



BSI Standards Publication

Solar energy — Calibration of a pyranometer using a pyr heliometer

National foreword

This British Standard is the UK implementation of ISO 9846:2025.

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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 9846

**Solar energy — Calibration of a
pyranometer using a pyr heliometer**

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

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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 9846:1993) which has been technically revised.

The main changes are as follows:

- focus on current calibration practices
- addition of a collimation tube calibration method;
- adapted recommendations for mathematical treatment of data;
- revised terminology in line with ISO 9060, ISO 9488 and ISO Guide 99;
- 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

This document aims to promote the uniform application of reliable methods to calibrate pyranometers by comparison to a reference pyrhelimeter. 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) 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) 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.

The World Meteorological Organization (WMO) World Radiometric Reference (WRR), which represents the SI units of solar irradiance, is determined by a group of selected pyrhelimeters. 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 pyrhelimeters that have a limited field of view (typically only 5 degrees) requires additional equipment such as shading discs or collimation tubes.

The pyranometer calibration procedures described in this document are traceable to the International System of Units (SI) through the WRR according to the WMO guidelines Reference [5]. The classification and specification used are prescribed in ISO 9060 Reference [6].

Due to the relatively high accuracy of pyrhelimeters, the methods in this document may lead to lower uncertainties than those obtained by calibration of a pyranometer using a reference pyranometer as given in ISO 9847.

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

Solar energy — Calibration of a pyranometer using a pyrhelimeter

1 Scope

This document specifies calibration methods for a pyranometer using a pyrhelimeter as a reference instrument. Three methods are specified in this document.

- a) Alternating sun and shade method. This method uses a shading disc to alternately shade and unshade a pyranometer to compare with the tracking pyrhelimeter. The test pyranometer can be horizontal, on a fixed tilt or tracking alongside the pyrhelimeter.
- b) Continuous sun and shade method. In this method, a shaded calibrated reference pyranometer is used in addition to the reference pyrhelimeter. The test pyranometer can be horizontal, on a fixed tilt or tracking alongside the reference pyrhelimeter, but the reference pyranometer must be mounted in the same plane as the test pyranometer (most often on the horizontal).
- c) Collimation tube method. In this method, the test pyranometer is mounted on a solar tracker and is equipped with a collimation tube designed to allow the test pyranometer to have the same geometric view as the reference pyrhelimeter for a direct comparison of the two instruments.

The methods in this document are applicable for calibration of all pyranometers 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 can 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 9059, *Solar energy — Calibration of pyrhelimeters by comparison to a reference pyrhelimeter*

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

ISO 9488, *Solar energy — Vocabulary*

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 terms and definitions given in ISO 9060, ISO 9488, ISO 9059 and the following 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

pyranometer

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

3.2

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°^[5] recommends that the opening half-angle (half field-of-view-angle) is 2,5° (6 x10⁻³ sr) 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^[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.]

3.3

instrument classification

pyranometers and 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 and 5.3.1.

3.4

test pyranometer

pyranometer being calibrated

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

3.5

reference radiometer

radiometer (pyranometer or pyrheliometer), that is well-characterized and well-maintained, to be used to measure the (input) irradiance when calibrating a *test pyranometer* ([3.4](#))

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

Note 2 to entry: Use of the reference radiometer 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 cavity radiometer

absolute pyrheliometer

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 pyrheliometers is given in ISO 9060:2018, 5.2.1.

3.7 field-of-view angle

FOV

opening angle

full angle of the geometrical cone which is defined by the centre of the receiver radiometer 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 definition has been revised.]

3.8 solar tracker

sun tracker

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

[SOURCE: ISO 9059:2025, 3.7]

3.9 equatorial tracker

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

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

[SOURCE: ISO 9488:2022, 3.1.13]

3.10 altazimuth tracker

sun-following device which uses the solar elevation angle and the azimuth angle the sun as coordinates of movement

[SOURCE: ISO 9488:2022, 3.1.14]

3.11 shading disc

shading ball

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

device used to limit the field of view of a pyranometer to match the *field of view* ([3.7](#)) and slope angle ([3.2](#), Note 1 to entry) of a pyrhelimeter

3.13 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 $\text{W}\cdot\text{m}^{-2}$.

Note 2 to entry: Approximately 97 % to 99 % of the direct solar irradiance received at the ground is contained within the wavelength range from 0,3 μm to 3 μm . Reference [\[9\]](#) (see [3.2](#), Note 2 to entry).

[SOURCE: ISO 9060:2018, 3.3]

3.14

direct normal incidence solar irradiance

G_{bn}

direct normal irradiance

DNI

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 radiation is measured by instruments with field-of-view angles (3.7) of up to 6° . 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 see Reference [8] and see ISO 9059:2025, Annex A.

3.15

hemispherical solar radiation

solar radiation received by a plane surface from a solid angle of 2π sr

Note 1 to entry: The tilt angle and the azimuth 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 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 $0,3\ \mu\text{m}$ to $3\ \mu\text{m}$ Reference [9].

Note 5 to entry: The SI units are $\text{W}\cdot\text{m}^{-2}$.

[SOURCE: ISO 9488:2022, 3.2.22, modified — Note 5 to entry added.]

3.16

global solar irradiance

G

GHI

global horizontal irradiance

hemispherical solar irradiance on a horizontal plane

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

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

3.17

diffuse solar irradiance

G_d

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

Note 3 to entry: The SI units are $\text{W}\cdot\text{m}^{-2}$.

[SOURCE: ISO 9488:2022, 3.2.24, modified — Notes 1 and 3 to entry added.]

3.18 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 previous edition of this document, calibration factor was also used which is the inverse of sensitivity.

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

[SOURCE: ISO 9059:2025, 3.10, modified — Note 1 to entry revised.]

3.19 calibration

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

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.

[SOURCE: ISO 9059:2025, 3.11, modified — Note 1 to entry revised and deleted Note 2 to entry.]

3.20 calibration conditions

conditions, ambient or instrument, during the calibration process

[SOURCE: ISO 9059:2025, 3.12]

3.21 reference operating conditions

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.]

3.22 world radiation reference WRR

primary measurement standard representing 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 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 [3.2](#), Note 2 to entry). Currently, the uncertainty of the WRR is 0,3 % (coverage factor $k = 3$) References [\[5\]](#), [\[10\]](#).

[SOURCE: ISO 9488:2022, 3.3.1, modified — Notes 1 to 3 to entry were revised and combined in to Note 1 to entry.]

3.23 sample

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

[SOURCE: ISO 9847:2023, 3.11]

3.24

sampling interval

time interval between sequential *samples* (3.23)

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

3.25

record

data recorded with the same timestamp and stored in data set, based on acquired *samples* (3.23)

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

3.26

data series

set of consecutive *records* (3.25) measured over a limited period of time

3.27

data set

collection of all data recorded during calibration period

3.28

offset correction

value added algebraically to a reading (voltage, current, irradiance, etc.) to compensate for a deviation from zero (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.

3.29

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 the systematic error cannot be known with absolute certainty, the compensation is not perfect.

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

3.30

response time

measure of the stabilization period of the radiometer output signal

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

Note 2 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.31

zero offset-A

instrument response to net thermal radiation

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.32

zero offset-B

measurement error due to a temperature gradient caused by differences in thermal time constants of various parts of the radiometer

Note 1 to entry: For example, the temperature gradient can be 5 K/hour.

Note 2 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.33**non-stability**

annual percentage change in the instrument sensitivity

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.34**non-linearity**

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

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.35**directional response**

range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring irradiance from any other directions

Note 1 to entry: Other directions include the zenith, azimuth, etc.

Note 2 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.36**spectral error**

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

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.37**temperature response**

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

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.38**tilt response**

percentage deviation of the instrument sensitivity at 0° tilt (horizontal) due to change in tilt from 0° to 180° at $1\,000 \text{ W}\cdot\text{m}^{-2}$ irradiance

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

3.39**signal processing errors**

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

Note 1 to entry: Definition based on ISO 9060:2018, 4.3.2.

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 (see [Clause 5](#) and [6](#)) 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 F](#) 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 (see [Clause 5](#)), if the pyranometer is mounted on a tracker at normal incidence, there are no directional response errors, and a lower calibration uncertainty may be obtained. In this 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 is $0 \text{ W}\cdot\text{m}^{-2}$ or for a well-ventilated pyranometer. Moreover, 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 can 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 method	Continuous sun-and-shade method	Collimation tube method
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
Irradiance for which test pyranometer is calibrated	Direct irradiance	Hemispherical irradiance	Direct irradiance
Zero offset-A included in Sensitivity	No, drops out	Included in calibration	No, dome is covered by tube
Zero offset-B included in Sensitivity	Yes, dynamic process; there could be a zero B	No, or small contribution	No, or small contribution
Directional response included in Sensitivity	No, if tracked Yes, if horizontal or if fixed tilt	No, if tracked Yes, if horizontal or if fixed tilt	No
Tilt response included in Sensitivity	Yes, if tracked No, if horizontal or if fixed tilt	Yes, if tracked No, if horizontal or if fixed tilt	yes
Number of datapoints	Due to required stabilization time, it takes long to collect data points	Easier to collect more data points, although clouds could influence global readings and datapoints may be unusable.	Easiest to collect many usable datapoints
Additional remarks		Only method for non-spectrally flat pyranometers	

While each method has advantages and disadvantages, one should use the method that most resembles the conditions expected for field use of the test pyranometer to achieve the lowest field measurement uncertainties (which are different from the calibration uncertainties), see Reference [\[4\]](#) and [Annex G](#) for details.

The calibration methods for non-tracking pyranometers rely on the sun incidence angle for the calculation of the sensitivity. It is therefore of critical importance that the time for the incidence angle calculation is accurately recorded (and that the time does not include daylight saving time shifts, see Reference [\[4\]](#) for more detail).

NOTE Conditions that vary over the course of the calibration period (e.g., temperature variation) can lead to measurement errors increasing the standard deviation. On the other hand, systematic errors can lead to a shift in sensitivity, and can be corrected for.

5 Alternating sun-and-shade method (shade/unshaded method)

5.1 Principle

The test pyranometer is alternatively shaded and unshaded by means of a movable sun shade disc, the difference of these two measurements corresponds to the response of the pyranometer to the direct sun

irradiance. In order to calibrate the pyranometer, the response to the direct component is evaluated against the reading from a reference pyr heliometer, allowing the sensitivity to be determined by:

$$S = \frac{V_{\text{unshaded}} - V_{\text{shaded}}}{G_{\text{bn,ref}} \times \cos(\theta)} \quad (1)$$

where

S is the sensitivity in units of output signal per $\text{W}\cdot\text{m}^{-2}$ for the test pyranometer to be calibrated;

V_{unshaded} is the output signal of the test pyranometer without shade disc;

V_{shaded} is the output signal of the test pyranometer with shade disc;

$G_{\text{bn,ref}}$ is the direct (beam) normal irradiance measured by reference pyr heliometer in $\text{W}\cdot\text{m}^{-2}$;

θ is the incidence angle relative to the normal on the pyranometer sensor plane.

If the pyranometer is tracked then the sun incidence angle is zero (see [Annex B](#)).

V_{unshaded} and V_{shaded} in [Formula \(1\)](#) refer to a generic electrical output, interchangeably a voltage or current signal, for any of the unshaded and shaded instruments.

For digital sensors, the signal reading can be substituted by the irradiance measurement. In that case, the result of [Formula \(1\)](#) would be a correction multiplier instead of a sensitivity, See also [5.2.5](#).

If any offset correction term or a modified measuring formula is used for calculating the $G_{\text{bn,ref}}$ reference irradiance (e.g., by using a temperature coefficient, by subtracting a measured output signal offset, etc.), then this should be taken into account for computation of the uncertainty (see [Annex H](#)).

NOTE The test pyranometer can be placed in fixed horizontal or tilted positions, or installed on a tracker to have its receiving surface normal to the Sun's beam.

In the following [subclauses \(5.2, 5.3, 5.4, 5.5, 5.6, 5.7\)](#), the basic method is described. Modifications of this method, which can improve the accuracy of the sensitivities but require more operational experience, are mentioned in [Annex D](#) and [Annex E](#).

5.2 Apparatus

5.2.1 Pyranometer

This method can be applied to any type of pyranometer.

5.2.2 Pyr heliometer

The choice of pyr heliometer used as the reference should be made according to the required accuracy and the operational conditions. Generally, absolute cavity radiometers or Class A instruments (see ISO 9060:2018, Table 2) which are regularly compared with primary standards represent a satisfactory level of accuracy (see also [Clause 8](#)). The pyr heliometer should produce at least one reference value every 120 s.

The general pyr heliometer geometry is shown in [Figure A.2](#).

5.2.3 Solar tracker

The tracker is used to allow the pyr heliometer to continuously point at the sun and may also be used to position the shade device (see [Annex A](#) for more detail). The admissible misalignment of the sun tracker and other details are described in ISO 9059:2025, 5.3.2.

NOTE A solar tracker can be either an altazimuth or equatorial tracker.