
**Solar energy — Pyranometers —
Recommended practice for use**

*Énergie solaire — Pyranomètres — Pratique recommandée pour
l'emploi*

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 9901:2021



STANDARDSISO.COM : Click to view the full PDF of ISO/TR 9901:2021



COPYRIGHT PROTECTED DOCUMENT

© ISO 2021

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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 pyrhelimeter 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 $k = 2$.

[STANDARDSISO.COM](https://standardsiso.com) : Click to view the full PDF of ISO/TR 9901:2021

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 ($1361,1 \text{ W/m}^2$)^[12] 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 pyrliometer 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 uninterruptible power supply.

4.5.1.1 Electronics input impedance

For pyranometers with an analogue voltage output, the input impedance of the datalogger or 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.

The electrical ground at the pyranometer may be at a different potential than the ground at the power supply of the data acquisition system. Such differences in ground potential can affect in particular the readings from pyranometers with analogue millivolt output and long cable connections^[12].

Be careful grounding pyranometers, as a measuring system may involve multiple grounds. There may be ground connections at the instrument body, at the power supply and in case of digital instruments at the digital master.

Using pyranometers with an analogue voltage output, the sensor output typically is of the order of millivolts. Even if the instrument is shielded, the sensor may be susceptible to electromagnetic interference which then produces noise. Proper shielding and electronics noise rejection may help.

For lightning protection avoid mounting the instrument on large, electrically conducting structures such as PV array mounting frames. If this cannot be avoided, surge protection may be added at both the instrument and the datalogger/digital master/power supply side. Use of optical isolation of some components may be helpful to create a single ground.

4.5.1.3 Electronics accuracy

When using instruments with an analogue (as opposed to digital) output, the measuring uncertainty of electronics accessories can be a significant part of the total measurement uncertainty of the irradiance measurement.

To determine criteria for the electronics accuracy users may look at the combined uncertainty evaluation of the entire measurement chain, see 5.6. In more detail: users may compare pyranometer accuracy specifications to those of the electronics. For example, consider comparing zero offset, linearity and temperature dependence specifications (you will find these both in the pyranometer and in the electronics specifications) over the entire range of operating temperatures. Especially for electronic systems installed outdoors the temperature dependences of offsets and sensitivity over the entire range of expected temperatures are important. It is common practice to choose electronics with a high accuracy, so that it has a low impact on the total uncertainty. Dataloggers of 16 bit or higher resolution are recommended.

For pyranometers, with amplified voltage output, current loop output or digital outputs, the accuracy of the electronics is part of the pyranometer specifications. When using a separate logger or amplifier, the uncertainty of these is separately taken into account and added to that of the pyranometer.

For pyranometers with an analogue millivolt output, the resolution of the data acquisition system usually is in the order of microvolts. It is important to take into account that millivolt amplifier accuracy is generally given for full-scale values while the pyranometer output can vary over two or three orders of magnitude.

4.5.2 Heating and ventilation systems

Heating and ventilation of pyranometers both have proven effective in all climates mitigating dew and frost deposition on the instrument. Heating is traditionally combined with external ventilation but may also be achieved by heaters alone. Ventilators themselves consume power and heat the ventilated air, but often are combined with additional electrical heaters to achieve a higher temperature increase. Mitigating dew and frost, using heating, ventilation or a combination of both usually leads to a significant improvement of measurement accuracy. However, heating may also introduce temperature gradients across the instrument, which lead to higher zero offsets and reduced measurement accuracy. Typically, ventilation reduces zero offsets as thermal gradients across the instrument are reduced by the transport of ventilated air with uniform temperature over the body and domes of the pyranometer.

Employing heating and/or ventilation, while keeping zero offsets within the limits of the instrument class, is therefore recommended in high accuracy measurements in all climates in which dew and frost often occur, and are included as a requirement in IEC 61724-1 and other recommended practices described in the WMO and BSRN manuals^{[21][3][8]}.

Deposition of dew, frost and soiling may be less of a concern for downfacing instruments than for upfacing instruments.

In summary, general heating and/or ventilation are reliable to:

- a) Mitigate dew and frost formation.
- b) Help rain droplets and snow to evaporate quickly.

In specific situations or when using specially designed systems, heating and/or ventilation can help.

- c) Reducing build-up of soiling and pollen by keeping the instrument dry so that particles do not stick to the instrument surface.

In specific situations or when using specially designed systems, external ventilation can help.

- d) Reducing build-up of soiling and pollen, prevention of rain and snow hitting the instrument by blowing clean filtered air over the instrument.
- e) Some of these ventilation systems may also help to reduce zero offsets —

Whether heating and/or ventilation realize their potential benefits as listed under c, d and e depends on —

- heating and ventilation system design, such as airflow, filtering of air, heating power;
- system maintenance, regular filter replacement;
- local conditions (total dust, snow load, type of snow, type of dust, humidity, temperature, presence of chemically aggressive air pollution).

Heating and ventilation units are briefly described in [Annex A](#). The information given in [Annex A](#) may be of assistance in deciding on a suitable system for a given application.

4.5.3 Mounting stands and supports

The pyranometer is designed to be securely attached to its mounting stand, using the holes or threads provided in the instrument. The stand usually is a rigid construction able to resist storms, temperature variations, humidity, etc. Mounting stand structures are designed to remain stable, so that instrument tilt and azimuth angles do not change over time. Typically, metal structures are preferred because they offer stability. A metal structure may help grounding the instrument body if it is connected to the common electrical ground. In some cases, electrical insulation may be added to avoid grounding the pyranometer body via a metal structure (see [4.5.1.2](#)). Wooden structures are generally less stable and do not electrically conduct.

It is common practice during the planning of installations, especially of systems with difficult access, to pay attention to the accessibility for inspection and cleaning.

4.6 Personal safety

PV arrays may generate high voltages (in the 1 000 V range) as well as high currents. Mounting of a pyranometer with its electrically conducting body onto a conducting PV array frame may create a safety hazard and is not recommended. In case of an electrical fault the pyranometer output cable may transmit these high voltages to the data acquisition system (e.g. when the cable shield is connected to the instrument housing). It is recommended to keep pyranometers away from high voltage sources. If this cannot be avoided, electrically insulate the pyranometer body from the source as well as the path that may act as electrical ground (also if this may happen only in exceptional situations) for the high voltage source.

5 Recommended practice for use

5.1 General

The following clauses comment on the most common applications of pyranometers in solar energy testing: measurement of plane of array, global horizontal, diffuse horizontal and reflected irradiance.

The more advanced measuring systems employ quality management system with a combination of:

- inspection and maintenance by on-site personnel;
- automated data review;
- remote instrument diagnostics;
- data review by experts;
- instrument recalibration.

[5.1](#) to [5.4](#) apply to outdoor use of pyranometers, including inspection and maintenance and data quality control.

The subjects of performance verification, recalibration and uncertainty evaluation, common to all measurements are addressed in separate [5.5](#) and [5.6](#).

[5.7](#) comments on indoor use of pyranometers, using a lamp source.

Please note that standards such as IEC 61724-1, the WMO manual and the BSRN manual and ASTM G183 have their own specific requirements for example relating to cleaning intervals, calibration intervals and redundancy in measurements. These are used here as examples to illustrate good practice.

5.2 Pyranometers measuring plane of array and global horizontal irradiance

5.2.1 General

Global horizontal irradiance (GHI) is measured by a horizontally installed pyranometer. Plane of array irradiance or POA in a tilted plane is measured using a tilted pyranometer. In all cases the sensor surface is parallel to the plane of interest. A tilted pyranometer will also receive (ground) reflected radiation. When using an ISO 9060 spectrally flat pyranometer, the same calibration is used for both measurements. When using non-spectrally flat instruments, users may consider spectral correction, for example of the POA measurement or of the GHI measurement under cloudy sky.

At most solar power plants you will find pyranometers to measure GHI as well as POA. This is required by IEC 61724-1 for class A systems. The GHI is often used as a starting point for modelling power plant performance. GHI is also used as a reference to compare to other sites or to meteorological databases, also having the advantage that it does not include contributions of ground reflected irradiance.

5.2.2 Installation

5.2.2.1 Selection of the installation site

The test object and the pyranometer measuring POA are as equally exposed as the situation permits; that means that the test surface and pyranometer receive the same irradiance and have the same inclination angle.

When the test object is not uniformly exposed, common solutions are application of a correction or using more than one pyranometer.

For POA as well as GHI measurement, choose the installation site with care. Avoid installation close to objects that shade the pyranometer, obscure part of the sky or reflect radiation to the pyranometer, such as trees, man-made structures, or strongly reflecting local surfaces.

For pyranometers measuring POA, the reflection of the ground, reflections from PV array rows in the field of view, as well as the local horizon (shading by/obstructions as seen by the pyranometer) at the location of installation are usually chosen to be as representative as possible of the horizon and reflection at the test object (which may be an entire PV power plant).

If the measurement site is not horizontal, but a slope, GHI measurement does not have the same slope in its field of view, because it then measures reflected irradiance, which leads to an overestimation of GHI and an underestimation of the albedo.

In WMO, Annex 1B,^[3] a “siting classification” on a scale of one to five is introduced for all meteorological observations, including GHI and DHI measurements. The siting classification helps determine the given site’s representativeness. This may be particularly relevant when comparing data to historical or satellite data. Hence, a class 1 site can be considered as a reference site. A class 5 site is a site where nearby obstacles create an inappropriate environment for a meteorological measurement that is intended to be representative of a wide area. The smaller the siting class, the higher the representativeness of the measurement for a wide area. In a perfect world, all sites would be in class 1, but the real world is not perfect, and some compromises are necessary. Each parameter being measured at a site has its own class, and is sometimes different from the others.

For example, criteria for a class 1 site for GHI and DHI are:

- a) No shade projected onto the sensor when the sun is at an angular height of over 5°. For regions with latitude $\geq 60^\circ$, this limit is decreased to 3°.
- b) No non-shading reflecting obstacles with an angular height above 5° and a total angular width above 10°.

Criteria for a class 2 site are:

- No shade projected onto the sensor when the sun is at an angular height of over 7°. For regions with latitude $\geq 60^\circ$, this limit is decreased to 5°.
- No non-shading reflecting obstacles with an angular height above 7° and a total angular width above 20°.

In general, when working according to WMO requirements, for pyranometers measuring GHI, the site is chosen to have a class 1 site classification according to WMO, so that no obstruction, in particular within the azimuth range of sunrise and sunset over the year, has an elevation exceeding 5°. In practical terms, when working according to WMO requirements: an object of height H above the pyranometer sensor is more than $10H$ away from it. Other obstructions do not reduce the field of view by more than 0,5 sr. At stations where this is not possible, complete details of the horizon and the solid angle subtended are included in the description of the station^[3]. Exceptions may be made if a measurement site including obstructions can reliably provide a more representative measurement of the solar irradiance input to a solar energy system.

The need for easy and safe access during maintenance usually is considered in selecting the installation site.

5.2.2.2 Mounting and levelling of the pyranometer

Levelling requirements depend on the application, but in many cases the possibilities are limited to alignment relative to the spirit level or to the instrument base plate using an external tilt sensor. The latter is possible only when the base plate is aligned with the level sensor surface. Digital pyranometers may have on-board tilt sensors.

For POA measurements, when working according to IEC requirements, if the tilt and azimuth angles of the test object are known, the pyranometer tilt and azimuth angles are aligned with those of the

test object within 1°. If these angles are not known the user may decide to use a weighted average (for example, weighed with installed power) to optimise installation angles or use multiple instruments^[2].

When the instrument is mounted in an inclined position, for example, for POA measurement, the cable or connector usually points down to avoid water penetrating the connector and reaching the signal or power supply wires.

Following the convention by WMO^[3], for GHI measurement, the pyranometer is oriented so that the cable or connectors are located north of the receiving surface in the northern hemisphere and south of the receiving surface in the southern hemisphere^[3].

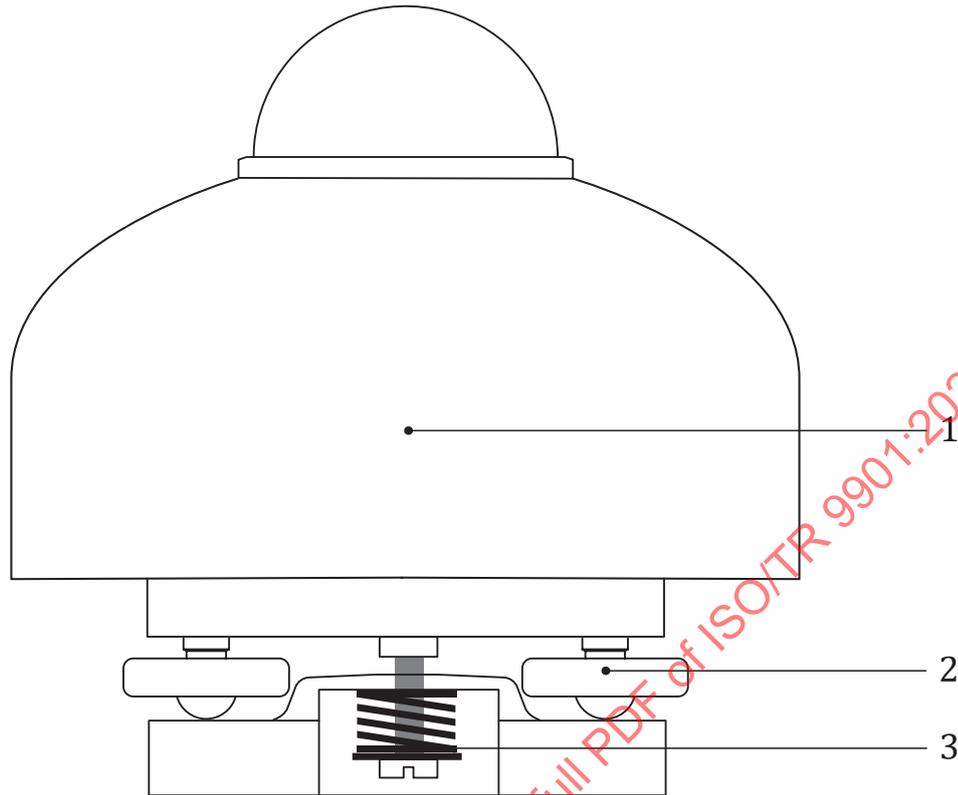
For GHI measurements, levelling requirements are different for each pyranometer accuracy class, and for each application. For class A instruments, typical levels allow horizontal levelling within 0.5°, class B instruments within 1°. In solar energy applications, mounting in POA, IEC 61724-1 requires class A measuring systems to have a tilt accuracy of 1° and an azimuth accuracy of 2°.

For high accuracy measurements, avoid that the instrument body is heated by solar radiation more than necessary. It is common practice to use the manufacturer-supplied sun shield. It shields the instrument body from direct radiation, while keeping it in contact with ambient air. It also reduces the temperature difference between ambient air and the instrument and minimises zero offsets due to thermal shocks by variable wind speed or rain showers.

If this can be avoided, radiation reflected from the ground or the stand does not reach the instrument body. For instruments facing down, use of the normal sun shield may not be possible. In such case, a plate mounted above the instrument can be used to shade the instrument. This plate is usually designed such that it does not obstruct natural ventilation of the instrument body.

The pyranometer usually is secured with screws or bolts. For horizontal installation it is levelled using its levelling screws and spirit level. When retaining screws are tightened, it is common practice to verify that the receiving surface remains horizontal, as indicated by the spirit level.

Alternatively, the levelling arrangement may comprise spring-loaded adjusting bolts (see [Figure 1](#)) which allow the pyranometer to be firmly fastened to the stand, and then levelled, without the need for an iterative procedure.

**Key**

- 1 pyranometer
- 2 levelling screws
- 3 spring-loaded adjusting bolt

Figure 1 — Mounting of a pyranometer

5.2.2.3 Electrical installation

Summarising WMO and BSRN recommendations: the cable connecting the pyranometer to its data acquisition equipment, power supply or digital network is waterproof. The cable is secured firmly to its mounting stand to minimize the chance of breakage or intermittent disconnection. Wherever possible, the cable is protected and buried underground if the next point of connection is located at a distance. The use of shielded cables is preferred.

5.2.3 Heating and ventilation

In high-accuracy monitoring stations pyranometers are often heated, ventilated or both heated and ventilated. For considerations see [4.5.2](#).

5.2.4 Inspection and maintenance

5.2.4.1 Recommended practice for inspection and maintenance

The objective of inspection is to verify that the instrument is measuring within its rated operating conditions; that means that it is clean and installed according to requirements. Working according to WMO and IEC^{[3][21]}, the results of inspection, usually a confirmation that all works within specified conditions, is recorded in an inspection log.

Inspection is usually combined with maintenance. However, even if need for maintenance is low, the inspection, serving as confirmation, remains necessary. The quality of the data, and its uncertainty,

depends strongly on the amount of attention given to maintenance. Frequent inspection and maintenance are encouraged in WMO, IEC and BSRN^{[3][21][8]}.

Pyranometers in continuous outdoor operation are inspected and maintained according to user requirements. For a checklist see [Table 2](#).

The user requirements typically aim for a certain measurement accuracy. The requirements for inspection and maintenance necessary to attain this level of accuracy strongly depend on the local conditions at the measurement site. Standards tend to define a fixed maintenance schedule, but these typically assume worst-case conditions. Users can adapt the schedule to local conditions.

For example, when working according to class A monitoring under IEC 61724-1, this inspection and maintenance takes place once per week. The original recommendation of ISO/TR 9901 in 1990 was once per day, for ASTM G183 it also is once per day. Inspections of specific attributes as described in [5.2.4.2](#) to [5.2.4.5](#) are designed to be carried out as daily, weekly, monthly, yearly and two-yearly routines.

To flag the moment of inspection, many systems include a maintenance button. By pushing the button, the start and finish of the maintenance action are marked. Users can gather data on the effects of soiling, by analysing the effect of cleaning on sunny days.

Table 2 — Check list for inspection and maintenance of pyranometers and accessories

Equipment	Object	Inspection/Check	Maintenance
Pyranometer	Glass dome or diffusor (outside)	Local pollution, sand, dust Frozen snow, rime, frost Cracks or scratches	Wipe clear and dry De-ice and wipe Report, check the sensitivity, when necessary replace instrument or dome ^a
	Glass dome (inside)	Condensation water	Open the instrument and dry it, possibly remove the outer dome; when necessary replace O-rings ^a
	Seals (Washer/O-ring)	Perishing/cracking, discoloration	Lubricate or replace ^a
	Sensing surface	Visual check: In case of black absorbers: black and even In case of diffusors: white and even	Report, check the sensitivity and when necessary replace the instrument
	Desiccator	Colour of desiccant Electronic humidity sensor	Replace when discoloured or humidity is beyond manufacturer's recommended limits
	Levelling	Spirit level Horizontal Electronic tilt sensor	Adjust levelling
	Sensor stability	Calibration date	Recalibrate according to manufacturer recommendations, or requirements of the applicable standard
Heating and ventilation	Operational state	Unusual noise, or air current Electronic ventilator speed (RPM) sensor	Report, and when necessary replace
	Heating	Formation of rime or frost Internal heater power sensor	Electrical check, when necessary replace
	Air ducts and filter	Dirt or soiling	Clean, replace when necessary

^a After disassembly, recalibrate the instrument. When replacing domes of class A instruments, repeat the directional response test.

Table 2 (continued)

Equipment	Object	Inspection/Check	Maintenance
Shading device	Shading	Position of shadow relative to the dome	Adjust
	Shadow ring	Paint, dirt	Clean and paint when necessary
		Angle to horizontal	Adjust
	Shade disk or ball	Motor	When necessary replace
Sun sensor	Stability of the mount	Adjust or when necessary replace	
Cables, connectors, contacts, connection box	Electrical connection	Visual inspection, cracks, connection, discoloration	When necessary replace
		Corrosion, humidity and dirt	Clean and tighten the box
		Loose junctions	Tighten contacts or replace
Data acquisition	As a wide variety of data acquisition and recording systems are used with pyranometers. It is common practice to follow the manufacturer's instructions. Calibration of amplifiers is typically done when calibrating the pyranometer		
Clock/time stamp	It is common practice to perform a monthly check that the clock of the recording data acquisition system is accurate to within ± 10 s of local standard time (not daylight-saving time!).		
^a After disassembly, recalibrate the instrument. When replacing domes of class A instruments, repeat the directional response test.			

5.2.4.2 Automated inspection/remote diagnostics

Automated data quality assurance and review by experts can generate warnings, for example by comparing measurement results of nearby redundant sensors, by comparing to data of nearby sites, by looking at night-time offsets, or by comparing data to extra-terrestrial irradiance (clearness index) and expected maximum and minimum values at that location and time.

Digital sensors and heating and ventilation systems may carry additional possibilities for remote instrument diagnostics. Examples are sensors included in pyranometers, measuring internal humidity and instrument tilt, and sensors in ventilation systems measuring heater power and ventilator speed. These may automate and replace some, but not all, of the below checks.

5.2.4.3 Daily routine

During inspections the optics (glass dome or diffuser made of glass or plastic) of the instrument is usually wiped clean and dry. If frozen snow, glazed frost, hoar frost or rime is present, it is common practice to remove the deposit gently, possibly with the sparing use of a de-icing fluid, after which the optics is wiped clean. It is common practice to check to determine whether any condensation is present inside the domes and whether the sensing surfaces are in good condition (black in case of pyranometers employing thermopiles with a visible black surface or white in case a diffuser is used).

It is common practice (in particular for new instruments) to check for any deterioration, of the domes, diffusers, absorber paint and seals. In case of visible deterioration, replacement of the instrument, an on-site performance verification/check (see 5.5.2) or a recalibration can be considered.

If air pollution or solids that remain after evaporation of rain droplets form a deposit on the optics (dome or diffuser), clean it gently, by either blowing off loose material, wiping with a splint-free soft cloth or wetting it. Prevent scratching the optics surface. Abrasive cleaning can alter the transmission of the optics. Non-perfect cleaning can cause significant measuring errors.

The ventilator operation can be checked. Unusual noise is a sign that servicing is needed.

It is common practice to perform a rough check of the measured data according to 5.2.6.

5.2.4.4 Weekly routine

Desiccators are kept charged with active material (usually a colour indicating silica gel). Normally the desiccant in small cartridges remains active for several months. Sealed instruments containing larger quantities of desiccant will remain dry for several (typically five) years. If used in a region with large temperature variations in combination with high humidity, more frequent replacement may be needed. If the desiccant is consumed rapidly, the cause might be a defective O-ring.

Inspection and cleaning of the filters of the ventilator is typically carried out on a weekly basis. In clean environments this can be reduced, for example to a two-weekly or monthly routine.

5.2.4.5 Monthly routine

Inspection of the azimuth and tilt angles (in the horizontal position by using the spirit level) is typically carried out monthly.

It is common practice to pay attention to the transmission and amplification of the signals. Both visual and electrical checks of the cable and data acquisition system are typically carried out monthly, and also when any of the equipment has been replaced and after any anomalies have been detected in the data. A check that the data acquisition system clock is keeping the correct time (usually ± 10 s is sufficient) is another common practice.

5.2.4.6 Yearly and two-yearly routine

Pyranometers and associated electronics are typically calibrated with a two-year interval. See the below clause on recalibration.

5.2.5 Data acquisition and storage

Maintenance of data acquisition systems is system-dependent but can include checks of time stamps, sensitivity, and zero-offset.

Data collection software, arranging communication with dataloggers, will generally have possibilities to compare the datalogger clock to the local PC clock, and an option for network synchronisation.

A typical calibration or acceptance test consists of replacing the pyranometers by a voltage or current source in order to determine any differences between input values and recorded signals. This test is usually extended over the anticipated output range of the pyranometer. Normally electronics are tested at the pyranometer output signal levels equivalent to irradiance levels of 0, 20 W/m² to 1 400 W/m². Such tests are typically carried out at the same interval as pyranometer calibrations.

We assume that a clock accuracy of ± 10 s is sufficient for most solar testing applications. See [5.2.5.2](#) for a detailed discussion.

5.2.5.1 Data sampling and recording interval

When integrating individual samples, the sampling and recording intervals are chosen to ensure that the recorded parameters and their accuracy are suitable for the application. This applies equally to a series of samples recorded by means of a fast-response multi-channel automatic data-logging system and to a series recorded manually. The recording interval is an integer multiple of the sampling interval, and an integer number of recording intervals fits within 1 h. The sampling interval depends on the application, on the pyranometer response time and on the application and instruments as illustrated by the following questions:

- a) What is the smallest time interval of interest?
- b) What is the response time of the pyranometer?
- c) What are required sampling and recording intervals?

- d) What statistical information is needed, average, min, max, standard deviations; can the data acquisition system calculate and store these parameters over the recording interval?
- e) Does the sensor itself (if it is digital), internally average the data?

Depending on the answers to these questions the sampling interval can range from one minute, to one second, or even faster. Generally, for the calculation of average values over a time interval between 6 min and 1 h, 100 samples allow the average values to be estimated with enough accuracy. For more information on sampling intervals, see Olivieri^[1].

Common practice for outdoor monitoring is to take samples over an interval of less than 3 s, but at least over the duration of one power line cycle (e.g. 0,02 s for 50 Hz). Whether the samples are further averaged (e.g. stored as 60 s averages) or stored as individual measurements depends on the application. However, it is noted that averaging usually is associated with the loss of statistical information unless this statistical information is stored at the moment of averaging.

For example, storing 720 one-second radiation samples taken at sampling intervals of 1 min may provide more information for a 12 h period than recording 720 one-minute averages. The 720 one-second samples not only can yield the approximate total energy received for the 12 h period, but also may provide a more accurate estimate for the variability of instantaneous solar radiation, as one-minute averages smooth out some rapid transitions between the clear and cloudy state.

IEC 61724-1 recommends for high accuracy class A measuring systems a sampling interval of at most 3 s and a maximum recording interval of 1 min.

Modern data acquisition systems can calculate and store not only the average, but also minimum, maximum and standard deviation of the set of samples over a recording interval.

5.2.5.2 Data time stamps

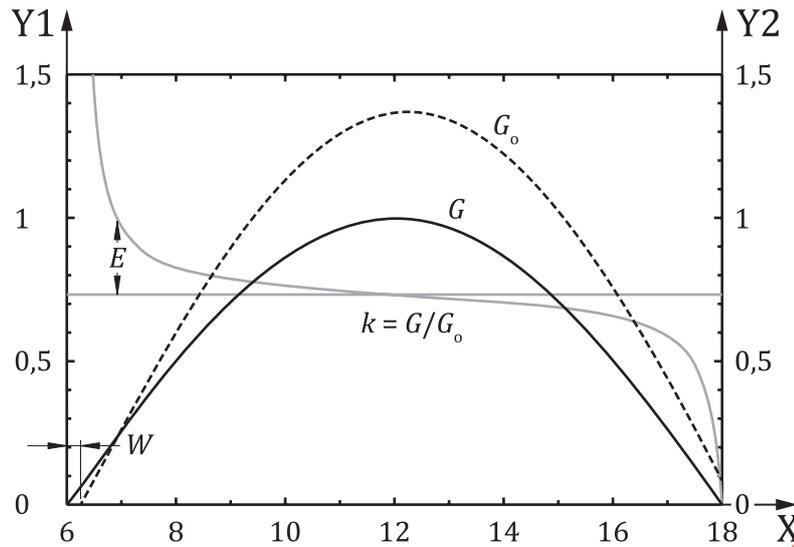
- a) Why accurate time keeping is important.

For the evaluation of solar system performance, the position of the sun is very important, and particular attention is given to the time associated with the solar radiation measurements. This is because the time is used in the calculation of sun angles when the radiation measurements are processed.

An example of the time affecting the solar radiation data processing is the calculation of the clearness index, $k = G/G_o$. If the recorded time does not agree with the true time for the radiation measurement (e.g. due to the clock of the data acquisition system being slow), the extra-terrestrial radiation G_o , which is calculated based on the recorded time, will be incorrect. As a result, very large errors in the clearness index can occur.

This is illustrated in [Figure 2](#) for a hypothetical day, where the clearness index is constant when the correct time is used for the calculation of G_o (horizontal grey line). However, when G_o is calculated with a time including a time error as shown in [Figure 2](#), the clearness index significantly deviates from the correct value, particularly in the early morning and late afternoon hours (curved grey line)^[9]. For example, for the 15 min time error assumed in [Figure 2](#) the calculated clearness index at 8:00 h solar time is approximately 13 % too large.

Accurate time keeping for the recording of solar radiation has received little attention in the past. However, more detailed radiation data, such as one-second or one-minute radiation recordings, are now frequently required for PV applications and accurate time keeping is essential. A particular problem with the time keeping arises for internet connected data acquisition systems using automatic time updates. In time zones observing daylight savings time such automatic updates can cause a 1-hour shift (error) in the recorded time [see item c) for more detail].



Error in clearness index, E , as a result of an incorrect time attached to the solar radiation measurement, G . The horizontal grey line shows the clearness index, $k = G/G_o$, calculated without time error (assumed constant at 0,73 in Figure 2) and the curved grey line the clearness index calculated with a 15 min (0,25 h) time error, W .

Key

- X solar time, hours
- Y1 global horizontal irradiance, kW/m²
- Y2 k - clearness index
- E error in clearness index
- W time error

Figure 2 — Error in the clearness index calculation

b) How the time and date are recorded.

When following IEC 61724-1 each stored radiation value (record) include a timestamp. It is recommended that the time stamp contains the time corresponding to the beginning of the recording interval and that the date associated for each recording is clearly identifiable from the recorded data. The recorded time refers either to local standard time or universal time to avoid a shift due to daylight savings time^[11]. See IEC 61724-1:2017, 6.2, for more information on the timestamp and Reference [11] for an overview on time conventions and an example calculation.

The accuracy of the time is usually kept within ± 10 s. Internal clocks of automatic data acquisition systems tend to gain or lose time during operation (of the order 1 min/year or more). For this reason, it is important that the time is not only accurately set at the beginning of the data recording, but also regularly checked (5.2.4.5 suggests monthly). As already mentioned, automatic time updates for internet connected data acquisitions systems can introduce a 1 h time error [see item c) for a discussion on how to avoid such errors].

When the recorded raw data are analysed, the time recordings usually need be converted from local to solar time. In the conversion involving the day of year, changes in the equation of time and declination are usually applied at least once a day. It is common practice that any computer conversion from local to solar time is initially checked by a hand calculation. It is important that the data acquisition system and data format are documented, that data time stamps are described and that the data contain a record of station coordinates.

c) Extra considerations for the recording of time.

The clock of a stand-alone data acquisition system, which does not receive automatic time updates from the internet, will inevitably lose or gain time during the solar radiation recording. For these systems it is essential that the time is not only initially set for the correct time zone, but also checked every month for the correct time, as set out in [5.2.4.5](#).

For data acquisition systems connected to the internet, where the time is automatically updated (e.g. for an internet connected computer linked to a data acquisition module), procedures are implemented to secure that the time remains accurate when no daylight-saving time is observed in the time zone (provided it has been initially set to the correct time zone). Typically, a regular check of the time is performed.

However, for time zones observing daylight saving time an automatic time update via the internet will result in sudden (e.g. 1 h) time change between summer and winter time. IEC 61724-1 refers to the use of either local standard time or universal time recordings to avoid such time changes.

In practice unwanted changes to daylight saving time can be avoided for most computer operating systems (e.g. Windows or Mac OS) by disabling the automatic time update and relying on the on-board clock. However, disabling the automatic time update makes regular (monthly) checks that the time attached to the solar radiation measurements is correct particularly important. Problems with the time recording are usually documented so they can be considered in the subsequent use of the data.

Time errors can be difficult to correct, but are detectable. For example, the solar radiation recordings of reasonably clear days can be plotted against solar time and compared to calculated clear sky or extra-terrestrial radiation (similar to [Figure 2](#)).

5.2.6 Data quality control and correction

Working according to WMO and IEC^{[3][21]}, data users keep a log on all instruments and major events such as inspection, inspection results, maintenance, dome cleaning, calibration, clock resetting, power failures, etc.

It is common practice to flag unreliable data and remove these from analysis or assign a higher than usual measurement uncertainty.

In solar testing some redundancy of the solar radiation measurement programme is desirable to estimate its accuracy.

The most commonly used forms of data quality control are:

- Comparison to nearby redundant sensors or neighbouring measurement sites.
- Comparison to the clearness index, i.e. extra-terrestrial solar irradiance at that time and location.
- Comparison to satellite data.

Corrections for instrument body temperature can be applied corresponding to manufacturer recommendations for the instruments.

The output of a pyranometers with a long response time, may not be able to follow the solar radiation during rapidly changing irradiance conditions. When this is relevant “fast response” pyranometers (95 % response time <0,5 s) can be used. However, for slower pyranometers accelerating the pyranometer response may also be an option. For example, this is possible when the dynamic response can be characterised by a single time constant, with [Formula \(1\)](#):

$$G = G_{\text{ind}} + \tau \frac{dG_{\text{ind}}}{dt} \quad (1)$$

where

G is the incident GHI;

G_{ind} is the radiation indicated by the pyranometer output;

τ is the pyranometer time constant (note comments below on the time constant).

[Formula \(1\)](#) suggests that adding $\tau \text{d}G_{\text{ind}}/\text{d}t$ to the measured radiation, G_{ind} compensates for the time lag of the pyranometer. This response time improvement is implemented in some digital pyranometers, but may also be implemented in post-processing^[10].

It is noted that a complete compensation of the time lag cannot be achieved with [Formula \(1\)](#), as high frequency noise is amplified by the differential term, $\text{d}G_{\text{ind}}/\text{d}t$, when the integration time of the radiation samples G_{ind} becomes too short (say $<0,1$ s). Care needs to be taken with the numerical approximation of derivatives. For the first derivative, $\text{d}G_{\text{ind}}/\text{d}t$, a centre difference approximation is used.

The transient response of many radiometers is characterised by more than a single time constant (see Driessle^[13]). However, a significant reduction in time lag can often still be achieved with a single approximately representative time constant and [Formula \(1\)](#). That time constant may be derived from the initial rate of change of the pyranometer response following a step change in radiation. For pyranometers with multiple time constants, where this approximation is insufficient, the work of Shen and Robinson^{[14][15]} and Zemel^[16] can be used. Before applying any time lag compensation scheme, a verification of the scheme with the pyranometer response to a radiation step change is performed.

Negative night-time irradiance values may occur. These are due to “zero offset A” as defined by ISO 9060. In data post-processing the night time irradiance is usually set to zero.

5.3 Pyranometers measuring diffuse radiation

5.3.1 General

For measuring diffuse radiation, the direct radiation is blocked so that it does not reach the sensor. This is done by a shading device. The pyranometer is usually mounted horizontally and shaded either by a small metal disc or ball held in the sun's beam by an automated solar tracker, or by a manually adjustable shadow band mounted on a polar axis. Also rotating shadow bands are used. Moreover, instruments exist that use shading masks which cast a shadow on one or various pyranometers depending on the solar position.

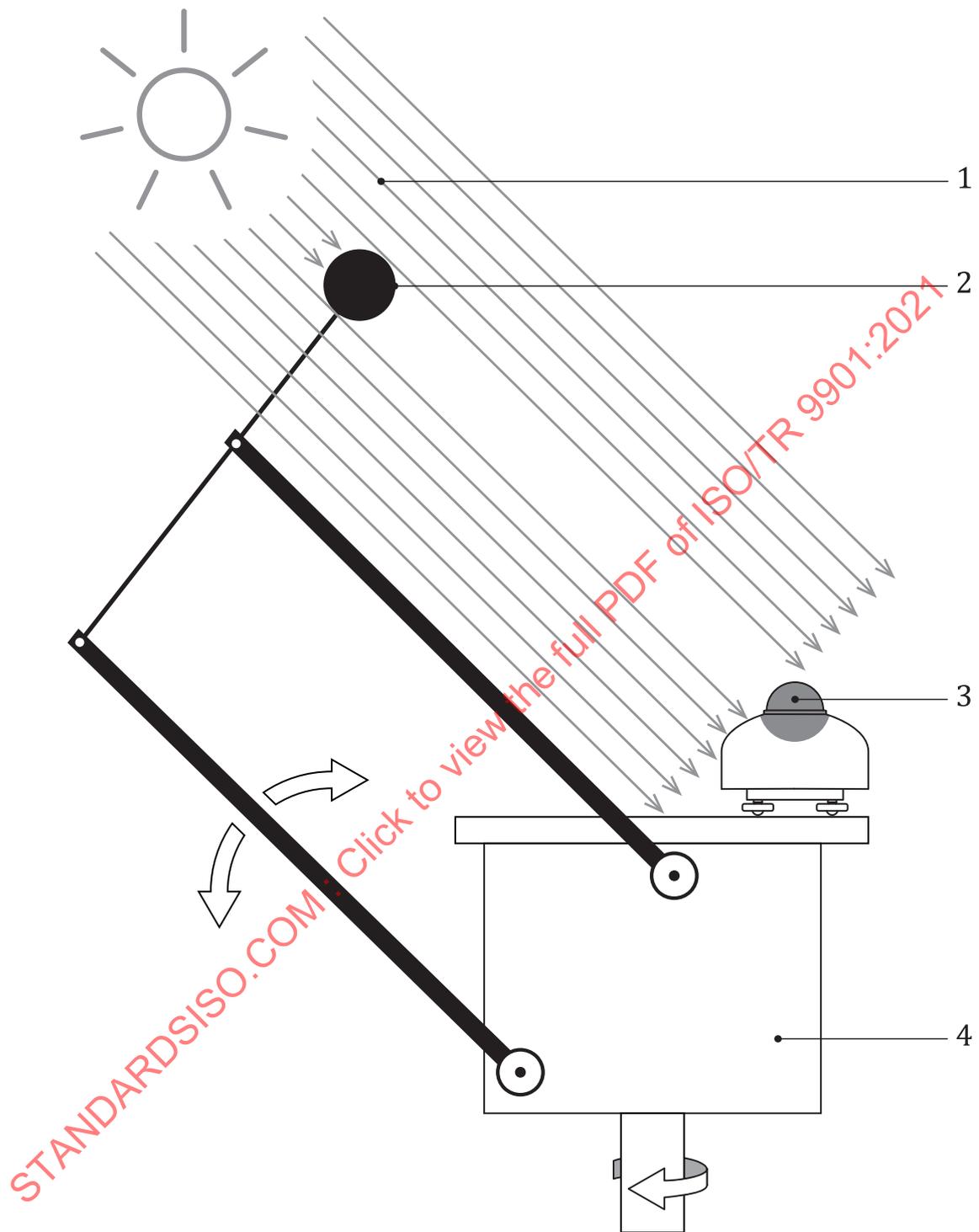
According to ISO 9060:2018 pyranometer combined with shading device is called diffusometer.

If the pyranometer has a glass dome, the shading device is designed to always or most of the time shade the entire glass dome, and not only the diffusor or black sensor surface, from direct radiation.

According to WMO preferably, the angular geometry of the combination pyranometer and shadowball or disc corresponds to the geometry recommended for pyrhemometers^[3].

When using a “spectrally flat” pyranometer for diffuse horizontal measurements, the same calibration as that for global horizontal irradiance measurements is used. For non-spectrally flat pyranometers an individual uncertainty evaluation is possible, and calibration for the specific diffuse spectrum may be considered.

A shade ball configuration on an automated solar tracker is shown in [Figure 3](#).



Key

- 1 solar radiation
- 2 shade ball blocking solar radiation
- 3 shadow which shades the pyranometer
- 4 suntracker keeping the ball in the right position

Figure 3 — High accuracy diffuse irradiance measurement

A classic shadow band involves manual re-adjustment, when working at a regular schedule typically every three days. It also requires mathematical correction of the measurement for the screening of part of the diffuse radiation by the shadow band. For details of the construction of a shadow band and the necessary corrections, see Dehne^[2]. These corrections are not perfect and go together with a significant measurement uncertainty. An uncorrected measurement with a shadow band will significantly underestimate the diffuse horizontal irradiance.

Rotating shadow bands rotate around the pyranometer. The combination is called a rotating shadow band radiometer. Typically, three irradiance measurements are done to obtain one single diffuse horizontal irradiance value. First the global horizontal irradiance is measured. As a second step the shadow band is rotated so that its shadow is nearly but not quite falling on the pyranometer sensor and the irradiance is measured. The difference between this irradiance and the global horizontal irradiance is the diffuse horizontal irradiance that is blocked by the shadow band. As the third and final step the irradiance is measured with the shadow centred on the sensor. This latter irradiance is added to the blocked diffuse horizontal irradiance to obtain the diffuse horizontal irradiance. A rotating shadow band not only provides a measurement of DHI but also of GHI. Manufacturers may suggest spectral and directional corrections.

A diffusometer employing a shade disc or ball, will generally provide a more accurate measurement than one using other shading devices. No corrections are needed because a disk or ball blocks only a small part of the diffuse sky.

When designing a measuring system for global and diffuse horizontal irradiance components, (for example the shadow band and diffusometer mentioned above) with a global horizontal, diffuse horizontal and possibly direct irradiance measurement by separate instruments, it is common practice to pay attention to instrument time constants and their spectral response. It is customary to use instruments, pyranometers as well as pyrhemometers, with identical spectral response and with similar time constants. The response time of the pyranometer measuring the slowly changing diffuse radiation may be less relevant.

Measuring diffuse horizontal irradiance, the directional response is not as critical as for global horizontal irradiance measurements. However, since the diffuse horizontal irradiance is lower than the global horizontal irradiance, the zero-offset and non-linearity specifications of diffuse radiometers are relatively more significant. The diffuse horizontal irradiance typically ranges from (0 to 200) W/m², sometimes reaching or exceeding 400 W/m². The total zero offsets (combined zero offset A, B and from other sources) of class A pyranometers may be in the order of 10 W/m².

Airflow generated by optional ventilation may help reduce zero offsets. Also, specific pyranometer models exist that exhibit low zero offsets.

5.3.2 Installation

5.3.2.1 General

The installation of a diffuse pyranometer is similar to that of a pyranometer for the measurement of global horizontal irradiance. Alignment of pyranometer and the shading device are critical. The relevant differences to the recommendations specified in 5.2.2 for GHI and POA measurements are given below.

5.3.2.2 Selection of the installation site

The diffuse pyranometer and its shading device are sited so that they minimally shade any neighbouring pyranometer. For that reason the GHI and POA pyranometer are located to the south of the diffuse pyranometer for locations in the northern hemisphere or to the north of the diffuse pyranometer for locations in the southern hemisphere. Such an arrangement will typically be satisfactory for latitudes up to about 60°. For high latitudes where the solar elevation angles, even at solar noon, can be very low, the question of shading neighbouring instruments may need special attention. On solar trackers the diffuse and global pyranometers are typically mounted side-by-side.

Suitable non-reflecting non-specular paint is typically used on all components in the field of view of the pyranometer.

5.3.2.3 Installation of a shading device

The positioning procedure of the pyranometer depends on the geographic latitude, and the design of the shading device. Generally, the diffuse pyranometer mounting stand is part of the shading device, and therefore the shading device is installed first. On a clear day one can adjust the stand accurately by observing the shadow falling on the sensor. The glass dome, diffusor and/or sensor is in the centre of the shadow if the sun is at zenith. For shadow bands one can check if it shades symmetrically at solar noon. The alignment requirements of rotating shadow bands depend on the specific device. Typically, for azimuth only a rough north/south alignment of the rotating shadow band is needed, but as these systems also measure GHI, the horizontal alignment is critical.

5.3.3 Heating and ventilation

The recommendations given in [5.2.3](#) apply equally for diffuse pyranometers.

Dew, frost, and also soiling can cause relatively large errors in diffuse horizontal irradiance measurement if alignment of the shading device is incorrect. Large errors occur in particular if the outer glass dome is not shaded totally. The water droplets, ice or deposited particles may then act as diffusors for direct radiation, which then is reflected towards the sensor and partly included in the measurement.

Some ventilation systems help reduce offsets, which is an added benefit for the measurement accuracy in view of the low diffuse horizontal irradiance levels.

5.3.4 Inspection and maintenance

In addition to the practices described in [5.2.4](#), the following applies.

The position of the shading device and the shadow is essential for a correct diffuse radiation measurement. For this reason, regular inspection is the usual way to verify the correct shading of the instrument. This is most critical after a period of days without sunshine, or, for shadow rings, during the months around the equinoxes when they require frequent adjustment.

Solar trackers often use 4-quadrant sun sensors for accurate control of the alignment of the tracker. This sensor takes over control above a certain level of direct radiation. It is common practice to follow manufacturer recommendations for quality control and cleaning of this sensor.

5.3.5 Data acquisition and storage

In addition to the practices described for global horizontal irradiance measurement, since the diffuse horizontal irradiance from a cloudless sky may be less than one-tenth the global horizontal irradiance, the low-range measurement accuracy of the data acquisition system receives special attention.

5.3.6 Data quality control and correction

The initial quality control procedure of diffuse and global horizontal irradiance data is to check that the diffuse horizontal irradiance is always less than or at most equal to the global horizontal irradiance.

Another simple method for data quality control is to compare the values of GHI and DHI irradiance on a day with a fully clouded sky.

It is common practice to be careful when comparing these data if the diffuse pyranometer is shaded by a band instead of a shade disk. Measurements with shadow bands needs a correction that depends on the ring geometry, the site latitude and the day of year.

When using a suntracker equipped with a pyrhelimeter and a shaded and unshaded pyranometer, a commonly used data quality check using global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI) and direct normal irradiance (DNI) is given by [Formula \(2\)](#):

$$\left| \text{GHI} - \text{DNI} \cdot \cos(\theta_z) - \text{DHI} \right| < 15 \text{ W/m}^2 \text{ or } 2 \% \text{ (whichever is less)} \quad (2)$$

for θ_z , the solar zenith angle, is $< 80^\circ$. The numbers in the equation are valid for well-maintained instruments of the highest accuracy class^[8].

5.4 Pyranometers measuring reflected radiation

5.4.1 General

Reflected radiation is measured using an inverted pyranometer. In open terrain the reflected horizontal irradiance (RHI) is directly related to the GHI via the albedo, which is the ground surface reflectivity.

There are two approaches to measurement of the contribution of reflected irradiance:

- In some solar energy studies, users choose to mount inverted pyranometers in plane of array, measuring rearside plane of array irradiance POA^{REAR} .
- Others derive the POA^{REAR} , for example by measuring the RHI in the open field or between arrays, and use mathematical modelling to convert this to POA^{REAR} .

The measurement uncertainty of reflected radiation measurements is often determined by the spatial variability of the ground surface and shading patterns. Some users carry out investigations of the ground surface reflectivity (albedo surveys) to quantify its variability. The ground surface properties not only vary from one location to the next, but also over time, for example, as a function of the condition of vegetation or temporary presence of snow. In many cases, the variability of ground surface properties in space and time are so large that modellers in solar energy work with the estimates of the local albedo (reflectance of the ground) from the surveys (typically with seasonal corrections). The reflected radiation between PV arrays is then calculated from GHI measurements combined with albedo and with shading models. Real time measurements are then used to validate the model.

At most sites the nature of the ground surface is unknown and changing over time. As a consequence, we usually do not know the reflected radiation spectrum. Users aiming for high measurement accuracy, therefore typically use spectrally flat pyranometers. When using a spectrally flat pyranometer, the same calibration as that for horizontal measurements can be used. See also [4.2](#).

If the measurement site is not horizontal, but sloped, the RI measurement is typically performed on part of the slope that is as representative as possible. However, the associated GHI measurement does not have the same slope in its field of view, because it then measures reflected irradiance, which leads to an overestimation of GHI and an underestimation of the albedo.

Deposition of dew, frost and soiling may be less of a concern for downfacing instruments measuring reflected radiation than for upfacing instruments.

5.4.2 Installation

The ground surface beneath the pyranometer can have a major impact on the validity or representativeness of the measurement. Surface homogeneity and properties such as soil type, soil humidity, vegetation, and the local shading pattern all play a role. For application in solar energy, users typically require that the surface is as much as possible representative of the solar power plant.

For bifacial solar power plants, to perform a representative measurement of POA^{REAR} or RI, it is common practice to measure between array rows, typically in the middle, and away from the ends of the rows. The ground in that area will be (depending on the solar position) partly shaded by the panels and partly sunny. Users of pyranometers typically try not to include mechanical structures or (inverter) housings in the field of view of the instruments.

When using POA^{REAR} instruments, it is common practice to mount these on the PV array mounting structure, (paying attention to grounding and personal safety see and [4.5](#) and [4.6](#)). Instruments are then installed parallel to the array backside, viewing the same representative area as the panels.

Also, it is common to install one measurement station outside the borders of a solar power plant. This measurement then provides a measurement over unshaded ground surface, which sets a “maximum” for the RHI that can be expected at the array.

Measurement of RHI at this separate station, not located between array rows will give data that is not representative of the actual RHI between rows, but is commonly used as input for modelling. It does not have the same shading of the ground surface by the arrays. However, provided that the soil and vegetation are similar, it may give a useful estimate of the albedo or ground surface reflectance and its seasonal variation.

A solution to further improve representativeness of the RHI measurement and also to estimate the uncertainty of the POA^{REAR} or albedo measurement is to determine averages and standard deviations of measurements by several sensors at different locations.

Pyranometers for measurement of reflected radiation can be equipped with a glare screen that prevents the instrument glass dome to reflect direct radiation onto the pyranometer sensor at low solar elevations. When working according to WMO recommendations, the angle sustained by a glare screen is less than 5°^[8].

The height of installation of downfacing pyranometers above the ground or other surfaces usually is between 1,5 m and 2 m. Lower mounting causes increasing errors due to shading losses (see [Annex B](#)). Mounting higher than 2 m makes it difficult to inspect and clean the pyranometer. For regions with much snow in winter, users can consider higher mounting.

Access to the pyranometer for inspection and levelling usually is designed to be possible with a minimum disturbance to the surface properties of the ground beneath, particularly when the surface is snow.

The mounting stand and other nearby objects are designed not to significantly change the reflection or cast shadows in the field of view of the instrument. Accordingly, the mounting arm of the pyranometer is to its north in the northern hemisphere and to its south in the southern hemisphere.

5.4.3 Inspection and maintenance

The practices described in [5.2.4](#) apply.

5.4.4 Data acquisition and storage

Reflected irradiance usually is only a small fraction of the global horizontal irradiance, except when the ground is snow covered. The output of the downfacing pyranometer is typically low. It is common practice to pay careful attention to the low-range measurement accuracy of the data acquisition system.

5.4.5 Data quality control and correction

If the reflecting ground surface is not horizontal, especially if the ground surface is covered with fresh snow, the reflected radiation may be greater than the global horizontal irradiance. Snow is not always a perfect Lambertian surface, and therefore it is common practice to carefully assess reflected radiation data obtained over surfaces covered with fresh snow.

Low sun elevation increases the chance of specular reflection. If specular reflection occurs measurement accuracies of reflected irradiance will be very low.

A common procedure for RHI measurement over horizontal ground is to start recording reflected radiation measurements at solar zenith angles >10°. This data filtering then takes over the function of the mechanical glare screen mentioned in [5.4.2](#).

5.5 Pyranometer calibration and performance verification

5.5.1 Calibration

Calibration involves a test to determine the instrument sensitivity, under well-defined reference operating conditions. Pyranometer calibration can be carried out according to ISO 9846, outdoors against a pyrhelimeter, or according to ISO 9847, indoors or outdoors against a reference pyranometer^{[19][20]}.

The recommended calibration interval differs from one manufacturer to the other; the most common manufacturer recommendation is a recalibration interval of two years. IEC 61724-1 recommends instrument recalibration every year for class A monitoring systems, and every two years for class B systems^[21].

There are two options for pyranometer calibration: indoors, in the laboratory and outdoors under the natural sun. There is a fundamental difference:

- a) Outdoor calibration is done by comparison of the pyranometer to a preferably higher-class reference standard, usually of a different type or model or even a combination of several instruments. Calibration reference conditions are the outdoor conditions during this calibration.
- b) Indoor calibration is done by comparison of the pyranometer to a reference standard of the same model, and thus of the same class. Calibration reference conditions are the conditions reported as valid for the calibration of the reference standard.

Calibration reference conditions can later, in the calibration report, be adapted to other conditions than those to which the calibration is traceable. This then leads to an adapted sensitivity and reduces the calibration accuracy.

Calibration laboratories can report multiple sensitivities valid for different calibration reference conditions, so that users may work with a sensitivity valid for conditions as close as possible to actual operating conditions.

Pyranometer calibration uncertainties are relatively large, while the expected instrument drift from one calibration to the next is typically small compared to the uncertainty of calibration. It is therefore often more probable that perceived sensitivity changes are caused by differences associated with calibration methods (even for application of the same method between different laboratories) or calibration reference instruments used, rather than by the non-stability of the calibrated pyranometer.

This situation is exceptional. In most other areas of metrology, the uncertainty of calibration is not a limiting factor; in these other areas it is possible to calibrate with an accuracy of much better than the 1 % uncertainty (expanded $k = 2$) that is attainable with pyranometers.

Both for ISO 9846 and for ISO 9847, the uncertainties contributed by the calibration method are in the order of 0,5 %, where the uncertainty using the calibration with a pyrhelimeter is lower than that with a pyranometer. Combined with other uncertainties such as those of the calibration reference sensor calibration and the WRR scale, these lead to calibration uncertainties of commercially available class A instruments in the order of 1,5 %.

Instrument drift of thermal pyranometers is typically smaller than 0,5 %/year.

When performing an off-site recalibration of a pyranometer its cable is sometimes left at the site. It is common practice to protect and cover any connectors that remain on-site to prevent soiling and corrosion of the connector pins exposed to the outdoor environment. Alternatively, the cable and connector can also be properly stored if no pyranometer is connected.

5.5.1.1 Indoor calibration according to ISO 9847

Most spectrally flat pyranometers are calibrated in indoor calibration facilities that work according to ISO 9847:1992, Annex A.

As an order of magnitude: typical indoor calibration uncertainties of better than 2 % are attainable for pyranometer class A and within 3 % for class B and C.

Indoor transfer of the sensitivity of a calibrated reference pyranometer according to ISO 9847 may only be carried under the condition that the calibration reference pyranometer is of the same model as the pyranometer that is calibrated. The calibration may then be carried out using a lamp as a source which has a different emission spectrum than that of the sun, and at a relatively low irradiance level [typically in the range of (300 to 600) W/m²].

ISO 9847 clarifies that, since the calibrated and reference pyranometer are of the same model, both instruments will respond in the same way when irradiance level, tilt and spectrum deviate from the conditions during outdoor calibration. (i.e. the linearity and spectral response of both instruments are identical, therefore these effects will cancel).

This way, the newly calibrated instrument will obtain a sensitivity that is valid under the same outdoor reference conditions of irradiance, tilt and spectrum under which the reference pyranometer was calibrated. The additional step of the indoor transfer calibration only leads to a small increase of the calibration uncertainty, it does not change the reference conditions of the calibration.

For example, in case the reference pyranometer has been calibrated under clear sky conditions (the radiation spectrum is not specifically defined) over a range of (500 to 1 000) W/m², the sensitivity of the newly calibrated sensor will also be valid for an irradiance range of (500 to 1 000) W/m² and for the clear sky conditions.

Calibration laboratories may change the calibration reference conditions. In that case this change is usually accounted for in the calibration uncertainty.

For example, ISO 9847 specifically describes how to correct for temperature dependence and how to calculate a sensitivity valid for a range of solar angles. It suggests using knowledge of the directional error and temperature dependence of the calibration reference instrument for this purpose.

For a calibration laboratory working with indoor calibration according to ISO 9847 there are several commonly used ways to report sensitivities and the associated calibration reference conditions:

Option 1: The standard way of ISO 9847: copying the outdoor reference conditions under which the reference pyranometer was calibrated to the newly calibrated instrument. This is justified under the assumption that the relevant instrument properties (most importantly temperature response, directional response, spectral response, tilt response) are sufficiently identical between instruments of the same model. There is no additional contribution to the uncertainty covering change of reference conditions.

Option 2: Copying the outdoor reference conditions under which the reference pyranometer was calibrated into the calibration reference conditions of the newly calibrated instrument, while also entering additional contributions to the calibration uncertainty. These contributions account for the differences between the outdoor reference conditions and conditions in the laboratory, and the fact that even between instruments of the same model, instrument properties may significantly differ.

Option 3: Using standardised calibration reference conditions determined by the calibration laboratory (for example aligned with ISO 9060, i.e. horizontal installation, 20 °C instrument temperature, normal incidence radiation), or valid for specific measurement conditions. This is done by correcting the sensitivity of the reference pyranometer to the specific conditions, and adding an uncertainty accounting for the differences in conditions (both for the reference pyranometer and the newly calibrated instrument), possibly also taking into account that that properties may significantly differ between instruments of the same model. This approach may have the benefit for the instrument user of simplifying the measurement uncertainty evaluation (see [5.6](#)) when instruments are used in the field.

5.5.1.2 Outdoor calibration according to ISO 9846 and ISO 9847

Calibration of a pyranometer according to ISO 9846 describes several outdoor calibration methods. It leads to the lowest calibration uncertainties, typically of around 1 %. However, this calibration is time consuming, restricted to clear sky conditions, and therefore expensive.

ISO 9847 covers not only indoor (described above) but also outdoor calibration by comparison to a reference pyranometer. However, this outdoor method cannot claim reliability or general effectiveness in all climates. The outdoor calibration uncertainty depends on environmental factors and site-specific conditions. ISO 9847 contains detailed procedures and describes the procedure, atmospheric stability requirements and data analysis. For a good result it is essential that the measurement is done over a sufficiently long period of time, and with sufficient clear sky exposure at low zenith angles. A few clear days are under ISO 9847 considered sufficient when working according this standard. In this outdoor calibration, the ambient temperature, zenith angle and stability of the source are not under control. Users of outdoor calibration methods will typically have to perform an individual uncertainty evaluation of each calibration, taking environmental conditions into account (see Notes 1 and 2)^[20].

The reported calibration reference conditions in outdoor calibration usually are conditions during this calibration. These may also be corrected to other conditions. In that case this change is usually accounted for in the calibration uncertainty.

NOTE 1 ISO 9846:1993, 5.3, mentions that for outdoor calibration, clear sky conditions are essential for reduced variance in the results and that in principle the other environmental conditions during the calibration are, when working according to ISO 9846, similar to the typical conditions during normal use of the pyranometer^[19].

NOTE 2 ISO 9847:1992, 5.2.2, mentions different sky conditions under which a calibration can take place, each with specific requirements for the data series^[20].

5.5.2 On-site performance verification/check

The outdoor calibration method described in ISO 9847 as described in [5.5.1](#), i.e. outdoor comparison to a reliable reference instrument, can also be used as a performance verification or on-site check. The status of such a verification is not the same as a calibration. The purpose of the check is reduction of the risk that the measured irradiance is not accurate and to detect mistakes such as using the wrong sensitivity. A check can also serve as a justification to extend the calibration interval.

5.5.3 Introduction of a new pyranometer sensitivity

Most users know that well-maintained thermal pyranometers are stable instruments with very limited drift of sensitivity over time.

When a pyranometer is recalibrated, it is recommended to compare the new sensitivity to its previous sensitivity. Before changing the sensitivity applied to generate data, the proposed change is compared to the calibration uncertainty. If the proposed change in sensitivity small compared to the calibration uncertainties, the change can be rated "not significant". If a change is introduced this could lead to an unnecessary discontinuity in the measured data. Making such comparison only the uncertainty related to the calibration methods of the calibrated instrument and the calibration reference need to be considered. Systematic errors (such as the WRR uncertainty relative to SI) are therefore excluded from the analysis.

Changing the instrument sensitivity may lead to discontinuities in data series and as a consequence to discontinuities of derived quantities such as the Performance Ratio measurements for PV systems.

If a new calibration result, a sensitivity, is different from the previous result here are several options open to the user:

Option 1: The new sensitivity and its associated uncertainty are introduced without any further consideration. This is common practice in metrology. A scale change and discontinuity in data series may then occur, but is accepted (see Note).

Option 2: The recalibration is considered as a verification of the sensitivity used at that moment (a “conformity test”). If the new sensitivity passes the decision rule of the conformity test, (see Note), the two results are metrologically compatible and original pyranometer sensitivity can be retained. Possibly this results in a more consistent data series than when working according option 1. However, when working according to this option the calibration uncertainty of the instrument is usually carefully reviewed. This uncertainty cannot be lower than that of the recalibration.

If several independent recalibrations consistently differ from the original, a new sensitivity can be introduced as per option 1.

Option 3: The user makes an elaborate evaluation and decides when to apply the new sensitivity, e.g. after a certain event.

If a significant change in sensitivity is found (see the decision rule in Note) it is recommended to investigate how and when this change has occurred. The data can be treated accordingly. If an event can be pinpointed that triggered the change, any data collected after that event can be reprocessed using the new sensitivity. If no specific cause of the change can be found, the user can either introduce the new sensitivity from the date of the recalibration and have a step-change in the data series, or if a gradual drift in sensitivity is more likely or evident from successive calibrations, the user can re-process the data, interpolating the sensitivity over the time between original and new calibration and applying a sensitivity that gradually changes over time to obtain an as-realistic-as-possible data series.

NOTE To decide if the new and old sensitivities $S(\text{new})$ and $S(\text{old})$, significantly differ, or are metrologically compatible as defined in JCGM 200: 2012, the E_n decision rule can be used as defined in ISO 13528 and EA-4/02. The uncertainty U only includes the uncertainty of the methods, not of the scale. In solar energy it is customary to use the expanded measurement uncertainty, U , with a coverage factor $k = 2$.

$$E_n = \frac{|S(\text{new}) - S(\text{old})|}{\sqrt{U(\text{new})^2 + U(\text{old})^2}} < 1$$

5.6 Uncertainty evaluation of the measurement

The evaluation of uncertainty of measurements with pyranometers can be carried out in accordance with ASTM G213-17^[23].

When following ASTM G213, WMO and IEC, the evaluation is performed in accordance with ISO/IEC Guide 98-3^{[3][21][23][27]}.

In solar testing it is customary to express uncertainty as an “expanded uncertainty”, which is obtained by multiplying the “standard uncertainty” with a “coverage factor”. In IEC and ISO it is customary to use a coverage factor “2” and this implies a high confidence (95 %, assuming normal distributions) that the measured value is in that particular interval. The WMO manual uses a 66 % confidence interval or a coverage factor of approximately $k = 1$, indicating that this is normal practice in the meteorological field.

The specification parameters of the instrument according to the list of ISO 9060 classification of pyranometers are usually entered as upper and lower bounds of a rectangular a-priori probability distribution.

There is a connection between the uncertainty evaluation and ISO 9060.

In ISO 9060, the conditions to which instrument specification and testing are traceable, are as follows:

Temperature response:	20 °C instrument temperature
Directional response:	Normal incidence radiation
Tilt response	Horizontal

The ISO 9060 reference conditions are the conditions used as a reference for defining instrument specifications and also for testing these instrument specifications at the factory.

In case the calibration reference conditions of the pyranometer certificate are not the same as those of ISO 9060, users can not immediately apply the ISO 9060 tolerance intervals for the uncertainty evaluation. They first “close the gap” and estimate an uncertainty related to the conversion to these ISO 9060 reference conditions.

For example, in case a calibration of a class B pyranometer has a reference condition of +5 °C, a common practice is to first estimate an uncertainty related to the conversion to 20 °C. Using the ISO specifications for class B pyranometers, this is 0,6 %. Only after that users can work with the ± 2 % temperature dependence specification for this pyranometer, which is specified relative to 20 °C. The alternative of using a ± 2 % temperature dependence relative to 5 °C, is incorrect because it assumes a linear behaviour. This assumption is not justified. Other examples where additional uncertainties may be needed; when using instruments calibrated in tilted positions and when using instruments calibrated under high solar zenith angles. Depending on the configuration, adding contributions to the uncertainty for non-linearity may not be necessary because related uncertainties are at least partly included in the directional response.

For the uncertainty evaluation the ISO 9060 tolerance interval (acceptance intervals plus guard band in the specification table) is used unless the manufacturer specifies otherwise, or unless the application asks for a different approach. Most error sources are analysed using type B evaluation of standard uncertainty. A separate estimate is usually entered to allow for estimated uncertainty due to the instrument maintenance level.

Also, the calibration uncertainty has to be entered.

All uncertainties are entered in measurement equation, either as an uncertainty in irradiance, sometimes also in the voltage output or in the pyranometer sensitivity.

In uncertainty analysis for pyranometers, the location and date of interest are entered. The path of the sun is calculated, and the direct and diffuse components are estimated, based on a model; the angle of incidence of direct radiation is a major factor in the uncertainty and is closely associated with the accuracy of the time recorded for measurements of solar radiation.

In case of special measurement conditions, typical specification values are chosen. These for example account for the measurement conditions (shaded/unshaded, ventilated/unventilated, horizontal/tilted) and environmental conditions (clear sky/cloudy, working temperature range).

Among the various sources of uncertainty, some are “correlated”; i.e. present during the entire measurement process, and not cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are not zero. Some are “uncorrelated”; cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are zero. Other sources are “not included in analysis”, which means that their contribution is put to a zero value. This applies for instance to non-linearity for pyranometers, because it is already included in the directional error, and the spectral error for spectrally flat pyranometers because it is already taken into account in the calibration process. An example of the results of an uncertainty evaluation is shown in [Figure 4](#).

Note that ISO 9060 specifies the spectral error for clear sky conditions only. This spectral error is not directly applicable to non-spectrally flat instruments when they are used for plane of array, for reflected or for diffuse measurements, or in measurement under cloudy skies. The correction of the pyranometer measurement or adapting the uncertainty evaluation for such effects can be of high importance.

Note that most pyranometer calibrations are, via the condition under which the reference pyranometer has been calibrated, traceable to clear sky conditions. For non-spectrally flat instruments these calibrations may not be valid when used for plane of array-, reflected- or diffuse measurements, or measurements under cloudy skies. Therefore, corrections may be needed to reach the required accuracy.