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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 9846

Solar energy — Calibration of a pyranometer using a pyrhelimeter

*Énergie solaire — Étalonnage d'un pyranomètre utilisant un
pyrhéliomètre*

ICS: 27.160

ISO/TC 180/SC 1

Secretariat: **SA**

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2024-08-20

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2024-11-12

This document is circulated as received from the committee secretariat.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 180, *Solar energy*, Sub-Committee SC 1, *Climate – Measurement and data*.

This second edition cancels and replaces the first edition (ISO 9846:1993) which has been technically revised.

[Annex A](#), [B](#), [C](#), [D](#), [E](#), [F](#), [G](#), [H](#), and I of this document are for information only.

The main changes compared to the previous edition are as follows:

- focus on current calibration practices
- adapted recommendations for mathematical treatment of data
- adaptation of the terminology to the revised ISO 9060:2018, and ISO Guide 99:1993
- added comments on uncertainty evaluation of the calibration with reference to ASTM G213 and ISO/IEC Guide 98-3

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document deals with calibration methods of a pyranometer using a pyr heliometer as a reference instrument. Calibration methods for pyranometers using a pyranometer as a reference are described in ISO 9847.

Calibration of measuring instruments is essential for accurate and reliable measurements. Accurate measurements of the solar irradiance are required for:

- a) the determination of the energy input to solar energy systems such as photovoltaic (PV), and solar thermal systems, as a basis for performance assessment,
- b) the testing and assessment of solar technologies,
- c) the geographic mapping of solar energy resources
- d) understanding climate change and extreme weather through the Surface Radiation Budget.
- e) other applications such as agriculture, building efficiency, material degradation and reliability, health, etc.

Today's solar energy performance assessment demands high accuracy measurements and low measurement uncertainties. To meet this demand, reliable and accurate solar irradiance measurements with synchronized time stamps^[1] and a correct uncertainty evaluation are required.

The WMO World Radiometric Reference (WRR), which represents the SI units of solar irradiance, is determined by a group of selected pyr heliometers. For hemispherical irradiance measurements, transfer of this scale to pyranometers has to be accomplished. In order to calibrate pyranometers, which have a field-of-view angle of 2π , with pyr heliometers that have a limited field of view (typically only 5 degrees) requires additional equipment such as shading discs or collimation tubes.

The calibration of pyranometer specified in this international standard is traceable to SI through the WRR according to the World Meteorological Organization (WMO) guidelines.^[2] The classification and specification used are prescribed in ISO 9060:2018^[3].

Due to the relatively high accuracy of pyr heliometers, the methods in this standard may lead to lower uncertainties than calibration of a pyranometer to a reference pyranometer as given in ISO 9847^[4].

Unless otherwise specified, uncertainties mentioned in this Standard are expanded uncertainties with a coverage factor $k = 2$.

Solar energy — Calibration of a pyranometer using a pyr heliometer

1 Scope

The object of this document is to promote the uniform application of reliable methods to calibrate pyranometers by comparison to a reference pyr heliometer.

Three methods are specified in this document:

The **Alternating Sun and Shade Method** uses a shading disc to alternately shade and unshade a pyranometer to compare with the tracking pyr heliometer. The test pyranometer can be horizontal, on a fixed tilt or tracking alongside the pyr heliometer.

The **Continuous Sun and Shade Method** requires a shaded calibrated reference pyranometer in addition to the reference pyr heliometer. The test pyranometer can be horizontal, on a fixed tilt or tracking alongside the reference pyr heliometer, but the reference pyranometer must be mounted in the same plane as the test pyranometer (most often on the horizontal).

The **Collimation Tube Method** requires the test pyranometer be mounted on a solar tracker and be equipped with a collimation tube designed to allow the test pyranometer to have the same geometric view as the reference pyr heliometer for a direct comparison of the two instruments.

In general, all pyranometers may be calibrated using the described methods provided that a proper uncertainty evaluation is performed. Unlike spectrally flat pyranometers, non-spectrally flat pyranometers have a sensitivity that strongly depends on the solar spectrum. Therefore, the calibration result may be valid under a more limited range of conditions.

The result of a calibration is the instrument sensitivity accompanied by an uncertainty. This document includes suggestions for uncertainty evaluation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9488, *Solar energy — Vocabulary*

ISO 9847, *Solar energy — Calibration of pyranometers by comparison to a reference pyranometer*

ISO/TR 9901, *Solar energy — Pyranometers — Recommended practice for use*

ASTM G213-17(2023), *Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyr heliometers*

ISO 9060, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9059, *Solar energy — Calibration of pyr heliometers by comparison to a reference pyr heliometer*

ISO Guide 99, *International vocabulary of basic and general terms in metrology (VIM)*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and Definitions

For the purposes of this document, the definitions given in ISO 9060, ISO 9488, and the following definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org>

3.1

pyranometer

radiometer using a hemispherical field of view for measuring solar irradiance within the wavelength range from approximately 0,3 μm to 3 μm

3.2

pyrheliometer

radiometer using a collimated detector for measuring direct solar irradiance under normal incidence

[SOURCE: ISO 9059]

3.3

instrument classification

pyranometers and pyrheliometers are classified on the basis of the measuring specifications of the instruments

[SOURCE: ISO 9060:2018]

3.4

test pyranometer

pyranometer being calibrated

[SOURCE: ISO 9847]

Note 1 to entry: Previously referred to as field pyranometer

3.5

reference radiometer

a well-characterized and well-maintained radiometer (pyranometer or pyrheliometer) to be used to measure the (input) irradiance when calibrating a test-radiometer

Note 1 to entry: It is recommended that an instrument used as a reference is selected based on quality, stability and accuracy and it is specifically tested for the better knowledge of all its properties

Note 2 to entry: Reference use should be restricted to comparisons and calibration activities. The instrument should be stored carefully in a laboratory under moderate ambient conditions when not used.

3.6

absolute pyrheliometer

absolute cavity radiometer

an absolute pyrheliometer offers a primary reference measurement procedure for irradiance, i.e., traceable to other physical quantities, in this case electrical power and surface area

[SOURCE: ISO 9060:2018]

3.7

field-of-view angle (FOV)

opening angle

full angle of the geometrical cone which is defined by the center of the receiver surface and the edge of its view-limiting optical aperture

[SOURCE: ISO 9488:2022, 3.3.6, modified]

3.8

solar tracker

sun tracker

mechanical device capable of following the arc or path of the sun in the sky

[SOURCE: ISO 9059]

3.9

equatorial tracker

sun-following device having an axis of rotation parallel to the Earth's axis

[SOURCE: ISO 9488]

Note 1 to entry: The parameters of motion are the hour angle and the declination of the sun (ISO 9488).

3.10

altazimuth tracker

sun-following device which uses the solar elevation angle [ISO 9488, 3.1.7] and the azimuth angle (ISO 9488, 3.1.4) of the sun as coordinates of movement

[SOURCE: ISO 9488]

3.11

shading disc

shading ball

a disc (or ball) positioned in such a way that the receiver of the pyranometer is shaded from the direct solar beam so that only the diffuse solar component is measured

Note 1 to entry: For calibration purposes, particularly those described in [Clause 5](#), quick removal of the disc is mandatory. Further details on shade disc devices used in calibrating pyranometers are given in [5.2.4](#).

3.12

collimation tube

a device used to limit the field of view of a pyranometer to match the field of view and slope angle of a pyrliometer

3.13

symbols for irradiance

G is the symbol used for Irradiance ($\text{W}\cdot\text{m}^{-2}$), G_b is for beam irradiance (direct solar radiation), G_{bn} is for normal beam irradiance, and G_d is for diffuse irradiance

3.14

direct solar irradiance

beam solar irradiance

Radiation received from a small solid angle centered on the sun's disc, on a given plane.

Note 1 to entry: Symbol: G_b , Unit: $\text{W}\cdot\text{m}^{-2}$

3.15

direct normal solar irradiance

direct normal irradiance (DNI)

direct solar radiation received by a plane at normal incidence

Note 1 to entry: Symbol: G_{bn} , Unit: $\text{W}\cdot\text{m}^{-2}$

Note 2 to entry: In general, direct normal radiation is measured by instruments with field-of-view angles of up to 6° . Historic pyrliometers of the Angström type (compensation pyrliometer) have a larger field of view of up to 15° . Therefore, a part of the scattered radiation around the sun's disc (circumsolar radiation or aureole) is also included. For a more detailed definition of circumsolar radiation and related parameters refer to [\[5\]](#) in the Bibliography and see ISO 9059, Annex A.

Note 3 to entry: Approximately 97 % to 99 % of the direct solar radiation received at the ground is contained within the wavelength range from $0,3\ \mu\text{m}$ to $3\ \mu\text{m}$.[\[6\]](#)

3.16

hemispherical solar radiation

solar radiation received by a plane surface from a solid angle of $2\pi\text{sr}$

[SOURCE: ISO 9488, 3.2.22]

Note 1 to entry: The tilt angle (3.10.1) and the azimuth (3.10.2) of the surface should be specified, e.g. horizontal.

Note 2 to entry: Hemispherical solar radiation is composed of direct solar radiation and diffuse solar radiation (solar energy scattered in the atmosphere as well as solar radiation reflected by the ground).

Note 3 to entry: Solar engineers commonly use the term global radiation (3.2.23) in place of *hemispherical radiation*. This use is a source of confusion if the referenced surface is not horizontal.

Note 4 to entry: Approximately 97 % to 99 % of the hemispherical solar radiation incident at the Earth's surface is contained within the wavelength range from 0,3 μm to 3 μm [6].

Note 5 to entry: Symbol: G , Unit: $\text{W}\cdot\text{m}^{-2}$

3.17

global solar irradiance

global horizontal irradiance

hemispherical solar irradiance on a horizontal plane

[SOURCE: ISO 9847:2023]

Note 1 to entry: Symbol: G , Unit: $\text{W}\cdot\text{m}^{-2}$

Note 2 to entry: Global irradiance always refers to a horizontal plane. Global irradiance should not be confused with global tilted irradiance, see hemispherical irradiance

3.18

diffuse solar irradiance

hemispherical solar radiation minus direct solar radiation

Note 1 to entry: For meteorological purposes, the solid angle from which the scattered radiative fluxes are measured shall be the whole hemisphere above the sensor surface, excluding a small solid angle around the sun's disc.

Note 2 to entry: Symbol: G_d , Unit: $\text{W}\cdot\text{m}^{-2}$

Note 3 to entry: The tilt angle and the azimuth of the receiving surface should be specified, e.g., horizontal

[SOURCE: ISO 9488:2022].

3.19

sensitivity

responsivity

quotient of the change in an indication of a measuring system and the corresponding change in a value of a quantity being measured

[SOURCE: ISO 9059]

Note 1 to entry: In the previous version of the standard, calibration factor was also used which is the inverse of sensitivity.

Note 2 to entry: Sensitivity symbol: S , Responsivity symbol: R

Note 3 to entry: In the particular case of pyranometer, the input quantity is solar irradiance and the indication can, for example, be an output voltage or current signal.

3.20

calibration of a test pyranometer

determination of the sensitivity of a test pyranometer to irradiance, with associated measurement uncertainties, under well-defined measurement conditions

[SOURCE: ISO 9059]

Note 1 to entry: For most pyranometers, the output varies linearly with the irradiance and the calibration result is expressed as a single sensitivity value.

3.21

calibration conditions

conditions, ambient or instrument, during the calibration process

[SOURCE: ISO 9059]

3.22

reference (operating) conditions

operating conditions prescribed for evaluating the performance of a measuring instrument or measuring system or for comparison of measurement results

[SOURCE: ISO 9847:2023]

Note 1 to entry: For practical purposes, these typically are the conditions specified for the reported sensitivity

3.23

world radiation reference (WRR)

primary measurement standard representing SI Unit of solar irradiance

[SOURCE: ISO 9488:2022, 3.3.1, modified]

Note 1 to entry: The reference was adopted by the World Meteorological Organization (WMO) and has been in effect since 1 July 1980. The WRR is maintained by the WMO World Radiation Centre at Davos, Switzerland. One of the distinguishing feature of traceability to WRR is that reference - operating conditions include the full spectrum of direct solar radiation because reference instruments do not use any glass window. Currently, the uncertainty of the WRR is less than $\pm 0,3\%$ (coverage factor $k = 3$)^[2].

3.24

sample

data acquired from a sensor or measuring device at a given time

[SOURCE: ISO 9847:2023]

3.25

sampling interval

time interval between subsequent samples

[SOURCE: ISO 9847:2023]

3.26

record

data recorded with the same timestamp and stored in data set, based on acquired samples

[SOURCE: ISO 9847:2023, modified]

3.27

(data) series

set of consecutive records (measured over a limited period of time).

3.28

data set

the collection of all data recorded during calibration period.

3.29

offset correction

value added algebraically to a reading (voltage, current, irradiance, etc.) to compensate for a deviation from zero in the meter (in respective units) when input excitation is null.

Note 1 to entry: The offset correction is equal to the negative of the deviation found. Offsets are usually considered as systematic errors generated by different sources.

3.30

correction factor

numerical factor by which the uncorrected result of a measurement is multiplied to compensate for systematic error

[SOURCE: ISO Guide 98-3]

Note 1 to entry: since the systematic error cannot be known with absolute certainty, the compensation is not perfect.

3.31

response time

a measure of the stabilization period of the radiometer output signal for an accurate reading under realistic irradiance changes

Note 1 to entry: The stabilization time of the radiometer signal output is at least three times the radiometers 95% response time

[SOURCE: ISO 9060:2018, 4.3.2]

3.32

zero offset-A

the instrument's response to net thermal radiation

[SOURCE: ISO 9060:2018, 4.3.2]

3.33

zero offset-B

measurement error due to a temperature gradient (e.g., 5K/hour) caused by differences in thermal time constants of various parts of the radiometer.

3.34

non-stability

the annual percentage change in the instrument sensitivity

3.35

non-linearity

percentage deviation from the responsivity at $500 \text{ W}\cdot\text{m}^{-2}$ due to the change in irradiance within $100 \text{ W}\cdot\text{m}^{-2}$ to $1\,000 \text{ W}\cdot\text{m}^{-2}$

[SOURCE: ISO 9060: 2018]

3.36

directional response

the range of errors caused assuming that the normal incidence responsivity is valid for all directions when measuring irradiance from any other directions (zenith, azimuth, etc.)

3.37

clear sky global horizontal irradiance spectral error

the error observed for a set of global horizontal irradiance clear sky spectra

3.38

temperature response

the relative change in instrument sensitivity due to a change in ambient temperature

3.39**tilt response**

the percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 180° at 1 000 W·m⁻² irradiance(SOURCE: ISO 9060:2018)

3.40**signal processing errors**

the additional errors that may be caused by internal electronics (digital instruments) or electronic noise in the cables and data acquisition system

4 Selection of methods

Three calibration methods have been selected for standardization (see [Table 1](#)), because they are widely used and are reliable. The first two methods use a shading disc for measuring diffuse solar radiation and are based on the hemispherical solar radiation being equal to the sum of direct and diffuse components. The third method uses a collimated tube to remove the diffuse component.

The derived instrument sensitivities are representative of cloudless or scattered cloud conditions (see [Clause 8](#) for uncertainties). A modification of the calibration method in [Clause 5](#) for application during less stable sky conditions is briefly described in [Annex D](#).

[Annex E](#) contains a short description of an extended version of the calibration method in [Clause 6](#) to determine the dependence of the calibration factors on incidence angles.

In the alternating method, if the pyranometer is mounted on a tracker at normal incidence, there are no directional response errors, and a lower calibration uncertainty can be obtained.

In the alternating method, the zero offset-A of the pyranometer is taken out, since the diffuse reading is subtracted from the global reading. The result is a pyranometer calibration which is valid for condition where longwave (net) radiation = 0 W·m⁻² or for a well-ventilated pyranometer.

In the alternating method, the irradiance varies in time due to switching between the shaded and un-shaded state. This can have effects on the temperature of the instrument and might therefore induce an uncertainty caused by zero offset-B. Unfortunately, this effect does not cancel out.

Table 1 — Comparison of the three methods

	Alternating sun-and- Shade	Continuous sun-and- Shade	Collimation Tube
Reference instrument(s) needed	Pyrheliometer	Pyrheliometer and pyranometer	Pyrheliometer
Specific apparatus needed	Tracker with automatic shutter (shading disc)	Tracker with regular shading disc for diffuse reference	Tracker with collimation tube
Spectrum for which test pyranometer is calibrated	Direct irradiance	Hemispherical irradiance	Direct irradiance
Zero offset A error included in Sensitivity	No, drops out	Included in calibration	No, dome is covered by tube
Zero offset B error included in Sensitivity	Yes, dynamic process; there could be a zero B	No, or small contribution	No, or small contribution
Directional error included in Sensitivity	No, if tracked Yes, if horizontal or if fixed tilt	No, if tracked Yes, if horizontal or if fixed tilt	No