Designation: C 1046 – 95

Standard Practice for
In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components[1]

1. Scope

1.1 This practice covers a technique for using heat flux transducers (HFTs) and temperature transducers (TTs) in measurements of the in-situ dynamic or steady-state thermal behavior of opaque components of building envelopes. The applications for such data include determination of thermal resistances or of thermal time constants. However, such uses are beyond the scope of this practice (for information on determining thermal resistances, see Practice C 1155).

1.2 Use infrared thermography with this technique to locate appropriate sites for HFTs and TTs (hereafter called sensors), unless subsurface conditions are known.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[2]
C 1060 Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings[2]
C 1130 Practice for Calibrating Thin Heat Flux Transducers[2]
C 1153 Practice for the Location of Wet Insulation in Roofing Systems Using Infrared Imaging[2]
C 1155 Practice for Determining Thermal Resistance of Building Envelope Components from In-Situ Data[2]

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *building envelope component*—a portion of the building envelope, such as a wall, roof, floor, window, or door, that has consistent construction.

3.2.1.1 *Discussion*—For example, an exterior stud wall would be a building envelope component, whereas a layer thereof would not be.

3.2.2 *thermal time constant*—the time necessary for a step change in temperature on one side of an item (for example, an HFT or building component) to cause the corresponding change in heat flux on the other side to reach 63.2 % of its new equilibrium value where one-dimensional heat flow occurs. It is a function of the thickness, placement, and thermal diffusivity (see Appendix X1) of each constituent layer of the item.[3]

3.3 Symbols Applied to the Terms Used in This Standard:

E = measured voltage from the HFT, typically in mV,
q = heat flux, W/m^2 (Btu/h·ft^2),
S = heat-flux transducer conversion factor that relates the output of the HFT, E, to q through the HFT for the conditions of the test, W/m^2·V (Btu/h·ft^2·mV). This may be a function of temperature, heat flux, and other factors in the environment as discussed in Section 7. This may also be expressed as $S(T)$ to connote a function of temperature,
T = temperature, K (°C, °R, or °F),
t = time, s (hours, days), and
τ = thermal time constant, s (hours, days).

4. Summary of Practice

4.1 Heat flux transducers are installed on or within a building envelope component in conjunction with temperature transducers, as required. Heat flux through a surface is influenced by temperature gradients, thermal conductance, heat capacity, density and geometry of the test section, and by convective and radiative coefficients. The resultant heat fluxes are determined by multiplying a conversion factor S of the HFT by its electrical output. The S values shall have been obtained

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[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.

[3] $t = \tau$ when $q(t) = q_1 + (q_2 - q_1)(1 - e^{t/\tau})$, where q_1 is the previous equilibrium heat flux, and q_2 is the new heat flux after the step change.

according to Practice C 1130.

5. Significance and Use

5.1 Traditionally, HFTs have been incorporated into laboratory testing devices, such as the heat flow meter apparatus (Test Method C 518), that employ controlled temperatures and heat flow paths to effect a thermal measurement. The application of heat flux transducers and temperature transducers to building components in situ can produce quantitative information about building thermal performance that reflects the existing properties of the building under actual thermal conditions. The literature contains a sample of reports on how these measurements have been used **(1-8)**.[4]

5.2 The major advantage of this practice is the potential simplicity and ease of application of the sensors. To avoid spurious information, users of HFTs shall: (*1*) employ an appropriate *S*, (*2*) mask the sensors properly, (*3*) accommodate the time constants of the sensors and the building components, and (*4*) account for possible distortions of any heat flow paths attributable to the nature of the building construction or the location, size, and thermal resistance of the transducers.

5.3 The user of HFTs and TTs for measurements on buildings shall understand principles of heat flux in building components and have competence to accommodate the following:

5.3.1 Choose sensor sites using building plans, specifications and thermography to determine that the measurement represents the required conditions.

5.3.2 A single HFT site is not representative of a building component. The measurement at an HFT site represents the conditions at the sensing location of the HFT. Use thermography appropriately to identify average and extreme conditions and large surface areas for integration. Use multiple sensor sites to assess overall performance of a building component.

5.3.3 A given HFT calibration is not applicable for all measurements. The HFT disturbs heat flow at the measurement site in a manner unique to the surrounding materials **(9, 10)**; this affects the conversion constant, *S*, to be used. The user shall take into account the conditions of measurement as outlined in 7.1.1. In extreme cases, the sensor is the most significant thermal feature at the location where it has been placed, for example, on a sheet metal component. In such a case, meaningful measurements are difficult to achieve. The user shall confirm the conversion factor, *S*, prior to use of the HFT to avoid calibration errors. See Section 7.

5.3.4 The user shall be prepared to accommodate nonsteady-state thermal conditions in employing the measurement technique described in this practice. This requires obtaining data over long periods, perhaps several days, depending on the type of building component and on temperature changes.

5.3.5 Heat flux has a component parallel to the plane of the HFT. The user shall be able to minimize or accommodate this factor.

6. Apparatus

6.1 Essential equipment for measuring heat flux and temperature includes the following:

6.1.1 *Heat Flux Transducer*—A rigid or flexible device (see Appendix X2) in a durable housing, composed of a thermopile (or equivalent) for sensing the temperature difference across a thin thermal resistive layer, which produces a voltage output that is a function of the corresponding heat flux and the geometry and material properties of the HFT.

NOTE 1—All calibrations relating output voltage to heat flux shall conform to Practice C 1130 and pertain to the measurement at hand. Manufacturers' calibrations supplied with HFTs often do not conform with Practice C 1130. Obtain the HFT conversion factor as described in Section 8 of Practice C 1130.

6.1.2 *Temperature Transducer*—A thermocouple, resistance thermal device (RTD), or thermistor for measuring temperatures on or within the construction, or for measuring air temperatures. Some HFTs incorporate thermocouples.

6.1.3 *Recorder*—An instrument that reads sensor output voltage and records either the voltage, heat flux, or temperature values calculated from appropriate formulas, with durable output (for example, magnetic tape, magnetic disk, punch tape, printer, or plotter).

6.1.4 *Attachment Materials*—Pressure-sensitive tape, adhesive, or other means for holding heat flux and temperature transducers in place on the test surface or within the construction.

6.1.5 *Thermal Contact Materials*—Gel toothpaste, heat sink grease, petroleum jelly, or other means to improve thermal contact between an irregular surface and a smooth HFT.

6.1.6 *Absorptance and Emittance Control Supplies*—Coatings or sheet material to match the radiative absorptance and emittance of the sensor with that of the surrounding surfaces.

7. HFT Signal Conversion

7.1 The conversion factor (*S*) is a function of the HFT design and the thermal environment surrounding the HFT **(8, 9)**. A difference between thermal conductivities of the HFT and its surroundings causes it to act either as a partial blockade or conduit for heat flux. Radiative heat passes into the HFT at a different rate than it does into the surrounding surface, depending on the mismatch between the absorptivities of HFT and surface. The presence of air moving across an HFT can change the conductance of the air film at the HFT and cause the heat flux through the HFT to differ from that through the surrounding surface.

7.1.1 Determine *S* according to the procedure outlined in Practice C 1130, as appropriate to the conditions of use, that is, surface-mounted or embedded and surrounded by materials that will be present.

7.2 Confirm that the time constant of the HFT is much less than the time constant of the building component to be measured if the temperatures throughout the HFT and the construction will not be steady state. If the mass of an HFT of a certain area is less than one fiftieth of the mass of the same area of building component, then its time constant is small enough. If not, then estimate the thicknesses and thermal diffusivities of the constituent layers of the HFT and the building component, using Appendix X1 or other recognized technique, to determine whether the time constant of the HFT

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

is less than one fiftieth of that of the component's time constant.

8. Selection of Sensor Sites

8.1 The user shall choose a place in the construction for siting the HFTs where one-dimensional heat flow perpendicular to the exterior surfaces occurs, unless the user is prepared to deal with multidimensional heat flow in the analysis of the data.

NOTE 2—For example, a sensor site in the center of a fully insulated stud cavity represents heat flow perpendicular to the wall surface, whereas a location near a stud or blocking does not. A wall incorporating concrete masonry units has significant multidimensional heat flow through the concrete webs and possible air convection cells in the block cores.[5] Similarly, an empty stud cavity has convection as a potential lateral heat flow mechanism and a masonry or stone wall has vertical heat conduction near the ground level. Air leakage can also be a source of multidimensional heat flow.

8.2 Do not place the HFTs where they contribute more than 1 % additional resistance to the construction subject to thermal measurement, unless the thermal properties of the HFTs are well known and the analysis technique is appropriate.

8.3 Do not place HFTs on surfaces with high lateral conductance, unless the S has been confirmed for the precise condition.

8.4 Install HFTs either on an indoor surface of the component if the construction is complete or within a building component when the component is being constructed and retrieval is not required. Infrared thermography is required when the internal configuration of the component is poorly known. Seek perpendicular flow, and avoid unforeseen thermal anomalies.

8.5 Use infrared thermography to determine the characteristics of candidate sensor sites on the building component when the internal configuration of the component is poorly known (see Practices C 1060 and C 1153).

NOTE 3—Close visual inspection of a stud wall can often reveal the locations of framing members when there are slight imperfections above nailheads, but thermography can reveal whether or not there is unexpected cross blocking, air leakage, or convection owing to missing, incorrectly applied, or shifted insulation.

NOTE 4—Thermographic instruments produce a two-dimensional image of a surface by measuring thermal radiation emanating from that surface. A temperature gradient on the surface is seen as a variation in contrast or in pseudocolor on a viewer screen. If the radiation gradients are caused by heat transfer variations in the wall because of thermal anomalies, these anomalies and their locations are made visible. Certain thermographic patterns can be recognized as framing, air leakage, or convection.

8.6 Determine whether to deploy sensors in a line or in some other arrangement, based on knowledge of the component's internal configuration. Note that a wall with suspected internal convection requires, at a minimum, sensors at the top, bottom, and center of the suspected convective area.

9. Test Procedures

9.1 *Sensor Site Selection*—Select appropriate sensor sites according to Section 8. The HFT shall cover a region of uniform heat flux on the chosen site. If the HFT covers a region with significantly nonuniform heat flux, then demonstrate that the HFT correctly averages the input it receives.

9.2 *Permanent Sensor Installation*:

9.2.1 Sensors built into the construction offer more reliable results than sensors mounted on an exterior surface, because they are usually protected from radiant heat sources and convection, which may affect the sensor differently than the surrounding building material. The measurement is also likely to have less variance.

9.2.2 Tape or glue the HFTs to a smooth surface within the construction to ensure good thermal contact.

9.2.3 Position temperature transducers on and within the construction, as required, to obtain temperature gradients across its thickness. Place sensors at the exterior surfaces and at interfaces between materials within the construction. Install sensors at the exterior surfaces in one of the following two ways:

9.2.3.1 Surface mount temperature transducers with tape or adhesive. Cover surface-mounted sensors with an opaque coating of the same surface absorptance as the surrounding material.

NOTE 5—Be aware that some visually opaque materials are transparent in the infrared spectrum.

NOTE 6—Surface mounting results in a slightly lower temperature reading in cool ambient conditions and a slightly higher reading in warm ambient conditions than the surface temperature, since the protruding sensor is more affected by air film temperature.

9.2.3.2 Flush mount temperature transducers by burying them at the same depth that the sensor is thick. Use the same paint, or in the case of a natural finish, such as brick or wood, a powder of that finish material made into a paste and glued around the sensor. For most nonmetallic materials (see Ref **(11)** or **(12)**), the absorptance is in the range of 0.85 to 0.90.

9.2.4 Check the uniformity of surface absorptance with an infrared imager or single-point radiometer. Check the match of absorptance of the covered HFT with that of the surrounding area by comparing the image or radiometer output of each area after a stabilization time of at least 15 min.

NOTE 7—Infrared imagers and single-point radiometers sense the radiation leaving a surface; they provide a direct relationship of visual or numerical output to surface absorptance for a given temperature. An HFT that changes the thermal resistance of the envelope component or diverts heat flux significantly will not be representative of its surroundings. Be aware that infrared devices are spectral in nature, so that the comparison is made for specific wavelength bands in the infrared, not for the total spectrum.

9.3 *Temporary Sensor Installation*:

9.3.1 Where the interior of the building construction is inaccessible or the sensor shall be removed nondestructively, mount the HFT on an accessible indoor surface of the construction. Place a layer of material over the entire exposed surface of the HFT that matches the HFT surface absorptance to that of the surrounding surface and creates a smooth transition for air flow.

NOTE 8—A layer of masking tape, or some other thin material, will both match the HFT absorptance with that of most nonmetallic finishes and provide a smooth transition for air flow. If the surface is metallic, refer to

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[5] Experience indicates, however, that the face of a concrete masonry unit distributes heat flux sufficiently that HFT placement is insensitive to location on the block.

a table of absorptivities or emissivities **(11, 12)** for guidance concerning an appropriate material, such as aluminum foil (shiny or dull side out). Furthermore, measurements on metallic surfaces are more sensitive to whether or not *S* represents field conditions. To test the match of HFT surface absorptance to the surrounding surface, confirm that the sensors are invisible to an infrared imager of sufficient spatial resolution to view objects one fifth the size of the HFT.

9.3.2 On smooth, flat surfaces, apply masking tape around the perimeter of the HFT and press it onto the surface to ensure good contact on the entire interface.

9.3.3 On rough surfaces, apply the HFT in the same manner as 9.3.2, except also apply a heat conductive material, such as gel toothpaste or petroleum jelly, between the sensor and the surface in a thin layer. Note that air gaps greater than 0.5 mm (0.02 in.) can cause errors from 2 to 10 % because of convection **(13)**.

9.3.4 As an alternative, place the HFT under a rectangular cover of gypsum wallboard or plywood with a recessed area in the center for the HFT and provision for the wires to exit from under the cover. Choose this method if rapid fluctuations in HFT output are undesirable for the measurement. Use a cover of material about 0.3 m^2(1 ft^2) for HFTs smaller than 0.1 m on a side. Note that the cover will both diminish the variations in heat flux swings and add thermal resistance to the building component.

9.3.5 Use HFTs with an integral temperature transducer (TT) or install a TT with the HFT. Mount TTs on the surface as described in 9.3.2.

9.3.6 Connect HFT and TTs for each location to the recorder.

9.4 *Data Acquisition and Analysis*:

9.4.1 Establish the frequency of reading heat fluxes and temperatures required (for measuring thermal resistances, see Practice C 1155). Monitor the fluctuations in temperature and heat flux to confirm that they are consistent with expectations. Adjust the frequency of readings, if required.

9.4.2 Establish the frequency for recording heat fluxes and temperatures with a data acquisition system or an integrating voltmeter appropriate for the required calculation or graphic representation. Average the data obtained between recording intervals with an electronic averaging function or, in the case of discrete readings, using an appropriate, recognized method.

9.5 *Duration of Measurement*:

9.5.1 For determining the thermal resistance of building envelope components, follow the guidance given in Practice C 1155.

9.5.2 For other measurements, obtain the required number of temperature and heat flux readings.

NOTE 9—The thermal time constant of a component, the presence of insulation, and the variation and average value of the temperature difference (ΔT) across a component all influence how long it takes to have a change in temperature at one location in the section affect heat flow elsewhere. In most cases ΔT is an important variable. Refer to the literature **(1-8)**.

10. Calculation

10.1 *Calculation of Heat Flux*—Calculate heat flux, *q*, according to the following equation, the time average of the HFT output:

$$q = S(T_i) \cdot E_i \qquad (1)$$

where:

E_i = the averaged voltage reading, of the *i*th measurement, and

T_i = the corresponding temperature of the *i*th measurement.

NOTE 10—*S* can also be a function of other thermal factors. See Section 7.

10.2 *Calculation of Temperature*—Calculate temperature for each averaged temperature transducer output according to the calibration values or formulas for the sensor.

11. Interpretation of Results

11.1 *Corroboration of Results*—Assess the efficacy of measurements with reference to independent forms of information, such as as-built drawings or thermograms. If the results appear contrary to expectations, inspect the interior of the component, as required.

11.2 *Generalization of Results*—Consider the possible causes of sensor output variation before assessing results from any single sensor or the average of a group of them. If required, use thermography of the greater region surrounding the sensor site and random sampling of measurements at similar locations to interpolate conditions that are within the bounds of those measured and observed on the component. Note that interpolated values away from sensor sites are less accurate than measurements obtained at sensor sites.

11.3 *Multidimensional Heat Flow*—Analysis of HFT data shall include assessment of possible sources of significant multidimensional heat flow, such as lateral conduction or convection within the construction or thermal bridges through the region of measurement. See Appendix X3.

12. Report

12.1 Report the following information, using SI or inch-pound units:

12.2 A general description of the relevant parts of the building, including:

12.2.1 Dimensions,

12.2.2 Construction of walls and roofs,

12.2.3 A site plan and photographs of elevations,

12.2.4 Type of occupancy during measurement, and

12.2.5 Type of HVAC equipment and operating schedule.

12.3 The purpose of the measurement (for example, to provide data for Practice C 1155).

12.4 The criteria for choosing sensor sites to satisfy the goals of the measurement. Document the locations with scale drawings depicting the exact locations of each sensor and, where possible, photographs showing the appearance of the instrumentation. Include drawings of the construction monitored, if available.

12.5 A statement describing how Practice C 1130 was used to determine *S* for the heat flux transducers and its appropriateness for the conditions of the test.

12.6 An explanation of efforts to make all sensors thermally similar to their surroundings. State absorptivities of materials found and those used for masking.

12.7 Provide a report of heat flux and the temperatures