Designation: ~~C1130 – 07 (Reapproved 2012)~~ C1130 – 17

Standard Practice for
~~Calibrating~~ Calibration of Thin Heat Flux Transducers[1]

This standard is issued under the fixed designation C1130; 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 practice, in conjunction with either Test Method C177, C518, C1114, or C1363, establishes ~~an experimental procedure for determining the sensitivity~~procedures for the calibration of heat flux transducers that are ~~relatively thin.~~dimensionally thin in comparison to their planar dimensions.

1.1.1 ~~For the purpose of this standard, the~~ The thickness of the heat flux transducer shall be less than 30 % of the narrowest planar dimension of the heat flux transducer.

1.2 This practice ~~discusses a method~~ describes techniques for determining the sensitivity, *S,* of a heat flux transducer ~~to one-dimensional~~ when subjected to one dimensional heat flow normal to the ~~surface and for determining the sensitivity of a heat flux transducer for an installed~~ planar surface or when installed in a building application.

1.3 This practice ~~should~~shall be used in conjunction with Practice C1046 and Practice C1155 when performing in-situ measurements of heat flux on opaque building components. This practice is comparable, but not identical, to the calibration techniques described in ISO 9869-1.

1.4 This practice is not intended to determine the sensitivity of heat flux transducers ~~that are~~used as components of heat flow meter apparatus, as in Test Method C518, or used for in-situ industrial applications, as covered in Practice C1041.

1.5 ~~This practice is not intended to determine the sensitivity of heat flux transducers used for in-situ industrial applications that are covered in Practice~~The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables ~~C1041.~~and figures) shall not be considered as requirements of the standard.

1.6 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard.

1.7 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation
C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C1041 Practice for In-Situ Measurements of Heat Flux in Industrial Thermal Insulation Using Heat Flux Transducers
C1044 Practice for Using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode
C1046 Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components
C1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus
C1155 Practice for Determining Thermal Resistance of Building Envelope Components from the In-Situ Data

---

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

Current edition approved ~~Sept. 1, 2012~~Sept. 1, 2017. Published ~~November 2012~~October 2017. Originally approved in 1989. Last previous edition approved in ~~2007~~2012 as ~~C1130 – 07.~~C1130 – 07 (2012). DOI: ~~10.1520/C1130-07R12.~~10.1520/C1130-17.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

C1363 Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

2.2 *ISO Standards:*[3]

ISO 9869-1 Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance – Part 1: Heat flow meter method

3. Terminology

3.1 *Definitions*—For definitions of terms relating to thermal insulating materials, see Terminology C168.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mask*—material (or materials) having the same, or nearly the same, thermal properties and thickness surrounding the heat flux transducer thereby promoting one-dimensional heat flow through the heat flux transducer.

3.2.2 *R-squared (R^2)*—coefficient of determination (also known as "goodness of fit") is a statistical measure of how close the data are to the fitted line.

3.2.3 *sensitivity*—the ratio of the electrical output of the heat flux transducer to the heat flux passing through the device when measured under steady-state heat flow.

3.2.4 *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:* R = thermal resistance, $m^2·K/W$ ($h·ft^2·F$ /Btu)~~
~~q = heat flux, W/m^2 (Btu/$h·ft^2$)~~
~~$Q_{expected}$ = heat flux expected in application, W/m^2 (Btu/$h·ft^2$)~~
~~E = measured output voltage, V~~
~~S = sensitivity, V/(W/m^2) (V/(Btu/$hr·ft^2$))~~
~~ΔT = temperature difference, K (°F)~~
~~R_{layer} = thermal resistance of a layer in the test stack, $m^2·K/W$ ($h·ft^2·F$ /Btu)~~
~~T = temperature, K (°F)~~
~~u_c = combined standard uncertainty~~
~~u_1 = standard uncertainty of the regression coefficients~~
~~u_2 = standard uncertainty for replicate measurements~~
~~u_3 = standard uncertainty for the measurement~~
~~ε = error term~~

3.3 *Symbols:*

3.3.1 *E*—measured HFT output voltage, V.

3.3.2 *q*—steady-state heat flux, W/m^2 (Btu/$h·ft^2$).

3.3.3 *S*—sensitivity, V/(W/m^2) (V/(Btu/$h·ft^2$)).

3.3.4 u_c—combined standard uncertainty, V.

3.3.5 u_1—standard uncertainty of the regression coefficients, V.

3.3.6 u_2—standard uncertainty for replicate measurements, V.

3.3.7 u_3—standard uncertainty for the measurement, V.

4. Summary of Practice

4.1 This practice presents three techniques for the laboratory calibration of heat flux transducers (**1**)[4]: *(1)* ideally guarded; *(2)* embedded; and, *(3)* surface mounted. These techniques establish a hierarchy defined by the extent that the assumption of one-dimensional heat flow is satisfied (**1**).

4.1.1 The ideally-guarded technique places the heat flux transducer (HFT) in a test stack consisting of homogeneous, thermally characterized materials that promotes one-dimensional heat flow normal to the planar dimensions of the HFT. The results of this technique provide a baseline calibration for the HFT.

4.1.2 The embedded technique places the HFT within a test stack consisting of material layers identical, or comparable to, the building construction to be studied under application.

4.1.3 The surface mounted calibration, which is the most complex, places the HFT on the external surface of a test stack and incorporates environmental effects that cause lateral heat flow in the locality of the HFT.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

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

4.2 The calibration results are intended for use with Practice C1046 to measure in-situ the heat flux through opaque building components and with Practice C1155 for the subsequent analysis of the measurement data. The intended application of the HFT is used to determine the appropriate calibration technique (**2**).

4.2.1 If the HFT is to be embedded in the building envelope, the HFT shall be calibrated in a test stack of materials that simulate the surrounding construction materials.

4.2.2 If the HFT is to be surface mounted on the building envelope construction, the HFT shall be calibrated using a hot box that is oriented similarly (horizontal, vertical, or inclined) as the measurement site.

5. Significance and Use

5.1 The ~~use of heat flux transducers on building envelope components provides the user with a means for performing in-situ heat flux measurements. Accurate translation of the heat flux transducer output requires a complete understanding~~application of HFTs and temperature sensors to building envelopes provide in-situ data for evaluating the thermal performance of an opaque building component under actual environmental conditions, as described in Practices C1046 and C1155 ~~of the factors affecting its output, and a standardized method for determining the heat flux transducer sensitivity for the application of interest.~~. These applications require calibration of the HFTs at levels of heat flux and temperature consistent with end-use conditions.

5.2 ~~The sensitivity~~ This practice provides calibration procedures for the determination of the heat flux transducer ~~is~~sensitivity, ~~*determined*~~*S,* ~~primarily by the sensor construction and~~that relates the HFT voltage output, ~~*temperature*~~*E,* ~~of operation and~~to a known input value of heat flux, ~~*the*~~ *q.*~~details of the application, including geometry, material characteristics, and environmental factors.~~

5.2.1 The applied heat flux, *q*, shall be obtained from steady-state tests conducted in accordance with either Test Method C177, C518, C1363, or C1114.

5.2.2 The resulting voltage output, *E*, of the heat flux transducer is measured directly using (auxiliary) readout instrumentation connected to the electrical output leads of the sensor.

NOTE 1—A heat flux transducer (see also Terminology C168) is a thin stable substrate having a low mass in which a temperature difference across the thickness of the device is measured with thermocouples connected electrically in series (that is, a thermopile). Commercial HFTs typically have a central sensing region, a surrounding guard, and an integral temperature sensor that are contained in a thin durable enclosure. Practice C1046, Appendix X2 includes detailed descriptions of the internal constructions of two types of HFTs.

~~NOTE 1—Practice C1046 includes an excellent description of heat flux transducer construction.~~

5.3 The HFT sensitivity depends on several factors including, but not limited to, size, thickness, construction, temperature, applied heat flux, and application conditions including adjacent material characteristics and environmental effects.

5.4 The subsequent conversion of the HFT voltage output to heat flux under application conditions requires *(1)* a standardized technique for determining the HFT sensitivity for the application of interest; and, *(2)* a comprehensive understanding of the factors affecting its output as described in Practice C1046.

5.5 The ~~presence of a heat flux transducer is likely to alter the heat flux that is being measured. To determine the heat flow that would occur in the absence of the transducer, it is necessary to either:~~ installation of a HFT potentially changes the local thermal resistance of the test artifact and the resulting heat flow differs from that for the undisturbed building component. The following techniques have been used to compensate for this effect.

5.5.1 Ensure that the installation is adequately guarded (~~1~~**3**). In some cases, an assumption is made that the change in thermal resistance is negligible, particularly for very thin HFTs with a large surrounding guard, or is incalculable (**1**).

5.5.2 ~~Adjust the results based on a detailed model or numerical analysis. Such analysis is beyond~~For the embedded configuration, analytical and numerical methods have been used to account for the disturbance of the heat flux due to the presence of the HFT. Such analyses are outside the scope of this ~~practice,~~practice but details ~~can be found in~~ are available in Refs (~~2~~**-4-68**).

5.5.3 ~~Use the empirically measured heat flux transducer sensitivity measured under conditions~~For the surface-mounted configuration, measurement errors have been quantified by Trethowen **that**(**9**). ~~adequately simulate the conditions of use in the final application.~~Empirical calibrations have also been determined by conducting a series of field calibrations or measurements. Such procedures are outside the scope of this practice but details are available in Orlandi et al. (**10**) and Desjarlais and Tye (**11**).

~~4.4 There are several methods for determining the sensitivity of heat flux transducers, including Test Methods C177, C518, C1114, and C1363. The selection of the appropriate procedure will depend on the required accuracy and the physical limitations of available equipment.~~

~~4.5 This practice describes techniques to establish uniform heat flow normal to the heat flux transducer for the determination of the heat flux transducer sensitivity.~~

~~4.6 The method of heat flux transducer application must be adequately simulated or duplicated when experimentally determining the heat flux transducer sensitivity. The two most widely used application techniques are to surface-mount the heat flux transducer or to embed the heat flux transducer in the insulation system.~~

~~NOTE 2—The difference between the sensitivity under uniform normal heat flow versus that for the surface-mounted or embedded configurations has been demonstrated using multiple mathematical techniques (**7-9**).~~

6. Specimen Preparation

6.1 ~~*Specimen Preparation for All Cases:*~~ *Preparation of the HFT, Test Stack, and Surface-Mounted Installation:*

6.1.1 *HFT*—~~Check~~Verify the electrical continuity of the ~~heat flux transducer. Connect the heat flux transducer voltage leads to the auxiliary measurement equipment (for example, voltmeter) having a resolution of ± 2 μV or better.~~HFT and temperature sensor. Where auxiliary readout instrumentation, that is, voltmeter, recorder, or data acquisition system, is needed, the user shall provide appropriate provision for calibration. The instrumentation shall have a resolution capability of 2 μV.

6.1.2 *Test Stack*—Place the HFT and temperature sensor in the test stack located within the central metering area of the apparatus plates (Test Methods C177, C518, or C1114).

6.1.3 *Surface-Mounted*—Place the HFT and temperature sensor in the central location of the metered area of the hot box (Test Method C1363).

6.1.4 *Sensor Leads*—~~When bringing the heat flux transducer voltage leads out of the test instrument, take care to avoid~~ The sensor output leads shall be placed in grooves or covered to minimize the presence of air gaps in the ~~mask or between the sample stack and the test instrument. Fill air gaps with a conformable material, such as toothpaste, caulk, or putty, or cover with tape.~~ test stack or surface mounted installation. The HFT need not be physically adhered to the mask or embedding material. Thermally conductive gel or paste is applied, if necessary, to one or both faces of the heat flux transducer to improve the thermal contact.

~~NOTE 3—The heat flux transducers do not need to be physically adhered to the mask or embedding material but should fit well enough to assure good thermal contact. If needed, apply thermally conductive gel to one or both faces of the heat flux transducer to improve the thermal contact. Material compatibility must be considered in the selection of any such gel.~~

~~5.1.3 Place a temperature sensor on or near the heat flux transducer. Connect temperature sensor(s) applied to the heat flux transducer to a readout device.~~

~~5.1.4 When compressible insulation is included in the test stack, manually control the distance between the hot and cold apparatus surfaces.~~

~~5.1.5 The heat flux transducer(s) must be located within the metered area of the apparatus. In a hot box apparatus, mount the heat flux transducers in the central portion of the metered area of the test panel.~~

~~5.2 Three separate test stack preparations are discussed to determine appropriately: the one-dimensional sensitivity, the sensitivity for embedded configurations, and the sensitivity for surface-mounted configurations.~~

6.2 ~~*One-Dimensional Sensitivity*—~~*Ideally Guarded Configuration (One-dimensional Heat Flow):* ~~The heat flux transducer shall be embedded in a test stack and surrounded with a mask, as shown in Fig. 1.~~

6.2.1 ~~The test stack shall consist of a sandwich of the heat flux transducer/masking layer between two layers of a compressible homogeneous material, such as high-density fibrous glass insulation board, to assure~~Refer to Fig. 1 ~~good thermal contact between the plates of the tester and the heat flux transducer/masking layer.~~for an illustration of the ideally-guarded stack configuration.

~~5.3.2 The mask must have the same thickness and thermal resistance as the heat flux transducer.~~

6.2.2 *Calibration of One HFT*—~~The mask or embedding material should be significantly larger than the metering area of the test equipment and ideally~~ Place the HFT and temperature sensor in the center of a guard mask have the same thickness and thermal resistance as the HFT. The outer dimensions of the guard mask shall be the same size as the ~~plates of the apparatus.~~apparatus plates.

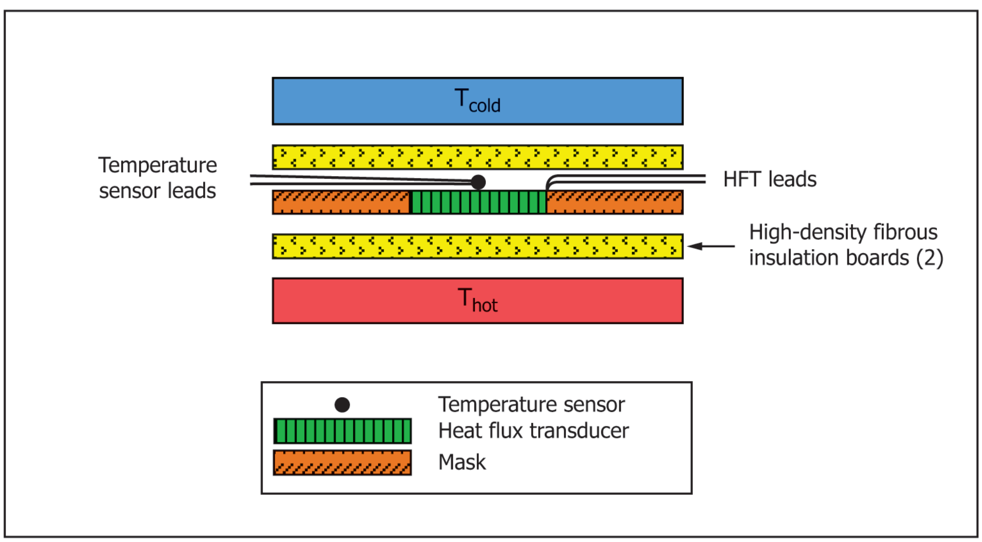

FIG. 1 ~~Example of a Test Stack Used to Measure Heat Flux Transducer Sensitivity, Side View~~Ideally Guarded Test Configuration for One HFT (Side View)

Place the HFT/guard assembly between two layers of high-density fibrous glass insulation board or other homogenous semirigid insulating material. It is recommended that the test stack have the smallest acceptable thickness and thermal resistance to minimize edge effects during testing.

6.2.3 *Calibration of multiple HFTs*—To ~~measure~~determine the sensitivity of multiple small heat flux transducers, ~~the heat flux transducer/mask~~ replace the HFT/mask layer shown in Fig. 1 ~~is replaced~~ with a layer containing an arrangement of ~~transducers~~HFTs located within the metered area of the apparatus as illustrated in Fig. 2.

NOTE 2—The plate designs of some apparatus utilize a circular geometry.

6.3 ~~*Sensitivity,*~~ *Embedded* ~~*Configuration—*~~*Configuration:* ~~Place the heat flux transducer, in a fashion identical to its end use application, in a test stack duplicating the building construction to be evaluated. An example of a test stack, for the case where the heat flux transducer is to be embedded in gypsum wallboard facing an insulated wall cavity, is shown in Fig. 3.~~

6.3.1 Consult Practice C1046 for details on the installation of the HFT within the building envelope component of interest. Construct the test stack to have the same, or comparable, physical properties as the end-use application replicating the building construction under evaluation. Place the HFT and temperature sensor within the test stack in the same arrangement as intended in the end-use application.

6.3.2 Refer to Fig. 3 for an illustration of an embedded stack configuration placed between the hot and cold apparatus plates. The example in Fig. 3 depicts a case where an HFT is embedded in gypsum wallboard and faces an insulated wall cavity. It is recommended that, when compressible materials are present, rigid spacer stops or other means be utilized to maintain a fixed plate separation during testing.

6.4 ~~*Sensitivity,*~~ *Surface-Mounted* ~~*Configuration—*~~*Configuration:* ~~Apply the heat flux transducer in a manner identical to that of actual use as specified in Practice C1046. Important considerations for surface mounting include thermal contact between the heat flux transducer and the surface and matching of the emittance of the heat flux transducer and test construction. An example of a test arrangement, for the case where the heat flux transducer is to be surface-mounted, is shown in Fig. 4.~~

6.4.1 Consult Practice C1046 for details on the installation of the HFT to the surface of the building envelope component of interest. Attach the HFT and temperature sensor to the surface of a test panel having the same, or comparable, physical properties as the building construction under evaluation replicating the end-use conditions. The test panel shall have the same orientation (horizontal, vertical, or inclined) as the building construction under evaluation.

NOTE 3—Trethowen (**12**) recommends mounting of the HFT on interior building surfaces. Exterior mounting of the HFT need only be considered if inside mounting is impossible.

6.4.2 It is recommended that a guard mask be placed around the HFT to compensate for local heat flux perturbations caused by the presence of the HFT. The guard mask shall have the same emittance as the HFT. Guidance on the determination of the size of the guard mask is available in Burch et al. (**3**), van der Graaf (**8**), and Trethowen (**9**).

6.4.3 Refer to Fig. 4 for an illustration of a surface-mounted configuration calibrated in a hot box (one chamber not shown). The example in Fig. 4 depicts a case where an HFT (guard mask not shown) is affixed to a homogeneous test specimen of known thermal resistance.

~~NOTE 4—In many cases, several surface-mounted heat flux transducers will be used at one time and can be analyzed for sensitivity simultaneously.~~

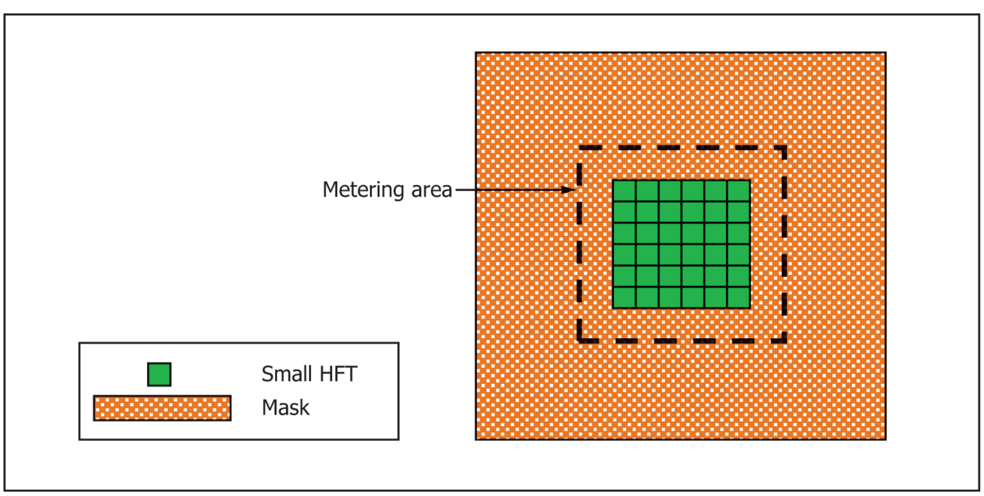

FIG. 2 ~~**Top View of the Heat Flux Transducer/Mask Layer Within the Test Stack for the Case Where Multiple Small Heat Flux Transducers are Evaluated Simultaneously**~~**Calibration of Multiple Small HFTs Evaluated Simultaneously (Top View)**

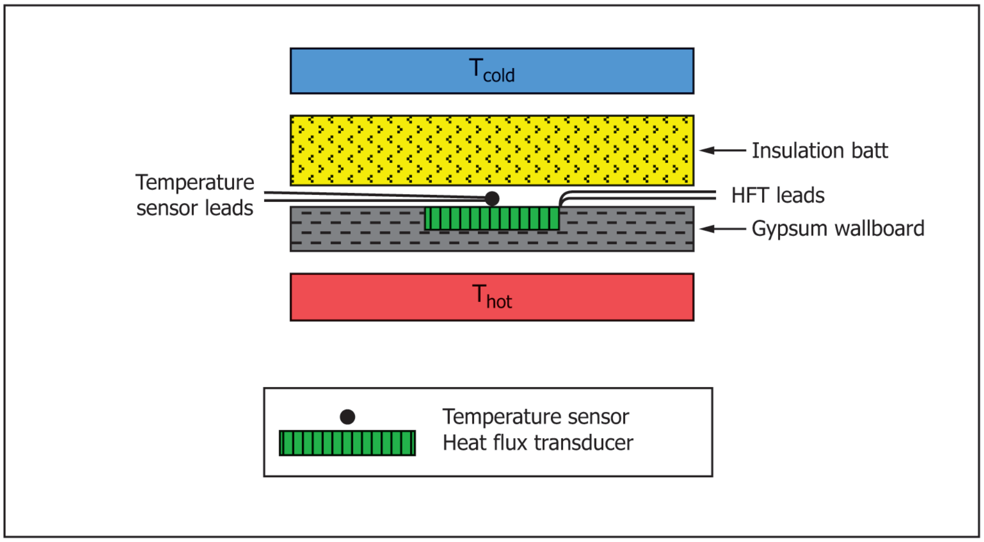

FIG. 3 ~~Example of~~ Test Stack ~~Emulating~~for an HFT Embedded ~~Position~~ Within an Insulated Wall ~~Cavity, Side View~~Cavity (Side View)

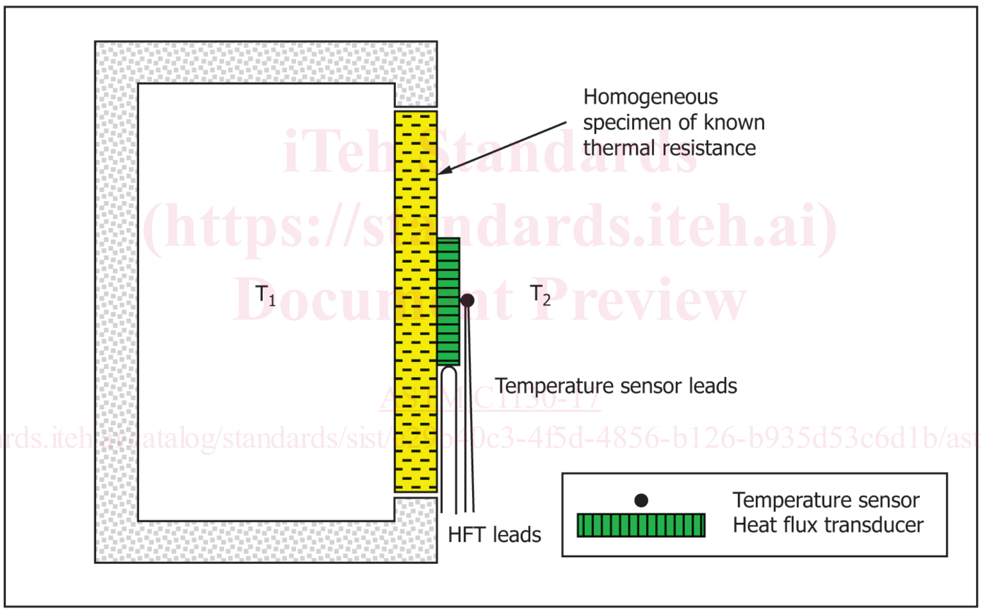

FIG. 4 ~~Example of a Test Stack for a Surface-Mounted Heat Flux Transducer~~ Surface Mounted HFT Configuration (Side View)

7. Procedure

7.1 Use a guarded-hot-plate, ~~heat flow meter, hot box, or thin-heater apparatus. Follow~~ thin-heater, heat-flow-meter, or hot box apparatus to calibrate the HFT/stack assembly and follow the test procedure of either Test Method C177, C518, C1363, or C1114, ~~including test stack conditioning, to measure the heat flux through the heat flux transducer. Apparatuses~~ respectively. For apparatuses that typically require two ~~samples should be operated~~specimens follow Practice C1044 ~~in the single-sided mode in conformance with Practice~~for operation of the apparatus in the single-sided ~~C1044.~~mode.

7.2 ~~Vary the hot- and cold-surface plates of the test instrument to produce the range of heat fluxes and mean temperatures according to the guidance found in~~Install the HFT/test stack assembly in the apparatus and connect the voltage output leads from the HFT(s) and temperature sensor(s) to the appropriate readout instrumentation. ~~Appendix X1 and Appendix X2.~~The presence of air gaps between the apparatus and test stack shall be minimized by sealing or covering with adhesive tape.

~~6.2.1 For surface-mounted heat flux transducers tested using Test Method C1363, also control the convection and radiation conditions to match the expected application.~~