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Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box¹

This standard is issued under the fixed designation C 976; 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.

^{ε1} NOTE—Keywords were added editorially in March 1996.

1. Scope

1.1 This test method, known as the calibrated hot box method, provides for the laboratory measurement of heat transfer through a specimen under controlled air temperature, air velocity, and radiation conditions established in a metering chamber on one side and in a climatic chamber on the other side. It is primarily intended for measurements under steady-state conditions and at temperatures typical of normal building applications. Heat transfer through the specimen is determined from net measured heat input to the metering chamber, corrected for the estimated loss through the chamber walls and estimated loss flanking the specimen at its perimeter, both estimates being based upon calibrations using specimens of known thermal properties. Heat loss through the metering chamber walls is limited by highly insulated walls, and, when necessary, by control of the surrounding ambient temperature, or by use of a partial guard. In the normal configuration, the metered area of the specimen is surrounded by perimeter insulation rather than by additional specimen area as is used in the guarded hot box Test Method C 236.

1.2 The calibrated hot box method is specially suited for large nonhomogeneous specimens such as building structures and composite assemblies of building elements. It can be used for measurements of individual building elements such as windows and doors. Recommended practices for measurement of window and door thermal performance are being developed in Committees C-16 and E-6. The calibrated hot box method may also be used to investigate the effect of structural members, piping, electrical outlets, or construction defects, such as insulation voids, on the performance of a building section. The calibrated hot box may also be used for nonhomogeneous specimens not necessarily related to buildings, or for homogeneous specimens. Examples of the design, construction, calibration, operation, and use of calibrated hot boxes are given in the References (1-13).²

struction, calibration, operation, and use of calibrated hot boxes are given in the References (1-13).²

NOTE 1—The guarded hot box method, Test Method C 236, is an alternative for such measurements.

1.2.1 Since a full specimen is normally tested in the calibrated hot box, it is unnecessary and improper to install internal convection barriers in excess of those normally a part of the specimen. Such barriers would be required for a vertical specimen with internal cavities extending above or below the metered area.

1.3 When constructed to measure heat transfer in the horizontal direction, the calibrated hot box can be used for testing walls and other vertical structures and is commonly called a wall test apparatus. When constructed to measure heat transfer in the vertical direction it can be used for testing roof, ceiling, floor, and other horizontal structures and is commonly called a floor/ceiling test apparatus. Other orientations are allowable, and the same apparatus may be used for both vertical and horizontal testing if it can be rotated or reassembled in either orientation.

1.4 This method is established for steady-state tests; however, the apparatus may be operated under dynamic (non-steady-state) conditions, either periodic or nonperiodic, in which temperatures are changed during the test as, for example, to follow a diurnal cycle. This standard does not establish procedures or criteria for conducting dynamic tests or for analysis of dynamic data but does require full reporting of test conditions and data analysis.

1.5 This test method provides for forced-air velocity either parallel or perpendicular to the specimen surface. It also allows operation under natural convection conditions.

NOTE 2—For either parallel or perpendicular forced-air velocity conditions, care should be taken to quantify the amount of air leakage between the climatic and metering chambers. This may be done by one of several techniques: (1) tracer gas methods, or (2) calibration of the air flow rate as a function of the pressure difference using Test Method E 283. For many

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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² The boldface numbers in parentheses refer to the list of references at the end of this test method.



window or door systems, it may be desirable to minimize the air leakage by sealing the window crack length with tape or caulk.

1.6 This method does not provide for mass transfer of air or moisture through the specimen during measurements of heat transfer. Such measurements, however, are not disallowed and if undertaken, all test conditions must be fully reported.

be specified in applicable regulations or specifications. In all cases the procedures used must be fully reported. The two procedures are:

1.8.1 For uniform and nearly uniform specimens, the average surface temperatures may be determined from area-weighted measurements from the temperature sensors installed

TABLE 1 Conversion Factors (International Table)

NOTE 1—Conversion factors for thermal resistivity and thermal conductance or transmittance can be found by using these tables in the reverse direction.

Thermal Conductivity ^A						
	W·m ⁻¹ ·K ⁻¹ (^B)	W·cm ⁻¹ ·K ⁻¹	cal·s ⁻¹ ·cm ⁻¹ ·K ⁻¹	kg-cal ·h ⁻¹ ·m ⁻¹ ·K ⁻¹	Btu·h ⁻¹ · ft ⁻¹ ·°F ⁻¹	Btu·in. ·h ⁻¹ ·ft ⁻² ·°F ⁻¹
1 W·m ⁻¹ ·K ⁻¹ =	1.000	1.000 × 10 ⁻²	2.388 × 10 ⁻³	0.8598	0.5778	6.933
1 W·cm ⁻¹ ·K ⁻¹ =	100.0	1.000	0.2388	85.98	57.78	693.3
1 cal·s ⁻¹ ·cm ⁻¹ ·K ⁻¹ =	418.7	4.187	1.000	360.0	241.9	2903.
1 kg-cal·h ⁻¹ ·m ⁻¹ ·K ⁻¹ =	1.163	1.163 × 10 ⁻²	2.778 × 10 ⁻³	1.000	0.6720	8.064
1 Btu·h ⁻¹ ·ft ⁻¹ ·°F ⁻¹ =	1.731	1.731 × 10 ⁻²	4.134 × 10 ⁻³	1.488	1.000	12.00
1 Btu·in. ⁻¹ ·h ⁻¹ ·ft ⁻² ·°F ⁻¹ =	0.1442	1.442 × 10 ⁻³	3.445 × 10 ⁻⁴	0.1240	8.333 × 10 ⁻²	1.000
Thermal Resistance ^A						
	K·m ² ·W ⁻¹ (^B)	K·cm ² ·W ⁻¹	K·cm ² ·s·cal ⁻¹	K·m ² ·h·kg-cal ⁻¹	°F·ft ² ·h·Btu ⁻¹	
1 K·m ² ·W ⁻¹ =	1.000	1.000 × 10 ⁴	4.187 × 10 ⁴	1.163	5.678	
1 K·cm ² ·W ⁻¹ =	1.000 × 10 ⁻⁴	1.000	4.187	1.163 × 10 ⁻⁴	5.678 × 10 ⁻⁴	
1 K·cm ² ·s·cal ⁻¹ =	2.388 × 10 ⁻⁵	0.2388	1.000	2.778 × 10 ⁻⁵	1.356 × 10 ⁻⁴	
1 K·m ² ·h·kg-cal ⁻¹ =	0.8598	8.598 × 10 ³	3.600 × 10 ⁴	1.000	4.882	
1 °F·ft ² ·Btu ⁻¹ =	0.1761	1.761 × 10 ³	7.373 × 10 ³	0.2048	1.000	

^A Units are given in terms of (1) the absolute joule per second or watt, (2) the calorie (International Table) = 4.1868 J, or the British thermal unit (International Table) = 1055.06 J.

^B This is the SI (International System of Units) unit.

NOTE 3—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, make it inadvisable to attempt standardization at this time. Further considerations for such testing are given in X1.2.

1.7 This method is primarily intended for use at temperatures typical of normal building applications. The usual consideration is to duplicate naturally occurring outside conditions, which in temperate zones may range from approximately -48°C to 85°C and normal inside residential temperatures of approximately 21°C. Other temperatures for industrial or special uses may be designed and engineered into the test facility.

NOTE 4—Primary units in this method are SI, but both SI and inch-pound units must be used in the report. Table 1 provides conversion factors between inch-pound units and SI.

1.8 When operated under steady-state conditions with temperatures held constant during a test, the results may be expressed as either thermal resistance, R , thermal conductance, C , overall thermal resistance, R_u , or transmittance, U . This test method allows two procedures to be used in the determination of thermal resistance, R . The choice between the two procedures depends, to some extent, upon the uniformity of the specimen and thus upon whether sufficiently uniform surface temperatures exist that they can be measured by temperature sensors and a representative average obtained. For some specimens the choice may be arbitrary and must be made by the user of the method, or by the sponsor of the test, or it may

as directed in 5.7.1. The thermal resistance, R , is then calculated using the measured heat transfer and the difference in the average temperatures of the two surfaces.

1.8.2 For very nonuniform specimens, meaningful average surface temperatures will not exist. In this case the thermal resistance, R , is calculated by subtracting surface resistances for the two surfaces from the measured overall thermal resistance, R_u . These surface resistances shall be determined from tests conducted under similar conditions (Note 5), but using a uniform test specimen of approximately the same thermal resistance.

NOTE 5—Surface resistances have been found to depend significantly on the magnitude of the heat flux as well as the ambient conditions affecting the surface. It is important that the heat flux for the uniform specimen be similar to that through the nonuniform specimen and that air temperature, air velocity, and the temperature of surfaces that exchange radiation with the specimen also be similar.

1.8.3 Generally the overall thermal resistance, R_u , or the thermal transmittance, U , should be determined under the conditions of interest. When this is not possible or when directed by applicable agreements or regulations, the overall resistance, R_u , may be determined from the thermal resistance, R , obtained as directed in 1.8.1 or 1.8.2, by adding standardized surface resistances. One source of standardized resistances is *ASHRAE Handbook—Fundamentals Volume*.³

NOTE 6—Overall resistances, R_u , obtained from measured resistances,

³ Available from the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329.



R , by adding standardized surface resistances typical of different conditions may not agree with overall resistances that would be measured directly under those conditions. Discrepancies are especially likely for nonuniform specimens with high conductance surface elements connected to thermal bridges when measured resistances, R , are obtained under still air conditions and the standardized surface resistances are typical of high wind velocities. The user is cautioned to be aware of such possible discrepancies.

1.9 This test method sets forth the general requirements covering a wide variety of apparatus constructions, test conditions, and operating procedures. Detailed directions for these considerations are not given but must be chosen within the constraints of the general requirements.

1.9.1 This test method does not specify all details necessary for the construction and operation of the apparatus. Decisions on details of sampling, specimen selection, preconditioning, specimen mounting and positioning, the choice of test conditions, and the evaluation of test data are left to the judgment of the user or to applicable product specifications or to government or other regulations.

1.10 In order to assure the level of precision and accuracy expected, persons applying this test method need to 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 are advisable for each apparatus to ensure that tests are in accordance with this test method.

1.11 It is recommended that the performance of an apparatus be proven by satisfactory measurements on appropriate standard specimens from the national standards laboratory of jurisdiction or, if such standards are not available, by satisfactory comparisons in an interlaboratory round-robin program or by satisfactory comparisons with a proven guarded hot box, Test Method C 236.

1.12 *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 Materials⁴

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus⁴

C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box⁴

C 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus⁴

C 1045 Practice for Calculating Thermal Transmission Properties from Steady-State Heat Flux Measurements⁴

E 230 Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples⁵

E 283 Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen⁶

3. Terminology

3.1 *General*—Certain terms relating to insulating materials and testing are in accordance with Definitions C 168 (see 3.1.1-3.2.4); these are provided to simplify their use in the Calculation Section of this test method.

3.1.1 *Discussion*—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.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *thermal resistance, R* —the mean temperature difference, at equilibrium, between two defined surfaces of material or a construction that induces a unit heat flow rate through a unit area. It is calculated as follows (see 3.2.1, Discussion):

$$R = (t_1 - t_2)/A/Q \quad (1)$$

3.2.1.1 *Discussion*—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.

3.2.2 *thermal conductance, C* —the time rate of heat flow through a unit area of a body, induced by a unit temperature difference between the body surfaces. It is calculated as follows (see 3.2.1, Discussion):

$$C = Q/A(t_1 - t_2) \quad (2)$$

3.2.3 *surface conductance, h* (often called surface or film coefficient)—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. Subscripts h and c are used to differentiate between hot side and cold side surface conductances, respectively. These conductances are calculated as follows (see 3.2.3, Discussion):

$$h_h = Q/A(t_h - t_1) \quad (3)$$

$$h_c = Q/A(t_2 - t_c) \quad (4)$$

3.2.3.1 *Discussion*—The surface conductance, h_i , and the corresponding surface resistance, R_i (see 3.2.5), are reciprocals; that is, their product is unity.

3.2.4 *thermal transmittance, U* (sometimes called overall coefficient of heat transfer)—the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. It is calculated as follows (3.2.4, Discussion):

$$U = Q/A(t_h - t_c) \quad (5)$$

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

$$1/U = (1/h_h) + (1/C) + (1/h_c) \quad (6)$$

⁴ Annual Book of ASTM Standards, Vol 04.06.

⁵ Annual Book of ASTM Standards, Vol 14.03.

⁶ Annual Book of ASTM Standards, Vol 04.07.



3.2.4.1 *Discussion*—Thermal transmittance, U , and the corresponding overall thermal resistance, R_u (see 3.2.6), are reciprocals; that is, their product is unity.

3.2.5 *surface resistance*, R_x —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 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 3.2.3, Discussion):

$$R_h = (t_h - t_1)A/Q \quad (7)$$

$$R_c = (t_2 - t_c)A/Q \quad (8)$$

3.2.6 *overall thermal resistance*, R_u —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 the sum of the resistances of the body or assembly and of the two surface films and may be calculated as follows (see 3.2.4, Discussion):

$$R_u = (t_h - t_c)A/Q = R_c + R + R_h \quad (9)$$

3.2.6.1 *Discussion*—In case of discrepancy the terminology of Definitions C 168 shall govern. In general, the defined terms apply to homogeneous uniform specimens. Their applicability to other specimens must be judged in each case.

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

- 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
- λ = thermal conductivity, $W/(m \cdot K)$
- C = thermal conductance, $W/(m^2 \cdot K)$
- R = thermal resistance, $K \cdot m^2/W$
- R_h = surface resistance, hot side, $K \cdot m^2/W$
- R_c = surface resistance, cold side, $K \cdot m^2/W$
- R_u = overall thermal resistance, $K \cdot m^2/W$
- U = thermal transmittance, $W/(m^2 \cdot K)$
- h_h = surface conductance, hot side, $W/(m^2 \cdot K)$
- h_c = surface conductance, cold side, $W/(m^2 \cdot K)$
- A = metered area, m^2
- L = length of heat loss path (usually the thickness of the test panel), m
- t_a = temperature of ambient air, K or $^{\circ}C$
- t_h = temperature of hot-side air, K or $^{\circ}C$
- t_1 = temperature of specimen hot surface, K or $^{\circ}C$
- t_2 = temperature of specimen cold surface, K or $^{\circ}C$
- t_c = temperature of cold-side air, K or $^{\circ}C$
- E = emf output of heat flux transducer or thermocouple, V
- M = heat flux transducer sensitivity (a function of temperature), W/m^2V

4. Significance and Use

4.1 A need exists for accurate data on heat transfer through insulations and through insulated structures. 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 methods such as Test Methods C 177 and C 518 generally are adequate in providing data on small-scale specimens bounded by temperature-controlled flat impervious plates. This test method and the guarded hot box Test Method C 236 are more suitable for providing such data for large specimens, usually of a built-up or composite nature, which are exposed to temperature-controlled air on both sides.

4.2 Data obtained by this test method are representative of performance only for the conditions of the test. To be representative of building constructions, typical full-scale sections shall be tested. It is unlikely that the test conditions will exactly duplicate conditions in use and the user of test results is cautioned to be aware of possible significant differences. For this reason, this test method does not standardize 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.

5. Apparatus

5.1 *Arrangement*—The major parts of a calibrated hot box apparatus are the metering chamber on one side of the specimen, the climatic chamber on the other, the specimen frame providing perimeter insulation, and the surrounding ambient space. These elements are designed together to provide the desired air temperature, air velocity, and radiation conditions on each side of the specimen and to measure the resulting heat transfer. All surfaces that can exchange radiation with the specimen must have a total hemispherical emittance greater than 0.8. Fig. 1 shows an example of a wall test apparatus for horizontal heat transfer. Fig. 2 shows an example of a floor/ceiling test apparatus for vertical heat transfer. Other arrangements may be used.

NOTE 7—The two opposite 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 cases, these temperatures may be reversed.

5.2 *Size*—The apparatus shall be sized according to the intended use. For building assemblies it shall accommodate typical full-scale sections. No one size is considered standard. For highest accuracy the specimen size should match that of the metering chamber while the climatic chamber may also match or be larger.

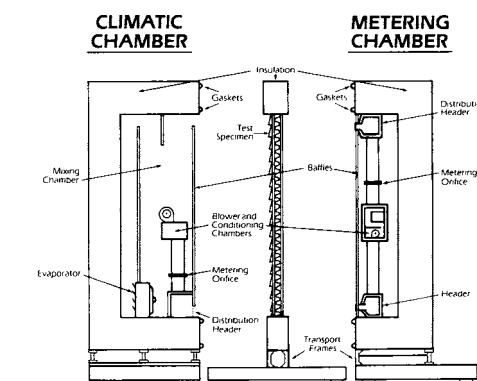
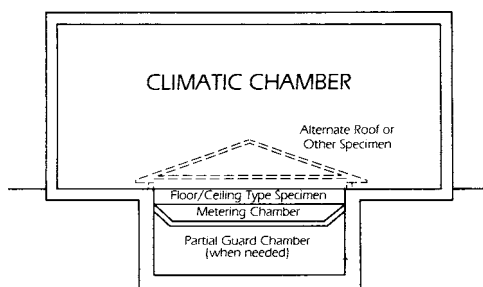


FIG. 1 Calibrated Hot Box—Wall Tester



NOTE 1—Each chamber shall contain suitable air conditioning and distribution systems as required to obtain desired conditions.

FIG. 2 Calibrated Hot Box—Floor/Ceiling Tester

NOTE 8—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 and 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. Other sizes are allowed.

5.3 Metering Chamber:

5.3.1 The purpose of the metering chamber is to provide for the control and measurement of air temperature and velocity on one face of the specimen under fixed radiation conditions and for the measurement of heat transfer through the specimen. The usual arrangement is a five-sided chamber containing electrical heaters and an air circulation system. At steady state the heat transfer through the specimen equals the electrical power to the heaters and blowers, corrected for the amount passing through the chamber walls or flanking the specimen or both, both of which shall be estimated from calibration measurements (see Section 7). If the metering chamber is to be cooled, then the heat extracted must also be determined (see 5.6.4.3).

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

5.3.2.1 The metering chamber wall loss, which may be estimated by the equations of Annex A1, must be kept small, by making the wall area small and its thermal resistance high. Experience indicates that the wall losses should preferably be as low as 1 or 2 % of the heat transfer through the specimen if the highest accuracy is to be achieved. Certainly the wall losses should never be greater than 25 % of the specimen heat transfer (Note 9). In some designs it has been necessary to use a partial guard to minimize metering chamber wall loss (see Fig. 2).

NOTE 9—The 25 % limit is chosen as a guide and is based upon owner experience and potential errors analysis. The choice of construction of the metering chamber can only be made 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 a non-steady ambient temperature upon the ability to maintain steady temperatures within the chamber must also be considered in choosing between highly insulated walls and tightly controlled room space conditioning.

5.3.2.2 The heat transfer through the metering chamber walls must be nearly uniform over the surfaces so that determinations by a limited number of heat flux transducers or differential thermocouples can represent larger areas. This

requirement can be met 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 must be located exterior to the insulation. Thermal bridges, structural cracks, insulation voids, and air leaks in the chamber walls must be avoided.

NOTE 10—One method of constructing satisfactory chamber walls is by gluing together large blocks of uniform low conductivity cellular plastic insulation such as urethane foam. Foam-in-place foam may also be used if carefully controlled and inspected. A covering of a thin layer of glass fiber-reinforced plastic or coated plywood is recommended to provide durability and moisture and air infiltration barriers to prevent unwanted exchanges between the ambient and test chambers.

5.3.3 The walls of the metering chamber must be instrumented in order to determine the heat transfer through them. Either of two methods or both may be used:

5.3.3.1 Separate heat flow meters may be placed on the metering chamber walls. Precautions must be taken in choosing and installing the heat flow meters to ensure that the thermal resistance of the wall and its surface emittance remain essentially unchanged. The outputs from these heat flux transducers may be measured separately, in which case they are calibrated separately and temperature sensors must be installed in or near them since calibrations are temperature-dependent. It is recommended that meters used in this manner be demountable from the surface so their calibrations, at heat fluxes typical of use, may be checked periodically. An alternative, but possibly less accurate calibration procedure is to calibrate the chamber with the heat meters in place, in which case the meter outputs may be connected in series to provide a single reading.

5.3.3.2 The walls themselves may be used as heat flow meters by application of a 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 must also be taken when determining the number of differential thermocouples. Based upon a survey of hot box operators (17), five differential thermocouples per square metre of specimen metering area is recommended as a minimum. At no time should 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. The junctions and the thermocouple wires for at least a 100-mm distance from the junctions shall be flush with, and in thermal contact with, the surface of the wall. The thermocouple pairs should be connected in series to form a thermopile in which the individual emfs are summed to give a single output or read out individually in cases where there are significant differences expected in the local heat flow levels.

5.4 Climatic Chamber:

5.4.1 The purpose of the climatic chamber is to provide for the control and measurement of air temperature and velocity



under fixed radiation 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 the test specimen and with sufficient depth to contain the required cooling, heating, and air circulation equipment. An acceptable alternative is to use a larger 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.

5.4.2 The walls of the climatic chamber should also be well insulated to reduce the refrigeration capacity required and to ensure that wall temperatures are not greatly different from the air temperature.

5.5 Specimen Frame:

5.5.1 A specimen frame shall be provided to hold and position the specimen and to provide the needed perimeter insulation. The frame should have interior dimensions matching those of the metering chamber opening and a thickness and thermal resistance of perimeter insulation at least equal to that of the metering chamber walls.

5.5.2 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.

5.6 Air Circulation and Conditioning:

5.6.1 The measured overall resistance, R_o , and, when applicable, the surface resistances, R_h or R_c , will depend upon the air velocity, surface geometry, and thermal characteristics of the specimen.

5.6.1.1 Air temperature differences of several degrees can exist from top to bottom due to natural convection in a wall test apparatus, and similar differences may exist in a floor/ceiling test apparatus without forced air movement. When desired, tests may be run under these natural convection conditions.

5.6.1.2 When more uniform air temperatures are desired, it is necessary to provide curtains of forced air moving past the specimen surfaces. This may be accomplished by directing the air flow either parallel with or perpendicular to the specimen surface. If still-air conditions are to be approximated, the air velocity should be below 0.5 m/s. For a well-insulated specimen the air temperature uniformity under these conditions may be within 1 K.

NOTE 11—The direction of air flow in a calibrated hot box apparatus is arbitrary and may be parallel, that is, up, down, horizontal, or perpendicular to the 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 this direction is often recommended. In some situations, however, the specification requirements may dictate that a specific direction is necessary to properly evaluate the system performance.

NOTE 12—The minimum velocity required to obtain an air temperature uniformity of 1 K depends upon the heat transfer through the specimen and the size of the specimen. A velocity of approximately 0.3 m/s has proven satisfactory for a wall test apparatus of 3-m height.

5.6.1.3 Higher air velocities are permissible when their effect upon heat transfer is to be determined. Velocities

commonly used to simulate parallel or normal wind conditions are 3.35 m/s for summer conditions and 6.70 m/s for winter conditions.

NOTE 13—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 cross winds, and may be achieved by moving a small amount of air confined in a narrow baffle space and therefore require relatively little 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 farther from the specimen surface and should have a porous section (a set of screens or a honeycomb air straightener) that directs the air stream at the specimen surface.

5.6.2 A baffle, parallel to the specimen surface, may be used to confine the air to a uniform channel, thus aiding in maintaining an air curtain with uniform velocities. The baffle thermal resistance should be adequate to shield the test panel surface from any heat sources located behind it. Practice has shown that a thermal resistance of 1 (K·m²/W) is adequate for this purpose. The baffle-to-specimen spacing may be adjustable to serve as one means of adjusting the air flow velocity. 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.

5.6.2.1 Uniform air flow across the specimen width is necessary and 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 other. The inlet header should incorporate an adjustable slot or louvers to aid in obtaining uniform distribution.

NOTE 14—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.

5.6.2.2 After construction of an air-circulation system, a velocity scan across the width of the air curtain shall be made. The air velocity profile shall be defined as uniform if all measurements from the 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.

5.6.3 The apparatus shall provide a means for determining air velocity past both the hot and cold faces of the specimen. Acceptable methods are as follows:

5.6.3.1 One method is to meter the volume 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).

5.6.3.2 An alternative method is to locate velocity sensors directly in the air curtain.

5.6.3.3 Still another method, which may 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.

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

5.6.4.1 One method of providing 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 and to control these heaters by a sensor located at the inlet to the air curtain.

NOTE 15—A satisfactory method of heater control is to use several individual heaters which may be switched on to provide fixed levels of heat which are then modulated by an additional heater connected to a controller. Another satisfactory method is to use a controller that varies the power to all the heaters.

5.6.4.2 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 automatically held at a constant temperature a few degrees below that desired, and a reheat and control system, similar to that for obtaining heated air (5.6.4.1), 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 16—One proven configuration for a wall tester climatic chamber utilizes two air circuits created by suitable baffles. The evaporator fan creates one circulation path which 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 use 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.

5.6.4.3 If cooling of the metering chamber is required, then it must be done in a manner in which the amount of heat extracted can be accurately measured. One method is to circulate a chilled liquid through a heat exchanger located in the metering chamber air circuit. The heat extracted is controlled by the inlet temperature, 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 accuracy will be lost if excessive heating must be used to compensate for large cooling. A good way to adjust cooling load is by changing the inlet coolant temperature.

5.6.4.4 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 must be used or the motor may be located outside of the metering chamber and the heat equivalent of the shaft power accurately measured. Precautions shall be taken to prevent air leakage around the shaft.

5.7 Temperature Measurement:

5.7.1 Specimen surface temperature sensors, when surface temperatures are desired, 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 ± 0.2 K of the temperature that would exist if the sensor had not been applied. This requirement is presumed to be met by thermocouples of wire no larger in diameter than 0.25 mm (No. 30 AWG) if they meet or are calibrated to the special limits of error specified in Tables E 230 for Type T, and if the junctions and at least 100 mm of adjoining wire are taped, cemented, or otherwise held in thermal contact with the surface using materials of emittance close to that of the surface. Alternative arrangements may be used if comparative measurements or calculations show that the basic requirements are met.

5.7.1.1 If the specimen construction (and therefore its thermal resistance) is uniform over its 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 9 (23).

5.7.1.2 If the specimen construction is relatively uniform in thermal resistance and repeats itself several times over its area, the number of sensors specified in 5.7.1.1 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.

5.7.1.3 If the surface temperatures are expected to be greatly nonuniform, additional sensors, often a great number, must be used to adequately sample the different temperature areas so that reliable weighted mean surface temperatures may be obtained.

5.7.1.4 When the average surface temperatures are difficult to determine, it is advisable to measure the transmission coefficient, U , or the overall resistance, R_u , and calculate the average panel resistance, R , of the sample by subtracting the previously measured surface thermal resistance. Note that the geometry and average temperature conditions must be similar for the calibration panel and test panel for this technique to have reasonable accuracy.

NOTE 17—Tests on samples 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 tests are to be comparable they must be run under similar conditions. This method does not attempt to standardize such conditions.

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

5.7.2.1 If thermocouples or other point sensors are used to measure air temperatures, their number and spacing shall be that specified for surface temperature sensors in 5.7.1.1. The