Designation: D8055 – 17

Standard Guide for Selecting an Appropriate Electronic Thermometer for Replacing Mercury Thermometers in D04 Road and Paving Standards[1]

This standard is issued under the fixed designation D8055; 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 The Interstate Mercury Education and Reduction Clearinghouse (IMERC) and the U.S. Environmental Protection Agency (EPA) are phasing out the use of mercury thermometers because of safety and environmental concerns. This guide was developed to support replacing mercury thermometers in D04 standards with appropriate electronic thermometers.

1.2 This guide provides assistance for the D04 subcommittees when selecting electronic thermometers for general use in water or oil baths and ovens and as possible replacements for Specification E1 mercury thermometers currently used in D04 road and paving standards. Guidance for using non-mercury liquid thermometers in place of mercury thermometers can be found in Specification E2251.

1.3 Some guidance is also provided for selecting a handheld infrared thermometer for use in field applications.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this guide.

1.5 *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.*

1.6 *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]

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

E1 Specification for ASTM Liquid-in-Glass Thermometers

E644 Test Methods for Testing Industrial Resistance Thermometers

E1137/E1137M Specification for Industrial Platinum Resistance Thermometers

E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

3. Summary of Practice

3.1 Guidance is provided for selecting a sensor based on a desired upper and lower range of temperatures, and accuracy. Guidance is also provided for selecting an appropriate sensor for replacing specific Specification E1 mercury thermometers currently used in D04 standards.

4. Significance and Use

4.1 General guidance is provided for electronic thermometers for general temperature measurements typically needed for D04 practices and test methods which need to monitor oven, water and oil bath, and material temperatures during drying, heating, aging, and mixing.

4.2 All ASTM standards under the management of the D04 Main Committee were individually reviewed, and a list of all Specification E1 mercury thermometers was prepared along with the required temperature range and information about the thermometer placement in each method.

4.2.1 This specific information was used to identify the most appropriate type(s) of electronic thermometers which can

[1] This guide is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.99 on Sustainable Asphalt Pavement Materials and Construction.

Current edition approved March 1, 2017. Published April 2017. Originally approved in 2017. DOI: 10.1520/D8055-17.

[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.

be used to replace mercury thermometers in the current D04 road and paving standards.

5. Electronic Thermometers

5.1 *Basic Background Information for Understanding Key Elements of Different Types of Electronic Temperature Sensors:*

5.1.1 Most sensors require multiple algorithms to convert electrical signals to temperature measurements. These algorithms are only useful over a portion of a temperature range, and different algorithms are needed above and below 0 °C.

5.1.2 Sensor accuracy is improved by increasing the number of algorithms which are applicable over narrower temperature ranges. The digital meter programming is critical to the accuracy of the temperature measurements, and the meter capabilities for accuracy need to be matched to the requirements for each type of sensor.

5.1.3 More than one sensor can be paired with a single digital meter, but temperature measurements with each sensor-digital meter pair need to be independently verified and documented.

5.1.4 Each sensor and digital meter needs to be labeled so that the sensor can be matched with the appropriate digital meter for laboratory accreditation documentation required in Specification D3666.

5.2 *Platinum Resistance Thermometers (PRTs):*

5.2.1 A platinum resistance thermometer is a specific type of resistance temperature device (RTD). A wide range of names are used by various sensor manufacturers and suppliers of these devices. Some suppliers market these sensors as simply RTDs and the information about the metal used in each sensor is only found in the more detailed sensor description. Other suppliers market electronic platinum RTD sensors as PT, for platinum, or PRT for platinum resistance thermometer. Specification E1137/E1137M uses the PRT abbreviation and provides the basic requirements for PRT sensors.

5.2.2 PRT sensors use one of two reference resistance levels: 100 ohms and 1000 ohms. PRT sensors with a resistance of 100 ohms have an upper temperature limit of 204 °C while a PRT sensor with a resistance of 1000 ohms has an upper temperature limit of 482 °C. PRT sensors with a resistance of 100 ohms are most useful for D04 application temperatures.

5.2.3 A reference temperature of 0 °C is the temperature at which the sensor accuracy is the best (that is, smallest ± range). PRT sensor accuracy decreases linearly with increasing or decreasing temperatures on either side of 0 °C.

5.2.3.1 The purity of the platinum greatly influences the accuracy of the sensor.

5.2.4 The wiring configuration of the PRT sensor also greatly influences the accuracy of the temperature readings. PRT sensors should be ordered with three- or four-wire configurations. Two-wire configurations should be avoided.

5.2.5 PRTs can be easily damaged if dropped or mishandled and should not be subjected to shock or vibration. This type of temperature sensor is best used when it can be permanently or at least semi-permanently mounted in or on the test equipment.

5.2.5.1 The sensor needs to be protected by a metal sheath and the wiring needs to be insulated to minimize heat transfer from surrounding environmental conditions and external electronic noise. The overall sheath length shall be least 50 mm greater than the immersion depth (see Section 7).

5.3 *Thermistors:*

5.3.1 Thermistors with negative temperature coefficients (NTC) have nonlinear decreasing resistance with increasing temperatures and are very sensitive to temperature changes. The beta value (B-value) is a function of the nonlinearity of the resistance-temperature relationship. Higher B-values indicate increased sensor sensitivity to small changes in temperature. Thermistors are characterized by manufacturers by their resistance, in ohms, at 25 °C, and their B-value.

5.3.2 Drift (stability) in the electronic thermometer readings over time occurs because of changes in the sensor resistance and B-value. Drift increases with increases in the temperatures which are measured with the sensor. More expensive thermistors can be preconditioned to provide very stable temperature measurements over years of service.

5.3.3 Thermistors are the most accurate with the least drift over time when used to measure temperatures from 0 °C to 70 °C. If thermistors are used for extended periods of time at temperatures over 100 °C, the electronic thermometer may need to be verified or recalibrated more frequently than required in Specification D3666.

5.3.4 Thermistor response time depends on the test medium. Response times are from 1 to 2 s in liquids and up to 25 s in air.

5.3.5 The sensor needs to be protected by a metal sheath and the wiring needs to be insulated to minimize heat transfer from surrounding environmental conditions and external electrical noise. The overall sheath length shall be least 50 mm greater than the immersion depth (see Section 7).

5.4 *Thermocouples:*

5.4.1 Thermocouples consist of a pair of dissimilar metals, twisted together at one end (that is, junction), which generate a small voltage when the temperature at the twisted end is different than the temperature at the other end (that is, reference temperature).

5.4.1.1 Type T has a lower temperature range from –250 °C to 0 °C and an upper temperature range from 0 °C to 350 °C. The thermocouple sensor accuracy decreases linearly, increasing or decreasing temperatures on either side of 0 °C. Type T thermocouple (ANSI Type T has a blue connector; IEC Type T has a brown connector). The National Institute of Standards (NIST) lists the expanded uncertainty as 0.4 °C for Type T thermocouple wire sensor, and Type T is the most useful type for the majority of ASTM D04 standards.

5.4.1.2 Type K has a lower temperature range from –200 °C to 0 °C and an upper temperature range from 0 °C to 1250 °C. The thermocouple sensor accuracy decreases linearly, with increasing or decreasing temperatures on either side of 0 °C. Type K thermocouple (ANSI Type K has a yellow connector; IEC Type K has a green connector) wire. NIST lists the expanded uncertainty as 1 °C, and Type K is useful for ASTM D04 applications which only require a low level of accuracy for temperature measurements.

5.4.2 Thermocouple wire can be protected by mounting in a metal sheath. The sheath gives the thermocouple wire a similar physical diameter and length to that of conventional mercury thermometers, which can minimize changes needed to mount electronic thermometer in existing equipment. The thermocouple junction needs to be grounded to the sheath and the overall sheath length shall be least 50 mm greater than the immersion depth.

5.4.3 When the thermocouple wire is not encased in a metal sheath, the two wires should be joined using a welded bead connection.

5.4.4 The thermocouple wire insulation needs to be selected based on the anticipated application temperature (Table 1).

5.5 *Hand-Held Infrared Thermometers:*

5.5.1 Hand-held infrared thermometers (that is, infrared "guns") are typically used for monitoring temperature during the construction of asphalt pavements. The accuracy of the readings is dependent a number of infrared gun characteristics, reflectivity of the object's surface, and the distance of the user from the object.

5.5.1.1 While this type of thermometer provides fast, noncontact temperature measurements, the measured temperature only reflects the surface temperature of the object.

5.5.2 Hand-held infrared thermometers combine the sensors and meter into a single device. The optical lens focal point concentrates light in the infrared range on a group of small thermocouple junctions (that is, thermopile). When the thermometer is pointed at a target, the average temperature within the field of view is the temperature shown on the thermometer display.

5.5.3 The field of view of a hand-held infrared thermometer is circular (spot) and dependent on the lens characteristics. The spot diameter is a function of the distance of the lens from the target and is characterized by manufacturers as the distance to spot ratio (D:S).

5.5.3.1 Common ratios range from 6:1 to 50:1. This is a fixed value for each thermometer. The typical user distance from the target and the area to be included in the temperature measurement need to be identified so the infrared thermometer with the appropriate D:S ratio is ordered.

5.5.4 Hand-held infrared thermometers with laser sighting for the spot diameter help ensure the target area of interest is included in the temperature measurement. When the spot diameter is too large, the temperatures of the area surrounding the target are included in the temperature measurement.

6. Sensor Selection

6.1 *Sensor Selection for General Applications*—A number of ASTM D04 standards require temperature measurements to control oven and water bath temperatures but do not specifically identify the thermometer to be used. Sensors for these applications can be selected from Table 2.

TABLE 1 Guide for Wire Insulation Based on Application Temperature

Insulation	Max. Temp.
Ceramic	980 °C
Glass Braid	482 °C
PFA	260 °C
FEP	200 °C
Polyvinyl	105 °C

6.2 *Replacing Specification E1 Mercury Thermometers*—The Specification E1 mercury thermometer designations used in ASTM D04 standards are listed in Table 3 along with potential sensor replacements with similar accuracy and application temperature limits and ranges. This table is organized by levels of accuracy needed for each thermometer.

6.2.1 An electronic sensor shall be selected which is capable of measuring temperatures over a specified temperature range with a specified tolerance.

6.2.2 The specified temperature range will be the minimum temperature range used for calibration, standardization, verification, or combinations thereof.

6.2.3 Tolerance varies with temperature. The tolerance specified for electronic thermometer used in a specific standard will be the largest tolerance associated with either the highest or lowest temperature of the specified temperature range.

6.3 The digital meter needs to be matched to the type of sensor and be capable of converting the sensor output into temperature measurements. The meter shall be capable of providing temperature measurements with an accuracy that reflects the accuracy of the sensor.

6.4 If there is more than one possible sensor which can be used to replace the mercury thermometer, the user needs to evaluate the advantages and disadvantages associated with each option. Manufacturer's technical support services are useful for evaluating device options as well for matching the sensor accuracy to the meter ability to report temperature at the sensor accuracy.

6.5 Care should be taken to ensure that electronic thermometers do not significantly change the reported test results. The ability to obtain statistically similar mean test results with similar or better precision should be verified prior to using electronic thermometers for acceptance testing.

6.6 The immersion depth required for the sensor may limit the potential for directly replacing mercury thermometers with electronic thermometers.

7. Determining the Minimum Immersion Depth

7.1 *Background:*

7.1.1 The surface area of the sensor over which temperature is measured and stable is the minimum depth of immersion. Each type of sensor has a unique sensor size.

7.1.2 Thermistor and thermocouple sensors measure temperature over a similar or smaller surface area than mercury thermometer tips. External environmental conditions may influence temperature measurements because of the sensor sheath characteristics, wiring insulation, or both. PRT-100 sensors use a longer surface area for temperature measurements and the minimum immersion depth needed to achieve a stable temperature in a bath or oven can vary.

7.1.3 The ability of an electronic thermometer to provide statistically similar mercury thermometer measurements needs to be evaluated before the sensor can be used as a direct replacement.

7.1.4 Ideally, the mercury thermometer and the replacement electronic thermometer should be evaluated side-by-side in the actual test method apparatus. If this is not possible due to size

TABLE 2 Temperature Sensors for Typical D04 Application Temperature Ranges and Tolerance Requirements

NOTE 1—". . ." = Configuration of wiring not applicable.

Sensor	Low Temp. °C	High Temp. °C	Tolerance °C	Designation/Classification	Wiring Configuration
PRT-100	0	100	±0.05	Class 1/10 DIN	4-wire configuration
	–50	150	±0.5	DIN/IEC Class AA	4-wire configuration
	–100	400	±1	DIN/IEC Class A	3- or 4-wire configuration
	–100	300	±2	DIN/IEC Class B	3- or 4-wire configuration
	0	500	±1	E1137/E1137M Class A	3- or 4-wire configuration
	–100	400	±2	E1137/E1137M Class B	. . .
Thermocouple	–250	350	±1	Type T; Special Error Limit Classification	. . .
Thermistor	–40	100	±0.2	±0.1 Classification	. . .
	0	70	±0.1	±0.1 Classification	. . .

TABLE 3 Possible Replacements for ASTM D04 Mercury Thermometers Historically Used in Committee Standards

NOTE 1—"NA" = Upper or lower temperature (or both) exceeds useful range of sensor type.

Accuracy °C	Specification E1 Designation	Low Temp. °C	High Temp. °C	PRT-100 Class and Wiring Requirements	Thermistor	Thermocouple
±0.05	ASTM 110C	133.6	136.4	Class 1/10 DIN; 4 Wire; Ultra-Precise	NA	NA
±0.1	ASTM 17C	19	27	Class 1/10 DIN; 3 or 4 Wire	±0.1	NA
	ASTM 19C	49	57	Class 1/10 DIN; 3 or 4 Wire	±0.1	NA
	ASTM 47C	58.6	61.4	Class 1/10 DIN; 4 Wire; Ultra-Precise	SPECIAL ORDER	NA
	ASTM 63C	–8	32	Class 1/10 DIN; 4 Wire; Ultra-Precise	SPECIAL ORDER	NA
	ASTM 64C	25	55	Class 1/10 DIN; 3 or 4 Wire	±0.1	NA
±0.2	ASTM 12C	–20	102	Class 1/10 DIN; 4 Wire; Ultra-Precise	NA	NA
	ASTM 15C	–2	80	Class AA; 3 or 4 Wire	±0.1	NA
	ASTM 23C	18	28	Class AA; 3 or 4 Wire	±0.2	NA
	ASTM 24C	39	54	Class AA; 3 or 4 Wire	±0.2	NA
	ASTM 25C	95	105	Class 1/10 DIN; 4 wire Ultra-Precise	NA	NA
±0.5	ASTM 113C	–1	175	Class 1/3 or 1/10 DIN; 4 Wire; Ultra-Precise	NA	NA
	ASTM 114C	–80	20	Class 1/10 DIN; 4 wire; Ultra-Precise	NA	NA
	ASTM 13C	155	170	DIN/IEC Class AA; 3 or 4 Wire	NA	NA
±1	ASTM 2C	–5	300	DIN/IEC Class A; 3 or 4 Wire	NA	Type T; Special Error Limit Classification
	ASTM 7C	–2	300	DIN/IEC Class A; 3 or 4 Wire	NA	Type T; Special Error Limit Classification
	ASTM 8C	–2	400	DIN/IEC Class A; 3 or 4 Wire	NA	Type T; Special Error Limit Classification
±2	ASTM 11C	–6	400	ASTM/DIN/IEC Class 1; 3 or 4 Wire	NA	Type T; Special Error Limit Classification

or fixture constraints (or both), a test container can be used for comparisons of temperature readings and to determine the minimum immersion depth.

NOTE 1—The procedure outlined in this section was adapted from Test Methods E644, Section 7, "Minimum Immersion Length Test," for use for evaluating electronic sensors which will be used in ASTM D04 standards.

7.2 *Apparatus for Simulating Test Method Conditions:*

7.2.1 *Test Container*—Glass, metal, or insulated chamber of sufficient size to hold the same medium (for example, water, oil, air, etc.) capable of providing the same movement of the medium (for example, stirred, stationary, unidirectional flow, forced air, etc.) and temperature ranges which replicate the desired test method conditions.

7.2.1.1 The test container needs to be of sufficient size to accommodate both mercury and replacement thermometers at the depth needed for the test method conditions being simulated.

7.2.2 *Thermometer Holders*—Use holders which replicate the method of mounting which will be used in the test method being simulated, as best possible, since mounting flanges, threads, clamps, etc. can influence heat transfer from the environment to the sensor.

7.3 *Procedure:*

7.3.1 Once the medium in the test container is at the conditions needed to simulate the desired test method, mount the mercury thermometer in the test container.

7.3.2 Record the time and temperature shown on the mercury thermometer. Repeat recordings every two minutes until the temperature in the test container is within the temperature range defined in the test method being simulated.

7.3.3 Once the test container conditions are stable as measured with the mercury thermometer, introduce the sensor into the test container near the mercury thermometer location so the tips of the mercury thermometer and sensor are at the same depth. Record the time, temperature, and tip depths for both the mercury thermometer and sensor.

7.3.4 Withdraw the sensor a small, measurable distance from the initial tip location. Record the new location, time, and temperature. Once the electronic thermometer temperature is stable, record the time and temperature again. Repeat this step until the electronic thermometer temperature is stable but differs from the previous reading by more than the thermometer accuracy.

7.3.5 The depth of immersion in the test chamber as measured from the tip of the sensor to the surface of the test chamber is the minimum immersion length.

8. Calibration of Electronic Thermometers

8.1 Electronic thermometers consist of a combination of an electronic sensor and an electronic means of reading or recording the temperature measurement such as a hand-held digital meter or a USB connection to a computer which is capable displaying measurements.

8.2 Calibration of electronic thermometers requires each electronic sensor, combined with the device which will be used to read or record the temperature data (or both), to be calibrated as a single device.

8.2.1 Once the electronic thermometer is calibrated, if the electronic sensor or the device used to read or record the temperature data (or both) is changed, the resulting combination of components needs to be recalibrated as a new electronic thermometer.

8.3 Calibration, standardization, or both needs to be done using the comparison method or by fixed point method.

NOTE 2—The fixed point method is rarely used.

8.4 Calibration or standardization by means of electronic simulation is not acceptable. Electronic simulation does not account for many of the factors that may contribute to device accuracy and measurement uncertainty.

9. Precision and Bias

9.1 Add the following note to the precision statement in any standard to which an electronic thermometer alternative is added and before round-robin testing has been conducted to verify statistically similar results are obtained:

NOTE 3—The existing precision and bias statement was prepared using data obtained using a mercury thermometer in the testing. The ability to obtain statistically similar mean test results with similar, or better, precision should be verified prior to using electronic thermometers for acceptance testing.

10. Keywords

10.1 mercury thermometer replacement; platinum resistance thermometers; PRT-100; thermistors; thermocouples