Designation: C1130 – 07 (Reapproved 2012)

Standard Practice for Calibrating 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 Test Method C177, C518, C1114, or C1363, establishes an experimental procedure for determining the sensitivity of heat flux transducers that are relatively thin.

1.1.1 For the purpose of this standard, 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 for determining the sensitivity of a heat flux transducer to one-dimensional heat flow normal to the surface and for determining the sensitivity of a heat flux transducer for an installed application.

1.3 This practice should be used in conjunction with Practice C1046 when performing in-situ measurements of heat flux on opaque building components.

1.4 This practice is not intended to determine the sensitivity of heat flux transducers that are components of heat flow meter apparatus, as in Test Method C518.

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 C1041.

1.6 *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:*[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

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

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 *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.

3.2.3 *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

[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.

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[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.

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

4. Significance and Use

4.1 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 of the factors affecting its output, and a standardized method for determining the heat flux transducer sensitivity for the application of interest.

4.2 The sensitivity of the heat flux transducer is determined primarily by the sensor construction and temperature of operation and the details of the application, including geometry, material characteristics, and environmental factors.

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

4.3 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:

4.3.1 Ensure that the installation is adequately guarded **(1)**.[3]

4.3.2 Adjust the results based on a detailed model or numerical analysis. Such analysis is beyond the scope of this practice, but details can be found in **(2-6)**.

4.3.3 Use the empirically measured heat flux transducer sensitivity measured under conditions that adequately simulate the conditions of use in the final application.

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)**.

5. Specimen Preparation

5.1 *Specimen Preparation for All Cases:*

5.1.1 Check 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.

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

5.1.2 When bringing the heat flux transducer voltage leads out of the test instrument, take care to avoid 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.

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.

5.3 *One-Dimensional Sensitivity*—The heat flux transducer shall be embedded in a test stack and surrounded with a mask, as shown in Fig. 1.

5.3.1 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 good thermal contact between the plates of the tester and the heat flux transducer/masking layer.

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

5.3.3 The mask or embedding material should be significantly larger than the metering area of the test equipment and ideally be the same size as the plates of the apparatus.

5.3.4 To measure the sensitivity of multiple small heat flux transducers, the heat flux transducer/mask layer shown in Fig. 1 is replaced with a layer containing an arrangement of transducers located within the metered area of the apparatus as illustrated in Fig. 2.

5.4 *Sensitivity, Embedded 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.

5.5 *Sensitivity, Surface-Mounted 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.

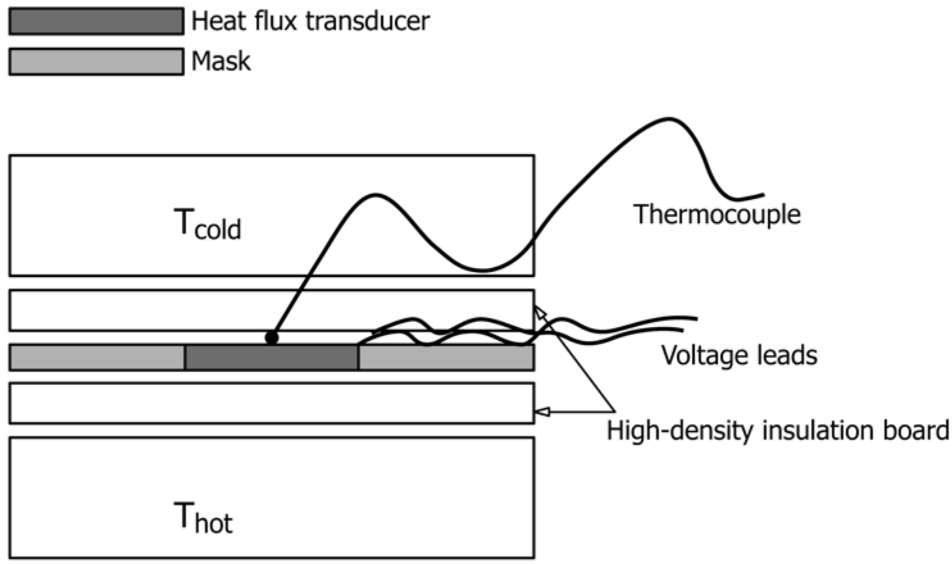
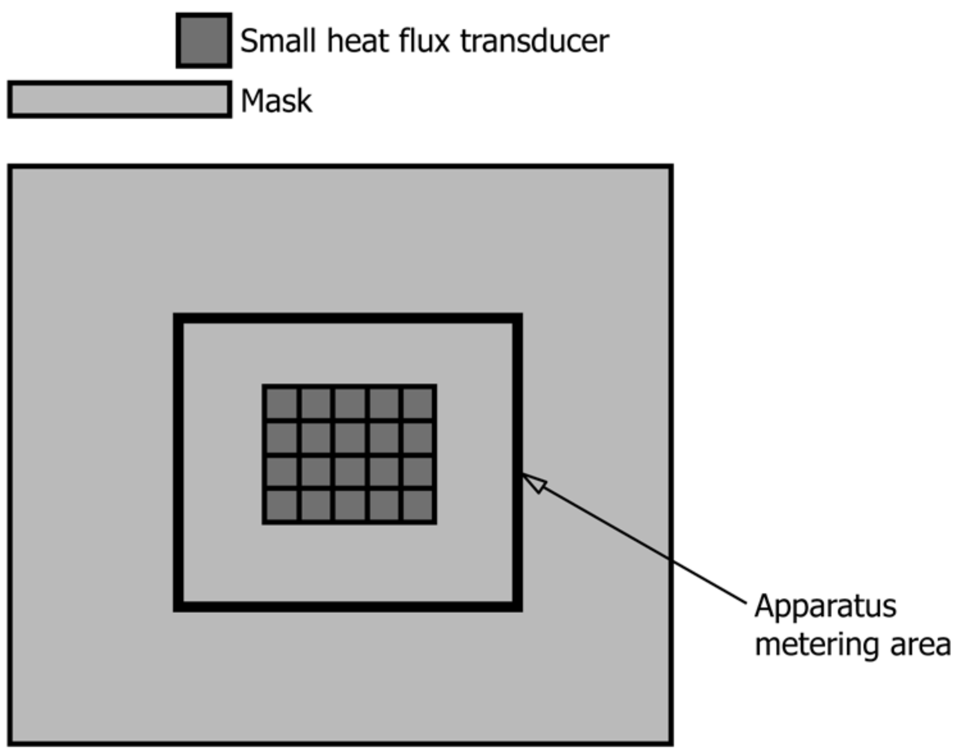


FIG. 1 Example of a Test Stack Used to Measure Heat Flux Transducer Sensitivity, Side View



NOTE 1—Some apparatus metering areas are round.

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

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

6. Procedure

6.1 Use a guarded-hot-plate, heat flow meter, hot box, or thin-heater apparatus. Follow Test Method C177, C518, C1363, or C1114, including test stack conditioning, to measure the heat flux through the heat flux transducer. Apparatuses that typically require two samples should be operated in the single-sided mode in conformance with Practice C1044.

6.2 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 Appendix X1 and Appendix X2.

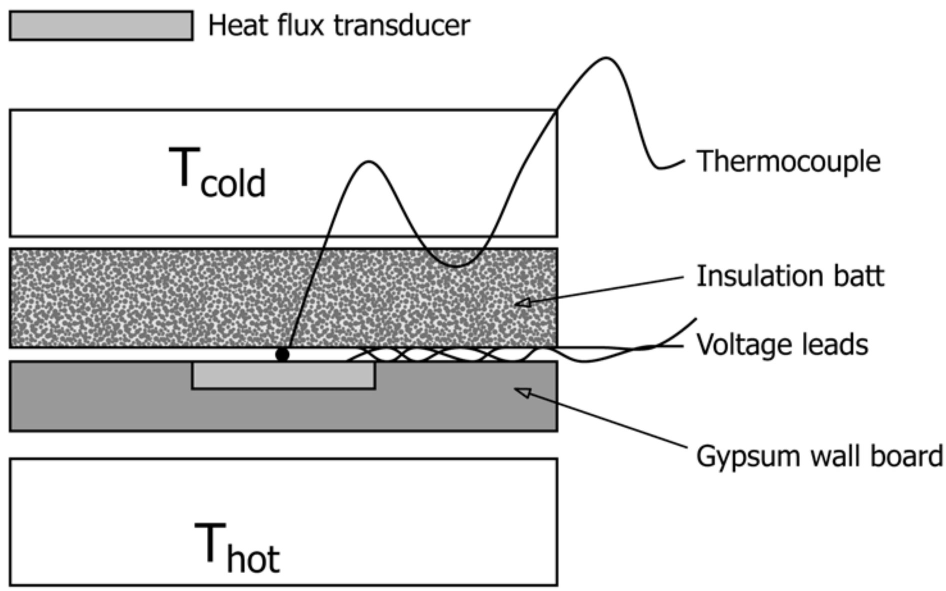
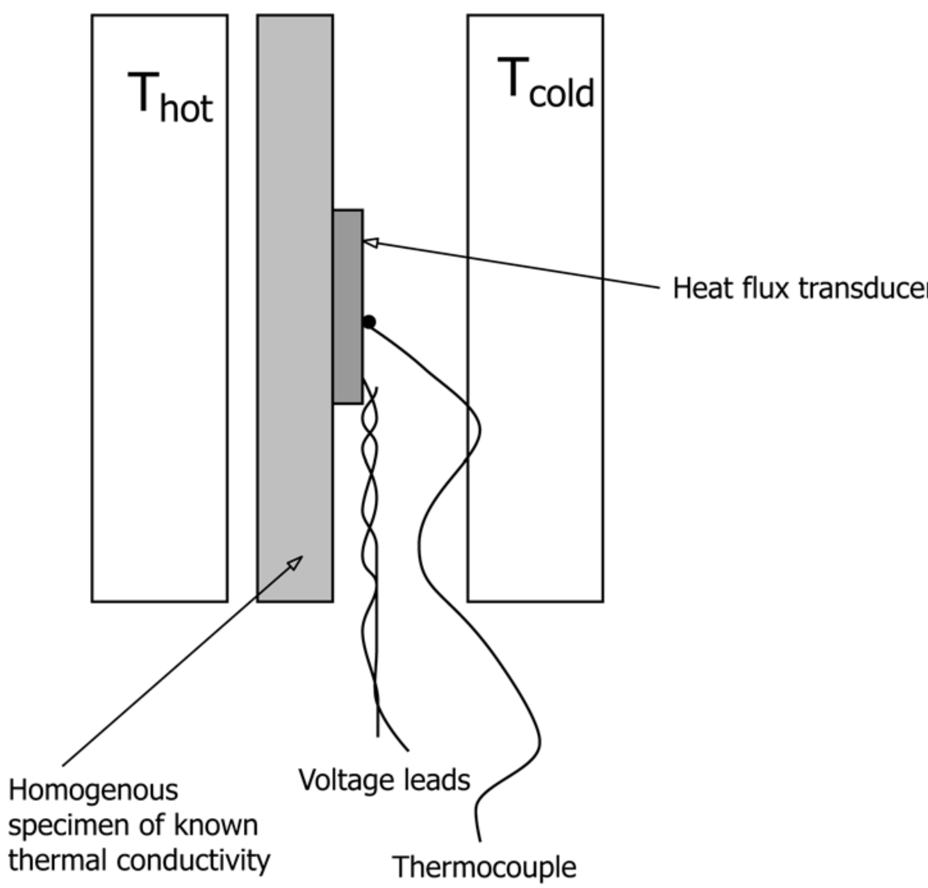


FIG. 3 Example of Test Stack Emulating an Embedded Position Within an Insulated Wall Cavity, Side View



NOTE 1—Drawing not to scale, heat flux transducer size exaggerated relative to hot box dimensions.

FIG. 4 Example of a Test Stack for a Surface-Mounted Heat Flux Transducer

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.

6.3 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.

6.4 Ensure that the test stack has reached a steady state condition before taking data, including the voltage output from the heat flux transducer leads. This may require a longer settling time than is typical for these test methods.

NOTE 5—Theoretically, the output of the heat flux transducer is zero when there is no heat flux through the transducer. Eq 1 and 2 are based upon this assumption. For a more rigorous check of heat flux transducer response, the user is referred to Appendix X1 which requires that the user flip the heat flux transducer over and repeat the test at the same temperature conditions. A simpler approach that has been used to check this assumption is to enclose the heat flux transducer within heavy insulation and place the heat flux transducer and insulation within a temperature-stable environment for 24 h before checking that the output voltage is indeed zero under conditions of no heat flux.

7. Calculation

7.1 For a single-point calibration, use the measured heat flux, q, and voltage, E to calculate the sensitivity, depending upon the test stack chosen, as shown in Eq 1.

$$S = \frac{E}{q} \quad (1)$$

7.2 When multiple data points are available, evaluate the data using the selected model as discussed in Appendix X1.

7.3 An example of a least square linear fit of sensitivity as a function of temperature is shown in Fig. 5. Alternative models and data analysis are discussed in Appendix X1.

NOTE 6—Do not confuse calibration terminology in this practice with that in other C16 application standards. For example, Practice C1046 uses the term "conversion factor" (which also is designated S and has units of (W/m^2) per V) to relate the measured HFT output to the flux through the building envelope. This practice advocates using the following form (Eq 2) for applications of heat flux transducers:

$$q = \frac{E}{S} \quad (2)$$

8. Report

8.1 Report the following information:

8.1.1 The heat flux transducer manufacturer, model identification, size, thickness, geometry (that is, square or round), and dimensions.

8.1.2 The ASTM Test Method used and the size of the apparatus plates.

8.1.3 The test stack composition, including the location of the heat flux transducer, the material used to mask or embed the heat flux transducer, and any additional layers of material used in the assembly.

NOTE 7—A diagram of the test stack is suggested.

8.1.4 The temperatures of the heat flux transducer and surface plates.

8.1.5 The heat flux transducer sensitivity and/or calibration factor. When multiple data points are available, provide correlations and R^2 values.

8.1.6 If known, provide the apparatus clamping pressure.

9. Precision and Bias

9.1 Precision data from one laboratory using Test Method C177 are given in Table 1 for two sizes of heat flux transducers having coplanar copper-constantan thermoelectric junctions in a glass-fiber reinforced epoxy substrate. The repeatability standard deviations were determined by pooling replicate data and weighting with their respective degrees of freedoms (**10**).

9.2 *Bias*—No information can be presented on the bias of the procedure in Practice C1130 for calibrating thin heat flux transducers because no transducer having an accepted reference value is available.

9.3 After the heat flux transducers are calibrated, they are used to measure heat flux in a building assembly. 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 % (**11**).

10. Measurement Uncertainty

10.1 Evaluate the uncertainty for the calibration results using current international guidelines (**12**). Determine the combined standard uncertainty using Eq 3.

$$u_c = \sqrt{u_1^2 + u_2^2 + u_3^2} \quad (3)$$

10.2 The measurement uncertainty includes the standard uncertainty of the test method used for calibration and the standard uncertainty of any auxiliary measurement equipment, for example, the voltmeter used to measure the DC output signal of the heat flux transducer(s).

10.3 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.

11. Keywords

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

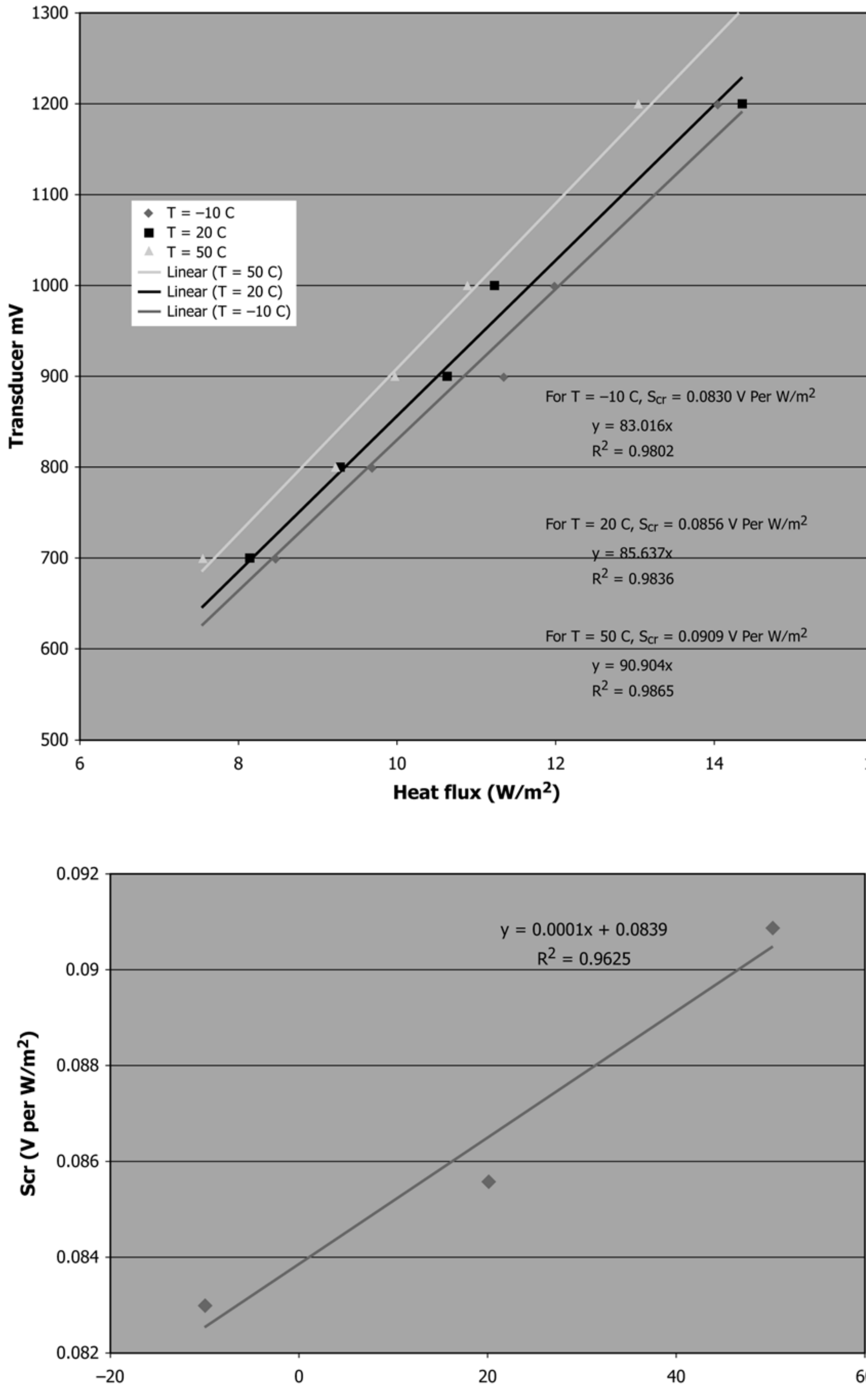


FIG. 5 An Example of Data Analysis for Sensitivity Measured as a Linear Function of Temperature, Least Squares Linear Fits Shown

TABLE 1 Repeatability Standard Deviations for a Heat Flux Transducer (10) Determined Using Test Method C177

Size	500 mm × 500 mm	610 mm × 610 mm
Meter Area	250 mm × 250 mm	305 mm × 305 mm
Nominal Thickness	0.8 mm	0.8 mm
S	94.0 μV/(W·m^2)	136.4 μV/(W·m^2)
Standard deviation	0.53 μV/(W·m^2)	0.40 μV/(W·m^2)
Number of Specimens	9	3

APPENDIXES

(Nonmandatory Information)

X1. DATA ANALYSIS MODELS

X1.1 A simple linear model, with the heat flux sensitivity shown as a simple function of temperature, is often used.

X1.2 Other models are possible and may be needed for certain transducers in certain environments. For example, over a large temperature range, it is likely that a non-linear equation may be necessary to fit the data.

X1.3 Base the design of experiment upon the data requirements of the selected model.

X1.3.1 For a linear model, it is customary to vary one variable at a time, for example first heat flux and then temperature.

X1.3.2 As noted in Zarr et al, a model linear in heat flux and temperature with an interaction term was assumed for calibrating HFTs (see Eq X1.1) (**10**). For that study, the design of experiment randomly varied both variables—heat flux (q) and temperature (T) to provide the data needed to evaluate that model. Note that in the final analysis of the HFT calibration data, the temperature effect over the range of 10 to 50°C was essentially negligible for the type of heat flux transducers studied (**10**).

$$E = a_0 + a_1 q + a_2 T + a_3 qT + \varepsilon \tag{X1.1}$$

X1.4 Whichever model is used, the R^2 statistic can be useful for evaluating the "goodness of fit." However, it is also a good idea to examine the residuals of the fit to check underlying assumptions in the calibration data.

X2. GUIDANCE FOR DETERMINING TEST BOUNDARY TEMPERATURES

X2.1 *If the Desired Heat Flux and Transducer Temperature are Known*—Using nominal values for the thermal resistance of each material in the test stack, calculate the required temperature difference to achieve the desired heat flux using Eq X2.1 and the hot and cold-side temperatures using Eq X2.2 and X2.3.

$$\Delta T = Q_{expected} \times \sum_{Test\ Stack} R_{layer} \tag{X2.1}$$

$$T_{cold} = T_{transducer} - \left(Q_{expected} \times \sum_{cold\ plate}^{transducer} R_{layer} \right) \tag{X2.2}$$

$$T_{hot} = T_{cold} + \Delta T \tag{X2.3}$$

X2.2 *If Boundary Conditions for the Application are Known*—Using nominal values for the thermal resistance of each material in the test stack and each material in the full application construction, calculate the hot and cold-side temperatures. For the case where the test stack includes the material facing the cold boundary condition, use Eq X2.4 and X2.5. For the case where the test stack includes the material facing the hot boundary condition, use Eq X2.4 and Eq X2.6.

$$Q_{expected} = \frac{T_{boundary\ hot} - T_{boundary\ cold}}{\sum_{Full\ Construction} R_{layer}} \tag{X2.4}$$

$$\left(\text{where} \sum_{Full\ Construction} R_{layer} \text{ includes the surface resistance} \right)$$

$$T_{hot} = T_{boundary\ cold} + \left(Q_{expected} \times \sum_{Test\ Stack} R_{layer} \right) \tag{X2.5}$$

$$T_{cold} = T_{boundary\ hot} - \left(Q_{expected} \times \sum_{Test\ Stack} R_{layer} \right) \tag{X2.6}$$

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