Hukseflux
Thermal Sensors

HUKSEFLUX THERMAL SENSORS
25
YEARS OF
INNOVATION

10th PVPMC Workshop 2019

Hukseflux Thermal Sensors

LATEST DEVELOPMENTS
IN SOLAR IRRADIANCE MEASUREMENT

Hukseflux
Thermal Sensors

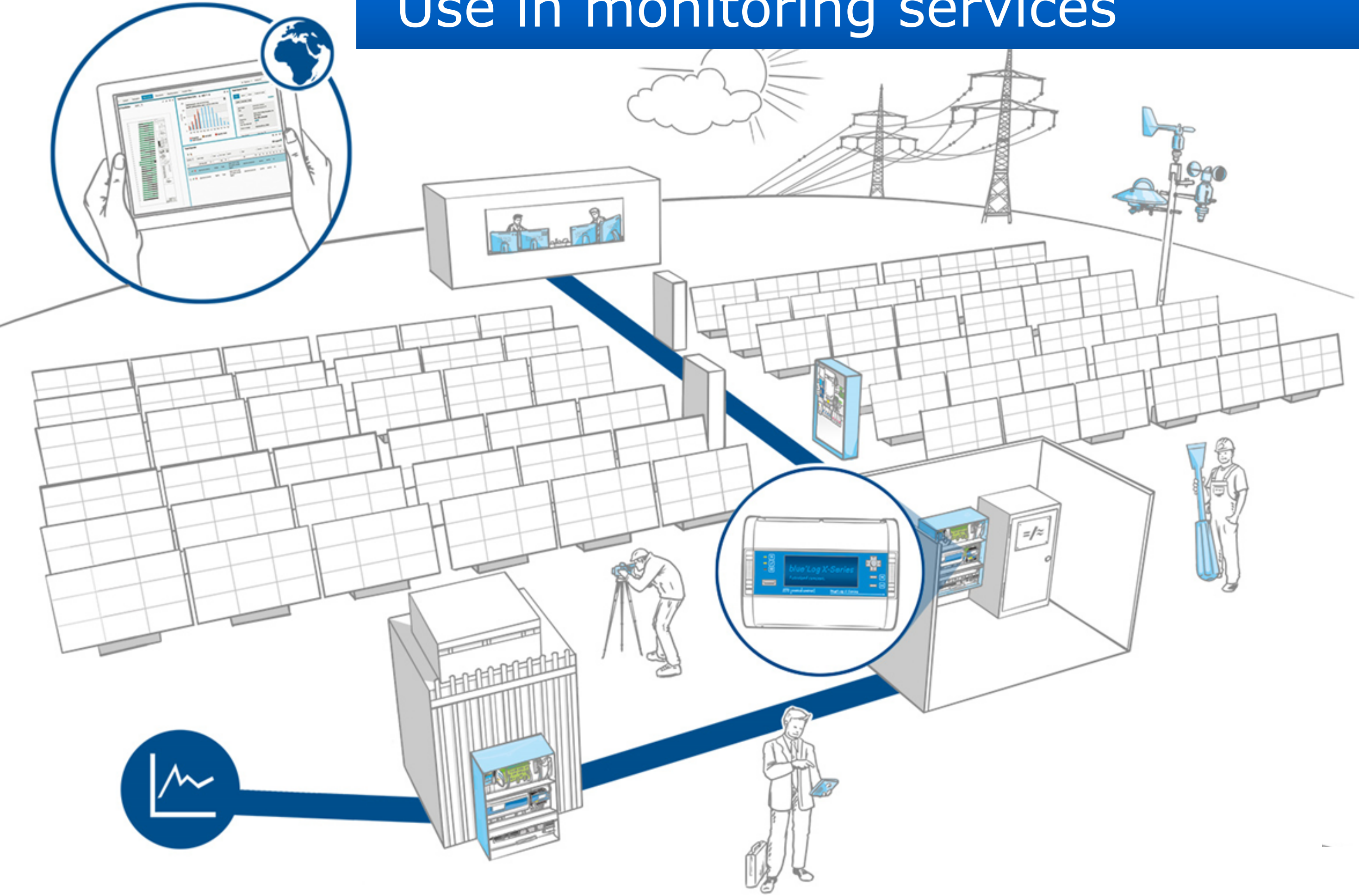
Presented by:

- Kees VAN DEN BOS
- Hukseflux Thermal Sensors

- Member ISO TC 180 / SC1
- Candidate member IEC TC 82

Pyranometers

Use in monitoring services



meteo control
Energy & Weather Services

Weakest link in the chain

Subjects

- solar irradiance measurement

- improving measurement accuracy
- improving data availability

- IEC 61724-1: PV system performance monitoring
- ISO 9060: classification standard
- ASTM G213: uncertainty evaluation of irradiance measurement
- ISO TR 9901: recommended practices

Hukseflux Thermal Sensors

What is new since May 2018

- Monitoring according to IEC 61724 rapidly becomes the standard
- ISO 9060 classification standard has been approved

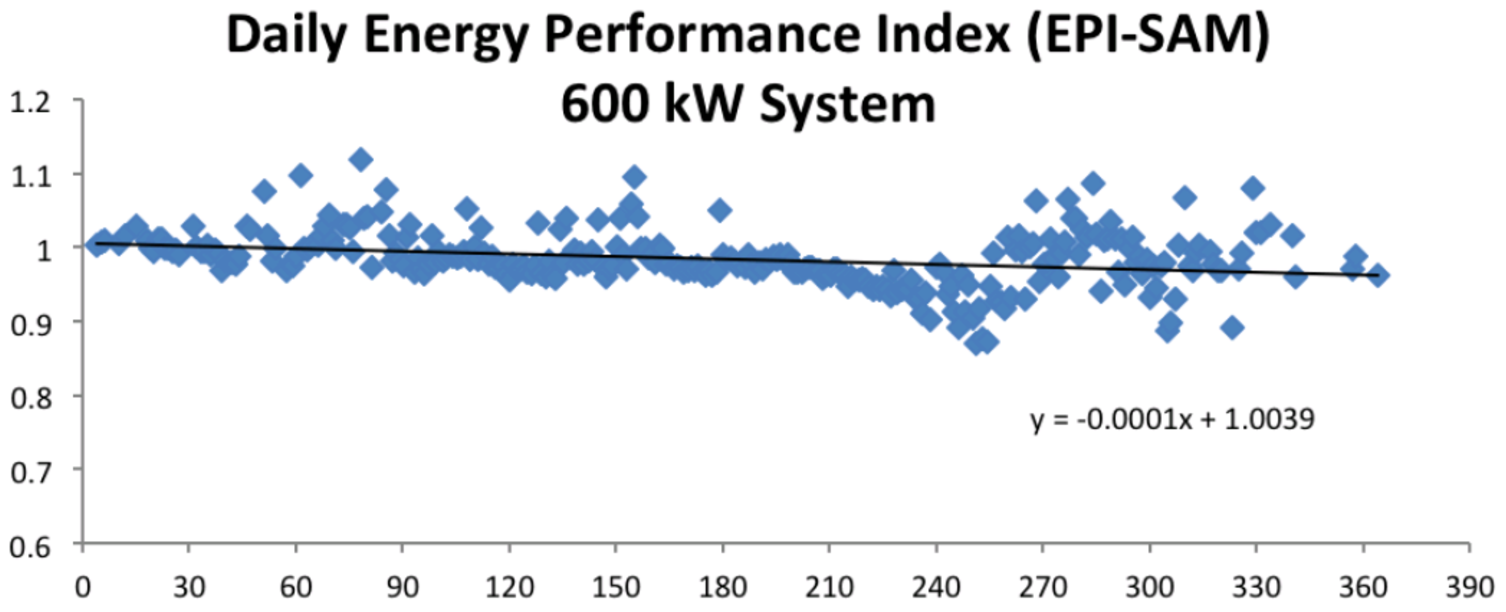
- Monitoring for bifacial systems (albedo)

PV system simplified

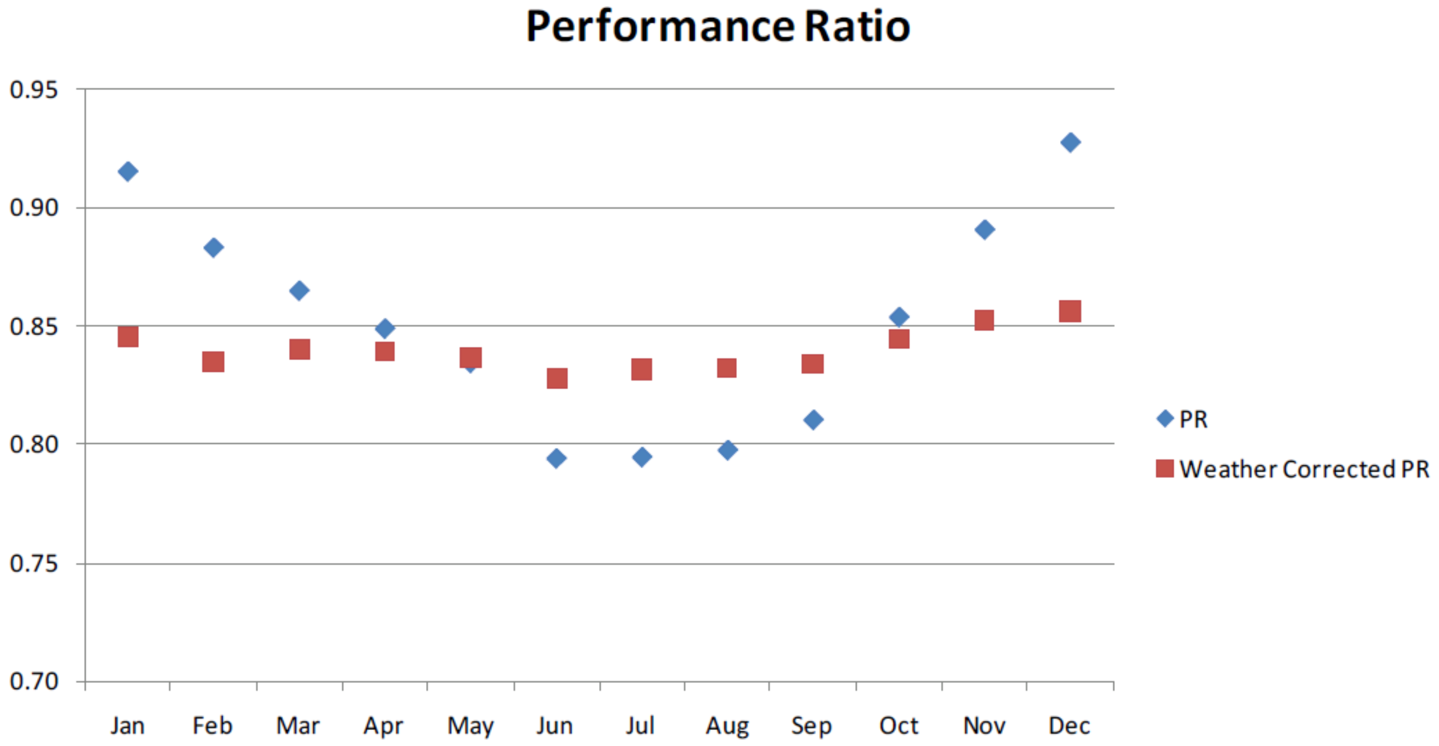
- A: Input: solar irradiance in W/m^2
- B: System: PV system in m^2
- C: Output: Electrical power in W

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

Test results



Test results



*** Annual PR is 0.84 for both situations.**

PV monitoring purposes

- Technical: Failure detection
- Technical: Creating a performance baseline

- Financial: Increase income
- Financial: Risk profile reduction
- Financial: Sale of the PV power plant

PV monitoring

- Monitoring is an industry
- Utility scale PV plants hire independent monitoring companies

Hukseflux
Thermal Sensors

IEC 61724-1: 2017

IEC 61724-1

INTERNATIONAL STANDARD

Photovoltaic system performance –
Part 1: Monitoring

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

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

POA + GHI + RHI

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

IEC: Electrical

Table 11 – Inverter-level electrical measurement requirements

Parameter	Measurement Uncertainty		
	Class A **High accuracy**	**Class B** **Medium accuracy**	**Class C** **Basic accuracy**
Input voltage (DC)	±2,0 %	n/a	n/a
Input current (DC)	±2,0 %	n/a	n/a
Input power (DC)	±2,0 %	n/a	n/a
Output voltage (AC)	±2,0 %	±3,0 %	n/a
Output current (AC)	±2,0 %	±3,0 %	n/a
Output power (AC)	±2,0 %	±3,0 %	n/a

Table 12 lists the requirements for electrical measurements at the output of the power plant, i.e. the aggregate output produced by all inverters in the system.

For multi-phase systems, each phase shall be measured, or 2 of 3 phases shall be measured (two wattmeter method).

Table 12 – Plant-level AC electrical output measurement requirements

Parameter	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
Active power and energy	Class 0,2 S as per IEC 62053-22	Class 0,5 S as per IEC 62053-22	Class 2 per IEC 62053-21
Power factor	Class 1 as per IEC 61557-12	Class 1 as per IEC 61557-12	n/a

Hukseflux Thermal Sensors

IEC: pyranometer class

NEW: IEC 61724-1:2017 requires use secondary standard pyranometers

IEC 61724-1 © IEC 2017 – 21 –

Table 5 lists sensor choices and accuracy requirements for in-plane and global irradiance measurement, and Table 7 lists maintenance requirements for these sensors.

The sensor, signal-conditioning electronics, and data storage shall provide a range including at least 0 $W \cdot m^{-2}$ to 1 500 $W \cdot m^{-2}$ and a resolution of ≤ 1 $W \cdot m^{-2}$.

NOTE Over-irradiance in the range 1 000 $W \cdot m^{-2}$ to 1 500 $W \cdot m^{-2}$ or higher can occur due to reflections from clouds under partly cloudy conditions.

Table 5 – Sensor choices and requirements for in-plane and global irradiance

Sensor Type	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
Thermopile pyranometer	Secondary standard per ISO 9060 or High quality per WMO Guide (Uncertainty ≤ 3 % for hourly totals)	First class per ISO 9060 or Good quality per WMO Guide (Uncertainty ≤ 8 % for hourly totals)	Any
PV reference device	Uncertainty ≤ 3 % from 100 $W \cdot m^{-2}$ to 1 500 $W \cdot m^{-2}$	Uncertainty ≤ 8 % from 100 $W \cdot m^{-2}$ to 1 500 $W \cdot m^{-2}$	Any
Photodiode sensors	Not applicable	Not applicable	Any

Each irradiance sensor type has its benefits:

- Thermopile pyranometers are insensitive to typical spectral variations and therefore measure total solar irradiance. However, this can vary from the PV-usable irradiance by 1 % to 3% (monthly average) under typical conditions. In addition, thermopile pyranometers have long response times compared to PV devices and photodiodes.
- Matched PV reference devices measure the PV-usable portion of the solar irradiance which correlates with the monitored PV system output. However, this may deviate from

Hukseflux Thermal Sensors

IEC: calibration

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

Hukseflux Thermal Sensors

IEC: heating + ventilation

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

Hukseflux Thermal Sensors

Summary: IEC 61724-1

- recommends the use of the best instruments if accuracy must be high
- high accuracy reduces “risk profiles”

- IEC 61724-1 identifies pyranometers as “weakest link” in analysis,
- stresses maintenance & calibration

GroundWork

Typical IEC Class A station

Hukseflux
Thermal Sensors

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]

Not easy to attain a high accuracy

- Uncertainty depends on:

- Moving sun
- Variable environmental conditions
- Maintenance
- Data availability (dew, frost, snow)
- Horizon
- Reflections (tilted installation)
- Albedo (bifacials)

Hukseflux Thermal Sensors

Typical uncertainty budget

- Calibration uncertainty
- Instrument specifications
- Maintenance
- …

Hukseflux Thermal Sensors

Analuysis according to ASTM

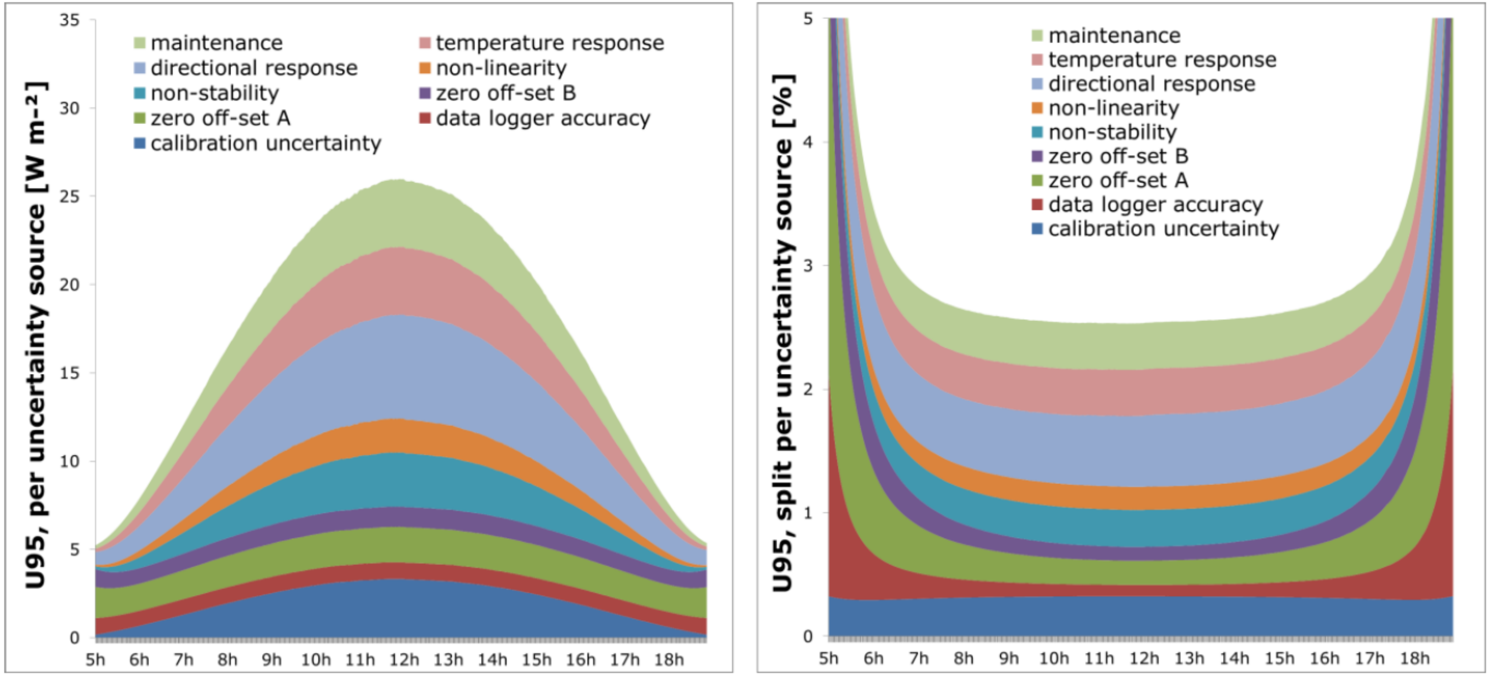


Fig. 2: Expanded uncertainty as function of time, split per uncertainty source.
The expanded uncertainty is expressed in a) absolute values in W m^{-2}, b) relative values in %.

Hukseflux
Thermal Sensors

ISO 9060 revision

DRAFT INTERNATIONAL STANDARD
ISO/DIS 9060

ISO/TC **180**/SC **1**

Secretariat: **SA**

Voting begins on:
2017-04-17

Voting terminates on:
2017-07-09

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

ICS: 27.160

Hukseflux
Thermal Sensors

Summary ISO 9060

- issued NOV 2018
- “Secondary Standard” replaced by “Spectrally Flat Class A”
- distinction between “normal”and “spectrally flat” instruments
- why use “spectrally flat” pyranometers in PV monitoring:
- POA requires spectrally flat response
- albedo requires spectrally flat response

Hukseflux Thermal Sensors

Class A instruments

- Test reports required for every instrument
- Temperature dependence + Directional response

- IEC requires compliance to latest version of ISO
- Not all installed base is OK

Hukseflux
Thermal Sensors

ISO to IEC connection

IEC monitoring class	A	B
ISO 9060:1990 pyranometer class	secondary standard	first class
ISO 9060:2018 pyranometer class	spectrally flat A	spectrally flat B
heating	yes	yes
ventilation	yes	no
calibration	1 yr	2 yr
cleaning	1 wk	2 wk

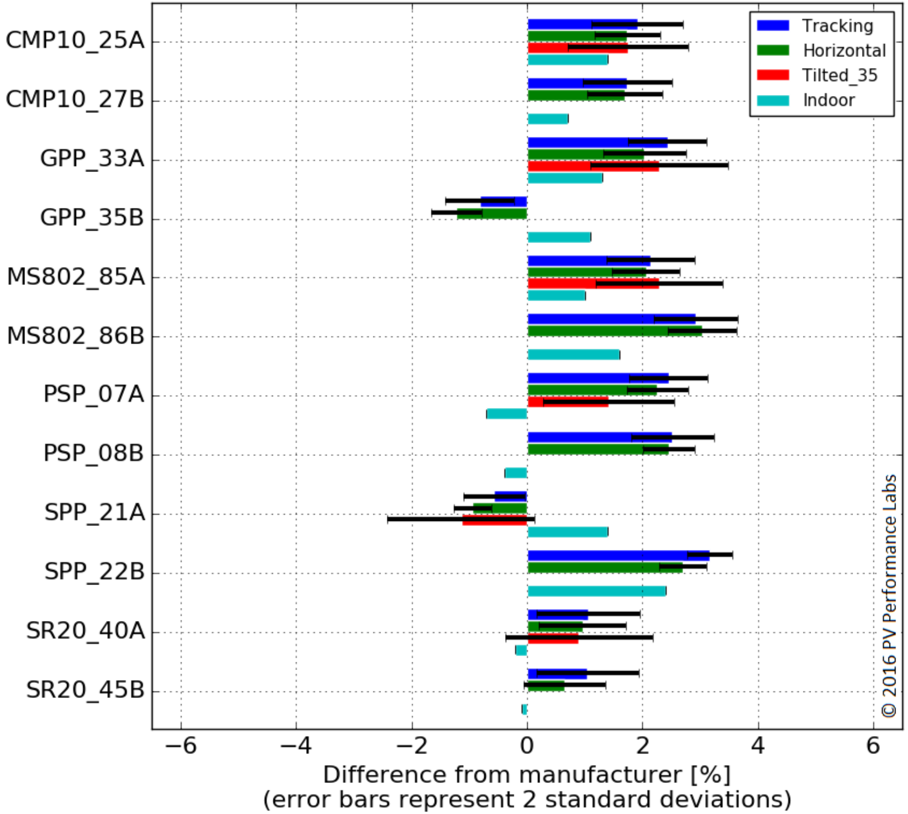
JRC Ispra / Sandia

2016 performance testing / ideal conditions

- Anton Driesse, Willem Zaaiman, Daniel Riley, Nigel Taylor, Joshua S. Stein, *Investigation of Pyranometer and Photodiode Calibrations under Different Conditions*, conference paper presented at IEEE PVSC 2016, published on internet, accessed 10-Oct-2016.

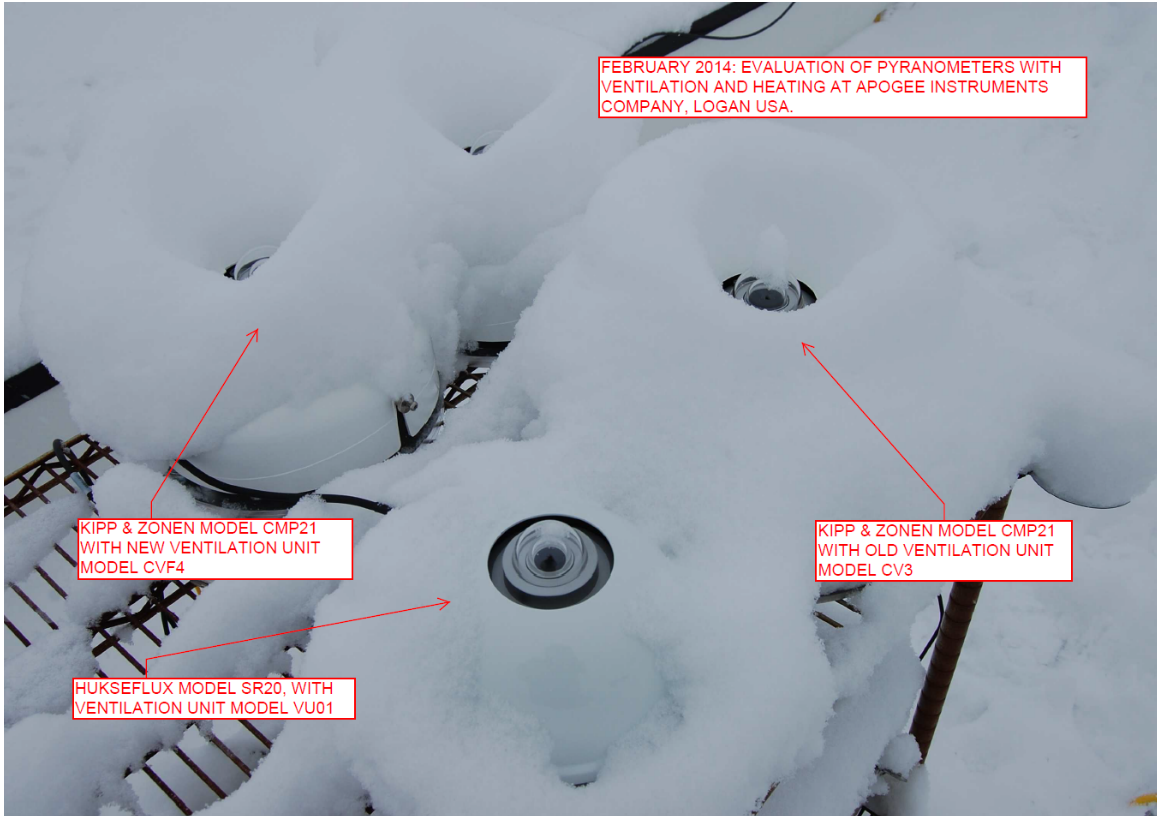
Hukseflux
Thermal Sensors

Errors in the 1 to 3 % range / ideal conditions



Meanwhile, in the real world, ..

powder snow in Utah USA

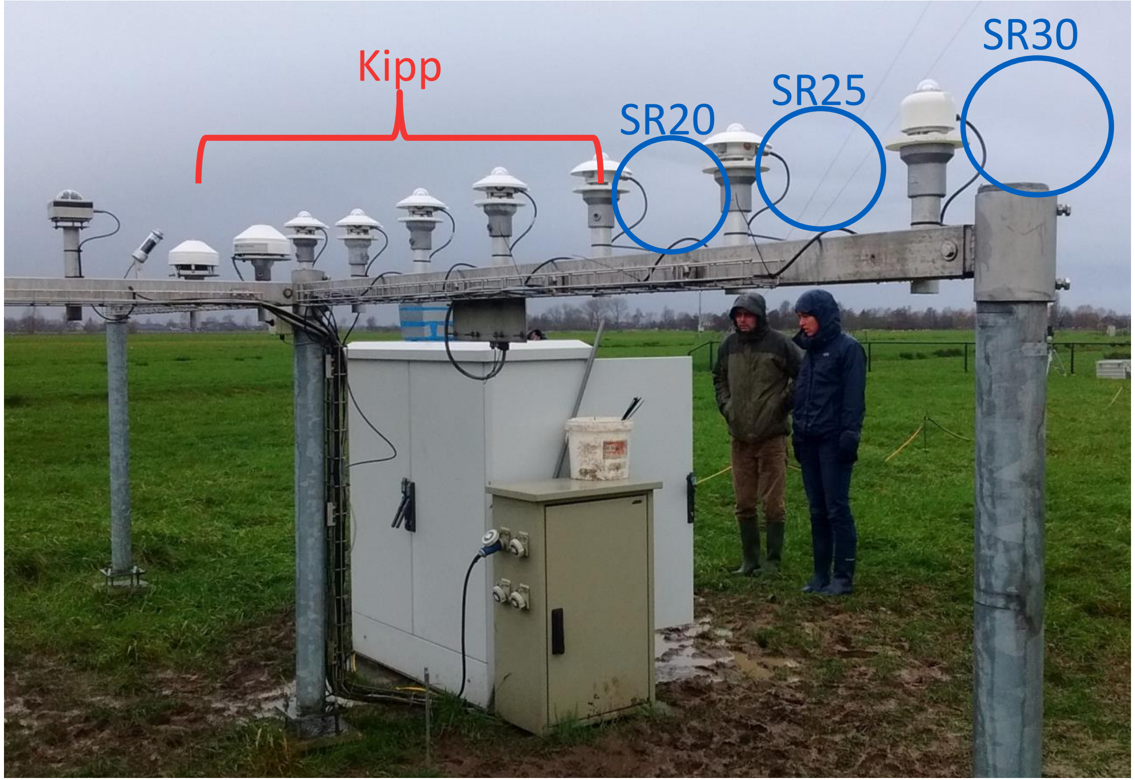


Hukseflux Thermal Sensors

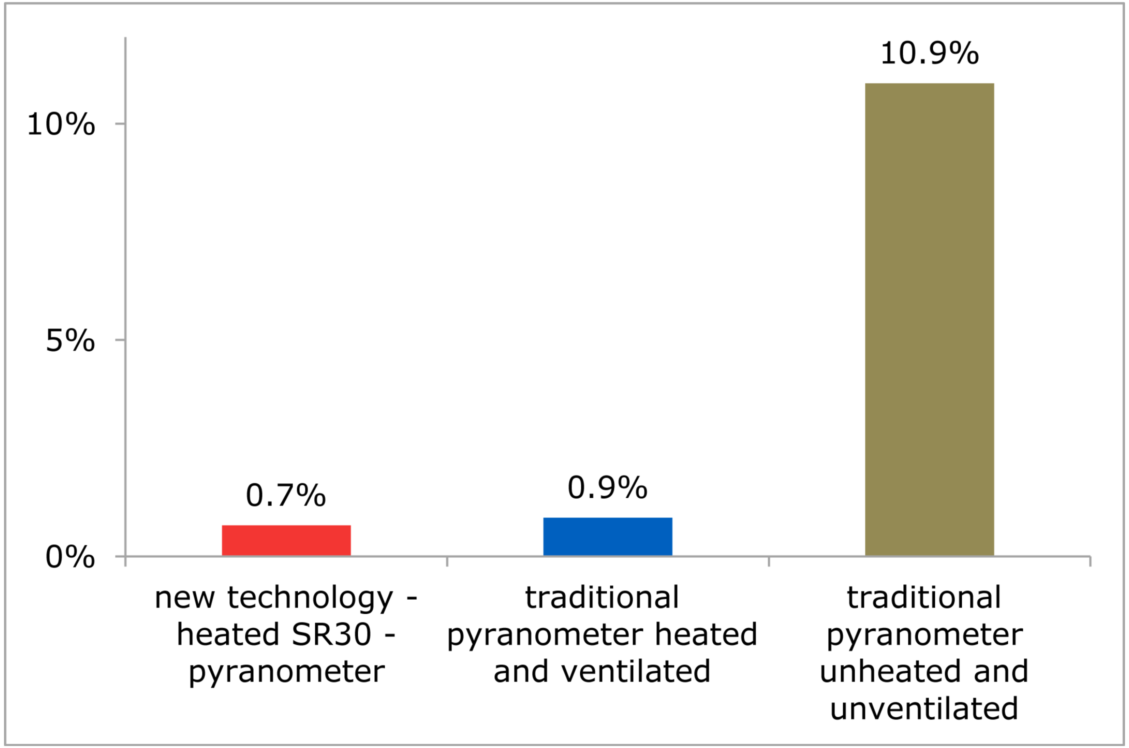
Webcam: NOAA USA

The Netherlands

Met office (KNMI) comparison



Unreliable data % of time



China ventilation not effective against soiling

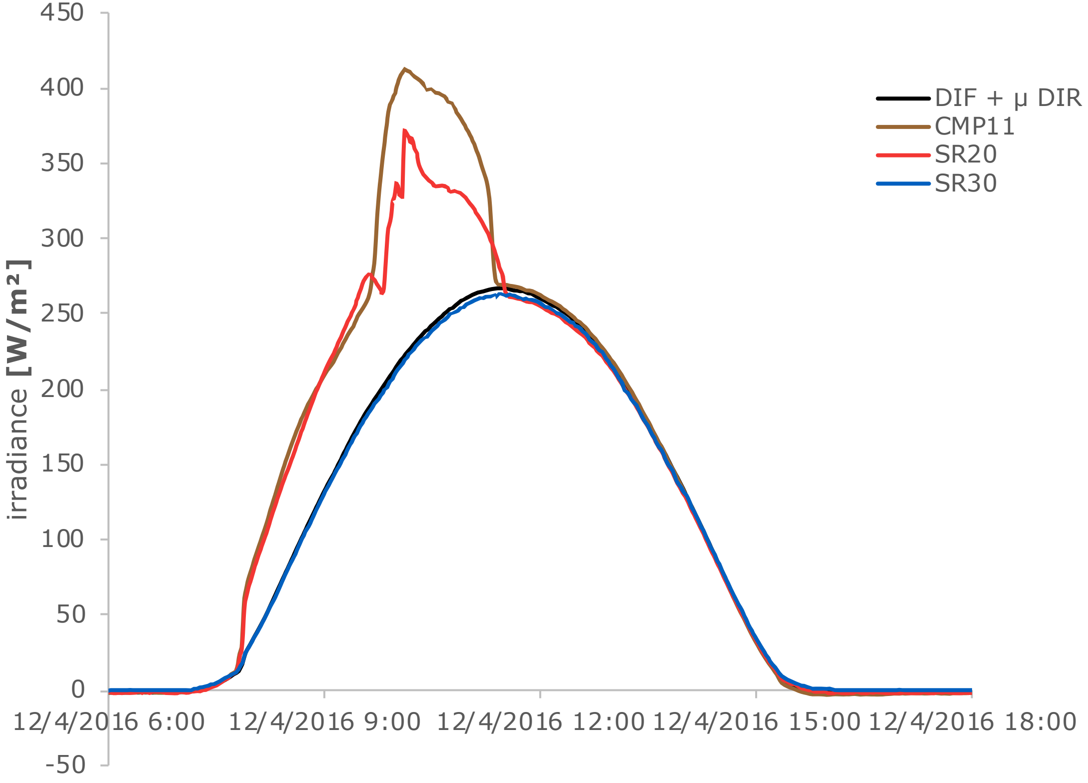
Clean after rain shower

After a few days

Ventilated

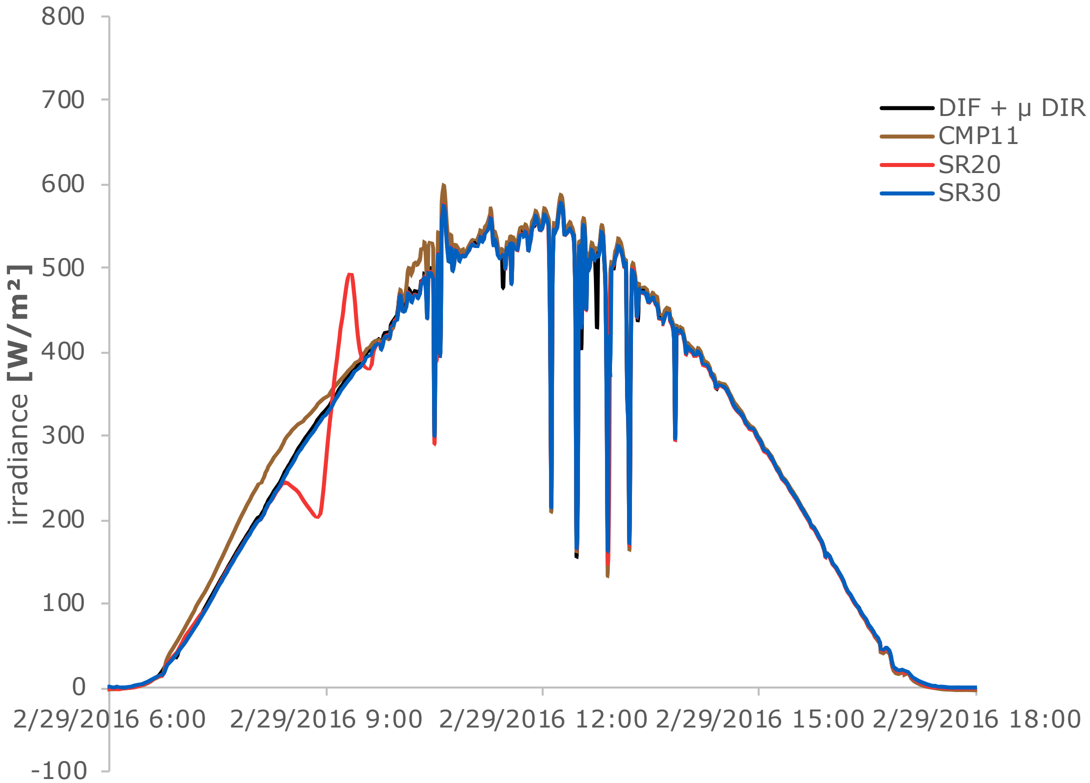
Not ventilated

Frost example



Hukseflux Thermal Sensors

Dew example



Hukseflux
Thermal Sensors

Good practices: calibration

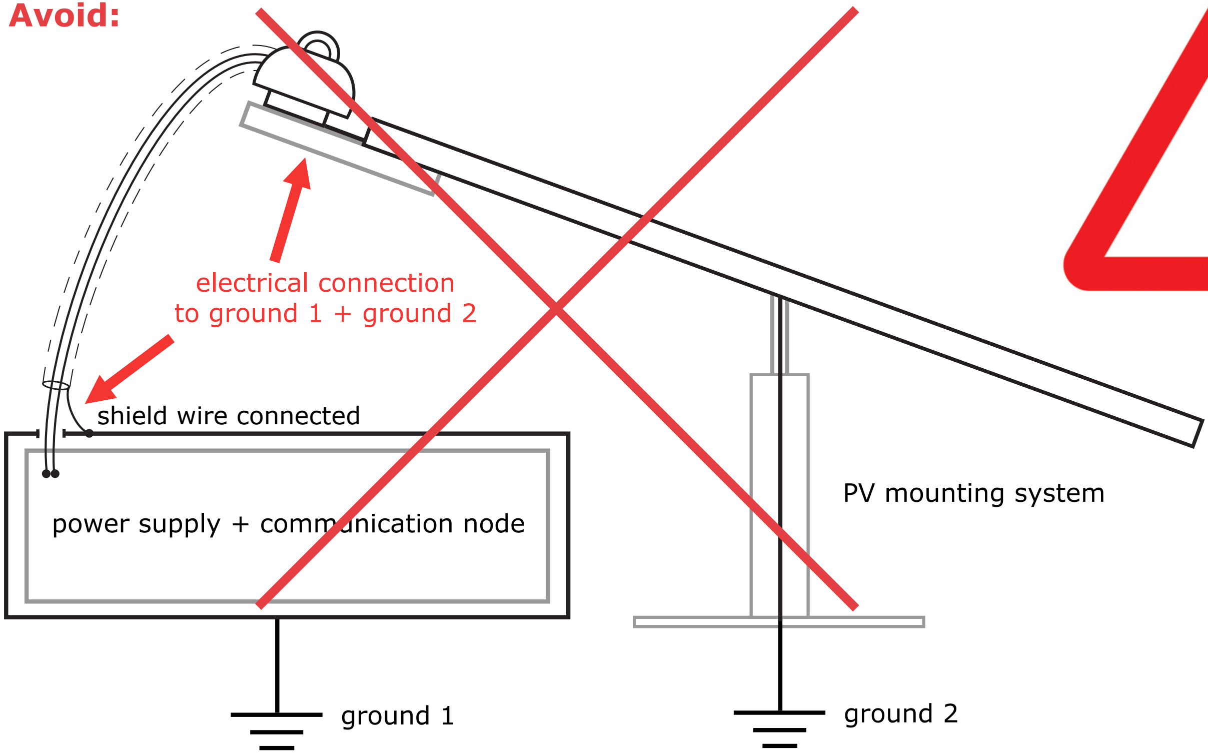
新气象
NEWSKY

Hukseflux Thermal Sensors

Good practices: Cleaning

Good practices: WARNING: electrical safety

Avoid:



Hukseflux Thermal Sensors

What sensor to use?

Hukseflux
Thermal Sensors

Evolution in instrument design

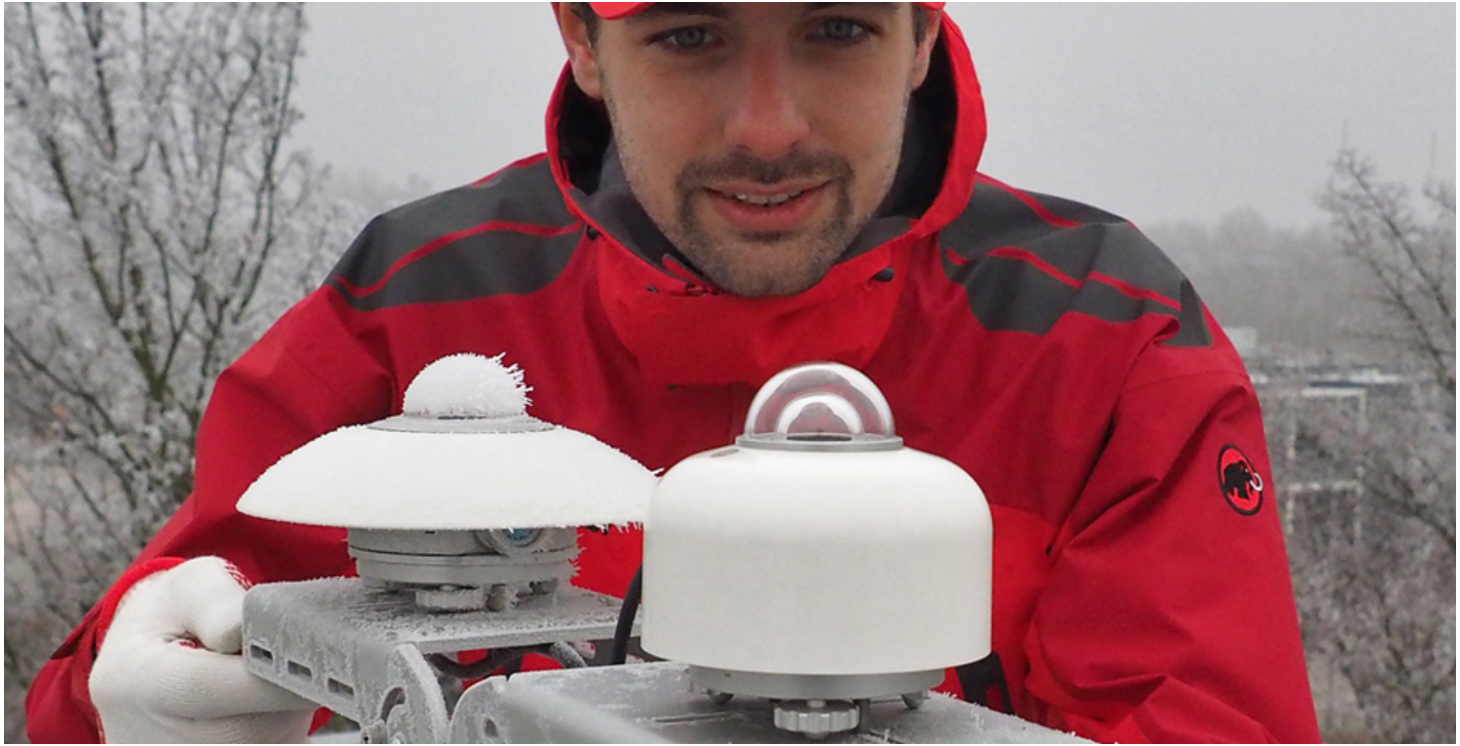
Hukseflux Thermal Sensors

Data availability

- Our opinion: Dew and frost are # 1 in creating unreliable data

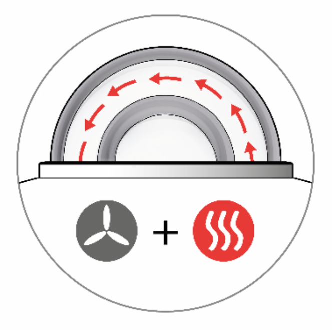
Hukseflux Thermal Sensors

Heated pyranometers (model SR30)



Hukseflux Thermal Sensors

Heating and added diagnostics



- heated
- homogeneously by internal ventilation
- internal humidity sensor
- tilt measurement

Low power

+ 2.1 W

= (

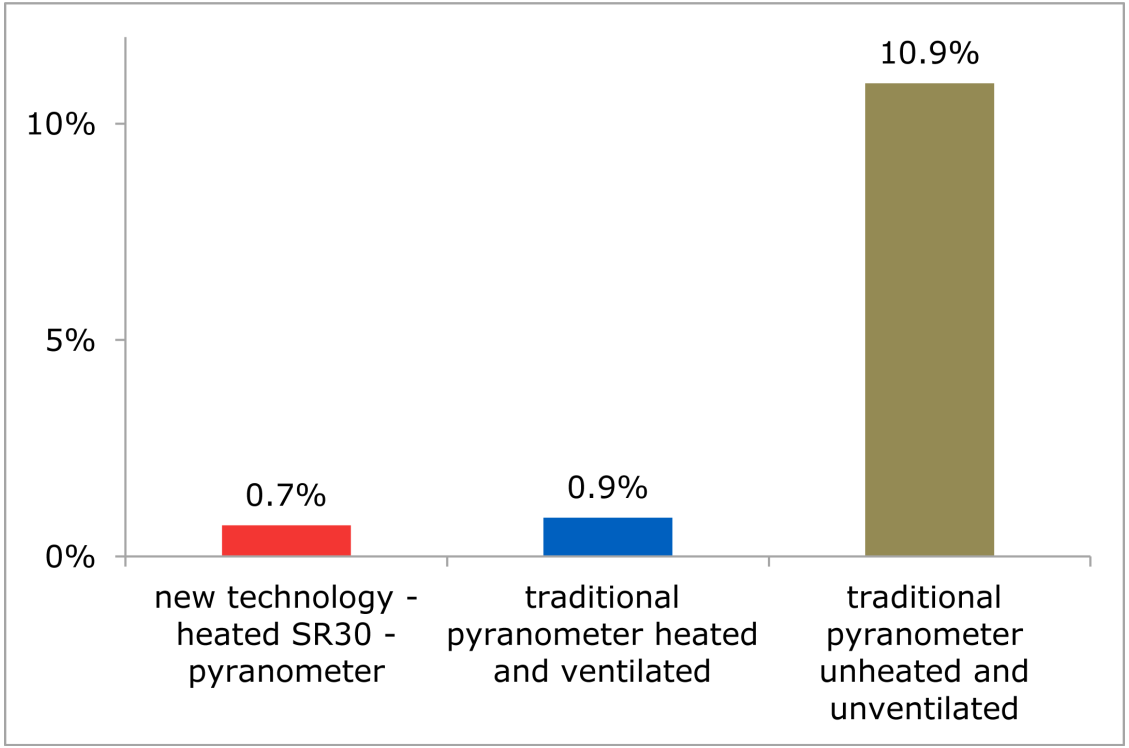
+

+ 10 W

)

Hukseflux Thermal Sensors

Unreliable data % of time



ISO TR 9901 revision

TECHNICAL REPORT

ISO TR 9901

First edition
1990-08-01

Reviewed and confirmed in 2013

Solar Energy — Field Pyranometers — Recommended practice for use

Énergie solaire — Pyranomètres de champ — Pratique recommandée pour l'emploi

Discussion points

- follow/ repeat IEC recommendations or not
- how to define benefits of heating
- how to define benefits of ventilation

Class A monitoring system

GroundWork

Pyanometer with tilt sensor on tracker (insulated)

GroundWork

Albedometer (facing up and down)

GroundWork

How to monitor for bifacial systems

How to monitor for bifacial systems

Hukseflux Thermal Sensors

Discussion points

- measuring versus modelling (satellite – measurement based)
- sensor locations in the array?
- Pyranometer versus PV reference cell
- averaging over many locations?
- Horizontal or tilted – PVSYST?
- IEC recommends 1 x RHI for every POA

- at least 1 station away from arrays for reference albedo

Reference station for albedo

Hukseflux Thermal Sensors

Summary recent developments

- many different developments
- combination leads to higher accuracies
- IEC 61724-1 acts as accelerator
- instruments and calibration become better
- under the best, IEC Class A, conditions uncertainties in the order of 3 % (k=2)
- watch out: specify “spectrally flat” instruments
- monitoring for bifacial systems is “work in progress”

Hukseflux Thermal Sensors

HUKSEFLUX THERMAL SENSORS 25 YEARS OF INNOVATION

Thank you!