Hukseflux Thermal Sensors

HUKSEFLUX THERMAL SENSORS • 25 YEARS OF INNOVATION •

IPC XIII update of standards

Hukseflux Thermal Sensors

Solar irradiance measurement:
update of development of standards in ISO and IEC

Hukseflux Thermal Sensors

Presented by:

- Kees VAN DEN BOS
- Project leader ISO TR 9901, and ISO 9847
- member of IEC working Group drafting IEC 61724-1

- Director of Hukseflux Thermal Sensors, manufacturer of pyranometers,
- ISO /IEC 17025 accredited lab (many thousands per year)


2018

Hukseflux international + calibration facilities

Amsterdam

New York

São Paulo

Tokyo

Beijing

New Delhi

Singapore

Sidney

Water cooled for 1000 x concentrated solar

Hukseflux Thermal Sensors

Subjects

Update:

- ISO TR 9901: pyranometers recommended practice for use
- ISO 9847: calibration of pyranometers against pyranometers

Sidelines e.g:

- ISO 9060: classification of instruments fore measuring hemispherical and direct solar irradiance

Hukseflux Thermal Sensors

Leading standards Solar / Meteorological

- IEC 61724 group of standards PV system performance evaluation
- -1: monitoring (general theory)
- -2: 1 day evaluation for commissioning
- -3: evaluation during operation

- WMO Guide to Instruments and Methods of Observation

Hukseflux Thermal Sensors

IMOP

Guide to Instruments and Methods of Observation (WMO-No. 8)

ACTIVITY AREAS (1)

- Instruments and Methods of Observation Programme (IMOP)

PROCESS FOR UPDATING THE WMO-No. 8

Procedure for updating the Guide to Instruments and Methods of Observation (WMO-No. 8)

Guidelines for drafting updates/new editions of the WMO-No. 8

(to obtain the MS-Word version of specific chapters of the WMO-No.8 to propose updates, please contact: iruedi@wmo.int and kpremec@wmo.int)

Found a typo/error in the WMO-No. 8?

Inform the Secretariat by sending an e-mail describing the error to: iruedi@wmo.int and kpremec@wmo.int.

PROVISIONAL 2020 EDITION OF THE WMO-No. 8 (Vol IV & Vol III/Ch 4)

The **Provisional 2020 Edition** of the Guide to Instruments and Methods of Observation (WMO-No. 8) Volume IV and Volume III/Chapter 4 is now ready for approval. To see the text of the **Provisional 2020 Edition** please click here.

Coherent system for practical use

- Perform measurements

- Classify systems (accuracy class)
- Classify instruments
- Standardise maintenance / calibration interval

- *estimate uncertainties of measurements*

Hukseflux Thermal Sensors

Standard development

Are written by solar renewable energy community

- ISO TC 180: solar energy ; measurement & data
- IEC TC 82 - Solar photovoltaic energy systems

No meteorological background

ASTM equivalents : G 03 Weathering and Durability

Standards logic Solar perspective

- IEC 61724 group of standards PV system performance evaluation
- -1: monitoring (general theory)
- -2: 1 day evaluation for commissioning
- -3: evaluation during operation

- ISO 9060 – classification of pyranometers (revised in 2017)
- ISO TR9901 – recommended use of field pyranometers
- ISO 9847 – calibration of pyranometers

- ASTM G 213 – uncertainty evaluation of pyranometer measurement

Hukseflux Thermal Sensors

Underlying

- ISO Guide 99 (VIM) International Vocabulary of Metrology
- ISO Guide 98 (GUM) Expression of uncertainty in measurements

- ISO / IEC 17025: Requirements for Competence of Testing and Calibration Labs

Under revision (2021)

- IEC 61724 group of standards PV system performance evaluation
- -1: monitoring (general theory)
- -2: 1 day evaluation for commissioning
- -3: evaluation during operation

- ISO 9060 – classification of pyranometers (revised in 2017)
- ISO TR9901 – recommended use of pyranometers (approved 2021)
- ISO 9847 – calibration of pyranometers

- ASTM G 313 – uncertainty evaluation of pyranometer measurement

Hukseflux
Thermal Sensors

IEC 61724 (group)

This is a preview - click here to buy the full publication

IEC 61724-1

Edition 2.0 2021-07
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Photovoltaic system performance –
Part 1: Monitoring

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160
ISBN 978-2-8322-1008-1

Warning! Make sure that you obtained this publication from an authorized distributor.

Hukseflux
Thermal Sensors

Pyranometers

Weakest link in the chain

Hukseflux Thermal Sensors

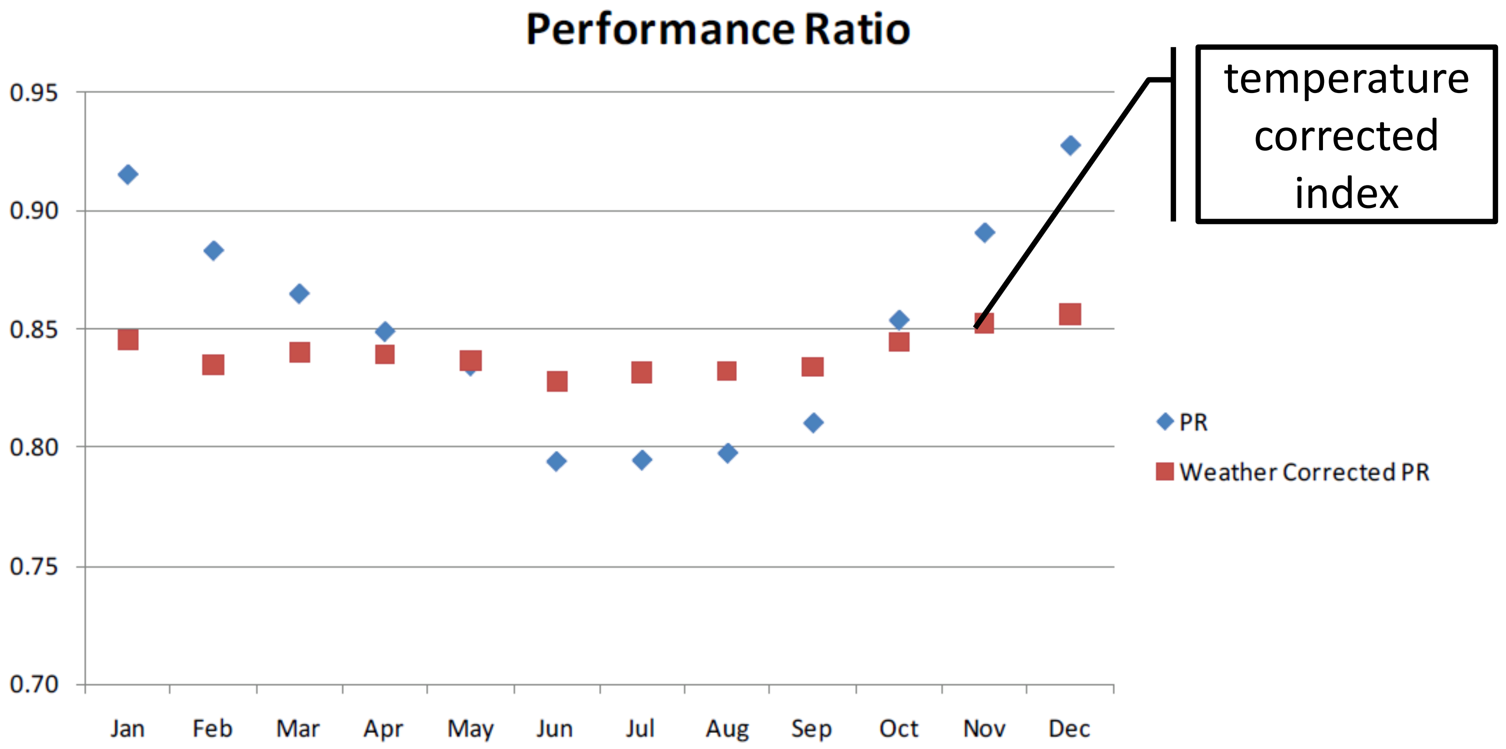
PV system simplified

- D: System efficiency: C/(A·B)
- Degradation: change of D versus time dD/dt

- performance ratios: system name-plate rating
- performance index: more detailed model of system performance.

Hukseflux Thermal Sensors

Test results comparing to “name plate”



* Annual PR is 0.84 for both situations.

Hukseflux Thermal Sensors

PV system performance monitoring

- Monitoring is an industry
- Industry is driven by investors (banks/ asset managers)
- Pyranometers are key to billions of investment capital / application of renewable energy
- SI traceability?!

POA + GHI + RHI

Typical IEC Class A station

GroundWork

Pyanometer with tilt sensor on tracker (insulated)

Reference station for albedo

ISO TR 9901 good practices: Cleaning

Hukseflux Thermal Sensors

Good practices: calibration

IEC: calibration & cleaning

7.2.1.7 **Sensor maintenance**

Irradiance sensor maintenance requirements are listed in Table 6.

Table 6 – Irradiance sensor maintenance requirements

Item	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
Recalibration	Once per year	Once every 2 years	As per manufacturer's requirements
Cleaning	At least once per week	Optional	

NEW: IEC 61724-1:2017 once per year calibration is required for class A systems

Change: next version of IEC 61724-1 Calibration 1 x / 2 yr

ISO TR 9901 good practices: heating

Hukseflux
Thermal Sensors

IEC: mitigation of dew and frost

NEW: IEC 61724-1:2017 heating of pyranometers and PV reference cells is required in class A and B systems. Hukseflux models SR30, SR20 (not the digital version) and SR12 are heated. We do not know of heated PV reference cells.

Heating to prevent accumulation of condensation and/or frozen precipitation	Required in locations where condensation and/or frozen precipitation would affect measurements on more than 7 days per year	Required in locations where condensation and/or frozen precipitation would affect measurements on more than 14 days per year	
Ventilation (for thermopile pyranometers)	Required	Optional	
Desiccant inspection and replacement (for thermopile pyranometers)	As per manufacturer's requirements	As per manufacturer's requirements	As per manufacturer's requirements

NEW: IEC 61724-1:2017 ventilation of pyranometers is required in class A systems. Hukseflux model SR30 is ventilated

possible to minimize the time that sensors are offline. If sensors are to be sent off-site for laboratory recalibration, the site should be designed with redundant sensors or else backup sensors should be used to replace those taken offline, in order to prevent interruption of monitoring.

Cleaning of irradiance sensors without cleaning the modules can result in a lowering of the measured PV system performance ratio (defined in **Fout! Verwijzingsbron niet gevonden.**). In some cases contract requirements may specify that irradiance sensors are to be maintained in the same state of cleanliness as the modules.

Night-time data should be checked to ensure accurate zero-point calibration.

NOTE It is common for pyranometers to show a small negative signal, -1 $W \cdot m^{-2}$ to -3 $W \cdot m^{-2}$, at night time.

7.2.1.8 Additional measurements

7.2.1.8.1 Direct normal irradiance

Direct normal irradiance (*DNI*) is measured with a pyrheliometer on a two-axis tracking stage which automatically tracks the sun.

Change: next version of IEC 61724-1 "ventilation" will be replaced by "mitigation of dew and frost"

Hukseflux
Thermal Sensors

PV monitoring according to IEC 61724

NEW: IEC 61724-1: 2017 defines monitoring systems of 3 accuracy classes (A, B and C)

$\lambda = \frac{|P|}{S}$

NEW: IEC 61724-1: 2017 you must define if the system complies with class A, B or C

4 Monitoring system classification

The required accuracy and complexity of the monitoring system depends on the PV system size and user objectives. This standard defines three classifications of monitoring systems providing varying levels of accuracy, as listed in Table 1.

The monitoring system classification shall be stated in any conformity declarations to this standard. The monitoring system classification may be referenced either by its letter code (A, B, C) or its name (High accuracy, Medium accuracy, Basic accuracy) as indicated in Table 1. In this document, the letter codes are used for convenience.

Class A or Class B would be most appropriate for large PV systems, such as utility-scale and large commercial installations, while Class B or Class C would be most appropriate for small systems, such as smaller commercial and residential installations. However, users of the standard may specify any classification appropriate to their application, regardless of PV system size.

Throughout this standard, some requirements are designated as applying to a particular classification. Where no designation is given, the requirements apply to all classifications.

Table 1 – Monitoring system classifications and suggested applications

Typical applications	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
Basic system performance assessment	X	X	X
Documentation of a performance guarantee	X	X	
System losses analysis	X	X	
Electricity network interaction assessment	X		
Fault localization	X		
PV technology assessment	X		
Precise PV system degradation measurement	X		

NEW: IEC 61724-1: 2017 see above: utility scale PV monitoring needs class A

5 General

Change: next version of IEC 61724-1 only class A and C system classes

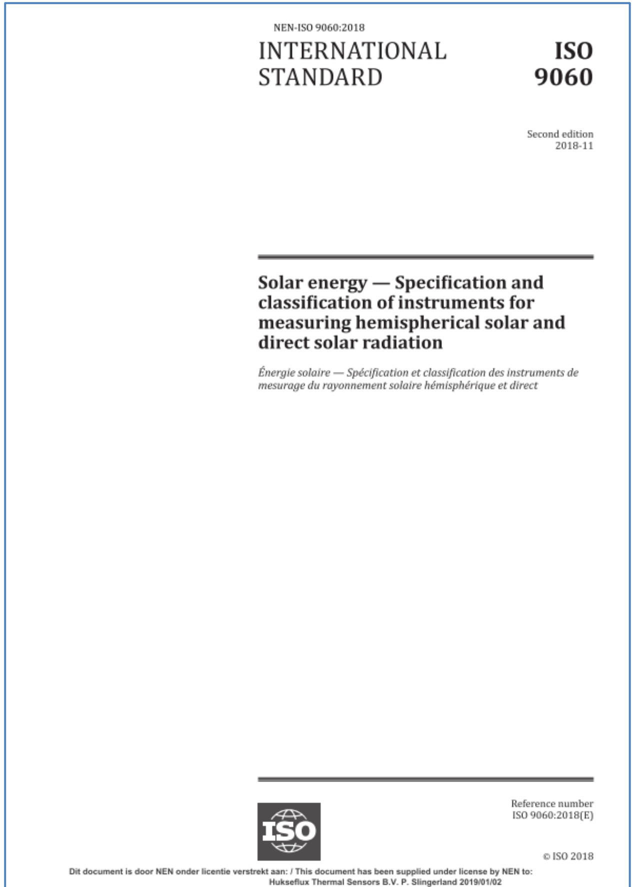
Hukseflux
Thermal Sensors

Summary: revised IEC 61724-1

- Classifies
- Moves towards high accuracy “Class A ” systems
- Recommends heating to mitigate dew and frost
- Stresses the need for maintenance, inspection
- Calibration interval requirement: 2 years

- Now includes albedo measurement

ISO 9060 classification



NEN-ISO 9060:2018

INTERNATIONAL STANDARD

ISO 9060

Second edition
2018-11

Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

Énergie solaire — Spécification et classification des instruments de mesurage du rayonnement solaire hémisphérique et direct

Reference number
ISO 9060:2018(E)

Hukseflux Thermal Sensors

ISO 9060 summary

- Classes A, B and C
- Accuracy class (VIM)
- Specification limits are expressed as "acceptance intervals" with a "tolerance interval"
- Reference conditions: clearly defined (20 °C for temperature, clear sky solar spectra for sprectral error)

Classification

- Classes A, B and C

- Normal classification: spectral error for set of clear sky global spectra
- Subclass spectrally flat: 1990 “spectral reponse”
- Old Secondary standard becomes : spectrally flat class A
- Subclass: fast-response
- Testing clarified for Class A

Hukseflux
Thermal Sensors

Uncertainty evaluation: ASTM G213-17

INTERNATIONAL

Designation: G213 – 17

Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers[1]

This standard is issued under the fixed designation G213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides guidance and recommended practices for evaluating uncertainties when calibrating and performing outdoor measurements with pyranometers and pyrheliometers used to measure total hemispherical- and direct solar irradiance. The approach follows the ISO procedure for evaluating uncertainty, the Guide to the Expression of Uncertainty in Measurement (GUM) JCGM 100:2008 and that of the joint ISO/ASTM standard ISO/ASTM 51707 Standard Guide for Estimating Uncertainties in Dosimetry for Radiation Processing, but provides explicit examples of calculations. It is up to the user to modify the guide described here to their specific application, based on measurement equation and

mendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

2.2 *ASTM Adjunct:*[2]

Hukseflux Thermal Sensors

Typical uncertainty budget

- Calibration uncertainty
- Instrument specifications (Class)
- Maintenance/cleaning
- …

Hukseflux Thermal Sensors

Analysis according to ASTM: example

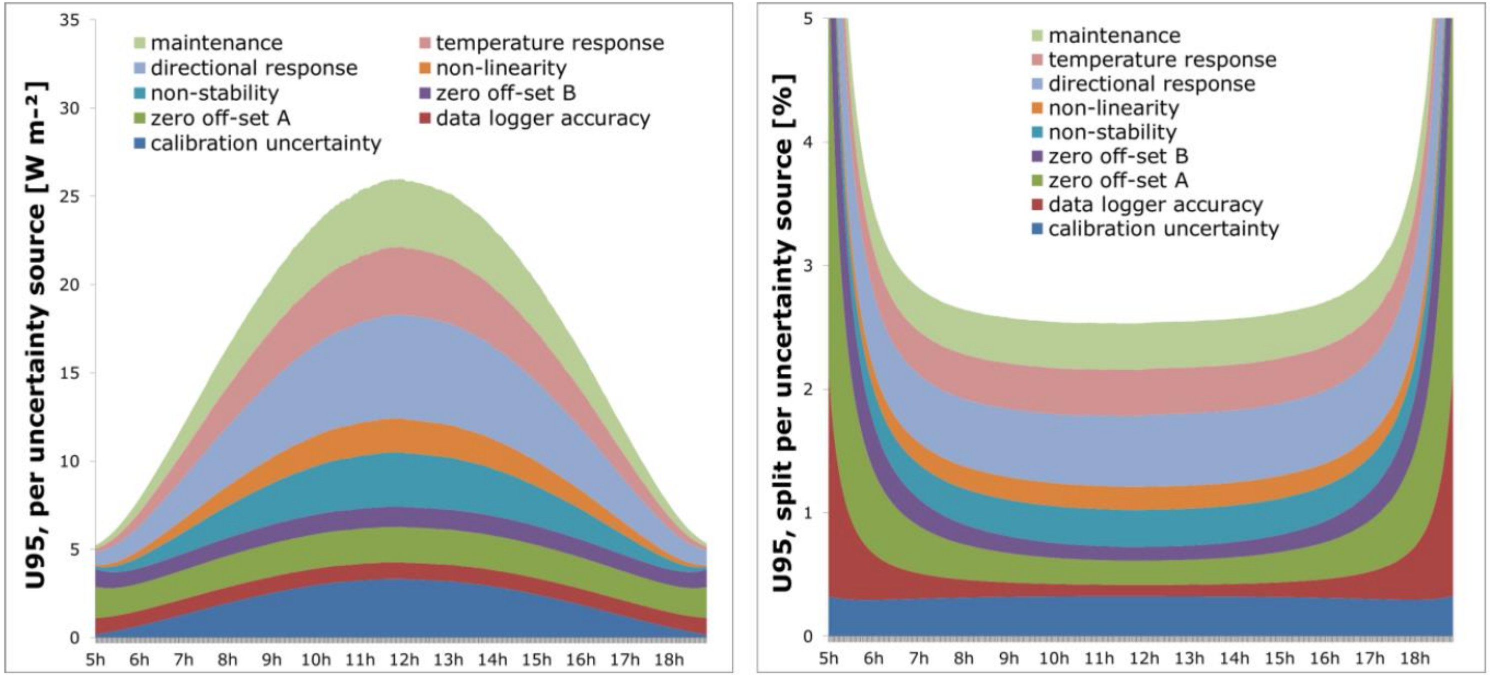


Fig. 2: Expanded uncertainty as function of time, split per uncertainty source.
The expanded uncertainty is expressed in a) absolute values in W m^{-2}, b) relative values in %.

INDOOR CALIBRATION uncertainty budget

- Uncertainty of sensitivity of reference: 1 %
- Transfer to lab conditions (temp, normal incidence) :0.5%
- Method (uncertainty of transfer): 0.5 %
- Calibration SQRT $(1^2 + 0.5^2 + 0.5^2) = 1.2$ %

- More information: Jorgen KONINGS

Hukseflux
Thermal Sensors

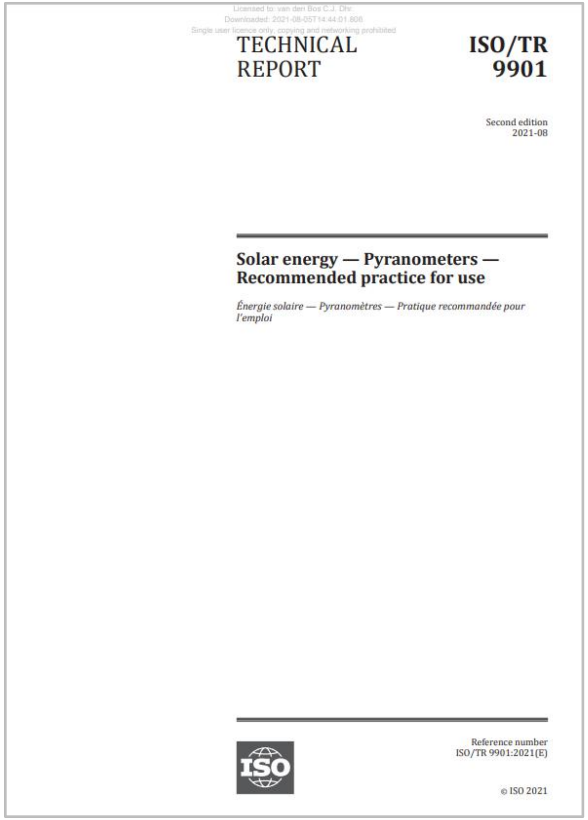
Work done / to be done

- ISO TR9901:1990: Field pyranometers - recommended practice for use
- ISO 9847:1992: calibration of field pyranometers by comparison to a reference pyranometer
- Revisions of 1990's versions

- All contained obsolete practices, originally from meteorology/ climatology
- Pyranometers are no longer exotic but used a lot in PV system performance monitoring

Hukseflux
Thermal Sensors

ISO TR 9901



TECHNICAL REPORT

ISO/TR 9901

Second edition
2021-08

Solar energy — Pyranometers — Recommended practice for use

Énergie solaire — Pyranomètres — Pratique recommandée pour l'emploi

Reference number
ISO/TR 9901:2021(E)

Hukseflux Thermal Sensors

Status

- Active participation: Australia, Netherlands, Japan, Germany, USA, Switzerland

Contents TR9901

- Re-arrangement of chapters
- Vocabulary adapted to *JGCM 200, ISO Guide 99, The international vocabulary of metrology—basic and general concepts and associated terms (VIM)*,
- Referral to non-spectrally flat pyranometers (as per ISO 9060 classification)
- Clarification of functionality of ventilation (dew and frost mitigation, and not cleaning)
- Referral to ASTM G213-17 *"Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers"*

Hukseflux Thermal Sensors

Contents TR9901

- Tuned to higher measurement accuracy (required in PV monitoring)
- Stressing that with a measurement comes an uncertainty
- Inclusion of digital instruments
- Pointing out that calibration uncertainty is in the order of 1 - 2 %
- Pointing out that time stamps are important
- Reference to IEC 61724-1

Estimates of achievable uncertainty

Table 3 — Estimates of achievable uncertainties of measurements with spectrally flat pyranometers

Pyranometer class ISO 9060	Season	GHI latitude or POA	Uncertainty minute totals at solar noon	Uncertainty hourly totals at solar noon	Uncertainty daily totals
State of the art Spectrally flat class A	Summer	Mid-latitude	1,8 %	1,8 %	2,3 %
		Equator or POA	1,8 %	1,8 %	2,3 %
		Pole	2,5 %	2,5 %	3,3 %
	Winter	Mid-latitude	3,5 %	3,6 %	5,1 %
State of the art Spectrally flat class B	Summer	Mid-latitude	3,9 %	4,0 %	4,9 %
		Equator or POA	4,0 %	4,0 %	4,9 %
		Pole	5,3 %	5,3 %	6,7 %
	Winter	Mid-latitude	7,2 %	7,3 %	10,3 %
State of the art Spectrally flat class C	Summer	Mid-latitude	5,2 %	5,2 %	6,5 %
		Equator or POA	5,2 %	5,2 %	6,4 %
		Pole	6,8 %	6,8 %	8,7 %
	Winter	Mid-latitude	9,3 %	9,4 %	13,6 %

NOTE 1 Uncertainty evaluation of other technologies such as PV reference cells (made and calibrated according to IEC 60904-2) under outdoor conditions is not comparable to that of pyranometers. This is because the directional response, temperature response and spectral response of these technologies are not bound by the limits of a classification system, and therefore are unknown. For example, PV reference cells are calibrated under standard test conditions (STC). The uncertainty evaluation supplied with reference cells is applicable for use under laboratory STC conditions only; 1 000 W/m^2 normal incidence airmass 1,5 irradiance at 20 °C cell temperature.

The above uncertainty evaluation for pyranometers covers outdoor use under the most common solar testing conditions.

NOTE 2 There is no international consensus on uncertainty evaluation of pyranometer measurements, users can perform their own uncertainty evaluation.

Hukseflux
Thermal Sensors

Calibration ISO 9847

INTERNATIONAL STANDARD

ISO 9847

First edition

1992-07-01

Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer

Énergie solaire - Étalonnage des pyranomètres de terrain par comparaison à un pyranomètre de référence

Reference number
ISO 9847:1992(E)

ISO/TC 180/SC1 N 207

ISO/CD 9847
ISO TC180/SC 1/WG 3
Date: 2021-06-11

Solar energy — Calibration of pyranometers by comparison to a reference pyranometer

CD stage

Warning for WDs and CDs

This document is not an ISO International Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as an International Standard.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

A model manuscript of a draft International Standard (known as "The Rice Model") is available at https://www.iso.org/iso/model_document-rice_model.pdf

Hukseflux Thermal Sensors

Status

- ISO 9847: calibration of field pyranometers by comparison to a reference pyranometer
- Draft drafting: CD submitted and to be discussed.
- next teleconference planned in NOV 2021
- Active participation: Australia, Netherlands, Japan, Germany, Spain, USA, China, Korea, Switzerland, ..

Contents ISO9847

- Change to title approved
- Re-arrangement of chapters
- Vocabulary adapted to *JGCM 200, ISO Guide 99, The international vocabulary of metrology—basic and general concepts and associated terms (VIM),*
- Referral to non-spectrally flat pyranometers (as per ISO 9060 classification)
- Referral to ASTM G213-17 *"Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers"*

Contents ISO9847

- Including digital sensors
- Deleting some practices nobody used (indoor tilted calibration)
- Outdoor calibration: changed requirements for the time series used for analysis, acceptable atmospheric conditions, data rejection, calculation of the result, uncertainty evaluation.

Contents ISO9847

- Vocabulary:
- Calibration reference – test (sensor)
- Calibration conditions (during test)
- Calibration reference conditions (on certificate, for which sensitivity is valid)

Hukseflux Thermal Sensors

Summary

- Lot of work done
- Well prepared for other ISO standards (pyranometer – pyrheliometer)
- Well prepared for IMOP

- Input for IMOP: be careful copying ISO 9060 elements (not spectrally flat instruments cannot be used for albedo / net radiation)

Hukseflux
Thermal Sensors

HUKSEFLUX THERMAL SENSORS
25
YEARS OF
INNOVATION

Thank you!