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Standard Practice for Measuring Surface Atmospheric Temperature with Electrical Resistance Temperature Sensors[1]

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1. Scope

1.1 This practice provides procedures to measure representative near-surface atmospheric (outdoor air) temperature for meteorological purposes using commonly available electrical thermometers housed in radiation shields mounted on stationary or portable masts or towers.

1.2 This practice is applicable for measurements over the temperature range normally encountered in the ambient atmosphere, –50 to +50°C.

1.3 Air temperature measurement systems include a radiation shield, resistance thermometer, signal cables, and associated electronics.

1.4 Measurements can be made at a single level for various meteorological purposes, at two or more levels for vertical temperature differences, and using special equipment (at one or more levels) for fluctuations of temperature with time applied to flux or variance measurements.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

E344 Terminology Relating to Thermometry and Hydrometry

E644 Test Methods for Testing Industrial Resistance Thermometers

E1137/E1137M Specification for Industrial Platinum Resistance Thermometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology D1356 and E344. Some definitions are repeated in this section for the reader's convenience.

3.1.2 *connecting wires*—the wires which run from the element through the cable end closure and external to the sheath.

3.1.3 *interchangeability*—the extent to which the thermometer matches a resistance-temperature relationship.

3.1.4 *inversion*—the increase in potential temperature with an increase in height (see 3.1.5 and 3.2.7).

3.1.5 *lapse rate*—the change in temperature with an increase in height (see 3.1.4 and 3.2.7).

3.1.6 *resistance thermometer*—a temperature-measuring device comprised of a resistance thermometer element, internal connecting wires, a protective shell with or without means for mounting, a connection head or connecting wire with other fittings, or both (see also 3.2.3).

3.1.7 *resistance thermometer element*—the temperature-sensitive portion of the thermometer composed of resistance wire, film or semiconductor material, its supporting structure, and the means for attaching connecting wires.

3.1.8 *thermistor*—a semiconductor whose primary function is to exhibit a monotonic change (generally a decrease) in electrical resistance with an increase in sensor temperature.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *ambient*—the portion of the atmosphere where the air temperature is unaffected by local structural, terrain, or heat source or sink influences.

3.2.2 *sensor*—used interchangeably with resistance thermometer (see 3.1.6) in this practice.

3.2.3 *shield*—a ventilated housing designed to minimize the effects of solar and terrestrial radiation on a temperature sensor while maximizing convective heat transfer between the sensor

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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.

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and the passing air, and to protect the sensor from contact with liquid moisture; also known as radiation shield.

3.2.4 *temperature differential*—the difference between two or more simultaneous temperature measurements, typically separated vertically at a single location; see 3.1.4 and 3.1.5.

3.2.5 *temperature variance*—a statistical measure, the deviation of individual temperature measurements from the mean of those measurements obtained over a user-defined sampling period.

3.2.5.1 *Discussion*—Temperature variance describes temperature variability at a fixed point in the atmosphere. The covariance of temperature and vertical velocity defines the sensible heat flux.

3.2.6 *transfer function*—the functional relationship between temperature sensor electrical resistance and the corresponding sensor temperature.

3.2.7 *vertical temperature gradient*—the change of temperature with height ($\Delta T/\Delta Z$ or $\delta T/\delta Z$), frequently expressed in °C/m; also known as lapse rate for temperature decrease, or inversion for a temperature increase (see 3.1.4 and 3.1.5).

3.3 *Symbols:*

agl = above ground level
ΔT = difference between two temperatures, also δT
ΔZ = difference between two heights above ground level, also δZ
T = temperature, degrees in appropriate scale, typically Celsius, °C
Z = height above ground level, typically metres
τ = time constant, the time for a sensor to change to approximately 63.2 % (1−l/e) of the value of the temperature change.

4. Significance and Use

4.1 *Applications*—Ambient atmospheric temperature measurements can be made using resistance thermometers for many purposes. The application determines the most appropriate type of resistance thermometer and data recording method to be used. Examples of three typical meteorological applications for temperature measurements follow.

4.1.1 Single-level, near-surface measurements for weather observations (**1**)[3], thermodynamic computations for industrial applications, or environmental studies (**2**).

4.1.2 Temperature differential or vertical gradient measurements to characterize atmospheric stability for atmospheric dispersion analyses studies (**2**).

4.1.3 Temperature fluctuations for heat flux or temperature, or variance computations, or both. Measurements of heat flux and temperature variance require high precision measurements with a fast response to changes in the ambient atmosphere.

4.2 *Purpose*—This practice is designed to assist the user in selecting an appropriate temperature measurement system for the intended atmospheric application, and properly installing and operating the system. The manufacturer's recommendations and the U.S. Environmental Protection Agency handbook on quality assurance in meteorological measurements (**3**) should be consulted for calibration and performance audit procedures.

5. Summary of Practice

5.1 Ambient air temperature measurements using resistance thermometers are typically made using either thermistors or platinum wire or film sensors, though sensors made from other materials with similar resistance properties related to temperature could also be suitable. The sensors are housed in naturally ventilated or mechanically aspirated shields. The sensor temperature is intended to be representative of the ambient air. To accomplish this, the sensor material and exposure in the shield are chosen to maximize convective heat transfer between the air and the sensor, and minimize solar or terrestrial radiation exchange with the sensor. The resistance thermometer (sensor) should be sufficiently rugged to withstand the operating environment without damage. The sensors are connected to electronic circuits capable of measuring the sensor resistance, and displaying or recording, or both, the corresponding temperature. Operational procedures containing quality control and quality assurance tasks suitable to the intended measurements are recommended (**1**, **2**, **3**, **4**).

6. Resistance Thermometers

6.1 *Temperature Measurement Requirements*—Define the range, resolution, response time, precision, and bias suitable for purposes of the measurement. The maximum recommended accuracy specification is an absolute error of ±0.5°C over the expected temperature range. For vertical temperature gradient measurements, there is an additional accuracy specification of a relative error between sensors of ±0.1°C over the range of expected temperature difference (**2**). The maximum recommended resolution is 0.1°C for most single-level measurements, and 0.01°C for vertical temperature difference and temperature fluctuation measurements. The recommended response time should be 5 s or less for typical measurements. Use a fast response thermometer and a temperature measurement system capable of 5 Hz or better data rate for temperature flux and variance applications. The electrical components of a temperature measurement system introduce uncertainty, noise, and drift. For example, a 13-bit analog-to-digital converter used with a thermometer operating over 100°C span can resolve ±0.012°C, but electric noise and drift can produce a system uncertainty of ±0.05°C.

NOTE 1—This practice really addresses the sensor time constant in air in the operational mounting or shield. A response time of 30 to 60 s in aspirated airflow may be more typical in application and will meet most standards and regulations.

6.2 *Sensor Characteristics*—Sensor characteristics to be considered when specifying a system include the following elements.

6.2.1 The temperature-to-resistance relationship (transfer function) needs to provide adequate data resolution considering the sensor installation and data processing equipment. It must be traceable to fixed temperature points and exhibit no singularities due to physical or chemical properties. The relationship

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

must not change significantly with sensor age. Optimum sensor interchangeability can be obtained if the individual sensors have very similar transfer functions.

6.2.2 The sensor must be able to repeatedly cycle through the range of expected temperatures and return to any temperature in the range with the required repeatability, minimizing hysteresis effects. The sensor must be able to dissipate the electrical power used in the measurement process without producing unacceptable measurement bias. The sensor resistance and radiative properties should not be altered by external stresses such as humidity, corrosion, and vibration.

6.2.3 The sensor time constant, τ, must be short enough to provide the necessary sampling rate for the intended measurement; constants less than 1 min are adequate for most meteorological applications. Time constant, τ, is often measured or calculated in still air, assuming that heat transfer only occurs by conduction and radiation. Proper installation in a ventilated shield will markedly reduce the time constant, because heat transfer is dominated by convection.

6.3 *Sensors Commonly Used*—There are two commonly used resistance thermometers (sensors) for meteorological applications—platinum (or other material) wires or films and thermistors. These two types of sensors differ in linearity of response to temperature change and nominal resistance at ambient temperatures. Sensor linearity is more important when matching multiple sensors for temperature difference measurements than for single level measurements.

6.3.1 Platinum resistance thermometer elements have a very linear transfer function (see Specification E1137/E1137M). The nominal resistance at 0°C typically is 100 Ω, with a corresponding resistance change of about 0.4 Ω/°C. This sensitivity calls for special care so the connecting wires and signal cables have no effect on the sensor resistance measurement.

6.3.2 Thermistors have nonlinear transfer functions. Typical sensors include two or three individual thermistors bound together in a circuit to provide for a reasonably linear transfer function in the kilohm range at ambient temperatures, which can be measured easily by modern data recorders.

7. Shields

7.1 Some of the largest error sources in air temperature measurements are due to solar and terrestrial radiation, and to moisture. Improper sensor exposure can lead to errors of 5°C or more. A resistance thermometer senses only the temperature of its probe, which is determined by the cumulative effects of the probe surroundings, including the temperature of the ambient air. There are also adverse effects, such as direct and reflected solar radiation, thermal radiation from surrounding objects, heat conduction from connecting wires and supports, and interference from moisture.

7.2 *Solar and Terrestrial Radiation Effects*—Electrical temperature sensors have different thermal properties than air. For example, the thermal conductivity of air is three to four orders of magnitude lower than the metals used in temperature probes, causing poor thermal contact between the probe and the ambient air. The result is a net temperature excess of the probe surface during exposure to solar radiation or terrestrial radiation heat sources, and a net temperature deficit during nocturnal cooling periods (5).

7.3 *Shield Design*—The shield shelters the temperature sensor from solar and terrestrial radiation, condensation, and precipitation while providing physical support and the ventilation required for convective heat transfer between the sensor and the ambient air. Shields can have either natural or forced aspiration and should allow air movement past the sensor as free as possible from contamination by extraneous heat sources (such as a nearby tower, or exhaust from the aspirator blower motor.)

NOTE 2—Forced aspirators should include sufficient means to prevent moisture from accumulating on the temperature probe, which could cause it to sense a reduced temperature (also known as the wet-bulb effect).

7.3.1 Naturally ventilated shields require no electric power and are often used at remote sites where electrical power is unavailable. These shields offer less radiation protection with wind speeds less than a few metres per second. Naturally ventilated shields are often used with small, fast response thermometer elements that require a minimum of ventilation.

NOTE 3—Temperature errors at lesser wind speeds could approach 5°C.

7.3.2 Forced aspiration is used to normalize convective heat transfer between the resistance thermometer probe and the air by providing a stream of ambient air moving at a reasonably constant velocity between approximately 3 and 10 m/s. Care must be taken to avoid drawing warm air from the shield exhaust into the shield intake. Shielding and aspiration rates should be identical for all thermometers used for temperature profile measurements.

7.3.3 The shield housing shall be made with and kept a reflective color, such as silver or white. Accumulations of surface contaminants such as dirt or animal droppings could reduce the capability of the shield to reflect solar or terrestrial radiation.

PROCEDURES

8. Siting the Temperature Measuring System

8.1 *Station Identification*—The temperature measurement system location shall be identified by an unambiguous label which shall include station location and sensor elevation above ground level using units and resolution suitable for the purposes of the measurement program, and any special purpose information related to the measurement.

8.2 *Measurement Height*—The typical measurement height for meteorological measurements is 1.5 to 2 m above ground level (agl). Consideration should be taken in selecting the sensor height for station locations that have surface vegetation or experience snow cover, or both, more than about 0.5 m in depth. The specific heights above ground level for temperature difference measurements depend on the application intended. For example, air pollution studies for U.S. Environmental Protection Agency purposes can include temperature difference measurements for atmospheric stability determinations using the 2–m agl and 10–m agl heights, and other heights determined by wind measurements (2).

8.3 *Site Representativeness*—Select a site representative of the area over which measurement is desired, such as grassy or desert land. The surface should be representative within a circle about 9 m in radius from the measurement. Avoid rooftops (which are generally warm) and sensor locations near thermal sources or sinks, or those downwind of thermal plumes. Follow additional siting guidance provided by the organization requiring the temperature monitoring program.

9. System Installation

9.1 *Sensor Installation*—Choose a combination of resistance thermometer, shield, and signal processing electronics suitable for the intended application. When mounting the shield, isolate the sensor and shield from the thermal influence of its supporting structure. The tower-mounted sensor (in its shield) should be at least 1.5 tower diameters away from its supporting tower. On aspirated shields, orient the intake away from the sun (downward, or towards north in the northern hemisphere if the shield has a horizontal intake) to minimize solar radiation effects.

9.2 *Signal Cable*—Ensure that the signal cable size and length between the sensor and the data recording equipment is suitable for the equipment being used. Typical systems require electronically shielded 18–gage wire less than about 150 m long. The signal from the temperature sensor is subject to interference and degradation because of changes in electrical grounding, stray inductance from nearby cables, and faults in the connectors and cabling. Instrument platform grounding may change due to varying moisture content in the soil. Spurious current can flow through ground loops if a voltage differential is established between the probe and electrical components. Stray interference can be minimized by ensuring that data cables are shielded and separated from power cables. If data and power cables must be in close proximity, they should cross at right angles. Long runs of adjacent parallel cables should be avoided. All cable shields should be grounded at one point only (normally at the data recorder location) to avoid ground loops. A discussion of several setups for platinum element thermometers is given in the appendix of Test Methods E644.

9.3 *Data Sampling and Output*—The sensor output should be sampled at a rate commensurate with other meteorological measurements, such as sampling at least once every 3 to 5 s. Rapidly changing measurements, such as wind, require faster sampling than temperature. The temperature samples are then averaged, again over a period commensurate with other meteorological measurements, such as 10 min or 1 h.

9.4 *Special Methods for Temperature Flux and Variance:*

9.4.1 Use four matched thermometers with interchangeability within ±0.05°C for near-surface gradient determinations. Carefully match shielding and aspiration for each thermometer element.

9.4.2 Use a fast response thermometer and a temperature measurement system capable of at least a 5–Hz data rate for temperature flux and variance applications. Use a data averaging period on the order of 15 min.

10. Calibration

10.1 Comparative temperature tests should be made after installation, and periodically (at least every 6 months) during operations, to confirm that the temperature measurement system is performing within applicable specifications. Follow sensor manufacturer or system fabricator calibration or testing instructions properly applied to the intended purpose of the measurement.

10.2 *Comparative Calibration Tests*—Compare the system output to the temperature indicated by a standard with the system and standard sensors in an artificial environment, such as a water or ice bath (keeping the sensor dry). Suggested methods for this technique are found in Test Methods E644 and (**2**). The comparative test could also be made in ambient air, providing the system and standard sensors are appropriately shielded.

10.3 *Resistance Substitution*—An additional step that can test the measuring circuit apart from the resistance thermometer is substituting a known resistance for the sensor. Choose resistance values over a range representative of the expected temperature range.

10.4 *Testing Range*—Make at least two temperature measurements. Space the tests over as much of the normal measurement range for the intended application as feasible for the given test. Observe the results for several minutes at each test level, checking for noise and drift before proceeding.

11. Precision and Bias

11.1 Temperature measurement precision and bias are cumulative effects from all system components. Record biases due to site influences when they are known.

12. Keywords

12.1 air temperature; platinum resistance thermometer; resistance thermometer; solar and terrestrial radiation shields; thermistor

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(4) DOE/EH-0173T, *"Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance,"* U.S. Department of Energy, Washington, DC, 1991.

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