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Standard Test Method for Calibration of a Pyranometer Using a Pyrheliometer[1]

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INTRODUCTION

Accurate and precise measurements of total global (hemispherical) solar irradiance are required in the assessment of irradiance and radiant exposure in the testing of exposed materials, determination of the energy available to solar collection devices, and assessment of global and hemispherical solar radiation for meteorological purposes.

This test method requires calibrations traceable to the World Radiometric Reference (WRR), which represents the SI units of irradiance. The WRR is determined by a group of selected absolute pyrheliometers maintained by the World Meteorological Organization (WMO) in Davos, Switzerland.

Realization of the WRR in the United States, and other countries, is accomplished by the intercomparison of absolute pyrheliometers with the World Radiometric Group (WRG) through a series of intercomparisons that include the International Pyrheliometric Conferences held every five years in Davos. The intercomparison of absolute pyrheliometers is covered by procedures adopted by WMO and is not covered by this test method.

It should be emphasized that "calibration of a pyranometer" essentially means the transfer of the WRR scale from a pyrheliometer to a pyranometer under specific experimental procedures.

1. Scope

1.1 This test method covers an integration of previous Test Method E913 dealing with the calibration of pyranometers with axis vertical and previous Test Method E941 on calibration of pyranometers with axis tilted. This amalgamation of the two methods essentially harmonizes the methodology with ISO 9846.

1.2 This test method is applicable to all pyranometers regardless of the radiation receptor employed, and is applicable to pyranometers in horizontal as well as tilted positions.

1.3 This test method is mandatory for the calibration of all secondary standard pyranometers as defined by the World Meteorological Organization (WMO) and ISO 9060, and for any pyranometer used as a reference pyranometer in the transfer of calibration using Test Method E842.

1.4 Two types of calibrations are covered: Type I calibrations employ a self-calibrating, absolute pyrheliometer, and Type II calibrations employ a secondary reference pyrheliometer as the reference standard (secondary reference pyrheliometers are defined by WMO and ISO 9060).

1.5 Calibrations of reference pyranometers may be performed by a method that makes use of either an altazimuth or equatorial tracking mount in which the axis of the radiometer's radiation receptor is aligned with the sun during the shading disk test.

1.6 The determination of the dependence of the calibration factor (calibration function) on variable parameters is called characterization. The characterization of pyranometers is not specifically covered by this method.

1.7 This test method is applicable only to calibration procedures using the sun as the light source.

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

1.9 *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.*

[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

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

2.2 *WMO Document:*[3]

World Meteorological Organization (WMO), "Measurement of Radiation" Guide to Meteorological Instruments and Methods of Observation, seventh ed., WMO-No. 8, Geneva

2.3 *ISO Standards:*[4]

ISO 9060:1990 Solar Energy—Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation

ISO 9846:1993 Solar Energy—Calibration of a Pyranometer Using a Pyrheliometer

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology E772.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *altazimuth mount, n*—a tracking mount capable of rotation about orthogonal altitude and azimuth axes; tracking may be manual or by a follow-the-sun servomechanism.

3.2.2 *calibration of a radiometer, v*—determination of the responsivity (or the calibration factor, the reciprocal of the responsivity) of a radiometer under well-defined measurement conditions.

3.2.3 *direct solar radiation, n*—that component of solar radiation within a specified solid angle (usually 5.0° or 5.7°) subtended at the observer by the sun's solar disk, including a portion of the circumsolar radiation.

3.2.4 *diffuse solar radiation, n*—that component of solar radiation scattered by the air molecules, aerosol particles, cloud and other particles in the hemisphere defined by the sky dome.

3.2.5 *equatorial mount, n*—see Terminology E772.

3.2.6 *field of view angle of a pyrheliometer, n*—full angle of the cone which is defined by the center of the receiver surface (see ISO 9060, 5.1) and the border of the limiting aperture, if the latter are circular and concentric to the receiver surface; if not, effective angles may be calculated (**1, 2**).[5]

3.2.7 *global solar radiation, n*—combined direct and diffuse solar radiation falling on a horizontal surface; solar radiation incident on a horizontal surface from the hemispherical sky dome, or from 2π Steradian (Sr).

3.2.8 *hemispherical radiation, n*—combined direct and diffuse solar radiation incident from a virtual hemisphere, or from 2π Sr, on any inclined surface.

3.2.8.1 *Discussion*—The case of a horizontal surface is denoted *global solar radiation* (3.2.7).

3.2.9 *pyranometer, n*—see Terminology E772.

3.2.10 *pyranometer, field, n*—a pyranometer meeting WMO Good Quality or better (that is, High Quality) appropriate to field use and typically exposed continuously.

3.2.11 *pyranometer, reference, n*—a pyranometer (see also ISO 9060), used as a reference to calibrate other pyranometers, which is well-maintained and carefully selected to possess relatively high stability and has been calibrated using a pyrheliometer.

3.2.12 *pyrheliometer, n*—see Terminology E772 and ISO 9060.

3.2.13 *pyrheliometer, absolute (self-calibrating), n*—a solar radiometer with a limited field of view configuration. The field of view should be approximately 5.0° and have a slope angle of from 0.75° to 0.8°, with a blackened conical cavity receiver for absorption of the incident radiation. The measured electrical power to a heater wound around the cavity receiver constitutes the method of self-calibration from first principles and traceability to absolute SI units. The self-calibration principle relates to the sensing of the temperature rise of the receiving cavity by an associated thermopile when first the sun is incident upon the receiver and subsequently when the same thermopile signal is induced by applying precisely measured power to the heater with the pyrheliometer shuttered from the sun.

3.2.14 *shading-disk device, n*—a device which allows movement of a disk in such a way that the receiver of the pyranometer to which it is affixed, or associated, is shaded from the sun. The cone formed between the origin of the receiver and the disk subtends an angle that closely matches the field of view of the pyrheliometer against which it is compared. Alternatively, and increasingly preferred, a sphere rather than a disk eliminates the need to continuously ensure the proper alignment of the disk normal to the sun. See Appendix X1.

3.2.15 *slope angle, n*—the angle defined by the difference in radii of the view limiting aperture (radius = R) and the receiver radius (= r) in a pyrheliometer. The slope angle, s, is the arctangent of R minus r divided by the distance between the limiting aperture and the receiver surface, denoted by L: $s = \mathrm{Tan}^{-1}(R - r)/L$. See Ref (**1**).

3.2.16 *thermal offset, n*—a non-zero signal generated by a radiometer when blocked from all sources of radiation. Believed to be the result of infrared (thermal) radiation exchanges between elements of the radiometer and the environment.

3.3 *Acronyms:*

3.3.1 *ACR*—Absolute Cavity Radiometer

3.3.2 *ANSI*—American National Standards Institute

3.3.3 *ARM*—Atmospheric Radiation Measurement Program

3.3.4 *DOE*—Department of Energy

3.3.5 *GUM*—(ISO) Guide to Uncertainty in Measurements

[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 World Meterological Organization, 7bis, avenue de la Paix, CP2300, CH-1211 Geneva 2, Switzerland, http://www.wmo.int.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

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

3.3.6 *IPC*—International Pyrheliometer comparison

3.3.7 *ISO*—International Standards Organization

3.3.8 *NCSL*—National Council of Standards Laboratories

3.3.9 *NIST*—National Institute of Standards and Technology

3.3.10 *NREL*—National Renewable Energy Laboratory

3.3.11 *PMOD*—Physical Meteorological Observatory Davos

3.3.12 *SAC*—Singapore Accreditation Council

3.3.13 *SINGLAS*—Singapore Laboratory Accreditation Service

3.3.14 *UKAS*—United Kingdom Accrediation Service

3.3.15 *WRC*—World Radiation Center

3.3.16 *WRR*—World Radiometric Reference

3.3.17 *WMO*—World Meteorological Organization

4. Significance and Use

4.1 The pyranometer is a radiometer designed to measure the sum of directly solar radiation and sky radiation in such proportions as solar altitude, atmospheric conditions and cloud cover may produce. When tilted to the equator, by an angle β, pyranometers measure only hemispherical radiation falling in the plane of the radiation receptor.

4.2 This test method represents the only practical means for calibration of a reference pyranometer. While the sun-trackers, the shading disk, the number of instantaneous readings, and the electronic display equipment used will vary from laboratory to laboratory, the method provides for the minimum acceptable conditions, procedures and techniques required.

4.3 While, in theory, the choice of tilt angle (β) is unlimited, in practice, satisfactory precision is achieved over a range of tilt angles close to the zenith angles used in the field.

4.4 The at-tilt calibration as performed in the tilted position relates to a specific tilted position and in this position requires no tilt correction. However, a tilt correction may be required to relate the calibration to other orientations, including axis vertical.

NOTE 1—WMO High Quality pyranometers generally exhibit tilt errors of less than 0.5 %. Tilt error is the percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000 W·m[23].

4.5 Traceability of calibrations to the World Radiometric Reference (WRR) is achieved through comparison to a reference absolute pyrheliometer that is itself traceable to the WRR through one of the following:

4.5.1 One of the International Pyrheliometric Comparisons (IPC) held in Davos, Switzerland since 1980 (IPC IV). See Refs (**3-7**).

4.5.2 Any like intercomparison held in the United States, Canada or Mexico and sanctioned by the World Meteorological Organization as a Regional Intercomparison of Absolute Cavity Pyrheliometers.

4.5.3 Intercomparison with any absolute cavity pyrheliometer that has participated in either and IPC or a WMO-sanctioned intercomparison within the past five years and which was found to be within ±0.4 % of the mean of all absolute pyrheliometers participating therein.

4.6 The calibration method employed in this test method assumes that the accuracy of the values obtained are independent of time of year, with the constraints imposed and by the test instrument's temperature compensation circuit (neglecting cosine errors).

5. Selection of Shade Method

5.1 *Alternating Shade Method:*

5.1.1 The alternating shade method is required for a primary calibration of the reference pyranometer used in the Continuous, Component-Summation Shade Method described in 5.2.

5.1.2 The pyranometer under test is compared with a pyrheliometer measuring direct solar irradiance (or, optionally, a continuously shaded control pyranometer; see Appendix X3 – Appendix X5). The voltage values from the pyranometer that correspond to direct solar irradiance are derived from the difference between the response of the pyranometer to hemispherical (unshaded) solar irradiance and the diffuse (shaded) solar irradiance. These response values (for example, voltages) are induced periodically by means of a movable sun shade disk. For the calculation of the responsivity, the difference between the unshaded and shaded irradiance signals is divided by the direct solar irradiance (measured by the pyrheliometer) component that is normal to the receiver plane of the pyranometer.

5.1.3 For meteorological purposes, the solid angle from which the scattered radiative fluxes that represent diffuse radiation are measured shall be the total sky hemisphere, excluding a small solid angle around the sun's disk.

5.1.4 In addition to the basic method, modifications of this method that are considered to improve the accuracy of the calibration factors, but which require more operational experience, are presented in Appendix X3 – Appendix X5.

5.2 *Continuous Sun-and-Shade Method (Component Summation):*

5.2.1 The pyranometer is compared with two reference radiometers, one of which is a pyrheliometer and the other a well-calibrated reference pyranometer equipped with a tracking shade disk or sphere to measure diffuse solar radiation. The reference pyranometer shall be either calibrated using the alternating sun-and shade method described in 5.1, or shall be compared against such a pyranometer in accordance with Test Method E824.

5.2.2 Global solar irradiance (or hemispherical solar irradiance for inclined pyranometers) is determined by the sum of the direct solar irradiance measured with a pyrheliometer multiplied by the cosine of the incidence angle of the beam to the local horizontal (or inclined plane parallel to the radiometer sensor), plus the diffuse solar irradiance measured with a shaded reference pyranometer mounted in the same configuration (tilted or horizontal) as the unit under test.

5.2.3 The smallest uncertainty realized in the calibration of pyranometers will occur when the pyrheliometer is a self-calibrating absolute cavity pyrheliometer and when the reference pyranometer has itself been calibrated over a range of air