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Standard Test Method for THERMAL TRANSMISSION PROPERTIES OF NONHOMOGENEOUS INSULATION PANELS INSTALLED VERTICALLY[1]

This standard is issued under the fixed designation C 1061; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method, known as the high-temperature hot box method (calibrated or guarded), covers the measurement of thermal conductance, thermal transference, and thermal transmittance of insulation panels from a heated surface temperature of approximately 40°C (104°F) to the maximum insulation design temperature, not to exceed 540°C (1000°F). In distinction to Test Method C 177, which is primarily applicable to homogeneous samples, and Test Method C 236, which is primarily applicable to measurements on panels representative of such constructions as walls, roofs, and floors of buildings, the high-temperature hot box method is designed for measurements on nonhomogeneous panels representative of such constructions as metal reflective insulation panels for nuclear power plants and prefabricated insulation panels for fossil power plants.

1.2 In a test method as complicated as the hot box method, it is not practical or desirable to establish the construction in such detail that the method could be used by a person not technically trained. However, the general principles outlined in this test method must be followed. It shall be understood, therefore, that those applying the 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. In standardizing this test method, it is recognized that it would be unwise to restrict, unnecessarily, the initiative of research workers who may wish to develop and improve the test method. Accordingly, in the description of the apparatus given in Section 6, the essential principles and the general arrangement of the apparatus are first given; any test following this method must satisfy these general requirements. The details of the apparatus and the suggested test procedure that follow are given, not as mandatory requirements, but simply as examples of methods and precautions that have been found useful in the past to satisfy the general principles. It is realized that the variation of types of structures to be tested may be so great, and the demands of the conditions so different, that it would be a mistake to restrict the test method unnecessarily and to confirm all measurements to a single experimental arrangement.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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 Definitions of Terms Relating to Thermal Insulating Materials[2]

C 177 Test Method for Steady-State Thermal Transmission Properties by Means of the

[1] This test method is under the jurisdiction of ASTM Committee C-16 on Manufactured Masonary Units and is the direct responsibility of Subcommittee C16.21 on Reflective Insulation.
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[2] *Annual Book of ASTM Standards*, Vol 04.06.

Guarded Hot Plate[2]

C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[2]

C 835 Test Method for Total Hemispherical Emittance of Surfaces from 20 to 1400°C[2]

C 976 Test Method for Thermal Performance of Building Assembly by Means of a Calibrated Hot Box[2]

E 691 Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *surface coefficients*—the ratio of the steady-state heat exchange rate (time rate of heat flow per unit areas of a particular surface by the combined effects of radiation, conduction and convection) between a surface and its external surroundings (air or other fluid and other visible surfaces) to the temperature difference between the surface and its surroundings (in SI units, $W/m^2 \cdot K$).

NOTE 1—In inch-pound units, the surface coefficient is expressed as $Btu \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ and other equivalent mathematical forms. The conversion factors given in Table 1 may, therefore, be found useful.

3.1.2 *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 (C in SI units, $W/m^2 \cdot K$).

NOTE 2—The average temperature of a surface is the area-weighted mean temperature of that surface.

NOTE 3—When the defined surfaces of a mass-type thermal insulation are not of equal areas, as in the case of thermal transmission in a radial direction, or are not of uniform separation (thickness), an appropriate mean value for area and thickness must be given.

NOTE 4—When other modes of heat transfer are present in addition to conduction, the apparent or effective thermal conductivity is obtained by multiplying the thermal conductance by the average thickness.

NOTE 5—For the case where there is air passage through the body, the effective thermal conductance must include details of the pressure difference across the body. For a material or assembly where radiant energy opacity or transparency affect the nature of heat transfer, the optical properties must be given.

NOTE 6—"Total" or "areal" thermal conductance are often used as synonyms for thermal conductance.

NOTE 7—In inch-pound units, thermal conductance is expressed as 25 $Btu \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ and other equivalent mathematical forms. The conversion factors given in Table 1 may, therefore, be found useful.

3.1.3 *thermal conductivity* (λ)—the time rate of heat flow through unit thickness of an infinite slab of a homogeneous material in a direction perpendicular to the surface, induced by unit temperature difference (λ in SI units, $W/m \cdot K$).

NOTE 8—For practical purposes, the lateral extent of a slab is considered to be infinite when heat flow laterally is less than 2 % of the transverse flow.

NOTE 9—A body is considered homogeneous when the above property is found by measurement to be independent of sample dimensions.

NOTE 10—The property must be identified with both a specific mean temperature, since it varies with temperature, and for a direction and orientation of thermal transmission since some bodies are not isotropic with respect to the thermal conductivity.

NOTE 11—For many thermal insulation materials, thermal transmission occurs by a combination of different modes of heat transfer, and the measured property should be referred to as an effective or apparent thermal conductivity for the specific conditions of test (sample thickness and orientation, environment, applied load, environmental pressure and temperature difference).

NOTE 12—Various units are found in the literature for thermal conductivity and thermal conductance. The conversion factors given in Table 1 may, therefore, be found useful. In inch-pound units, thermal conductivity is expressed as $Btu \cdot in. \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ and other equivalent mathematical forms.

3.1.4 *thermal transference* (T_r)—the steady-state heat flow from (or to) a body through applied thermal insulation and to (or from) the external surroundings by conduction, convection, and radiation. It is expressed as the time rate of heat flow per unit area of the body surface per unit temperature difference between the body surface and the external surroundings (in SI units, $W/m^2 \cdot K$).

NOTE 13—In inch-pound units thermal transference is expressed as $Btu \cdot h^{-1} \cdot ft^{-2} \cdot °F^{-1}$ (temperature difference between hot service on one side and air on the other side).

3.1.5 *thermal transmittance* (U)—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 (in SI units, $W/m^2 \cdot K$).

NOTE 14—This heat transmission rate has been called the overall coefficient of heat transfer (U).

3.2 *Symbols*—The symbols in 3.1.1 to 3.1.5 have the following significance:

λ = thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$,
C = thermal conductance, $W \cdot m^{-2} \cdot K^{-1}$,
h_o = surface coefficient, inside, $W \cdot m^{-2} \cdot K^{-1}$,

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

h_1 = surface coefficient, outside, $W \cdot m^{-2} \cdot K^{-1}$,
T_r = thermal transference, $W \cdot m^{-2} \cdot K^{-1}$,
q = time rate of heat flow through area A, W,
A = area normal to heat flow, m^2,
t_o = temperature of heated surface, K,
t_1 = temperature of insulation hot surface, K,
t_2 = temperature of insulation cold surface, K,
t_c = temperature of air 75 mm or more from the insulation cold surface, K,
t_h = temperature of air 75 mm or more from the hot surface, K,
U = thermal transmittance, $W \cdot m^{-2} \cdot K^{-1}$,
L = thickness of sample, m, and
e_i = error in variable i, ± %.

4. Significance and Use

4.1 The thermal transference, transmittance, and conductance as determined by this test method can be used to find the heat loss through a nonhomogeneous insulation panel. The thermal transference, transmittance, and conductance, calculated from actual heat loss, include the effects of joints and variations of construction within the area of the insulation specimen tested.

4.2 The thermal transference and transmittance is a means of comparing insulations, either homogeneous or nonhomogeneous. Normally a thermal conductance plus an insulation outer surface heat transfer coefficient are needed to describe adequately the heat losses. Thermal transference and transmittance incorporate both an insulation conductance and a surface heat transfer coefficient and are, therefore, valid for comparing homogeneous and nonhomogeneous insulations.

4.3 Due to the requirements as to test conditions prescribed in this test method, it should be recognized that the thermal transference, transmittance, and conductance obtained will not necessarily be the values pertaining under all service conditions. As an example, the test method provides that the coefficients shall be obtained by tests on dry specimens, while such a condition may not be realized in service. The results obtained, therefore, are true only for the conditions of test and for product construction as set forth in the report (Section 10). The results must not be applied without proper adjustment when the material is used at other conditions, such as ambient temperatures that differ appreciably from those of the test or forced convection on the outer surface. With these qualifications in mind, the values of thermal transference, transmittance, and conductance obtained by this test method may be applied as follows:

4.3.1 For assessing the insulating value of a dry material under conditions similar to those of the test.

4.3.2 For comparing the insulating values of two materials when both are used on the same wall size, at the same wall and ambient temperatures, and in the same environment.

4.3.3 As basic data for computing the heat transference of materials used in construction. However, when used in this way, the results for a particular material obtained by this test method will not apply where, in the application, any of the factors (structure, temperatures, or forced convection) differ from those used in the test. The variations in the contribution of each heat transfer mode as the dimensions change must be accounted for. This involves creating a mathematical model of the insulation system and properly accounting for the individual modes of heat transfer (conduction, convection, and radiation).

NOTE 15—Because of the difficulties in the extrapolation of data and model development, any analysis should be performed by an expert trained in this field.

4.4 For satisfactory results in conformance with this test method, the principles governing the size, construction, and use of apparatus described in this test method should be followed. If the results are to be reported as having been obtained by this test method, then all of the pertinent requirements prescribed in this test method shall be met.

5. General Principles

5.1 From the equations in Section 9, it is apparent that in order to determine the conductance (C), transference (T_r), and the transmittance (U), of any specimen, it is necessary to know the area (A), the heat flow (q), and the temperature differences, all of which must be determined under such conditions that the flow of heat is steady. The hot box, either guarded or calibrated, is an apparatus designed to determine C, T_r, or U for representative test panels and is simply an arrangement by means of which a desired steady temperature difference can be established and maintained across a test panel to ensure that a constant heat flux can be maintained for a period of time adequate to measure the heat flow and temperature to the desired accuracy. In such an arrangement, the measurements of the area and the temperatures present no difficulty, at least in principle. The heat flow (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 hot surface of the test panel. If, ideally, the temperatures within the metering box and in the space surrounding it are maintained the same, then no heat interchange between the metering box and the surrounding space can occur, and the heat input to the metering box is a measure of the heat flow through a known area of the panel. Except possibly at the metering box gaskets, the heat flow into the hot surface of the panel is not affected by the presence of the metering box. The portion of the panel outside the test area, laved by the air of the surroundings, constitutes a guard area to minimize lateral heat flow in the test panel near the metering area.

5.2 In practice, it is not always feasible or convenient to satisfy the ideal condition of zero temperature difference across the metering box walls required to prevent a net interchange of heat between the metering box and guard space. Since the total wall area of the metering box is usually more than twice the metering area of the panel, small temperature gradients through the walls may cause heat flows totaling an undesirably large fraction of the heat input to the metering box. For this reason, it is a general principle for a hot box apparatus that the metering box walls be equipped to serve as a heat flow meter so that heat flow through them can be minimized by adjusting conditions during tests and estimated so that a correction can be applied in calculating test results.

6. Apparatus

6.1 *Arrangement*—Figure 1 (*a*) shows a schematic arrangement of the test panel and of various major elements of the apparatus; Figures 1 (*b*) and 2 (*b*) show alternate arrangements. Still other arrangements, accomplishing the same purpose, may be preferred for reasons of convenience of ease of installing panels. In general, the size of the metering box determines the minimum size of the other elements.

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 testing panels of standard size, the metering area should span an area that includes all components of the panel. For most types of panels, a metering box width of 0.82 to 1.22 m (32 to 48 in.) between centers of the gaskets is practical. The height of the metering box is not ordinarily subject to the same limitations, and it can be made of convenient height but not less than the width.

6.2.2 *Thermal Conductance*—The metering box walls shall have a thermal conductance of not more than 1.2 $W \cdot m^{-2} \cdot K^{-1}$. In order that the conductance of the box wall shall be uniform over all the box area, a construction without ribs should be used, for example, a homogeneous structural insulation board. The edge in contact with the panel shall be narrowed on the outside only to hold a gasket not more than 25 mm (1 in.) wide. The metering area of the panel shall be taken as the area included between the center lines of the gaskets. The inner surface of the metering box should be painted with a high emittance paint to increase radiation interchange and to minimize temperature differences within the box cavity.

6.2.3 *Heat Supply and Temperature Control*—Figure 2 shows a possible arrangement of equipment in the metering box. Electric heaters are mounted near, but not in contact with, the heated surface to ensure an even temperature distribution without gross hot spots due to the high temperatures encountered in the performance of this test. Fans are not used in the metering box for circulation as are specified in Test Method C 236. Air in the guard box should be circulated in such a manner that the temperature in the guard box is automatically controlled to maintain a near-zero temperature difference across the metering box walls. Power supplied to the heaters may be either ac or dc.

6.2.4 *Heat Flow Meter*—To equip the metering box walls to serve as a heat flow meter, a number of differential thermocouples connected in series to form a thermopile shall be applied to the inside and outside surfaces of the metering box walls. There shall be at least one differential pair of thermocouple junctions located directly opposite each other and a minimum of one pair for every 0.2 m^2 (2 ft^2) of each of the five sides of the metering box. The junctions and the thermocouple wires for at least a 100-mm (4-in.) distance from the junctions shall be mounted practically flush with the surface of the wall. The thermocouples shall be connected in series so