Standard Guide for
Selection and Use of Wideband, Low Temperature Infrared Thermometers[1]

This standard is issued under the fixed designation E2758; 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 This guide covers electronic instruments intended for measurement of temperature by detecting intensity of thermal radiation exchanged between the subject of measurement and the sensor.

1.2 The devices covered by this guide are referred to as IR thermometers.

1.3 The IR thermometers covered in this guide are instruments that are intended to measure temperatures below 1000°C and measure a wide band of thermal radiation in the infrared region.

1.4 This guide covers best practice in using IR thermometers. It addresses concerns that will help the user make better measurements. It also provides graphical tables to help determine the accuracy of measurements.

1.5 Details on the design and construction of IR thermometers are not covered in this guide.

1.6 This guide does not cover medium- and high-temperature IR thermometry (above 1000°C). It does not address the use of narrowband IR thermometers.

1.7 The values of quantities stated in SI units are to be regarded as the standard. The values of quantities in parentheses are not in SI and are optional.

1.8 *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]

E1256 Test Methods for Radiation Thermometers (Single Waveband Type)

E1862 Practice for Measuring and Compensating for Reflected Temperature Using Infrared Imaging Radiometers

E1897 Practice for Measuring and Compensating for Transmittance of an Attenuating Medium Using Infrared Imaging Radiometers

E1933 Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers

2.2 *IEC Standards:*[3]

IEC 62492-1 TS Industrial Process Control Devices—Radiation Thermometers—Part 1: Technical Data for Radiation Thermometers

2.3 *BIPM Standards:*

JCGM 200:2012 International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM)

3. Terminology

3.1 *Definitions:*

3.1.1 *absolute zero, n*—a temperature of 0 K (-273.15°C).

3.1.2 *atmospheric attenuation, n*—a ratio showing how much thermal radiation in a given spectral range is absorbed or scattered in air over a given distance.

3.1.3 *atmospheric transmission, n*—a ratio showing how well thermal radiation in a given spectral range at a given distance travels through a certain distance of air.

3.1.4 *attenuating medium, n*—a semi-transparent solid, liquid or gas, such as a window, filter, external optics, or an atmosphere that reduces thermal radiation, or combinations thereof.

3.1.5 *background radiation*—see *reflected radiation*.

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[1] This guide is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.02 on Radiation Thermometry.

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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.

[3] Available from International Electrotechnical Commission (IEC), 3, Rue de Varembé, CH-1211 Geneva 20, Switzerland, www.iec.ch.

3.1.6 *blackbody, n*—the perfect or ideal source of thermal radiant power having a spectral distribution described by Planck's Law.

3.1.7 *blackbody simulator, n*—a device with an emissivity close to unity that can be heated or cooled to a stable temperature.

3.1.8 *calibration adjustment, n*—the correction to an IR thermometer based on its calibration.

3.1.9 *center wavelength, n*—the simple average of the lower and upper spectral range limits.

3.1.10 *celestial radiation, n*—flux coming from the sky.

3.1.11 *contact thermometer, n*—an instrument that is adapted for measuring temperature by means of thermal conductance by determining the temperature at the moment when negligible thermal energy flows between the thermometer and the object of measurement.

3.1.12 *dew point, n*—the temperature at which water vapor condenses into liquid water.

3.1.13 *diffuse reflector, n*—a surface that produces a diffuse image of a reflected source.

3.1.14 *distance ratio, n*—the ratio of the measuring distance to the diameter of the field-of-view, when the target is in focus.[4]

3.1.15 *electromagnetic radiation, n*—physically occurring radiant flux classified according to wavelength or frequency.

3.1.16 *emissivity (ε), n*—the emissivity of a surface is the ratio between the radiation emitted from this surface and the radiation from a blackbody at the same temperature.

3.1.16.1 *Discussion*—The emissivity describes a thermophysical material characteristic, which in addition to the chemical composition of the material may also be dependent on the surface structure (rough, smooth), the emission direction as well as on the observed wavelength and the temperature of the measured object.[4]

3.1.17 *emissivity setting, n*—an adjustment on an IR thermometer to compensate for an emissivity of non-unity.

3.1.17.1 *Discussion*—In most measuring situations a radiation thermometer is used on a surface with an emissivity significantly lower than one. For this purpose most thermometers have the possibility of adjusting the emissivity setting. The temperature reading is then automatically corrected.[4]

3.1.18 *emissivity tables, n*—a list of objects and their measured emissivity for a particular IR thermometer.

3.1.19 *field-of-view (FOV), n*—a usually circular, flat surface of a measured object from which the radiation thermometer receives radiation.[4]

3.1.20 *frost point, n*—the temperature at which water vapor condenses into solid water or ice.

3.1.21 *infrared (IR), adj*—referring to electromagnetic radiation with a wavelength from approximately 0.7 to 30 µm.

3.1.22 *infrared reflector, n*—a material with a reflectance in the infrared region as close as possible to unity.

3.1.23 *infrared sensing device, n*—one of a wide class of instruments used to display or record (or both) information related to the thermal radiation received from any object surfaces viewed by the instrument.

3.1.24 *infrared (IR) thermometer, n*—optoelectronic instrument adapted for noncontact measurement of temperature of a subject by utilizing thermal radiation exchange between the subject and the sensor.

3.1.24.1 *Discussion*—IR thermometers are a subset of radiation thermometers. Most manufacturers use the term IR thermometer for handheld radiation thermometers. In general, these devices are wideband and use a thermopile detector.

3.1.25 *IR thermometry, n*—the use of IR thermometers to determine temperature by measuring thermal radiation.

3.1.26 *irradiance (E), n*—the radiant flux (power) per unit area incident on a given surface in units of W/m^2.

3.1.27 *limit of error, n*—the extreme value of measurement error of an infrared thermometer reading, relative to reference temperature standards, as permitted by a specification.

3.1.27.1 *Discussion*—Manufacturers sometimes use the term accuracy in their specifications to represent limit of error.

3.1.27.2 *Discussion*—A manufacturer's accuracy specification may apply only to well defined conditions.

3.1.28 *low-temperature, adj*—for radiation and IR thermometry, referring to any temperature below 660°C.

3.1.29 *measurement uncertainty (accuracy), n*—non-negative parameter, characterizing the dispersion of the values that could reasonably be attributed to the measurement of the quantity values being attributed to a measurand, based on the information used.[4,5]

3.1.30 *measuring distance, n*—distance or distance range between the radiation thermometer and the target (measured object) for which the radiation thermometer is designed.[4]

3.1.31 *measuring temperature range, n*—temperature range for which the radiation thermometer is designed.[4]

3.1.32 *noise equivalent temperature difference (NETD), n*—parameter which indicates the contribution of the measurement uncertainty in °C, which is due to instrument noise.[4]

3.1.33 *opaque, adj*—referring to the property of a material whose transmittance is zero for a given spectral range.

3.1.34 *operating temperature range and air humidity range, n*—the permissible temperature range and humidity range within which the radiation thermometer may be operated. For this temperature range and humidity range the specifications are valid.[4]

3.1.34.1 *Discussion*—This is the range of ambient temperature and humidity the instrument may operate within and be expected to meet its specification. It may be thought of as the ambient operating temperature range and the ambient operating humidity range.

3.1.35 *radiance (L), n*—the flux per unit projected area per unit solid angle leaving a source or, in general, any reference surface.

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[4] See IEC 62492-1.

[5] See BIPM JCGM 200:2012.

3.1.35.1 *Discussion*—If $\partial^2\Phi$ is the flux emitted into a solid angle $\partial\omega$ by a source element of projected area $\partial A\cos(\theta)$, the radiance is defined as:

$$L = \frac{\partial^2\Phi}{\partial\omega\partial A cos(\theta)}$$

where:

θ = the angle between the outward surface normal of the area element ∂ *A* and the direction of observation (unit = W/sr•m^2).

3.1.36 *radiant power density (M), n*—the radiant flux per unit area leaving a surface that is,

$$M = \frac{\partial\Phi}{\partial A}$$

where:

$\partial\Phi$ = flux leaving a surface element ∂A (unit = W/m^2).

3.1.37 *reflectance, n*—the ratio of the radiant flux reflected from a surface to that incident upon it.

3.1.38 *reflected radiation, n*—the thermal radiation incident upon and reflected from the measurement surface of the specimen.

3.1.39 *reflected temperature, n*—the temperature of the radiant flux incident upon and reflected from the measurement surface of a specimen.

3.1.40 *response time, n*—time interval between the instant of an abrupt change in the value of the input parameter (object temperature or object radiation) and the instant from which the measured value of the radiation thermometer (output parameter) remains within specified limits of its final value.[4]

3.1.41 *sensor, n*—device designed to respond to IR radiation and convert that response into electrical signals.

3.1.42 *size-of-source effect, n*—the difference in the radiance- or temperature reading of the radiation thermometer when changing the size of the radiating area of the observed source.[4]

3.1.43 *spectral range, n*—parameter which gives the lower and upper limits of the wavelength range over which the radiation thermometer operates.[4]

3.1.43.1 *Discussion*—Spectral range is sometimes referred to as bandwidth.

3.1.43.2 *Discussion*—These limits are generally defined as the wavelengths where the power or signal is attenuated by a defined amount.

3.1.44 *spectral response, n*—the numerical quantity of a given phenomenon at a specific wavelength in the electromagnetic spectrum.

3.1.45 *standard atmosphere, n*—a model of how electromagnetic radiation is transmitted through the atmosphere based on variations in pressure, temperature and humidity.

3.1.46 *surface-modifying material, n*—any material that is used to change the emissivity of the specimen surface.

3.1.47 *table of offsets, n*—a list of calibration points and calibration adjustments to be used when no internal calibration adjustment is available.

3.1.48 *thermal radiation, n*—electromagnetic radiation which is caused by an object's temperature and is predicted by Planck's Law.

3.1.49 *thermal shock, n*—subjecting an IR thermometer to a rapid temperature change.

3.1.50 *thermopile detector, n*—a thermopile detector's output is voltage. Incident radiation heats the disk. When the disk is heated, its temperature rises above the sensor's reference temperature (ambient temperature) producing a temperature difference (ΔT). The potential of the thermopile is related to the temperature difference based on the Seebeck Effect.

3.1.51 *transmittance (t), n*—the ratio of the radiant flux transmitted through a body to that incident upon it.

3.1.52 *true temperature, n*—temperature attributed to a particular site of a subject or object of measurement and accepted as having a specified uncertainty.

3.1.53 *wideband, adj*—referring to the situation where the spectral range of an instrument is at least 1⁄10 of its center wavelength.

4. Significance and Use

4.1 This guide provides guidelines and basic test methods for the use of infrared thermometers. The purpose of this guide is to provide a basis for users of IR thermometers to make more accurate measurements, to understand the error in measurements, and reduce the error in measurements.

5. Basic Use of IR Thermometry

5.1 *General Considerations:*

5.1.1 An IR thermometer can be used in a number of applications. Although they are generally not as accurate as contact thermometers, their quickness of measurement and their ability to measure the temperature of an opaque surface without contacting it make them desirable instruments for some temperature measurements.

5.1.2 Most handheld IR thermometers are equipped with a trigger to start and stop the measurements.

5.1.3 As objects vary in temperature, they emit a varying amount of thermal radiation. This amount of thermal radiation is predictable based on the object's temperature, emissivity and reflected temperature.

5.1.4 Handheld IR thermometers measure thermal radiation in a given spectral range and determine the relationship between the measured thermal radiation and temperature. The sensor mainly used in these instruments is a thermopile.

5.2 *Basic IR Measurement:*

5.2.1 Before making a measurement, the emissivity setting of the IR thermometer should be set to the object's effective emissivity in the instrument's spectral range. Some IR thermometers do not allow the user to adjust the emissivity because their emissivity is fixed. In these cases there are mathematical compensations that can be made.

5.2.2 To make a measurement, the IR thermometer's lens should be pointed at the object being measured. The measurement should be initiated. If the IR thermometer has a trigger, this is done by pulling the trigger. The trigger should be held at least as long as the IR thermometer's specified response time.

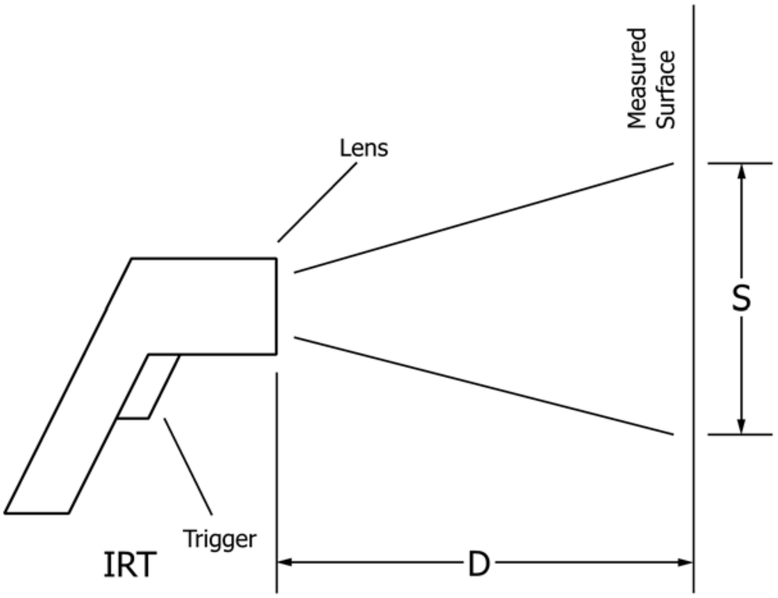


FIG. 1 Basic IR Thermometer Measurement

The measured temperature is usually frozen on the display after the trigger is released.

5.2.3 Fig. 1 shows a diagram of how much of a surface an IR thermometer measures. 'S' is the size or diameter that is measured by the infrared thermometer's field-of-view. 'D' is the measuring distance. Subsection 11.1 discusses spot size and distance ratio.

5.2.4 Fig. 2 shows how much surface area is needed for temperature measurement when considering the IR thermometer's spot size. The part of the figure labeled 'poor' shows a situation where the object being measured is smaller than the spot size. Such situations are undesirable. The part of the figure labeled 'OK' shows a situation where the object being measured is slightly larger than the spot size. Such situations should produce acceptable temperature measurements. The part of the figure labeled 'better' shows a situation where the object being measured is significantly larger than the spot size. This situation will produce the best temperature measurements.

5.3 *Accuracy:*

5.3.1 To make accurate measurements, many factors must be considered. The first is that the IR thermometer in use should be calibrated with traceability to the International System of Units (SI) through a national metrological institute (NMI). A list of NMIs can be found by visiting the BIPM website: http://www.bipm.org/en/cipm-mra/participation/signatories.html. Calibration results can be implemented in subsequent measurements in two ways. If the IR thermometer has an internal calibration adjustment, the user can use the reading on the readout. Some IR thermometer calibrations will provide a table of offsets. In such cases, the user must make a manual calculation to determine the true temperature.

5.3.2 There are many other considerations in making accurate measurements with IR thermometry. These are discussed in the following sections.

6. Wideband Instruments

6.1 Most handheld low-temperature IR thermometers are wideband instruments. As a result, their measurements can vary if emissivity varies over their spectral range. The most common spectral range for these instruments is 8 to 14 µm. However, some instruments have a spectral range of up to 5 to 20 µm. In any case, the IR thermometer should have a specified spectral range. The end user of an IR thermometer most likely will not have instrumentation to test the spectral range.

6.2 Atmospheric transmission is dependent on spectral range. Any measurement made over a long distance should consult a standard atmosphere model to determine atmospheric transmission. Guidance on accounting for atmospheric transmission is given in subsection 12.5.

7. Spectral Emissivity

7.1 *Spectral Emissivity in General:*

7.1.1 An IR thermometer measures the thermal radiation coming off of an object. If an object is opaque, this radiation energy is a combination of the object's emitted radiation and its reflected radiation. The ability to emit energy is known as emissivity. A perfect blackbody has an emissivity of unity, $\varepsilon = 1$. All actual surfaces emit less thermal radiation than a perfect blackbody and have an emissivity less than unity. Fig. 3 shows the relationship between the radiation emitted by a perfect blackbody, $E(T)$, and the radiation emitted by a surface, $\varepsilon E(T)$. In reality, a perfect blackbody is not achievable. One possible approximation to a perfect blackbody is a cavity radiator.

7.1.2 The higher the emissivity an object has, the better the temperature can be determined from its thermal radiation. Non-metals tend to have much higher emissivity values than metals. Non-oxidized metals tend to have lower emissivity

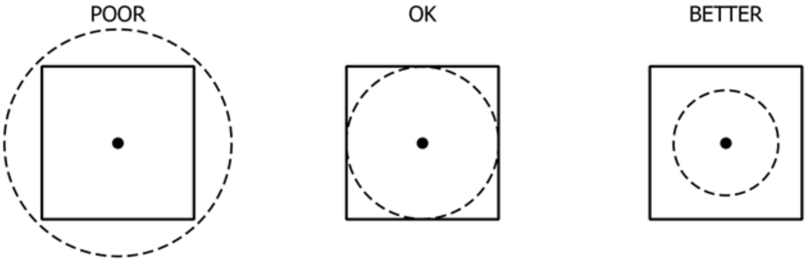


FIG. 2 Filling the IR Thermometer's Spot

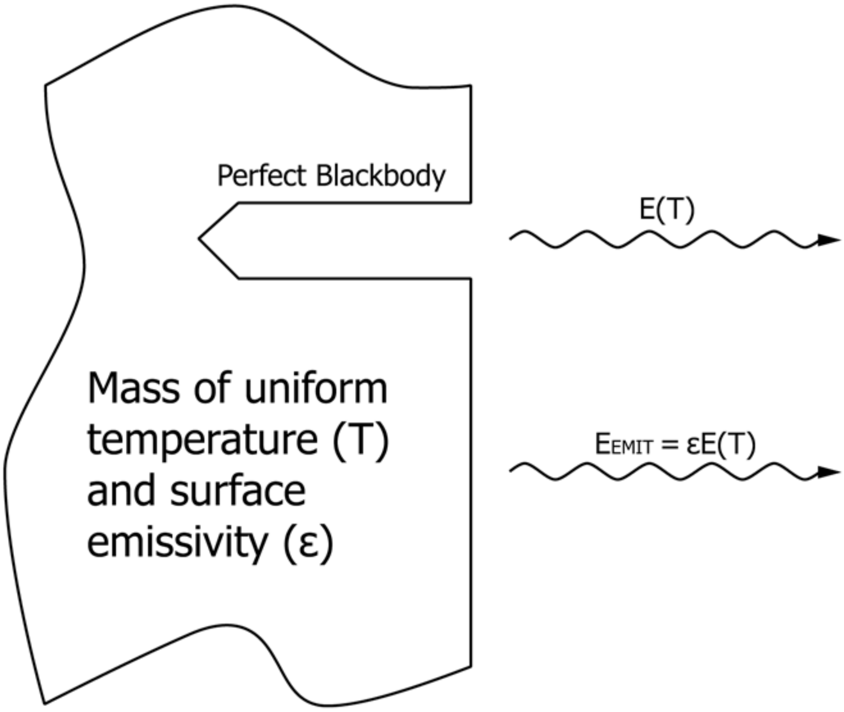


FIG. 3 Blackbody and Surface Emissivity

than oxidized metals. Rough surfaces will have higher emissivity values than polished surfaces of the same material.

7.1.3 Wideband infrared thermometers are excellent tools for measuring the surface temperatures of materials with high emissivity values. Materials such as wood, brick, painted surfaces, plants and foods generally have emissivity values of 0.85 or higher.

7.2 *Determining and Compensating for Emissivity:*

7.2.1 A number of methods to determine and compensate for emissivity are included in Section 16.

8. Methods of Determining Emissivity

8.1 *Emissivity Tables:*

8.1.1 Many manufacturers will provide a table of emissivity values for specific materials. These tables are instrument-specific. They also contain a certain amount of uncertainty.

8.2 *Fourier Transform Infrared Testing:*

8.2.1 Fourier Transform Infrared (FTIR) testing collects data through a reflective method. It is normally done in a laboratory and most likely will not be available for the end user of an IR thermometer.

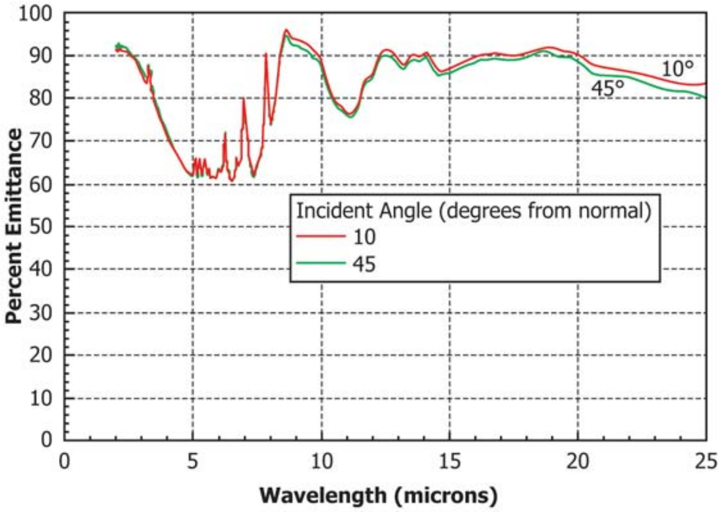
8.2.2 FTIR data provides spectral emissivity values at various wavelengths in the electromagnetic spectrum. The spectral emissivity values are derived from the reflectivity results obtained in the tests. Fig. 4 shows an example of FTIR test results.

8.3 *Compensating for Emissivity:*

8.3.1 The preferred way to compensate for unknown emissivity is to use the emissivity setting on the IR thermometer.

8.3.2 If the IR thermometer does not have an adjustable emissivity setting, use the mathematics described in subsection X2.3 to determine how much difference there is between the IR thermometer reading and the true temperature of the surface. This calculation has a degree of uncertainty.

8.3.3 If the emissivity of an object is given as a range, it is best to measure temperature with the emissivity set to at least the lower and upper end of the range, plus the middle of the range. For instance, if a materials emissivity range is given as 0.80 to 0.86, temperature measurements should be taken at $\varepsilon = 0.80$, $\varepsilon = 0.83$, and $\varepsilon = 0.86$. This will indicate a median temperature (at $\varepsilon = 0.83$) along with a low temperature (at $\varepsilon = 0.80$) and a high temperature (at $\varepsilon = 0.86$).



Courtesy of Surface Optics Corporation, San Diego, California.

FIG. 4 Example of FTIR Test Results

9. Reflected Radiation

9.1 *General Considerations:*

9.1.1 The thermal radiation detected by an IR thermometer measuring an opaque object is a combination of the thermal radiation emitted by the object and the reflected radiation, which is radiation originating from other sources and reflected by the object. IR thermometers will compensate for the reflected radiation in some manner. This compensation may be by a reflected temperature or a reflected temperature setting. In some cases reflected radiation compensation is done inside the IR thermometer. Fig. 5 shows the relationship between emitted radiation and reflected radiation.

9.1.2 Reflected radiation is minimized by measuring a flat or convex object that has surroundings at a temperature much less than the measured object (see Section 10). Reflected radiation can be very high if the measured object is at a relatively low temperature or has surroundings at a temperature equal or greater to the measured object (for example, the measured object is inside an operating furnace). Reflected radiation may also be very high when the temperature of reflective surfaces such as metals are being measured. Low-temperature measurements are covered in Section 10. Measurement of the temperature of metals is covered in Section 13. In such cases it is important that the reflected temperature is known and well controlled.

9.1.3 When making measurements outdoors, it is important to shield the measured object from reflected celestial radiation. Celestial radiation can have a temperature anywhere from close to absolute zero to the temperature of the sun.

9.1.4 The effect of miscalculation of background temperature is shown in subsection X2.4.

10. Measurements of Surfaces Below Ambient Temperature

10.1 *Reflected Radiation:*

10.1.1 The effects of reflected temperature are much greater at temperatures below ambient temperatures. These effects are shown in subsection X2.4.

10.2 *Dew Point or Frost Point:*

10.2.1 If the surface being measured is below the dew point or frost point, there are two additional problems which need to be considered.

10.2.2 In this situation, the emissivity of the surface is likely to change. If the surface is completely covered with dew, then the surface will have the emissivity of the liquid water formed on the surface. If the surface is completely covered with frost, then the emissivity will be that of the frost.

10.2.3 Another effect is that frost or liquid water forms an insulating layer between the object being measured and the surrounding air. The surface temperature of the insulating layer may be closer to ambient, depending on how deep the insulative layer is.

11. Optical Considerations

11.1 *Distance Ratio:*

11.1.1 Most IR thermometers come with a distance-to-size diagram or specification. This specification may be referred to as D:S, distance ratio, distance-to-size ratio, field of view, or size of source.

11.1.2 This distance ratio specification shows that at a distance D, a certain percentage of the thermal radiation measured by the IR thermometer is within a diameter S. Care should be taken to ensure that the object being measured is larger than this diameter, or it is within the IR thermometer's field of view.

11.1.3 Fig. 6 shows two examples of D:S diagrams that commonly come with IR thermometers. An example is given for an open focus IR thermometer and a closed focus IR thermometer.

11.1.4 It should be noted that in most cases, a significant amount of energy comes from outside of this diameter D. If this energy is not accounted for, it can cause inaccuracy in IR thermometry measurements. Section 8 of Test Methods E1256 can be used to determine this effect.

11.2 *Laser Pointers:*

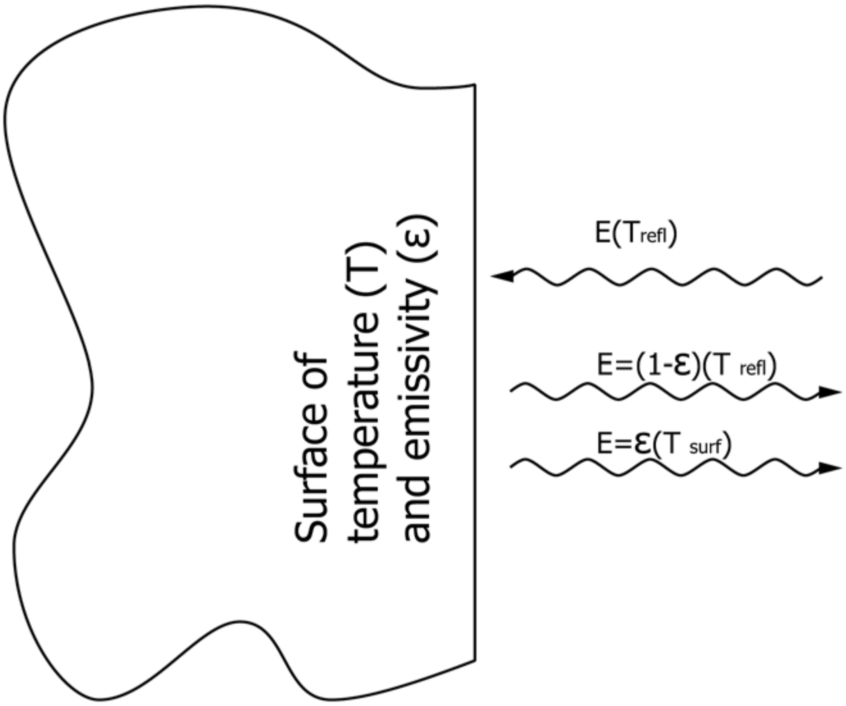
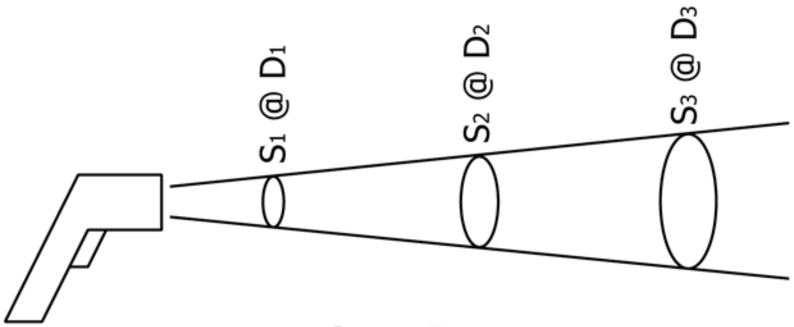
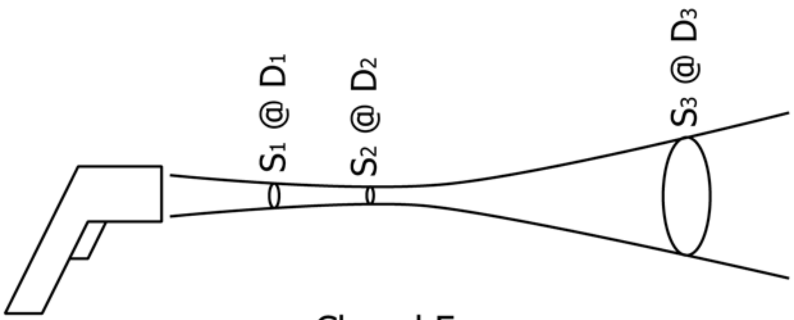


FIG. 5 Emission and Reflection



Open Focus



Closed Focus

FIG. 6 Distance-to-Size Diagrams

11.2.1 An IR thermometer is often equipped with a laser pointer. The purpose of the laser pointer is to give the user a rough idea of where the IR thermometer is pointed. The point where the laser pointer strikes the object may not be where the exact center of the spot is located.

11.2.2 A test similar to that described in subsection 8.3.3 of Test Methods E1256 can be used to determine how close the laser pointer is to the center of the spot for a given distance.

11.3 *Lens Cleanliness:*

11.3.1 Since these measurements are based on optics, it is important that the lens of the IR thermometer be kept free of foreign objects, such as dust and grease, and free of scratches.

11.3.2 The IR thermometer manufacturer's instructions should be consulted for acceptable cleaning and maintenance practices.

12. Physical Considerations

12.1 *Thermal Shock:*

12.1.1 Thermal shock is caused by quickly changing the temperature of the IR thermometer housing. This can happen when transporting the IR thermometer from one environment to another, especially when the environments have significantly different temperatures.

12.1.2 When changing the ambient temperature of an IR thermometer, it is best to allow the IR thermometer to reach thermal equilibrium before taking measurements. This will vary from IR thermometer to IR thermometer, depending on the IR thermometer's thermal mass.

12.1.3 If the IR thermometer manufacturer recommends a time to allow for an IR thermometer to reach thermal equilibrium, this time should be used. Otherwise, some experimentation should be done to determine this time.

12.1.4 If the thermal shock results in the IR thermometer temperature being lower than the dew or frost point temperature of the ambient environment, moisture may condense on the IR thermometer optics. Measurements should wait until the optics show no signs of moisture condensation.

12.2 *Measurements at a Short Distance:*

12.2.1 Being too close to the surface being measured presents several problems. This is because the IR thermometer is absorbing a certain amount of convected heat from the surface being measured.

12.2.2 Having the IR thermometer too close to the surface being measured can cause thermal shock which is discussed in subsection 12.1.

12.2.3 Having the IR thermometer too close to the surface being measured can cause damage to the IR thermometer due to heating from the convective source. This damage may be to just the housing. However, it may also cause damage to the lens and even the sensor if held too close to the surface being measured.

12.3 *Steam and Dust:*

12.3.1 IR thermometry measurements should not be made when there is a significant amount of particulates between the surface being measured and the IR thermometer. In such cases, a significant amount of the thermal radiation incident on the IR thermometer comes from the particulates and not the surface of interest.

12.4 *Surface Measurement of Temperature:*

12.4.1 When measuring the temperature of a surface, it is important to keep in mind that the temperature measured is the surface temperature. It may not be an accurate representation of the temperature below the surface. This is especially true when thermally insulative materials are being measured or when the object being measured is thick.

12.5 *Atmospheric Transmission:*

12.5.1 An IR thermometer measures thermal radiation through a certain distance of atmosphere. A certain amount of attenuation that takes place over this distance. At distances under 2 m, this attenuation is small. At greater distances, attenuation may become significant.

12.5.2 For distances under 1 m, the worst case attenuation factor is 0.0003.[6] The calculation of the effect of this attenuation on temperature measurement is discussed in subsection X2.5.

12.5.3 There are three areas in the IR region of the electromagnetic spectrum that are usually considered windows because there is little atmospheric attenuation in these regions. These regions are 2.0 to 2.5 µm, 3.5 to 4.2 µm, and 8 to 14 µm. The 8 to 14 µm window is the most suitable for low-temperature IR measurements.

13. Measuring Metal Surfaces

13.1 *General Considerations:*

13.1.1 Wideband generally refers to IR thermometers measuring radiation in the 8-14 µm region. Given the scope of this standard, it must be understood by the user of this document that bare metal surfaces inherently cannot be measured reliably with wideband low-temperature infrared thermometers. However, in some cases, an inaccurate but highly repeatable radiometric (infrared) temperature measurement may be as valuable as measuring the true temperature.

13.1.2 Highly reflective metallic surfaces such as polished steel, aluminum, and silver plating have low emissivity values, since the reflectivity ρ is related to emissivity by $\rho = 1 - \varepsilon$. A highly reflective surface is a very poor emitter of thermal radiation (that is, the surface has a low value of emissivity). These values are often less than 0.50 and can be as low as 0.05.

13.2 *Changing the Surface's Emissivity:*

13.2.1 One way to measure a reflective surface is to make a portion of the surface more emissive. This should only be done when practical. Consult the test method in subsection 16.1 for guidance in using surface-modifying materials.

13.2.2 The second alternative technique for metal process IR temperature control and measurement is the roll nip measurement. This technique involves using the IR temperature sensor to view the crevice between two metal rollers or a metal roller and a sheet. A roll nip measurement is shown in Fig. 7. The spot size should be much less than the diameter of the roller for an accurate measurement. The geometry of the roller and sheet approximates a blackbody, increasing the effective emissivity of the roller and sheet. For such a measurement, emissivity should be set to 0.99 with an uncertainty of ±0.01.

13.3 *Gold Cup Measurements:*

13.3.1 Gold cup measurements use an integrating hemisphere with an IR thermometer to block out reflected energy

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[6] Fischer, J.; Saunders, P.; Sadli, M.; Battuello, M.; Park, C.W.; Zundong, Y; Yoon, H.; Li, W; van der Ham, E.; Sakuma, F.; Yamada, Y.; Ballico, M.; Machin, G.; Fox, N.; Hollandt, J.; Matveyev, M; Bloembergen, P.; and Ugur, S.; CCT-WG5 on Radiation Thermometry - Uncertainty Budgets for Calibration of Radiation Thermometers below the Silver Point, Bureau International des Poids et Mesures, 2008, p. 24.

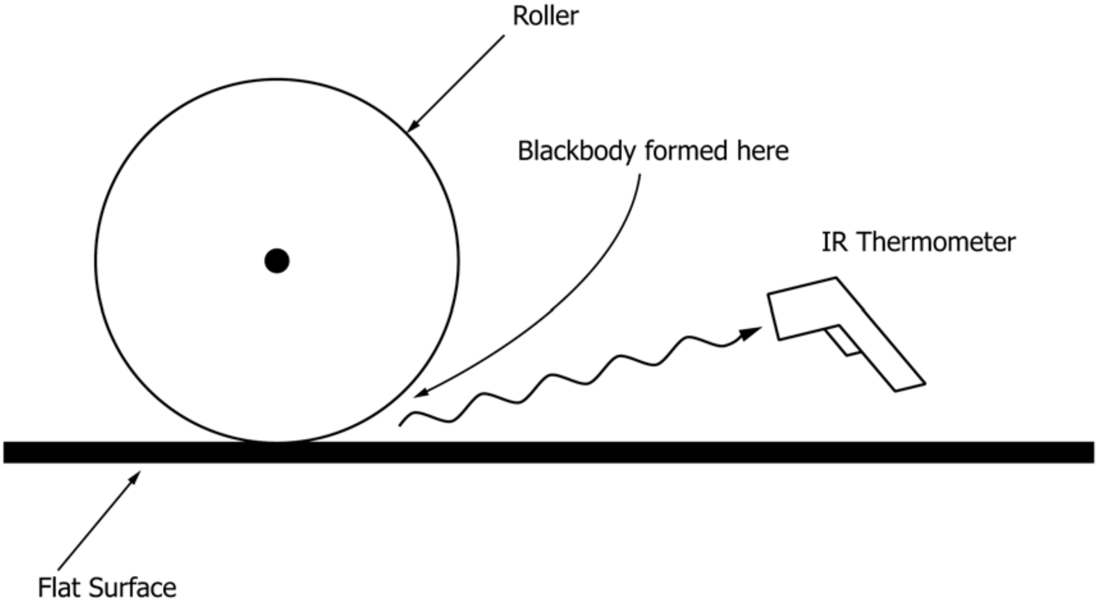

FIG. 7 Roll Nip Measurement

sources and focus all of the emitted energy on the IR detector. This type of device can be used for lower temperature steel surfaces as well as higher temperature aluminum surface temperatures. Aluminum has a melting temperature of approximately 660°C, and there is extensive interest in measuring the temperature of aluminum at temperatures below 660°C for processing and forming aluminum. The gold reflector causes thermal radiation from the object surface to be reflected back onto the surface, resulting in an effective emissivity near unity. For such a measurement, emissivity should be set to 0.99 with an uncertainty of ±0.01. A gold cup measurement is shown in Fig. 8.

13.4 *Oxidized Metal Surfaces:*

13.4.1 The reflectivity of an oxidized metal surface decreases as temperature increases, both because of changes in the intrinsic properties of metals and because of increased oxidation/weathering. One could refer to well-established metal emissivity tables for estimates at a given temperature and cross check with the mathematics described in Appendix X2.3.

13.4.2 If a metallic surface requires regular periodic thermal scanning for tracking its thermal signature, one might want to cause small variations (for example, anodizing) in a specific area to increase its emissivity value permanently. At low temperatures moisture (water) has a higher emissivity than metallic surfaces and could be used as an emergency measure of the surface temperature.

13.5 *Determination of Emissivity:*

13.5.1 The methods outlined in Section 16 can be used to determine the emissivity of the metal being measured. It should be noted that any of these methods has a larger uncertainty due to the reflective nature of the metal.

14. Thin Films, Hot Gas and Flame

14.1 *Thin Films:*

14.1.1 To measure the transmittance of an attenuating medium, use the following sequential steps:

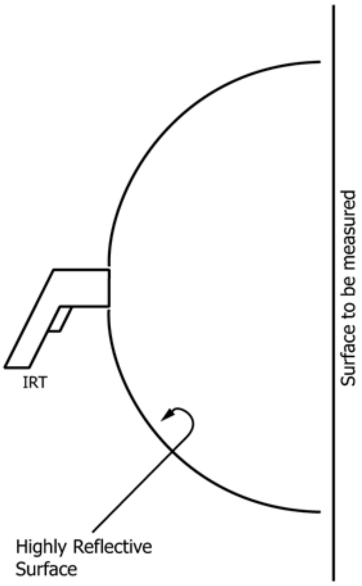

FIG. 8 Gold Cup Measurement

14.1.2 Some thin films are highly transparent to infrared radiation, causing high values of transmission. In such cases, the temperature of the films may not be determined by IR thermometry. Experimentation to determine the effect of transmission through thin films should be performed. Section 17 includes test methods to determine transmissivity.

14.1.3 Infrared temperature measurement is highly dependent on the absorbtive, transmissive, and reflective properties of the material to be measured. Thin films and hot gases represent very special cases for infrared temperature measurement which are beyond the scope of this document. However, the sections below give some general guidance to users of this document.

14.1.4 Thin films are most often represented by plastic materials. These thin films are primarily transmissive to

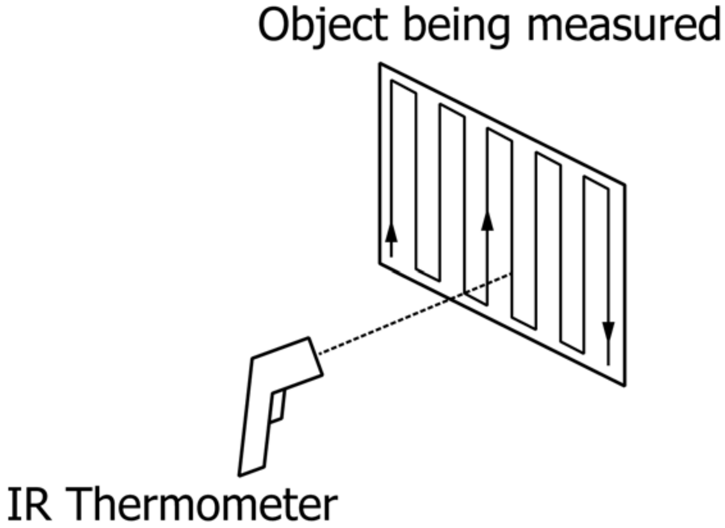

FIG. 9 Scanning of an Object

wideband IR thermometers. This means that the typical wideband IR thermometer "sees through" the material and is not capable of making a material temperature measurement.

14.1.5 Depending upon the chemistry of the thin film, there are two specific narrow bands that are opaque: 3.43 and 7.9 µm. The proper wavelength depends on the chemistry of the plastic, as they are not interchangeable. The thickness is also a critical factor. Very thin films are less opaque (more transmissive) and thicker films are more opaque (less transmissive).

14.2 *Hot Gas and Flame:*

14.2.1 It is not recommended that the temperatures of hot gases or flames be measured with wideband IR thermometers.

14.2.2 The temperature of hot gases is considerably more difficult to measure than that of a thin film since the composition of the gas is often less well defined than the chemical composition of a thin film.

14.2.3 The principal factor in measuring the temperature of hot gas is the carbon dioxide absorbance band, provided that the gas has an appreciable carbon dioxide concentration. This band is prominent in the IR range at approximately 4.2 to 4.3 µm. Similarly it is possible to "see through" hot gases and measure a surface temperature inside a hot atmosphere by selecting approximately 3.86 µm.

14.2.4 These applications require professional expertise in order to obtain accurate results, as there are many other factors that affect the ability to make accurate temperature measurements.

14.3 *Glass:*

14.3.1 Glass tends to be opaque (not transparent) in the 8 to 14 µm band. Therefore its temperature can be measured with an IR thermometer.

14.3.2 To verify glass transparency, perform the test method in Section 17.

TEST METHODS

15. Basic IR Thermometry Measurement

15.1 *Locating a Hot or Cold Spot:*

15.1.1 To find a hot or cold spot, aim the thermometer outside the desired area. Then, slowly scan across the area with an up-and-down motion until the hot or cold spot is located. This motion is shown in Fig. 9. The arrows indicate the direction of scanning.

16. Determination of Emissivity

16.1 *Comparison Methos*[7]:

16.1.1 Place the infrared thermometer on the tripod or support device at the desired location and distance from the specimen.

16.1.2 Point the infrared thermometer at the specimen and point it at the portion where the emissivity is to be measured.

16.1.3 If available, use an appropriate infrared thermometer measurement function to measure and compensate for the reflected temperature error incident upon the specimen.

16.1.4 Apply the surface-modifying material to, or immediately adjacent to, the portion of the specimen where the emissivity is to be measured. Make sure the surface-modifying material is dry and in good contact with the specimen. The size of the surface modifying material must be larger than the IR thermometer's spot size at the measurement distance.

16.1.5 Enter the known emissivity value of the surface-modifying material in the infrared thermometer's emissivity setting (sometimes referred to as ε).

16.1.6 Use the infrared thermometer to measure the temperature of the surface-modifying material. Record this temperature.

16.1.7 Point the infrared thermometer on the portion of the specimen immediately adjacent to the surface-modifying material (where the emissivity is to be measured), or remove the surface-modifying material and point the infrared thermometer on the previously modified specimen (where the emissivity is to be measured).

16.1.8 Without moving the infrared thermometer, adjust its emissivity setting until the infrared thermometer's readout

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[7] See Test Method E1933.

indicates the temperature recorded in 16.1.6. The indicated emissivity value is the measured emissivity of the specimen at this temperature and spectral waveband.

16.1.9 Repeat 16.1.1 – 16.1.8 a minimum of three times and average the emissivity values to yield an average emissivity.

16.1.10 Between readings of the bare and modified surface, the actual surface temperature should not vary by more than the desired measurement uncertainty. Temperature drift of the surface may be determined by monitoring the indicated temperature of the modified surface using a fixed emissivity setting.

16.1.11 Compensate for emissivity errors by entering the known average emissivity value of the specimen in the infrared thermometer's emissivity setting (sometimes referred to as ε).

16.2 *Contact versus Non-Contact Method:*

16.2.1 Place the infrared thermometer on the tripod or support device at the desired location and distance from the specimen.

16.2.2 Point the infrared thermometer at the portion of the specimen where the emissivity is to be measured.

16.2.3 If available, use an appropriate infrared thermometer measurement function to measure and compensate for the reflected temperature error incident upon the specimen.

16.2.4 Use the contact thermometer to measure the temperature of the point or area just measured in 16.2.3. Best results are obtained if the contact thermometer is mounted in a hole running parallel to the surface and located just under the surface, or otherwise thermally anchored to the surface. Poor results will be obtained if only the tip of a contact thermometer is placed in contact with the surface. Record this temperature.

16.2.5 Without moving the infrared thermometer, adjust its emissivity setting (ε) until the infrared thermometer's readout indicates the temperature recorded in 16.2.4. The indicated emissivity value is the measured emissivity of the specimen, at this temperature and spectral waveband.

16.2.6 Repeat 16.2.1 – 16.2.5 a minimum of three times and average the emissivity values to yield an average emissivity.

16.2.7 Between readings of the contact thermometer and the IR thermometer, the actual surface temperature should not vary by more than the desired measurement uncertainty. Temperature drift of the surface may be determined by monitoring the indicated temperature of the modified surface using a fixed emissivity setting, or by monitoring the contact thermometer reading.

16.3 *Blackbody Method:*

16.3.1 This method is potentially destructive to the medium being measured.

16.3.2 Bore a hole into the object to be measured. The hole's diameter shall be at least twice the size (S) at the measuring distance (D) as predicted by the instrument's distance-to-size ratio (D:S). For example, if the D:S is 30:1, and the measurement distance is 300 mm, the size will be 10 mm. The diameter of the blackbody hole shall be at least 20 mm.

16.3.3 The hole's depth shall be at least five times its diameter. For example, if the hole's diameter is 20 mm its depth shall be at least 100 mm.

16.3.4 Coat the hole with an emissive medium such as paint.

16.3.5 Place the infrared thermometer on the tripod or support device at the desired location and distance from the specimen.

16.3.6 Point the infrared thermometer at the hole on the specimen.

16.3.7 Enter an emissivity value of 1.00 in the infrared thermometer's emissivity setting (sometimes referred to as ε).

16.3.8 Use the infrared thermometer to measure the temperature of the surface-modifying material. Record this temperature.

16.3.9 Point the infrared thermometer on a portion of the object that has not been modified. This diameter of the portion shall be at least the diameter determined in 16.3.2.

16.3.10 Use an appropriate infrared thermometer measurement function to measure and compensate for the reflected temperature error incident upon the specimen.

16.3.11 Without moving the infrared thermometer, adjust its emissivity setting until the readout indicates the same temperature recorded in 16.3.8. The indicated emissivity value is the measured emissivity of the specimen, at this temperature and spectral waveband.

16.3.12 Repeat 16.3.5 – 16.3.11 a minimum of three times and average the emissivity values to yield an average emissivity.

16.3.13 Between readings of the blackbody and the unmodified surface, the actual surface temperature should not vary by more than the desired measurement uncertainty. The temperature drift of the surface may be determined by monitoring the indicated temperature of the blackbody.

16.3.14 The temperature non-uniformity of the object must be sufficiently small so that the temperature variation of the blackbody walls, from the aperture to the bottom of the hole, does not vary by more than the desired measurement uncertainty.

17. Thin Film Measurements

17.1 *Measuring the Transmittance of Thin Films*[8]:

17.1.1 Place the infrared thermometer on the tripod or support device at the desired location and distance from the blackbody simulator.

17.1.2 Point the infrared thermometer at the blackbody simulator and point it at a portion that has an emissivity of 0.95 or greater. Make sure that the blackbody simulator is at a stable temperature at least 20°C above the ambient temperature.

17.1.3 If available, use an appropriate infrared thermometer measurement function to measure and compensate for the reflected temperature error incident upon the blackbody simulator.

17.1.4 With the infrared thermometer's emissivity setting at 1.00, measure and record the apparent temperature of this same portion of the blackbody simulator.

17.1.5 Position the attenuating medium (the thin film or window to be tested) between the infrared thermometer's detector or lens and the blackbody simulator.

17.1.6 Without moving the infrared thermometer, adjust its emissivity setting until the infrared thermometer's readout

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[8] See Test Method E1897.

TABLE 1 Radiometric Constants Used[A]

Name	Symbol	Value	Units
First Radiation Constant for Spectral Radiance	c_{1L}	$1.191\ 042\ 869 \times 10^{-16}$	$W\ m^2\ sr^{-1}$
Second Radiation Constant	c_2	$1.438\ 7770 \times 10^{-2}$	m K
Wien wavelength displacement law constant[B]	c_3	$2.897\ 7721 \times 10^{-3}$	m K
Stefan-Boltzmann Constant	σ	$5.670\ 373 \times 10^{-8}$	$W\ m^{-2}\ K^{-4}$

[A] National Institute of Standards and Technology (NIST), "2010 CODATA recommended values," http://physics.nist.gov/cuu/index.html.

[B] Also called "Third Radiation Constant."

indicates the same temperature as recorded in 17.1.4. The indicated "emissivity" value is the transmittance of the attenuating medium at this blackbody simulator temperature and radiometer's spectral waveband.

17.1.7 Repeat 17.1.1 – 17.1.6 a minimum of three times and average the transmittance values to yield an average transmittance.

17.2 *Measuring the Temperature of a Surface through a Thin Film*[8]:

17.2.1 To measure the temperature of a specimen having a known emissivity through an attenuating medium having a known transmittance, use the following sequential steps.

17.2.2 Point the infrared thermometer at the portion of the specimen where the temperature is to be measured. Place the attenuating medium having a known transmittance between the infrared thermometer's detector or lens and the specimen.

17.2.3 Instead of 1.00, enter the measured transmittance percentage of the attenuating medium under the infrared thermometer's emissivity setting. Use an appropriate infrared thermometer function to measure and compensate for the reflected temperature error incident upon the specimen.

17.2.4 Calculate the combined emissivity and transmittance correction value by multiplying the known emissivity of the specimen times the known transmittance of the attenuating medium. Record this combined correction value.

17.2.5 Repeat 17.2.1 – 17.2.3 a minimum of three times and average the values to yield an average combined correction value.

17.2.6 Compensate for emissivity and transmittance errors by entering the combined correction value recorded in 17.2.3 in the infrared radiometric infrared thermometer's computer under the "emissivity" input.

17.2.7 Proceed to measure the temperature of the measured object.

17.3 *Compensation for Unknown Transmittance and Emissivity*[8]:

17.3.1 To measure and compensate for unknown transmittance and emissivity errors when the specimen temperature is known, use the following sequential steps. Use an appropriate infrared thermometer function to measure and compensate for the reflected temperature error incident upon the specimen.

17.3.2 Point the infrared thermometer at the specimen and the portion of the specimen having an unknown emissivity. Place the attenuating medium(s) with an unknown transmittance(s) between the infrared thermometer's detector or lens and the specimen.

17.3.3 With a contact thermometer, measure and record the temperature of the portion of the specimen delineated with the infrared thermometer's measurement function. The contact thermometer must have good thermal contact with the surface to be measured.

17.3.4 With the infrared thermometer still pointed at the same portion of the specimen, adjust the infrared thermometer's emissivity setting until the indicated temperature is the same as the temperature recorded in 17.3.3. Record this "emissivity" value which is the combined correction value for errors produced by the transmittance of the attenuating medium and the emissivity of the specimen at this medium temperature and radiometer's spectral waveband.

17.3.5 Repeat 17.3.1 – 17.3.4 a minimum of three times and average the emissivity values to yield an average combined correction value.

17.3.6 Enter this average combined correction value in the infrared thermometer under the emissivity input to compensate for errors produced by this attenuating medium when measuring a specimen with the same emissivity.

17.3.7 Proceed to measure the temperature of the measured object with the IR thermometer.

18. Keywords

18.1 background radiation; blackbody; emissivity; field-of-view; handheld thermometer; infrared; infrared thermometer; IR gun; IR thermometer; laser thermometer; low temperature; non-contact thermometer; pyrometer; radiation thermometer; radiometer; reflected radiation; size-of-source effect; spot pyrometer; spot size; spot thermometer; temperature gun; temperature measurement; thermometry usage; wideband

APPENDIXES

(Nonmandatory Information)

X1. GRAPHICAL SUMMARY OF EQUATIONS FOR INFRARED THERMOMETRY

X1.1 General

X1.1.1 The following graphs summarize the basic mathematical equations for infrared and radiation thermometry.[9]

X1.1.2 These graphs provide a better understanding of the mathematics behind infrared thermometry. They are not intended to make calculations.

X1.2 Stephan-Boltzmann Equation

X1.2.1 The Stephan-Boltzmann Equation (Eq X1.2) gives the total irradiance of a perfect blackbody over the entire electromagnetic spectrum. A graphical example of the Stephan-Boltzmann Equation is shown in Fig. X1.1.

$$M = \sigma T^4 \tag{X1.1}$$

where:

M = power density in W/m^2,
σ = Stefan-Boltzmann Constant, and
T = temperature in K.

X1.2.2 Eq X1.2 is related to Planck's Law by Eq X1.1.

$$M = \sigma T^4 = \pi \int_0^\infty L(\lambda,T)\,d\lambda \tag{X1.2}$$

X1.3 Planck's Law

X1.3.1 Planck's Law (Eq X1.3) shows the blackbody spectral radiance at a given wavelength and a given temperature. Planck's Law plotted at several different temperatures is shown in Fig. X1.2.

$$L(\lambda,T) = \frac{c_{1L}}{\lambda^5\left[exp\left(\frac{c_2}{\lambda T}\right) - 1\right]} \tag{X1.3}$$

X1.3.2 At a fixed wavelength, or band of wavelengths, the radiance increases as the temperature increases. This relationship is the fundamental physical basis for using infrared radiation to make temperature measurements.

X1.4 Wien's Displacement Law

X1.4.1 Wien's Displacement Law (Eq X1.4) gives the peak wavelength for a blackbody radiator as predicted by Planck's Law. Fig. X1.3 gives a plot of Wien's Displacement Law for temperatures between -50 and 660°C.

$$\lambda_{max} T = c_3 \tag{X1.4}$$

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[9] Zhang, Z. M., Tsai, B. K., and Machin, G., eds.,*Radiometric Temperature Measurements I. Fundementals,* Academic Press, Oxford, UK, 210, pp. 5–8.

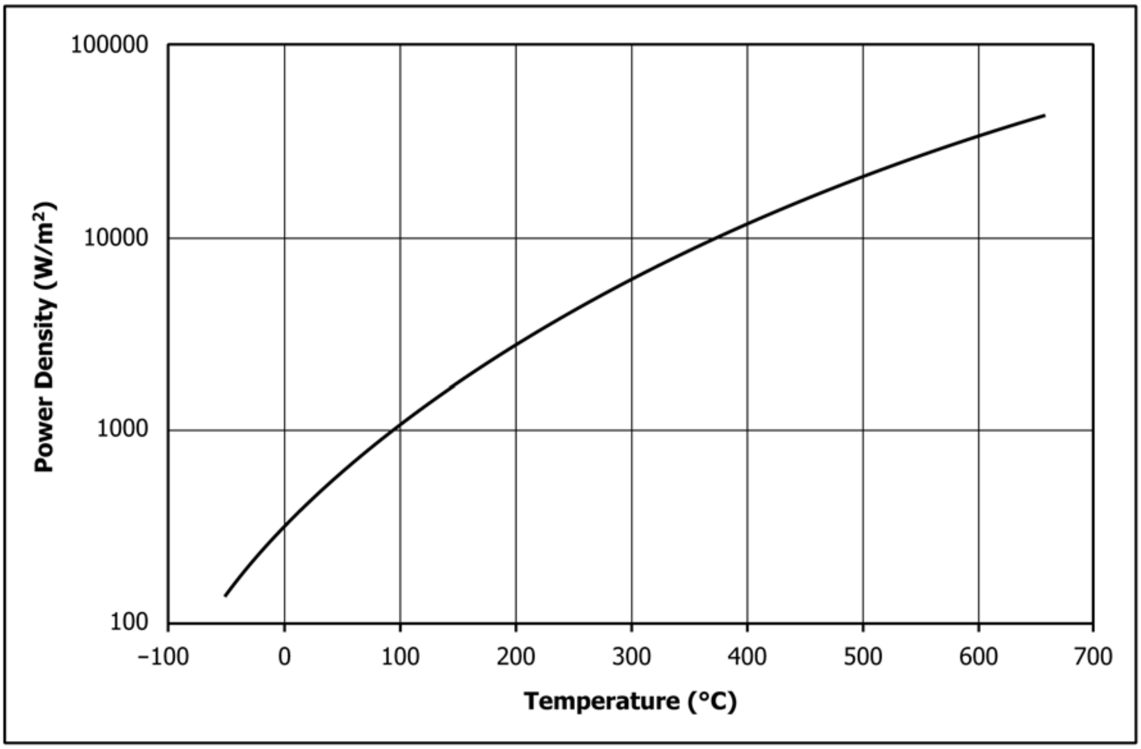

FIG. X1.1 Stefan-Boltzmann Equation

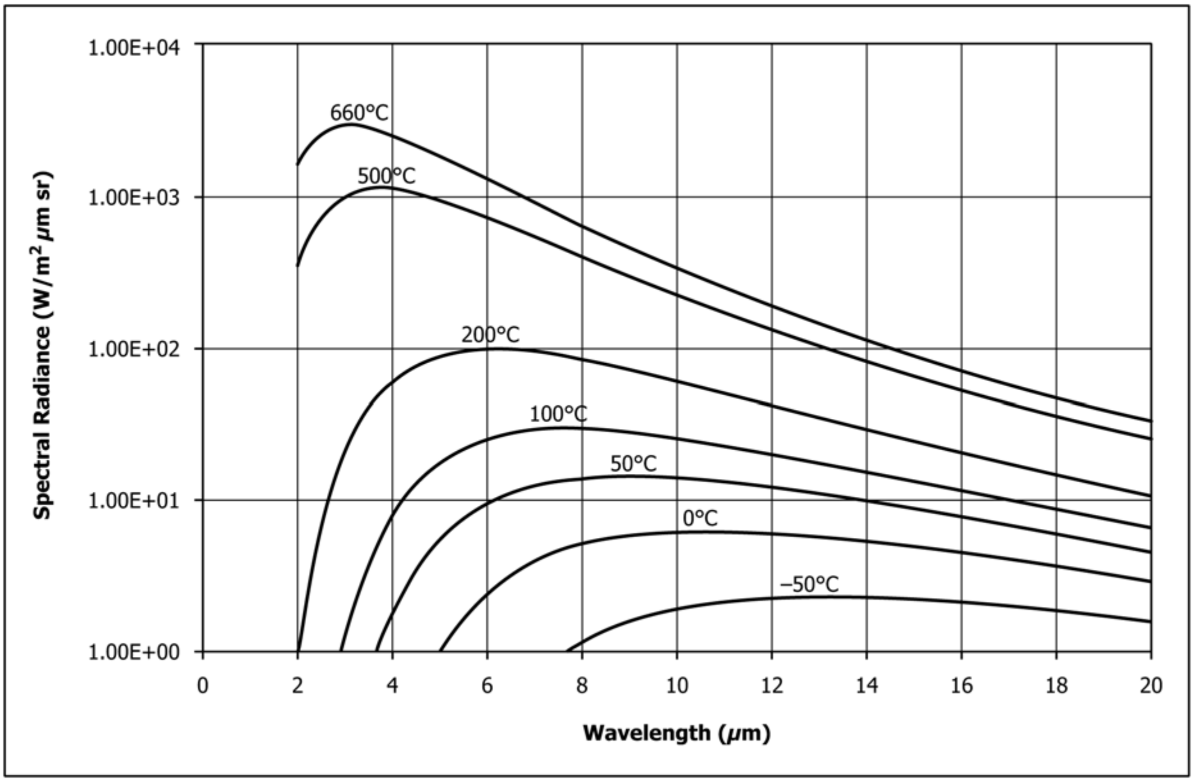

FIG. X1.2 Planck's Law

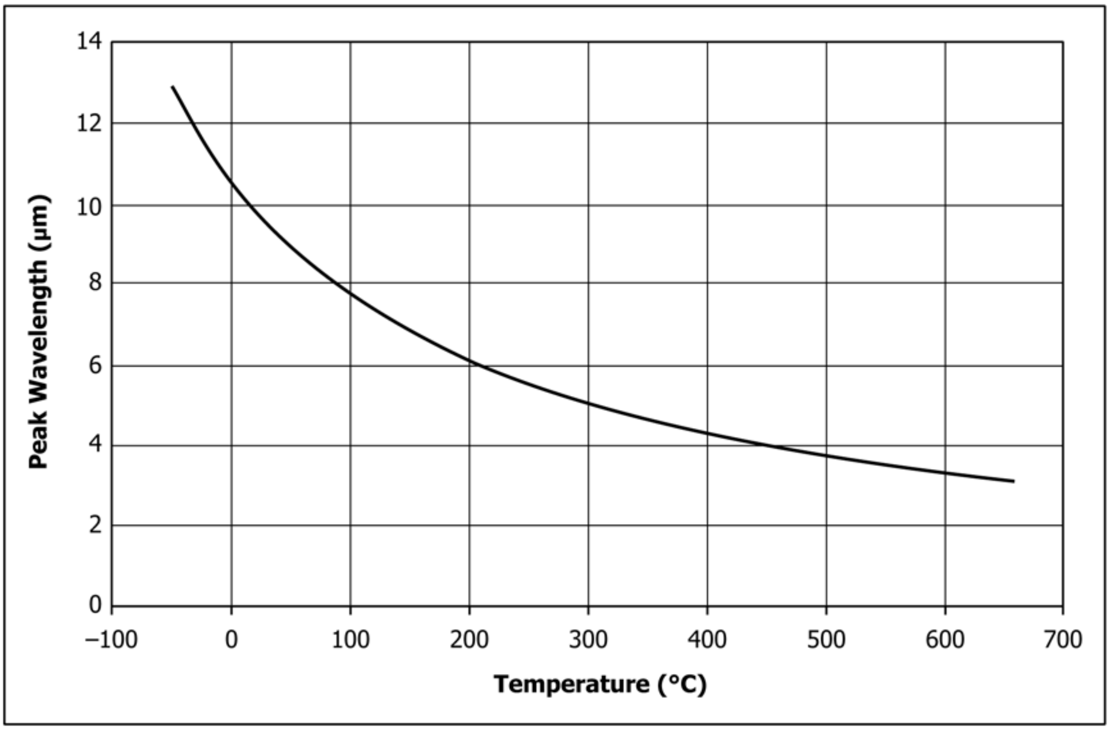

FIG. X1.3 Wien's Displacement Law

X2. BAND LIMITED RADIANT POWER DENSITY 8 TO 14 μm BAND

X2.1 General

X2.1.1 Wideband infrared thermometers measure radiation in a specific electromagnetic band. Using Planck's Law to model the effects of wideband radiation is complicated. A method to make this calculation is presented here.[10]

X2.2 Sakuma-Hattori Equation (Planckian Form)

X2.2.1 The Sakuma-Hattori Equation is shown in Eq X2.1. The inverse of Sakuma-Hattori Equation is shown in Eq X2.2. The first derivative of the Sakuma-Hattori is shown in Eq X2.3. When doing the mathematics using these equations, temperature must be expressed in kelvins instead of degrees Celsius. For purposes of this calculation, S in Equations is dimensionless and is a scalar to the amount of radiant flux received by the detector.

$$S(T) = \frac{C}{exp\left(\frac{c_2}{AT+B}\right) - 1} \quad \text{(X2.1)}$$

$$T = \frac{c_2}{Aln\left(\frac{C}{S}+1\right)} - \frac{B}{A} \quad \text{(X2.2)}$$

$$\frac{\partial S}{\partial T} = [S(T)]^2 \frac{Ac_2}{C(AT+B)^2} exp\left(\frac{c_2}{AT+B}\right) \quad \text{(X2.3)}$$

X2.2.2 In Eq X2.1-X2.3, c_2 is a physical constant. A, B, C are constants derived from the IR thermometer's relationship between the signal received and the temperature. A and B are derived from the IR thermometer's spectral response. C is a scalar based on the IR thermometer gain and can be considered as unity for this analysis. Calculation for these constants is shown in Eq X2.4-X2.7. The value for Δλ is the IR thermometer's spectral range. The value for λ_0 is the IR thermometer's center wavelength based on a simple average of the IR thermometer's high and low spectral range limits.

$$A = \lambda_0\left(1 - \frac{\Delta\lambda^2}{2\lambda_0^2}\right) \quad \text{(X2.4)}$$

$$B = \frac{c_2\Delta\lambda^2}{24\lambda_0^2} \quad \text{(X2.5)}$$

$$C = 1.0 \quad \text{(X2.6)}$$

$$c_2 = 14387.752 \mu mK \quad \text{(X2.7)}$$

X2.2.3 For an example, the 8 to 14 μm band is considered. For the 8 to 14 μm band, λ_0 = 11 μm and Δλ = 6 μm. Using Eq X2.4 and X2.5, A = 9.364 μm and B = 178.4 μmK.

X2.2.4 The following subsections give examples of how to use the Sakuma-Hattori Equation for analysis. The basis for these calculations is the measurement equation shown in Eq X2.8.

$$\epsilon_{SURF}S(T_{SURF}) + (1 - \epsilon_{SURF})S(T_{REFL}) = \epsilon_{IRT}S(T_{IRT}) + (1 - \epsilon_{IRT})S(T_{REFL-IRT}) \quad \text{(X2.8)}$$

where:

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[10] *MSL Technical Guide 22 - Calibration of Low-Temperature Infrared Thermometers*, Measurement Standards Laboratory of New Zealand, 2008, pp 1 – 3.

ε_{SURF} = true effective emissivity of surface,
ε_{IRT} = IR thermometer emissivity setting,
T_{SURF} = true temperature of surface,
T_{REFL} = true background temperature,
T_{IRT} = IR thermometer readout temperature, and
$T_{REFL\text{-}IRT}$ = IR thermometer's reflected temperature (used by its internal computation).

X2.3 Determining the Effects of a Error in Emissivity

X2.3.1 For this calculation Eq X2.8 is rearranged to Eq X2.9. Assuming that the reflected temperature is accurately compensated for by the IR thermometer.

$$S(T_{SURF}) = \frac{\epsilon_{IRT}}{\epsilon_{SURF}} S(T_{IRT}) + \frac{(\epsilon_{SURF} - \epsilon_{IRT})}{\epsilon_{SURF}} S(T_{REFL}) \quad (X2.9)$$

X2.3.2 In this example the readout (T_{IRT}) of the 8 to 14 µm infrared thermometer indicates 100°C. The emissivity setting (ε_{IRT}) of the IR thermometer is 0.95. The correct emissivity (ε_{SURF}) of the surface is 0.94. The reflected temperature is 23°C (T_{REFL}). The temperatures must be converted to kelvins, so T_{IRT} = 373.15 K and T_{REFL} = 296.15 K.

X2.3.3 The first step is to find the energy values ($S(T_{IRT})$ and $S(T_{REF})$). Using Eq X2.1, these are calculated as $S(T_{IRT})$ = 0.020292 and $S(T_{REF})$ = 0.007697.

X2.3.4 The second step is to calculate $S(T_{SURF})$ using Eq X2.9. This gives the result shown in Eq X2.10.

$$S(T_{SURF}) = \frac{0.95}{0.94} 0.020292 + \frac{-0.01}{0.94} 0.007697 = 0.020426 \quad (X2.10)$$

X2.3.5 To obtain a temperature for TSURF, use the inverse Sakuma-Hattori Equation (Eq X2.2). This gives T_{SURF} = 373.80K or 100.65°C. This means that the incorrect assumption of emissivity caused an error of -0.65°C in readout temperature.

X2.4 Determining the Effects of an Error in Reflected Temperature

X2.4.1 In this example, the emissivity setting (ε) of the infrared thermometer is correctly set at 0.95. The infrared thermometer readout (T_{IRT}) is 20°C. The infrared thermometer calculates the reflected temperature ($T_{REF\text{-}IRT}$) at 23°C. The actual reflected temperature (T_{REF}) is 37°C. In kelvins, these temperature values correspond to T_{IRT} = 293.15K, $T_{REF\text{-}IRT}$ = 296.15K, and T_{REF} = 310.15K.

X2.4.2 To solve this, Eq X2.8 is rearranged into Eq X2.11.

$$S(T_{SURF}) = S(T_{IRT}) + \frac{1-\epsilon}{\epsilon}\left[S(T_{REFL-IRT}) - S(T_{REFL})\right] \quad (X2.11)$$

X2.4.3 Using Eq X2.1, these are calculated as $S(T_{IRT})$ = 0.007342, $S(T_{REFL\text{-}IRT})$ = 0.007697, and $S(T_{REFL})$ = 0.009486.

X2.4.4 These values are inserted into Eq X2.11 giving Eq X2.12.

$$S(T_{SURF}) = 0.007342 + \frac{0.05}{0.95}\left[0.007697 + 0.009486\right] = 0.002748 \quad (X2.12)$$

X2.4.5 Using the inverse Eq X2.2, $S(T_{SURF})$ = 0.007248 corresponds to T_{SURF} = 292.34K or 19.19°C. In other words, a measurement error of 0.81°C occurred.

X2.5 Atmospheric Effects

X2.5.1 For this example, the effects of attenuation will be solved by Eq X2.13.

$$error = \frac{1}{\left(\frac{\partial S}{\partial T}\right)} \frac{\Delta S}{S} S \quad (X2.13)$$

X2.5.2 In 12.5.2, it is stated that the maximum attenuation at distances below 1m is 0.0003. This is the value for ΔS/S in Eq X2.13

X2.5.3 As an example consider a temperature measured at 100°C (373.15 K). Using the Sakuma-Hattori Equation first derivative (Eq X2.3), $\partial S/\partial T = 0.0002068\ K^{-1}$. Using Eq X2.1, S = 0.020292. Using these three values, the maximum error due to atmospheric effects can be calculated as shown in Eq X2.14.

$$error = \frac{0.0003}{0.0002068K^{-1}} 0.020292 = 0.029K \quad (X2.14)$$

X2.6 Graphical Representation

X2.6.1 Fig. X2.1 shows a graphical representation of the example in X2.3. It is meant as an example of the effects of an emissivity setting error and not for calculation. The x-axis shows the read-out temperature and the y-axis represents measurement error. The emissivity setting of the infrared thermometer is 0.95 and the surface emissivity is 0.94. The reflected temperature is 23°C.

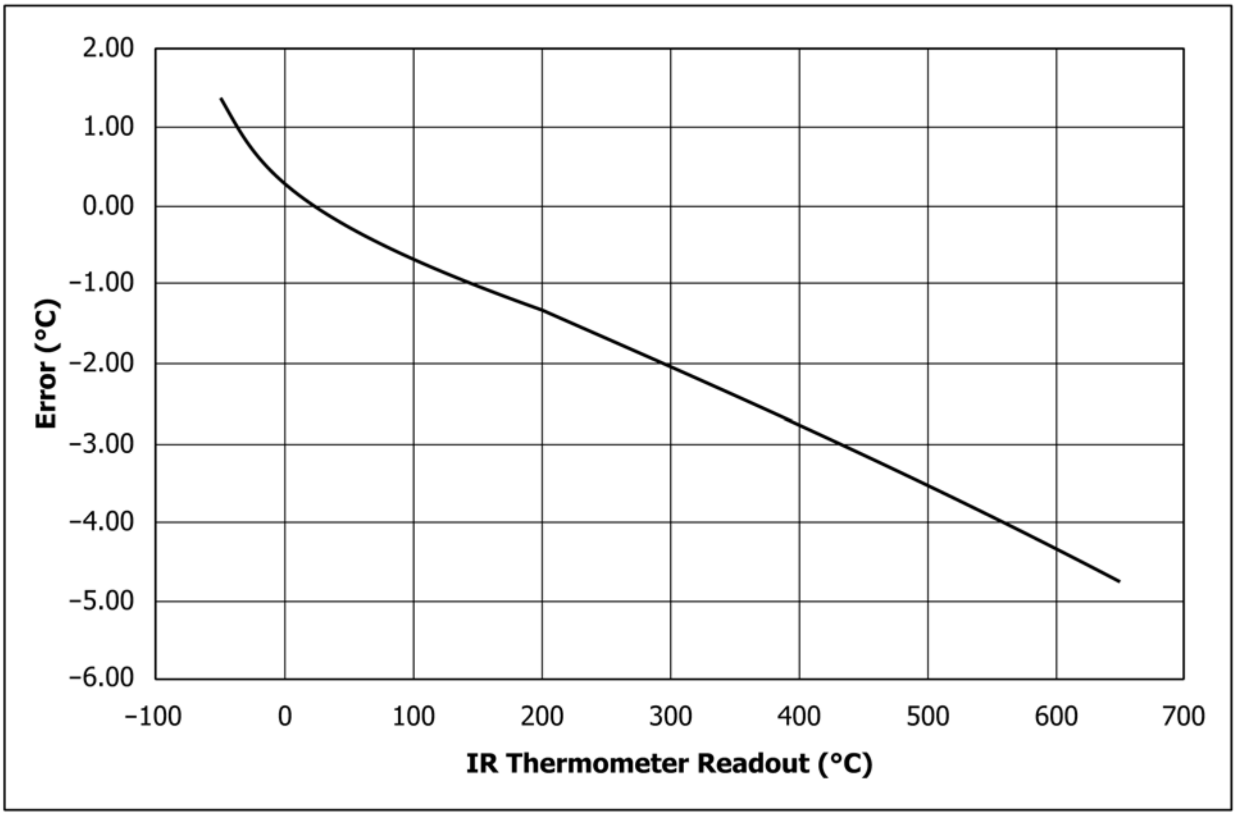

FIG. X2.1 Error Caused by a -0.01 Change in Emissivity (see X2.3)

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