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Standard Practice for Calibrating Thin Heat Flux Transducers[1]

This standard is issued under the fixed designation C 1130; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Keywords were added editorially in October 1995.

1. Scope

1.1 This practice establishes an experimental procedure for determining the sensitivity of heat flux transducers (HFTs) that are relatively thin. The term *sensitivity* in this practice refers to the ratio of HFT electrical output to heat flux through the HFT.

1.1.1 For the purpose of this standard, the thickness of the HFT shall be less than 15 % of the narrowest planar dimension of the HFT.

1.2 This practice discusses two methods for determining HFT sensitivity. The first method is the calibration of the HFT in unperturbed heat flow normal to the surface of the HFT, while the second method is the sensitivity of the HFT in actual use, or the HFT conversion factor.

1.3 This practice should be used in conjunction with Practice C 1041 when measuring in-situ heat flux and temperature on industrial insulation systems, and with Practice C 1046 when performing in-situ measurements of heat flux on opaque building components.

1.4 This practice is not intended to determine the sensitivity of HFTs that are components of heat flow meter apparatus, as in Test Method C 518. Refer to Practice C 1132 for this purpose.

1.5 The following safety caveat pertains only to the Specimen Preparation and Procedure portions, Sections 5 and 6, of this practice: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulating Materials[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 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[2]

C 335 Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation[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 976 Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box[2]

C 1041 Practice for In-Situ Measurements of Heat Flux in Industrial Thermal Insulation Using Heat Flux Transducers[2]

C 1044 Practice for Using the Guarded-Hot-Plate Apparatus in the One-Sided Mode to Measure Steady-State Heat Flux and Thermal Transmission Properties[2]

C 1046 Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components[2]

C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[2]

C 1132 Practice for Calibration of the Heat Flow Meter Apparatus[2]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to thermal insulating materials, see Definitions C 168.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heat flux transducer*—a device containing a thermopile (or equivalent) that produces an output which is a function of the heat flux passing through the HFT.

3.2.2 *sensitivity*—the ratio of the electrical output of the heat flux transducer to the heat flux passing through the HFT. The sensitivity of the HFT will be a function of the HFT temperature, the HFT construction, its curvature, and the method with which it is applied to the building component.

3.2.3 *heat flux transducer calibration factor*—the sensitivity of the heat flux transducer when measured in an undisturbed one-dimensional temperature field.

3.2.4 *heat flux transducer conversion factor*—the sensitivity of the heat flux transducer for the thermal conditions surrounding the HFT in actual use.

3.2.4.1 The relationship between the heat flux transducer

[1] This practice is under the jurisdiction of ASTM Committee C-16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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

calibration and conversion factors is indicative of the magnitude of the heat flux distortion created by the application of the HFT.

3.2.5 *temperature field*—a set of temperatures, where each temperature is associated with a point or small domain of space in a region of interest. An example is the distribution of temperatures within a slab of insulation.

3.2.6 *test stack*—a layer or a series of layers of material put together to comprise a test sample (for example, a roof system containing a membrane, an insulation, and a roof deck).

3.3 *Symbols*:

q = heat flux, W/m^2 [Btu/h·ft^2].
V = measured output voltage of the HFT, V[3].
S = sensitivity of the HFT, V/(W/m^2) [V/(Btu/hr·ft^2)].

4. Significance and Use

4.1 The use of heat flux transducers on industrial equipment or building envelope components provides the user with a relatively simple means for performing in-situ heat flux measurements. Accurate translation of the heat flux transducer output requires a complete understanding of the factors affecting its output, and a standardized method for determining the HFT sensitivity for the application of interest.

4.2 The placement of an HFT in a temperature field (see 3.2.5) will probably disturb that field. If a disturbance in the temperature field occurs when the HFT is applied, the user must account for that disturbance when determining the sensitivity of an HFT.

4.3 There are several methods for determining the sensitivity of HFTs (see 6.1). The selection of the best procedure will depend on the required accuracy and the physical limitations of available equipment.

4.4 The presence of a heat flux transducer is likely to alter the heat flux that is being measured. This disturbance is difficult to predict without sufficient knowledge of the construction of the HFT and the thermal conductivities of both the HFT components and its surroundings. With such knowledge, analytical **(1, 2)**[4] and numerical **(3, 4, 5)** methods have been used to account for the disturbance in heat flux caused by the presence of an HFT.

4.5 If an HFT calibration factor is sought, the user of this standard must assure that parallel heat flow, normal to the HFT, is achieved. If the user wishes to obtain a conversion factor, then the user must account for the end-use conditions of the HFT, either by using an acceptable and verifiable mathematical technique to correct the calibration factor, or by performing a series of experiments that adequately simulates the conditions of use to obtain the conversion factor empirically **(6, 7, 8)**.

4.6 This practice describes techniques to establish uniform heat flow normal to the heat flux transducer for the determination of the HFT calibration factor, or how to establish conditions that simulate those that the HFT will encounter when in use.

4.7 The method of HFT application must be adequately simulated or duplicated when experimentally determining the HFT sensitivity. The two most widely used application techniques are to surface-mount the HFT or to embed the HFT in the insulation system.

5. Specimen Preparation

5.1 Preparation of the HFT depends on which type of sensitivity is desired and the method of HFT application to be employed.

5.1.1 Three separate cases are discussed: the determination of the calibration factor and the measurement of the conversion factor for embedded and surface-mounted HFTs.

5.2 The HFT for which sensitivity is determined will measure the heat flux at the position of the HFT in the test stack. It is recommended that the HFT be installed near the metering side of the test instrument and in a relatively thin stack assembly to reduce the impact of edge effects. The thickness and thermal resistance of the test stack should be selected after considering its impact on the accuracy of the chosen test method.

5.3 *Calibration factor*—The HFT shall be embedded in a stack of materials and surrounded with a framing material or mask. Guarded-hot-plate and heat flow meter apparatuses (Test Method C 177 and C 518, respectively) have been successfully used for this purpose.

5.3.1 The sample stack used to determine the calibration factor of HFTs shall consist of a sandwich of the HFT/masking layer between two layers of a compressible homogeneous material, such as high-density fiberglass insulation board, to assure good thermal contact between the plates of the tester and the HFT/masking layer. The use of a thermally conductive gel is another technique to improve good thermal contact.

5.3.2 The mask used in determining the HFT calibration factor must have the same thickness and thermal resistance as the HFT. The matching of the mask and HFT is sensitive to the HFT size and on whether the HFT incorporates an intrinsic mask surrounding its active sensing area. An effective masking technique that has been employed for small sensors is to utilize other identical sensors as a mask.

5.4 *Conversion factor, embedded*—The HFT shall be placed, in a fashion identical to its end use application, in a stack of materials duplicating the building construction to be evaluated. The instruments listed in 5.3 along with the thin-heater apparatus (see Test Method C 1114) have been used for this analysis.

5.5 *Conversion factor, surface mounted*—The HFT shall be applied in a manner identical to that of actual use to a homogeneous test panel or pipe insulation of similar thermal resistance, surface-layer thermal conductance, and orientation. Pipe tester (Test Method C 335), guarded-hot-box (Test Method C 236), and calibrated-hot-box (Test Method C 976) apparatuses have been used to perform these procedures.

5.5.1 The sample stack for use in determining HFT conversion factors shall comprise a sandwich of the same materials to be found in the construction to be analyzed. The HFT shall be placed in the same exact location as that in end use. For embedded applications, the HFT shall be placed between the same layers within the sample stack. For surface-mounted

[3] For the purpose of this practice, the HFT output shall be assumed to be a voltage, although other outputs, such as current, may exist.

[4] The boldface numbers in parentheses refer to the references at the end of this practice.

applications, the HFT shall be mounted as specified in either Practices C 1041 or C 1046. Important considerations for surface mounting include thermal contact between the HFT and panel or pipe surface and matching of the emittance and curvature of the HFT and test construction.

5.6 *Specimen Preparation for All Cases*:

5.6.1 **Caution—**When bringing the signal output leads out of the test instrument, take care to avoid air gaps in the mask or between the sample stack and the test instrument. Air gaps should be filled with a conformable material, such as toothpaste, caulk, or putty, or covered with tape.

5.6.2 The HFTs do not need to be physically adhered to the mask or embedding material but should fit well enough to assure good thermal contact.

5.6.3 The mask or embedding material should be significantly larger in cross-section than the metering area of the test equipment used to determine the HFT sensitivity and ideally be the same size as the plates of the apparatus. When masking, the ideal assembly avoids any focusing or distortion of the heat flux around or through the HFT.

6. Procedure

6.1 Guarded-hot-plate, pipe tester, heat flow meter, guarded-hot-box, calibrated-hot-box, and thin-heater apparatuses have been successfully utilized for determining the sensitivity of HFTs. The requirements of the appropriate ASTM test method must be followed. Apparatuses that typically require two samples should be operated in the single-sided mode in conformance with Practice C 1044 or in a double-sided configuration, provided that the percentage of heat flow to each side is known.

6.1.1 The sensitivity methods will be performed under steady-state conditions as required by the appropriate ASTM test method.

NOTE 1—**Caution:** The steady-state conditions of these procedures will most likely differ from those when the HFT is used.

6.2 *For Surface Mounted Cases*:

6.2.1 The HFTs shall be mounted in the central area of the test panel or pipe that is within a boundary that is wider than one-fourth of the smallest dimension of the exposed face of the test panel in calibrated hot boxes and within the metering area of guarded hot boxes and pipe testers.

6.2.2 In many cases, several surface-mounted HFTs will be used at one time and can be analyzed for sensitivity simultaneously.

6.3 *For All Applications*:

6.3.1 A device shall be provided to measure the voltage output from the HFT. The resolution of this device should be such that the desired accuracy of the sensitivity determination is attained. For HFTs of typical construction, voltmeters with a resolution of ± 2 µV have been found to be satisfactory for this purpose.

6.3.2 HFT sensitivity shall be determined for the range of heat fluxes, mean temperatures, and curvatures expected in the actual application. The hot- and cold-surface plates of the test instrument shall be adjusted to satisfy these requirements. Care shall be taken to perform these tests at heat fluxes that are large enough to limit errors due to the readout electronics and that are similar to the anticipated levels of heat flux in the end-use experiment. A temperature sensor shall be located in or near the HFT to adequately measure its temperature during the sensitivity tests.

6.3.3 For the calibration of small HFTs where other sensors are used for masking, at least three tests shall be performed with the HFTs arranged according to a randomized plan that guarantees that systematic errors due to HFT placement are minimized. Enough experiments shall be performed to ensure that all the HFTs that are being calibrated are tested within the metered area of the test apparatus.

7. Report

7.1 The report shall give a general description of the heat flux transducer that was calibrated. The physical characteristics of the HFT shall be identified, and any pertinent data available from the manufacturer shall be reported.

7.2 The type of sensitivity (calibration or conversion) and the ASTM test method used shall be detailed.

7.3 The test stack assembly that was used to install the HFT into the test instrument shall be fully described. This description shall include the location of the HFT, the material used to mask or embed the HFT, and any additional layers of material used in the assembly. The geometry and thermal performance characteristics of the assembly materials should be included in the descriptions.

7.4 The temperatures of the HFT and surface plates are to be recorded. The temperature difference between the surface plates and the heat flow direction shall be recorded and reference made to the appropriate test method if the method specifies the temperature difference required to measure heat flux.

7.5 Tables and plots of heat flux as a function of mean temperature or heat flux, or both, versus HFT output should be included in the report.

8. Precision and Bias

8.1 For each type of HFT, at least three replications of the sensitivity tests are required to determine the precision and bias of the procedure. If this has been done previously for similar applications of identical HFTs, the precision and bias determined then can be used for the present tests. The precision and bias of this practice must include the uncertainty from the test method that is used to determine the HFT sensitivity.

8.2 To evaluate the consistency of the test results, an analysis is to be made of the sensitivity data. Assuming the sensitivity of the HFT to be a linear function of mean temperature, departure from linearity for each HFT can be determined. A linear regression can be performed for each of the HFTs and the least-squares difference between the midpoint and the regression curve will serve as an indication of the departure from linearity.

8.3 The uncertainty of the heat flux and the HFT output must be determined along with the departure from unidirectional heat flow when the masking technique is employed. The magnitude of this effect can be determined by performing a series of experiments with masks of varying thermal resistances.

8.4 The heat flux measured by two different types of independently calibrated HFTs installed at the same time in the same roof assembly measured a difference in heat flux of approximately 8 % **(9).**

9. Keywords

9.1 calibration; heat flux transducer; in situ testing; sensitivity

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