



BSI Standards Publication

Solar energy — Calibration of pyrheliometers by comparison to a reference pyrheliometer

National foreword

This British Standard is the UK implementation of ISO 9059:2025.

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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**International
Standard**

ISO 9059

**Solar energy — Calibration of
pyrheliometers by comparison to a
reference pyrheliometer**

*Énergie solaire — Étalonnage des pyrhéliomètres par
comparaison à un pyrhéliomètre de référence*

**Second edition
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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 document 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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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 9059:1990) which has been technically revised.

The main changes are as follows:

- focus on current calibration practices;
- adapted recommendations for mathematical treatment of data;
- revised terminology in line with ISO 9060, ISO 9488, ISO Guide 99 and BIPM VIM^[2];
- added comments on uncertainty evaluation of the calibration with reference to ASTM G213^[3] 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

Pyrheliometers measure the direct solar irradiance, expressed in Watts per square meter ($\text{W}\cdot\text{m}^{-2}$), received from the sun when the instrument is pointed directly at it.

Accurate measurements of the direct solar irradiance are required for:

- a) determination of the energy input to solar energy systems such as photovoltaic (PV), and solar thermal systems, as a basis for performance assessment;
- b) testing and assessment of solar technologies;
- c) 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.

Current 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 (see Reference [4]) and a correct uncertainty evaluation are required.

Calibration of measurement instrumentation is an essential part of the uncertainty evaluation and part of any quality management system. Regular instrument recalibration according to this document helps attain the required low measurement uncertainties. Consistent calibration results indicate instrument stability combined with best measurement practices confirm that the measurement data collected over the time interval from the previous to the present calibration are reliable.

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

The calibration of pyrheliometers specified in this document is traceable to the international system of units (SI) through the world radiometric reference (WRR) according to the world meteorological organization (WMO) guidelines.[5] The classification and specification used are given in ISO 9060.

Solar energy — Calibration of pyrheliometers by comparison to a reference pyrheliometer

1 Scope

This document specifies methods for calibration of pyrheliometers using reference pyrheliometers and specifies the calibration procedures for the transfer of the calibration.

This document is applicable for use by calibration service providers and test laboratories to enable a uniform quality of accurate calibration sensitivities to be achieved.

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

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 following terms and definitions apply.

ISO and IEC maintain terminology 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

pyrheliometer

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

Note 1 to entry: Typical opening half angles of common and historical pyrheliometers range from 2,5° to 7,5°. Reference [5] recommends that the opening half-angle (half field-of-view-angle) is 2,5° (6×10^{-3} sr) (see 5.4.2 and Figure 2) and the slope angle 1° for all new designs of direct solar radiation instruments. The slope angle is the angle defined by the edges of the apertures at the ends of the collimating tube (see Figure 2). For mathematical definitions of the angles, see ISO 9060:2018, 5.1 b) and Figure 2 of this document. For a detailed description of the influence of circumsolar radiation on the pyrheliometers refer to References [6-8] and Annex A.

Note 2 to entry: The spectral responsivity of pyrheliometers is often limited by the use of a glass window to the range of approximately 0,3 μm to near 3 μm , depending on the window transmittance properties. The spectral range (50 % points) given is only nominal. Depending on the radiometer design, the spectral limits of its responsivity can be different from the limits mentioned above.

[SOURCE: ISO 9488:2022, 3.3.5, modified — Notes 1 and 2 to entry added.]

3.2

pyrheliometer classification

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

Note 1 to entry: Additional information can be found in ISO 9060:2018, 4.3.1

3.3

test pyrheliometer

pyrheliometer being calibrated

[SOURCE: ISO 9847:2023, 3.7, modified — term changed from "field pyranometer".]

3.4

reference pyrheliometer

pyrheliometer that is well-characterized and well-maintained, to be used to measure the (input) irradiance when calibrating a *test pyrheliometer* (3.3)

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

Note 2 to entry: Use of the reference pyrheliometer should be restricted to comparisons and calibration activities. The instrument should be stored carefully in a laboratory under moderate ambient conditions when not used.

Note 3 to entry: The reference pyrheliometer should be of equal, or preferably, higher classification than the test pyrheliometer

Note 4 to entry: An *absolute cavity pyrheliometer* (3.5) is recommended.

3.5

absolute cavity pyrheliometer

absolute radiometer

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

Note 1 to entry: Additional information on absolute cavity pyrheliometers is given in ISO 9060:2018, 5.2.1.

3.6

field-of-view angle

FOV

opening angle

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

[SOURCE: ISO 9488:2022, 3.3.6, modified — opening angle has been added as an accepted term and the abbreviation "FOV" has been added.]

3.7

solar tracker

sun tracker

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

3.8

direct solar irradiance

G_b

beam solar irradiance

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

Note 1 to entry: The SI units are $W \cdot m^{-2}$

Note 2 to entry: Approximately 97 % to 99 % of the direct normal solar irradiance received at the ground is contained within the wavelength range from 0,3 μm to 3 μm Reference [9] (see 3.1, Note 2 to entry).

[SOURCE: ISO 9060:2018, 3.3]

3.9**direct normal incidence solar irradiance** G_{bn}

direct normal irradiance

direct solar radiation received by a plane at normal incidence

Note 1 to entry: The SI units are $\text{W}\cdot\text{m}^{-2}$

Note 2 to entry: In general, direct normal solar irradiance is measured by instruments with *field-of-view angles* (3.6) of up to 6° . Therefore, a part of the scattered radiation around the sun's disc (circumsolar radiation or aureole) is also included (see 5.2). For a more detailed definition of circumsolar radiation and related parameters refer to References [6-8] and see Annex A.

3.10**sensitivity** S

responsivity

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

Note 1 to entry: In the particular case of pyrheliometers, the input quantity is solar irradiance and the indication can, for example, be an output voltage or current signal.

Note 2 to entry: This term is often used interchangeably with responsivity denoted by R .

[SOURCE: ISO 9847:2023, 3.4]

3.11**calibration**determination of the sensitivity of the test pyrheliometer to irradiance, with associated measurement uncertainties, under well-defined *calibration conditions* (3.12)

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

Note 2 to entry: Additional information on calibration is given in References [2-4, 10, 11].

3.12**calibration conditions**

conditions, ambient or instrument, during the calibration process

[SOURCE: ISO 9847:2023, 3.8.]

3.13**reference operating condition**

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

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

[SOURCE: ISO 9847:2023, 3.9, modified — Note 2 to entry deleted.]

3.14**world radiometric reference****WRR**

primary measurement standard representing the SI unit of solar irradiance

Note 1 to entry: The reference was adopted by the World Meteorological Organization (WMO) and has been in effect since 1 July 1980. One of the distinguishing features of the WRR is that *reference operating conditions* (3.13) include the full spectrum of direct solar radiation. This is achieved using open cavity radiometers that do not have glass windows that can introduce a spectral response attenuation (see 3.1, Note 2 to entry). Currently, the uncertainty of the WRR is 0,3 % (coverage factor $k = 3$) References [5, 12, 13].

[SOURCE: ISO 9488:2022, 3.3.1, modified — Notes to entry 1 to 3 to entry of the original term were edited and combined in to Note 1 to entry.]

**3.15
sample**

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

[SOURCE: ISO 9847:2023, 3.11, modified — Note 1 to entry removed.]

**3.16
sampling interval**

time interval between sequential *samples* ([3.15](#))

[SOURCE: ISO 9847:2023, 3.12, modified — Note 1 to entry removed.]

**3.17
record**

data recorded with the same timestamp and stored in data log, based on acquired *samples* ([3.15](#))

[SOURCE: ISO 9847:2023, 3.13, modified — Note 1 to entry removed and "with the same timestamp" added to definition.]

**3.18
data series**

set of consecutive *records* ([3.17](#)) measured over a limited period of time

**3.19
data set**

collection of all data recorded during calibration period

**3.20
offset correction**

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

**3.21
correction factor**

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

Note 1 to entry: Since all systematic errors cannot be known perfectly, the compensation cannot be complete.

[SOURCE: ISO/IEC GUIDE 98-3:2008, B.2.24, modified — added "each" to the definition and modified Note 1 to entry.]

**3.22
tilt angle**

angle between the horizontal plane and the plane of the *pyrheliometer* ([3.1](#)) sensor surface

Note 1 to entry: For an aligned pyrheliometer, the tilt angle equals the *zenith angle* ([3.23](#)).

[SOURCE: ISO 9847:2023, 3.19, modified — changed pyranometer to pyrheliometer and added a note 1 to entry]

**3.23
zenith angle**

angle of incidence of radiation, relative to zenith

Note 1 to entry: The zenith is the angle between the earth's surface normal and the line to the sun.

[SOURCE: ISO 9847:2023, 3.21, modified — part of the definition was moved to Note 1 to entry.]