TECHNICAL REPORT

ISO/TR 9901

Second edition
2021-08

Solar energy — Pyranometers — Recommended practice for use

Énergie solaire — Pyranomètres — Pratique recommandée pour l'emploi

Reference number
ISO/TR 9901:2021(E)

Contents

Page

Foreword .... **iv**

Introduction .... **v**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 Selection of pyranometers and accessories **4**
- 4.1 General 4
- 4.2 Pyranometer selection based on accuracy class 4
- 4.3 Pyranometer and accessory selection based on other considerations 6
- 4.4 Measuring system redundancy and spatial resolution 6
- 4.5 Common pyranometer accessories 7
  - 4.5.1 Electronics, data acquisition and power supply 7
  - 4.5.2 Heating and ventilation systems 8
  - 4.5.3 Mounting stands and supports 9
- 4.6 Personal safety 9

5 Recommended practice for use **10**
- 5.1 General 10
- 5.2 Pyranometers measuring plane of array and global horizontal irradiance 10
  - 5.2.1 General 10
  - 5.2.2 Installation 10
  - 5.2.3 Heating and ventilation 13
  - 5.2.4 Inspection and maintenance 13
  - 5.2.5 Data acquisition and storage 16
  - 5.2.6 Data quality control and correction 19
- 5.3 Pyranometers measuring diffuse radiation 20
  - 5.3.1 General 20
  - 5.3.2 Installation 22
  - 5.3.3 Heating and ventilation 23
  - 5.3.4 Inspection and maintenance 23
  - 5.3.5 Data acquisition and storage 23
  - 5.3.6 Data quality control and correction 23
- 5.4 Pyranometers measuring reflected radiation 24
  - 5.4.1 General 24
  - 5.4.2 Installation 24
  - 5.4.3 Inspection and maintenance 25
  - 5.4.4 Data acquisition and storage 25
  - 5.4.5 Data quality control and correction 25
- 5.5 Pyranometer calibration and performance verification 26
  - 5.5.1 Calibration 26
  - 5.5.2 On-site performance verification/check 28
  - 5.5.3 Introduction of a new pyranometer sensitivity 28
- 5.6 Uncertainty evaluation of the measurement 29
- 5.7 Indoor use of pyranometers 32

Annex A (informative) **Heating and ventilation systems** **34**

Annex B (informative) **Shading losses in reflected radiation measurement** **36**

Bibliography **38**

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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*, Subcommittee SC 1, *Climate — Measurement and data*.

This second edition cancels and replaces the first edition (ISO/TR 9901:1990), which has been technically revised.

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

— adaptation of the terminology to the revised ISO 9060:2018 including reference to new “non-spectrally flat” and “fast response” instruments;

— added recommended practices for use of modern pyranometers with a digital output, including internal diagnostics;

— added recommended practices for use of pyranometers to measure “plane of array” and reflected radiation;

— added references to the main standards used in solar energy application of pyranometers: IEC 61724-1:2017, ASTM G213-17 and ASTM G183-15.

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 contains recommendations for use of pyranometers in solar energy applications. It summarises the state of the art and updates the first edition of 1990. In recent years the application of solar radiation measurement, using pyranometers, has risen sharply. The main application of pyranometers now is no longer scientific research, but assessment of the performance of PV solar power plants, that is power plants employing photovoltaic solar modules. The reflected irradiance measurement also has become more relevant with the increasing application of bifacial modules.

Between 1990 and now the use of pyranometers has been further standardized. Two examples are the 2017 revision of IEC 61724, the group of standards governing use of PV system performance monitoring, and the 2018 revision of ISO 9060 covering pyranometer and pyrheliometer specification and classification. The IEC standard implicitly recognises that solar irradiance is a critical and often the least accurately known parameter in solar energy performance assessment. For those users that choose to work according to this standard, IEC 61724-1 now defines 3 monitoring system classes and offers detailed guidelines for use of pyranometers including requirements (not recommendations) for the pyranometer classes that must be used, for instrument heating and for inspection-, cleaning and recalibration intervals.

The solar community also has come to realize that a measurement without an uncertainty evaluation is meaningless. IEC 61724-1 requires this evaluation when measurement results are reported, usually as PV performance ratio and performance index. ASTM has issued the G213 standard in 2017 for uncertainty evaluation of the measurement with pyranometers.

The 1990 version of ISO TR 9901 included reference only to “spectrally flat” pyranometers. Now that ISO 9060 in its latest version also defines and classifies “non-spectrally flat” pyranometers, this document also refers to the use of these instruments.

As in all above documents, uncertainties mentioned in this document are expanded uncertainties with a coverage factor $k = 2$.

Solar energy — Pyranometers — Recommended practice for use

1 Scope

This document gives recommended practice for the use of pyranometers in solar energy applications (e.g. testing of solar photovoltaic panels, solar thermal collectors or other devices, and performance monitoring of solar energy systems). It is applicable for both outdoor and indoor use of pyranometers, when measuring plane of array, global horizontal and reflected irradiance, or radiation from a solar simulator. The measurement may be carried out on either a horizontal or an inclined surface, and the pyranometer may be part of a diffusometer, i.e. combined with a sun-shading device to measure diffuse radiation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and 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 http://www.electropedia.org/

3.1
pyranometer
radiometer designed for measuring the irradiance on a plane receiver surface which results from the radiant fluxes incident from the hemisphere above within the wavelength range from approximately 0,3 µm to about 3 µm to 4 µm

[SOURCE: ISO 9060:2018, 3.5, modified — Note 1 to entry was deleted.]

3.2
hemispherical radiation
solar radiation received by a plane surface from a solid angle of 2π sr

[SOURCE: ISO 9060:2018, 3.1, modified — Note 1 to entry was deleted.]

3.3
global horizontal irradiance
GHI
hemispherical radiation (3.2) received by a horizontal plane surface, also denoted as G

[SOURCE: ISO 9060:2018, 3.2, modified — "GHI" was added as abbreviated term and "also denoted as G" was added at the end of the definition.]

3.4
direct radiation
radiation received from a small solid angle centred on the sun's disc, on a given plane

Note 1 to entry: Reference [3] recommends an opening half angle of 2,5° and a slope angle of 1°. In general, direct radiation is measured by instruments with field-of-view angles of up to 6°. Therefore, a part of the scattered radiation around the sun's disc (circumsolar radiation or aureole) is also included (see ISO 9060:2018, 5.1).

Note 2 to entry: Approximately 97 % to 99 % of the direct radiation received at the ground is contained within the wavelength range from 0,3 µm to 3 µm.

[SOURCE: ISO 9060:2018, 3.3, modified — "solar" was deleted from the term, Note 1 to entry was modified and Note 3 to entry was deleted.]

3.5
direct normal irradiance
DNI
radiation received from a small solid angle centred on the sun's disc, on a plane normal to its direction

3.6
diffuse radiation
hemispherical radiation (3.2) minus coplanar *direct radiation* (3.4)

Note 1 to entry: For the purposes of solar energy technology, diffuse radiation includes solar radiation scattered in the atmosphere as well as solar radiation reflected by the ground, depending on the inclination of the receiver surface.

[SOURCE: ISO 9060:2018, 3.4, modified — Note 2 to entry was deleted.]

3.7
diffuse horizontal irradiance
DHI
global horizontal irradiance (3.3) minus coplanar direct (the portion emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of 5°)

[SOURCE: IEC 61724-1:2017]

3.8
plane of array irradiance
POA
sum of direct, diffuse, and ground-reflected irradiance incident upon the frontside of an inclined surface parallel to the plane of the modules in the PV array

[SOURCE: IEC 61724-1:2017]

3.9
reflected irradiance
RI
ground-reflected irradiance incident upon a defined surface, typically parallel to the plane of the modules in the (bifacial) PV array

[SOURCE: IEC 61724-1:2017]

3.10
rearside plane of array irradiance
POA^{REAR}
sum of direct, diffuse, and ground-reflected irradiance incident on the back side of an inclined surface parallel to the plane of the modules in the PV array

[SOURCE: IEC 61724-1:2017]

3.11
reflected horizontal irradiance
RHI
ground-reflected irradiance incident upon a surface, oriented horizontally facing down

[SOURCE: IEC 61724-1:2017]

3.12
accuracy class
class of measuring instruments or measuring systems that meet stated metrological requirements that are intended to keep measurement errors or instrumental uncertainties within specified limits under specified operating conditions

[SOURCE: JCGM 200:2012]

3.13
sample
data acquired from a sensor or measuring device

[SOURCE: IEC 61724-1:2017]

3.14
sampling interval
time between samples

[SOURCE: IEC 61724-1:2017]

3.15
record
data recorded and stored in data log, based on acquired samples

[SOURCE: IEC 61724-1:2017]

3.16
recording interval
time between records

[SOURCE: IEC 61724-1:2017]

3.17
clearness index
k
ratio of the *global horizontal irradiance* (3.3) to the irradiance that would be available without the earth's atmosphere (i.e. the GHI divided by the extra-terrestrial irradiance received at the same sun incidence angle, $k = G/G_0$)

Note 1 to entry: The extra-terrestrial irradiance at normal incidence used for calculation of the clearness index is the Solar constant (1361,1 W/m^2)[17] corrected by a sinusoidal variation of amplitude 3,3 % to account for the sun-earth distance variation over the year. The clearness index may be considered as an attenuation factor of the atmosphere or the atmospheric transmittance.

3.18
reference operating condition
reference condition
operating condition 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 are often the conditions for which the calibration is valid.

[SOURCE: JCGM 200:2012]

3.19
calibration of a pyranometer
determination of the instrument sensitivity, under well-defined *reference operating conditions* (3.18)

Note 1 to entry: See also ISO 9846.

4 Selection of pyranometers and accessories

4.1 General

A pyranometer performs a hemispherical irradiance measurement in W/m^2. It is important to realize that in many applications for example when working according to monitoring standards IEC 61724-1[21], ASTM G183[22] and WMO[3] a measurement are accompanied by a time stamp. Both the irradiance and the time stamp have a measurement uncertainty. See 5.2.5.2 and 5.6 for more details on uncertainty evaluation.

The pyranometer selection is often based on the wish to attain a certain measurement uncertainty. There also may be other considerations:

a) Task-specific criteria, such a maximum response time, or the requirement to comply with a standard.

b) Operational criteria, such as dimensions, weight, stability, measures to mitigate dew, frost, precipitation and soiling, and maintenance requirements of the instrument and accessories.

c) Economic criteria, costs of mechanical and electrical integration in a system depend on the instrument characteristics. Also costs of recalibration, inspection and maintenance may be considered.

When selecting an instrument there are two common ways to make a choice, described in the following clauses:

— related to the pyranometer accuracy class;

— related to the specifications of the pyranometer and its accessories.

4.2 Pyranometer selection based on accuracy class

In some applications the choice of instrument is driven by the pyranometer accuracy class. The class is often, but not necessarily related to the type, i.e. the technology used (e.g. with photodiode or thermopile sensors).

The choice of a certain accuracy class is often driven by the requirements of standards. Table 1 summarizes the required pyranometer accuracy class for the most common application of PV system performance monitoring according to IEC.

NOTE IEC 61724-1 is due for revision in 2021, and requirements will possibly change.

ISO 9060:2018 defines 3 pyranometer classes, A, B and C. These classes are “accuracy classes”, which are defined by JCGM 200:2012 to meet stated metrological requirements that are intended to keep measurement errors or instrumental uncertainties within specified limits under specified operating conditions[24].

The accuracy classification as used in ISO 9060 does not by definition mean that a higher class pyranometer will provide a higher accuracy measurement; this entirely depends on the application.

Besides classification as class A, B, and C, ISO 9060 makes a further distinction between 2 main types and an independent sub-category:

— *spectrally flat pyranometers*; most thermoelectric pyranometers are in this category;

— (non-spectrally flat) *pyranometers*; photodiode pyranometers may qualify for this category;

a further sub-category of *fast-response pyranometers*.

Table 1 — Application of pyranometers of different ISO 9060 accuracy classes for the most common solar energy studies

Application for solar energy studies	ISO 9060 instrument accuracy class and comments
IEC 61724-1 PV system performance monitoring class A	ISO 9060 spectrally flat class A, with dew and frost mitigation in case these have a significant impact on the measurement accuracy
IEC 61724-1 PV system performance monitoring class B	ISO 9060 spectrally flat class B, with dew and frost mitigation in case these have a significant impact on the measurement accuracy
NOTE IEC 61724-1 is expected to be updated in 2021, and requirements of a new version of the standard may be different from those stated in above table.	

Pyranometers classified in ISO 9060 as “spectrally flat” have a spectral selectivity of less than 3 % (guard bands 2 %) in the 0,35 µm to 1,5 µm spectral range. This is the same requirement as in the previous ISO 9060:1990 for secondary standard pyranometers. Spectrally flat pyranometers are typically more accurate over a wide range of conditions, and applicable not only for horizontal measurement of global horizontal irradiance, GHI, but also for measurements of plane of array irradiance, POA, and reflected irradiance, RI, as well as for artificial solar sources such as lamps. IEC 61724-1 requires use of instruments of a specified accuracy class for its class A and B monitoring systems. There is consensus that the spectral selectivity specifications of ISO 9060 “spectrally flat” pyranometers have a negligible (zero) spectral error and that they can be used for all the common outdoor measurements in solar energy studies with the same calibration (typically performed with the clear sky solar spectrum as the source) without significant loss of accuracy. The clear sky solar spectrum is one of the reference operating conditions for pyranometers if it is the source under which an instrument is calibrated or the source under which a calibration reference standard has been calibrated.

Pyranometers employing photodiodes (otherwise known as silicon-pyranometers), are not classified as “spectrally flat” in ISO 9060. The spectral error of pyranometers is defined for a set of clear sky solar spectra only. This implies that their spectral error for other than clear sky spectra cannot be based on the classification alone. The spectral error of pyranometers, in particular if they are not spectrally flat, may be larger for measurements of DHI, POA or RI than for clear sky GHI. The user may perform an individual uncertainty evaluation depending on the manufacturer specification of the instrument and the spectra of the measured radiation. The factory calibration of non spectrally flat instruments is typically valid for a set of clear sky solar spectra. Their sensitivity and uncertainty of their sensitivity may both change for different conditions.

Non spectrally flat pyranometers also may offer specific advantages; they generally are inexpensive, small and have a fast response time. They may be used for example for temporally highly resolved measurements, when overall accuracy requirements are not too high, or where constant spectrum conditions exist (for example, working with artificial sources, or only working under clear sky conditions). They also may be used for high-accuracy applications when calibrated under the working conditions.

In summary, spectrally flat pyranometers can be used for the most common solar testing applications, including GHI, POA, RI and albedo measurements using traceability to the same clear sky spectrum calibration. When using non-spectrally flat pyranometers for other than clear-sky GHI measurements, the spectral error may be larger than the spectral error specified in ISO 9060.

If a higher measurement accuracy is required than may be attained with a class A pyranometer, there also are class A pyranometers with improved directional error- and zero-offset specifications.

For the highest accurate measurement it is recommended to derive the hemispherical radiation from the combined measurements of a pyrheliometer and a shaded (i.e. shielded from direct radiation) pyranometer. These measure direct radiation and diffuse radiation respectively. There is international consensus that this type of measuring system provides the most accurate measurement possible[8].

Fast response pyranometers or spectrally flat fast response pyranometers are used when a fast response leads to a higher measurement accuracy. This may be to study highly variable sky conditions or over-irradiance events. ISO 9060 requires a 95 % response time <0,5 s to qualify for this sub-category.

4.3 Pyranometer and accessory selection based on other considerations

The accuracy classification of ISO 9060 does not by definition mean that a higher class pyranometer will provide a higher accuracy measurement; this entirely depends on the application. Users need to consider the suitability of a pyranometer not only based on the type or accuracy class, but also based on the detailed specifications of the pyranometer and its accessories.

As a first step, the requirements for the spectral response, see 4.2, and the operating conditions (temperature, irradiance, angle of incidence, tilt angle) may be established. The range of irradiance and ranges of operating conditions in indoor tests are usually smaller than those in outdoor tests, see 5.7 for indoor testing.

As a second step users could look at the accessories.

Reference is usually made to measuring and other specifications such as:

— specifications possibly exceeding those necessary for ISO 9060 classification, such as low zero offsets, good directional response, extended spectral range, faster response time, extended temperature range, as given by the manufacturer, or as established by testing;

— specifications of accessories such as external ventilations systems, shading mechanisms, etc.;

— additional measurements such as instrument temperature or internal humidity;

— type of output signal (digital vs analogue) or analogue output range;

— materials used; corrosive environments may require stainless steel;

— the price of instruments and accessories.

4.5 gives information about the most common accessories such as electronics and heating- and ventilation systems.

For studying events related to fast changes of irradiance, the response time may be the limiting factor. A fast response instrument, even if its classification may be lower, will then likely attain a higher measurement accuracy than a slower sensor. The sampling interval of the datalogger is typically chosen to be smaller than the instrument response time.

4.4 Measuring system redundancy and spatial resolution

To provide high-quality data, it is common practice to cross-check different radiation measurements or components and to have redundancy in each measurement. This also helps to reduce the risk of data loss and increase spatial resolution or coverage.

In many applications, duplicate measuring systems are installed; this is also practical for calibration; if one instrument is sent away for calibration another still provides measurement data.

Redundant measurement stations also provide input for uncertainty evaluation. The difference between the measurement at one station and another provides information on spatial variability, in particular when the measured parameters include reflected irradiance, which is the case for POA or RI measurements.

A standard such as IEC 61724-1 contains a set of redundancy recommendations, specifying the number of POA and GHI measurements for different PV system sizes, expressed in megawatt power rating.

When measuring at large PV power plants, spatial resolution may play a role in design of the measuring system.

4.5 Common pyranometer accessories

4.5.1 Electronics, data acquisition and power supply

Traditionally pyranometers were passive instruments with an analogue output in the millivolt range.

Nowadays pyranometers may also have an amplified voltage output, a current loop output or a digital output. Users select a pyranometer output based on their local requirements. When using pyranometers with an analog (as opposed to digital) output, the measurement specifications of the data acquisition system are an important factor influencing the measurement accuracy.

For electrical installation it is common practice to follow manufacturer recommendations.

Automatic data acquisition systems usually record either individual samples or integrated totals or averages of these samples over a specified interval.

Although a variety of equipment is available for data-recording and processing purposes, microprocessor-controlled data loggers using a variety of support systems for data storage are now the standard. On PV power plants, pyranometers with a digital output may directly be integrated with the local Supervisory Control and Data Acquisition (SCADA) system.

In solar energy applications the pyranometer output is just one of the parameters to be monitored. It is common practice to ensure that all measurements have accurate and synchronised time stamps.

In case the response time plays a significant role in the test; ISO 9060 defines a special category of “fast response” pyranometers. These require a shorter sampling interval to take advantage of this fast response. See also 5.2.6.

Unscheduled interruptions of the data recordings through power failures/flat batteries, which potentially also affect the data time stamps of the records, can be avoided by employing an uninterruptable power supply.

4.5.1.1 Electronics input impedance

For pyranometers with an analogue voltage output, the input impedance of the datalogger of analogue to digital conversion system is usually selected to be more than 1 000 times the value of the internal electrical resistance of the instrument. The cable electrical resistance, which is a function of conductor cross section and cable length, usually is smaller than the instrument electrical resistance. When this is not possible, for example when using very long cables, a voltage amplifier or current converter can be introduced near the pyranometer. Also use of a pyranometer with a digital output can then be considered.

BSRN recommends that whenever a cable resistance is higher than 10 ohm, pre-amplifiers are used, see Reference [8].

4.5.1.2 Electronics grounding, lightning protection

General recommendation:

— keep cables short;

— ground pyranometer instrument body, cable shield and other measurement equipment connected to it, using a low resistance conductor to a common electrical ground.