~~Designation:C1199–97~~ Designation: C 1199 – 00 (Reapproved 2008)

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

This standard is issued under the fixed designation C 1199; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers 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 ~~0.75~~ 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.*

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[1] This test method is under the jurisdiction of ASTM Committee ~~C-16~~ C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

~~Current edition approved Nov. 10, 1997. Published July 1998. Originally published as C1199–91. Last previous edition C1199–91.~~

Current edition approved Oct. 15, 2008. Published July 2009. Originally approved in 1991. Last previous edition approved in 2000 as C 1199 – 00.

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 ~~Terminology Relating to Thermal Insulating Materials~~ Terminology Relating to Thermal Insulation

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box

C 518 Test Method for Steady-State Thermal ~~Heat Flux Measurements and~~ Transmission Properties by Means of the Heat Flow Meter Apparatus

C 976 Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box

C 1045 ~~Practice for Calculated Thermal Transmission Properties from Steady-State Heat Flux Measurements[2]~~ Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus

C 1363 Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

E 283 ~~Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors~~ Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

E 631 Terminology of Building Constructions

E 783 Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

E 1423 Practice for Determining ~~the Steady-State~~ Steady State Thermal Transmittance of Fenestration Systems

2.2 *ISO Standards:*

ISO 8990 Thermal Insulation-Determination of Steady-State Thermal Transmission Properties—Calibrated and Guarded Hot Box[2]

~~ISO/DIS 12567Thermal~~ ISO12567–1:2000 Thermal Insulation—Determination of Thermal Resistance of Components—Hot Box Method for Windows and Doors[2]

2.3 *Other Standards:*

NFRC 100-97 Procedure for Determining Fenestration Product Thermal U-factors[3]

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[4]

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[4]

ASHRAE Fundamentals Handbook, 1997[5]

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).

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:

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

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[2] Annual Book of ASTM Standards, Vol 04.06.

[2] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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

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

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

[4] Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsi-global.com.

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

[5] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.
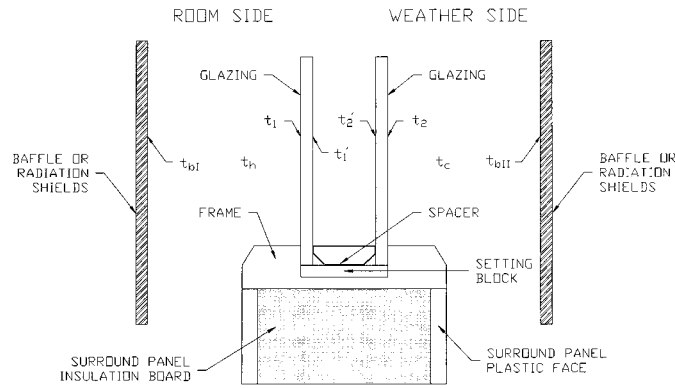
FIG. 1 Schematic Representation of Various Temperatures for Fenestration Systems

and using the area weighting (AW) method:

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

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:

$$r_h = 1/h_h \qquad (4)$$

$$r_c = 1/h_c \qquad (5)$$

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 ~~must~~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:

$$t_h = t_{b1} \ (\pm 1 \ ^\circ C), \qquad (6)$$
$$h_h = Q_S/[(A_{S \ or \ h})(t_h - t_1)]$$

when:

$$t_h \neq t_{b1} \ (\pm 1^\circ \ C), \qquad (7)$$
$$h_h = (q_{r1} + q_{c1})/(t_h - t_1)$$

when:

$$t_c = t_{b2} \ (\pm 1 \ ^\circ C),$$
$$h_c = Q_S \ /[(A_{S \ or \ c}) \ (t_2 - t_c)]$$

~~when:~~)]

3

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:

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

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, m²,
A_c	=	total heat transfer (or developed) surface area of test specimen on weather side, m²,
A_{b1}	=	area of room side baffle and all other surfaces in view of the test specimen, m²,
A_{b2}	=	area of weather side baffle and all other surfaces in view of the test specimen, m²,
A_S	=	projected area of test specimen (same as open area in surround panel), m²,
A_{sp}	=	projected area of surround panel (does not include open area in surround panel), m²,
α	=	absorbtance of surface,
C_g	=	thermal conductance of glass or acceptable transparent plastic facing on calibration transfer standard, W/(m²•K),
C_{sp}	=	thermal conductance of surround panel (surface to surface), W/(m²•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/(m²•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/m²•K),
h_{STc}	=	standardized surface heat transfer coefficient, weather side, (W/m² •K),
h_h	=	surface heat transfer coefficient, room side, W/(m²•K),
h_c	=	surface heat transfer coefficient, weather side, W/(m²•K),
K_c	=	convection coefficient, W/(m²•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/m²,

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 <u>area weighted</u> temperature of test specimen room side surface, K or °C,
t_2	=	average <u>area weighted</u> temperature of test specimen weather side surface, K or °C,
$t_{1'}$	=	average <u>area weighted</u> temperature of room side glass/core interface of calibration transfer standard, K or °C,
$t_{2'}$	=	average <u>area weighted</u> 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 ~~from~~<u>using</u> 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 ~~two-dimensional~~<u>flat</u> Calibration Transfer Standard tested under the same conditions. In this standardizing procedure, 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~~<u>resistance</u> 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.

4.3.4 ~~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/calculated comparisons of the thermal transmittance can be made with the actual thermal transmittance, U_S.~~

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 ~~effects~~ 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 ~~board~~ 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 ~~board~~ 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 ~~board~~ core of the surround panel should be no more than ~~50~~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 ~~150~~125 mm, the surround panel core thickness should be ~~150~~125 mm. For test specimen maximum thicknesses greater than ~~150~~125 mm and up to ~~200~~150 mm, the surround panel core thickness should be ~~200~~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 ~~these~~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 (surface to surface including facing and core materials) of a sample of the surround panel (~~) of all materials used shall be included with the test report. It is required that the thermal conductance (C_{sp} ~~) be measured in a guarded hot place (Test Method C177~~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
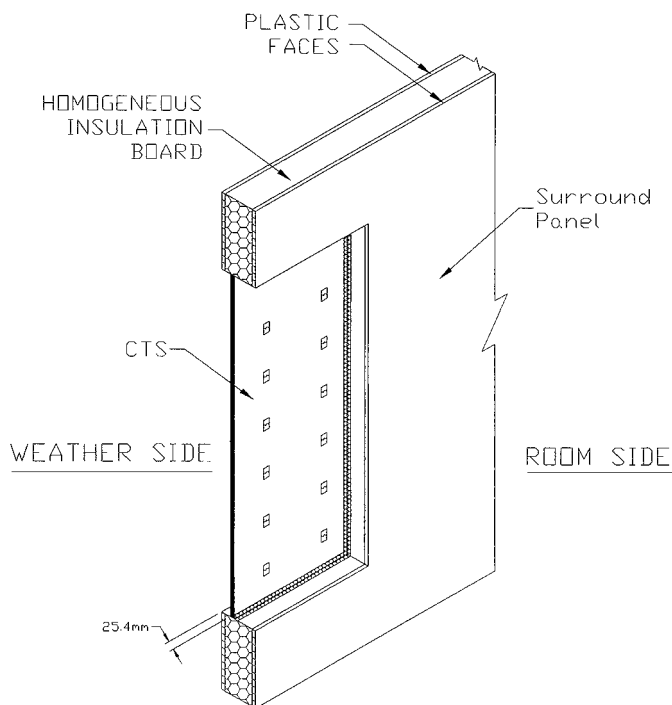
FIG. 2 Surround Panel With CTS

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 ~~shall~~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 streams at the same horizontal plane as the surface temperature sensors. 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.~~ — The room side and weather side air stream temperatures in a horizontal plane parallel 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
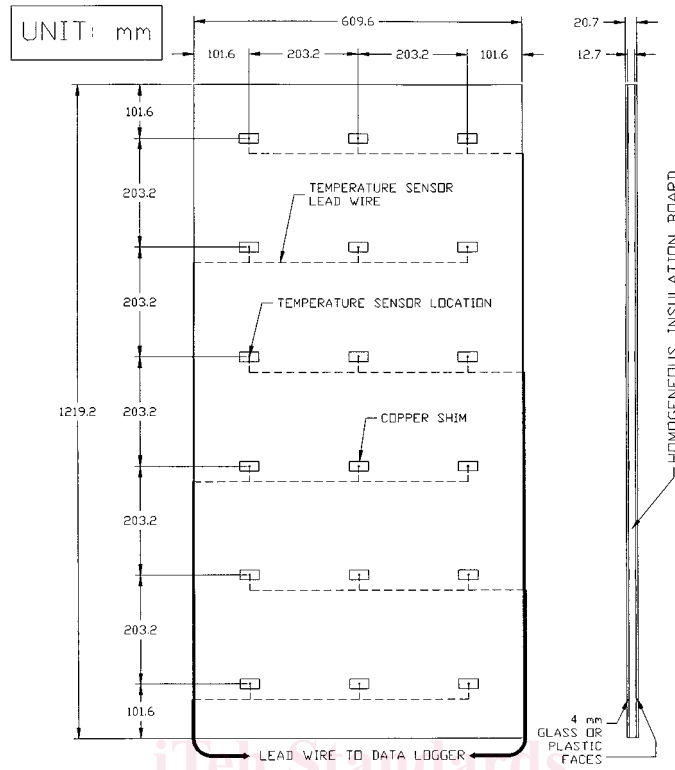
FIG. 3 (a)   Example Calibration Transfer Standard Design Information

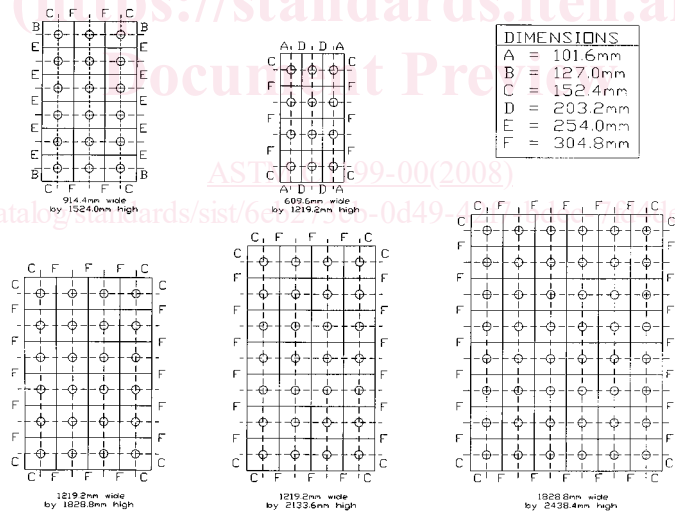| DIMENSIONS |
|---|
| A = 101.6mm |
| B = 127.0mm |
| C = 152.4mm |
| D = 203.2mm |
| E = 254.0mm |
| F = 304.8mm |

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

provide more accurate average temperature (air and surface) values.

5.1.5 *Air leakage—Precaution—*All potential air leakage sites on the test specimen, the surround panel, and at the interface between the surround panel and the test specimen, must be sealed with nonmetallic tape or caulking, or both, as close to the primary seal as possible to minimize or eliminate air leakage between the room side and weather side chambers. The thermal performance can be affected by the method and placement of the test specimen air seal. Therefore, the test specimen is to be sealed at the room side of the test specimen with tape, caulking, or other material of similar surface emittance to that of the adhering surface. Perimeter joints between the test specimen and the surround panel shall be sealed on both sides of the test specimen. In no case shall the tape or caulk cover more than 12.7 mm (0.50 in.) of the test specimen frame or edge. As an additional precaution to minimize the potential for leakage of air through and around the sealed test specimen, means may be provided to measure and equalize the pressure difference across the test specimen. For hot boxes that have a perpendicular (to the test specimen weather side surface) wind direction, this is accomplished by balancing the weather side total pressure with the room side static pressure to 0 ± 10 Pa. For hot boxes that have a parallel (to the test specimen weather side surface) wind direction, this is accomplished

by balancing the weather side static pressure with the room side static pressure to 0 ± 10 Pa. The pressure sensors used should be located outside the boundary layer on the glazing surface and oriented perpendicular to the center of the test specimen room side and weather side surfaces.

Note 7—Sealing techniques should be concerned with two primary criteria: (1) The sealant applied should be of similar (±0.1) emittance as the surface to which it is being applied; and (2) The sealant is applied in as minimal an amount as possible to achieve the reduction in air leakage. One method to characterize and minimize the air leakage through and around the test specimen is by performing the following steps. (A) Prior to the thermal tests, conduct an air leakage test with the test specimen installed and sealed in the surround panel. The air leakage test can be Test Methods E283 or E783, whichever is more appropriate for a particular hot box test facility. The recommended test conditions are 27 Pa (0.56 lbf/ft^2) and 75 Pa (1.57 lbf/ft^2) equivalent to approximately 24 km/hr (15 miles per hour) and 40 rm/hr (25 miles per hour) wind speed, respectively. (B) After determining the net flow rate at each of these test pressures, the interior of the unit is sealed until the net air leakage is less than the flow equivalent of 0.0006 cubic meters per minute per square meter (0.002 cubic feet per minute per square foot) of fenestration system area at 75 Pa (1.57 lbf/ft^2) pressure differential. This would be approximately 0.0014 cubic meters per minute (0.05 cubic feet per minute) total flow for a fenestration test specimen with a 1.52 m (60 in.) by 1.02 m (40 in.) projected area. (C) It is intended that employing this level of sealing prior to the thermal test will minimize the air leakage to a level that will not significantly interfere with the conduction heat transfer through the fenestration test specimen during the thermal tests. Good laboratory practice would include periodic assessment of the quality of the sealing methods used by monitoring closely the fenestration test specimen heat flux and temperature measurements during the duration of the thermal tests to ensure that there are no changes in the thermal performance due to losses in the seal integrity.

5.1.6 As an alternative method to determine whether or not air leakage occurs, the following technique currently in use by one laboratory has been found to be useful. Place a sheet of 0.1 mm (4 mil) polyethylene over the calibration transfer standard (or fenestration test specimen) on the room side and seal it with tape to the surround panel at least 12 cm (4.7 in.) outside the perimeter of the specimen. Balance the pressure between the room side and weather side chambers as indicated above and monitor the pressure difference. If the polyethylene sheet has not moved appreciably, it can be assumed that no net air leakage exists and the polyethylene sheet can be removed. Control the pressure balance during the test to 0 ± 10 Pa (0 ± 0.21 lbf/ft^2). If the polyethylene sheet has moved toward the specimen, it can be assumed that a net air leakage in the direction of infiltration exists. If this situation still exists after rechecking and modifying the sealing tape or caulk as necessary (removable weatherstripping has been used with success here), the pressure balance setting can be adjusted in 2.5 Pa (0.05 lbf/ft^2) increments until the polyethylene sheet has moved back to its original position or is bowed slightly away from the specimen. (Wait at least 5 minutes after each adjustment before making observations.) The polyethylene sheet then can be removed and the pressure balance controlled during the test to within this new setting ±10 Pa (±0.21 lbf/ft^2). If the polyethylene sheet has bowed away from the specimen, it can be assumed that a net air leakage in the direction of exfiltration exists. If this situation still exists after rechecking and modifying the sealing tape or caulk as necessary the pressure balance setting can be adjusted in 2.5 Pa (0.05 lbf/ft^2) increments until the polyethylene sheet has moved back to its original position or is bowed slightly away from the specimen. (Again, wait at least 5 minutes after each adjustment before making observations.) The polyethylene sheet then can be removed and the pressure balance controlled during the test to within this new setting ±10 Pa (±0.21 lbf/ft^2). In a similar manner, if air leakage is found to exist through the combination of the calibration transfer standard (or fenestration test specimen) and the surround panel due to leakage sites at the surround panel/test frame interface, the pressure balance system can be set to allow a minimal amount of exfiltration. However, this should only be done after all attempts to seal these air leakage sites have been exhausted. — For sealing procedures, see Practice E 1423.

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 C1363. Seal the surround panel to the conditions specified in 5.1.5, 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) 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.) 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:

$$Q_{FL} = Q - Q_{sp}$$ (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} = $k_{C_{sp}} \bullet A_{sp} \bullet (t_{sp1} - t_{sp2})$, 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 1363steady-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:

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

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

where:
A_{sp} = surround panel area, m^2,
$t_{sp\,1}$ = area weighted room side surround panel surface temperature, °C, and
$t_{sp\,2}$ = 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 $t_{b1} \neq \geq t_h \pm 1$°C ($\pm 2$°F) and $+1$°C (2°F) or $t_{b1} < t_h -1$°C (2°F) and $t_{b2} \neq \geq t_c \pm 1$°C ($\pm 2$°F), after calculating t_{+1}°C (2°F) or $t_{b2} < t_c -1$°C (2°F), after calculating t_1 and t_2 from Eq 5 and 1from 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:

$$h_h = [Q_S/A_S (t_h - t_1)]$$ (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:

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