Designation: G207 – 11

Standard Test Method for Indoor Transfer of Calibration from Reference to Field Pyranometers[1]

This standard is issued under the fixed designation G207; 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.

INTRODUCTION

Accurate and precise measurements of total solar and solar ultraviolet irradiance are required in: (1) the determination of the energy incident on surfaces and specimens during exposure outdoors to various climatic factors that characterize a test site, (2) the determination of solar irradiance and radiant exposure to ascertain the energy available to solar collection devices such as flat-plate collectors, and (3) the assessment of the irradiance and radiant exposure in various wavelength bands for meteorological, climatic and earth energy-budget purposes. The solar components of principal interest include total solar radiant exposure (all wavelengths) and various ultraviolet components of natural sunlight that may be of interest, including both total and narrow-band ultraviolet radiant exposure.

This test method for indoor transfer of calibration from reference to field instruments is only applicable to pyranometers and radiometers whose field angles closely approach 180° ... instruments which therefore may be said to measure hemispherical radiation, or all radiation incident on a flat surface. Hemispherical radiation includes both the direct and sky (diffuse) geometrical components of sunlight, while global solar irradiance refers only to hemispherical irradiance on a horizontal surface such that the field of view includes the entire hemispherical sky dome.

For the purposes of this test method, the terms pyranometer and radiometer are used interchangeably.

1. Scope

1.1 The method described in this standard applies to the indoor transfer of calibration from reference to field radiometers to be used for measuring and monitoring outdoor radiant exposure levels.

1.2 This test method is applicable to field radiometers regardless of the radiation receptor employed, but is limited to radiometers having approximately 180° (2π Steradian), field angles.

1.3 The calibration covered by this test method employs the use of artificial light sources (lamps).

1.4 Calibrations of field radiometers are performed with sensors horizontal (at 0° tilt from the horizontal to the earth). The essential requirement is that the reference radiometer shall have been calibrated at horizontal tilt as employed in the transfer of calibration.

1.5 The primary reference instrument shall not be used as a field instrument and its exposure to sunlight shall be limited to outdoor calibration or intercomparisons.

NOTE 1—At a laboratory where calibrations are performed regularly it is advisable to maintain a group of two or three reference radiometers that are included in every calibration. These serve as controls to detect any instability or irregularity in the standard reference instrument.

1.6 Reference standard instruments shall be stored in a manner as to not degrade their calibration.

1.7 The method of calibration specified for total solar pyranometers shall be traceable to the World Radiometric Reference (WRR) through the calibration methods of the reference standard instruments (Method G167 and Test Method E816), and the method of calibration specified for narrow- and broad-band ultraviolet radiometers shall be traceable to the National Institute of Standards and Technology (NIST), or other internationally recognized national standards laboratories (Standard G138).

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.*

[1] This test method is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.09 on Radiometry.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

E816 Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers

E824 Test Method for Transfer of Calibration From Reference to Field Radiometers

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance

G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

2.2 *Other Standards:*[3]

ISO 9847 Solar Energy Calibration of Field Pyranometers by Comparison to a Reference Pyranometer

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology E772 and G113 for terminology relating to this test method.

4. Summary of Test Method

4.1 Mount the reference pyranometer, and the field (or test) radiometers, or pyranometers, on a common calibration table for horizontal calibration. Adjust the height of the radiation receptor of all instruments to a common elevation.

4.2 Connect the signal cables from the reference and test sensors to a data acquisition system.

4.3 Adjust the data acquisition system to record data at the selected data collection interval.

NOTE 2—Data collection interval should be function of the time constant of the sensor. Sensor time constant is the period of time required for a sensor to reach 1 – 1/e = 63% of the maximum minus the minimum amplitude of a step change in input stimulus. (e is base of natural logarithms, 2.718282...). Often, "one over e" (1/e) time constants are reported for radiation sensors, for example "1/e response time = 3 seconds". This represents the time for the sensor signal to reach 37% of the full range step change representing the step change in the stimulus. Four times the 1/e time constant can be considered the time for the sensor to fully respond to a step change in stimulus.

4.4 Energize the source to be used for the transfer of calibration.

NOTE 3—It is mandatory that the spectral distribution of the source be known or well characterized. Indoor calibration transfers between narrow band radiometers such as Ultraviolet and Photopic detectors shall be accomplished using sources with spectral irradiance distributions as similar as possible to the spectral distribution of the sources to be monitored. This will reduce spectral mismatch errors arising from differences in the spectral response of sensors and dissimilar calibration and 'test' source spectral distributions. In the special case of pyranometers for solar radiation measurements, as long as the reference radiometer has a relatively flat and broad (greater than 700 nm passband) spectral response (for example, black thermopile), or has been calibrated outdoors, the difference between calibration and source spectral distributions is less important, however should be taken into consideration.

4.5 Monitor the output signal of the reference radiometer at the selected data collection interval.

4.6 Ensure the temporal stability of the source, as indicated by the reference radiometer output, has stabilized at reasonable amplitude. Recommended source amplitude for broadband solar radiometers is in the range 500 Wm^{-2} to 1000 Wm^{-2}. For narrowband radiometers, a source amplitude (spectral irradiance distribution integrated over with respect to wavelength over the pass band of the radiometers) of 50% to 125% of the peak amplitude to be expected in the source monitored by the test instruments is recommended.

4.7 The analog voltage signal from each radiometer is measured, digitized, and stored using a calibrated data-acquisition instrument, or system. A minimum of 30 data readings is required.

4.8 The test data are divided by the reference radiometer data, employing the instrument constant of the reference instrument to determine the instrument constant of the radiometer being calibrated. The mean value, the standard deviation, and coefficient of variation are determined.

5. Significance and Use

5.1 The methods described represent a means for calibration of field radiometers employing standard reference radiometers indoors. Other methods involve the natural sunlight outdoors under clear skies, and various combinations of reference radiometers. Outdoor these methods are useful for cosine and azimuth correction analyses, but may suffer from a lack of available clear skies, foreground view factor and directionality problems. Outdoor transfer of calibrations is covered by standards G167, E816, and E824.

5.2 Several configurations of artificial sources are possible, including:

5.2.1 Point sources (lamps) at a distance, to which the sensors are exposed

5.2.2 Extended sources (banks of lamps, or lamp(s) behind diffusing or "homogenizing" screens) to which the sensors are exposed

5.2.3 Various configurations of enclosures (usually spherical or hemispherical) with the interior walls illuminated indirectly with lamps. The sensors are exposed to the radiation emanating from the enclosure walls.

5.3 Traceability of calibration for pyranometers is accomplished when employing the method using a reference global pyranometer that has been calibrated, and is traceable to the World Radiometric Reference (WRR)[4]. For the purposes of this test method, traceability shall have been established if a parent instrument in the calibration chain can be traced to a

[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 Available from International Standards Organization (ISO), 1 Rue De Varembre, Geneva, Switzerland CH-1211 20

[4] WMO—No. 8, "Guide to Meteorological Instruments and Methods of Observation," Fifth Ed., World Meteorological Organization, Geneva, Switzerland, 1983

reference pyrheliometer which has participated in an International Pyrheliometric Comparison (IPC) conducted at the World Radiation Center, (WRC), Davos, Switzerland.

5.3.1 The reference global pyranometer (for example, one measuring hemispherical solar radiation at all wavelengths) shall have been calibrated by the shading-disk, component summation, or outdoor comparison method against one of the following instruments:

5.3.1.1 An absolute cavity pyrheliometer that participated in a World Meteorological Organization (WMO) sanctioned IPC's (and therefore possesses a WRR reduction factor).

5.3.1.2 An absolute cavity radiometer that has been intercompared (in a local or regional comparison) with an absolute cavity pyrheliometer meeting 5.3.1.1.

5.3.1.3 Alternatively, the reference pyranometer may have been calibrated by direct transfer from a World Meteorological Organization (WMO) First Class pyranometer that was calibrated by the shading-disk method against an absolute cavity pyrheliometer possessing a WRR reduction factor, or by direct transfer from a WMO Standard Pyranometer (see WMO's Guide WMO—No. 8 for a discussion of the classification of solar radiometers). See Zerlaut[5] for a discussion of the WRR, the IPC's and their results.

NOTE 4—Any of the absolute radiometers participating in the above intercomparisons and being within ±0.5 % of the mean of all similar instruments compared in any of those intercomparisons, shall be considered suitable as the primary reference instrument.

5.4 Traceability of calibration of narrow band (for example,, Ultraviolet) radiometers is accomplished when employing the method using a reference narrow band radiometer that has been calibrated and is traceable to the National Institute of Standards and Technology (NIST), or other national standards organizations.

5.4.1 The reference narrow band radiometer, regardless of whether it measures total ultraviolet solar radiation, or narrowband UV-A or UV-B radiation, or a defined narrow band segment of ultraviolet radiation, shall have been calibrated by one of the following:

5.4.1.1 By comparison to a standard source of spectral irradiance that is traceable to NIST or to the appropriate national standards organizations of other countries using appropriate filters and filter correction factors [for example, Drummond [6]].

5.4.1.2 By comparison of the radiometer output to the integrated spectral irradiance in the appropriate wavelength band of a spectroradiometer that has itself been calibrated against such a standard source of spectral irradiance,

5.4.1.3 By comparison to a spectroradiometer that has participated in a regional or national Intercomparison of Spectroradiometers, the results of which are of reference quality.

NOTE 5—The calibration of reference ultraviolet radiometers using a spectroradiometer, or by direct calibration against standard sources of spectral irradiance (for example, deuterium or 1000 W tungsten-halogen lamps) is the subject of Standard G138.

5.5 The calibration method employed assumes that the accuracy of the values obtained with respect to the calibration source used are applicable to the deployed environment, with additional sources of uncertainty due to logging equipment and environmental effects above and beyond the calibration uncertainty.

5.6 The principal advantages of indoor calibration of radiometers are user convenience, lack of dependence on weather, and user control of test conditions.

5.7 The principal disadvantages of the indoor calibrations are the possible differences between natural environmental influences and the laboratory calibration conditions with respect to the spectral and spatial distribution of the source radiation (sun and sky versus lamps or enclosure walls).

5.8 It is recommended that the reference radiometer be of the same type as the test radiometer, since any difference in spectral sensitivity between instruments will result in erroneous calibrations. However, The calibration of sufficiently broadband detectors (approximately 700 nm or more), such a silicon photodiode detectors with respect to extremely broadband (more than 2000 nm) thermopile radiometers is acceptable, as long as the additional increased uncertainty in the field measurements, due to spectral response and spectral mismatch limitations, is acceptable. The reader is referred to ISO TR 9673[7] and ISO TR 9901[8] for discussions of the types of instruments available and their use.

6. Interferences

6.1 In order to minimize systematic errors the reference and test radiometers must be as nearly alike in all respects as possible.

6.1.1 The spectral response of both the reference and test radiometers should be as nearly identical as possible.

6.1.2 The spectral content (spectral power distribution) of the calibration source and the source to be monitored in the field experiment should be matched to greatest extent possible. If not, the relative spectral differences should be characterized, reported, and the spectral mismatch characterized.

6.2 Source stability. The measurements selected in determining the instrument constant shall be made during periods of essentially uniform levels or slow (less than 0.5% of full scale per minute) rates of change of radiation (as measured by the reference radiometer). Measurements selected under varying source amplitudes may result in erroneous calibrations if the reference and test radiometers possess significantly different response times.

[5] Zerlaut, G. A., "Solar Radiation Instrumentation," Chapter 5 in Solar Resources, The MIT Press, Cambridge, MA, 1989, pp. 173–308.

[6] Drummond, A.J, and A.K. Ångström, "Derivation of the Photometric Flux of Daylight from Filtered Measurements of Global (Sun and Sky) Radiant Energy", Applied Optics Vol 10 # 9, September 1971.

[7] ISO Technical Report TR 9673, "Solar Radiation and Its Measurement for Determining Outdoor Weathering Exposure Levels," International Standards Organization, Geneva, Switzerland.

[8] ISO/TR 9901:1990, "Solar Energy—Field Pyranometers—Recommended Practice for Use."