Hukseflux
Thermal Sensors

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 field 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 I, and its equivalent ASTM E824, transfers the sensitivity of calibration reference sensor to a lower or equal 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.

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. A better method is to perform outdoor calibration against a pyrheliometer and shaded pyranometer according to ISO 9847.

ISO 9001:2015 - risk based thinking

The instrument installation, data analysis, data rejection and uncertainty evaluation are complicated procedures. Because of variable environmental conditions, 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, and involving personnel not employed by the organisation that is responsible for the calibration, requires review of their competence according to ISO 9001 paragraph 8.4 – control of externally provided processes, products and services.

Calibration reference

The reference pyranometer must be calibrated less than 12 months ago, against a pyrheliometer. (ISO 9847 paragraph 4.2)
The reference sensor must be calibrated according to ISO 9846.

Data analysis by experts

ISO 9847 paragraph 5.4.1.3 requires data analysis for each measurement series, rejecting data points that deviate > 2%.

Uncertainty evaluation by experts

ISO 9847 paragraph 7.2 requires that “the accuracy of the calibration factor has to be determined on a case by case basis”. The result depends on measurement conditions and quality of both the reference and the field instrument.
We recommend using the new standard ASTM G217 *standard guide for evaluating uncertainty in calibration and field measurements of broadband irradiance with pyranometers and pyrheliometers.*

Time consuming, typically > 5 days

Test duration requirements of ISO 9846:
Sky with some clouds: 5 to 14 days
Perfectly cloudless sky: > 2 days.

Not all-season

In a lot of locations, only a limited number of months in the year are suitable for calibration, 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 in to account that the outdoor measurement uncertainty of a calibration reference instrument is higher than its calibration uncertainty. The best secondary standard calibration reference pyranometers, calibrated against a primary standard pyrheliometer, have a 0.8 % calibration uncertainty. When using such instrument as a reference under conditions potentially different from the reference conditions of their own calibration, at least the uncertainty due 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 the best attainable. However, the resulting calibration is valid only for the solar angles during the calibration. The calibration reference condition for pyranometers typically (in particular for PV monitoring in Plane of Array) is normal incidence solar radiation. For the uncertainty of the transfer from the solar angles during calibration to normal incidence we take 1 % for secondary standard pyranometers and 2 % for first class pyranometers.

The overall calibration uncertainty under the above, very favourable, conditions is in the order of 2 % for secondary standard instruments and 3 % for first class 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	secondary standard pyranometer	Calibrated < 12 months ago	Calibrated against pyrheliometer ISO 9846	
competence of personnel	Installation	Data rejection and analysis	Uncertainty evaluation	
Calibration duration	Perfectly clear > 2 days	Partly cloudy: 5 to 14 days		In seasons and locations where the solar angles are close (within 40 degrees) to normal incidence
Dataset and analysis	Perfectly clear: > 15 series of 10 to 20 min intervals, > 21 instantaneous data points	Partly cloudy: > 15 series of 1 to 5 min intervals, > 21 instantaneous data points	Individual analysis for every calibration. Reject instantaneous data points if the sensitivity deviates > 2 % from the average of the series	ASTM G217 *Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers*

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

	SECONDARY STANDARD PYRANOMETER	**FIRST CLASS 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 MEASUREMENT UNCERTAINTY	ISO 9847 OUTDOOR CALIBRATION SUITABILITY	REQUIRED CALIBRATION CONDITIONS
IEC 61724-1: 2017	A	Utility-scale PV system	3 % hourly totals	No, not sufficiently accurate	
IEC 61724-1: 2017	B	Large commercial scale PV system	8 % hourly totals	Potentially if calibration accuracy is better than 5 %	Secondary standard or first class pyranometer stable atmospheric conditions, predominantly clear sky
EXPIRED STANDARDS					
IEC 71724-1: 1998	N/A	All PV systems	5 % (including electronics)	Potentially for secondary standard pyranometers and only if calibration accuracy is in the order of 3 %	Secondary standard pyranometer stable atmospheric conditions predominantly clear sky

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 secondary standard 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 first class 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

Hukseflux
Thermal Sensors

When to employ outdoor calibration

Hukseflux recommends indoor calibration.
Outdoor calibration according to ISO9847 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 accredited laboratory

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 condition 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 secondary standard 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 Thermal Sensors offers measurement solutions for the most challenging applications. We design and supply sensors as well as test & measuring systems, and offer related services such as calibration, engineering and consultancy. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux is ISO 9001:2008 certified. Hukseflux sensors, systems and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

Interested in our products and services?
E-mail us at: info@hukseflux.com