



**KIPP &
ZONEN**
SINCE 1830

Interpreting Solar Irradiance Data From Pyranometers

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Passion for Precision

UNCERTAINTY, NOT ACCURACY

‘Accuracy’ is a term with no specific international definition and its use is no longer encouraged.

The International Standards Organisation (ISO) and the World Meteorological Organisation (WMO) now only refer to ‘uncertainty’ in the measurement of a parameter under specific conditions.

In general, uncertainties (and pyranometer specifications) are expressed at the 95 % confidence level ($k=2$).

‘Overall’ uncertainties can be calculated by taking the Root Sum Square (RSS) of the contributing uncertainties.

SOLAR RADIATION UNCERTAINTY

Most of the measured solar radiation data available from around the world is from thermopile type pyranometers monitoring the Global Horizontal Irradiance (GHI), but how 'uncertain' is this?

For the purposes of this discussion we are considering the pyranometer specifications and performance only.

We assume that the pyranometer is correctly installed and maintained – not always the case!

We also assume that the data acquisition, logging and processing contribute insignificant additional errors or uncertainties - also not always true!

PYRANOMETER UNCERTAINTY DEFINITIONS

Sources of uncertainty in pyranometers are defined in ISO 9060:1990 the “specification and classification of instruments for measuring hemispherical solar and direct solar radiation”.

For each parameter, the deviation or change is the maximum allowable for the three categories of pyranometers;

Second Class

First Class

Secondary Standard

There is no ‘Primary Standard’ pyranometer. This is, in fact, a measurement calculated very accurately from Diffuse and Direct Irradiance and the solar zenith angle.

SOURCES OF PYRANOMETER UNCERTAINTY

ISO 9060:1990		Second Class	First Class	Secondary Standard
Ref.No.	Specification	Lower	→	Higher
1	Response time (95 %)	< 60 s	< 30 s	< 15 s
2	Zero offsets			
	(a) Response to 200 W/m ² net thermal radiation (ventilated if necessary)	± 30 W/m ²	± 15 W/m ²	± 7 W/m ²
	(b) Response to 5 K/hr change in ambient temperature	± 8 W/m ²	± 4 W/m ²	± 2 W/m ²
3a	Non-stability percentage change in responsivity per year	± 3.0 %	± 1.5 %	± 0.8 %
3b	Non-linearity percentage deviation from the responsivity at 500 W/m ² due to the change of irradiance within the range 100 W/m ² to 1000 W/m ²	± 3 %	± 1 %	± 0.5 %
3c	Directional response (for beam radiation) the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction a beam of radiation with normal incidence irradiance of 1000 W/m ²	± 30 W/m ²	± 20 W/m ²	± 10 W/m ²

SOURCES OF PYRANOMETER UNCERTAINTY

ISO 9060:1990		Second Class	First Class	Secondary Standard
Ref.No.	Specification	Lower	→	Higher
3d	Spectral selectivity percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 0.35 μm and 1.5 μm	$\pm 10\%$	$\pm 5\%$	$\pm 3\%$
3e	Temperature response percentage deviation due to change in ambient temperature within an interval of 50 K	8%	4%	2%
3f	Tilt response percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000 W/m^2 irradiance	$\pm 5\%$	$\pm 2\%$	$\pm 0.5\%$

A STANDARD DAY

Measurement uncertainties arise because the local conditions are different from the pyranometer calibration conditions.

Typically the pyranometers are calibrated in a laboratory at +20°C and with a simulated sun directly overhead (at 0° zenith angle).

It is necessary to make some assumptions regarding the change in the measurement conditions during any ‘typical day’ in a year.

For example, the ambient temperature in mid-latitudes is usually in the range -10°C to +40°C and the sun is never at zenith.

It is necessary to convert all the deviations and changes into percentages for the ‘typical day’ conditions.

In the following table this is done using the actual pyranometer performance figures, not the ISO minimum limit values.

KIPP & ZONEN DAILY UNCERTAINTIES

Sources of Uncertainty	CMP3	SMP3	CMP6	C/SMP10 C/SMP11 C/SMP21	C/SMP22
	Second Class		First Class	Secondary Standard	
Zero offset a)	1.5 %	1.5 %	1.2 %	0.7 %	0.3 %
Zero offset b)	0.3 %	0.3 %	0.3 %	0.1 %	0.1 %
Non-linearity	1.0 %	1.0 %	1.0 %	0.2 %	0.2 %
Directional response	2.0 %	2.0 %	2.0 %	1.0 %	0.5 %
Spectral selectivity	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
Temperature response	5.0 %	2.5 %	4.0 %	1.0 %	0.5 %
Tilt response (not relevant for GHI)	(1.0 %)	(1.0 %)	(1.0 %)	(0.2 %)	(0.2 %)
Typical daily uncertainty - horizontal, GHI	5.7 %	3.7 %	4.7 %	1.6 %	0.8 %
Typical daily uncertainty - tilted vertically	5.8 %	3.8 %	4.8 %	1.6 %	0.8 %

These daily uncertainties are, in effect, ‘worst case’ values.

They should be achievable in mid-latitude, non-extreme, climate conditions throughout the year.



CALIBRATION UNCERTAINTY

The daily uncertainties given are all relative to the radiometer sensitivity given on the instrument label and calibration certificate.

Therefore, it is important that the calibration is valid (ideally not more than 2 years old).

There is also an absolute uncertainty of the radiometer calibration compared to the World Radiometric Reference (WRR) at the World Radiation Center (WRC) in Davos, Switzerland.

Typical calibration uncertainty at the 95% confidence level is:

- | | | |
|-----------------|--------------------|------|
| • C/SMP3 | Second Class | 4% |
| • C/SMP6 | First Class | 3% |
| • C/SMP10/11/21 | Secondary Standard | 1.5% |
| • C/SMP22 | Secondary Standard | 1% |

The exact value is given on the calibration certificate.

KEEP THE DOME CLEAN !

If you have a pyranometer capable of an uncertainty in daily measurements of 2%, or less, it will be readily appreciated that it does not take much in the way of deposits on the dome to completely disrupt the readings.

Dew and raindrops will absorb and scatter radiation.

Frost, and snow are highly reflective.

Dust, dirt and sand will block radiation from reaching the detector and may stick to a damp dome and form a hard layer.

Atmospheric pollutants on the dome attenuate radiation and also alter the spectrum of the radiation reaching the detector.

Most sites do not have permanent staff who can clean all the domes before sunrise everyday! What can you do?

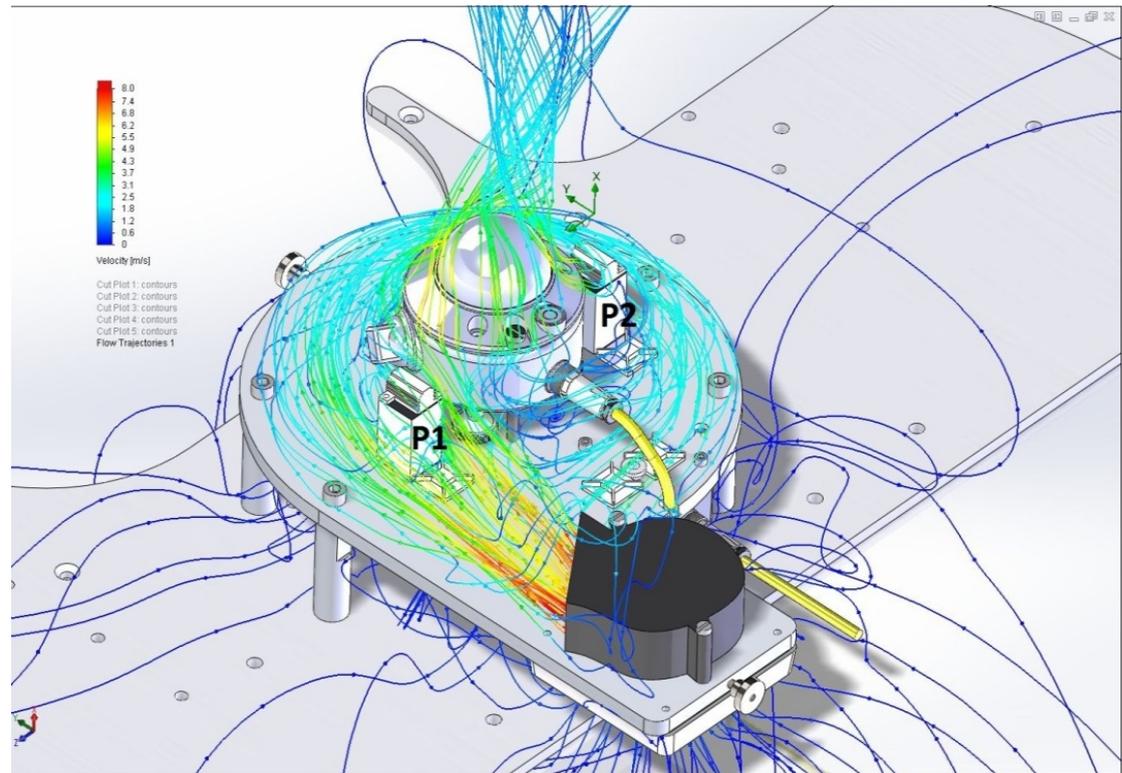


FIT A VENTILATION UNIT

A high-flow radial fan produces a swirling, spiral, airflow close to the dome.

This provides a barrier layer of air against deposition and evaporates dew and raindrops.

The fan runs from 12 VDC at 5 W and the speed can be monitored.

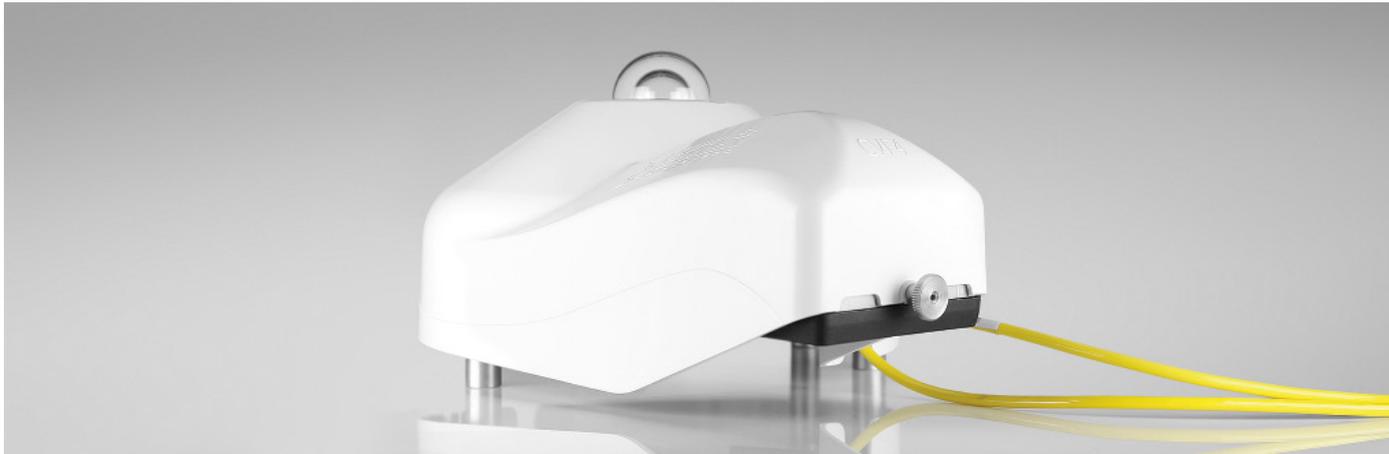


WHAT ARE THE BENEFITS OF VENTILATION ?

Ventilation stabilises the temperature of the radiometer close to that of the ambient air and can reduce thermal offsets that are produced by heating or cooling of the pyranometer dome(s).

Heating the airflow will melt frost and snow.

The result is a much greater up-time of high quality, reliable measurement data and reduced frequency of cleaning.



PLANE OF ARRAY ISSUES

For the uncertainty calculations just shown it is assumed that the pyranometer has a clear view of the hemisphere above its detector plane.

For a horizontal pyranometer measuring GHI this may be true, at least down to 5° above the horizon; at which angle any errors are small in the context of the daily total of irradiance.

When a pyranometer is tilted it is typically at the same angle as an installation of PV panels, in the Plane of Array (POA). The objective being to measure the ‘tilted global’ radiation available to the panels.

The pyranometer no longer sees the complete diffuse sky.

A proportion of the pyranometer view is of the ground and, often, the backs of rows of panels in front of the pyranometer.

TYPICAL POA AND GHI VIEWS





CAUSES OF 'STRANGE' MEASUREMENTS – ARRAY

When measuring within the arrays there are several issues:

- There may be reflections of light from the panel frames and supports, depending upon the sun position.
 - A part of the view is usually the rear of panels, which are generally fairly dark and in shadow.
 - Part of the view is the ground below and the surface albedo (reflectivity) will affect the readings, grass will be different from concrete and it will change with snow on the ground.
 - Some of the day the ground may be in shade, and sometimes (morning and evening) in the sun.
 - The tilted pyranometer will always does not see the whole sky, so the diffuse component measured will be different from that seen by a horizontal GHI pyranometer.
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MOUNTING HEIGHT



The black detector surface must be above the PV panel frame!

CAUSES OF 'STRANGE' MEASUREMENTS – SITE

When measuring tilted global irradiance for the site, clear of the arrays, things are simpler.

There are no issues with reflections and shading.

In general, POA irradiance cannot be calculated from GHI (the errors are large), it must be measured.



DATA LOGGERS

High quality pyranometers are capable of measuring with an absolute daily uncertainty of better than 2% under most conditions.

The data logger performance should not be worse than this. Ideally, it should be much better. However, this is often not the case.

The analogue inputs of data loggers have amplifiers, analogue-to-digital converters (ADC) and other components that can significantly degrade the incoming pyranometer signal. An uncertainty of $\pm 5 \text{ W/m}^2$ is not unusual.

This is not an issue when acquiring digital data from the SMP series. There are validation checks on the message string and if it is stored, it is correct.

SAMPLING FREQUENCY

It is not unusual in PV plants to take a single measurement every 10 minutes, but this may not be representative of the solar irradiance period.

It may represent the one cloud in a clear sky that is in front of the sun, or the one clear patch in a cloudy sky.

It is strongly advised to sample at least every 10 seconds and store 1 minute averages, especially when used for real-time performance ratio and efficiency calculations.

Data memory is cheap and you cannot get back information that was never recorded.

THE BOTTOM LINE

It is not enough to just have some numbers representing the irradiance measurements.

It is important to know how the solar irradiance data was obtained and the measurement 'chain', so that an uncertainty or 'error band' can be placed on it.

A daily uncertainty in the recorded data of $\pm 5\%$ is not uncommon and often not the fault of the pyranometer.

However, better than $\pm 2\%$ is achievable with good equipment, installation and maintenance.



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