Designation: C 1363 – 97

Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus[1]

This standard is issued under the fixed designation C 1363; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the laboratory measurement of heat transfer through a specimen under controlled air temperature, air velocity, and thermal radiation conditions established in a metering chamber on one side and in a climatic chamber on the other side.

1.2 This test method generally is used for large homogeneous or nonhomogeneous specimens. This test method may be applied to any building structure or composite assemblies of building elements for which it is possible to build a representative specimen of a size that is appropriate for the apparatus.

NOTE 1—This test method was prepared for the purpose of replacing Test Methods C 236 and C 976. The test method was developed by combining the technical information contained in the two existing hot box methods with some additional information added to improve the test accuracy and reproducibility. Test apparatus, designed and operated under Test Methods C 236 and C 976, should, in most cases, meet the requirements of this test method with only slight modifications to calibration and operational procedures.

1.3 This test method is intended for use at conditions typical of normal building applications. The usual consideration is to duplicate naturally occurring outside conditions that in temperate zones may range from approximately –48 to 85°C and normal inside residential temperatures of approximately 21°C. Building materials used to construct the specimens are generally pre-conditioned to typical laboratory conditions of 23°C and 50 % relative humidity prior to assembly. Practice C 870 may be used as a guide for sample conditioning. Further conditioning prior to testing may be performed to provide moisture conditioned samples, if necessary.

1.4 This test method permits operation under natural or forced convective conditions at the specimen surface. The direction of air flow motion may be either perpendicular or parallel to the surface.

1.5 The hot box apparatus also can be used for measurements of individual building elements that are smaller than the metering area. Special calibration specimens and procedures are required for these tests. The general testing procedures for these cases are described in Annex A4.

1.6 Specific procedures for the thermal testing of window and door systems are described in Test Method C 1199 and Practice E 1423. The hot box also may be used to investigate the effect of non-homogeneous building assemblies such as structural members, piping, electrical outlets, or construction defects such as insulation voids.

1.7 This test method governs steady-state tests and does not establish procedures or criteria for conducting dynamic tests or for analysis of dynamic test data. However, several hot box apparatuses have been operated under dynamic (non-steady-state) conditions **(1)**. Dynamic control strategies have included both periodic or non-periodic temperature cycles, for example, to follow a diurnal cycle.

1.8 This test method does not permit intentional mass transfer of air or moisture through the specimen during measurements of energy transfer. Air infiltration or moisture migration can significantly alter net heat transfer. Complicated interactions and dependence upon many variables, coupled with only a limited experience in testing under such conditions, have made it inadvisable to include this type of testing in this test method. ASTM Subcommittee C16.30 has several task groups that are researching this testing need, and will be preparing a separate standard. Further considerations for such testing are given in Appendix X1.

1.9 This test method sets forth the general design requirements necessary to construct and operate a satisfactory hot box apparatus, and covers a wide variety of apparatus constructions, test conditions, and operating conditions. Detailed designs conforming to this test method are not given, but must be developed within the constraints of the general requirements. Examples of analysis tools, concepts, and procedures used in the design, construction, calibration, and operation of a hot box apparatus are provided in Refs (1-26).

1.10 This test method does not specify all details necessary for the operation of the apparatus. Decisions on sampling, specimen selection, preconditioning, specimen mounting and positioning, the choice of test conditions, and the evaluation of test data shall follow applicable ASTM test methods, guides,

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

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practices, or product specifications or government regulations. If no applicable standard exists, sound engineering judgment that reflects accepted heat transfer principles shall be used and documented.

1.11 In order to ensure the level of precision and accuracy expected, persons applying this test method must possess a knowledge of the requirements of thermal measurements and testing practice and of the practical application of heat transfer theory relating to thermal insulation materials and systems. Detailed operating procedures, including design schematics and electrical drawings, should be available for each apparatus to ensure that tests are in accordance with this test method.

1.12 The hot box apparatus, when constructed to measure heat transfer in the horizontal direction, can be used for testing walls and other vertical structures. When constructed to measure heat transfer in the vertical direction, the hot box can be used for testing roof, ceiling, floor, and other horizontal structures. Other orientations are also permitted. The same apparatus may be used in several orientations but may require special design capability to permit repositioning to each orientation. Whatever the test orientation, the apparatus performance first shall be verified at that orientation with a traceable specimen in place to confirm its ability to accurately obtain results at that orientation.

1.13 *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]

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 Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[2]

C 870 Practice for Conditioning of Thermal Insulating Materials[2]

C 976 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box[2]

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

C 1058 Practice for Selecting Temperatures for Reporting and Evaluating Thermal Properties of Thermal Insulations[2]

C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[2]

C 1132 Practice for Calibration of the Heat Flow Meter Apparatus[2]

C 1130 Practice for Calibrating Thin Heat Flux Transducers[2]

C 1199 Test Method for Measuring the Steady State Thermal Transmittance of Fenestration Systems Using Hot Box Methods[2]

E 230 Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples[3]

E 283 Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors[4]

E 1423 Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems[4]

E 1424 Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen[4]

2.2 *Other Documents:*

ASHRAE Handbook 1993 Fundamentals Volume, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.[5]

ISO Standard 8990 Thermal Insulation Determination of Steady State Thermal Properties—Calibrated and Guarded Hot Box, ISO 8990-1994(E)[6]

3. Terminology

3.1 *Definitions*—Definitions of terms relating to insulating materials and testing used herein are governed by Terminology C 168. All terms discussed in this test method can be assumed to be those associated with thermal properties of the tested specimen unless otherwise noted.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *metering box energy flow*, *n*—The time rate of energy loss or gain through the walls of the metering box that must be subtracted from or added to the energy input to the metering chamber as part of the determination of the net energy flow through the test specimen. A more complete discussion of the metering box loss is provided in Annex A1.

3.2.2 *flanking path energy flow*, *n*—The time rate of energy loss or gain from the metering chamber to the climatic chamber that passes through the sample or sample holder beyond the boundaries of the metering chamber. This energy exchange must also be subtracted from or added to the energy input to the metering chamber as part of the determination of the net energy flow through the test specimen. A more complete discussion of the flanking loss is provided in Annex A3.

3.2.3 *surface resistance,* R_i—the quantity determined by the temperature difference, at steady state, between an isothermal surface and its surroundings that induces a unit heat flow per unit area by the combined effects of conduction, convection, and radiation. Subscripts h and c are used to differentiate between hot side and cold side surface resistances, respectively. Surface resistances are calculated as follows (see Note 5):

$$R_h = \frac{A \bullet (t_{env,h} - t_1)}{Q} \tag{1}$$

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

[3] *Annual Book of Standards*, Vol 14.01.

[4] *Annual Book of Standards*, Vol 04.07.

[5] Available from ASHRAE Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329.

[6] Available from ANSI, 105-111 South State St., Hackensack, New Jersey 07601.

$$R_c = \frac{A \bullet (t_2 - t_{env,c})}{Q} \tag{2}$$

3.2.4 Overall thermal resistance, R_u – the quantity determined by the temperature difference, at steady state, between the environments on the two sides of a body or assembly that induces a unit heat flow per unit area by the combined effects of conduction, convection and radiation. It is equal to the sum of the resistances of the body or assembly and of the two surface resistances and may be calculated as follows:

$$R_u = \frac{A \bullet (t_{env,h} - t_{env,c})}{Q} \tag{3}$$

$$= R_c + R + R_h$$

3.2.5 Surface Coefficient Determination – An expanded discussion of the interactions between the radiation and convective heat transfer at the surfaces of the test sample is included in Annex A6. The material presented in Annex A6 must be used to determine the magnitude of the environmental temperature which may be required to correct for radiation heat flow from the air curtain baffle.

3.2.6 For very non-uniform specimens where the heat transfer is greatly different from one area to another, and if detailed temperature profiles are not known, only the net heat transfer through the specimen may be meaningful. In these cases, only the overall resistance, R_u, and transmission coefficient, U, are permitted.

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

A = metered area, m^2

λ = thermal conductivity, W/(m•K)

C = thermal conductance, W/(m^2•K)

E = emf output of heat flux transducer or thermocouple, V

h_h = surface heat transfer coefficient, hot side, W/(m^2•K)

h_c = surface heat transfer coefficient, cold side, W/(m^2•K)

h_{conv} = convective surface heat transfer coefficient, W/(m^2•K)

h_{rad} = radiative surface heat transfer coefficient, W/(m^2•K)

L = length of the heat loss path (usually the thickness of the test panel), m

q = heat flux (time rate of heat flow through unit area *A*), W/m^2

Q = time rate of heat flow, total power input to the metering box, W

R = thermal resistance m^2•K/W

R_h = surface resistance, hot side, m^2•K/W

R_c = surface resistance, cold side, m^2•K/W

R_u = overall thermal resistance, m^2•K/W

S = heat flux transducer calibration factor (a function of temperature), W/(m^2•V)

t_a = temperature of ambient air, K or °C

t_{env} = the effective environmental temperature including radiation and convective effects, K or °C (See Annex A6)

t_h = average air temperature 75 mm or more from the hot side surface, K or °C

t_1 = area weighted temperature of specimen hot surface, K or °C

t_2 = area weighted temperature of the specimen cold surface, K or °C

t_c = average air temperature 75 mm or more from the cold side surface, K or °C

t_m = average specimen temperature—average of two opposite surface temperatures, K or °C

Δt = temperature difference between two planes of interest, K or °C

$\Delta t_{s\text{-}s}$ = temperature difference—surface to surface, K or °C

$\Delta t_{a\text{-}a}$ = temperature difference—air to air, K or °C

τ_{eff} = effective thermal time constant of combined apparatus and specimen, *s*

U = thermal transmittance, W/(m^2•K)

3.4 *Equations*—The following equations are defined here to simplify their use in the Calculations section of this test method.

3.4.1 *apparent thermal conductivity:*

$$\lambda = \frac{Q \bullet L}{A\ (t_1 - t_2)} \tag{4}$$

NOTE 2—Materials are considered homogeneous when the value of the thermal conductivity is not significantly affected by variations in the thickness or area of the sample within the range of those variables normally used.

3.4.2 *thermal resistance, R*:

$$R = \frac{A \bullet (t_1 - t_2)}{Q} \tag{5}$$

3.4.3 *thermal conductance, C*:

$$C = \frac{Q}{A \bullet (t_1 - t_2)} \tag{6}$$

NOTE 3—Thermal resistance, *R*, and the corresponding thermal conductance, *C*, are reciprocals, that is, their product is unity. These terms apply to specific bodies or constructions as used, either homogeneous or heterogeneous, between two specified isothermal surfaces.

3.4.4 *surface heat transfer coefficient, h*, is often called surface conductance or film coefficient. Subscripts *h* and *c* are used to differentiate between hot side and cold side surface conductances, respectively. These conductances are calculated as follows:

$$h_h = \frac{Q}{A \bullet (t_{env,h} - t_1)} \tag{7}$$

$$h_c = \frac{Q}{A \bullet (t_2 - t_{env,c})} \tag{8}$$

NOTE 4—The surface heat transfer coefficient, h_i, and the corresponding surface resistance, R_i, (see 3.5.1) are reciprocals, that is, their product is unity.

3.4.5 *thermal transmittance, U* (sometimes called overall coefficient of heat transfer). It is calculated as follows:

$$U = \frac{Q}{A \bullet (t_{env,h} - t_{env,c})} \tag{9}$$

The transmittance can be calculated from the thermal conductance and the surface heat transfer coefficients as follows:

$$1/U = (1/h_h) + (1/C) + (/h_c) \quad (10)$$

NOTE 5—Thermal transmittance, U, and the corresponding overall thermal resistance, R_u (see 3.5.2), are reciprocals, that is, their product is unity.

4. Summary of Test Method

4.1 The hot box apparatus is designed to determine thermal performance for representative test specimens by establishing and maintaining a desired steady temperature difference across the test specimen for the period of time necessary to ensure constant energy flux and steady temperatures, and for an additional period adequate to measure these quantities to the desired accuracy.

4.2 To determine the conductance, C, the transmittance, U, or the resistance, R, of any specimen, it is necessary to know the area, A, the net energy flow,Q and the temperature differences, ΔT, all of which must be determined under such conditions that the flow of energy is steady.

4.3 The area and temperatures can be measured directly. The energy flow Q, however, cannot be directly measured. To determine the net energy flow through the specimen, a five-sided metering box is placed with its open side against the warm face of the test panel.

4.4 If there were no net energy exchange across the walls that of the metering box and the flanking loss around the specimen is negligible, then the heat input from the fan and heaters minus any cooling coil energy extraction from the metering box would be a measure of the energy flux through the metered area of the specimen.

4.5 Since it is impractical to have the condition described in 4.4, the hot box apparatus must be designed to obtain an accurate measure of the net sample heat flow. The net energy transfer through the specimen is determined from net measured energy input to the metering chamber, corrected for the losses through the chamber walls and flanking loss for the specimen at the perimeter of the metering area.

4.6 The heat loss rate through the metering chamber walls is limited by the use of highly insulated walls, by control of the surrounding ambient temperature, or by use of a temperature controlled guard chamber.

4.7 The portion of the specimen or specimen frame outside the boundary of the metering area, exposed to the guarding space temperature, constitutes a passive guard to minimize flanking heat flow in the test panel near the perimeter of the metering area (see Annex A3 and Annex A4).

4.8 Both the metering chamber wall loss and the flanking loss corrections are based upon a series of calibration tests using specimens of known thermal properties that cover the range of anticipated performance levels and test conditions (see Annex A1-Annex A3 for details).

5. Significance and Use

5.1 There is a need for accurate data on heat transfer through insulations and through insulated structures. The data are needed to judge compliance with specifications and regulations and are needed for design guidance, for research evaluations of the effect of changes in materials or constructions, and for verification of, or use in, simulation models. Other ASTM standards such as Test Methods C 177 and C 518 are adequate in providing data on small scale, homogeneous specimens bounded by temperature controlled flat impervious plates. This test method is more suitable for providing such data for large specimens, usually of a built-up or composite nature, that are exposed to temperature-controlled air on both sides.

5.2 For the results to be representative of a building construction, only representative full-scale sections should be tested. The specimens should duplicate framing geometry, material composition and installation practice, and orientation of construction.

5.3 This test method does not establish test conditions, specimen configuration, or data analysis procedures, but leaves these choices to be made in a manner consistent with the specific application being considered. Data obtained by the use of this test method will be representative of the specimen performance only for the conditions of the test. It is unlikely that the test conditions will exactly duplicate in-use conditions and the user of test results must be warned about possible significant differences.

5.4 Detailed heat flow analysis should precede the use of the hot box apparatus for large, complex structures. Structures which contain cavity spaces between adjacent surfaces, that is, an attic section including a ceiling with sloping roof, may be difficult to test properly. Consideration must be given to the effects of specimen size, natural air movement, ventilation effects, radiative effects, baffles at the guard/meter interface, etc. when designing the test arrangement.

5.5 For vertical specimens with air spaces that significantly affect thermal performance, the metering chamber dimension should ideally match the construction height. If this is not possible, horizontal convection barriers shall be installed inside the test specimen air cavities at the metering chamber boundaries to prevent air exchange between the metering and guarding areas.

5.6 Since this test method is used to determine the total energy flow through the test area demarcated by the metering box, it is possible to determine the energy flow through a building element smaller than the test area, such as a window or representative area of a panel unit, if the parallel heat flow through the remaining surrounding area is independently determined. See Annex A4 for the general method.

5.7 Discussion of all special conditions used during the test shall be included in the test report (see Section 12).

6. Apparatus

6.1 *Introduction*—The design of a successful hot box apparatus is influenced by many factors. Before beginning the design of an apparatus meeting this test method, the designer should review the discussion on limitations and accuracy in Section 13, discussions of metering box loss inAnnex A1 and Annex A2, and flanking loss, Annex A3. This, hopefully, will provide the designer with an appreciation of the required technical design considerations.

6.2 *Definition of Location and Areas*—The major components of a hot box apparatus are (1) the metering chamber on one side of the specimen, (2) the climatic chamber on the other, (3) the specimen frame providing specimen support and perimeter insulation, and (4) the surrounding ambient space.

These elements must be designed as a system to provide the desired air temperature, air velocity, and radiation conditions for the test, and to accurately measure the resulting net heat transfer. A diagram of the relative arrangement of those spaces is shown in Fig. 1.

6.2.1 The basic hot box apparatus can be assembled in a wide variety of sizes, orientations, and designs. Two configurations historically have been used for a majority of the designs. The first is the classic guarded hot box, which has a controlled "guard" chamber surrounding the metering box. An example of this configuration is presented in Fig. 2.

6.2.2 The second configuration is known as the calibrated hot box. This configuration can be considered a special case of the guarded hot box in which the surrounding ambient is used as the guard chamber. An additional design consideration for this hot box design is that the metering chamber walls must have sufficient thermal resistance to reduce the metering wall energy flow to an acceptable level. The calibrated design is generally used for testing of large specimens where the cost of a large guard chamber is prohibitive. Fig. 3 shows an example of a calibrated apparatus for horizontal heat transfer.

NOTE 6—The two opposing chambers or boxes are identified as the metering chamber and the climatic chamber. In the usual arrangement, the temperature of the metering chamber is greater than that of the climatic chamber and the common designations of "hot box" and "cold box" apply. In some apparatus, either direction of energy flow may apply.

6.3 *Apparatus Size*—The overall apparatus shall be sized according to its intended use. For building assemblies, it shall accommodate typical full-scale sections. No one size is considered standard. Generally, the maximum accuracy is obtained when the specimen size is at least that of the metering chamber while the climatic chamber must also match or be larger.

NOTE 7—A large apparatus is desirable in order to minimize perimeter effects in relation to the metered area, but large boxes also exhibit longer equilibrium times, thus a practical compromise must be reached. Typical heights for wall testers are 2.5 to 3 m with widths equal to or exceeding the height. Floor/ceiling testers up to 4 by 6 m have been built.

6.4 *Construction Materials*—Materials used in the construction of the hot box apparatus require a high thermal resistivity. Polystyrene or other foam materials have been used since they combine both high thermal resistivity, good mechanical properties, and ease of fabrication. One potential problem with some foams is that they exhibit time-dependent thermal properties that would adversely affect the thermal calibration of the apparatus. Most problems associated with the use of these materials can be avoided if material is selected that is initially well along the aging process and by periodic checks of calibration to guarantee that the calibration has not changed significantly over time.

6.5 *Metering Chamber*:

6.5.1 The minimum size of the metering box is governed by the metering area required to obtain a representative test area of specimen and for maintenance of reasonable test accuracy. For example, for specimens incorporating air spaces or stud spaces, the metering area should exactly span an integral number of spaces (see 5.5). The depth of the metering box should no be greater than that required to accommodate its necessary equipment. Measurement errors in testing with a hot box apparatus are, in part, proportional to the length of the perimeter of the metering area. The relative influence of this diminishes as metering area is increased. Hot Box operators' experience has demonstrated that for the guarded hot box configuration, the minimum size of the metering area is 3 times the specimen thickness or 1 m^2, whichever is larger **(18)**. From the same experience base, the calibrated box configuration, a minimum specimen size is 1.5 m^2.

6.5.2 The purpose of the metering chamber is to provide for the control and measurement of air temperatures and velocities on one face of the specimen under fixed conditions and for the measurement of the net energy transfer through the specimen. The usual arrangement is a five-sided chamber containing electrical heaters, cooling coils (if desired), and an air circulation system. At steady-state conditions, the energy transfer through the specimen equals the electrical power to the heaters

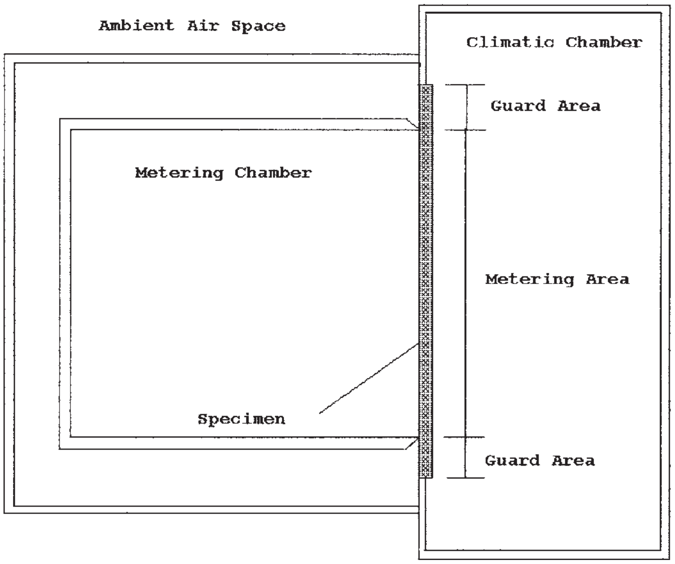

FIG. 1 Typical Hot Box Apparatus Schematic—Definition of Locations / Areas

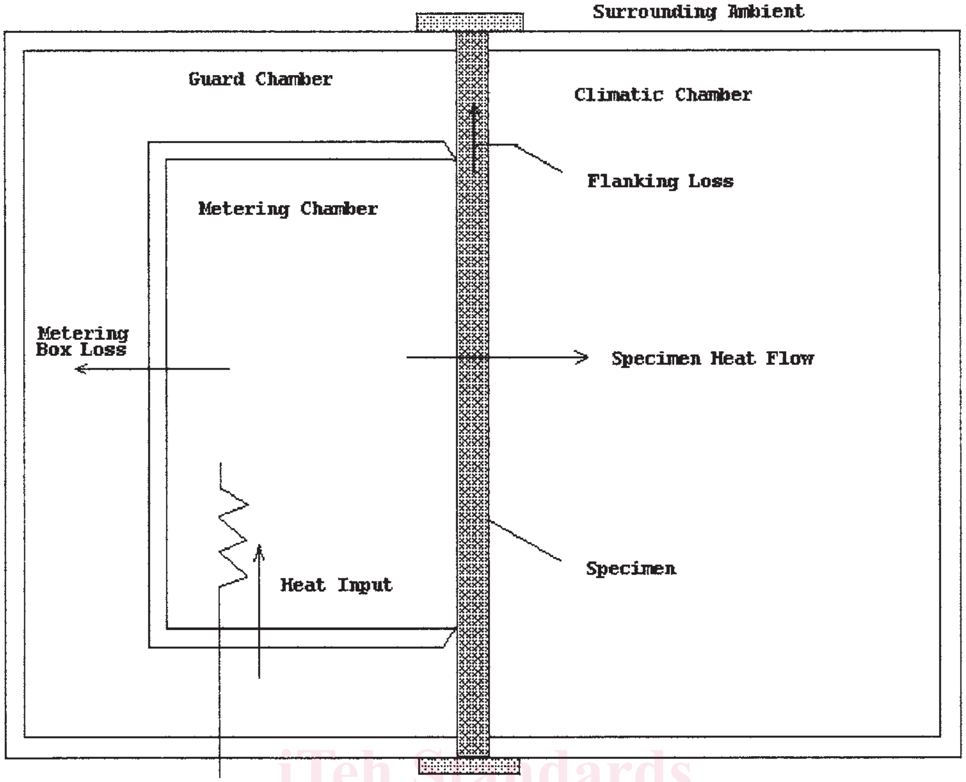

FIG. 2 Schematic Guarded Hot Box

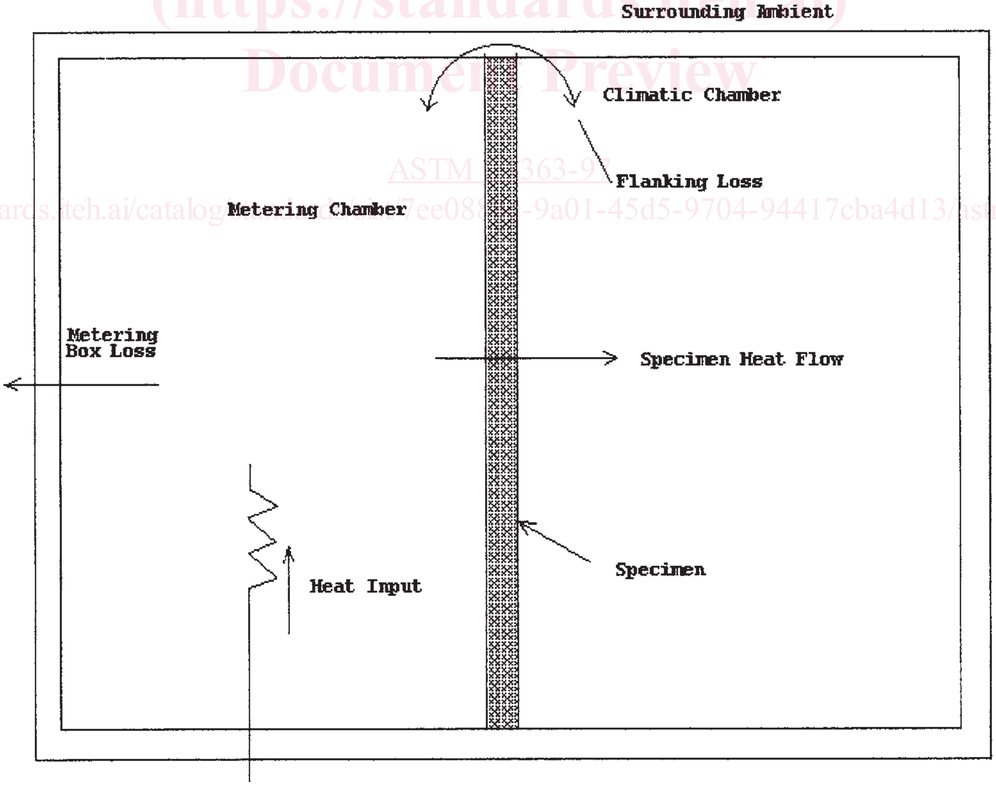

FIG. 3 Typical Calibrated Hot Box Apparatus

and blowers minus the cooling energy extraction, corrected for the energy passing through the chamber walls and flanking the specimen. Both the metering box wall energy flow and flanking path energy flow are determined from calibration measurements (see Section 8).

6.5.3 To minimize measurement errors, several requirements are placed upon the metering chamber walls and the adjoining ambient space:

6.5.3.1 The metering chamber energy corrections, which may be estimated for design purpose by the equations in Annex A1, Annex A2, and Annex A3, must be kept small, by making the metering box wall area small, keeping its thermal resistance high, or by minimizing the temperature difference across the wall (see Note 8). However large the wall losses are, the uncertainty of the resulting corrections to the net energy flow shall not exceed 0.5 % of the net energy flow through the specimen. In some designs, it has been necessary to use a partial guard to minimize metering chamber wall loss.

6.5.3.2 The metering chamber wall losses should be as low as 1 or 2 % of the heat transfer through the specimen and should never be greater than 10 % of the specimen heat transfer if the highest accuracy is to be achieved. In any case, the minimum thermal resistance of the metering chamber walls shall be greater than 0.83 m^2K/W.

NOTE 8—The 10 % limit is recommended as an extreme and is based upon operator experience and potential errors analysis. The choice of construction of the metering chamber can be made only after review of the expected test conditions in which chamber wall losses and their uncertainties are considered in relation to the anticipated heat transfer through the test specimen and its desired maximum uncertainty. The influence of the guarding temperature upon the ability to maintain steady temperatures within the metering chamber also must be considered in choosing between highly insulated walls and a tightly controlled guard space conditioning.

6.5.3.3 For best results, the heat transfer through the metering chamber walls should be uniform so that a limited number of heat flux transducers or differential thermocouples can be used to characterize the energy flow from each representative area. This goal is best approximated by the use of a monolithic, uniform insulation uninterrupted by highly conducting structural members, and by eliminating any localized hot or cold sources from the adjoining space. Any structural members shall not be within the insulation. Thermal bridges, structural cracks, insulation voids, air leaks, and localized hot or cold spots from the conditioning equipment inside the metering chamber walls should be avoided as much as possible.

NOTE 9—One method of constructing satisfactory chamber walls is by gluing together large blocks of an aged, uniform low conductivity cellular plastic insulation such as extruded polystyrene foam. A thin covering of a reinforced plastic or coated plywood is recommended to provide durability, moisture, and air infiltration control.

6.5.3.4 To ensure uniform radiant heat transfer exposure of the specimen, all surfaces that can exchange radiation with the specimen shall have a total hemispherical emittance greater than 0.8.

6.5.3.5 In applications where the metering chamber contacts the specimen at locations within its edge boundaries, an air-tight seal between the specimen and metering wall shall be provided. The cross section of the contact surface of the metering chamber with the specimen shall be narrowed to the minimum width necessary to hold the seal. A maximum width of 13 mm, measured parallel to the specimen surface plane, shall be used as a guide for design. Periodic inspections of the sealing system are recommended in order to confirm its ability to provide a tight seal under test conditions.

6.5.4 Since one basic principle of the test method is to characterize the energy flow through the metering box walls, adequate controls and temperature-monitoring capabilities are essential. Small temperature gradients through the walls can occur due to the limitations of controllers. Since the total wall area of the metering box is often more than twice the metering area of the panel, these small temperature gradients through the walls may cause energy flows totaling a significant fraction of the energy input to the metering box. For this reason, the metering box walls shall be instrumented to serve as a heat flow transducer so that energy flow through them can be minimized and measured and a heat flow correction for metering chamber wall energy flow shall be applied in calculating test results. The use of one of the following methods is recommended for monitoring metering box wall heat loss.

NOTE 10—The choice of transducer types and mounting methods used to measure the heat flow through the metering chamber walls is arbitrary. However, they must provide adequate coverage and output signal to properly quantify the metering chamber wall heat loss during testing.

6.5.4.1 The walls may be used as heat flow transducers by application of a large number of differential thermocouples connected between the inside and outside surfaces of the metering chamber walls. Caution should be taken when determining locations of the differential thermocouples, as temperature gradients on the inside and outside of the metering box walls are likely to exist and have been found to be a function of metering and environmental air velocities and temperatures. Precautions shall also be taken when determining the number of differential thermocouples. Based upon a survey of hot box operators **(18)**, five differential thermocouple pairs per m^2 of metering box wall area are recommended as a minimum. At no time shall there be less than one pair of differential thermocouples on each of the five sides of the metering chamber. The thermocouple junctions shall be located directly opposite each other and, preferably, located at the centers of approximately equal areas. Small pieces of foil, having surface emittance matching the remainder of the box walls, may be attached to the thermocouples to facilitate the thermal contact with the wall surface. The junctions and the attached thermocouple wires shall be flush with, and in thermal contact with, the surface of the wall for at least a 100 mm distance from the junctions. The thermocouple pairs may be connected in series to form a thermopile in which the individual emf's are summed to give a single output or readout individually in cases where significant differences may occur or be expected in the local heat flow levels.

6.5.4.2 Separate heat flux transducers may be placed on the metering chamber walls. Precautions shall be taken in choosing and installing the transducers to ensure that the thermal resistance of the wall and its surface emittance remain essentially unchanged. The transducers should initially be calibrated separately to ensure that the relative sensitivities are approximately the same. Since the transducer sensitivity is also temperature-sensitive, temperature sensors shall be installed at the same or adjacent location. The outputs from these transducers may be measured separately or as a group. If measured separately, the transducers should be demountable from the surface so their calibrations, at heat flux levels typical of use, may be checked periodically (see Practice C 1130). If the measurement procedure is to calibrate the chamber with the heat flux transducers in place, the transducer outputs may be connected in series to provide a single reading.

6.5.4.3 Regardless of the method of hot box metering wall instrumentation used, the metering box wall losses shall be correlated with the signal outputs during the calibration process. See Section 8 and Annex A2 for this process.

6.6 *Climatic Chamber*:

6.6.1 The purpose of the climatic chamber is to provide for the control and measurement of the air temperature and velocity under fixed conditions on the side of the specimen opposite the metering chamber. In the usual arrangement, it consists of a five-sided insulated chamber with internal dimensions matching or greater than the test specimen and with sufficient depth to contain the required cooling, heating, and air circulation equipment. An acceptable alternate is to utilize a large environmental chamber with an opening matching the specimen size. This arrangement is specially suited for a floor/ceiling test apparatus in which large roof/attic structures are to be tested.

6.6.2 The walls of the climatic chamber also should be well insulated to reduce the refrigeration capacity required.

6.6.3 Heaters, fans, and cooling coils should be placed such that the internal surface temperatures as seen by the specimen are not greatly different from the air temperatures. The internal surfaces of the climatic chamber shall also meet the criteria of 6.5.3.4 for surface emittance.

6.7 *Specimen Frame*:

6.7.1 A specimen frame shall be provided to support and position the specimen and to provide the needed perimeter insulation. The frame opening shall have dimensions at least of those of the metering chamber opening. In the direction of energy flow, the frame shall be at least as thick as the thickest specimen to be tested. In the outward direction perpendicular to the normal heat flow direction, the wall thickness of the specimen frame shall be at least equal to that of the metering chamber walls or 100 mm, whichever is greater.

6.7.2 Care must be taken in the design and construction of specimen frames so that flanking losses are minimized. Thus the thermal resistance of flanking paths that would allow heat to bypass the specimen must be kept high. Conductive plates, fasteners, or structural members shall not be used in the flanking paths and the thickness and conductance of skins must be kept to a minimum.

6.8 *Air Circulation*:

6.8.1 The measured overall resistance, R_u, and, when applicable, the surface resistances, R_h or R_c, depend upon the velocity, temperature uniformity, and distribution patterns of the air circulated past the sample surface.

6.8.2 Circulation air temperature differences of several degrees can exist from air curtain entrance to exit due to heating or cooling of the air curtain as it passes over the sample surface. The magnitude of this difference is a function of the energy flow through the specimen and the velocity and volume of the air flow. When natural convection is desired, the temperature differences will be larger. A forced air flow reduces the magnitude of this difference.

6.8.3 Natural convection tests may be required for a wall test apparatus or in a floor/ceiling test apparatus without forced ventilation. When desired, tests may be run under these natural convection conditions. The air velocity shall be below 0.5 m/s if natural convective air conditions are to be approximated with some forced air flow to maintain temperature control.

6.8.4 When more uniform air temperatures are desired, it is necessary to provide curtains of forced air moving past the specimen surfaces.

6.8.5 The design of the air circulation system will have an impact on this difference, and trade-offs during design must be made between the desired uniformity of the air curtain temperatures and the operational mode of convective flow. A velocity of approximately 0.3 m/s has proven satisfactory for a wall test apparatus of 3 m height when testing insulated wall systems.

6.8.6 For the most uniform test results, the maximum temperature change for the circulating air exposed to the test panels shall be less than 2 % of the overall air-to-air temperature difference. The gradient along the direction of flow should be held to less than 1 K/m.

6.8.7 The direction of air flow in a hot box apparatus is arbitrary and may be parallel, that is, up, down, horizontal, or perpendicular to surface. However, less fan power is required to maintain air movement in the direction of natural convection (down on the hot side, up on the cold) and that direction is recommended. In some situations, however, the specification requirements may dictate that a specific direction is necessary to evaluate the system performance.

6.8.8 Higher air velocities are permissible when their effect upon heat transfer is to be determined. Velocities commonly used to simulate parallel or perpendicular wind conditions on the exterior side are 3.4 m/s for summer conditions and 6.7 m/s for winder conditions.

NOTE 11—Distinction should be made between the effects and requirements of air velocity parallel to the specimen surface and those for velocity perpendicular to it. Parallel velocities simulate the effect of the cross winds, and may be achieved by moving a small amount of air confined in a narrow baffle space and therefore require relatively little blower power. Perpendicular velocities simulating direct wind impingement require moving larger amounts of air with corresponding larger power requirements. The baffles in the second case must be placed further from the specimen surface and should have a porous section (a set of screens or a honeycomb air straightener) that directs the air stream to the specimen surface. Fig. 4 shows an example of climatic chamber arrangement for perpendicular flow.

6.8.9 *Air baffles*—For parallel flow, a baffle, parallel to the specimen surface, shall be used to confine the air to a uniform channel, thus aiding in maintaining an air curtain with uniform velocities.

6.8.9.1 The baffle thermal resistance should be adequate to shield the test panel surface from any heat sources located behind it. A baffle thermal resistance of 1 (K m^2/W) is recommended for this purpose.

6.8.9.2 The baffle-to-specimen spacing may be adjustable to serve as one means of adjusting the air flow velocity. For the

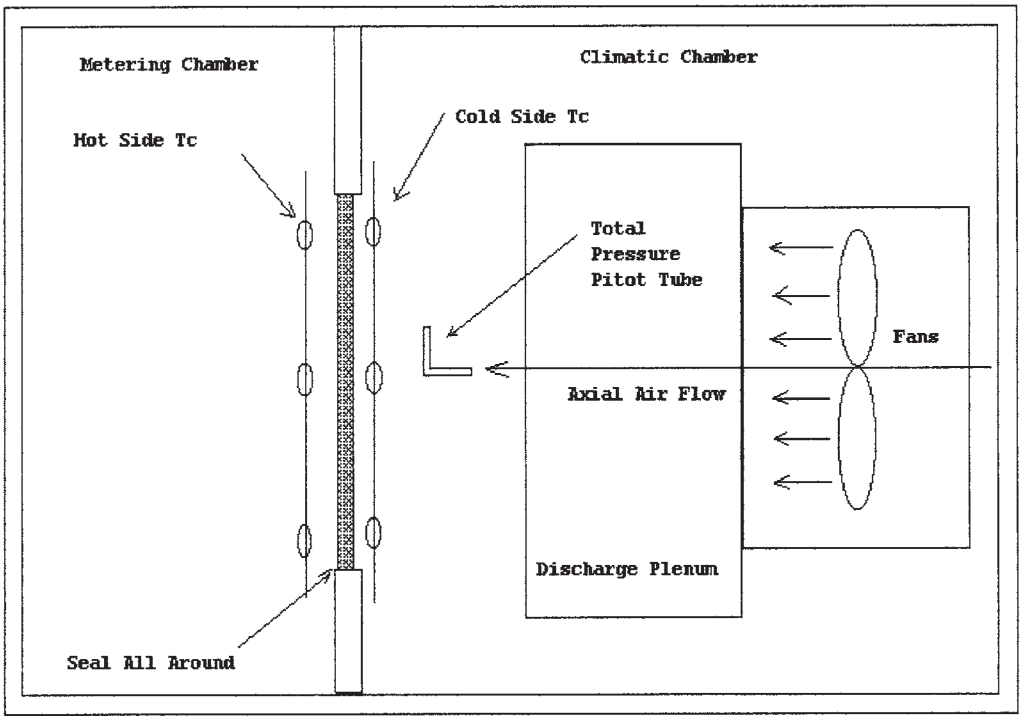

FIG. 4 Hot Box Arrangement for Perpendicular Air Flow

purpose of maintaining a well-mixed and characterized air curtain, a spacing of 150 to 200 mm is recommended.

6.8.9.3 A baffle also serves as a radiation exchange surface with a uniform temperature only slightly different than that of the air curtain. The baffle surface facing the specimen shall have an emittance greater than 0.8.

6.8.10 *Air curtain velocity uniformity*—Uniform air flow across the specimen width may be achieved by use of multiple fans or blowers or by use of an inlet distribution header across one edge of the baffle and an outlet slot across the opposite. The inlet header should incorporate adjustable slots or louvers to air in obtaining uniform distribution.

6.8.10.1 After construction of an air circulation system, an air velocity profile shall be made across the area perpendicular to the direction of air flow in the proximity of the specimen. The air velocity profile shall be defined as uniform if all measurements from the profile scan are within 10 % of the mean of all measurements. If the profile is not uniform, additional adjustments shall be made to the inlet header slot or louvers or in the placement of fans or blowers to achieve an air curtain with uniform velocity across its width. The velocity profiles shall be verified whenever modification or repairs of the distribution system are made that might cause a change in flow patterns. Also, the profiles shall be verified during calibration checks.

NOTE 12—Linear air diffusers designed for ceiling air distribution systems have been found satisfactory to use as distribution headers. For large floor/ceiling testers, it may be necessary to use more than one set of fans or inlet and outlet headers creating opposing zones to obtain the required temperature uniformity.

6.8.11 *Air velocity measurement*—The apparatus design shall provide a means for determining mean air velocity past both the hot and cold faces of the specimen during each test. Acceptable methods are as follows:

6.8.11.1 One method is to meter the volumetric air flow in the duct to the inlet distribution header by using a calibrated orifice or other flow measuring device. The average baffle space velocity is then calculated from the volume flow and the size of the space between the specimen and the parallel baffle (assuming the baffle to be well-sealed).

6.8.11.2 Another method, which should be used only as a check of the previous methods, is to calculate the velocity from a heat balance between the rate of loss or gain of heat by the air as it moves through the baffle space, as indicated by its temperature change, and the rate of heat transfer through the test panel, average values of which can be determined from the test data.

6.8.11.3 The recommended method is to locate velocity sensors directly in the air curtain. For test purpose, wind velocity shall be measured at a fixed location that represents the average free stream condition. For both perpendicular and parallel flow patterns, this location shall 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 distance of 75 to 150 mm out from the test specimen surface at the center point is recommended. On the room side, where low circulation velocities are generally used, a properly located sensor is also required. The operator's experience and knowledge of the air distribution system obtained in the profiles from 6.8.9 should be used to determine the optimum sensor location.

6.9 *Air Temperature Control*:

6.9.1 Air entering the air curtains shall be uniform in temperature across its width and for steady-state tests it shall not change during the measurement period.

6.9.2 One method of providing controlled heated air is to install open wire, low thermal mass electrical heaters in an insulated low emittance section of the blower duct or other part of the air circulation system and to control these heaters using a sensor located at the inlet to the air curtain.

NOTE 13—Another method of heater control is to use several individual heaters that may be switched on to provide fixed levels of heat. Fine tuning is provided by an additional heater that is modulated by a controller. Another satisfactory method is to use a controller that varies the power to all the heaters.

6.9.3 Methods for cooling the climatic chamber include operating a refrigeration system evaporator inside the chamber, ducting in chilled air from an external source, or injecting liquid nitrogen. Usually the evaporator or external chilled air is controlled at a constant temperature a few degrees (typically <5 °C) below the desired setpoint. Then, a reheat and control system similar to that for obtaining heated air (see 6.9.2) is used to achieve fine control of the temperature at the inlet to the specimen air curtain. When liquid nitrogen is used, a valve regulating its flow may be pulsed on-off or modulated to obtain fine temperature control.

NOTE 14—One proven configuration for a climatic chamber utilizes two air circuits created by suitable baffles. The evaporator fan creates one circulation path that includes a mixing chamber from which air is circulated by a separate blower to the specimen air curtain and returned. An air reheat and control system provides fine control of air temperature at the distribution header inlet. Other proven configurations utilize only a single air circuit containing both cooling and reheat elements. Under certain conditions a desiccant may be needed to remove moisture from the air stream.

6.9.4 Metering chamber blowers should be small and efficient, since without cooling, they determine the least possible net heat input to the metering chamber. If large fans or blowers are necessary, then compensatory cooling with inherent loss in accuracy shall be used. Some heat may be removed by locating the blower motor outside of the metering chamber and accurately measuring the heat equivalent of the shaft power. Precautions shall be taken to prevent air leakage around the shaft.

6.9.5 When cooling of the metering chamber is required, it must be done in a manner in which the amount of energy extracted can be measured accurately. One method is to circulate a chilled liquid through a heat exchanger located in the metering chamber air circuit. The rate of energy extraction is controlled by the inlet-to-chamber air temperature difference, the flow rate, the liquid properties, and the heat exchanger efficiency. The amount of cooling used should be limited to that necessary to overcome any excess blower or other heating loads or to that necessary to achieve desired dynamic cool-down rates since test accuracy will be lost if excessive heating must be used to compensate for large cooling. For example, if both the heating and cooling energies are known to within 1 %, but the difference of these two energy levels is 10 % of the net heating or cooling, then the net energy exchange is known only to ±10 %.

6.9.6 *Special considerations, humidity control*—Moisture migration, condensation, and freezing within the specimen can also cause variations in heat flow. To avoid this, the dew point temperature on the warm side must be kept below the temperature of the cold side when the warm surface is susceptible to ingress of moisture vapor. In general, tests in the hot box apparatus are conducted on substantially dry test specimens, with no effort made to impose or account for the effect of the vapor flow through or into the specimen during the test.

6.10 *Temperature Measurement*:

6.10.1 When surface temperatures are required, specimen surface temperature sensors shall be located opposite each other on the two faces of the specimen. These sensors shall be chosen and applied to the surface in a manner such that the indicated temperature is within ± 0.2K of the temperature that would exist if the sensor had not been applied. This requirement is met by thermocouples if: (1) the wire is no larger in diameter than 0.25 mm (No. 30 AWG.); (2) they meet or are calibrated to the special limits of error as specified in Tables E 230; (3) if the junctions are twisted and welded or soldered; and (4) if at least 100mm of adjoining wire are taped, cemented, or otherwise held in thermal contact with the surface using materials of emittance close (± 0.05) to that of the surface. Application of alternate temperature sensor systems may be used if comparative measurements or calculations show that the basic requirements are met.

6.10.2 If the specimen construction, and therefore its thermal resistance, is uniform over its entire area, a minimum number of sensors spaced uniformly and symmetrically over the surface is sufficient. The required minimum number of sensors per side shall be at least 2 per square meter of metering area but not less than nine **(24)**.

6.10.2.1 If each element of the specimen construction is relatively uniform in thermal resistance and is repeated several times over the entire surface, the number of sensors specified in 6.10.2 may still be sufficient. In this case, the sensors shall be located to obtain the average surface temperature over each type of construction element and, for each type of element, shall be distributed approximately uniformly and symmetrically over the specimen area. The average surface temperature of the specimen shall be calculated by area weighting of the averages for the different types of construction elements.

6.10.2.2 If the surface temperatures are expected to be greatly nonuniform, additional sensors (often a great number such as two or three times the normal amount, as determined by trial and error) must be used to adequately sample the different temperature areas so that a reliable area weighted mean surface temperature may be obtained.

6.10.2.3 If an accurate determination of the average surface temperatures cannot be obtained, measure the transmission coefficient, U, or the overall resistance, R_u, and calculate the average panel resistance, R, of the specimen by subtracting off the previously determined surface thermal resistances established using a transfer standard of similar thermal resistance, size, surface configuration, and roughness. Note that the geometry, average temperatures, and energy exchange conditions must be similar for the calibration transfer standard and test panel for this technique to have reasonable accuracy (see Practice C 1199).

NOTE 15—Tests on specimens containing thermal bridges require special care because of the possible great differences in thermal resistance and temperatures between the thermal bridge areas and those of surrounding insulated structures. Added complications arise when tests are run at higher air velocities since temperatures and heat transfer can depend significantly upon bridge geometry relative to the overall sample as well as the velocity and direction of air movement. If test results are to be comparable for competing systems, they must be run under similar conditions. This method does not attempt to standardize such conditions.

6.10.3 Temperatures of the air on each side of the specimen may be measured by thermocouples or temperature-sensitive resistance wires or other sensors.

6.10.3.1 The minimum number and locations of sensors used to measure air temperatures shall be that specified for surface temperature sensors in 6.10.2. These sensors must be radiation shielded or otherwise protected to provide an accurate indication of the temperature of the air curtain. Sensors shall be small to ensure fast response to changing temperatures. Resistance wires, if used, shall be distributed uniformly in the air curtain.

NOTE 16—A suitable radiation shield may be made by using 12 mm diameter, 75 mm long pieces of thin walled plastic tubing covered on the inside and outside with aluminum foil tape. The air thermocouple is placed at the center of the tube to measure the air stream temperature and yet be shielded from radiation sources.

6.10.3.2 The best location for temperature sensors depends upon the type of air curtain convection (natural or forced). In natural convection situations, it is usually possible to identify the temperature of still air outside the boundary layer. Consequently, when natural convection is established, air temperature sensors shall be located in a plane parallel to the specimen surface and spaced far enough away from it that they are unaffected by temperature gradients of the boundary layer. For minimum velocities required to attain temperature uniformities (see 6.8 and Note 10) a minimum spacing from the specimen surface of 75 mm is suggested. At higher velocities, the required minimum spacing may be higher. The boundary layer thickness increases sharply at the transition from laminar to turbulent flow. With fully developed turbulent flow, the boundary layer occupies the full space between the specimen and the baffle. When forced convection is established and the flow is fully developed, the sensors shall be located at a distance from the specimen surface corresponding to ⅔ up to ¾ of the specimen-to-baffle distance. This is to detect a temperature approaching the air flow bulk temperature.

6.10.3.3 Thermocouple sensors used for measurement of air temperatures shall be made of wire not larger than 0.25 mm (No. 30 AWG) that meet or are calibrated to the special limits of error specified in Tables E 230 for Type T thermocouples. Other sensors are acceptable if they have similar time response and are calibrated so that the measurements are accurate within ± 0.5 K.

6.10.4 The surface temperature of the baffles in the metering and climatic chambers shall be measured by placing sensors on all surfaces seen by the specimen. A minimum area density of five sensors per meter squared of baffle area, but not less than one sensor per baffle surface, is recommended. Although not a specific requirement for some tests, this measurement is highly recommended for all tests since this data **(1)** can be used to determine any difference between the baffle surface and air curtain temperatures; **(2)** permits corrections to be made to the radiation component of the surface film conductances due to differences in these temperatures; and **(3)** is a necessary component of the data analysis for specimens such as windows that have a high thermal conductance (see discussion on mean radiant temperature determination in Annex A6).

6.11 *Specimen Pressure Difference*:

6.11.1 For some tests, it will be necessary to establish and measure the air pressure differential between the faces of the test specimen. This is especially important for window and other samples where the air flow resistance between the specimen surfaces is low. When this measurement is required, the specimen test pressure difference is defined as the difference, side to side, in local pressure measured in the direction perpendicular to the specimen surface, at a location at the geographic center of the metered area at a distance 75 mm from the surfaces of the sample. For a discussion of balancing pressure difference in a hot box apparatus, see Practice C 1199.

6.12 *Instruments*:

6.12.1 All signal conditioning and data logging instruments should be located outside of the apparatus, and shall meet the following requirements:

6.12.1.1 All instrumentation shall have adequate speed of sensor and readout response, time constants, so that the scanning speed will not adversely affect the measurement results.

6.12.1.2 Temperatures shall be readable to ±0.05 K and be accurate within ±0.5 K.

6.12.1.3 Heat flux transducer outputs shall be measured to the precision required to limit the error in estimation of the metering box wall heat transfer to less than ±0.5 % of the specimen heat transfer. This requires a heat flux transducer calibration accuracy of 5 % or better.

6.12.1.4 The types of acceptable air velocity sensors are not specified here as many are possible depending on the box design and test conditions. However, an accuracy of ±5 % of the reading is required and a sensor whose signal can be processed by automatic data acquisition equipment is recommended.

6.12.1.5 Pressure difference measurements shall be accurate to within ±5 % of reading.

6.12.1.6 Total average power (or integrated energy over a specified time period) to the metering box shall be accurate to within ±0.5 % of reading under conditions of use. Power measuring instruments shall be compatible with the power supplied, whether ac, dc, on-off, proportioning, etc. Voltage stabilized power supplies are strongly recommended. Metered cooling instruments shall be calibrated together as a system to similar accuracy by balancing cooling against measured heating.

6.12.1.7 Temperature controllers for steady-state tests shall be capable of controlling temperatures constant to within ±0.25K (see 6.9).

7. Sampling and Test Specimens

7.1 Test specimens shall be representative of typical product (field) applications. As such, tests on apparatus requiring smaller than representative specimens should be avoided. The construction details of the specimen to be investigated may be modified but only as necessary for test purposes. It must be