Outdoor pyranometer calibration by comparison to a reference pyranometer: not recommended

“high-risk”, requiring high operator competence levels, variable uncertainty

The ISO 9847 standard describes calibration of pyranometers relative to a reference pyranometer. The method can be performed on-site. However, the outdoor calibration is “high risk” in terms of ISO 9001 risk-based thinking. The resulting calibration accuracy is not a constant and will only, under exceptionally stable conditions, be sufficient to meet requirements for utility scale PV system performance monitoring.

Introduction

The outdoor calibration method of ISO 9847, type B, and its equivalent in ASTM E824, transfers the sensitivity of calibration reference sensor to a preferably lower class test sensor under the outdoor natural sun.

Outdoor calibration of pyranometers has the advantage that it can be done on-site.
In addition, an advantage to meteorologists, local calibration at realistic solar angles and temperatures includes the unknown directional error and temperature response into the calibration.

However, although the procedure may appear simple, working under variable atmospheric stability and unknown solar position is inherently - in terms of quality management - “high-risk”. It is therefore seldom used, and discouraged by Hukseflux.

- the preferred method is to perform indoor calibration according to ISO 9847 type A
- an alternative, but more time-consuming and expensive method is outdoor calibration against a pyrheliometer and shaded pyranometer according to ISO 9846

ISO 9001:2015 – Risk-based thinking

In outdoor calibration, instrument installation, data analysis, data rejection and uncertainty evaluation are complicated procedures. Because of variable environmental conditions during outdoor calibration, the process cannot be automated, and is “high risk” in terms of the risk-based thinking required by ISO 9001:2015 – quality management systems – requirements- paragraph 0.3.3. Installation is critical, competence of personnel is critical and must be reviewed according to ISO 9001 paragraph 8.4 – control of externally provided processes, products and services.

Calibration reference

The reference pyranometer is preferably of a higher accuracy class and preferably calibrated against a pyrheliometer (ISO 9847 paragraph 7.2) according to ISO 9846.

Data analysis by experts

ISO 9847 paragraph 7.4.5 requires data analysis for each measurement series, in the following steps

- calculation of input ratios
- outlier rejection in case of more than 2 % deviation
- statistical analysis
- calculation of sensitivity
- individual uncertainty evaluation, including the standard deviation of the measurement

Uncertainty evaluation by experts

ISO 9847 paragraph 7.4.7 requires that the uncertainty of the calibration has to be determined on a case-by-case basis. The result depends on measurement conditions and measurement uncertainty of both the reference and the field instrument.
We recommend using the standard ASTM G217 *standard guide for evaluating uncertainty in calibration and field measurements of broadband irradiance with pyranometers and pyrheliometers.*

Hukseflux
Thermal Sensors

Time-consuming, typically 2 days with sun

ISO 9847 7.4.2 requires for outdoor horizontal calibration type B1 as well as for type B2, tilted and B3, normal incidence:

- minimum 2-day period
- solar zenith angles < 70 °
- minimum of 15 data series each of 10 to 20 minutes long with 20 or more records in each series
- at least 240 records passing filters for data rejection
- 30 % of the records taken within ± 2 hr around solar noon

Not all-season

In a lot of locations, only a limited number of months in the year are suitable for calibration with a reasonable level of accuracy, either due to low solar zenith angles (for example in winter) or low atmospheric stability.
Although the standard leaves the possibility open, we consider days with a lot of clouds not suitable.

Low calibration accuracy

Typical contributions to the uncertainty budget are:

- the uncertainty of the calibration reference
- the uncertainty of the method
- instrument-related uncertainties, depending on the instrument class

Most users forget to take into account that the outdoor measurement uncertainty of a calibration reference instrument is higher than its calibration uncertainty. The best Class A calibration reference pyranometers, calibrated against a primary standard pyrheliometer, have a 0.8 % calibration uncertainty. When using such instrument, as a calibration reference under conditions potentially different from the reference conditions of their own calibration, at least the uncertainty due to its directional response must be added. This is in the range of 1 %. ASTM E824 paragraph 11.1.3 mentions 2 % as an expected within-laboratory precision, using the same calibration reference. We translate this to a repeatability or "uncertainty of the method" of ± 1 %.
Taking the RMS of the above, an outdoor calibration uncertainty of 1.6 % (k=2) seems realistically attainable. However, the resulting calibration is valid only for the solar azimuth and zenith angles during the calibration. The calibration reference condition for pyranometers typically (in particular for PV monitoring in Plane of Array) is normal incidence (at zenith angle of 0 °) solar radiation. For the uncertainty of the transfer from the solar angles during calibration to normal incidence, we take 1 % for class A pyranometers and 2 % for class B pyranometers.

The overall calibration uncertainty under the above, very favourable, conditions is in the order of 2 % for class A instruments and 3 % for class B instruments. By contrast, indoor calibration may reach uncertainties of 1.2 % and 1.5 % respectively.

Table 1 *Requirements for outdoor calibration according to ISO 9847, recommended analysis.*

	REQUIREMENTS OF ISO 9847	**HUKSEFLUX' RECOMMENDATION**
Calibration reference	Class A pyranometer Calibrated against pyrheliometer ISO 9846	
competence of personnel	Installation Data rejection and analysis Uncertainty evaluation	
Calibration duration	> 2 days Preferably clear sky Solar zenith angles < 70 ° 30 % of the records taken within ± 2 hr around solar noon	Only work in seasons and locations where the solar angles are close (within 40 degrees) to normal incidence
Dataset and analysis	Minimum of 15 data series each of 10 to 20 minutes long with 20 or more records in each series at least 240 records passing filters for data rejection outlier rejection in case of more than 2 % deviation individual uncertainty evaluation, including the standard deviation of the measurement	ASTM G217 *Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers*

Table 2 *Hukseflux's estimate of the best attainable calibration- and measurement uncertainty following ISO 9847.*

	CLASS A PYRANOMETER	CLASS B PYRANOMETER
Calibration uncertainty estimate at solar angles during calibration	1.6 %	1.6 %
Calibration uncertainty estimate transferred to the common "normal incidence" reference condition	2 %	3 %
Measurement uncertainty estimate for instruments calibrated outdoor when employed outdoor under all solar angles	4 %	6 %

Table 3 *Outdoor calibration of pyranometers according to ISO 9847 is not the right solution for utility scale PV system performance monitoring.*

PV MONITORING STANDARD	CLASS	APPLICATION	REQUIRED CALIBRATION UNCERTAINTY	ISO 9847 OUTDOOR CALIBRATION SUITABILITY
IEC 61724-1: 2021	A	Utility-scale PV system	2 %	No, not sufficiently accurate except in the best attainable situation
IEC 61724-1: 2021	B	Large commercial scale PV system	3 %	Potentially, when using Class A pyranometers
EXPIRED PV MONITORING STANDARDS				
IEC 61724-1: 1998	N/A	All PV systems	5 % (including electronics)	Potentially, when using Class A or Class B pyranometers

Measurement uncertainty of pyranometers is higher than calibration uncertainty

Measurement uncertainties with pyranometers are a function of:

- calibration uncertainty
- instrument class
- environmental conditions including maintenance
- re-calibration time interval (non-stability)

Taking 1 % margin for instrument fouling, and 0.5 % margin for instrument non-stability, for Class A pyranometers the measurement uncertainty under optimal conditions is of the order of 2 % higher than the calibration uncertainty. If this instrument has been calibrated outdoors, this means a measurement uncertainty on the order of 4 %.
For Class B pyranometers, the measurement uncertainty is of the order of calibration uncertainty plus 3 %. If this instrument has been calibrated outdoors, this means a measurement uncertainty on the order of 6 %.
These estimates apply to measurements at relatively low angles of incidence.
The difference between hourly and daily totals is low.

Suitability for PV monitoring

As Table 3 shows, the uncertainty in outdoor calibration is larger than required for a class A system of the IEC 61724-1 standard. It may, at best, comply with class B. By contrast, calibration indoors or outdoors against a pyrheliometer is more accurate and typically suitable for a class A system.

Standards

ISO 9847: Solar Energy – Calibration of field pyranometers by comparison to a reference pyranometer
ASTM E824 - 05 Standard test method for transfer of calibration from reference to field radiometers
ASTM G217 Standard guide for evaluating uncertainty in calibration and field measurements of broadband irradiance with pyranometers and pyrheliometers

Calibration reference conditions

Reference conditions are not standardised, but the main manufacturers use:

- irradiance level 1000 W/m^2
- normal incidence irradiance

- instrument temperature 20 °C
- horizontal instrument position
- spectrum: solar irradiance on a clear day

When to employ outdoor calibration

Hukseflux recommends indoor calibration. Outdoor calibration according to ISO 9847 is recommended only:

- as a check of instrument functionality using guarded rejection. For example sending the instrument away for an accurate calibration if the outdoor calibration shows a deviation of > 5 %
- under near perfect conditions, at an ISO 17025 accredited laboratory, at normal incidence

Why indoor calibration is preferred

Modern instruments are produced within known and narrow performance limits. For these sensors, indoor calibration is best.

Advantages are:

- calibration at normal incidence, which is the reference condition for directional response
- calibration at 20 °C which is the reference condition for instrument temperature
- change of sensitivity is directly traceable to sensor / coating degradation
- reference conditions comply with IEC Standard Test Conditions for solar energy testing (STC), as applied in Photovoltaic (PV) module and system testing
- fast, independent of weather
- independent of day of year and local latitude
- known and fixed temperature
- known and fixed uncertainty
- accuracy for class A pyranometer calibration is sufficient for utility scale PV system performance monitoring, class A of IEC 61724-1

About this review

This review intends to provide objective information about preferred calibration methods. We appreciate suggestions for improvement of this review.

About Hukseflux

Hukseflux is the leading expert in measurement of energy transfer. We design and manufacture sensors and measuring systems that support the energy transition. We are market leaders in solar radiation and heat flux measurement. Customers are served through our headquarters in the Netherlands, and locally owned representative sales offices in the USA, Brazil, India, China, Southeast Asia and Japan.

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