Designation: C 236 – 89 (Reapproved 1993)$^{\epsilon 1}$

Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[1]

This standard is issued under the fixed designation C 236; 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.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—Section 12 was added editorially in September 1993.

1. Scope

1.1 This test method, known as the guarded hot box method, covers the measurement of the steady-state thermal transfer properties of panels. In distinction to Test Method C 177, which is primarily applicable to homogeneous samples, the guarded hot box method provides for the evaluation of thermal performance of building assemblies. This test method is suitable for building construction assemblies, building panels, and other applications of nonohomogeneous specimens at similar temperature ranges. It may also be used for homogeneous specimens.

1.2 This test method may be applied to any building construction for which it is possible to build a reasonably representative specimen of size appropriate for the apparatus.

NOTE 1—A calibrated hot box, Test Method C 976, may also be used for the described measurements and may prove more satisfactory for testing assemblies under dynamic conditions (nonsteady-state) and to evaluate the effects of water migration and air infiltration. The choice between the calibrated or the guarded hot box should be made only after careful consideration of the contemplated use.

1.3 In applying this test method, the general principles outlined must be followed; however, the details of the apparatus and procedures may be varied as needed.

1.3.1 The intent of this test method is to give the essential principles and the general arrangement of the apparatus. Any test using this apparatus must follow those principles. The details of the apparatus and the suggested procedures that follow are given not as mandatory requirements but as examples of this test method and precautions that have been found useful to satisfy the essential principles.

1.3.2 Persons applying this test method shall be trained in the methods of temperature measurement, shall possess a knowledge of the theory of heat flow, and shall understand the general requirements of testing practice.

1.4 *This standard does not purport to address all of the safety problems, 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.*

NOTE 2—While various units may be found for thermal properties, the International System of units is used exclusively in this test method. For conversion factors to inch-pound and kilogram-calorie systems, see Table 1.

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 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[2]

C 578 Specification for Preformed Cellular Polystyrene Thermal Insulation[2]

C 976 Test Method for 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]

E 178 Practice for Dealing With Outlying Observations[3]

E 230 Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples[4]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[3]

3. Terminology

3.1 Definitions— For definitions of terms used in this test method, refer to Terminology C 168.

3.2 *Symbols:*Symbols:

3.2.1 The symbols used in this test method have the following significance:

[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 Measurement.

Current edition approved Sept. 29, 1989. Published June 1990. Originally published as C 236 – 60. Last previous edition C 236 – 87.

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

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 14.03.

TABLE 1 Conversion Factors for Thermal Conductivity[A]

	W/(m·K)[B]	W/(cm·K)	cal/(s·cm·K)	kg-cal/(h-m·K)	Btu/(h·ft·°F)	Btu·in./(h·ft²°F)
1 $W \cdot m^{-1} \cdot K^{-1}$ =	1.000	1.000×10^{-2}	2.388×10^{-3}	0.8598	0.5778	6.933
1 $W \cdot cm^{-1} \cdot K^{-1}$ =	100.0	1.000	0.2388	85.98	57.78	693.3
1 $cal \cdot s^{-1} \cdot cm^{-1} \cdot K^{-1}$ =	418.7	4.187	1.000	360.0	241.9	2903.00
1 $kg\text{-}cal \cdot h^{-1} \cdot h^{-1} \cdot K^{-1}$ =	1.163	1.163×10^{-2}	2.778×10^{-3}	1.000	0.6720	8.064
1 $Btu \cdot h^{-1} \cdot ft^{-1} \cdot °F^{-1}$ =	1.731	1.731×10^{-2}	4.134×10^{-3}	1.488	1.000	12.00
1 $Btu \cdot in. \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ =	0.1442	1.442×10^{-3}	3.445×10^{-4}	0.1240	8.333×10^{-2}	1.000
	Thermal Conductance[A]					
	W/(m²·K)[B]	W/(cm²·K)	cal/(s·cm²·K)	kg-cal/(h·m²·K)	Btu/h·ft²·°F)	
1 $W \cdot m^{-2} \cdot K^{-1}$ =	1.000	1.000×10^{-4}	2.388×10^{-5}	0.8598	0.1761	
1 $W \cdot cm^{-2} \cdot K^{-1}$ =	1.000 × 104	1.000	0.2388	8598	1761	
1 $cal \cdot s^{-1} \cdot cm^{-2} \cdot K^{-1}$ =	4.187×10^{4}	4.187	1.000	3.600×10^{4}	7373	
1 $kg\text{-}cal \cdot h^{-1} \cdot m^{-2} \cdot K^{-1}$ =	1.163	1.163×10^{-4}	2.778×10^{-3}	1.000	0.2048	
1 $Btu \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ =	5.678	5.678×10^{-4}	1.356×10^{-4}	4.882	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 unit.

λ = thermal conductivity, W/(m·K),
C = thermal conductance, W/(m^2·K),
h = surface conductance, W/(m^2·K),
U = thermal transmittance, W/(m^2·K),
q = heat flux (time rate of heat flow through Area A), W/m^2,
Q = time rate of heat flow, total input to the metering box, W,
A = metering area normal to heat flow, m^2,
L = length of path of heat flow (thickness of specimen), m,
N = minimum number of thermocouples (see Eq 1, 6.5.1.1),
r = surface resistance, K·m^2/W,
R = thermal resistance, K·m^2/W,
R_u = overall thermal resistance, K·m^2/W,
t_h = average temperature of air 75 mm or more from the hot surface, K,
t_1 = area weighted average temperature of hot surface, K,
t_2 = area weighted average temperature of cold surface, K, and
t_c = average temperature of air 75 mm or more from cold surface, K.

4. Summary of Test Method

4.1 To determine the conductance, C, the thermal transmittance, U, and the thermal resistance, R, of any specimen, it is necessary to know the area, A, the heat flux, q, and the temperature differences, all of which must be determined under such conditions that the flow of heat is steady. The hot box is an apparatus designed to determine thermal performance for representative test panels and is an arrangement for establishing and maintaining a desired steady temperature difference across a test panel for the period of time necessary to ensure constant heat flux and steady temperature, and for an additional period adequate to measure these quantities to the desired accuracy. The area and the temperatures can be measured directly. The heat flux, q, however, cannot be directly measured, and it is to obtain a measure of q that the hot box has been given its characteristic design. In order to determine q, a five-sided metering box is placed with its open side against the warm face of the test panel. If the average temperature across the walls of the metering box is maintained the same, then the net interchange between the metering box and the surrounding space is zero, and the heat input to the metering box is a measure of the heat flux through a known area of the panel. The portion of the panel outside the meter area, laved by the air of the surrounding guard space, constitutes a guard area to minimize lateral heat flow in the test panel near the metering area. Moisture migration, condensation, and freezing within the specimen can 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. It is expected that, in general, tests in the guarded hot box apparatus will be conducted on substantially dry test panels, with no effort made to impose or account for the effect of the vapor flow through or into the panel during the test.

4.2 Since the basic principle of the test method is to maintain a zero temperature difference across the metering box walls, adequate controls and temperature-monitoring capabilities are essential. It is recognized that small temperature gradients could 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, small temperature gradients through the walls may cause heat flows totaling a significant fraction of the heat input to the metering box. For this reason, the metering box walls may also be equipped to serve as a heat flow meter so that heat flow through them can be estimated and minimized by adjusting conditions during tests, and so that a heat flow correction can be applied in calculating test results.

5. Significance and Use

5.1 When the guarded hot box is constructed to test assemblies in the vertical orientation, it is suited for evaluating walls and other vertical structures. When constructed to test assemblies in the horizontal orientation, it is suited for evaluating roof, ceiling, floor, and other horizontal structures. Other orientations are allowable. The same apparatus may be used for both vertical and horizontal testing if it can be rotated or reassembled in either orientation.

NOTE 3—Horizontal structures that incorporate attic spaces between a ceiling and a sloping roof are highly complex constructions, and testing in the guarded hot box would be extremely difficult. Proper consideration must be given to specimen size, natural air movement, ventilation effects, radiative effect, baffles at the guard-meter demarcation, etc. All of these special conditions must be included in the report (10.1.1). Consideration should be given to the use of the calibrated hot box for such large, complex constructions.

5.2 For vertical specimens with air spaces that significantly affect thermal performance, the metering box height should ideally match the construction height. If this is not possible, horizontal convection barriers must be installed to prevent air exchange between meter and guard areas, unless it can be shown that the omission of such barriers does not significantly affect results.

5.3 For all specimens it is necessary to maintain a near zero lateral heat flow between the guard area and the meter area of the specimen. This can be achieved by maintaining a near zero temperature difference on the specimen surface between the metered and guard areas. In specimens incorporating an element of high lateral conductance (such as a metal sheet), it may be necessary to separate the metered and the guard areas of the highly conductive element by a narrow gap such as a saw cut.

5.4 Since this test method determines the total flow of heat through the test area demarcated by the metering box, it is possible to determine the heat 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 or mask is determined (see Annex A1).

6. Apparatus

6.1 *Arrangement*—Fig. 1 (*a*) shows a schematic arrangement of the test panel and of various major elements of the apparatus; Fig. 1(*b*) and (*c*) show alternative arrangements. Still other arrangements, accomplishing the same purpose, may be preferred for reasons of convenience or ease of installing panels. In general, the size of the metering box determines the minimum size of the other elements.

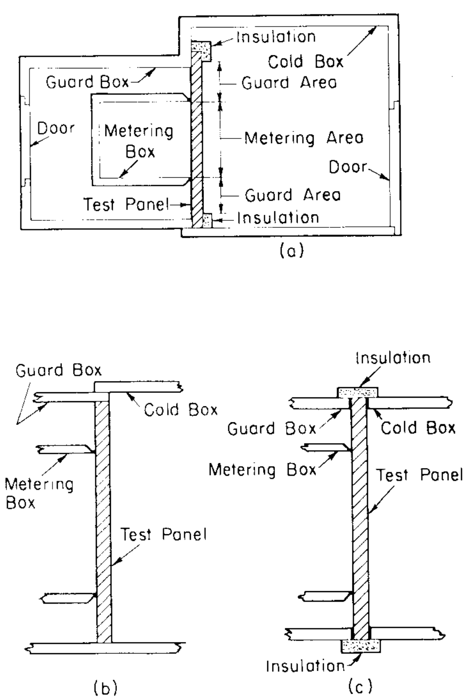


FIG. 1 General Arrangements of Test Box, Guard Box, Test Panel, and Cold Box

6.2 *Metering Box*:

6.2.1 *Size*—The size of the metering box is largely governed by the metering area required to obtain a representative test area of panel. For example, for panels incorporating air spaces or stud spaces, the metering area, preferably, should exactly span an integral number of spaces. The height of the metering box should be not less than the width and is subject to the limitations as described in 5.2. The depth of the metering box should be not greater than that required to accommodate its necessary equipment.

6.2.2 *Thermal Resistance*—The metering box walls shall have a thermal resistance of not less than 0.83 m^2 K/W. In order that the resistance of the box wall shall be uniform over the entire box area, a construction without internal ribs shall be used, for example, a glued balsa wood or a sandwich construction with aged urethane foam core. The edge in contact with the panel shall, if necessary, be narrowed on the outside only, to hold a gasket not more than 13 mm wide. If necessary, a wood nosepiece can be used to carry the gasket. The metering area of the panel shall be taken as the area included between the center lines of the gaskets. All surfaces that can exchange radiation with the specimen must have a total hemispherical emittance greater than 0.8.

6.2.3 *Heat Supply and Air Circulation*—Fig. 2 shows a possible arrangement of equipment in the metering box to assure an even, gentle movement of air over the metering area of the panel. The electric heaters are mounted in a housing with walls of resistance not less than 0.83 m^2 K/W, and with a low emittance outside surfacing to minimize radiation heat transfer to the metering box walls. In this arrangement air is continuously circulated by a small fan upward through the cylindrical housing and downward between the baffle and the panel in accordance with the motion that would result from natural convection forces. A slat-type baffle is placed some distance above the outlet of the cylindrical housing to prevent impingement of a jet of heated air against the top inner surface of the metering box. For large meter boxes the cylindrical housing may cause concentrations of air flow. To direct the air properly across the specimen, other fan arrangements may be preferable. A curved vane is mounted at the top of the baffle to smooth the entrance of air into the baffle space. In a hot box apparatus used for testing panels in a vertical position only, the moderate circulation of air resulting from natural convection may be sufficient without the use of a fan. The change in temperature of the air as it moves along the surface of the panel will, in general, be greater with natural circulation than with a fan. If a fan is used, its motor should be within the metering box, its electrical input should be as small as feasible, and the input should be carefully measured. If it is necessary to locate the motor outside the metering box, the heat equivalent of the shaft power must be accurately measured, and air leakage into or out of the metering box around the shaft must be zero.

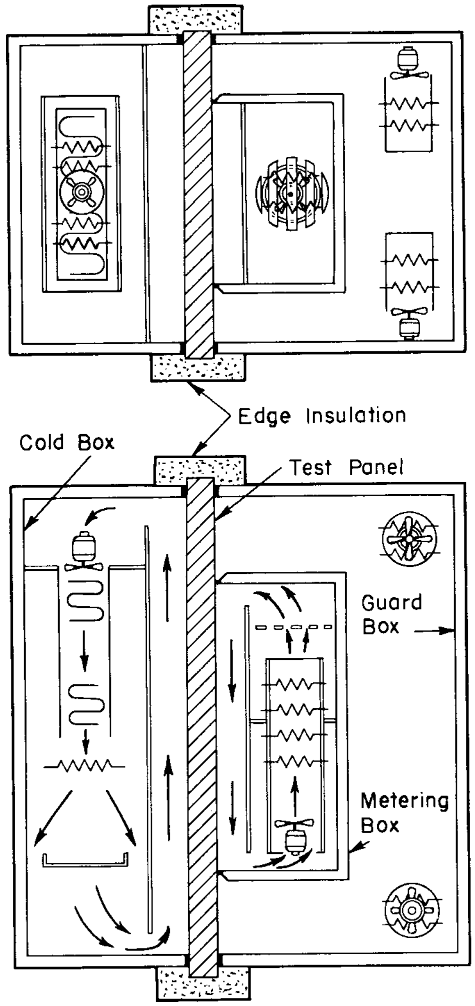


FIG. 2 Arrangement of Equipment During the Test

6.2.4 *Temperature Control*—To obtain reliable test results, accurate temperature control equipment must be utilized. Temperature controllers must be capable of controlling temperature within 0.25 K during the test period. The heaters should be the open-wire type of minimal heat capacity and lag.

6.2.5 *Gaskets*—The contact edges of the metering box should ensure, by a gasket or other means, a tight air seal against the surface of the test panel. For some panels special provisions may be necessary. The metering box should be pressed tightly against the panel by suitable means. Some gasket materials age with time and service. Periodic inspection of gaskets is recommended in order to confirm their ability to provide a tight seal under test conditions.

6.2.6 *Heat Flux Transducer*—To equip the metering box walls to serve as a heat flux transducer, a means of detecting the temperature difference across the metering box walls or the heat flux through the metering box walls shall be provided. One method found satisfactory for this purpose is to apply a number of differential thermocouples connected in a series to the inside and outside surfaces of the metering box walls to form a thermopile. Precautions must be taken when determining the number of differential thermocouples. Based on a survey of guarded hot box operators, the number of differential thermocouple pairs located on metering box walls shall be five pairs per square metre of specimen metered area located on the metering box sides. At no time shall there be less than 1 pair of differential thermocouples on each of the five sides of the metering box **(1)**.[5] Precautions must also 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 guard box air velocities and temperature. 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 output of the thermocouple pairs shall be averaged.

6.2.7 *Thermopile emf and Heat Flow Relationship*—The relationship between thermopile emf and heat flow through the metering box walls shall be determined. This relationship shall be determined for each set of metering box conditions (temperature and air velocity). A suggested method of accomplishing this objective is outlined in Appendix X1.

6.3 *Guard Box*:

6.3.1 *Size*—It is recommended that the guard box be large enough so that there is a clear distance between its inner wall and the nearest surface of the metering box of not less than the thickness of the thickest panel to be tested, but in no case less than 150 mm.

6.3.2 *Thermal Conductance*—To assure that there shall be a temperature difference of no more than a few degrees between the guard box air and its inner surfaces, the walls shall have a thermal conductance not greater than 0.6 W/(m^2·K). A low conductance is also desirable for operating reasons, to assure that the heat flow into or out of the guard box from outside will be only a small fraction of the heat flow through the guard area of the test panel.

6.3.3 *Heat Supply and Air Circulation*—One or more reflective-surfaced cylindrical heater units with a fan may be used to supply heat to the guard box air and also to circulate the air to avoid stratification. The fan air intake of at least one such heater unit should be located at the lowest point in the guard box, to prevent pooling of cool air at the bottom. The air discharged from the heater cylinder shall not impinge directly against either the metering box or the test panel.

6.3.4 *Temperature Control*—The guard box air temperature and heat input can be controlled by a differential thermopile such as that used on the metering box for a heat flow meter, or by a sensitive bridge circuit with opposed temperature-sensitive arms located in the guard and metering boxes. To avoid hunting due to the small periodic temperature variations of the metering box air, as its thermostat functions, it is desirable to put the temperature-sensitive element of the differential control in the metering box in good thermal contact with the inside surfaces of the metering box. The temperature-sensitive element in the guard box should be placed to avoid being directly in the air stream of the heater units and should be of minimum thermal lag. The control equipment used to maintain guard box temperatures must be capable of controlling to within 0.25 K.

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

6.4 *Cold Box*:

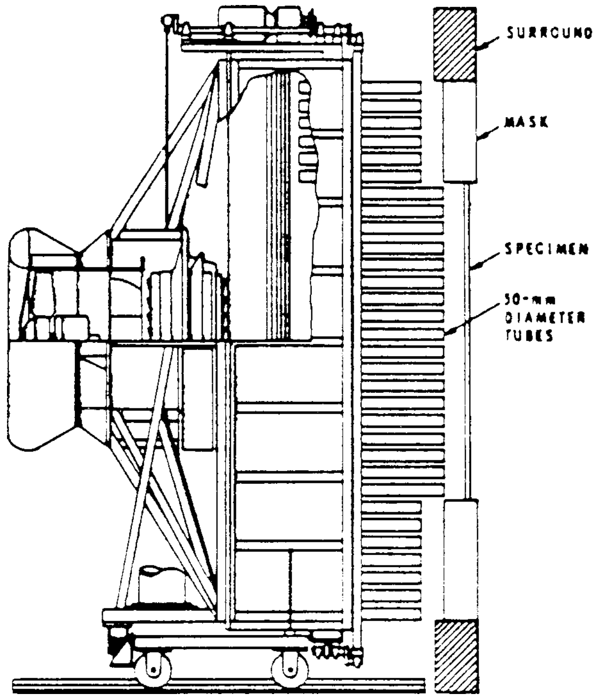
6.4.1 *Size*—The size of the cold box is governed by the size of the test panel or by the arrangement of boxes used, as illustrated in Fig. 1.

6.4.2 *Insulation*—The cold box should be heavily insulated to reduce the required capacity of the refrigerating equipment, and the exterior of the cold box should be provided with a good vapor barrier to prevent ingress of vapor and heavy frost accumulations on the cooling coils.

6.4.3 *Temperature Control*—The cold box may be cooled in any manner that is capable of the close control of air temperature necessary during a test. An arrangement of equipment similar to that in the metering box may be used with a fan to force air downward through the enclosed refrigerating coils and upward through the space between a baffle and the test panel as indicated in Fig. 2. It has been found satisfactory with an arrangement of this sort to operate a unit refrigeration system continuously, with the evaporation temperature of the coil held constant by an automatic back-pressure regulating valve, and refrigerant supplied to the coil through an automatic expansion valve. An alternative method is to use an exterior located refrigeration system and insulated ducts to supply chilled air to the cold box. Liquid nitrogen in connection with a solenoid valve regulating its flow may also be used. For fine control of the cold box, installation of open wire electrical heaters in the blower duct or other fast moving part of the air circulation system and controlling these heaters by a sensor located in the discharge of the air circulation system is recommended. The use of desiccants to remove excessive moisture in the recirculating cold air may be useful. Temperature controllers for steady-state tests must be capable of controlling temperatures within ± 0.25 K.

6.4.4 *Air Circulation*—High air velocities are permissible when their effect upon heat flow is to be determined. This may be accomplished by directing the airflow either parallel or perpendicular to the specimen cold surface. One method of obtaining parallel uniform velocity is to force air through a space between the specimen and a parallel baffle whose spacing may be adjustable to aid in changing the air curtain velocity. Parallel velocities, as provided in this test method, aid in obtaining uniform specimen surface temperatures and simulate the effect of cross winds. Velocities commonly used to simulate cross wind conditions are 3.35 m/s for summer conditions and 6.70 m/s for winter conditions. Perpendicular velocities, simulating direct wind impingment require moving larger amounts of air than most parallel situations, with corresponding larger power requirements. Also, the baffle should be placed further from the specimen surface and should have a porous section (a screen or honeycomb flow straightener) that directs the wind at the specimen surface (see Figs. 3 and 4). Velocities commonly used to simulate wind conditions are 3.35 m/s for summer conditions and 6.70 m/s for winter conditions. Air leakage through the specimen should be eliminated by sealing all cracks and joints with tape, caulk, or foam strips.

6.4.4.1 After construction of the air circulation system a velocity scan across the air curtain is required to verify that a uniform air curtain is formed. The apparatus should provide a means for determining air velocity past the specimen surface. One method is to locate velocity sensors directly in the air curtain.



NOTE 1—One inch is equal to 25.4 mm.

FIG. 3 DBR Wind Machine

6.5 *Temperature-Measuring Equipment*:

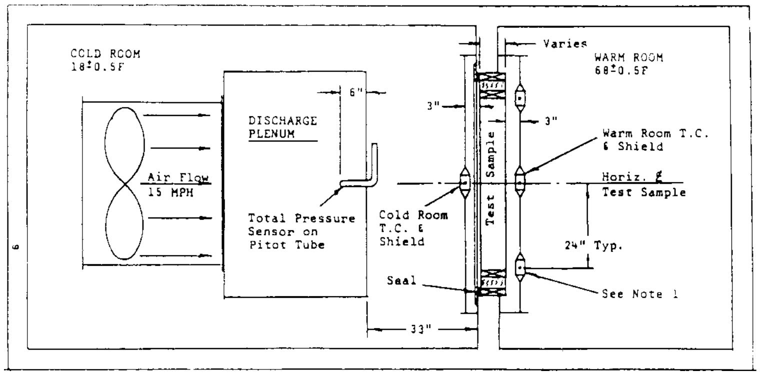
6.5.1 *Surface Temperatures*—Thermocouples of wire not larger in size than 0.25 mm (No. 30 AWG gage), and which meet or are calibrated to the special limits of error specified in Tables E 230, are recommended for measuring surface temperatures in the apparatus (larger thermocouples can be used if it can be shown that there is no difference in bias); for this purpose the thermocouple junction and the adjoining lead wires for a distance of at least 100 mm should be taped, or preferably cemented, tightly to the surface. The emittance of the surfacing material tape or cement should be close to the emittance of the surface.

6.5.1.1 If the specimen (and therefore its thermal resistance) is uniform, or nearly so, over the area and thus the surface temperatures vary only slightly at lower air velocities, a minimum number of thermocouples spaced uniformly and symmetrically over the surface is sufficient. This minimum number depends on the specimen size. Experience has shown that the required minimum number of thermocouples, N, can be determined from the relation that:

$$N = A/(0.07 + 0.08\sqrt{A}) \quad (1)$$

where A is the metering area in m^2. If the number of thermocouples used is within 10 % of the number determined by this relation, then the requirements of this section are judged to be met.

6.5.1.2 If the specimen is of nonuniform construction, the number of thermocouples specified in 6.5.1.1 may still be sufficient. In this case the thermocouples shall be judiciously located to represent each of the construction elements. Such



NOTE 1—Thermocouples and shields on the warm side are movable to maintain 3 in. spacing to test sample.

NOTE 2—Overall chamber length may vary.

NOTE 3—One inch is equal to 25.4 mm.

NOTE 4—Thirty-two degrees farenheit is equal to 0°C.

FIG. 4 Thermal Chamber Diagram

representation shall be distributed approximately uniformly and symmetrically over the specimen surface.

6.5.1.3 If the surface temperatures are expected to be greatly nonuniform, additional thermocouples must be used to sample adequately the different temperature areas so that reliable weighted mean temperatures may be obtained.

6.5.1.4 With some nonhomogeneous walls, such as concrete, it may be advisable to use copper shim stock under the thermocouples to average the temperature. Large aggregates in the concrete can create biased temperature readings.

6.5.1.5 At least two surface thermocouples shall be placed on the guard area of the specimen at suitable locations to indicate the effectiveness of the guard area.

6.5.1.6 Surface temperatures on the cold side of the test panel shall be measured by surface thermocouples placed directly opposite those on the warm side.

6.5.2 Air temperatures may be measured by thermocouples, temperature sensitive resistance wires, or other sensors. Air thermocouples shall be made of wire not larger than 0.51 mm (No. 24 AWG).

6.5.2.1 If thermocouples or other point sensors are used, they shall be located in the metering box area in the same quantity and spacing as that specified for surface thermocouples in 6.5.1.1. The thermocouple shall be located midway between the face of the panel and the baffle, if one is used, but in no case less than 75 mm from the face of the panel. The junctions of the thermocouples shall have bright metallic surfaces and shall be as small as possible to minimize radiation effects. Another method is to shield the thermocouple junction. The thermocouples may be placed directly opposite the surface thermocouples; in any case they should be located as uniformly as possible over the metering area.

6.5.2.2 Thermocouples shall also be placed in the guard space at suitable locations, to indicate the degree of uniformity of guard space air temperatures; preferably, one should be placed opposite each guard area surface thermocouple, but not less than 75 mm from the panel.

6.5.2.3 Air temperatures on the cold side of the panel shall be measured by one thermocouple placed directly opposite each of the warm side air temperature thermocouples and located in a plane parallel to the specimens surface and spaced far enough away that they are unaffected by temperature gradients in the boundary layer. The thermocouples shall be located midway between the face of the panel and the baffle, if one is used. For low velocities, a minimum spacing of 75 mm from the specimen surface is required. At higher velocities the required minimum spacing is less but in no case less than 20 mm. No thermocouples need be placed in the cold space opposite guard space thermocouples remote from the panel surface.

6.5.2.4 If air temperatures are to be measured by means of resistance wire grids, the wire shall be distributed uniformly to indicate approximately the average temperature of the air on both sides of the panel at a plane midway between the baffle and the panel but in no case less than 75 mm from the panel.

6.5.2.5 It is recommended that the surface temperature of the baffles on the hot and cold sides be measured by placing thermocouples on all surfaces the specimen can see.

NOTE 4—This is not a requirement of this test method but is highly recommended. There are several reasons for the recommendation: (*1*) this indicates any difference between the baffle surface and air temperatures; (*2*) it will allow corrections to be made to the radiation component of the surface conductances due to differences in these temperatures; and (*3*) it is necessary to do this for specimens such as glass which have a high-thermal conductance.

6.6 *Instruments*:

6.6.1 All thermocouples or other temperature sensors for observing surface and air temperatures shall have their leads brought out individually to suitable measuring instruments capable of indicating temperatures to within ± 0.05 K.

6.6.2 Total average power (or integrated energy over a specified time period) for all energy to the meter box shall be accurate to within ± 0.5 % of reading under conditions of use. Power measuring instruments must be compatible with the power supplied whether ac, dc, on-off proportioning, etc. Voltage stabilized power supplies are strongly recommended.

6.6.3 Velocities of air over both surfaces of the panel should be measured with suitable instruments or be calculated from a heat balance between the rate of loss or gain of heat as it moves through the baffle space, as indicated by its temperature change, and the rate of heat flow through the test panel, average values of which can be determined from the test data. It should be recognized that radiant transfer between the baffle and the specimen can affect the calculation if the radiation is significant. For this reason direct velocity measurement is desirable.

NOTE 5—It is recommended that a central control location be established, that automatic scanning and recording equipment for unattended operation be used, and that data be computer processed.

6.7 *Verification*—When a new or modified apparatus is constructed, verification tests shall be conducted on panels made from materials of known conductance that does not exceed 1.5 W/(m^2·K) as determined in Test Methods C 177 or Test Method C 518[6]. Any differences in results should be carefully analyzed and corrective measures taken. Further periodic checks are recommended.

7. Sampling and Test Specimens

7.1 Specimens shall be representative of the construction to be investigated but may be modified if necessary for test purposes as mentioned in 5.2 and 5.3. It must be recognized that modifications to the construction may result in conditions that do not represent true field conditions. In many cases conduction and convection paths have considerable effect on the performance of the specimen and must be left intact. Other considerations are:

7.1.1 *Sensors*—Install temperature sensors as directed in 6.5. When desired, temperature and other sensors may be installed throughout the interior of the specimen for special investigations.

7.1.2 *Conditioning*—The usual pre-test conditioning is in ambient air long enough to come to practical equilibrium. Assemblies that may have significant moisture content, which can influence test results, must be allowed to reach steady-state moisture conditions. Since the specimen size will probably preclude oven drying, concrete wall specimens may require 6 to 8 weeks of room temperature aging.

7.1.3 *Edge Insulation*—When a test panel is installed, its edges shall, if necessary, be insulated to prevent edge effect from overtaxing the guarding effect of the guard area of the panel. For this purpose, the edges of the panel may be protected against heat loss or gain by a thickness of insulation with an *R* of 1 or 1.25 K·m^2/W. It may be necessary to vapor-proof the insulation to prevent condensation of moisture in the edges of the panel, if a test arrangement similar to that shown in Fig. 1(*c*) is used. The edge of the specimen should be well sealed to prevent air infiltration between the guard and the cold box.

8. Procedures

8.1 Test conditions of temperature and orientation should be chosen to correspond as closely as possible to the circumstances of use of the construction to be tested. This test method is primarily designed for the temperatures encountered in normal building use, however, it is recognized that the method may find application in testing conditions that are outside this normal range. It is recommended that a minimum temperature differential of approximately 25 K be maintained for accurate measurement.

8.2 The required stabilization and test periods are as follows:

8.2.1 Impose steady-state conditions for at least 4 h prior to final data collection. This condition is satisfied when, over this 4-h period, the average surface temperature did not vary by more than ± 0.06°C (± 0.1°F) and the average power in the meter area did not vary by more than ± 1 % and the data did not change unidirectionally. During this period, data shall be collected at intervals of 1 h or less.

8.2.2 After the conditions in 8.2.1 have been satisfied, continue the test period at least 8 h, but do not terminate the test until two or more successive 4-h periods produce results that do not differ by more than 1 %. During this period take data at intervals of 1 h or less. The average of the data for the two or more successive 4-h periods that agree within 1 % are used in calculating the final results. In testing panels that are heavily insulated, very massive, or both, it may be necessary to extend the duration of the test beyond the minimum period of two consecutive 4-h periods in order to be assured that conditions are steady, as it has been observed that continuing but small incremental changes can give a premature appearance of stability.

8.2.3 The calculation of a time constant, generated from apparatus measurements (Note 6) combined with an estimate of the thermal properties of the specimen, will help in estimating the time required for the test set-up to reach equilibrium. **(2)** It is also suggested that *C* and *U* values be calculated for the test specimen, utilizing known properties of the components. This will serve as general check of the measured results and avoid serious errors in measurement.

NOTE 6—The thermal mass of the apparatus may be the major factor contributing to the time constant of the system.

8.3 Data to be determined include:

8.3.1 The total net energy or average power through the specimen during a measurement interval. This includes all meter box heating and power to fans or blowers, and any corrections for meter box wall heat flow.

8.3.2 All air and surface temperatures specified in 6.5.1 and 6.5.2 (Note 7).

8.3.3 The effective dimensions of the metered area.

NOTE 7—In 6.5 the locations of thermocouples or temperature-measuring elements at various points are stipulated, for example, in the guard space and on the guard area of the test panel. The temperatures indicated by such thermocouples are of great value in evaluating the uniformity of temperatures prevailing in the guard space and on the test panel surfaces, but it is not feasible to stipulate generally the limits within which certain of these measured temperatures must agree. It must, therefore, be the responsibility of the test engineer to observe and weigh the significance of these temperatures to ascertain their effect upon the validity of a particular test measurement.

9. Calculation

9.1 Calculate the final test results by means of the following equations using the average data obtained in 8.2.2 for the two 4-h periods that agree within 1 %:

[6] Practice C 1045 must be used in conjunction with Test Methods C 177 and Test Method C 518.

$U = Q/A\ (t_h - t_c)$
$C = Q/A\ (t_1 - t_2)$
$R = (t_1 - t_2)A/Q$
$R_u = (t_h - t_c)A/Q = r_c + R + r_h$
$r_h = (t_h - t_1)A/Q$
$r_c = (t_2 - t_c)A/Q$
$h_h = Q/A\ (t_h - t_1)$
$h_c = Q/A\ (t_2 - t_c)$
$\lambda = QL/A\ (t_1 - t_2)$

9.1.1 For a relatively uniform but nonhomogeneous specimen such as normal walls, floors, ceilings, etc., the properties that may be calculated are transmittance U, conductance C, resistance R, overall resistance R_u, surface resistances and surface conductances, h.

9.1.2 For uniform and homogeneous specimens all of the properties listed in 9.1.1 may be calculated plus thermal conductivity λ.

9.1.3 For elements smaller than the metering area, the properties that apply to the element, according to the distinctions of 9.1.1 and 9.1.2 may be calculated if tests have been run that allow the element heat flow to be determined. Annex A1 presents considerations for these calculations.

10. Report

10.1 Report the following information:

10.1.1 Name, and any other identification or description of the test construction, including if necessary a blueprint showing important details, dimensions, and all modifications made to the construction, if any, and specimen orientation. Description of the test construction and a complete and detailed description of all materials. This includes the generic name of the material and its density. (For hygroscopic materials, such as some concrete materials and wood, the moisture content should also be given). If the thermal conductivities of these materials, at the test conditions, have been measured in a hot box facility (Test Method C 236 or Test Method C 976), a guarded hot plate (Test Method C 177) or a heat flow meter (Test Method C 518), these values should also be included.

NOTE 8—By generic description, the name of the material in addition to the brand name should be given (for example, preformed, cellular polystyrene Type VIII with a density of 22 kg/m^3; spruce-pine-fir with a moisture content of 12 % and a dry density of 486 kg/m^3).

10.1.2 Pertinent information in regard to preconditioning of the test panel.

10.1.3 Size and dimensions of the metering and guard areas of the test panel.

10.1.4 Average values during the test period of the temperatures and velocities of the air on both sides of the metering area of the panel, and of the temperature of the surfaces on both sides. (If significant, give the average values of the temperature of specific areas of the surface of the panel.)

10.1.5 Average rate of net heat input to the metering box.

10.1.6 Any thermal transmission properties calculated in 9.1 and the known precision of the equipment. Precision of the equipment should be checked using the propagation of errors theory.

NOTE 9—Discussions of this method can be found in many textbooks on engineering experimentation and statistical analysis **(3).**

10.1.7 Test duration and date.

10.2 All values shall be reported in both SI and inch-pound units unless specified otherwise by the client.

10.3 Where this test method is specifically referenced in published test reports and published data claims, and where deviations from the specifics of the test method existed in the tests used to obtain said data, the following statement shall be required to accompany such published information: “This test did not fully comply with the following provisions of Test Method C 236” (followed by a listing of specific deviations from this test method and any special test conditions that were applied).

11. Precision and Bias

11.1 *Background*—A round robin for guarded and calibrated hot boxes was conducted in accordance with Practice E 691. This round robin involved 21 different laboratories of which 16 had guarded hot boxes **(4).** Data were reported for 100-mm (4-in.) thick homogeneous specimens of expanded polystyrene board (Specification C 578). Each laboratory received material from a special manufacturer’s lot that was controlled to maintain a uniform density. Data reduction and analysis using Practice E 178 identified one of the 16 laboratories as a statistical outlier. Results from the other 15 laboratories showed that at a mean temperature (t) of 24°C (75°F), the average R value was determined to be 2.78 K m^2/W (15.77 F ft^2 h/Btu). The regression equation for the data set was:

$$R = 3.146 - 0.016\,t\ (R \text{ in K·m}^2\text{/W and } t \text{ in °C}) \tag{2}$$

$$R = 17.867 - 0.028\,t\ (R \text{ in F ft}^2\text{h/Btu and } t \text{ in °F}) \tag{3}$$

over the mean temperature range from 4°C to 43°C (40°F to 110°F). The mean specimen density ranged from 20.2 to 23.9 kg/m^3 (1.26 to 1.49 lbs/ft^3).

11.2 *Precision*—At a specimen thermal resistance of R = 2.78 K·m^2/W (15.76 F ft^{2}h/Btu) and on the basis of test error alone, the difference in absolute value of two test results obtained in different laboratories on the same specimen materials will be expected to exceed the reproducibility interval only 5 % of the time according to Table 2. For example, measurements from two different laboratories on the same specimen could differ by up to ± 7.8 % at a mean temperature of 24°C (75°F) 95 % of the time.

11.3 *Bias*—Based on guarded hot plate data (Test Method C 177) from the National Institute of Standards and Technology—Center for Building Technology and supported by measurements from other laboratories, the true value for the round-robin specimen is a thermal resistance of 2.81 K·m^2/W (15.94 F ft^{2}h/Btu). The mean value measured by the guarded hot box differed by − 1.07 %.

TABLE 2 Precision for Test Method C 236

Mean Temperature, °C (°F)	Thermal Resistance, K·m^2/W (Fft^{2}h/Btu)	Reproducibility Interval, %	Change in R, K·m^2/W(Fft^{2}h/Btu)
4 (40)	2.95 (16.75)	± 7.3	± 0.22 (± 1.23)
24 (75)	2.78 (15.77)	± 7.8	± 0.22 (± 1.23)
43 (110)	2.60 (14.79)	± 8.6	± 0.22 (± 1.27)

NOTE 10—Another test series was conducted on homogeneous common lot specimens in three guarded hot boxes at different laboratories. **(5, 6)**R-values of the specimens ranged from approximately 0.5 to 2.1 K·m^2/W (3 to 11.8 F ft^{2}h/Btu) at mean temperatures of 4, 24, and 43°C (40, 75, and 110°F). This series indicated that results with precision of ± 5 % may be achieved.

NOTE 11—Both round robins used a homogeneous specimen, an ideal wall section. Actual wall sections will be nonhomogeneous. The precision and bias has not yet been determined for nonhomogeneous specimens. The above statements provide a bound.

12. Keywords

12.1 building assemblies; guarded hot box; test method; thermal performance; thermal resistance

ANNEX

(Mandatory Information)

A1. USING THE GUARDED HOT BOX TO DETERMINE HEAT TRANSFER THROUGH A BUILDING ELEMENT SMALLER THAN THE METERING AREA

A1.1 General Considerations

A1.1.1 In this use, the building cement area (A_a) is located centrally in the metering area (A_b) demarcated by the hot box, and is surrounded by a masking partition which extends homogeneously beyond the area A_b into the guard area. The area of the mask (A_m) within the metering area equals ($A_b - A_a$). The total heat flow rate Q_b determined by the hot box measurement consists of two heat flow rates in parallel, in accordance with the equation

$$Q_b = Q_r + Q_m \tag{A1.1}$$

where Q_r is the total through the building element area $A_\infty$and Q_m is that through the mask area A_m.

A1.1.2 In conducting a test to ascertain Q_r for a particular building element, Q_b is determined by the hot box measurement, and Q_m is inferred from the results of calibration measurements. The calibration is made by means of hot box tests of the masking partition either before the aperture for the building element is cut out or with a blank of known thermal conductance installed in place of the building element. The error in Q_e is evidently equal to the difference of the algebraic errors in Q_b and Q_m. The fractional error is given by

$$\begin{aligned}\Delta Q_e/Q_e &= (\Delta Q_h - \Delta Q_m)/(Q_b - Q_m)\\ &= [(\Delta Q_h/Q_h) - (\Delta Q_m/Q_b)]/(1 - Q/Q_b)\end{aligned} \tag{A1.2}$$

where (ΔQ_e) is the algebraic error in $Q\infty$ etc. An estimate of the fractional error (ΔQ_m)/Q_b is dependent upon the method which is used to calibrate the mask. If the calibration is made before the aperture for the building element is cut out then

$$\Delta Q_m/Q_h = (\Delta Q'_h/Q_h) \times (A_m/A_b) \tag{A1.3}$$

where ($\Delta Q'_h$) is the error in heat flow measured during the calibration test. If a blank of known thermal conductance is used to calibrate the mask then

$$\Delta Q_m/Q_h = (\Delta Q'_h - \Delta Q_{b1})/Q_b \tag{A1.4}$$

where (ΔQ_{b1}) is the algebraic error in determination of heat flow through the blank. Little can be said in general about the magnitudes of the algebraic fractional errors (ΔQ_h)/Q_b and (ΔQ_m)/Q_b, since these depend on the quality and management of the particular hot box apparatus and upon the accuracy of determination of heat flow through the blank, but is is evident that the systematic portion of the error (ΔQ_r)/Q_r is reduced as Q_m/Q_b is made small. Also, as Q_m is made small, the term ($\Delta Q_m/Q_h$) is presumably also made less significant. Thus, the fractional systematic error possible in the determination of Q_r is reduced by increasing either the area of the building element (if feasible), or the total thermal resistance of the mask.

A1.1.3 The need to infer the mask heat flow Q_m accurately requires that the mask be designed to act as a heat flow meter with an emf output and temperature difference of Δ_t proportional to the total heat flow through it. This consideration is the basis for the specific recommendations which follow.

NOTE A1.1—Additional error may arise due to the possible influences of the building element in causing two or three dimensional heat flow at the boundary with the mask and thus affecting the mask heat flow in regions adjacent to the element. Thus mask heat flow, determined under a given set of conditions with a calibration standard in place, may change when the building element is installed, even though the test conditions remain unchanged. The user of this procedure should be aware of such possible errors and should attempt to evaluate their magnitude in relation to the desired accuracy of the test.

A1.2 Recommendations

A1.2.1 It is recommended that the mask be made of a suitable uniform thickness of a homogeneous and stable material of low thermal conductivity having adequate strength to support the weight of the building elements to be tested. Suitable materials are faced high-density glass fiber or polystyrene boards laminated together as necessary. Stronger masks can be fabricated by sandwiching layers of insulation between layers of rigid materials such as plywood. Such masks, though nonhomogeneous, are uniform in the direction perpendicular to the direction of heat flow and are calibrated in the same manner as homogeneous masks. It may be necessary in some cases to incorporate framing in the mask to support heavy building elements such as heavy-duty metal frame windows or masonry sections. Such nonuniform masks are necessarily calibrated using blanks of known thermal conductance. Framing members must be kept away from the juncture with the building element and with the boundary of the metering area so as not to contribute excessively to lateral heat transfer at these points. It is important that the mask be low in hygroscopicity to minimize changes in its thermal resistance with ambient humidity conditions, and that it be substantially impervious to air flow through it.

A1.2.2 Thermocouples for measuring the temperature difference across the mask should be permanently installed uniformly flush with or just under its surfaces. These may be connected in series-differential for determination of the mask temperature difference, or as individual thermocouples for exploring the temperature distributions on the faces of the mask. It is recommended that there be at least eight thermocouple junctions on each face of uniform masks: four at positions bisecting the four lines from the corners of the building element aperture to the corresponding corners of the metering area, and four at positions bisecting the sides of the rectangle having the first four thermocouples at its corners. A suitable thermocouple arrangement would have to be chosen for nonuniform masks that would provide representative average surface temperatures. This is particularly important when natural convection is used and air temperatures and film coefficients vary over the metering surface. If framing members are used, an area-weighted average of temperatures measured over the members and away from them is necessary. The mask, as a heat flow meter, should be calibrated and used in terms of the average temperature (or thermocouple emf) difference across it indicated by the permanently installed thermocouples.

A1.2.3 To protect the surfaces of the mask and the permanently installed thermocouples, and if necessary to render the surfaces impervious to air, a permanent coating or thin facing on each face of the mask is desirable. However, the coating or facing must be of low conductance laterally so that it does not contribute excessively to lateral heat transfer at the juncture with the building element or at the boundary of the metering area. The emittance of the mask surfaces should be uniform, and unchanged after calibration of the mask; in cases where the transmittance (rather than the conductance) of the building element is of particular interest, it is preferable that the emittance of the mask surfaces be large.

A1.2.4 In view of the desirability of high thermal resistance of the mask relative to that of the building element, the uniform thickness of the mask should in general not be less than that of the building elements to be tested, and may be greater than that of the thinner elements. Mask thickness greatly exceeding that of the building element is to be avoided if possible because of lateral heat flow in the mask due to its exposure at uncovered areas of its aperture. (In special instances, for example, a window designed to be set a few inches outward from the plane of the inner surface of a wall, a special calibration of the mask as a heat flow meter may be necessary using a blank of known thermal conductance in the precise position of the window at the juncture with the mask aperture.)

A1.2.5 The mask aperture in which the building element is installed for test should fit the element specimen snugly. Cracks between them should be minimal in width, and should be filled completely with a good fibrous insulation and caulked or otherwise sealed at the mask surfaces to prevent air leakage. It is desirable that the insulation used to fill cracks have approximately the same conductivity as the mask material; it would then be possible, if the cracks aggregate an area significant in relation to the mask area, to compensate roughly for the increased virtual mask area by increasing the mask heat flow indicated by its temperature drop in proportion to the increase of area.

A1.2.6 It is probable that many building elements to be tested are inhomogeneous or nonuniform in construction for structural reasons, and in consequence that the local thermal conductances differ considerably at different frontal areas of the element. The variations are inherent, and the result of the test is an average conductance or transmittance value for the total construction, provided that the conductance variations at edges do not seriously impair the validity of using the mask as an adequate heat flow meter. This is a matter which varies with the case, and therefore must rest on the judgment and discretion of those conducting the test measurement. A useful guiding principle is that nothing should be incorporated in, or omitted from, a building element specimen being tested that would make it not representative of the assembly that would be found in actual installation in service. For example, if a metal window ordinarily is installed with inset wood framing, the test specimen should include just so much of the wood framing as is properly chargeable to it.

A1.3 Calibration of the Mask as a Heat Flow Meter

A1.3.1 The calibration of the mask is made by means of hot box tests either before the aperture for the building elements is cut out or with a blank of known thermal conductance installed in place of the building element. The mask must be fully prepared with the permanent differential thermocouples installed and any final facings or coatings applied. Several tests are made, adequately covering the range of mask mean temperatures (and perhaps mask temperature drops and box air velocities) at which the mask will be operated in tests of building elements. In each test, under steady-state conditions, the metering box heat flow Q'_t and the corresponding mask temperature drop Δ_t, indicated by its permanently installed thermocouples, are determined. The net mask heat flow Q'_m corresponding to Δt is calculated as $Q'_b(A_m/A_b)$ when the calibration is made before the aperture is cut, where A_m and A_b are as defined earlier, and as $(Q'_i - Q_{b1})$ for the calibrated-blank method where Q_{b1} is the calculated heat flow through the blank. In the latter method of calibration, a suitable blank must first be prepared and calibrated.

APPENDIX

(Nonmandatory Information)

X1. THERMOPILE EMF AND HEAT FLOW RELATIONSHIP (7, 8)

X1.1 The procedure given in this Appendix outlines the steps suggested to obtain the relationship between heat flow and thermopile output. This method addresses the technique that will yield the heat flow relationship as a function of the thermopile output and a thermopile offset, if present.

X1.1.1 It is essential that the number of fans and power input in the metering, guard, and environmental boxes be held constant along with all temperatures throughout the calibration (and measurement) phase. By holding the fan number and input along with the surface temperatures constant, the operator assures a constant heat transfer film coefficient to the specimen throughout testing. The E_o value associated with negligible net heat flow across the meter box walls is then obtained from the relationship between Q_m and E. The equation that describes the total heat flow drawn schematically in Fig. 4 is:

$$Q_F + Q_H + Q_m = Q_s = \frac{A\Delta T}{R} \quad \text{(X1.1)}$$

where:

Q_F = heat flow due to fan, W,
Q_H = heat flow due to heater, W,
Q_m = heat flow through the metering box walls, W,
Q_s = heat flow through specimen, W,
R = thermal resistance of specimen, $m^2 \cdot K/W$,
A = heat flow metered area, m^2,
ΔT = temperature difference across specimen, K,
E_o = thermopile emf when net heat flow through metering box walls is negligible, and
E = thermopile emf.

The goal is to make Q_m equal to zero. Q_m can be described by:

$$Q_m = fn\,(E) = m\,E + b \quad \text{(X1.2)}$$

X1.1.2 To quantify m, at least two test runs must be performed with differing levels of E. E must be held constant within each test. The specimen surface to surface temperature difference for all tests must be constant and of the same value. Q_s can be approximated by assuming the design R. It is not necessary to know the R of the specimen. Plot Q_m calculated from Eq X1.1 versus E. The slope of the line is m.

The next step is to quantify b in Eq 2. Set the temperature difference across the specimen surface equal to zero ($Q_s = 0$). Substituting Eq X1.2 into Eq X1.1 and setting $Q_s = 0$ reduces Eq X1.1 to:

$$Q_F + Q_H = -(m\,E + b) \quad \text{(X1.3)}$$

X1.1.3 Set E to a value such that the fan wattage is at operational conditions and the heater wattage is at the minimum value that maintains temperature control. This will assure that no heat is flowing anywhere except through the meter box walls. During this test, lateral heat flow must still be negligible. Using m that was determined, Eq X1.3 will yield b. The thermopile emf value that pertains to negligible net heat flow through the meter box walls E_o can then be calculated using Eq X1.2:

$$E_o = -(b/m) \quad \text{(X1.4)}$$

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