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Standard Guide for Selection and Use of 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 2700 °C and measure a narrow to 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 addresses general information on emissivity and how to deal with emissivity when making measurements with an IR thermometer.

1.7 This guide contains basic information on the classification of different types of IR thermometers.

1.8 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.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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*.

[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, 1st floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, https://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 *celestial radiation, n*—flux coming from the sky.

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

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 µm 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*—nonnegative 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.

[4] See IEC 62492-1.

[5] See BIPM JCGM 200:2012.

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.

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.

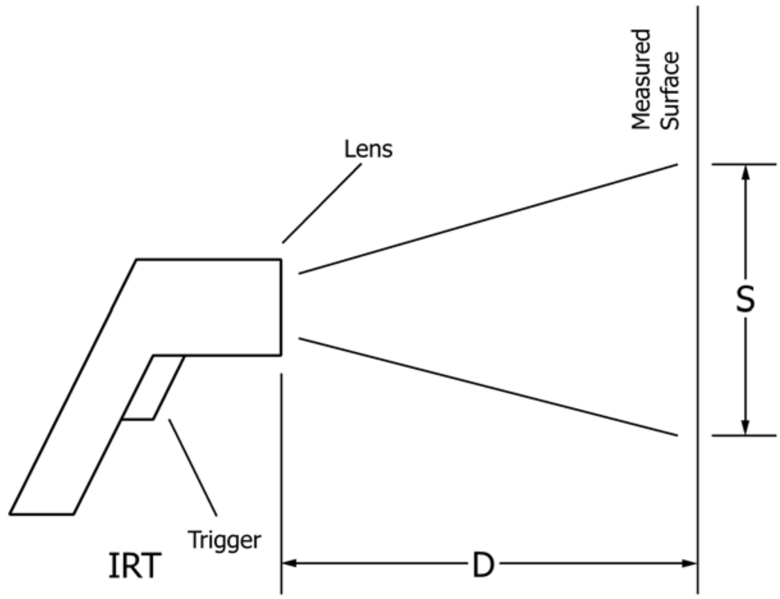


FIG. 1 Basic IR Thermometer Measurement

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. 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 µm to 14 µm. However, some instruments have a spectral range of up to 5 µm 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.

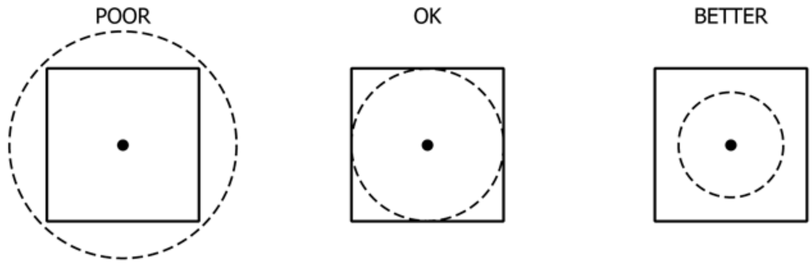


FIG. 2 Filling the IR Thermometer's Spot

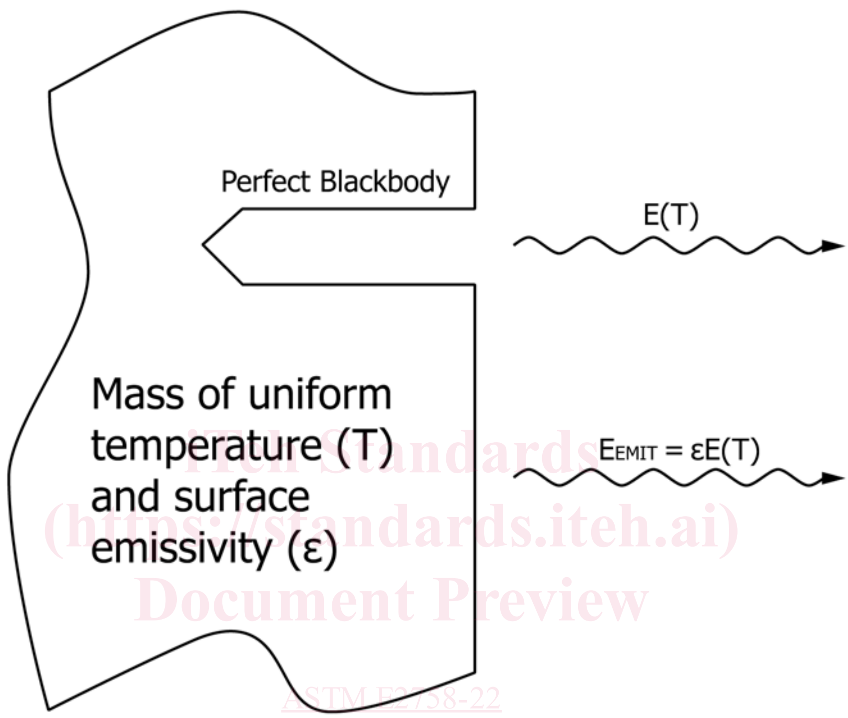


FIG. 3 Blackbody and Surface Emissivity

Non-metals tend to have much higher emissivity values than metals. Non-oxidized metals tend to have lower 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.

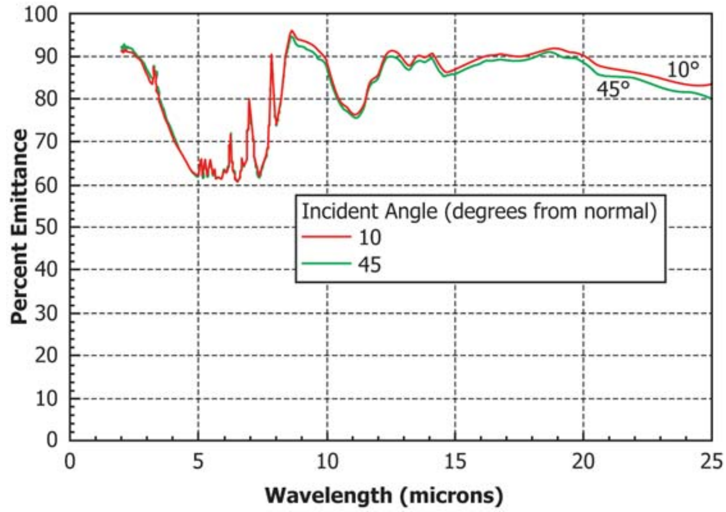
8.2.2 FTIR data provides spectral emissivity values at various wavelengths in the electromagnetic spectrum. The spectral emissivity values are derived from the reflectivity results obtained in the tests. Fig. 4 shows an example of FTIR test results.

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



Courtesy of Surface Optics Corporation, San Diego, California.

FIG. 4 Example of FTIR Test Results

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 $\varepsilon = 0.86$).

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.

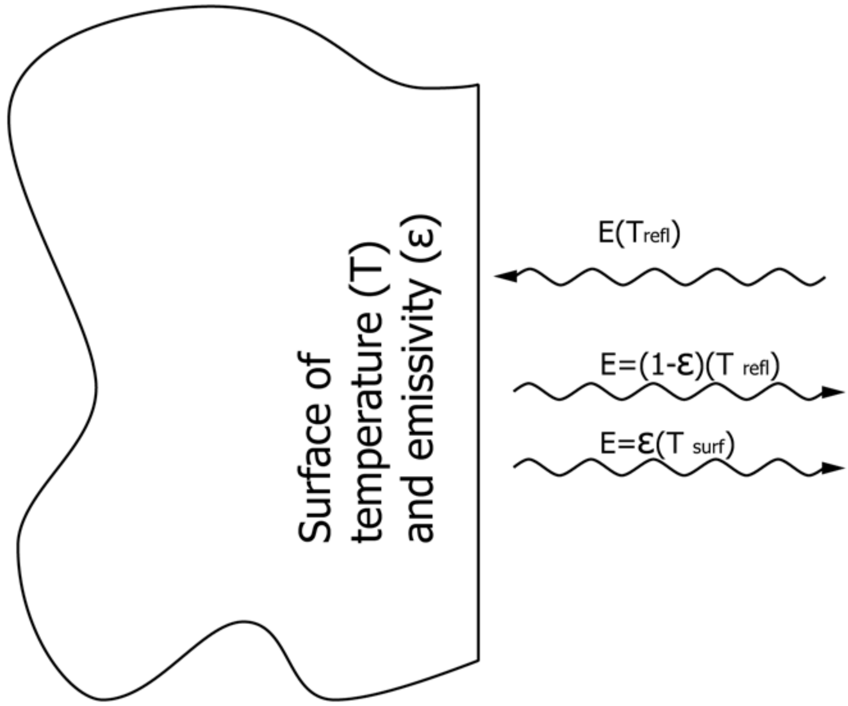


FIG. 5 Emission and Reflection

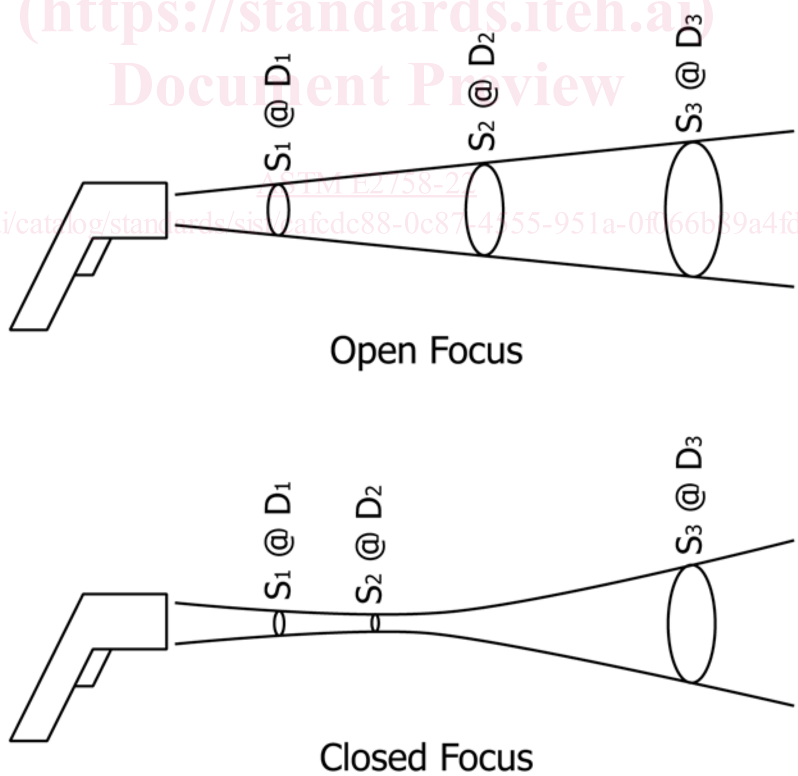


FIG. 6 Distance-to-size Diagrams