



## 1. Introduction

- 1.1. The purpose of this document is to clearly define acceptance criteria for thermometers for AASHTO Accreditation purposes and to define thermometer calibration and standardization requirements.
- 1.2. The type of thermometer required is dependent upon the application for which the thermometer is used. The individual test method requirements must be understood before selecting an appropriate thermometer.

## 2. Terminology

- 2.1. Terms related to metrology are found in the [International Vocabulary of Metrology – Basic and General Concepts and Associated Terms \(VIM\)](#). The terminology in this section has been modified to address specific issues related to thermometers and temperature measurement.
- 2.2. *Accuracy, n*—a qualitative assessment of the size of the measurement error.
  - 2.2.1. *Discussion*—In most standards, values are associated with accuracy. These values are likely intended to be the maximum permissible error for the measurement device to conform to the requirements applicable to its usage. However, in some cases, the readability or resolution of the measurement instrument appear to have been erroneously referred to as accuracy.
- 2.3. *Calibration, n*—the process of comparing the readings of a thermometer with the readings of a reference thermometer including the determination of associated measurement uncertainties to determine whether the thermometer conforms to the requirements applicable to its usage.
- 2.4. *Calibration Curve, n*—a graphical representation of the differences between the readings of a thermometer being calibrated or standardized and the readings of the reference thermometer.
- 2.5. *Measurement Error, n*—the difference between the reading of the test thermometer and the reading of the reference thermometer at a given temperature.
- 2.6. *Measurement Uncertainty, n*—a numerical representation of the dispersion of values attributed to a measured quantity.
  - 2.6.1. *Discussion*—In this document, measurement uncertainty refers to the expanded measurement uncertainty or overall uncertainty.
- 2.7. *Offset Correction, n*—the difference of the readings of a thermometer being calibrated or standardized and the readings of the reference thermometer.
- 2.8. *Readability, n*—the smallest values that can be read on a thermometer.
- 2.9. *Reference Thermometer, n*—high accuracy thermometers that are ideal for checking the accuracy of temperature testing equipment, such as other thermometers, dataloggers, ovens, etc.
- 2.10. *Standardization, n*—the process of comparing the readings of a thermometer with the readings of a reference thermometer to determine whether the standardized thermometer conforms the requirements applicable to its usage.
- 2.11. *Test Uncertainty Ratio (TUR), n*—a comparison between the accuracy of the thermometer being calibrated or standardized and the estimated measurement uncertainty of the reference thermometer.
- 2.12. *Tolerance, n*—the permitted variation of a measured value from the true value.
- 2.13. *Unit Under Test (UUT), n*—the thermometer being standardized or calibrated.
- 2.14. *Working Thermometer, n*—the thermometer used for daily testing.

## 3. General Thermometer Requirements and Selection

### 3.1. Types of Thermometers

- 3.1.1. There are many types of digital and non-digital thermometers used in the construction materials testing industry. These include, but are not limited to, digital thermometers that use thermocouple, resistance

- thermal detector, and thermistor sensors; and non-digital varieties such as liquid-in-glass and bimetallic thermometers.
- 3.1.2. Infrared thermometers can be used as working thermometers in extremely limited applications if they are specifically allowed by a test standard. Infrared thermometers cannot be used as reference thermometers.
- 3.1.3. Bimetallic, or dial-spring, thermometers can be used as working thermometers, unless specifically prohibited by an applicable written standard. Bimetallic thermometers cannot be used as reference thermometers.
- 3.2. **Purpose: Reference Thermometers and Working Thermometers**
- 3.2.1. A reference thermometer is a thermometer that is used to calibrate or standardize other thermometers.
- 3.2.2. A working thermometer is a thermometer that is used in daily testing or to perform other standardization activities and equipment checks, such as oven standardizations and volume determinations (molds, unit weight buckets, specific gravity flasks, etc.).
- 3.2.2.1. A working thermometer cannot be used to calibrate or standardize other thermometers, unless specifically allowed by a standard.
- 3.3. **Readability**
- 3.3.1. The readability of a working thermometer shall be better than or at least the same as that specified in applicable written standards.
- 3.3.2. The readability of a reference thermometer shall be better than or at least the same as the readability required for itself as a working thermometer.
- 3.4. **Range**
- 3.4.1. The range of a working thermometer shall encompass the range specified for it by applicable standards.
- 3.4.2. The range of a reference thermometer shall encompass the range required for fulfilling the calibration or standardization requirements for the working thermometer.
- 3.5. **Accuracy**
- 3.5.1. The accuracy of a working thermometer shall be equal to or smaller than the value specified by the applicable standards.
- Example:** If a standard specifies an accuracy of 0.5°C for the working thermometer, the readings of the reference thermometer shall be within 0.5°C of the true value of the temperature.
- 3.5.2. The accuracy of a reference thermometer shall not exceed half of the accuracy value specified for the working thermometer being standardized or calibrated by the reference thermometer.
- 3.5.2.1. For a reference thermometer, measurement uncertainty also shall be considered before a determination is made on conformance. The estimated measurement uncertainty of a reference thermometer shall be no more than half of the accuracy value specified for the working thermometer being standardized or calibrated by the reference thermometer.
- Example:** If a standard specifies an accuracy of 0.5°C for the working thermometer, the readings of the reference thermometer used to standardize that working thermometer shall have errors and measurement uncertainties no larger than 0.25°C.
- 3.5.3. If there are values for the accuracy defined in the standard, the temperature indicated by the working thermometer shall be within 1 percent of the temperature indicated by the reference thermometer.

## 4. Thermometer Calibration and Standardization

### 4.1. General Requirements

- 4.1.1. Reference thermometers shall be calibrated, working thermometers shall be standardized. Working thermometers only need to be calibrated if specifically required by a standard.
- 4.1.2. The calibration or standardization of a digital thermometer shall be performed with the central processing unit (CPU) and the probe as one unit unless the thermometer is used at high temperatures (above 200°C).
  - 4.1.2.1. For high temperatures, the calibration or standardization of the CPU and the sensor may be performed together or separately with the results combined. If performed separately, the CPU shall be calibrated or standardized electronically, and the sensor shall be calibrated or standardized thermodynamically.
- 4.1.3. For ASTM E230 conforming base metal thermocouples used at high temperatures, the wire from a calibrated lot may be used to construct the sensor. The thermocouples constructed from this wire shall be considered single-use thermocouples if the high temperatures are likely to cause drift or damage to the wire. The calibration report for the wire shall indicate the applicable tolerances from Table 1 of ASTM E230, and these tolerances shall be the results that get combined with the calibration or standardization results of the CPU.

**Note 1:** The CPU is also called a readout device, multimeter, or meter. The probe is also called a sensor.

### 4.2. Process

- 4.2.1. The calibration or standardization of a thermometer shall be performed by a thermodynamic method, either fixed point or comparison.
  - 4.2.1.1. **Fixed-Point:** Fixed-point calibrations or standardizations are calibrations or standardizations performed in a fixed-point cell with temperatures determined by triple points, freezing points, or melting points of various mediums, such as water, mercury, or tin. The temperatures of these physical events serve as the reference standard.
  - 4.2.1.2. **Comparison:** Comparison calibrations or standardizations are calibrations or standardizations performed at various temperatures with the readings of a reference thermometer serving as the reference standard.
    - 4.2.1.2.1. A calibration performed by comparison shall be performed using either a dry block or a stirred liquid bath.

**Note 2:** See ASTM E77 or E644 for more information on comparison calibrations and standardizations.

- 4.2.2. Calibrations or standardizations performed by electrical means, such as comparing the thermometer CPU to resistors, or use of an electronic calibrator that simulates temperature output through electrical resistance may be a necessary step in the overall calibration or standardization of a thermometer. However, it is the thermodynamic calibration or standardization performed at the end of the process that is being specified by this document.

### 4.3. Number of Points

- 4.3.1. The number of calibration or standardization points depends on the type of thermometer and how it is used.
  - 4.3.1.1. If the thermometer is only being used to measure temperature at a single temperature, a one-point calibration or standardization may be performed at that temperature, or within +/- 5°C (9°F) of that temperature.
  - 4.3.1.2. If the thermometer is used within a small range of temperatures (10°C (18°F)), a one-point calibration or standardization may be performed within that range.
  - 4.3.1.3. If the thermometer is used over a wide range of temperatures, the thermometer shall be calibrated or standardized accordingly based on the type of thermometer:

- 4.3.1.3.1. Liquid-in-glass thermometers shall be calibrated or standardized at a minimum of two points bracketing the range of use. In addition, there shall be no more than 100 scale divisions between the test points, and additional test points shall be added within this range to meet this requirement.

**Example:** If the liquid-in-glass thermometer has a range of -1 to 51°C in 0.1 divisions, and it will be used across a range from 4 degrees to 37 degrees, it needs to be calibrated or standardized at 0, 10, 20, 30 and 40°C to in order to bracket the range of use and to include a test point every 100 scale divisions.

- 4.3.1.3.2. Digital thermometers shall be calibrated or standardized at a minimum of two points bracketing the range of use. For ranges over 100 °C, at least one additional intermediary point shall be included.

#### 4.3.2. **Offset Corrections and Calibration Curves**

- 4.3.2.1. If, during calibration or standardization, any thermometer readings fall outside of the tolerance defined by the maximum permissible measurement error, offset corrections shall be applied to the readings of the thermometer, when allowed. This is accomplished through the addition or subtraction of an offset correction value or by the application of a calibration curve equation, depending on the situation.

- 4.3.2.1.1. **One Point Standardization or Calibration:** If a one-point calibration or standardization was performed, the difference between the reading of the UUT and the reading of the reference thermometer is the offset and can be used to correct the reading to within the tolerance.

- 4.3.2.1.2. **More Than One Point:** If the calibration or standardization was performed at more than one point so that the thermometer can be used over a range of temperatures, a calibration curve may be used to correct the readings of the UUT.

#### 4.4. **Frequency**

- 4.4.1. Reference thermometers shall be calibrated at least once every thirty-six (36) months, or more frequently, if specified by applicable standards.
- 4.4.2. Working thermometers shall be standardized or calibrated at least once every twelve (12) months, or more frequently, if specified by applicable written standards.

#### 4.5. **General Records Requirements**

- 4.5.1. The calibration record for any thermometer and the standardization record for a working thermometer shall meet the applicable requirements of AASHTO R 18.
- 4.5.2. All thermometer readings shall be documented to the resolution of that thermometer.
- 4.5.3. If an offset or calibration curve equation is used to correct the readings, the offset or calibration curve equation shall be documented on the calibration or standardization record itself or in a separate document that is referenced by the calibration or standardization record and traceable to it.
- 4.5.3.1. A statement about the need for an offset or calibration curve correction based on the most recent calibration or standardization shall be included on the thermometer itself or on the container in which it is stored.
- 4.5.3.2. If using liquid-in-glass thermometers are used for both reference and testing, and one reads in °C and the other reads in °F, the units can be converted mathematically. In documenting this, all original readings shall be recorded, and all mathematically derived readings shall be clearly labeled. Mathematically converted values shall be documented to at least the same number of decimal places as the readability of the thermometer.

#### 4.5.4. **Digital Thermometers Records Requirements**

- 4.5.4.1. There shall be clear indication on the records that the measurements were taken using the probe and CPU together.
- 4.5.4.2. If the probe is a removable probe, the record shall include separate unique identification numbers for both the readout and the probe. Only the unique combination of the specific CPU and probe used during calibration or standardization is considered calibrated or standardized.

4.5.4.3. If the CPU has multiple channels for receiving multiple probes, the channel used during the calibration or standardization of any CPU-probe combination shall also be identified. Only the unique combination of the specific CPU, probe, and channel used during calibration or standardization is considered calibrated or standardized.

4.5.5. **Calibration Records for Reference Thermometers:** The calibration record for a reference thermometer shall meet the following additional requirements:

4.5.5.1. The data from the calibration record shall be used to establish a relation for obtaining a measurement result from any unit under test (UUT) reference thermometer reading such that these measurement results will always fall within a range of one-half of the maximum permissible error specified for the thermometers you are trying to calibrate or standardize with this reference thermometer. This is the test uncertainty ratio (TUR).

**Example:** If a standard specifies an accuracy of 0.5°C for the working thermometer, the readings of the reference thermometer used to standardize that working thermometer shall have *measurement errors* no larger than 0.25°C.

4.5.5.2. If all readings of the UUT reference thermometer included on the calibration record are within this tolerance, it can be assumed that any reading of the UUT reference thermometer within the range of calibration will meet this requirement.

4.5.5.3. If the readings of the UUT reference thermometer included on the calibration record are not within this tolerance, but an offset or equation for a suitable calibration curve can be applied to the readings to bring all measurement results to within this tolerance at the test points included on the calibration record, it can be assumed that application of the offset or calibration curve equation to any reading of the UUT reference thermometer within the range of calibration will meet this requirement.

4.5.6. When used as a reference thermometer, the measurement uncertainties at applicable test points shall be smaller than or equal to one-half of the maximum permissible measurement error specified for the thermometers being calibrated or standardized with this reference thermometer.

**Example:** If a standard specifies an accuracy of 0.5°C for the working thermometer, the readings of the reference thermometer used to standardize that working thermometer shall have measurement uncertainties no larger than 0.25°C.

4.5.7. The AASHTO Accreditation Program will use the information contained in the following tables to qualify measurement uncertainty statements included on thermometer calibration reports.

4.5.8. If the type of thermometer being evaluated is known, and it is also known that the calibration of that thermometer was performed in the same manner as the calibrations performed to determine the uncertainties included in the tables below, the measurement uncertainties attributed to the readings of that thermometer cannot be smaller than those listed below. If they are smaller, the record of the calibration of that thermometer will be rejected and a new calibration may be required.

**Table 1: BIPM Key Comparison Database Values**

Type of Device	Measurement Uncertainty
<i>Industrial Platinum Resistance Thermometers (IPRTs), ASTM E1137</i>	0.0023°C
<i>Film-Type Industrial Platinum Resistance Thermometers</i>	0.01°C
<i>Thermistors</i>	0.0018°C
<i>Thermocouples, Type B</i>	0.3°C
<i>Thermocouples, Type E</i>	0.9°C
<i>Thermocouples, Type J</i>	0.7°C
<i>Thermocouples, Type K*</i>	1°C
<i>Thermocouples, Type N*</i>	1°C
<i>Thermocouples, Type R</i>	0.13°C
<i>Thermocouples, Type S</i>	0.13°C
<i>Thermocouples, Type T</i>	0.4°C
<i>Liquid-in-Glass Thermometer, Hg, Partial, 0.1°C graduations</i>	0.02°C

\* 1°C was determined for temperatures up to 1000°C. See table 2 for more specific values.

**Table 2: NIST IR 5340 Values for Type K and N Thermocouples**

Temperature (°C)	Measurement Uncertainty
<b>-200</b>	0.4°C
<b>-100</b>	0.2°C
<b>0</b>	0.02°C
<b>100</b>	0.1°C
<b>200</b>	0.2°C
<b>300</b>	0.3°C
<b>400</b>	0.4°C
<b>419.58 (Zn)</b>	0.4°C
<b>500</b>	0.5°C

- 4.5.9. **Standardization Records:** The standardization record for a working thermometer shall meet the following additional requirements:
- 4.5.9.1. The data from the standardization record shall be used to establish a relation for obtaining a measurement result from any working thermometer reading such that these measurement results will always fall within a range of the maximum permissible error (“tolerance”) specified by applicable written standards.
- 4.5.9.2. If all readings of the working thermometer included on the standardization record are within this tolerance, it can be assumed that any reading of the working thermometer within the range of standardization will meet this requirement.
- 4.5.9.3. If the readings of the working thermometer included on the standardization record are not within this tolerance, but an offset or equation for a suitable calibration curve can be applied to the readings to bring all measurement results to within this tolerance at the test points included on the standardization record, it can be assumed that application of the offset or calibration curve equation to any reading of the working thermometer within the range of standardization will meet this requirement.
- Note 3:** If a standard does not allow for the application of a calibration curve to the readings of thermometers, the user cannot apply a calibration curve.
- 4.5.9.4. Although calibration and measurement uncertainty determinations are not typically required for a working thermometer, if the working thermometer has been calibrated, the measurement

uncertainties at applicable test points shall be smaller than or equal to the maximum permissible *measurement error* specified for the thermometer by applicable written standards.

#### 4.6. **Agency Requirements**

##### 4.6.1. **To Perform Calibration**

4.6.1.1. Reference thermometers shall be calibrated by one of the following entities:

4.6.1.1.1. A calibration agency accredited to ISO/IEC 17025 by an accreditation body that is a signatory to the International Laboratory Accreditation Cooperation Mutual Recognition Arrangement (ILAC MRA).

4.6.1.1.2. A national metrology institute (NMI) such as the National Institute of Standards and Technology (NIST).

4.6.1.1.3. An agency with a current certificate of measurement traceability issued by the NIST Office of Weights and Measures.

##### 4.6.2. **To Perform Standardization**

4.6.2.1. A working thermometer can be calibrated or standardized using a suitable reference thermometer and calibration or standardization procedure, either by the laboratory or by an external calibration agency.

##### 4.6.3. **External Agencies**

4.6.3.1. The laboratory shall confirm that the agency being used to calibrate or standardize its reference and working thermometers has suitable reference thermometers and capabilities to meet the laboratory's testing needs.

4.6.3.2. **ISO/IEC 17025:** If the agency is accredited to ISO/IEC 17025, the laboratory can find the scope of the calibration agency's accreditation online and determine from the scope whether the agency can provide a thermodynamic calibration or standardization in the range that is needed.

4.6.3.3. **NIST:** An agency with a current certificate of measurement traceability issued by the NIST Office of Weights and Measures will not have its calibration and measurement capability (CMC) uncertainty published. If the agency's scope includes temperature, the laboratory shall request the calibration record for the reference thermometer the agency will be using, so that the laboratory can verify that the calibration of the reference thermometer meets the requirements of this document.

## 5. **Special Cases**

### 5.1. **Ice-Point Verifications for Mercury Liquid-in-Glass Thermometers**

5.1.1. Mercury-in-glass reference thermometers can be fully calibrated once, provided that they are then verified yearly at the ice-point.

5.1.1.1. The original calibration record shall include the ice-point as one of the test points.

5.1.1.2. The verifications shall be performed at the frequency specified above for reference thermometers.

5.1.1.3. The verifications shall be performed by an agency capable of performing this calibration, as stated in their scope of accreditation.

5.1.1.4. The ice-point verification reading of the thermometer shall be compared with the ice-point reading on the original calibration. Any changes in this reading shall be reflected in all readings included on the record for the original calibration.

5.1.1.5. A separate record that references both the record of the original calibration and the record of the most recent verification needs to be prepared. This record can be prepared by the laboratory. The record shall include a table of values that summarizes the new corrections based on the change in the reading at the ice-point, or a calibration curve.

**Note 4:** See Table 1 of NIST SP 1088 and Figure 8 of NIST SP 1088 for additional guidance.

### 5.2. **Using Reference Thermometers as Working Thermometers**

5.2.1. Reference thermometers may be used as working thermometers if they meet all previous requirements, with the additional conditions:

5.2.1.1. The thermometer shall be calibrated at least once every twelve (12) months, or more frequently, if specified by applicable written standards.

- 5.2.1.2. Once the thermometer is used for any daily testing, the thermometer shall not be used as a reference thermometer again until it is re-calibrated.

## 6. References

- 6.1. AASHTO R 18, *Establishing and Implementing a Quality System for Construction Materials Testing Laboratories*
- 6.2. AASHTO R 61, *Standard Practice for Establishing Requirements for Equipment Calibrations, Standardizations, and Checks*
- 6.3. BIMP Key Comparison Database - <http://kcdb.bipm.org/>
- 6.4. Euramet Guide cg-13, *Calibration of Temperature Block Calibrators*
- 6.5. International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) - <https://jcgm.bipm.org/vim/en/index.html>
- 6.6. ASTM E1, *Standard Specification for ASTM Liquid-in-Glass Thermometers*
- 6.7. ASTM E77, *Standard Test Method for Inspection and Verification of Thermometers*
- 6.8. ASTM E230, *Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples*
- 6.9. ASTM E563, *Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature*
- 6.10. ASTM E644, *Standard Test Methods for Testing Industrial Resistance Thermometers*
- 6.11. ASTM E879, *Standard Specification for Thermistor Sensors for General Purpose and Laboratory Temperature Measurements*
- 6.12. ASTM E1137, *Standard Specification for Industrial Platinum Resistance Thermometers*
- 6.13. ASTM E2251, *Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids*
- 6.14. ASTM E2488, *Standard Guide for the Preparation and Evaluation of Liquid Baths Used for Temperature Calibration by Comparison*
- 6.15. ASTM E2877, *Standard Guide for Digital Contact Thermometers*
- 6.16. To find a calibration agency in the United States that is accredited to ISO/IEC 7025, the laboratory can consult the search directories of the following accreditation bodies:
- 6.16.1. <https://search.anab.org/>
- 6.16.2. <https://customer.a2la.org/index.cfm?event=directory.index>
- 6.16.3. <https://www.iasonline.org/search-accredited-organizations-2/>
- 6.16.4. <https://www-s.nist.gov/niws/index.cfm?event=directory.search#no-back>
- 6.16.5. <https://www.pjilabs.com/search-accredited-organizations>
- 6.17. To find an agency that has a current certificate of conformance with NIST Handbook 143 and ISO/IEC 17025, you may consult the following page. These agencies are mentioned in this document:
- 6.17.1. <https://www.nist.gov/pml/owm/external-resources-weights-and-measures/state-metrology-laboratories>