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

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.

ε^1 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]

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

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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.

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 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 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,

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])	$W·cm^{-1}·K^{-1}$	$cal·s^{-1}·cm^{-1}·K^{-1}$	$kg\text{-}cal·h^{-1}·m^{-1}·K^{-1}$	$Btu·h^{-1}·ft^{-1}·°F^{-1}$	$Btu·in.·h^{-1}·ft^{-2}·°F^{-1}$
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 $kg\text{-}cal·h^{-1}·m^{-1}·K^{-1}$ =	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 $Btu·in.·h^{-1}·ft^{-2}·°F^{-1}$ =	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])	$K·cm^2·W^{-1}$	$K·cm^2·s·cal^{-1}$	$K·m^2·h·kg\text{-}cal^{-1}$	$°F·ft^2·h·Btu^{-1}$
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 $K·m^2·h·kg\text{-}cal^{-1}$ =	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.

[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 Materials[4]

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus[4]

C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[4]

C 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[4]

C 1045 Practice for Calculating Thermal Transmission Properties from Steady-State Heat Flux Measurements[4]

E 230 Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples[5]

E 283 Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen[6]

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):

$$R = (t_1 - t_2)A/Q \tag{1}$$

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):

$$C = Q/A(t_1 - t_2) \tag{2}$$

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):

$$h_h = Q/A(t_h - t_1) \tag{3}$$

$$h_c = Q/A(t_2 - t_c) \tag{4}$$

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):

$$U = Q/A(t_h - t_c) \tag{5}$$

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

$$1/U = (1/h_h) + (1/C) + (1/h_c) \tag{6}$$

[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.