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METHOD OF TEST FOR THERMAL CONDUCTANCE AND TRANSMITTANCE OF BUILT-UP SECTIONS BY MEANS OF GUARDED HOT BOX

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METHOD OF TEST FOR THERMAL CONDUCTANCE AND TRANSMITTANCE OF BUILT-UP SECTIONS BY MEANS OF GUARDED HOT BOX

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 8 January 1980, after the draft finalized by the Thermal Insulation Materials Sectional Committee had been approved by the Chemical Division Council.

0.2 In a method as complicated as the hot box method it is impossible and undesirable to establish the construction in such detail that the method could be used by a person not technically trained. It should be understood, therefore, that those applying the 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 method it is recognized that it would be unwise to restrict the initiative of research workers who may wish to develop and improve upon the method. Accordingly, in the description of the apparatus given in **4**, the essential principles and the general arrangement of the apparatus are first given and any test following this method shall 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 example of methods and precautions that have been found useful in the past to satisfy the general principles. It is realized that the variation in types of structures to be tested may be so great, and the demands of the conditions so different, that it would be wrong to restrict the test method unnecessarily and to confine all measurements to a single test arrangement.

0.3 This method may be applied to any construction for which it is possible to build a reasonably representative panel of size appropriate for the apparatus. It should be recognized that, in order to obtain a suitable test panel, it may be necessary to modify the details of some constructions. For example, for constructions incorporating air spaces, in order to prevent interchange of air between test area and guard area, it may be necessary to provide in the test panel a barrier that does not occur in the full-scale construction. Likewise, in construction incorporating an element of high lateral conductance (such as a metal sheet), it may be necessary to separate the test and guard areas of the high-conductance element by a narrow gap such as a saw cut.

0.3.1 Heat transfer across an air space depends on the orientation of that air space and, therefore, panels incorporating air spaces must be tested in that orientation in which the construction is to be used.

0.3.2 Since the method determines the total flow of heat from the warmer to the cooler side through the test area demarcated by the metering box, in principle 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 determinable.

0.4 In distinction to IS : 3346-1966* which is primarily applicable to homogeneous samples, the guarded hot box method is designed for measurements on non-homogeneous panels representative of construction such as walls, roofs, and floors of buildings.

0.5 In the preparation of this standard considerable assistance has been derived from ASTM C 236-66 'Standard test method for thermal conductance and transmittance of built-up sections by means of the guarded hot box', published by the American Society for Testing and Materials, and is gratefully acknowledged.

0.6 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960†.

1. SCOPE

1.1 This standard prescribes a method, known as the guarded hot box method, for the measurement of the thermal conductance and thermal transmittance of panels (*see* **0.3**).

NOTE — In applying this method, the general principles outlined here shall be followed. However, the details of the apparatus may be varied in order to suit the convenience of the individual operator.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definition of terms, symbols and units given in IS : 3069-1965‡ shall apply.

*Method for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method).

†Rules for rounding off numerical values (*revised*).

‡Glossary of terms, symbols and units relating to thermal insulation materials.

3. GENERAL PRINCIPLES

3.1 In order to determine the conductance *C*, and the transmittance *U* of any specimen, it is necessary to know the area *A*, the heat flux *q* and the temperature differences, all of which shall be determined under such conditions that the flow of heat is steady. The hot box is an apparatus designed to determine *C* or *U* for representative test panels and is an arrangement by means of which a desired steady temperature difference can be established and maintained 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. In such an arrangement the measurements of area and temperature present no difficulty, at least in principle. 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, 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 flux through a known area of the panel. Except possibly at the metering box gaskets, the heat flow into the warm side of the panel is not affected by the presence of the metering box. The portion of the panel outside the test areas, 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. Condensation within the specimen causes errors in heat flow; in order to avoid this, the dew point temperature on the warm side must be kept below the temperature of the cold side.

3.2 In practice, however, 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 tamperature gradients through the walls may cause heat flows totalling 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 shall be equipped to serve as a heat flow meter so that the heat flow through them can be minimized by adjusting conditions during tests, and so that a correction can be applied in calculating test results.

4. APPARATUS

4.1 Arrangement — Figure 1A shows a schematic arrangement of the test panel and of various major elements of the panel apparatus; Fig. 1B and 1C 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 other elements.

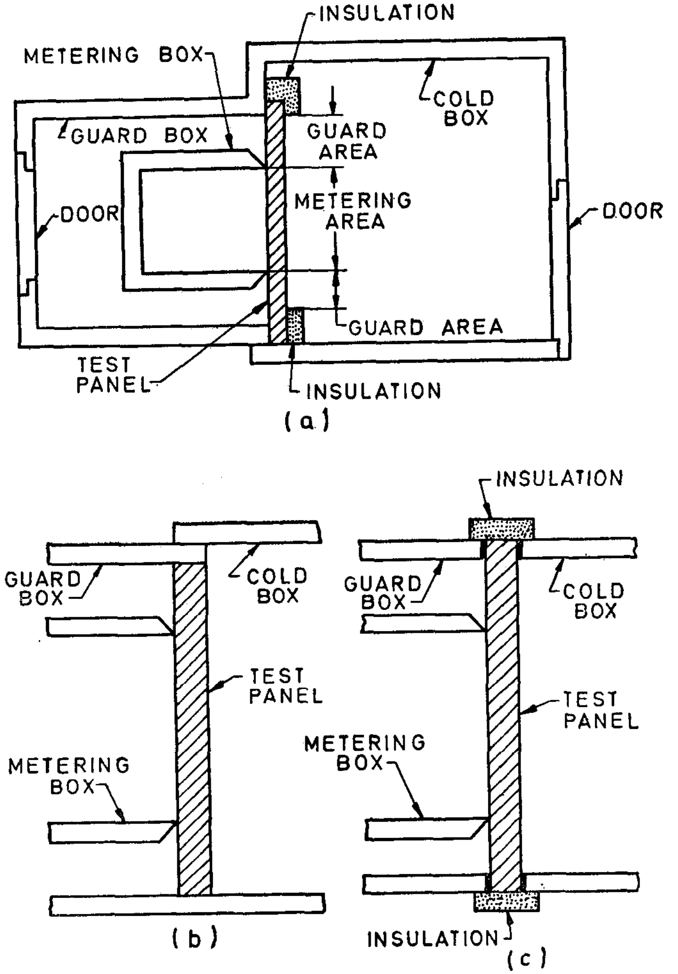

FIG. 1 GENERAL ARRANGEMENT OF TEST BOX, GUARD BOX, TEST PANEL AND COLD BOX

4.2 Metering Box

4.2.1 *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. For most types of panels, a metering box width of 0·82 or 1·22 m between centres of the gaskets is practical. The height of the metering box is not ordinarily subject to the same limitations and it may be made of any convenient height, preferably not less than the width. The depth of the metering box should be not greater than that required to accommodate its necessary equipment.

4.2.2 *Thermal Conductance* — The metering box walls shall have a thermal conductance of not more than 1·2 W/m^2K. 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 glued balsa wood or a sandwich construction. 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 nose piece may be used to carry the gasket. The metering area of the panel shall be taken as the area included between the centre lines of the gaskets.

4.2.3 *Heat Supply and Air Circulation* — A possible arrangement of equipment in the metering box to assure an even, gentle movement of air over the metering area of the panel is shown in Fig. 2. The electric heaters are mounted in a cylindrical housing with walls of conductance not greater than 1·2 W/m^2K, and with reflective 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 at 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. 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, and its motor is contained within the metering box, its electrical input must be metered, and its electrical input should be as small as feasible, since it represents the least possible heat input to the metering box. If the motor is located outside of the metering box, the heat equivalent of the shaft power delivered to the fan blades must be accurately known, and precautions must be taken to prevent air leakage into or out of the metering box around the shaft.

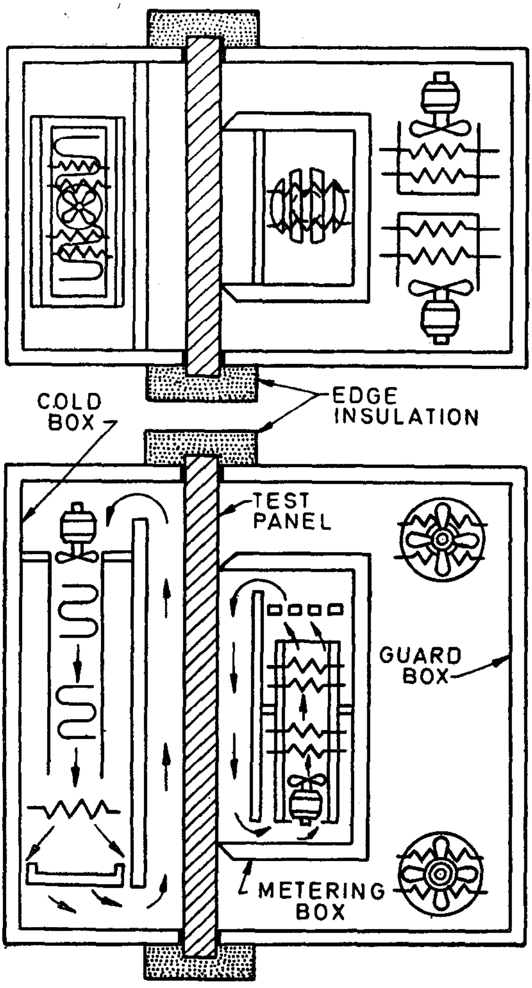

FIG. 2 ARRANGEMENT OF EQUIPMENT DURING THE TEST

4.2.4 *Temperature Control* — A reliable thermostat may be used to control the metering box air temperature and heat input. For convenience, the setting of the thermostat should be adjustable from outside the apparatus; for best operation, the heaters controlled by the thermostat should be open-wire heaters of minimal heat capacity and lag. The sensitive element of the thermostat may be placed in any region of relatively fast moving air. As an alternative to using thermostat, it is possible to supply electrical energy to the metering box at a constant but adjustable rate. With constant electrical input and other conditions steady, the temperature of the metering box should become constant without the use of a thermostat.

4.2.5 *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, such as springs or exteriorly tightened screws, exerting a thrust on the back of the metering box.

4.2.6 *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 surface of the metering box walls. There shall be at least one differential pair of thermocouple junctions located directly opposite each other at the centre of each of the five sides of the metering box; more than five are preferable, located at the centres of approximately equal areas, if the metering box is large, or if uniformity of temperatures within the metering box is considered unlikely. The junctions and the thermocouple wires for at least a 100 mm distance from the junctions shall be glued or cemented practically flush with the surface of the wall. The thermocouples shall be connected in series so that their individual differential emfs are all additive in the same direction when the inside of the metering box is warmer than the outside.

4.2.7 *Thermopile EMF and Heat Flow Relationship* — The relationship between thermopile emf and heat flow through the metering box walls may be determined by the following method. Place a homogeneous panel of conductance not greater than 2·3 W/m²K in the apparatus, and establish a steady temperature difference of 28 K or more from air to air on the two sides. Adjust the guard box air temperature so that when steady temperature conditions prevail, the guard box air is (a) several degrees warmer, and (b) several degrees cooler, than the metering box air. Record the average steady power input to the metering box Q and the air temperatures on the two sides of the panel, for each of these two conditions of temperature unbalance. It is then possible, assuming that the U-value of the test panel and the heat flow meter coefficient, *M*, are constants, to write two equal equations of the following form:

$$Q + ME = AU\,(t_h - t_c)$$

where *M* is the thermopile constant, and *E* is the thermopile emf. From these equations the value of *M* may be calculated (care should be taken that the polarity of the thermopile is identified properly). It will be noted that the left hand side of the equations is the net heat flowing through the metering area of the panel, if the polarity of the thermopile is chosen properly. In routine tests adjust the guard box air temperature to yield as small a thermopile reading as is feasible, and use the coefficient *M* to compute the heat interchange that occurs between the guard box and metering box under these conditions. This heat interchange shall in no test exceed 3 percent of the metering box input.

4.3 Guard Box

4.3.1 *Size* — The guard box shall 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.

4.3.2 *Thermal Conductance* — To ensure that there is a temperature difference of not 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^2K. 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.

4.3.3 *Heat Supply and Air Circulation* — One or more reflective-surfaced cylindrical heater units with a fan, of the type used in the metering box, may be used to supply heat to the guard box air and also to circulate the air gently around the metering box in a roughly oval path parallel to the face of the test panel. 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.

4.3.4 *Temperature Control* — The guard box air temperature and heat input may be controlled by a reliable thermostat, or by means of a differential thermostat sensitive to slight differences in temperature between the metering box and guard box air. Several arrangements are possible for such a differential thermostat, for example a relay controlled either 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 in the guard box air, and should be of minimum thermal lag. The setting of the thermostat or of the differential thermostat should be exteriorly adjustable so that it is possible to adjust it according to the indications of the metering box heat flow meter thermopile.

4.4 Cold Box

4.4.1 *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.

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

4.4.3 *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 if desired, 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 value, and refrigerant supplied to the coil through an automatic expansion valve. For fine control of the circulating air temperature, an open-wire heating grid of minimum heat capacity may be placed in the air discharged from the coil, electrical input to which is controlled by a sensitive thermostat in the cold box air.

4.5 Temperature Measuring Equipment

4.5.1 *Surface Temperatures* — Thermocouples of wire not larger in size than 0·25 mm are recommended for measuring surface temperatures in the apparatus; 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. Either thermocouples or grids of temperature-sensitive resistance wire may be used to measure air temperatures in the boxes. The surface temperature of the metering area of the test panel shall be measured on the warm side by at least one surface thermocouple for each 0·2 m² of metering area, located judiciously with respect to structural members in the panel. If such members are deemed important in their effect on heat transfer, additional surface thermocouples shall be used. If possible, the thermocouples should be distributed symmeterically over the metering area. At least two surface thermocouples shall be placed on the guard area of the panel at suitable locations to indicate the effectiveness of the guard area. Surface temperatures on the cold side of the test panel shall be measured by surface thermocouples placed directly opposite those on the warm side of the panel.

4.5.2 *Air Temperatures* — Air temperatures in the metering box shall be measured, if thermocouples are used, by at least one thermocouple for 0·2 m² of metering area of the test panel. The junctions of the thermocouples used for measuring air temperature shall have bright metallic surfaces and shall be small, to minimize radiation effects. 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 thermocouples may, if desired, be placed directly opposite the surface thermocouples; in any case, they should be located as symmetrically as possible over the metering area. 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. 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 midway between the cold side baffle and the panel, but in no case less than 75 mm from the panel. No thermocouples need be placed in the cold space opposite guard space thermocouples remote from the panel surface.

4.5.2.1 If air temperatures are to be measured by means of resistance wire grids, the wire shall be distributed so as 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, with nearly symmetrical distribution of the resistance wire over the metering area, and similarly over the guard area.

4.5.3 *Measuring Instruments* — All thermocouples or temperature-indicating elements 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. If an average instantaneous air temperature is desired, the leads of the appropriate air-temperature thermocouples may be temporarily connected in series or parallel, as preferred, or a separate set of thermocouples located at nearly the same positions may be permanently installed for this purpose.

4.6 Auxiliary Equipment

4.6.1 *Refrigerating Unit and Voltage Supply* — If refrigeration is used and a large refrigerating plant is not available, it is desirable to refrigerate the cold box with a small compressor unit wholly devoted to this apparatus, to avoid effects of other loads on the system. For a similar reason, it is advantageous to furnish the electric power for the compressor and for the fans, heaters, and other equipment from a stabilized voltage supply.

4.6.2 *Meter* — All electric power input to the metering box shall be accurately metered. A small domestic type integrating watt-hour meter may be used for this purpose if it is carefully calibrated, and if it has a dial that can be read by interpolation to the nearest watt-hour. The effect of the on-off action of a thermostat on a portion of the load on such a meter is not a significant source of error.

4.6.3 *Temperature Recorder* — A temperature recorder for recording certain salient temperatures, that is, an air and perhaps a surface temperature in the metering area on both sides of the panel, is not essential, but is very useful to indicate constancy of temperature conditions when other temperature readings are not being taken. The accuracy of the recorded temperatures is not important, since they are used only to show constancy or trends of temperature.

4.6.4 *Fans* — The fans used in the boxes shall be capable of operating continuously and uniformly for the duration of a test. Velocities of air over both surfaces of the panel should either be measured with suitable instruments, or be calculated from a heat balance between the rate of loss or gain of heat by the air as it moves through the baffle space, as indicated by its temperature change, and the rate of heat flow through the test panel, average values of which may be determined from the test data.

4.6.5 *Insulation for Test Panel Edges* — When a test panel is installed, its edges shall, if necessary, be carefully insulated to prevent edge effects from overtaking the guarding effect of the guard area of the panel. For this purpose, the edges of the panel should be protected against heat loss or gain by a thickness of at least 50 mm of good insulation. It may be necessary to vapour-proof the insulation to prevent condensation of moisture on the edges of the panel, if a test arrangement similar to that shown in Fig. 1C is used.

4.7 Special Conditions — 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 effects of water vapour flow through or into the panel during tests. It is recognized that the heat transfer characteristics of many constructions may be effected significantly by simultaneous vapour flow. It is believed that the test apparatus described in this method could be used for making tests with imposed vapour pressure differentials across the test panel if proper modifications were made, including vapour-sealing of the metering box and guard box, andi nstrumentation to impose and measure the vapour-pressure conditions desired. Extension of the application of the hot box method of test in this direction is to be expected and encouraged, building upon the basic established in this method for determining the heat transfer coefficients of test panels.

5. PREPARATION OF TEST SPECIMEN

5.1 Select and prepare a test panel so that the specimen is representative of the construction to be investigated, and yet suitable for test purposes in that necessary modifications such as blocking of air spaces, slotting of conductive faces, and similar measures mentioned in **0.3** and **0.3.1** have been made. Carefully study the panel construction to determine in advance whether, and where, peculiarities of the construction make it desirable to install extra thermocouples to facilitate analysis of the test results. When the test panel has been installed, take care to assure a tight seal of the metering box against the face of the panel to prevent movement of air into or out of the metering box, and to apply adequate insulation at the edges of the test panel, vapour-sealing it, if necessary.

6. PROCEDURE

6.1 Choose the test conditions of temperature and orientation to correspond as closely as possible to the circumstances of use of the construction to be tested. Impose and maintain the test conditions until substantially constant temperature and heat flow readings are attained, before beginning the test period proper. Continue the test period thereafter for at least 8 hours but do not terminate the test until the values of thermal transmittance, *U*, and thermal conductance *C*, calculated from the average values of at least two sets of readings taken over a period of not less than 4 hours, do not differ by more than 1 percent from the values of *U* and *C* obtained similarly for the preceding period of not less than 4 hours. 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 hours periods in order to be assured that conditions are steady.

NOTE — In **4.5** 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 should agree. It should, 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.

7. CALCULATION

7.1 Calculate the final test results by means of the equations given below using average values of all the data during the entire test period.

$$\text{Thermal conductivity, } \lambda = \frac{q\,L}{A(\,t_1 - t_2\,)} \text{ W/m K}$$

$$\text{Thermal conductance, } C = \frac{q}{A(\,t_1 - t_2\,)} \text{ W/m}^2\text{ K}$$

$$\text{Inside surface coefficient, } h_1 = \frac{q}{A(\,t_h - t_1\,)} \text{ W/m}^2\text{ K}$$

$$\text{Outside surface coefficient, } h_o = \frac{q}{A(\,t_c - t_2\,)} \text{ W/m}^2\text{ K}$$

$$\text{Thermal transmittance, } U = \frac{q}{A(\,t_h - t_c\,)} \text{ W/m}^2\text{ K}$$

where

q = time rate of heat flow through area A in W,

L = length of path of heat flow (thickness of specimen) in m,

A = area normal to heat flow in m^2,

t_1 = temperature of hot surface in K,

t_2 = temperature of cold surface in K,

t_h = temperature of air 75 mm or more from hot surface in K, and

t_c = temperature of air 75 mm or more from the cold surface in K.

8. REPORT

8.1 The report shall include the following information:

8.1.1 Name, and any other identification or description of the test construction, including if necessary a blueprint showing important details, dimensions, and modifications, if any.

8.1.2 Pertinent information in regard to pre-conditioning of the test panel.

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

8.1.4 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 temperatures of the surfaces on both sides. (If significant, give the averge values of the temperature of specific areas of the surface of the panel.)

8.1.5 Duration of the test period and the average rate of net heat input to the metering box.

8.1.6 Average values of thermal transmittance U, thermal conductance C, inside surface coefficient h_1 and outside surface coefficient h_0.