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## Standard Guide for Selecting an Appropriate Electronic Thermometer for Replacing Mercury Thermometers in D04 Road and Paving Standards<sup>1</sup>

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 ( $\epsilon$ ) 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 ~~hand-held~~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~~safety, health, and health~~environmental~~ 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:*<sup>2</sup>

- [D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials](#)
- [E1 Specification for ASTM Liquid-in-Glass Thermometers](#)
- [E230/E230M Specification for Temperature-Electromotive Force \(emf\) Tables for Standardized Thermocouples](#)
- [E644 Test Methods for Testing Industrial Resistance Thermometers](#)
- [E1137/E1137M Specification for Industrial Platinum Resistance Thermometers](#)

<sup>1</sup> 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.

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

[E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids](#)

[2.2 IEC Standards:](#)<sup>3</sup>

[IEC 60584-1 Thermocouples—Part 1: EMF Specifications and Tolerances](#)

[IEC 60751 Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors](#)

### 3. Summary of PracticeGuide

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

NOTE 1—Accuracy is expressed as a tolerance range in the tables in this standard because the relevant sensor standards use the term “tolerance” in their tables to specify sensor characteristics.

### 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 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.

<sup>3</sup> Available from International Electrotechnical Commission (IEC), 3, rue de Varembe, 1st floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, <https://www.iec.ch>.

5.2.3 A reference temperature of 0 °C is the temperature at which the sensor accuracy is the best (that is, smallest  $\pm$  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 linearly~~ 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 and Technology (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 linearly~~ 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~~ The thermocouple sensor, which is the junction of the two wires, 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. When a metal sheath is used, the junction can be attached to the metal sheath, encased but separate from the sheath, or exposed at the tip of the sheath.~~

Connecting the junction to the sheath improves heat transfer and provides a faster response time than when the junction is isolated from the sheath. An exposed junction provides the fastest response time, but does not protect the wires and can limit their usefulness in corrosive or pressurized environments. 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 (see Section 7).

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~~ Handheld Infrared Thermometers:

5.5.1 ~~Hand-held~~ Handheld 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, non-contact temperature measurements, the measured temperature only reflects the surface temperature of the object.

5.5.2 ~~Hand-held~~ Handheld 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~~ handheld 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~~ Handheld 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.

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.

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

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

NOTE 1—“. . .” = Configuration of wiring not applicable.

NOTE 2—DIN: Deutsches Institut für Normung (German Institute for Standards); IEC: International Electrotechnical Commission.

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	
	-50	150	±0.5	Class AA (IEC 60751)	4-wire configuration	
	-100	400	±1	DIN/IEC Class A	3- or 4-wire configuration	
	-100	400	±1	Class A (IEC 60751, ASTM E1137/E1137M)	3- or 4-wire configuration	
-100	300	±2	DIN/IEC Class B	3- or 4-wire configuration		
-200	650	±1.24	Class A (ASTM E1137/E1137M)	3- or 4-wire configuration		
θ	500	±1	E1137/E1137M Class A	3- or 4-wire configuration		
Thermocouple		-200	250	±1	Type T (Class 1, IEC 60584; Special Class, ASTM E230/E230M)	...
		-100	400	±2	E1137/E1137M Class B	...
		-200	350	±1.5	Type T (Class 1, IEC 60584; Special Class, ASTM E230/E230M)	...
Thermocouple		350	±1	Type T, Special Error Limit Classification	...	
		-200	500	±2	Type K (Class 1, IEC 60584; Special Class, ASTM E230/E230M)	...
Thermistor	-40	100	±0.2	±0.1 Classification	...	
	0	70	±0.1	±0.1 Classification	...	

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6.2.3 Tolerance varies with temperature. The tolerance specified for the 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 sheath, or wiring when using an unshielded thermocouple, over which temperature is measured and stable is the minimum depth of immersion. Each type of sensor has a unique sensor size/minimum immersion depth.

7.1.2 Thermistor/Thermistors and thermocouple sensors—thermocouples sensors are typically bead-size sensors and measure temperature over a similar or smaller surface area than mercury thermometer tips—thermometers. 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; are typically larger and may have larger minimum immersion depths.