requiring the calibration transfer standard's surface emittance. Polycarbonate sheets of thickness 4 mm, with a nominal thermal conductivity of 0.2 W/(m K) and a nominal surface hemispherical emittance of 0.90 have been used with success). It is required, prior to assembly of the calibration transfer standard, that the thermal conductivity of the material used for the core of the calibration transfer standard be measured in a guarded hot plate (see Test Method C 177) or a heat flow meter (see Test Method C 518) at a minimum of three temperatures over the range of use (–10°C, 0°C, and 10°C are recommended).

A1.2 The temperature sensors are area-weighted and located in the manner shown in Fig. 3a and 3b. The minimum number of temperature sensors per side for a wide range of calibration transfer standard sizes is given in Table A1.1. Also included in Table A1.1 are the recommended number of sensors per side along with a recommended array to meet the minimum required sensor densities. The temperature sensors should be laid out equal areas to simplify the area weighting calculation (that is, the average row, column, or overall area weighted temperature becomes the average temperature of the row, column, or total sensors for a side). The temperature sensors should be able to measure accurately the temperature difference across the core material of the calibration transfer standard. It has been found satisfactory to use 30-gage (0.3 mm) or smaller diameter copper-constantan insulated thermocouple wire from the same wire lot for both sides of the calibration transfer standard to obtain an accurate core temperature difference. The small diameter wire pair should have

TABLE A1.1 Calibration Transfer Standard (CTS) Temperature Sensor Requirements

CTS Size[A] in.× in. (m × m)	CTS Area[B] ft^2 (m^2)	Minimum Number of Sensors Per Side[C]	Recommended Number of Sensors Per Side	Recommended Arrays	Recommended Sensor Densities[D] Sensors/ft^2 (Sensors/m^2)
24 × 48 (0.61 × 1.22)	8 (0.74)	12	12 18	3 × 4 3 × 6	1.5 (16.1) 2.25 (24.3)
36 × 60 (0.91 × 1.52)	15 (1.39)	18	18 24	3 × 6 4 × 6	1.2 (12.9) 1.6 (17.3)
48 × 72 (1.22 × 1.83)	24 (2.23)	24	24 32	4 × 6 4 × 8	1.0 (10.8) 1.33 (14.3)
48 × 84 (1.22 × 2.13)	28 (2.60)	28	28 42	4 × 7 6 × 7	1.0 (10.8) 1.5 (16.2)
72 × 80 (1.83 × 2.03)	40 (3.72)	40	42 48	6 × 7 6 × 8	1.05 (11.3) 1.2 (12.9)
80 × 80 (2.03 × 2.03)	44.4 (4.13)	45	49 64	7 × 7 8 × 8	1.10 (12.2) 1.44 (15.5)
72 × 96 (1.83 × 2.44)	48 (4.46)	48	48 64	6 × 8 8 × 8	1.0 (10.8) 1.33 (14.3)
96 × 96 (2.44 × 2.44)	64 (5.95)	64	64 72	8 × 8 8 × 9	1.0 (10.8) 1.13 (12.1)

[A] The minimum Calibration Transfer Standard (CTS) size is 24 in. × 48 in. (0.61m × 1.22m) or 8 ft^2 (0.74 m^2).

[B] The temperature sensors must be laid out in an equal area array. See Fig. 2 for recommended arrays for typical CTS.

[C] To minimize disturbing the room side and weather side air flows on the CTS surface, all sensors are to be located between the CTS faces and the CTS core material.

[D] Higher temperature sensor densities are recommended for research purposes.

the insulation stripped off to expose approximately 10 mm of bare wire and then each wire is separately soldered to one side of a thin (3 mil [0.003 in (0.08 mm)] nominal thickness) copper shim material approximately 20 by 20 mm in size. The constantan wire should be soldered to the center of the copper shim and the copper thermocouple wire should be separately soldered to the copper shim approximately 6 mm in distance from the constantan-shim solder point. The recommended solder is resin core, lead 60/40, 6 mm nominal diameter, and the resulting solder joints should be cleaned with alcohol to remove excess solder material and resin residue. The reverse smooth side of the shim material is then adhered with a thin film of two part epoxy (Loctite Minute Bond 312 has been found satisfactory.) to the glazing facing inner surfaces. After the epoxy has dried and all epoxy removed from the surrounding glazing surface, the glazing facing inner surfaces and the expanded polystyrene core material faces are coated with a thin film of a polystyrene compatible water-based contact adhesive (HB Fuller XR-1377-24-LT Blue Contact adhesive has been found satisfactory). After allowing the contact adhesive to dry (A minimum of 24 h at room temperature with a relative humidity less than 50 % is recommended; when dry, the contact adhesive will not stick to the touch.), the expanded polystyrene is adhered to the glazing facings by applying an ample uniform pressure to the glazing outer faces for an amount of time to allow the glazing faces to permanently bond to the expanded polystyrene.

A1.2.1 Since the thermal conductivity of the core material is known (previously measured by Test Methods C 177, C 518, or C 1114), and it is possible to accurately measure its thickness, the conductance of the core material can be calculated. This allows the heat flux through the calibration transfer standard to be determined from measurement of the temperature difference across the core material.

A2. RADIATION HEAT TRANSFER CALCULATION PROCEDURE

A2.1 This calculation procedure is to be used when the assumption that the fenestration system and baffle surfaces are parallel surfaces and the fenestration system only exchanges radiation heat transfer with the isothermal baffles is not true. In many situations, the fenestration system also exchanges radiation heat transfer with the surround panel opening surfaces and with nonisothermal baffle and other surfaces. In those situations, the radiation calculation procedure described in this annex is required. Before using the calculation procedure described in this annex, it is recommended the section on radiation heat transfer found in Chapter 3 of the 1997 (or the most recent version) ASHRAE Fundamentals Handbook be studied. The material in the following sections of this annex closely follows the radiation heat transfer material given in the 1997 ASHRAE Fundamentals Handbook.

A2.2 *Radiation Heat Transfer in An Enclosure*:

A2.2.1 In addition to heat transfer by convection (mass motion plus conduction), there is radiation heat transfer between different surfaces in enclosures. In an enclosure such as the six-sided one shown in Fig. A2.1, there are multiple reflections between the different surfaces, and there may be partial absorption at each surface of the enclosure.

A2.2.2 In order to determine the net radiative heat transfer per unit surface area, q_r, from each surface, the following assumptions are made. It is assumed that each surface of the enclosure is at a uniform (or isothermal) temperature. Although the temperature of each surface is not exactly uniform, the temperature variation is usually not significant. Therefore, a uniform temperature (the average temperature of the surface) can be assumed in the analysis of the radiative heat transfer. Assuming isothermal surfaces also makes it possible to assume a uniform radiosity and irradiation of each surface of the enclosure. Any surface where the assumption of a uniform temperature is not valid shall be divided into smaller uniform temperature area elements and the radiosity and irradiation of each area element should be considered in analyzing radiative heat transfer between different surfaces. This will make the analysis substantially more complex so it is advantageous to design an enclosure with uniform temperature surfaces.

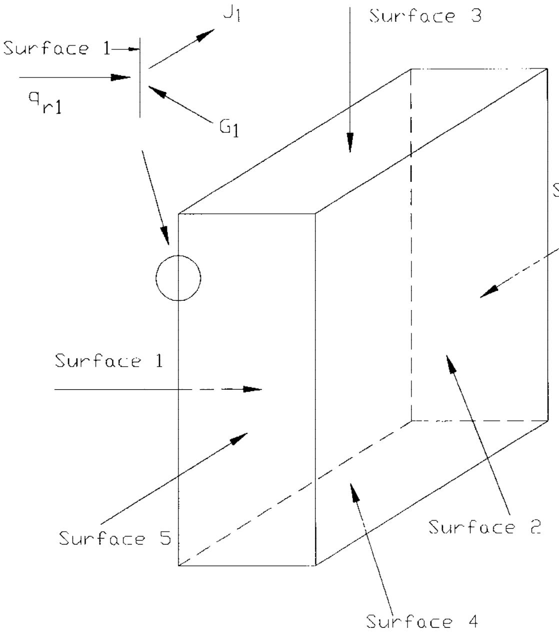

FIG. A2.1 Thermal Radiation Exchange Between Different Surfaces of a Rectangular Enclosure

A2.2.3 Radiosity, J, is the radiation heat transfer energy that leaves a surface. Irradiation, G, accounts for all of the radiation heat transfer energy received by a surface. In order to determine the net radiative heat transfer per unit surface area, q_{ri}, from each surface i, it is assumed that the surfaces are diffuse-gray, and opaque (no transmission of radiation through the surface), and that the medium inside the enclosure is nonparticipating (that is, non-absorbing and non-emitting).

A2.2.4 The net rate at which radiation leaves surface i, q_{ri}, is equal to the difference between the radiosity and irradiation of surface i:

$$q_{ri} = A_i \cdot (J_i - G_i) \tag{A2.1}$$

where J_i is the radiosity and G_i is the irradiation of surface i. By definition, radiosity is a combination of the energy emitted from the surface and the portion of the irradiation energy that is reflected from the surface. Mathematically this can be written as:

$$J_i = E_i + \rho_i \cdot G_i \tag{A2.2}$$

where E_i is the emissive power and ρ_i is the reflectance of surface i. Substituting Eq A2.2 into Eq A2.1, the net radiative heat transfer can also be expressed as:

$$q_{ri} = A_i \cdot (E_i - \alpha_i \cdot G_i) \tag{A2.3}$$

where $\alpha_i = 1 - \rho_i$ is the absorptance. If the irradiation has a similar wavelength distribution as the emitted energy (that is, the surfaces are made of the same material and are at similar temperatures), we can assume that the absorptance is equal to the emittance of the surface.

$$\epsilon_i = \alpha_i \tag{A2.4}$$

where the emittance, ϵ_i, is defined as the ratio of the actual radiant heat transfer energy emitted to the radiant heat transfer energy emitted from a perfect radiator:

$$\epsilon_i = E_i/E_{bi} \tag{A2.5}$$

where:

$$E_{bi} = \sigma \cdot T_i^4 \tag{A2.6}$$

For an opaque surface, the radiosity, using Eq A2.4, Eq A2.5, and Eq A2.6 can be written as:

$$J_i = \epsilon_i \cdot E_{bi} + (1 - \epsilon_i) \cdot G_i \tag{A2.7}$$

Solving for G_i in Eq A2.7 and substituting into Eq A2.1, it follows that:

$$q_{ri} = (E_{bi} - J_i)/[(1 - \epsilon_i)/(\epsilon_i \cdot A_i)] \tag{A2.8}$$

A2.2.5 The surface radiosity, J_i, must be known in order to evaluate the radiation heat transfer q_{ri}, in Eq A2.8. The irradiation of surface i is evaluated from the radiosities of all of the surfaces in the enclosure. Using the definition of the view factor (see the definition of the angle or view factor in Chapter 3 of the 1993 ASHRAE Fundamentals Handbook and the figure of angle factors for surfaces that make up a rectangular enclosure), the total rate at which radiation reaches surface i from all surfaces is:

$$A_i \cdot G_i = \Sigma F_{ji} \cdot A_j \cdot J_j \tag{A2.9}$$

where Σ is the summation over $j = 1$ to ns.

Using the reciprocity relation for view factors ($A_i \cdot F_{ij} = A_j \cdot F_{ji}$) and substituting Eq A2.9 into Eq A2.1, we can obtain an alternative expression for the net radiation heat flux from surface i:

$$q_{ri} = \Sigma A_i \cdot F_{ij} \cdot (J_i - J_j) \tag{A2.10}$$

where ns is the total number of surfaces in the enclosure. Combining Eq A2.8 and Eq A2.10:

$$(E_{bi} - J_i)/[(1 - \epsilon_i)/(\epsilon_i \cdot A_i)] = \Sigma (J_i - J_j) \cdot (A_i \cdot F_{ij}) \tag{A2.11}$$

Using an electric analog network representation to help solve radiation problems is an effective tool for visualizing radiation exchange in an enclosure (see Fig. A2.2). For any number of surfaces ns ($ns = 6$ for the rectangular enclosure shown in Figs. A2.1 and A2.2), the radiosities can be determined by solving a system of ns simultaneous equations. Rearranging Eq A2.11, it can be written in the matrix form as:

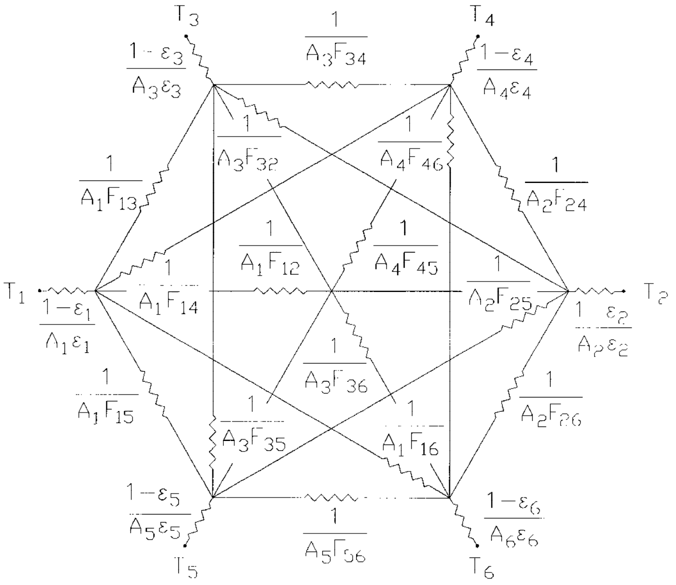

FIG. A2.2 Network Representation of Radiation Exchange Between Six Surfaces of a Rectangular Enclosure

$$[K] \cdot \{J\} = \{E\} \tag{A2.12}$$

The full details of the matrix $[K]$ and the vector $\{E\}$ for a six-sided rectangular enclosure are shown in A2.3. The radiosities, J, can be found by solving the following equations in matrix form:

$$\{J\} = [K]^{-1} \cdot \{E\} \tag{A2.13}$$

Once the values of the radiosities, J_i, are known, the net radiation heat transfer from any surface i can be obtained from Eq A2.8.

A2.3 *Evaluation of Radiation Heat Transfer*:

A2.3.1 In order to calculate the radiation heat transfer between different surfaces of an enclosure, it is necessary to obtain the radiosity corresponding to different surfaces of the enclosure. In A2.2.5, Eq A2.11 was obtained as the following:

$$(E_{bi} - J_i)/[(1 - \epsilon_i)/(\epsilon_i \cdot A_i)] = \Sigma (J_i - J_j)\ (A_i \cdot F_{ij}) \quad \text{(see Eq A2.11)}$$

Defining the following variables to simplify the notation:

$$c_i = (1 - \epsilon_i)/(\epsilon_i \cdot A_i) \tag{A2.14}$$

$$b_{ij} = A_i \cdot F_{ij} \tag{A2.15}$$

Note that $A_i \cdot F_{ij} = A_j \cdot F_{ji}$. Therefore:

$$b_{ij} = b_{ji} \tag{A2.16}$$

We also have:

$$E_{bi} = \sigma \cdot T_i^4 \quad \text{(see Eq A2.6)}$$

Substituting the above relationships into Eq A2.11, we obtain the following equation:

$$(E_{bi} - J_i)/c_i = \Sigma(J_i - J_j)b_{ij} \tag{A2.17}$$

Expanding Eq A2.17 for each surface of the airspace:

$$(Eb_1 - J_1)/c_1 = 0 = + b_{12}(J_1 - J_2) + ... + b_{16}(J_1 - J_6) \tag{A2.18}$$

$$(Eb_2 - J_2)/c_2 = b_{21}(J_2 - J_1) + 0 + ... + b_{26}(J_2 - J_6)$$

$$\begin{array}{ccc} . & . & . \\ . & . & . \\ . & . & . \end{array}$$

$$(E_{b6} - J_6)/c_6 = b_{61}(J_6 - J_1) + b_{62}(J_6 - J_2) ..+ b_{65}(J_6 - J_5) + 0$$

Rearranging Eq A2.18, we get the following:

$$J_1(b_{12} + b_{13}+...+ b_{16}+ 1/c_1) - b_{12}J_2 - b_{13}J_3 -...-b_{16}J_6 = E_{b1}/c_1 \tag{A2.19}$$

$$J_2(b_{21} + b_{23}+...+ b_{26}+ 1/c_2) - b_{21}J_1 - b_{23}J_3 -...-b_{26}J_6 = E_{b2}/c_2$$

$$\begin{array}{ccc} . & . & . \\ . & . & . \\ . & . & . \end{array}$$

$$J_6(b_{61} + b_{62}+...+ b_{65}+1/c_6) - b_{61}J_2 - b_{63}J_2 - b_{65}J_5= E_{b6}/c_6$$

Eq A2.19 can be written in the matrix form as:

$$[K] \bullet \{J\} = \{E\} \qquad \text{(see Eq A2.12)}$$

where the matrix $\{J\}$ is defined as:

$$\begin{array}{r} |J_1| \\ |J_2| \\ |J_3| \\ \{J\} = |J_4| \\ |J_5| \\ |J_6| \end{array} \tag{A2.20}$$

and the matrix $\{E\}$ is defined as:

$$\begin{array}{r} |E_{b1}/a_1| \\ |E_{b2}/a_2| \\ |E_{b3}/a_3| \\ \{E\} = |E_{b4}/a_4| \\ |E_{b5}/a_5| \\ |E_{b6}/a_6| \end{array} \tag{A2.21}$$

and the components of the matrix $[K]$ are defined as:

$$K_{11} = b_{12} + b_{13} + b_{14} + b_{15} + b_{16} + 1/c_1 \tag{A2.22}$$

$$K_{22} = b_{21} + b_{23} + b_{24} + b_{25} + b_{26} + 1/c_2$$

$$\begin{array}{ccc} . & . & . \\ . & . & . \\ . & . & . \end{array}$$

$$K_{66} = b_{61} + b_{62} + b_{63} + b_{64} + b_{65} + 1/c_6$$

and

$$K_{12} = -b_{12}; K_{13} = -b_{13}; K_{14} = -b_{14}; K_{15} = -b_{15}; K_{16} = -b_{16}$$

Similarly, for K_{ij}, i=2,3,4,5,6, and $j \neq i : K_{ij} = -b_{ij}$.

Therefore, a set of linear simultaneous equations in the radiosities, J_i, needs to be solved. This may be solved by several classical methods of matrix inversion like Gaussian Elimination or Gauss-Seidel Iteration. The result is depicted below:

$$\{J\} = [K]^{-1} \bullet \{E\} \qquad \text{(see Eq A2.13)}$$

Once vector $\{J\}$ is obtained, the radiation heat transfer at surface i can be calculated as:

$$q_{ri} = (E_{bi} - J_i)/[(1 - \epsilon_i)/(\epsilon_i \bullet A_i)] \qquad \text{(see Eq A2.8)}$$

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