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SOLAR ENERGY
INTERNATIONAL STANDARDS

WHITE PAPER | ISO 9060, IEC 61724-1, ISO 9846 and 9847, ISO/IEC 17025

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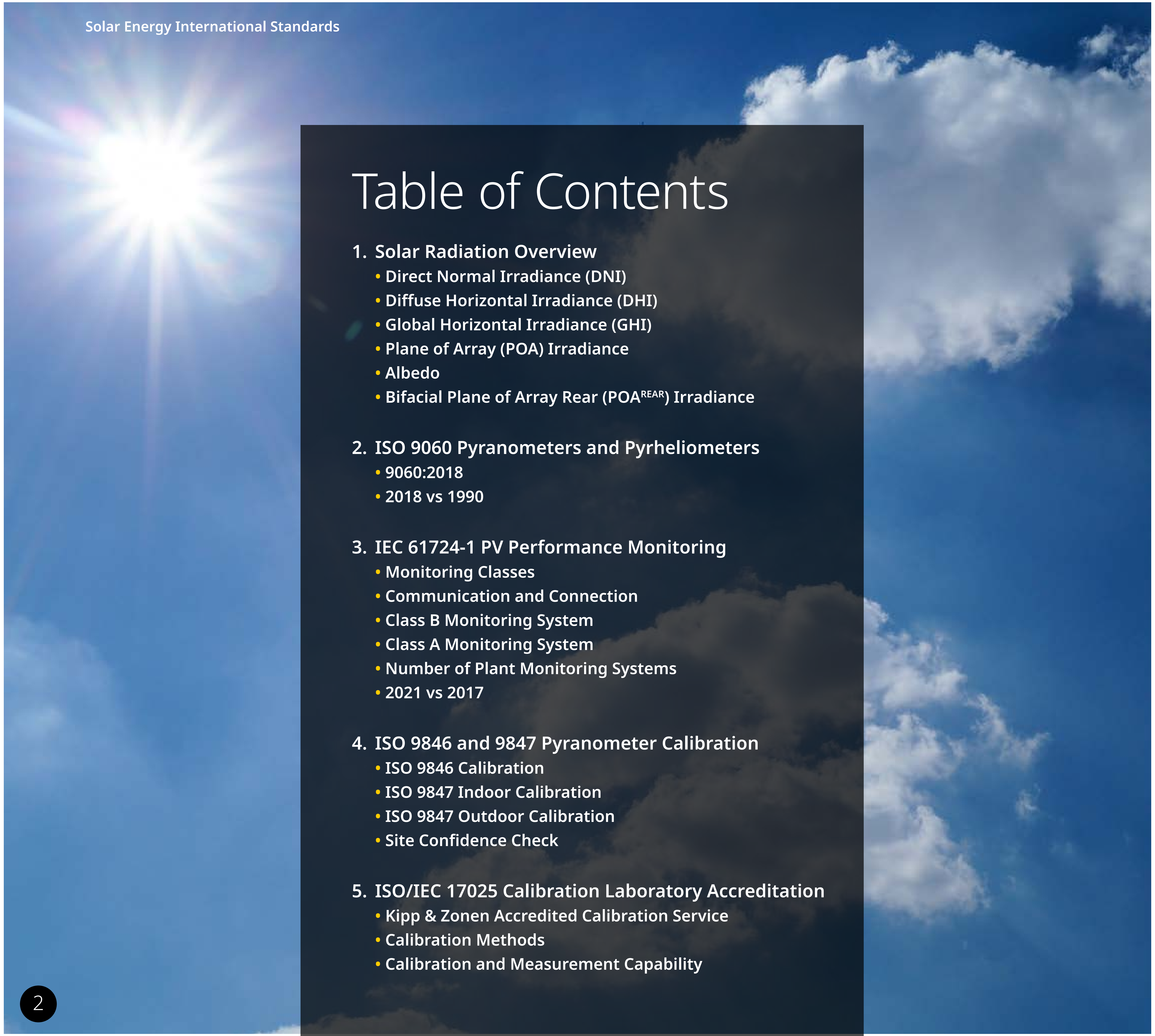

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Solar Energy International Standards:

ISO 9060, IEC 61724-1, ISO 9846 and 9847, ISO/IEC 17025

At Kipp & Zonen we are frequently asked questions about the above international standards that are the ones most commonly referred to regarding the design, operation and maintenance of Photovoltaic (PV) power plants. Some of the considerations can also apply to resource mapping, site prospecting and Concentrating Solar Power (CSP) thermal energy systems.

To make sure that everyone is referring to the same parameters, we start with an overview of the components of solar radiation and how they are measured. Then a look at ISO 9060, which defines pyranometers and pyrheliometers for measuring solar radiation, and the implications of the update from the original 1990 edition to the 2018 version.

IEC 61724-1 is much misunderstood, and has been significantly changed in the update published in July 2021. We pick out the main points that affect the solar and environmental monitoring equipment. This leads on to the calibration standards for pyranometers that are commonly specified in other international standards related to solar energy, ISO 9846 and ISO 9847. We conclude with explaining ISO/IEC 17025, using as an example the accreditation of the radiometric calibration laboratory at the Kipp & Zonen factory in Delft, The Netherlands.

1. Solar Radiation Overview

The sun provides 99.97 % of the energy for our planet (the rest is geothermal) and it is responsible, directly or indirectly, for the existence of life on Earth, weather and climate. The energy emitted is approximately 63 MW for every m^2 of its surface, about 3.72 x 10^{20} MW in total.

The unit of irradiance (radiative flux) is Watts per square meter (W/m^2). At the mean distance between Earth and sun of 150 million kilometers, the flux of the solar radiation reaching the Earth's atmosphere is 1,360.8 ± 0.5 W/m^2 (NASA, 2008). This quantity is named the Solar Constant.

However, it is not actually constant. The Earth is closest to the sun in January and the radiation at the edge of the atmosphere is 6.6 % higher than in June, when we are furthest away. There are various processes inside the sun and at its surface, such as the cycle that controls sun spots and solar flares, that cause fluctuations in the emitted radiation – but these are not more than 0.1 %.

Energy from the sun reaches the Earth's atmosphere as a direct beam of radiation, but as it passes through the atmosphere some of it is scattered in all directions and is termed 'diffuse' radiation. On a day with a clear sky the total irradiance reaching the Earth's surface is typically in the range from 700 to 1,300 W/m^2 at local solar noon; depending on the latitude, altitude and time of year.

High quality ground-based measurements of solar radiation are made using radiometers that respond to radiation in the wavelength range from 300 nm or less to 3,000 nm or more, covering up to 99 % of the energy arriving at the Earth's surface.

Energy from the sun reaches the Earth's atmosphere as a direct beam of radiation, but as it passes through the atmosphere some of it is scattered in all directions and is termed 'diffuse' radiation.

Direct Normal Irradiance (DNI)

When the direct radiation from the sun falls on a plane surface at 90° (normal) to the beam, and scattered light from the sky is excluded, the radiative flux is the direct normal irradiance. On a clear day up to 95 % of the energy received at the Earth's surface is DNI, but on a cloudy day it is close to zero.

DNI is of most importance to solar energy technologies that rely on focusing the light from the sun; Concentrating Solar Power (CSP) thermal systems and Concentrating Photovoltaic (CPV). It is measured with a pyrheliometer that has a field of view of 5° and is mounted on an automatic sun tracker that moves to keep the instrument pointed accurately at the sun from sunrise to sunset.

Diffuse Horizontal Irradiance (DHI)

The solar radiation scattered by the atmosphere is generally taken to be diffuse and of approximately equal distribution across the sky above the measurement location. On a clear day it is about 5% of the total energy received at the Earth's surface, but almost 100 % on a cloudy day. PV modules respond to light from a wide range of incident angles, so they can utilize this diffuse radiation to produce energy on cloudy days.

When the diffuse radiation from the hemisphere of sky falls on a horizontal plane surface the radiative flux is the diffuse horizontal irradiance. DHI is measured with a horizontal pyrometer mounted on a sun tracker and continuously shaded from the direct sun beam throughout the day. The 5° of sky that is obscured matches the 5° seen by a pyrheliometer.

Global Horizontal Irradiance (GHI)

When all the radiation from the sun (DNI) and sky (DHI) falls on a horizontal plane surface the radiative flux is the global (total) horizontal irradiance. However, GHI is not simply DHI + DNI.

If the sun is directly overhead it makes a circular beam on the horizontal surface, but as it moves down in the sky the beam spreads out into an ellipse – in the same way that shadows get longer in the evening. The DNI is the same in W/m^2 but spread over a larger area so the irradiance on the horizontal surface decreases.

The relationship is a cosine function:
GHI = DHI + DNI*cos(θ)
θ is the solar zenith angle (SZA), where vertically above the location is 0° and horizontal is 90°.
So, GHI = DHI + DNI only occurs at solar noon and if the sun is at 0° SZA (which never happens outside the tropics).

GHI is important because it is the parameter measured in weather and climate networks, derived from satellite instruments and calculated with clear sky energy models. It is measured with a horizontal pyranometer.

Local pyranometer GHI measurements allow comparison of the available solar energy between sites and between data sets and the validation of satellite and model estimates for the specific location.

Plane of Array (POA) Irradiance

When a pyranometer is mounted at an angle it measures the global tilted irradiance (GTI). If the azimuth and zenith tilt angles are the same as the adjacent PV modules, it is in the same plane as that array and measures all the solar radiation available to it. It also includes reflections from the ground and from the structure of array frames in front of the pyranometer. This varies with the module tilt angle, the row spacing and the surface reflectance (albedo).

Accurate measurement of POA irradiance is critical to calculating plant efficiencies, performance ratios and return on investment.

Albedo

When global solar radiation impinges upon a surface a proportion of the radiation is reflected back towards the sky. The amount reflected depends upon the optical characteristics of the surface, its albedo. Albedo is a dimensionless quantity and ranges from 0 (perfectly non-reflective) to 1 (perfectly reflective). Short green grass, for example, has an albedo of about 0.15, whereby 15% of the incoming radiation is reflected.

An albedometer consist of two similar pyranometers mounted on the same axis (back-to-back), to measure GHI and the reflected horizontal irradiance (RHI) in W/m^2. The ratio of the two is the albedo of the surface below.

$$Albedo = \frac{RHI}{GHI}$$

A glare screen prevents direct solar radiation reaching the lower detector when the sun is low.

For meteorology, climate research and agriculture, the albedometer is usually at a height of up to 10 m to measure the reflected radiation integrated over a large area and to validate satellite data.

In a PV plant some solar radiation is reflected onto the front face of a module by the surface before it. However, the main interest is in the light reflected towards the rear face of a bifacial module by the surface behind and below. This varies with the type of surface, weather conditions, angle of the sun and shading effects.

IEC 61724-1:2021 includes recommendations for the measurement of horizontal albedo:

- The minimum height of the lower pyranometer detector from the ground is 1 m to reduce self-shading of the surface, but 1.5 m will improve the accuracy of the measurements.
- No shading by vegetation or structures (including arrays/modules) within 160° field of view – this largely means the view of the upwards facing pyranometer, but it also refers to shading of the surface below.
- Given the typical height of fixed arrays is about 2.5 m, this means that, if the mounting rod of the albedometer is at 1.5 m height, there should be a clear area around the albedometer vertical axis of at least 8.5 m radius.
- Minimize shading by the support. The pole in the ground needs to be on the side away from the equator and it should not extend upwards beyond the plane of the upper pyranometer detector. It should be as small in diameter as is practical for rigidity, to minimize the segment of the lower pyranometer view that is blocked by the pole. Ideally the support should be non-reflective.
- Multiple albedometers should be used if there are significant surface variations; it is unlikely that it is the same everywhere in a larger plant.
- For PV purposes, albedometers do not need to be as accurate as GHI and POA irradiance pyranometers as it is the ratio of the GHI and RHI at that location that matters; not the absolute values.
- The data is best used from around 2 hours each side of local solar noon, to minimise shading and solar angle effects.

Bifacial Plane of Array Rear (POA^{REAR}) Irradiance

There is growing interest in the solar energy market for photovoltaic modules with bifacial construction, in which both sides of a solar cell can absorb sunlight and contribute to energy production.

Bifacial modules require more space between the arrays to allow the direct beam and diffuse sky radiation to reach the ground and be scattered back to the rear faces. Depending upon the type and height of the modules, row-to-row spacing, support structures and how reflective are the surfaces visible to the rear of the module (primarily the ground), the energy gain can be from 10% to 25%.

However, the amount of extra energy varies with sky and surface conditions (changing albedo), with the angle of the sun during the day and with the variation in the path of the sun during the year (solar declination). In addition, the extra radiation will not be the same at all points on the rear of arrays.

This means that it is problematic to reliably estimate the radiation reaching the rear face of a bifacial PV module from albedo measurements and a model. It is unlikely within a time-frame, and with an uncertainty, to be useful in calculating the additional yield contribution of the rear face in performance ratio calculations.

Therefore, interest is growing in measuring the actual irradiance incident on the rear face of the modules, and IEC 61724-1:2021 includes recommendations regarding this:

- The irradiance reaching the rear of a PV array varies up and down the array and when close to the ends.
- The spatial distribution of the reflected irradiance on the rear face varies throughout a day and seasonally. This is particularly the case with tracking systems.
- Typically, 3 sensors are required to measure the irradiance profile and establish an average value for performance ratio calculations.
- Arguably, rear sensors do not need to be as accurate as for front POA and GHI as the rear irradiance is a relatively small proportion of the total.

Accurate measurement of $POA^{(REAR)}$ irradiance will probably become necessary for calculating plant efficiencies, performance ratios and return on investment with regard to the additional purchase, installation and maintenance costs of bifacial systems; for example the need to clean the rear faces of the modules.

"The sun provides 99.97% of the energy for our planet."

2. ISO 9060 Pyranometers and Pyrheliometers

ISO 9060 is titled 'Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation'. It defines what a pyranometer is for measuring global horizontal or tilted irradiance (GHI and POA) and, when shaded, DHI. It also defines what is a pyrheliometer for measuring DNI.

Note | The standard does not refer to how performance testing should be carried out or to how the instruments should be calibrated.

The standard specifies the minimum performance requirements for pyranometers and pyrheliometers in a number of classifications. The main parameters specified are: response time, zero off-sets, non-stability, non-linearity, directional response (not applicable to pyrheliometers), spectral response/ error, temperature response and tilt response.

Ideally, a solar radiometer should have a flat response over a wide spectral bandwidth, to measure all the available incoming solar energy independent of types of PV modules or solar collectors used. In the original ISO 9060 of 1990 this is defined as 'spectral selectivity', the deviation from the mean within the range from 350 nm to 1500 nm. To achieve this, measurement is usually made by a 'thermoelectric' type of detector with a black coating that absorbs the incoming radiation, heats up a thermopile, and converts the temperature rise into a small voltage.

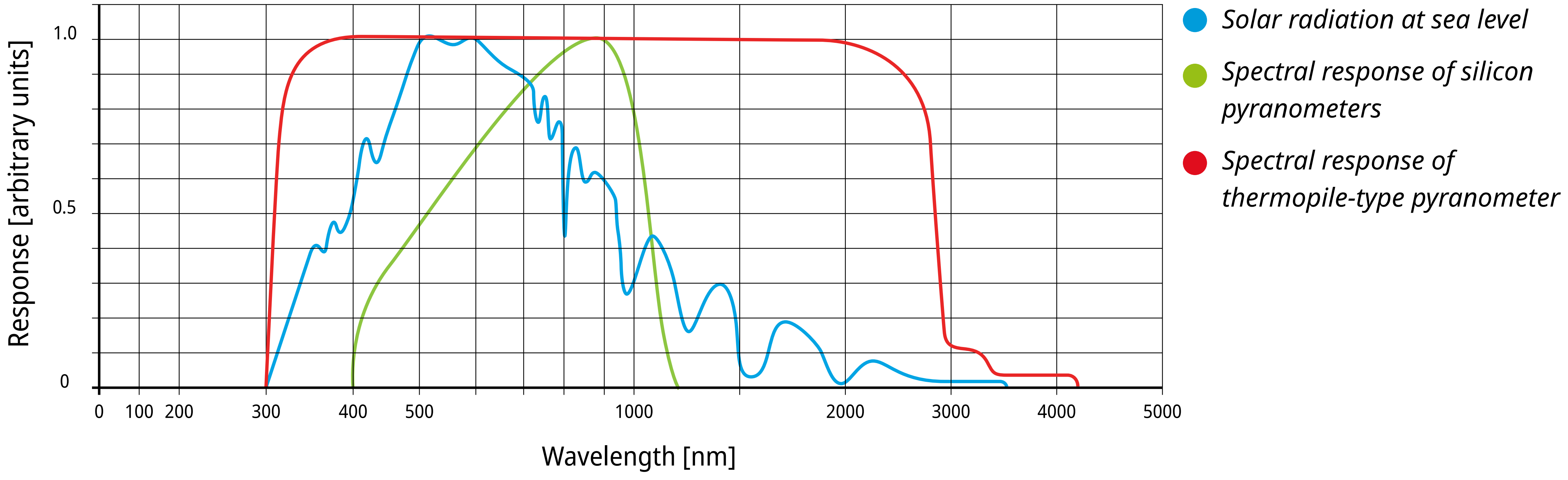
Nearly all ISO 9060:1990 pyranometers use an optical quality glass for their hemispherical single or double domes to protect the black detector surface from dirt and environmental effects. Depending upon the glass type the transmission is from 300 nm, or less, to about 3,000 nm. Double domes, or a dome and a diffuser, give better stability under dynamically changing conditions by further 'insulating' the sensor surface from environmental effects such as wind and rapid temperature fluctuations.

In essence, a pyrheliometer is a pyranometer with a collimation tube that restricts the view to 5° and usually has a glass or quartz disk as the entrance window for the radiation.

Photoelectric sensors, including silicon cells and photodiodes, have a limited and uneven spectral response that does not meet the spectral selectivity specifications for a pyranometer or pyrheliometer as defined by ISO 9060:1990; and thus, had to be described as a 'Silicon Pyranometer', or similar terminology.

The graphs below show a clear sky solar radiation spectrum at sea level and the response of an entry-level glass dome thermopile pyranometer, such as the Kipp & Zonen CMP3 and SMP3 models, and a typical silicon photodiode sensor, like the Kipp & Zonen SP Lite2 and RT1.


Solar Panel Roof in Sukaresmi, Indonesia



Classifications of pyranometers and pyrheliometers in ISO 9060:1990 are: Second Class, First Class and Secondary Standard in order of improving measurement performance.

There is no Primary Standard pyranometer classification; for the lowest measurement uncertainty, GHI is calculated from very accurate diffuse and direct irradiance measurements and the solar zenith angle (θ), using the formula GHI = DHI + DNI*cos(θ).

ISO 9060:1990 does refer to a primary standard for pyrheliometers, but it is not designated as a performance classification. This is an 'absolute cavity radiometer' (ACR) that is expensive and can only make measurements in fine weather conditions, such as the PMO8 available from Davos Instruments, Switzerland.

Most ISO 9060:1990 pyranometers were only supplied with a sensitivity calibration certificate. Models used in 'scientific' applications, such as the Kipp & Zonen CMP21 and CMP22 were normally supplied with individual temperature response and directional response test reports so that measurement data can be post-corrected if required.

ISO 9060:2018

The updated Second Edition was published in November 2018. There are two major changes in the specifications:

1. In 1990 specification parameters have limit values, for example ± 0.5 %. In 2018 there are 'guard bands', representing the interval between a tolerance limit and a corresponding acceptance limit so that the value could become ± 0.5 % with a 0.2 % guard band, this is intended to represent the uncertainty in determining the actual value.

2. Regarding spectral response, the change is from 'spectral selectivity' in 1990 to 'clear sky irradiance spectral error' in 2018. This is calculated by convolving reference solar spectra for air mass 1.5 and air mass 5 with the measured spectral response of the radiometer. This represents GHI and DNI through a clear atmosphere at solar zenith angles of 48° and 78° and covers at least 90% of the radiation received at a site.

The basic classifications of pyranometers and pyrheliometers in ISO 9060:2018 are:

Class C   Class B   Class A

in order of improving measurement performance.

This means that a Spectrally Flat Class A pyranometer is essentially the same as 1990 Secondary Standard. However, Spectrally Flat Classes B and C have better spectral selectivity than 1990 First Class and Second Class, respectively.

There is a new 'zero offset (c)' taking into account offsets in electronics of active pyranometers and a new parameter 'additional signal processing errors'. This applies to internal or external signal or data processing that forms a part of the radiometer irradiance measurement output.

If the radiometer meets the 1990 'spectral selectivity' criteria for a Secondary Standard pyranometer the term 'spectrally flat' can be used under ISO 9060:2018

Spectrally Flat Class C   Spectrally Flat Class B   Spectrally Flat Class A

in order of improving measurement performance.

If the 95 % response time is less than 0.5 second, the term 'fast response' can be used; for example, 'Fast Response Class C' would be typical for the analog output signal of a photodiode sensor without amplification. Analog amplifiers often include filtering that slows the response time. Note that radiometers with RS-485 Modbus® RTU serial data communication may have the response time limited by the update rate in the output data registers.

ISO 9060:2018 requires that Class A pyranometers must be individually tested to ensure that the temperature and directional responses comply with the classification requirements.

There is an additional classification, Class AA for 'reference' pyrheliometers that, by implication, must be 'spectrally flat' and be an absolute cavity radiometer. There is also an extra parameter for pyranometers and pyrheliometers, 'Additional signal processing errors'. This applies to internal or external signal or data processing that forms a part of the radiometer irradiance measurement output.

The term 'diffusometer' is introduced, referring to a pyranometer together with the structure or mechanism to shade it from the direct solar radiation.

2018 vs 1990

The key point to bear in mind is that the pyranometers and pyrheliometers have not significantly changed. A model such as the Kipp & Zonen CMP10 delivered up to October 2018 was ISO 9060:1990 Secondary Standard, but from November 2018 it became ISO 9060:2018 Spectrally Flat Class A.

The instrument is the same and so is the performance, calibration uncertainty, and the overall uncertainty of the measured irradiance data. The main difference for the end-user is that they now receive temperature and directional error test reports in addition to the sensitivity calibration certificate.

Kipp & Zonen Pyranometer ISO 9060 Classifications

ISO 9060:2018	Class C	Spectrally Flat Class C	Spectrally Flat Class B	Spectrally Flat Class A
ISO 9060:1990	Not allowed	Second Class	First Class	Secondary Standard
Performance	Lower	→	→	Higher
Passive pyranometers	SP Lite2 (Fast Response)	CM4 CMP3	CMP6	CMP10 CMP11 CMP21 CMP22
Smart pyranometers	RT1	SMP3	SMP6	SMP10 SMP11 SMP12 (NEW) SMP21 SMP22

Note | An ISO 9060:1990 Secondary Standard pyranometer cannot be reclassified as ISO 9060:2018 Spectrally Flat Class A unless the temperature and directional response tests are carried out, which are normally done by returning the instrument to the manufacturer.

3. IEC 61724-1 PV Performance Monitoring

There are several international standards regarding the monitoring of solar energy plant performance that have become adopted by major stakeholders around the world.

The newest and most comprehensive of these is IEC 61724-1, Photovoltaic system performance - Part 1: Monitoring, which was published in March 2017. It also serves as a basis of two standards for performance analysis that rely upon the data collected, IEC TS 61724-2 and IEC TS 61724-3 published in 2016.

IEC 61724-1 outlines equipment, methods, and terminology for the performance monitoring and analysis of grid-connected solar energy plant systems, from irradiance input to AC power output. It is applicable to fixed angle, single-axis tracking and dual-axis tracking conventional PV modules and to concentrator (CPV) systems.

As a result of industry feedback, this standard was substantially revised to Ed2 and the update was published in July 2021. It is strongly recommended to purchase the document from the IEC Webstore.

Part 1 of IEC 61724-1 addresses sensors, installation, and accuracy for monitoring equipment in addition to the data acquisition of measured parameters, quality checks, calculated parameters, and performance metrics. Here is an overview of how it relates to monitoring solar irradiance and other environmental factors.

Monitoring Classes

Two classes of monitoring systems are defined in IEC 61724-1:2021, corresponding to different levels of monitoring uncertainty and the intended commercial and industrial (C & I) and utility-scale applications:

TYPICAL APPLICATIONS	Class B - Medium Accuracy	Class A - High Accuracy
Intended application	Roof top and small-medium C & I	Large C & I and utility-scale
Maximum sampling interval for irradiance, temperature, wind, and electrical output	1 min	5 sec
Maximum sampling interval for soiling, rain, snow, and humidity	Not specified, assumed to be the same as the maximum recording interval	Not specified, assumed to be the same as the maximum recording interval
Maximum recording interval	15 min	5 min 1 min recommended

For Class A all parameters must be monitored at the site. For Class B it is acceptable to estimate the measurements from other data sources, such as meteorological networks or satellites, but these may not be available with sufficient proximity or in real-time.

The parameters to be monitored and the types of sensors required for each monitoring station depend upon the Monitoring Class. Measurement of DNI and DHI is included in Class A for specific purposes, but here we will concentrate on the measurement of GHI and POA irradiance.

Note

IEC 61724-1:2021 refers to ISO 9060:2018 pyranometer classifications.

Communication and Connection

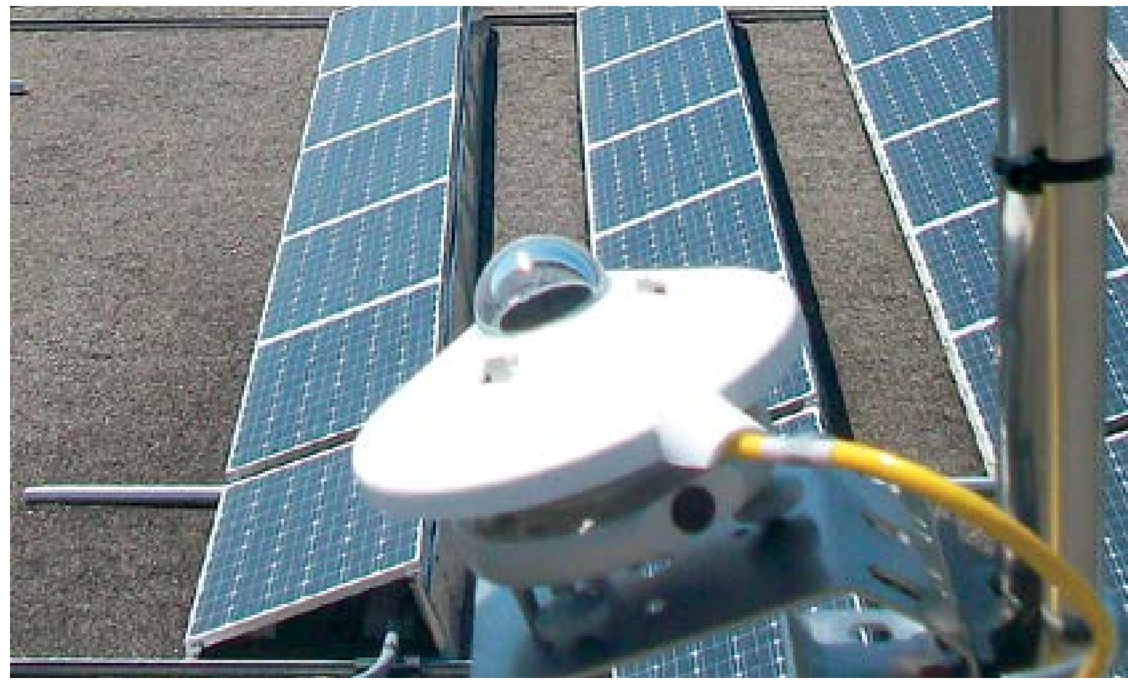
The solar energy industry standard for serial data communication within PV plants is 2-wire RS-485 with Modbus® RTU protocol, using individually addressable monitoring equipment on a small number of data bus loops. Power is distributed 12 or 24 VDC.

Inverters, hubs and gateways now use this and many no longer have any analog inputs. Often, there is no local data logging in the field and all the sensors connect back to the site supervisory control and data acquisition (SCADA) system for data storage, analysis and visualization by the plant monitoring software and for remote access.

Typically, there is a weatherproof junction box under an array to which all the sensors connect for data and DC power, using DIN rail terminal blocks. This should have a good Protective Earth / Ground and is also where any necessary surge / spike / lightning / ESD protection should be located for the DC power and RS-485 lines to the monitoring instruments.

Shielded RS-485 cabling usually runs underground from the junction box to the control room and SCADA system. SCADA systems are programmed to communicate with the site monitoring equipment by the plant owner or operator IT engineers.

Where a Modbus® RTU output is not available from a sensor, 4-20 mA is usually the preferred analog output type for use with the inputs of low-cost industrial data loggers and/or long cables.



Class B Monitoring Station

1 x GHI and 1 x POA Irradiance Sensors

ISO 9060:2018 Class C or IEC 60904-2 'working reference' photovoltaic device.

Calibration uncertainty:	≤ 3 % at 1000 W/m²
Measurement range:	up to 1500 W/m²
Resolution:	≤ 1 W/m²

Most silicon photodiode and cell sensors do not meet this calibration uncertainty specification.

POA alignment:	within 1° tilt, 2° azimuth
GHI alignment	within 0.5°
Maintenance:	as recommended by the manufacturer
Recalibration:	as recommended by the manufacturer
Cleaning and soiling mitigation:	not specified
Dew and frost mitigation:	not specified

1 x PV Module Temperature Sensor

Measurement uncertainty:	± 1 °C or better
Resolution:	≤ 0.1 °C
Recalibration:	as recommended by the manufacturer

Other Environmental Parameters

- Ambient air temperature with forced ventilation – for historical trending analysis
- Wind speed – affects surface cooling of the modules
- Rainfall – to correlate with power generation loss due to water on the modules

Periodic sensor site confidence checks are recommended.
Complete system inspection at least annually.

Recommended equipment:

All with RS-485 Modbus® RTU data communication.

- 2 x Kipp & Zonen SMP3 ISO 9060:2018 Spectrally Flat Class C pyranometers

or

- 2 x Kipp & Zonen SMP6 ISO 9060:2018 Spectrally Flat Class B pyranometers

- 1 x Lufft WS600-UMB all-in-one weather station – also measures wind direction, air pressure and humidity, and calculates dew point

- 1 x Lufft WT1 module temperature sensor – plugs into the WS600

Humidity is not required to be monitored, but it is measured by the WS600 and is useful because it is needed to calculate the air dew-point, which can be correlated with power loss caused by dew or frost. This is mentioned in the standard as a benefit.

The WS-600 radar precipitation sensor needs no regular maintenance and outputs precipitation in real-time to correlate with the power generated. In dry, dusty areas a tipping bucket rain gauge will need regular cleaning and in light drizzle it can take a long time before the bucket tips, and the water might evaporate before it does.

Note | There are strict guidelines in IEC 61724-1 regarding module temperature sensors, position, thermal conductivity of the mounting, and the overall accuracy of the measurement

Class A Monitoring Station

1 x GHI and 1 x POA Irradiance Sensors

ISO 9060:2018 Spectrally Flat Class A or IEC 60904-2 'working reference' photovoltaic device.

Calibration uncertainty:	≤ 2 % at 1000 W/m²
Measurement range:	up to 1500 W/m²
Resolution:	≤ 1 W/m²

Only the best and most expensive IEC 60904-2 cell sensors might meet this calibration uncertainty specification.

POA alignment:	within 0.5° tilt, 1° azimuth
GHI alignment	within 0.5°
Maintenance:	as recommended by the manufacturer
Recalibration:	every 2 years, more often if recommended by manufacturer
Inspection:	POA check weekly for soiling, misalignment and faults
Cleaning and soiling mitigation:	clean weekly, but less frequently if conditions allow or if technology mitigates, or corrects for, soiling equivalent to weekly cleaning or soiling detection is employed
Dew and frost mitigation:	required if dew and frost expected for > 2% of annual GHI hours; means can include heating and external ventilation; heating shall not disturb the accuracy or classification, internal or external ventilation may be used to maintain accuracy

3 x POA^{REAR} Irradiance Sensors

ISO 9060:2018 Class C (or better).

Calibration uncertainty:	≤ 3 % at 1000 W/m²
Measurement range:	up to 1500 W/m²
Resolution:	≤ 1 W/m²

Most silicon photodiode and cell sensors do not meet this calibration uncertainty specification.

Maintenance:	as recommended by the manufacturer
Recalibration:	as recommended by the manufacturer
Cleaning and soiling mitigation:	not specified
Dew and frost mitigation:	not specified

Minimum 3 x PV Module Temperature Sensors

Measurement uncertainty:	± 1 °C or better
Resolution:	≤ 0.1 °C
Recalibration:	as recommended by the manufacturer

Other Environmental Parameters

- Ambient air temperature – for historical trending analysis
- Wind speed – affects surface cooling of the modules
- Wind direction – for historical trending analysis
- Rainfall – to correlate with power generation loss due to water on the modules
- Snow – to correlate with power generation loss; if typical annual snow losses without cleaning are > 2 % and not identified by soiling measurement
- Soiling ratio – if typical annual soiling losses without cleaning are > 2 %

Periodic sensor site confidence checks are recommended.
Complete system inspection at least annually.

Recommended equipment:

All with RS-485 Modbus® RTU data communication.

- 2 x Kipp & Zonen SMP12 ISO 9060:2018 Spectrally Flat Fast Response Class A pyranometers with built-in heating (no moving parts) to prevent dew or frost formation on the dome

or

- 2 x Kipp & Zonen SMP10 ISO 9060:2018 Spectrally Flat Class A pyranometers with CVF4 heating and ventilation units if soiling mitigation is the main issue

- 1 x Lufft WS600-UMB all-in-one weather station – in addition to the advantages of the WS-600 mentioned under Class B monitoring it can also distinguish rainfall from snowfall
- 1 x Lufft WT1 module temperature sensor – plugs into the WS600
- 1x Kipp & Zonen DustIQ Soiling Monitoring System including module temperature sensor – if required

IEC 61724-1:2021 includes soiling measurement devices based on optical principles, detecting soiling particles on a collection surface according to their effect on either reflection or transmission of light (as in the DustIQ).

In the recommended system there are one or two module temperature sensors. For the remaining 1 or 2 measurement points required for Class A monitoring (minimum 3 units) separate Modbus® RTU sensors will be required, for example the Ingenieurbüro Mencke & Tegtmeyer (IMT) Tm-RS485-MB.

Plant capacity (AC)	Number of monitoring systems
< 40 MW	2
≥ 5 MW to < 100 MW	3
≥ 100 MW to < 300 MW	4
≥ 300 MW to < 500 MW	5
≥ 500 MW to < 700 MW	6
≥ 700 MW	7 (+ 1 per additional 200 MW)

2021 vs 2017

There are many significant changes in IEC 61724-1:2021, compared to the original 2017 edition of the standard, that are largely based upon industry feedback.

- The original standard had 3 qualities of PV plant performance monitoring. However, Class C (Basic Quality) had insufficient accuracy to be useful for grid-connected plants and has been deleted.
- For Classes B and A monitoring the irradiance sensor specifications have been update to ISO 9060:2018 and other changes have made. For example the required calibration intervals have changed. For Class A monitoring irradiance sensors the mitigation solutions for soiling, dew and frost have been expanded and clarified. Pyranometer alignment limits have been tightened.
- The number of PV module temperature sensors per station has been reduced to 1 for Class B and minimum of 3 for Class A.
- For Class A, albedo and POA^{REAR} irradiance monitoring have been added.
- Optical technology soiling monitors are included, these were not available before 2017.

Where sites have varying module angles there should be additional POA and soiling monitoring, or some modules could be facing East and some facing West.

4. ISO 9846 and 9847 Pyranometer Calibration

Various international standards related to solar energy require that pyranometers for the measurement of Global Horizontal Irradiance (GHI) or Global Tilted Irradiance (GTI, including Plane of Array, POA) are calibrated in accordance with ISO 9846:1993 or ISO 9847:1992.

ISO 9846 is for outdoor calibration of a pyranometer using a reference pyrheliometer. ISO 9847 is for calibration of a field pyranometer against a reference pyranometer and there are methods for both outdoor and indoor calibrations.

An outdoor pyranometer calibration to either ISO 9846 or ISO 9847 requires 2-3 days of clear skies (longer if partially cloudy). There are strict requirements on mounting the field / test pyranometer and the reference instruments, cleaning during the period, data logging, data processing and data validation. Because of these time and weather constraints all manufacturers of pyranometers calibrate indoors to ISO 9847 under controlled conditions.

IEC 61724-1:2021 stipulates that for Class A monitoring irradiance sensors must be recalibrated every 2 years, and for Class B as per the manufacturer's instructions. Kipp & Zonen recommends recalibration of field pyranometers every two years.

Calibrations must be traceable to the World Radiometric Reference (WRR), which has an uncertainty of ± 0.3% at the 95% confidence level. The WRR is located at the World Radiation Centre (WRC) in Davos, Switzerland and WRC is operated by the Physikalisch-Meteorologisches Observatorium Davos (PMOD) by appointment of the World Meteorological Organisation (WMO).

To be in compliance with the standards there is a lot of information that must be included on the instrument calibration certificate. The key points are:

- Test pyranometer and reference instrument details
- Calibration method, location, date and time
- Hierarchy of traceability to the WRR
- Calibration conditions; range of solar zenith angles, temperature and irradiance
- Result of the calibration, typically in μV/W/m² or Wm²/μV
- Overall uncertainty of the result

Calibration of reference pyrheliometers at the WRC

ISO 9846 Calibration

ISO 9846 'Solar Energy - Calibration of a pyranometer using a pyrheliometer' is for outdoor calibration using a reference pyrheliometer mounted on a precision automatic sun tracker that measures Direct Normal Irradiance (DNI). This is the recommended calibration standard for pyranometers that are intended to be used as reference instruments, including for ISO 9847 calibrations.

There are two methods, where 'sun' refers to the global radiation and 'shade' refers to the diffuse radiation:

Continuous sun and shade

The test pyranometer measures GHI. A reference pyranometer is continuously shaded to measure DHI, whilst DNI is measured by the pyrheliometer. From these two values and the incident angle of the direct beam the 'reference' GHI can be calculated and compared to the test pyranometer GHI values.

For the DHI measurement the reference pyranometer should be heated and ventilated to minimize zero offsets. However, the test pyranometer is usually not heated or ventilated and therefore includes higher offsets in its GHI measurement.

Continuous sun and shade is the more commonly used method, as it is easier to carry out with production equipment and a number of test pyranometers can have a simple horizontal mounting table and be calibrated simultaneously. However, it does require clear skies for good results.

Alternating sun and shade

There is no reference pyranometer. The test pyranometer has a shading assembly to block the direct beam from the sun and it can also be moved out of the view of the pyranometer such that the measurement alternates between GHI (sun) and DHI (shade). From these two values and the incident angle of the direct beam the DNI seen by the pyranometer can be calculated and compared to the reference pyrheliometer DNI values.

An advantage of this method is that the zero offsets are effectively the same for both sun and shade measurements and are therefore taken out of the sensitivity calibration. The sky view is also the same for both measurements and the alternating method provides better results under scattered cloud conditions.

If the test pyranometer is mounted on a sun tracker to point at the sun throughout the day (as the pyrheliometer does) and is alternately shaded and unshaded, the direct beam is always normal to the pyranometer detector and there is no directional error affecting the sensitivity and this further reduces the calibration uncertainty.

In both methods a better classification of pyrheliometer will provide a lower calibration uncertainty of the test pyranometer. For the lowest uncertainty the pyrheliometer should be an absolute cavity radiometer (ACR).

The reference pyranometers for the calibration facilities operated by Kipp & Zonen / OTT Hydromet are calibrated using the tilted alternating sun and shade method and an ACR reference pyrheliometer, as described above.

ISO 9847 Indoor Calibration

ISO 9847 is titled 'Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer' and this covers two types of method. Type I is for outdoor calibration using solar radiation as the source, whilst Type II is for indoor calibration employing an artificial radiation source under controlled conditions. Reference instruments should have a suitable calibration that is not more than 12 months old at the time of use.

Type IIc is for direct beam indoor calibration, as described in Annex A 'Calibration Devices Using Artificial Sources'. The equipment and method referred to in Annex A.3.1 is the 'Kipp & Zonen Device and Procedure'. This is the calibration method used by almost all manufacturers of pyranometers. Kipp & Zonen has improved this procedure since the original 1992 description.

The calibration equipment is located in a dark-room with secure access and the temperature is controlled, this is usually at around + 20°C. A reference pyranometer and a test pyranometer of the same type are illuminated equally by a beam of light from a metal-halide lamp that is directly above them and has a very stable power supply. The irradiance at the pyranometer detectors is adjusted to be approximately 500 W/m², this is the reference level for the ISO 9060 non-linearity specification.

To account for inhomogeneity in the lamp beam the reference and test pyranometers are mounted on a turntable that can be rotated accurately through 180 degrees to interchange their positions in the light field. The two pyranometers can be shaded simultaneously to determine offsets caused by thermal effects under the lamp.

"Reference instruments should have a suitable calibration no more than 12 months old."

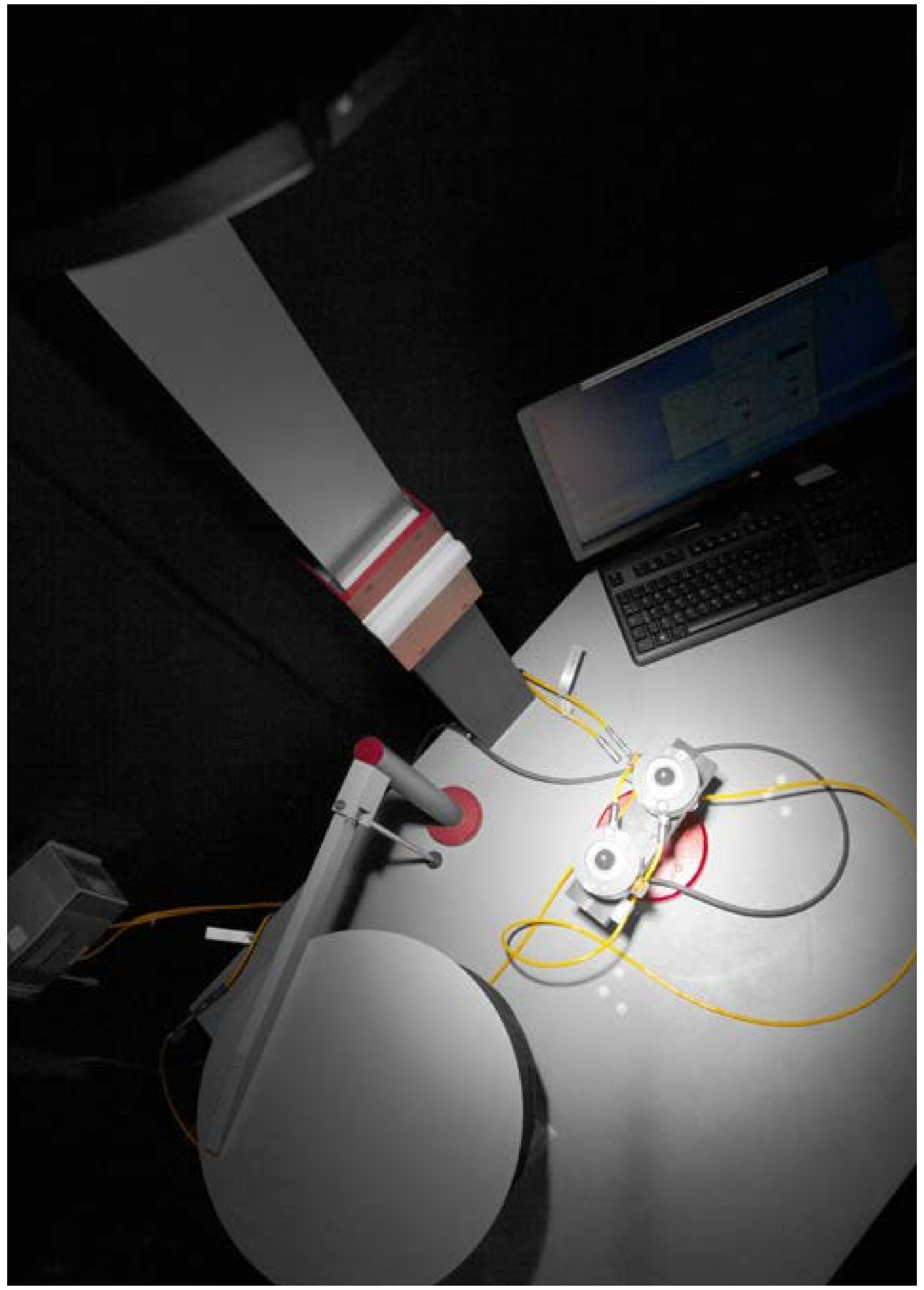
ISO 9847 states that reference pyranometers should be calibrated outdoors to ISO 9846 and the sensitivity was for the measurement conditions at that time, as given in the hierarchy of traceability to the WRR on the calibration certificate. For this reason, to transfer the reference calibration to the field pyranometer indoors it is very important that the two pyranometers have similar construction, response time, thermal and spectral characteristics.

The combined uncertainty of the calibration is the positive 'root sum square' of the expanded uncertainty in the reference pyranometer calibration referred to the WRR and the expanded uncertainty of the transfer procedure in the Kipp & Zonen laboratory (estimated to be ± 0.5 %). The estimated total uncertainty can be as low as ± 1 % for the CMP22 model pyranometer at the 95% confidence level (k=2).

The calibration equipment and procedures are the same at Kipp & Zonen / OTT Hydromet regional calibration centers as at the factory in Delft, The Netherlands. The process is largely automated and works through a calibration server and database at the factory and is the same for new production pyranometers and for customer field instruments, which are inspected, cleaned and tested before recalibration.

There are a large number of QA/ QC checks automatically carried out, including checking that the correct type of reference pyranometer is being used and that its calibration is valid. Each reference pyranometer is uniquely identified by a radio frequency identification device (RFID) linked to the database. The calibration history of field pyranometers is available and can be checked for stability.

If the QA/QC checks are passed, a detailed calibration certificate and an instrument label are generated by the server, stored in the database and sent to the calibration facility printers. The certificate is printed on the original headed paper of the Kipp & Zonen authorized calibration center.



ISO 9847 Outdoor Calibration

ISO 9847 allows for pyranometers to be calibrated outdoors in a choice of 3 orientations. Type Ia is horizontal (GHI), Ib is tilted (GTI or POA) and Ic is mounted on an automatic tracker and pointing at the sun. Type Ia is most commonly used because it is easy to ensure that the reference and field pyranometers are all at the same angle (horizontal) and have the same largely unobstructed view of the sky.

As previously mentioned, an outdoor pyranometer calibration requires 2-3 days of clear skies (longer if partially cloudy) and there are strict requirements on mounting the reference and field pyranometers. They must be kept clean during the calibration period and it is unlikely that the typical PV plant data logging / acquisition system will meet the data processing and data validation requirements. Probably, a high-quality scientific data logger will be required.

It is not usually practical or cost-effective to make on-site calibrations to ISO 9847 and therefore PV O&M contractors usually send pyranometers to a manufacturer calibration center at the scheduled intervals, typically every two years.

However, it is possible to more easily and quickly carry out a 'site confidence check' of field pyranometer measurements as described next. The majority of the points made also apply to making preparations for an actual ISO 9847 outdoor calibration.

Field pyranometers being calibrated at UNAM, Mexico

Site Confidence Check

IEC 61724-1:2021 recommends periodic cross-checks of each sensor against sister sensors or reference devices in order to identify out-of-calibration sensors. The WMO does allow for (and recommend) 'Routine checks on calibration factors' by comparison with a reference pyranometer between scheduled calibrations.

This type of site confidence check for pyranometers is similar to an outdoor calibration to ISO 9847; but with simpler mountings, a shorter measurement period, a lot less data processing and no detailed certificate. It can be carried out at a solar plant by O&M personnel or a third party.

When to make the comparison?

Typically, two to three hours each side of local solar noon (not 12:00 clock time) on a day when the sun is clear; some scattered clouds that are away from the sun won't make a significant difference. Ideally, this would be done in the summer when the sun's path is highest in the sky.

Prepare the field pyranometer

First the field pyranometer must be inspected and any damage noted (preferably photographs taken) and corrected. It must be cleaned, desiccant changed (if applicable), cabling and alignment checked, and the weather conditions noted.

Reference Pyranometer

A clean, well-maintained reference pyranometer with a recent and reliable traceable calibration is required and it should be at least as good in performance as the field pyranometer (ideally, a Kipp & Zonen CMP22 or SMP22 to minimize the reference measurement uncertainty). If the reference pyranometer is kept warm, dry and in the dark when not in use for the confidence checks, the sensitivity will not change significantly with time.

CMP22 and SMP22 have a sensitivity uncertainty of about ± 1 % at the 95 % confidence level (k=2) compared to the relevant calibration conditions. When measuring outdoors, the conditions are different and are changing during the day, so additional measurement errors/uncertainties are introduced. SMP22 has excellent internal temperature correction < 0.3 % (-40 °C to +70 °C), low thermal offsets, and good directional response and non-linearity. In a confidence check a SMP22 should measure within ± 1.1 % of the 'true' value.

Mounting

The best comparison result will be obtained by mounting both reference and field pyranometers horizontally and close to each other and with a clear view of the sky, to measure global horizontal irradiance (GHI). However, you can mount the reference pyranometer accurately tilted at the same angles as a Plane of Array (POA) field pyranometer and close to it. Ensuring that they have the same view of the ground and arrays in front of them is the key point.

There should be no shadows on the pyranometer domes during the comparison period. If this cannot be avoided because of site structures, the data at this time should be excluded from the analysis.

Data Loggers

Both pyranometers should be connected to the same high-quality portable data logger; because there could be issues with the site cabling, power, or data logger / SCADA systems.

LOGBOX SE

LOGBOX SE is compact, weatherproof, has multiple inputs and the internal batteries can easily run SMP pyranometers for the comparison period (CMP models do not require power). Usually, you sample every second and log 1-minute averages with the maximum and minimum and standard deviation. This allows the downloaded data to be screened for outliers before comparing the measurements in a spreadsheet.

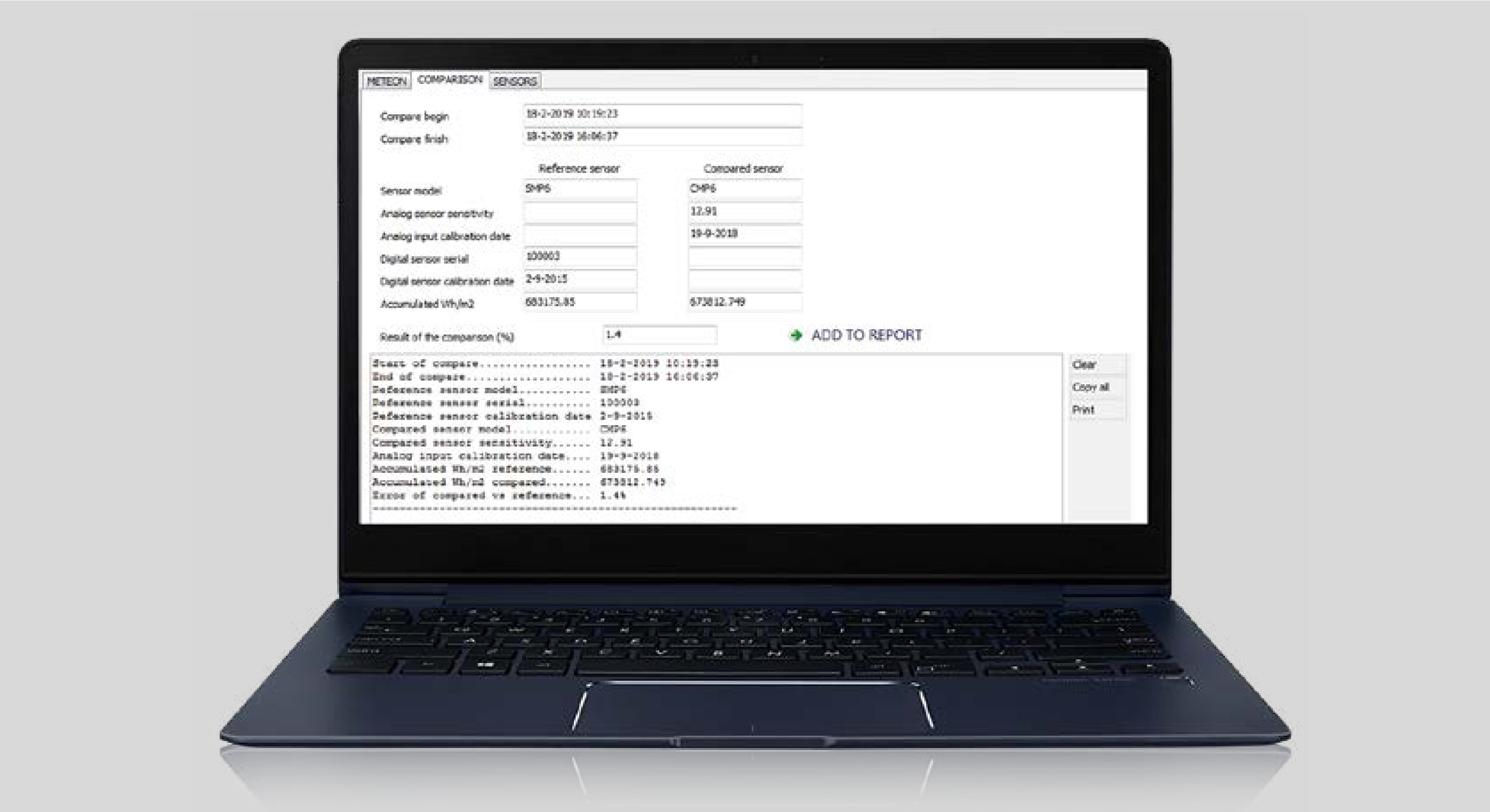
There is no display on the LOGBOX SE but it can be configured on site, live data viewed, and logged files downloaded via USB using a laptop computer and the Windows™ setup software.

METEON 2.0

METEON 2.0 is not weatherproof, but the confidence check is only carried out in fine conditions. The field pyranometer is often a CMP model and METEON 2.0 only has one analogue input, so the reference should usually be a SMP type.

METEON 2.0 can run smart pyranometers from the internal batteries and has a display so that live data can be seen. It has Windows™ software and USB communication to a laptop and can log like the LOGBOX SE, but it does not calculate standard deviation.

METEON 2.0 comes in a rugged case with space for a reference pyranometer and cable, making an easily portable kit. It has a unique comparison mode that does most of the work for you. It sums the total irradiance during the logging period from each pyranometer and a report is generated in the logger that shows the difference between these two totals as a percentage.



METEON 2.0 comparison mode cannot screen the data within the total for outliers. So, ensure that nothing affects the pyranometer readings during the measurement period; such as shadows from site structures or people walking nearby.

After the Logging Period

Reconnect the field pyranometer to the plant cable and check the data against the reference pyranometer/ logger to see if there is a problem with the site systems. Depending upon the site logging interval this might need to be for up to 30 minutes.

Site Visit Report

Analyze the data and make a report that includes all the relevant information; inspection details, work carried out, weather conditions, equipment used, and the difference between the total irradiances measured by the reference and field pyranometers.

The important issue is whether this difference is within the expected uncertainty. If not, it can be recommended that the field pyranometer should be recalibrated or exchanged and not wait until the next scheduled date.

What is the Expected Uncertainty?

The expected likely measurement difference depends upon the models of reference and field pyranometers and the environmental conditions. The most commonly specified pyranometers in solar energy applications comply with the requirements of

ISO 9060:1990 Secondary Standard or ISO 9060:2018 Spectrally Flat Class A. Typically, these are a Kipp & Zonen CMP10 or CMP11 model or the Smart SMP10 or SMP11 equivalents. These all have a calibration uncertainty of about ± 1.4 %.

Field measurement conditions differ from the calibration conditions, mainly temperature and the angle of the direct sun beam, causing additional errors. But, in most environments it can be expected that a freshly calibrated (or new) CMP10, CMP11, SMP10 or SMP11 will measure the 'check' total within ± 2 % of the 'true' value. ISO 9060:2018 allows Class A pyranometers to have a non-stability (change in responsivity) in operation of up to ± 0.8 % per year (with a guard band of ± 0.25 %). However, well designed and manufactured thermopile pyranometers, if correctly maintained, should have a temporal drift that is significantly smaller than this and over 1 or 2 years it is likely to be within the (re) calibration uncertainty.

If the reference pyranometer is a SMP22, it is likely that the measured total of irradiance over the period of the check is within ± 1.1 % of the 'true' value. If the field CMP10, CMP11, SMP10 or SMP11 has been correctly maintained it should be within ± 2%.

In principle, the reference could be reading 1.1 % high and the field pyranometer 2 % low (or the other way around). So, the difference could be up to ± 3.1 % and because the uncertainties are all at the 95% confidence level, in 5 % of cases the difference could be greater. However, this is unlikely and probably they will be within 2% of each other.

What to do Next?

Site O&M circumstances and QA/QC requirements vary. However, it could be recommended (for the scenario described) that, if the difference is more than ± 2.5 % the field pyranometer should be recalibrated.

If the difference is significantly larger, it is possible that the field pyranometer has been damaged in some way and it should be investigated, repaired and recalibrated. Issues could be damage as a result of dropping it (or some other impact), lightning or other electrical damage; or a failure to inspect and change external desiccant, causing it to become damp internally at some time.

Whilst this is not a calibration to ISO 9847, it is a reliable method to check field pyranometers on-site to see whether they are measuring solar irradiance within the expected uncertainty.

5. ISO/IEC 17025 Calibration Laboratory Accreditation

The title of the ISO/IEC 17025 standard is: ‘General requirements for the competence of testing and calibration laboratories’. When a laboratory is accredited according to this standard, the management system has been approved, the methods used for calibration are validated, the calibration results have been independently compared to results of other accredited labs and the claimed uncertainties have been verified. Procedures for the entire calibration process are in place, making sure all instruments get a proper, correct calibration and constant quality will be delivered.

ISO/IEC 17025 accreditation is the single most important standard for calibration and testing laboratories around the world. The accreditation helps an end-user minimize risk by improving confidence in the irradiance measurements. Many industrial users, including in solar energy, require calibrations of measuring instruments by accredited laboratories. This includes pyranometers and pyrheliometers used for the performance monitoring of solar power plants.

Kipp & Zonen Accredited Calibration Service

The radiometric calibration laboratory at the Kipp & Zonen factory in Delft, The Netherlands has been accredited to the ISO/IEC 17025 quality management standard for the sensitivity calibration of pyranometers and pyrheliometers. Accreditation is by the Dutch Accreditation Council, ‘Raad van Accreditatie’ (RvA) which is appointed by law as the national accreditation body for the Netherlands and is therefore a member of the European co-operation for Accreditation (EA). RvA is a co-signatory to both the International Laboratory Accreditation Cooperation (ILAC) for laboratories and inspection bodies and the International Accreditation Forum (IAF) for certification bodies. Kipp & Zonen CMP series, SMP series and CM4 pyranometers are now supplied with sensitivity calibration certificates carrying the logos of RvA and ILAC.

This also applies to the PR1 pyranometer and PH1 pyrheliometers fitted to the RaZON^{+} all-in-one solar monitoring system and to the CHP1 and SHP1 pyrheliometers that are normally used with the SOLYS sun trackers. All the above radiometer models can be recalibrated to ISO/IEC 17025, and also many older instruments: CM3, CM6B, CM11B, CM21, CM22 and CH1.

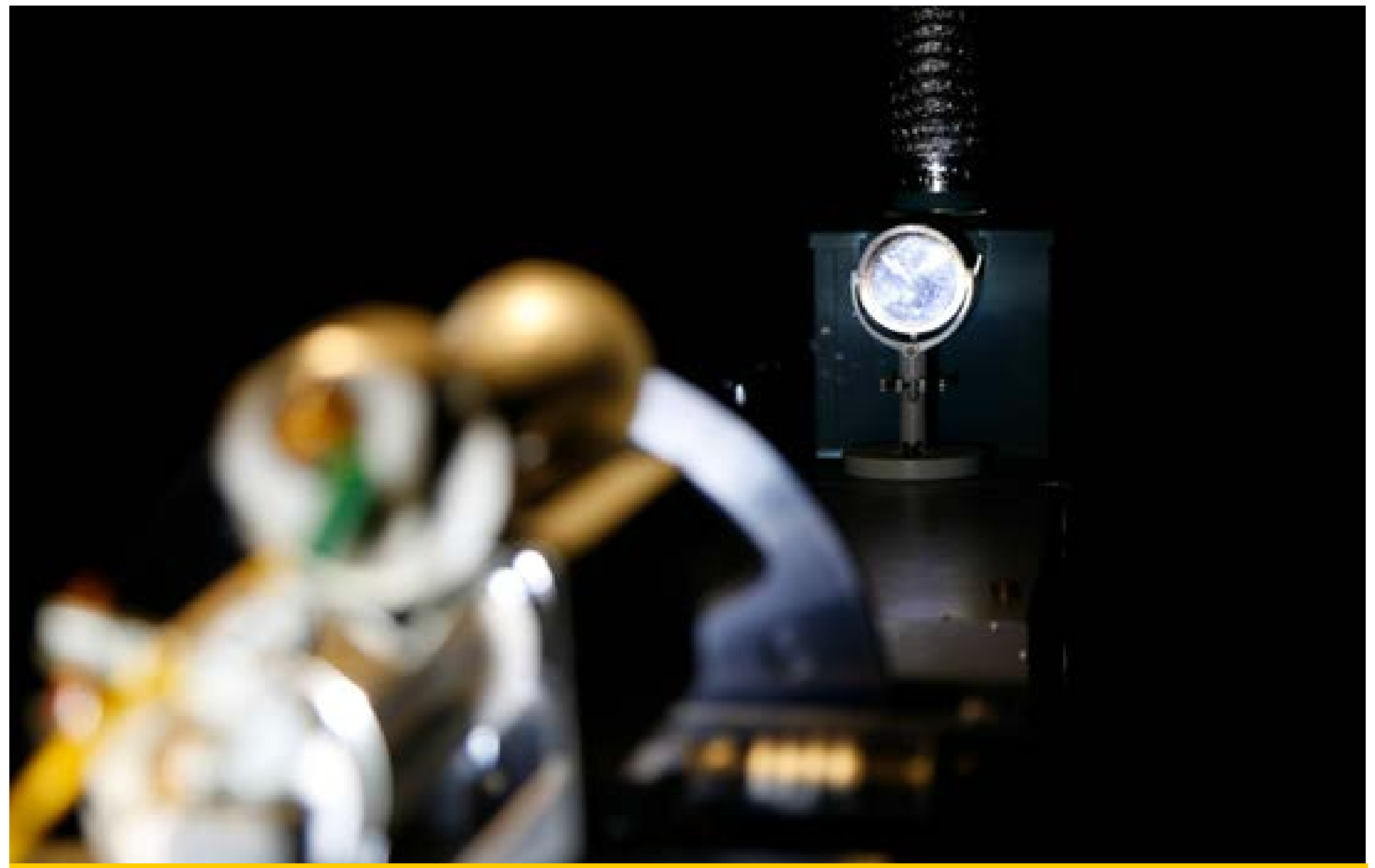
Calibration Methods

Pyranometers are calibrated indoors to ISO 9847:1992 type IIc, Annex A.3.1 'Kipp & Zonen Device and Procedure' as previously described. This is the current factory procedure as improved since the original 1992 description. The reference pyranometers are calibrated outdoors to ISO 9846:1993 using the tilted alternating sun and shade method and an ACR reference pyrheliometer.

Pyrheliometers are calibrated indoors using a similar comparison method of reference and test radiometers, but with a horizontal simulated direct sun beam and the reference and test pyrheliometers are moved alternately into and out of the center of the light field. This method has been developed and refined by Kipp & Zonen over many years and is proven in many international pyrheliometer comparisons and the Accreditation Council has determined that this is a valid and accurate method.

Reference pyrheliometers are calibrated outdoors against an absolute cavity radiometer (ACR) to ISO 9059:1990 'Solar Energy – calibration of field pyrheliometers by comparison to a reference pyrheliometer'.

All Kipp & Zonen pyranometer and pyrheliometer calibrations are traceable to the World Radiometric Reference (WRR) which represents the SI units of irradiance and itself has an uncertainty of ± 0.3% at the 95% confidence level.



Pyrheliometer calibration close-up

Calibration and Measurement Capability

One of the most important parameters on any ISO/IEC 17025 accreditation certificate is the Calibration and Measurement Capability (CMC) at the 95 % coverage / confidence level. This is the best calibration uncertainty that can be achieved, and it varies from laboratory to laboratory depending upon the processes and traceability used.

Kipp & Zonen is accredited for sensitivity calibration with excellent CMC values of 0.9 % for pyranometers and 1.1 % for pyrheliometers. The individual instrument calibration uncertainty given on the certificate depends upon the model of radiometer and its performance characteristics, but the accredited CMC's demonstrate the high level of the factory methods, procedures and quality processes.

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Insights for Experts

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