



USER MANUAL **SR05-A1**

Analogue second class pyranometer



Warning statements



For proper instrument grounding: use SR05 with its original factory-made SR05 cable. See chapter on grounding and use of the shield.



Putting more than 12 Volt across the sensor wiring can lead to permanent damage to the sensor.



Do not use “open circuit detection” when measuring the sensor output.

Contents

Warning statements	2
Contents	3
List of symbols	4
Introduction	5
1 Ordering and checking at delivery	8
1.1 Ordering SR05	8
1.2 Included items	9
1.3 Quick instrument check	10
2 Instrument principle and theory	11
3 Specifications of SR05-A1	14
3.1 Specifications SR05-A1	14
3.2 Dimensions of SR05-A1	17
4 Standards and recommended practices for use	18
4.1 Classification standard	18
4.2 General use for solar radiation measurement	18
4.3 General use for sunshine duration measurement	18
4.4 Specific use for outdoor PV system performance testing	19
4.5 Specific use in meteorology and climatology	20
5 Installation of SR05-A1	21
5.1 Site selection and installation	21
5.2 Mounting and levelling SR05	22
5.3 Installing SR05	22
5.4 Installing SR05 with its ball levelling and tube mount	23
5.5 Electrical connection of SR05-A1	27
5.6 Grounding and use of the shield	27
5.7 Using SR05-A1's analogue millivolt output	28
6 Making a dependable measurement	29
6.1 The concept of dependability	29
6.2 Reliability of the measurement	30
6.3 Speed of repair and maintenance	31
6.4 Uncertainty evaluation	31
7 Maintenance and trouble shooting	34
7.1 Recommended maintenance and quality assurance	34
7.2 Trouble shooting	35
7.3 Calibration and checks in the field	36
7.4 Data quality assurance	37
8 Appendices	39
8.1 Appendix on cable extension / replacement	39
8.2 Appendix on tools for SR05-A1	41
8.3 Appendix on spare parts for SR05-A1	41
8.4 Appendix on standards for classification and calibration	42
8.5 Appendix on calibration hierarchy	43
8.6 Appendix on meteorological radiation quantities	44
8.7 Appendix on ISO and WMO classification tables	45
8.8 Appendix on definition of pyranometer specifications	46
8.9 Appendix on terminology / glossary	47
8.10 EU declaration of conformity	48

List of symbols

Quantities

	Symbol	Unit
Voltage output	U	V
Sensitivity	S	V/(W/m ²)
Solar irradiance	E	W/m ²
Temperature	T	°C
Electrical resistance	R _e	Ω
Solar radiant exposure	H	W·h/m ²
Time in hours	h	h

(see also appendix 8.6 on meteorological quantities)

Subscripts

Not applicable

Introduction

SR05 series is the most affordable range of pyranometers meeting ISO 9060 second class requirements. They are ideal for general solar radiation measurements in (agro-) meteorological networks and PV monitoring systems. SR05's are easy to mount and install. Various outputs are available, both digital and analogue, for ease of integration.

SR05 pyranometer measures solar radiation received by a plane surface, in W/m^2 , from a 180° field of view angle. Different configurations are available, depending on its mounting and the output needed.

SR05 employs a thermopile sensor with black coated surface, one dome and an anodised aluminium body with visible bubble level. SR05 series has a variety of industry standard outputs, both digital and analogue:

- Version SR05-D1A3: digital sensor with Modbus over RS-485 and analogue 0-1 V output
- Version SR05-D2A2: digital sensor with Modbus over TTL and analogue 4-20 mA output
- Version SR05-A1: analogue sensor with analogue millivolt output

This user manual covers use of the analogue sensor in the SR05 series range: SR05-A1. Specifications of this version differ from those of the digital versions of model SR05: SR05-D1A3 and SR05-D2A2, offering various digital and analogue outputs. For SR05-D1A3 and SR05-D2A2 use, consult the SR05 series user manual.

SR05-A1 benefits:

- Analogue millivolt output: easy implementation
- Easy mounting and levelling
- Pricing: second class pyranometers finally affordable for large networks

Using the analogue SR05-A1 is easy: the pyranometer can be connected directly to commonly used data logging systems. The irradiance in W/m^2 is calculated by dividing the SR05-A1 output, a small voltage, by the sensitivity. This sensitivity is provided with SR05-A1 on its calibration certificate.

The central equation governing SR05-A1 is: $E = U/S$ (Formula 0.1)

Suggested use for SR05:

- general solar radiation measurements
- (agro-)meteorological networks
- PV power plant monitoring

Optionally SR05 has a unique ball levelling mechanism with or without tube mount, for easy installation.



Figure 0.1 On the left SR05-A1 analogue second class pyranometer with bubble level and M12-A cable connector in its standard configuration (3 metre cable standard included); on the right SR05-A1 with optional ball levelling, for easy mounting and levelling on (non-) horizontal surfaces (included mounting screws not displayed)



Figure 0.2 SR05-A1 analogue second class pyranometer with optional ball levelling and tube mount for easy mounting and levelling on a tube (tube not included)

All SR05 versions should be used in accordance with the recommended practices of ISO, WMO and ASTM.

The ASTM E2848 “Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance” (issued end 2011) confirms that a pyranometer is the preferred instrument for PV system performance monitoring. SR05-A1 pyranometer complies with the requirements of this standard. For more information, see our [pyranometer selection guide](#).

WMO has approved the “pyranometric method” to calculate sunshine duration from pyranometer measurements in WMO-No. 8, Guide to Meteorological Instruments and Methods of Observation. This implies that SR05-A1 may be used, in combination with appropriate software, to estimate sunshine duration. This is much more cost-effective than using a dedicated sunshine duration sensor. Ask for our application note.

1 Ordering and checking at delivery

1.1 Ordering SR05

There is one standard configuration for SR05-A1:

- SR05-A1: with analogue millivolt output
standard cable length: 3 metres

Common options are:

- longer cable (10, 20 metres). Specify total cable length
- extension cable with connector pair (10, 20 metres). Specify total cable length
- ball levelling
- tube mount with ball levelling (for tube diameters 25 to 40 mm)

Ball levelling and tube mount are suited for retrofitting.

Table 1.1.1 *Ordering codes for SR05-A1*

VERSIONS OF SR05-A1 (part numbers), without cable	
SR05-A1	analogue second class pyranometer, with millivolt output
CABLE FOR SR05, with female M12-A connector at sensor end, non-stripped on other end	
`-03' after SR05 part number	standard cable length: 3 m
`-10' after SR05 part number	cable length: 10 m
`-20' after SR05 part number	cable length: 20 m
LEVELLING OPTIONS FOR SR05	
BL01	ball levelling, for levelling of SR05
TMBL01	tube mount with ball levelling, for mounting SR05 on a tube
CABLE EXTENSION FOR SR05, with male and female M12-A connectors	
C06E-10	cable length: 10 m
C06E-20	cable length: 20 m

An extension cable (with connector pair) can be used in combination with a regular cable (with one connector at sensor end) to make alternative SR05 cable lengths possible.

Example: Cable length needed: 15 m. In this case, it is easiest to buy SR05 with a 20 m cable and to cut it to desired length.

Example: Cable length needed: 30 m. In this case, it is easiest to buy SR05 with 10 m cable and a cable extension of 20 m.

1.2 Included items

Arriving at the customer, the delivery should include:

- pyranometer SR05-A1
- cable of the length as ordered
- product certificate matching the instrument serial number

Please store the certificate in a safe place.

When ordering mounting options BL01 or TMBL01 with SR05, the delivery should also include:

- BL01:
 - ball levelling
 - 4 mm hex key
 - 1 x shim
 - 2 x M5x20 bolts
 - 2 x M5 nuts
- TMBL01:
 - ball levelling
 - 4 mm hex key
 - 1 x shim
 - 2 x M5x20 bolts
 - 2 x M5 nuts
 - tube mount
 - 2 x M5x30 bolts
 - 2 x M5x40 bolts



Figure 1.2.1 From left to right: SR05-A1, SR05-A1 with mounting option BL01, and SR05-A1 with tube mounting option TMBL01 (nuts and bolts, tools and certificates are not shown, tube itself is not included)

1.3 Quick instrument check

A quick test of the instrument can be done by using a simple handheld multimeter and a lamp.

1. Check the electrical resistance of the sensor between the grey (-) and white (+) wire. Use a multimeter at the 200 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. The typical resistance of the wiring is 0.1 Ω /m. The measured resistance should be the typical sensor resistance of 40 to 80 Ω plus 1 Ω for the total resistance of two wires (back and forth) of each 3 m. Infinite resistance indicates a broken circuit; zero or a low resistance indicates a short circuit.
2. Check if the sensor reacts to light: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100×10^{-3} VDC range or lower. Expose the sensor to a strong light source, for instance a 100 W light bulb at 0.1 m distance. The signal should read $> 2 \times 10^{-3}$ V now. Darken the sensor either by putting something over it or switching off the light. The instrument voltage output should go down and within one minute approach 0 V.
3. If applicable, remove the optional sun screen, using the hex key (see chapter on installation of the sun screen). Inspect the bubble level.
4. Inspect the instrument for any damage.

2 Instrument principle and theory

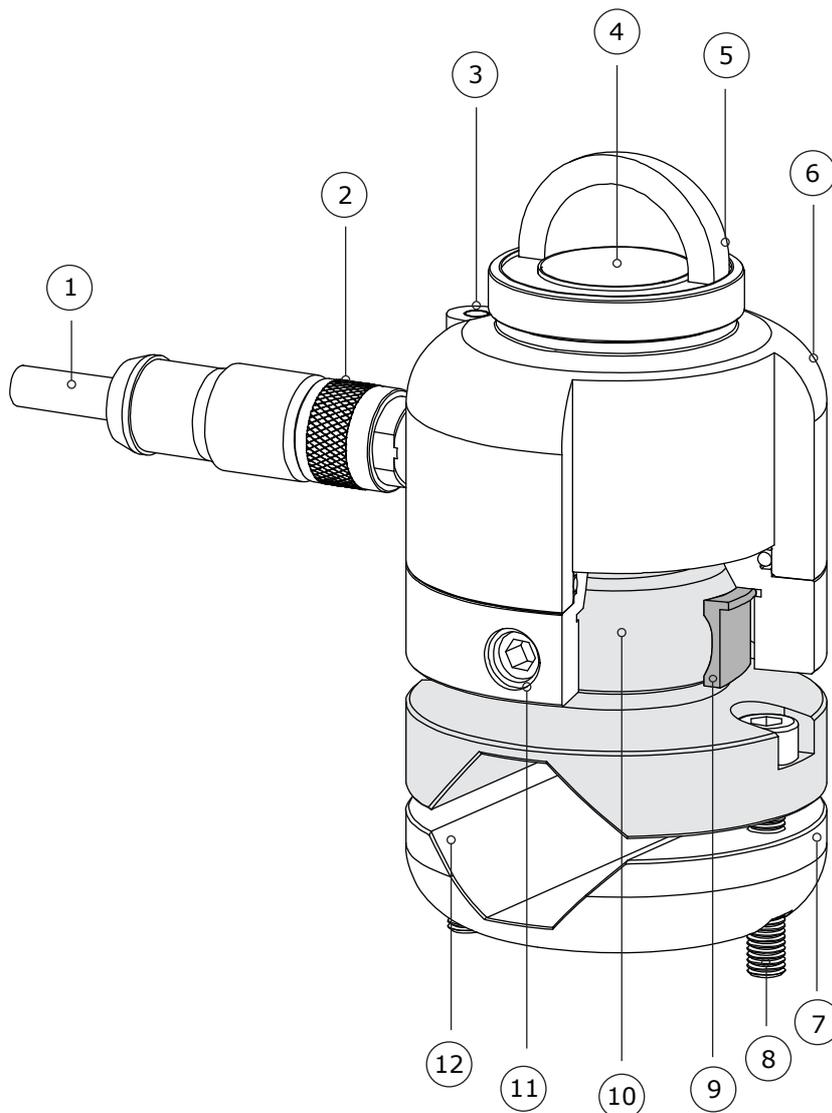


Figure 2.1 Overview of SR05-A1 (shaded areas in exploded view show ball levelling mount and shim). Numbers 7 to 12 are included when ordering option BL01 or TMBL01:

- (1) cable (standard length 3 metres, optional longer cable)
- (2) connector
- (3) bubble level
- (4) thermal sensor with black coating
- (5) glass dome
- (6) sensor body
- (7) tube mount (included with TMBL01)
- (8) mounting screw (included with BL01 and TMBL01; requires 4 mm hex key)
- (9) shim (included with BL01 and TMBL01; needed for ball levelling mount)
- (10) ball levelling mount (included with BL01 and TMBL01)
- (11) countersunk set screw for levelling adjustment (included with BL01 and TMBL01; requires 4 mm hex key)
- (12) opening for \varnothing 25 to \varnothing 40 mm tube when using ball levelling and tube mount

SR05's scientific name is pyranometer. A pyranometer measures the solar radiation received by a plane surface from a 180 ° field of view angle. This quantity, expressed in W/m^2 , is called "hemispherical" solar radiation. The solar radiation spectrum extends roughly from 285 to 3000×10^{-9} m. By definition a pyranometer should cover that spectral range with a spectral selectivity that is as "flat" as possible.

In an irradiance measurement by definition the response to "beam" radiation varies with the cosine of the angle of incidence; i.e. it should have full response when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 ° angle of incidence), zero response when the sun is at the horizon (90 ° angle of incidence, 90 ° zenith angle), and 50 % of full response at 60 ° angle of incidence.

A pyranometer should have a so-called "directional response" (older documents mention "cosine response") that is as close as possible to the ideal cosine characteristic.

In order to attain the proper directional and spectral characteristics, a pyranometer's main components are:

- a thermal sensor with black coating. It has a flat spectrum covering the 200 to 50000×10^{-9} m range, and has a near-perfect directional response. The coating absorbs all solar radiation and, at the moment of absorption, converts it to heat. The heat flows through the sensor to the sensor body. The thermopile sensor generates a voltage output signal that is proportional to the solar irradiance.
- a glass dome. This dome limits the spectral range from 285 to 3000×10^{-9} m (cutting off the part above 3000×10^{-9} m), while preserving the 180 ° field of view angle. Another function of the dome is that it shields the thermopile sensor from the environment (convection, rain).

Pyranometers can be manufactured to different specifications and with different levels of verification and characterisation during production. The ISO 9060 - 1990 standard, "Solar energy - specification and classification of instruments for measuring hemispherical solar and direct solar radiation", distinguishes between 3 classes; secondary standard (highest accuracy), first class (second highest accuracy) and second class (third highest accuracy).

From second class to first class and from first class to secondary standard, the achievable accuracy improves by a factor 2.

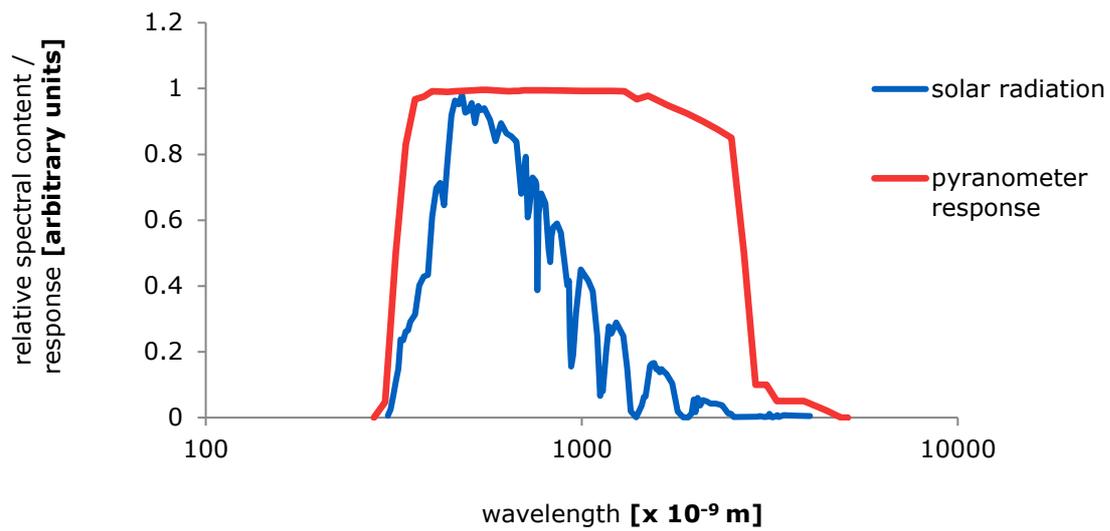


Figure 2.2 Spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum.

3 Specifications of SR05-A1

3.1 Specifications SR05-A1

SR05-A1 measures the solar radiation received by a plane surface from a 180 ° field of view angle. This quantity, expressed in W/m², is called “hemispherical” solar radiation.

SR05-A1 offers irradiance in W/m² as an analogue millivolt output. SR05-A1 is a passive sensor and does not need a power supply. It can be connected directly to commonly used data logging systems. The irradiance in W/m² is calculated by dividing the SR05-A1 output, a small voltage, by the sensitivity. This sensitivity is provided with SR05-A1 on its calibration certificate.

This user manual covers use of the analogue sensor in the SR05 series range: SR05-A1. Specifications of this version differ from those of the digital versions of model SR05: SR05-D1A3 and SR05-D2A2, offering various digital and analogue outputs. For SR05-D1A3 and SR05-D2A2 use, consult the SR05 series user manual.

The instrument is classified according to ISO 9060 and should be used in accordance with the recommended practices of ISO, IEC, WMO and ASTM.

Table 3.1.1 *Specifications of SR05-A1 (continued on next pages)*

SR05 MEASUREMENT SPECIFICATIONS: LIST OF CLASSIFICATION CRITERIA OF ISO 9060*	
ISO classification (ISO 9060: 1990)	second class pyranometer
WMO performance level (WMO-No. 8, seventh edition 2008)	moderate quality pyranometer
Response time (95 %)	18 s
Zero offset a (response to 200 W/m ² net thermal radiation)	< 15 W/m ² unventilated
Zero offset b (response to 5 K/h change in ambient temperature)	< ± 4 W/m ²
Non-stability	< ± 1 % change per year
Non-linearity	< ± 1 % (100 to 1000 W/m ²)
Directional response	< ± 25 W/m ²
Spectral selectivity	< ± 5 % (0.35 to 1.5 x 10 ⁻⁶ m)
Temperature response	< ± 3 % (-10 to +40 °C)
Tilt response	< ± 2 % (0 to 90 ° at 1000 W/m ²)

*For the exact definition of pyranometer ISO 9060 specifications see the appendix.

Table 3.1.1 Specifications of SR05-A1 (continued)

SR05-A1 ADDITIONAL SPECIFICATIONS	
Measurand	hemispherical solar radiation
Measurand in SI radiometry units	irradiance in W/m ²
Optional measurand	sunshine duration
Field of view angle	180 °
Measurement range	0 to 2000 W/m ²
Sensitivity range	7 to 30 x 10 ⁻⁶ V/(W/m ²)
Sensitivity (nominal)	10 x 10 ⁻⁶ V/(W/m ²)
Required sensor power	zero (passive sensor)
Expected voltage output	application under natural solar radiation: -0.1 to +50 x 10 ⁻³ V
Measurement function / required programming	E = U/S
Measurement function / optional programming for sunshine duration	programming according to WMO guide paragraph 8.2.2
Rated operating temperature range	-40 to +80 °C
Spectral range (20 % transmission points)	285 to 3000 x 10 ⁻⁹ m
Sensor resistance range	40 to 80 Ω
Required readout	1 differential voltage channel or 1 single ended voltage channel, input resistance > 10 ⁶ Ω
Irradiance resolution	depends on readout equipment; 7 x 10 ⁻⁶ V datalogger resolution is sufficient for 1 W/m ² resolution in irradiance
Standard governing use of the instrument	ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use ASTM G183 - 05 Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers
Standard cable length (see options)	3 m
Cable diameter	4.8 x 10 ⁻³ m
Chassis connector	M12-A straight male connector, male thread, 5-pole
Chassis connector type	M12-A
Cable connector	M12-A straight female connector, female thread, 5-pole
Cable connector type	M12-A
Connector protection class	IP67
Cable replacement	replacement and extension cables with connector(s) can be ordered separately from Hukseflux
Mounting (see options)	2 x M5 bolt at 46 mm centre-to-centre distance on north-south axis, requires 4 mm hex key
Levelling (see options)	bubble level is included
Levelling accuracy	< 0.6 ° bubble entirely in ring
Desiccant	silica gel, 1.0 g, in a HDPE bag, (25 x 45) mm
IP protection class	IP67
Gross weight	approx. 0.5 kg
Net weight	approx. 0.5 kg
HEATING	
Heater	no heating
CALIBRATION	
Calibration traceability	to WRR
Calibration hierarchy	from WRR through ISO 9846 and ISO 9847, applying a correction to reference conditions
Calibration method	indoor calibration according to ISO 9847, Type IIc

Table 3.1.1 *Specifications of SR05-A1 (started on previous pages)*

CALIBRATION	
Calibration uncertainty	< 1.8 % (k = 2)
Recommended recalibration interval	2 years
Reference conditions	20 °C, normal incidence solar radiation, horizontal mounting, irradiance level 1000 W/m ²
Validity of calibration	based on experience the instrument sensitivity will not change during storage. During use under exposure to solar radiation the instrument "non-stability" specification is applicable.
MEASUREMENT ACCURACY AND RESOLUTION	
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis. see the chapter on uncertainty evaluation
WMO estimate on achievable accuracy for daily sums (see appendix for a definition of the measurement conditions)	10 %
WMO estimate on achievable accuracy for hourly sums (see appendix for a definition of the measurement conditions)	20 %
OPTIONS	
Longer cable: 10,20 m Cable with M12-A female connector on sensor end, non-stripped on other end	option code = total cable length
Extension cable with connector pair: 10, 20 m. Cable with male and female M12-A connectors	option code = C06E-10 for 10 metres, C06E-20 for 20 metres
Ball levelling (BL01)	mountable on (non-)horizontal surfaces with angle compensation up to 10 °; retrofittable; one shim, two M5x20 mounting bolts and two M5 nuts included; requires 4 mm hex key for levelling and 4 mm hex key and 8 mm wrench for mounting
Tube mount with ball levelling (TMBL01)	mountable on tubes Ø 25 to Ø 40 mm with angle compensation up to 10 °; retrofittable; one shim, two M5x30 and two M5x40 mounting bolts included; requires 4 m hex key for levelling and mounting

3.2 Dimensions of SR05-A1

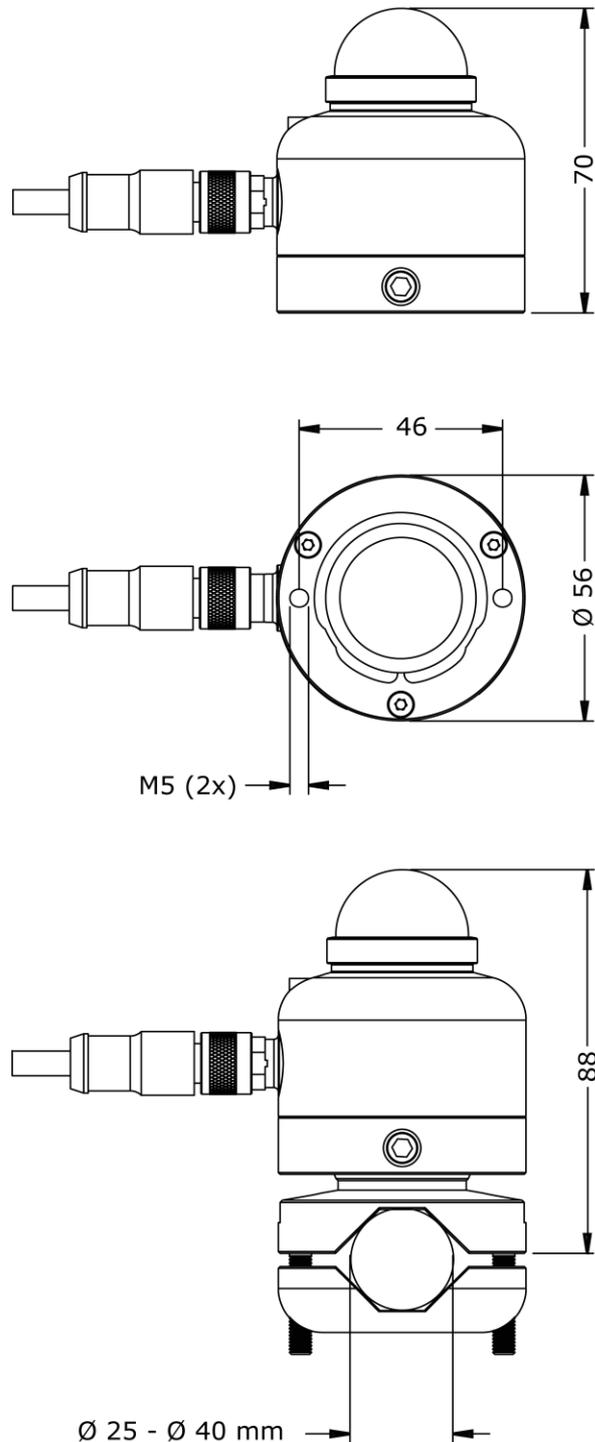


Figure 3.2.1 Dimensions of SR05 in $\times 10^{-3}$ m. The bottom drawing shows the height of SR05 combined with its optional ball levelling mount and the tube diameter required for use with SR05's optional tube mount. M5 mounting bolts and the countersunk set screw require a 4 mm hex key for mounting and levelling.

4 Standards and recommended practices for use

Pyranometers are classified according to the ISO 9060 standard and the WMO-No. 8 Guide. In any application the instrument should be used in accordance with the recommended practices of ISO, IEC, WMO and / or ASTM.

4.1 Classification standard

Table 4.1.1 *Standards for pyranometer classification. See the appendix for definitions of pyranometer specifications, and a table listing the specification limits.*

STANDARDS FOR INSTRUMENT CLASSIFICATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO 9060:1990 Solar energy -- specification and classification of instruments for measuring hemispherical solar and direct solar radiation	Not available	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation

4.2 General use for solar radiation measurement

Table 4.2.1 *Standards with recommendations for instrument use in solar radiation measurement*

STANDARDS FOR INSTRUMENT USE FOR HEMISPHERICAL SOLAR RADIATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use	ASTM G183 - 05 Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation

4.3 General use for sunshine duration measurement

According to the World Meteorological Organization (WMO, 2003), sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 W/m².

WMO has approved the “pyranometric method” to estimate sunshine duration from pyranometer measurements (Chapter 8 of the WMO Guide to Instruments and Observation, 2008). This implies that a pyranometer may be used, in combination with appropriate software, to estimate sunshine duration. Ask for our application note.

Table 4.3.1 *Standards with recommendations for instrument use in sunshine duration measurement*

STANDARDS FOR INSTRUMENT USE FOR SUNSHINE DURATION

WMO

WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 8, measurement of sunshine duration, 8.2.2 Pyranometric Method

4.4 Specific use for outdoor PV system performance testing

Pyranometers are used for monitoring PV power plant efficiency, in order to measure incoming solar radiation independently from the PV system. Pyranometers can be placed in two positions:

- plane of array (POA), parallel to the PV panels, for measurement of the in-plane irradiance (also noted as G_i in IEC 61724-1)
- horizontally, for measurement of the global horizontal irradiance (E , also noted as GHI in IEC 61724-1)

SR05-A1 is applicable in outdoor PV system performance testing. See also Hukseflux model **SR20** “secondary standard pyranometer”.

Table 4.4.1 *Standards with recommendations for instrument use in PV system performance testing*

STANDARDS ON PV SYSTEM PERFORMANCE TESTING

IEC / ISO STANDARD	EQUIVALENT ASTM STANDARD
IEC 61724-1; Photovoltaic system performance monitoring – guidelines for measurement, data exchange and analysis	ASTM 2848-11; Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance
COMMENT: Allows pyranometers or reference cells according to IEC 60904-2 and -6. Pyranometer reading required accuracy better than 5% of reading (Par 4.1)	COMMENT: confirms that a pyranometer is the preferred instrument for outdoor PV testing. Specifically recommends a “first class” pyranometer (paragraph A 1.2.1.)
COMMENT: equals JISC 8906 (Japanese Industrial Standards Committee)	

4.5 Specific use in meteorology and climatology

The World Meteorological Organization (WMO) is a specialised agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the earth's atmosphere and climate. WMO publishes WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, in which a table is included on "level of performance" of pyranometers. Nowadays WMO conforms itself to the ISO classification system.

5 Installation of SR05-A1

5.1 Site selection and installation

Table 5.1.1 Recommendations for installation of pyranometers

Location	the situation that shadows are cast on the instruments is usually not desirable. The horizon should be as free from obstacles as possible. Ideally there should be no objects between the course of the sun and the instrument.
Mechanical mounting / thermal insulation	preferably use the ball levelling mount included with BL01 and TMBL01 to mount SR05 to a (non-) horizontal surface. A pyranometer is sensitive to thermal shocks. Do not mount the instrument on objects that become very hot (black coated metal plates).
Instrument mounting with 2 bolts	<p>2 x M5 bolt at 46 mm centre-to-centre distance on north-south axis, connection through the sensor bottom in SR05's standard configuration.</p> <p>with BL01 ball levelling option: 2 x M5 bolt at 46 mm centre-to-centre distance, connection through ball levelling mount, M5x20 bolts and M5 nuts included.</p> <p>with TMBL01 ball levelling on tube mount option: 2 x M5 bolt at 46 mm centre-to-centre distance, connection through tube and ball levelling mount, M5x30 and M5x40 bolts included.</p>
Performing a representative measurement	<p>the pyranometer measures the solar radiation in the plane of the sensor. This may require installation in a tilted or inverted position. The black sensor surface (sensor bottom plate) should be mounted parallel to the plane of interest.</p> <p>In case a pyranometer is not mounted horizontally or in case the horizon is obstructed, the representativeness of the location becomes an important element of the measurement. See the chapter on uncertainty evaluation.</p>
Levelling	in case of horizontal mounting use the bubble level and optionally the ball levelling mount. The bubble level is visible and can be inspected at all times.
Instrument orientation	by convention with the cable exit pointing to the nearest pole (so the cable exit should point north in the northern hemisphere, south in the southern hemisphere).
Installation height	in case of inverted installation, WMO recommends a distance of 1.5 m between soil surface and sensor (reducing the effect of shadows and in order to obtain good spatial averaging).

5.2 Mounting and levelling SR05

SR05 in its standard configuration is equipped with a visible bubble level and two mounting holes. For easy mounting and levelling on a (non-)horizontal surface, SR05's optional ball levelling, included with BL01 and TMBL01, is recommended. Ball levelling offers:

- easy levelling
- easy cable orientation
- easy instrument exchange
- easy mounting (mounting screws and nuts included)

When installing SR05, ball levelling allows SR05 to rotate 360 ° and to tilt up to 10 °. This allows compensation for up to a ten degree angle when installing on a non-horizontal surface. A 4 mm hex key (un)locks the ball levelling mechanism. When using a tube or rod for installing SR05, the optional tube mount, included with TMBL01, is recommended. Combined with ball levelling it allows mounting to a 25 to 40 mm diameter tube with the same ease of levelling and instrument exchange.



Figure 5.2.1 From left to right: SR05 in its standard configuration with 3 metre cable; with optional ball levelling for easy mounting and levelling on a (non-)horizontal surface; with optional ball levelling and tube mount for easy installation on a 25 to 40 mm diameter tube. Mounting screws are included with the ball levelling and / or tube mount.

5.3 Installing SR05

SR05 without ball levelling and tube mounting options can be mounted using two M5 bolts (not included). For the required screw lengths, 5 to 7 mm should be added to the thickness of the user's mounting platform. See the chapter on required tooling.

5.4 Installing SR05 with its ball levelling and tube mount

Two M5x20 bolts and two M5 nuts are included with SR05's BL01 (and TMBL01) ball levelling option. These screws are to be used to mount SR05 with its ball levelling to a (non-)horizontal surface when mounting SR05 with BL01.

Two M5x30 bolts and two M5x40 screws are included with SR05's TMBL01's tube mount with ball levelling option. These screws are to be used to clamp both ball levelling and tube mount to a 25 to 40 mm diameter tube. For tube diameters larger than or equal to 33 mm, use the M5x40 bolts instead of the M5x30 bolts for a secure fit.

The unique ball head mechanism of SR05's ball levelling mount is used to level SR05. When ordering ball levelling with SR05, it is delivered separately from SR05.

In case SR05 is not attached to its ball levelling mount yet, the user has to ensure a shim is placed properly in the centre of the bottom plate of SR05 before mounting and levelling. The shim allows smooth levelling and is shown top left in Figure 5.4.1. Follow steps 1 to 5 in Section 5.4.1 for placing the shim. Once a shim is in place, follow steps 6 to 9 in Section 5.4.2 to mount and level SR05 with its BL01 or TMBL01 ball levelling option. See Section 5.4.3 for removing the ball levelling mount and its shim.

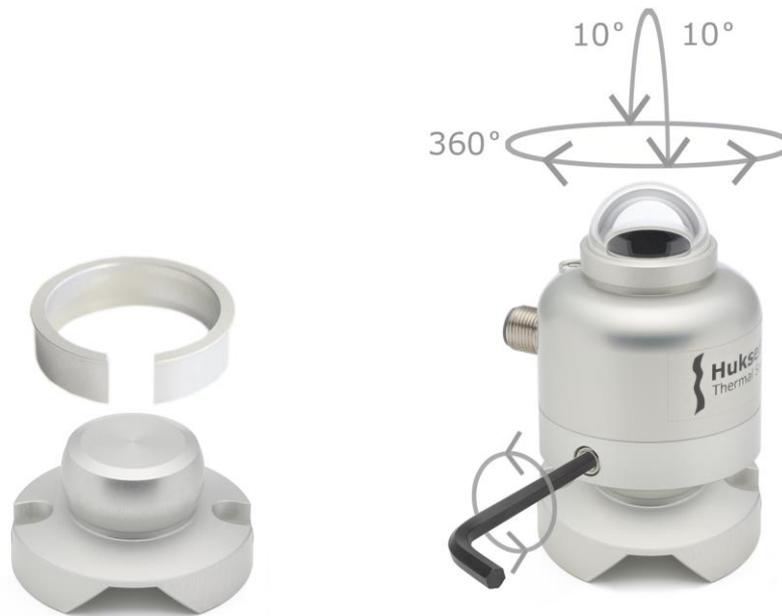


Figure 5.4.1 On the left SR05's ball levelling including shim (mounting bolts not displayed) and on the right SR05 placed on the ball levelling mount. Loosen the countersunk set screw on SR05's side to unlock, allowing placement of the ball head and SR05 levelling, and tighten it to lock the ball head mechanism. A 4 mm hex key is the only tool needed to place and remove the ball levelling and to allow and disallow levelling adjustment. The shim, included when ordering ball levelling, allows for smooth levelling and should be positioned properly in the centre of the bottom plate of SR05.

5.4.1 Placing SR05's ball levelling shim

When ordering SR05 pyranometer and its optional ball levelling or when exchanging a SR05 sensor on a ball levelling mount (retrofitting), the user has to ensure a dedicated shim is placed properly in the centre of the bottom plate of SR05. The aluminium shim ensures a secure fit between SR05 and ball levelling and allows the ball head to rotate smoothly for easy levelling. The shim, a loose set screw, a 4 mm hex key, two M5x20 mounting bolts and two M5 nuts are included when ordering the BL01 or TMBL01 ball levelling mount.

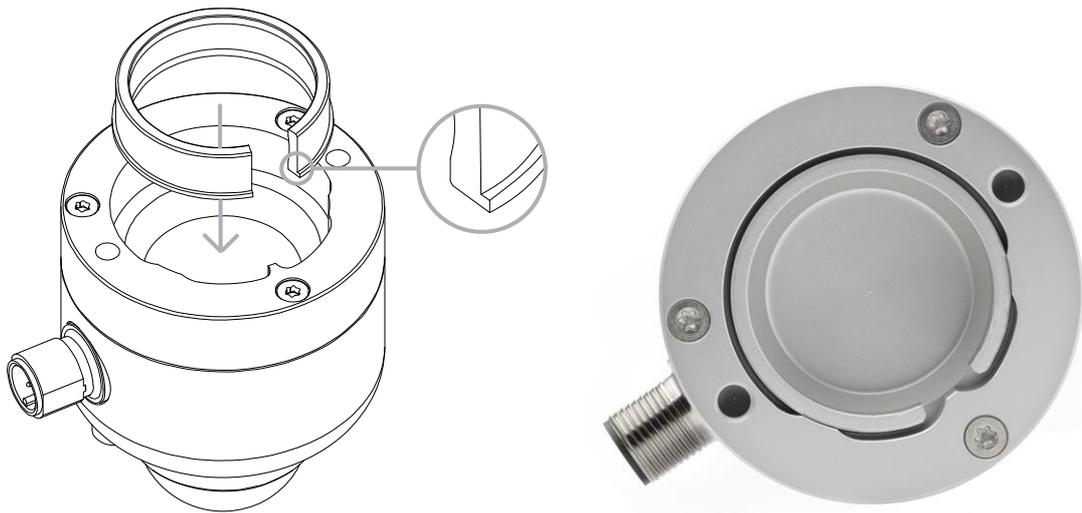


Figure 5.4.1.1 Line drawing indicating placement of the aluminium shim and photo showing the shim properly positioned in the centre of SR05's bottom plate. Note the position of the protruding ledge when placing the shim.

The shim can be placed into SR05's bottom plate following these steps:

- 1) If your SR05 has a small black plastic cover cap on the countersunk set screw opening on SR05's side, remove it. A small flathead screwdriver may be used. Then insert the loose set screw with a 4 mm hex key by turning the hex key clockwise until the screw is only slightly protruding (sticking out).
- 2) Hold SR05 in one hand, the shim in the other.
- 3) Ensure the orientation of the shim fits with that of SR05's bottom plate. Note the position of the protruding ledge (see Figure 5.5.1).
- 4) Pinch the shim slightly in order to reduce its diameter and to make it fit easily into SR05's bottom plate.
- 5) While pinching, push the shim into its position on SR05's bottom plate. The shim is placed.

Continue with the following section for mounting and levelling SR05 with ball levelling.

5.4.2 Mounting and levelling SR05 with BL01 or TMBL01

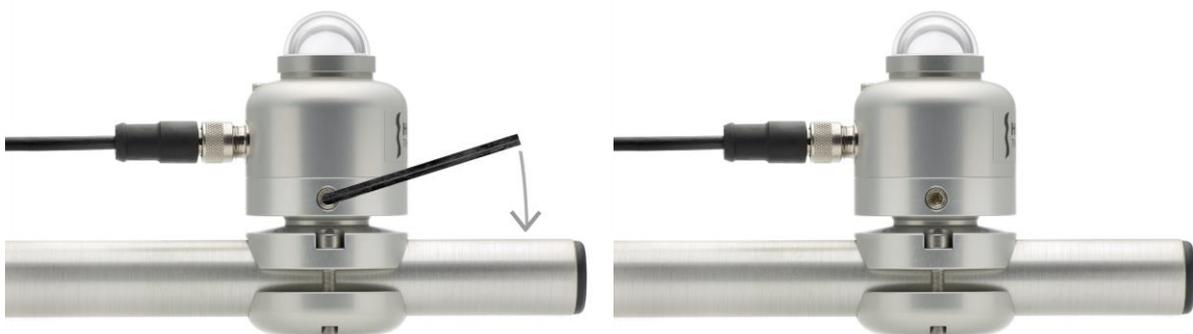
When the shim is properly in place (see steps 1 to 5), SR05 can be mounted and levelled using BL01 or TMBL01. Continue with the following steps:

- 6) Mount the ball levelling to a surface or platform with its M5 bolts and nuts. See chapter on tooling required.
- 7) SR05, with its shim positioned, can now be placed on the ball levelling mount. Gently push the sensor onto the ball head until it clicks.
- 8) The ball head can be rotated 360 ° and allows angle compensation on non-horizontal surfaces up to 10 °.
- 9) When SR05 is mounted and levelled, judging by its bubble level, lock the ball head mechanism by turning the set screw clockwise with a 4 mm hex key until it is tightened. The set screw should be countersunk and not protruding (not sticking out).

A similar approach is followed when levelling SR05 on its tube mount in the field:



1) judge bubble level and cable orientation 2) loosen set screw to tilt and rotate SR05



3) tighten set screw to lock ball levelling 4) SR05 is mounted and levelled

Figure 5.4.2.1 *Levelling steps for SR05 when mounted on tube mount with ball levelling*

5.4.3 Removing the ball levelling mount and its shim

- 1) Loosen SR05's countersunk set screw with a 4 mm hex key by turning the hex key counter clockwise until the screw is slightly protruding (sticking out).
- 2) Hold SR05 in one hand, the ball levelling mount in the other.
- 3) Separate SR05 from the ball levelling mount by gently pulling out the ball levelling mount. Make sure the glass dome is protected at all times.

When (TM)BL01's ball head is not inserted in SR05, the shim makes a minor rattling noise when moving SR05. This is normal, caused by mechanical freedom between the two parts.

The shim can be removed from SR05's bottom plate by hand with the assistance of a small flathead screwdriver. See the chapter on tooling required. Let the screwdriver gently tip the shim out. When removing or placing the shim, make sure the glass dome is protected at all times.

5.5 Electrical connection of SR05-A1

This user manual covers use of the analogue sensor in the SR05 series range: SR05-A1. Specifications of this version differ from those of the digital versions of model SR05: SR05-D1A3 and SR05-D2A2, offering various digital and analogue outputs. For SR05-D1A3 and SR05-D2A2 use, consult the SR05 series user manual.

In order to operate, a pyranometer should be connected to a measurement system, typically a so-called datalogger. SR05-A1 is a passive sensor that does not need any power. Cables generally act as a source of distortion, by picking up capacitive noise. We recommend keeping the distance between a datalogger or amplifier and the sensor as short as possible. For cable extension, see the appendix on this subject.

Table 5.5.1 *Wiring diagram of SR05-A1*

PIN	WIRE	SR05-A1 analogue millivolt output
1	Brown	not connected
4	Black	not connected
3	Blue	not connected
2	White	signal [+]
5	Grey	signal [-]
	Yellow	shield

Note 1: at the connector-end of the cable, the shield is connected to the connector housing

5.6 Grounding and use of the shield

Grounding and shield use are the responsibility of the user. The cable shield (called shield in the wiring diagram) is connected to the aluminium instrument body via the connector. In most situations, the instrument will be screwed on a mounting platform that is locally grounded. In these cases the shield at the cable end should not be connected at all. When a ground connection is not obtained through the instrument body, for instance in laboratory experiments, the shield should be connected to the local ground at the cable end. This is typically the ground of the datalogging system. In exceptional cases, for instance when both the instrument and a datalogger are connected to a small size mast, the local ground at the mounting platform is the same as the network ground. In such cases ground connection may be made both to the instrument body and to the shield at the cable end.

5.7 Using SR05-A1's analogue millivolt output

Using the analogue SR05-A1 is easy: the pyranometer can be connected directly to commonly used data logging systems. The irradiance in W/m^2 is calculated by dividing the SR05-A1 output, a small voltage, by the sensitivity. This sensitivity is provided with SR05-A1 on its calibration certificate.

The central equation governing SR05-A1 is: $E = U/S$ (Formula 0.1)

5.7.1 Requirements for data acquisition / amplification

SR05-A1 is a passive sensor that does not need any power. In order to operate, a pyranometer should be connected to a measurement system, typically a so-called datalogger. The selection and programming of dataloggers is the responsibility of the user. Please contact the supplier of the data acquisition and amplification equipment to see if directions for use with the SR05-A1 are available. In case programming for similar instruments is available, this can typically also be used. SR05-A1 can usually be treated in the same way as other thermopile pyranometers. Pyranometers usually have the same programming as heat flux sensors.

When using SR05-A1 combined with read-out unit / datalogger LI19, please consult the LI19 manual as well.

Table 5.7.1 Requirements for data acquisition and amplification equipment for SR05-A1 in its standard configuration

Capability to measure small voltage signals	preferably: 5×10^{-6} V uncertainty Minimum requirement: 20×10^{-6} V uncertainty (valid for the entire expected temperature range of the acquisition / amplification equipment)
Capability for the data logger or the software	to store data, and to perform division by the sensitivity to calculate the solar irradiance. $E = U/S$ (Formula 0.1)
Data acquisition input resistance	$> 1 \times 10^6 \Omega$
Open circuit detection (WARNING)	open-circuit detection should not be used, unless this is done separately from the normal measurement by more than 5 times the sensor response time and with a small current only. Thermopile sensors are sensitive to the current that is used during open circuit detection. The current will generate heat, which is measured and will appear as an offset.

6 Making a dependable measurement

6.1 The concept of dependability

A measurement with a pyranometer is called “dependable” if it is reliable, i.e. measuring within required uncertainty limits, for most of the time and if problems, once they occur, can be solved quickly.

The requirements for a measurement with a pyranometer may be expressed by the user as:

- required uncertainty of the measurement (see following paragraphs)
- requirements for maintenance and repairs (possibilities for maintenance and repair including effort to be made and processing time)
- a requirement to the expected instrument lifetime (until it is no longer feasible to repair)

It is important to realise that the uncertainty of the measurement is not only determined by the instrument but also by the way it is used.

See also ISO 9060 note 5. In case of pyranometers, the measurement uncertainty as obtained during outdoor measurements is a function of:

- the instrument class
- the calibration procedure / uncertainty
- the duration of instrument employment under natural sunlight (involving the instrument stability specification)
- the measurement conditions (such as tilting, ventilation, shading, instrument temperature)
- maintenance (mainly fouling)
- the environmental conditions*

Therefore, ISO 9060 says, “statements about the overall measurement uncertainty under outdoor conditions can only be made on an individual basis, taking all these factors into account”.

* defined at Hukseflux as all factors outside the instrument that are relevant to the measurement such as the cloud cover (presence or absence of direct radiation), sun position, the local horizon (which may be obstructed) or condition of the ground (when tilted). The environmental conditions also involve the question whether or not the measurement at the location of measurement is representative of the quantity that should be measured.

6.2 Reliability of the measurement

A measurement is reliable if it measures within required uncertainty limits for most of the time. We distinguish between two causes of unreliability of the measurement:

- related to the reliability of the pyranometer and its design, manufacturing, calibration (hardware reliability).
- related to the reliability of the measurement uncertainty (measurement reliability), which involves hardware reliability as well as condition of use.

Most of the hardware reliability is the responsibility of the instrument manufacturer. The reliability of the measurement however is a joint responsibility of instrument manufacturer and user. As a function of user requirements, taking into account measurement conditions and environmental conditions, the user will select an instrument of a certain class, and define maintenance support procedures.

In many situations there is a limit to a realistically attainable accuracy level. This is due to conditions that are beyond control once the measurement system is in place. Typical limiting conditions are:

- the measurement conditions, for instance when working at extreme temperatures when the instrument temperature is at the extreme limits of the rated temperature range.
- the environmental conditions, for instance when installed at a sub-optimal measurement location with obstacles in the path of the sun.
- other environmental conditions, for instance when assessing PV system performance and the system contains panels at different tilt angles, the pyranometer measurement may not be representative of irradiance received by the entire PV system.

The measurement reliability can be improved by maintenance support. Important aspects are:

- dome fouling by deposition of dust, dew, rain or snow. Fouling results in undefined measurement uncertainty (sensitivity and directional error are no longer defined). This should be solved by regular inspection and cleaning.
- sensor instability. Maximum expected sensor aging is specified per instrument as its non-stability in [% change / year]. In case the sensor is not recalibrated, the uncertainty of the sensitivity gradually will increase. This is solved by regular recalibration.
- moisture condensing under pyranometer domes resulting in a slow change of sensitivity (within specifications). This is solved by regular replacement of desiccant or by maintenance (drying the entire sensor) in case the sensor allows this. For non-serviceable sensors like most second class pyranometers, this may slowly develop into a defect. For first class and secondary standard models (for instance model SR11 first class pyranometer and SR20-D2 digital secondary standard pyranometer) extra desiccant (in a set of 5 bags in an air tight bag) is available.

Another way to improve measurement reliability is to introduce redundant sensors.

- the use of redundant instruments allows remote checks of one instrument using the other as a reference, which leads to a higher measurement reliability.
- in PV system performance monitoring, in addition to instruments measuring in the plane of array, horizontally placed instruments are used for the measurement of global radiation. Global irradiance data enable the user to compare the local climate and system efficiency between different sites. These data can also be compared to measurements by local meteorological stations.

6.3 Speed of repair and maintenance

Dependability is not only a matter of reliability but also involves the reaction to problems; if the processing time of service and repairs is short, this contributes to the dependability.

Hukseflux pyranometers are designed to allow easy maintenance and repair. The main maintenance actions are:

- replacement of desiccant
- replacement of cabling

For optimisation of dependability a user should:

- estimate the expected lifetime of the instrument
- design a schedule of regular maintenance
- design a schedule of repair or replacement in case of defects

When operating multiple instruments in a network Hukseflux recommends keeping procedures simple and having a few spare instruments to act as replacements during service, recalibrations and repair.

6.4 Uncertainty evaluation

The uncertainty of a measurement under outdoor or indoor conditions depends on many factors, see paragraph 1 of this chapter. It is not possible to give one figure for pyranometer measurement uncertainty. The work on uncertainty evaluation is "in progress". There are several groups around the world participating in standardisation of the method of calculation. The effort aims to work according to the guidelines for uncertainty evaluation (according to the "Guide to Expression of Uncertainty in Measurement" or GUM).

6.4.1 Evaluation of measurement uncertainty under outdoor conditions

Hukseflux actively participates in the discussions about pyranometer measurement uncertainty; we also provide spreadsheets, reflecting the latest state of the art, to assist our users in making their own evaluation. The input to the assessment is summarised:

- 1) The formal evaluation of uncertainty should be performed in accordance with ISO 98-3 Guide to the Expression of Uncertainty in Measurement, GUM.
- 2) The specifications of the instrument according to the list of ISO 9060 classification of pyranometers and pyrhemometers are entered as limiting values of possible errors, to be analysed as type B evaluation of standard uncertainty per paragraph 4.3.7. of GUM. A priori distributions are chosen as rectangular.
- 3) A separate estimate has to be entered to allow for estimated uncertainty due to the instrument maintenance level.
- 4) The calibration uncertainty has to be entered. Please note that Hukseflux calibration uncertainties are lower than those of alternative equipment. These uncertainties are entered in measurement equation (equation is usually Formula 0.1: $E = U/S$), either as an uncertainty in E (zero offsets, directional response) in U (voltage readout errors) or in S (tilt error, temperature dependence, calibration uncertainty).
- 5) In uncertainty analysis for pyranometers, the location and date of interest is entered. The course of the sun is then calculated, and the direct and diffuse components are estimated, based on a model; the angle of incidence of direct radiation is a major factor in the uncertainty.
- 6) In uncertainty analysis for modern pyrhemometers: tilt dependence often is so low that one single typical observation may be sufficient.
- 7) In case of special measurement conditions, typical specification values are chosen. These should for instance account for the measurement conditions (shaded / unshaded, ventilated/ unventilated, horizontal / tilted) and environmental conditions (clear sky / cloudy, working temperature range).
- 8) Among the various sources of uncertainty, some are "correlated"; i.e. present during the entire measurement process, and not cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are not zero. Paragraph 5.2 of GUM.
- 9) Among the various sources of uncertainty, some are "uncorrelated"; cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are zero. Paragraph 5.1 of GUM.
- 10) Among the various sources of uncertainty, some are "not included in analysis"; this applies for instance to non-linearity for pyranometers, because it is already included in the directional error, and the spectral response for pyranometers and pyrhemometers because it is already taken into account in the calibration process.

Table 6.4.1.1 Preliminary estimates of achievable uncertainties of measurements with Hukseflux pyranometers. The estimates are based on typical pyranometer properties and calibration uncertainty, for sunny, clear sky days and well maintained stations, without uncertainty loss due to lack of maintenance and due to instrument fouling. The table specifies expanded uncertainties with a coverage factor of 2 and confidence level of 95 %. Estimates are based on 1 s sampling. **IMPORTANT NOTE:** there is no international consensus on uncertainty evaluation of pyranometer measurements, so this table should not be used as a formal reference.

Pyranometer class (ISO 9060)	season	latitude	uncertainty minute totals at solar noon	uncertainty hourly totals at solar noon	uncertainty daily totals
secondary standard	summer	mid-latitude	2.7 %	2.0 %	1.9 %
		equator	2.6 %	1.9 %	1.7 %
		pole	7.9 %	5.6 %	4.5 %
	winter	mid-latitude	3.4 %	2.5 %	2.7 %
first class	summer	mid-latitude	4.7 %	3.3 %	3.4 %
		equator	4.4 %	3.1 %	2.9 %
		pole	16.1%	11.4 %	9.2 %
	winter	mid-latitude	6.5 %	4.5 %	5.2 %
second class (SR05 series)	summer	mid-latitude	8.4 %	5.9 %	6.2 %
		equator	7.8 %	5.5 %	5.3 %
		pole	29.5 %	21.6 %	18.0 %
	winter	mid-latitude	11.4 %	8.1 %	9.9 %

6.4.2 Calibration uncertainty

New calibration procedures were developed in close cooperation with PMOD World Radiation Center in Davos, Switzerland. The latest calibration method results in an uncertainty of the sensitivity of less than 1.8 %, compared to typical uncertainties of higher than 3.5 % for this pyranometer class. See the appendix for detailed information on calibration hierarchy.

7 Maintenance and trouble shooting

7.1 Recommended maintenance and quality assurance

SR05-A1 can measure reliably at a low level of maintenance in most locations. Usually unreliable measurements will be detected as unreasonably large or small measured values. As a general rule this means that regular visual inspection combined with a critical review of the measured data, preferably checking against other measurements, is the preferred way to obtain a reliable measurement.

Table 7.1.1 Recommended maintenance of SR05-A1. If possible the data analysis and cleaning (1 and 2) should be done on a daily basis. (continued on next page)

MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	1 week	data analysis	compare measured data to maximum possible / maximum expected irradiance and to other measurements nearby (redundant instruments). Also historical seasonal records can be used as a source for expected values. Analyse night time signals. These signals may be negative (down to -5 W/m^2 on clear windless nights), due to zero offset a. In case of use with PV systems, compare daytime measurements to PV system output. Look for any patterns and events that deviate from what is normal or expected
2	2 weeks	cleaning	use a soft cloth to clean the dome of the instrument, persistent stains can be treated with soapy water or alcohol
3	6 months	inspection	inspect cable quality, inspect connectors, inspect mounting position, inspect cable, clean instrument, clean cable, inspect levelling, change instrument tilt in case this is out of specification, inspect mounting connection, inspect interior of dome for condensation
4	2 years	desiccant replacement	desiccant is specified to last for minimum 2 years. In case the user wants to replace desiccant himself, this is at own risk and should only be executed in an ESD-safe work environment. The bottom plate of SR05 should be removed by unscrewing 3 x T10 screws with a Torx 10 screwdriver. The desiccant bag is taped on the bottom plate of SR05. Care should be taken when mounting the bottom plate on SR05
5	2 years	recalibration	recalibration by side-by-side comparison to a higher standard instrument in the field according to ISO 9847
6		lifetime assessment	judge if the instrument should be reliable for another 2 years, or if it should be replaced
7	6 years	parts replacement	if applicable / necessary replace the parts that are most exposed to weathering; cable, connector. NOTE: use Hukseflux approved parts only

MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE (continued)

8	internal inspection	if applicable: open instrument and inspect / replace O-rings; dry internal cavity around the circuit board
9	recalibration	high-accuracy recalibration indoors according to ISO 9847 or outdoors according to ISO 9846

7.2 Trouble shooting

7.2.1 Trouble shooting SR05-A1

Table 7.2.2.1 *Trouble shooting for SR05-A1 (continued on next page)*

The sensor does not give any signal	<p>Check the electrical resistance of the sensor between the grey (-) and white (+) wire. Use a multimeter at the 200 Ω range. Measure the sensor resistance first with one polarity, than reverse the polarity. Take the average value. The typical resistance of the wiring is 0.1 Ω/m. The measured resistance should be the typical sensor resistance of 40 to 80 Ω plus 1 Ω for the total resistance of two wires (back and forth) of each 3 m. Infinite resistance indicates a broken circuit; zero or a low resistance indicates a short circuit.</p> <p>Check if the sensor reacts to light: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100 x 10⁻³ VDC range or lower. Expose the sensor to strong light source, for instance a 100 W light bulb at 1 x 10⁻¹ m distance. The signal should read > 2 x 10⁻³ V now. Darken the sensor either by putting something over it or switching off the light. The instrument voltage output should go down and within one minute approach 0 V. Check the data acquisition by applying a 1 x 10⁻⁶ V source to it in the 1 x 10⁻⁶ V range. Check the condition of the connectors (on chassis as well as the cable).</p>
-------------------------------------	--

The sensor signal is unrealistically high or low.	<p>Note that night-time signals may be negative (down to -5 W/m² on clear windless nights), due to zero offset a.</p> <p>Check if the pyranometer has clean domes.</p> <p>Check the location of the pyranometer; are there any obstructions that could explain the measurement result.</p> <p>Check the orientation / levelling of the pyranometer.</p> <p>Check if the right calibration factor is entered into the algorithm. Please note that each sensor has its own individual calibration factor, as documented in its calibration certificate.</p> <p>Check if the voltage reading is divided by the calibration factor in review of the algorithm. Check the condition of the wiring at the logger.</p> <p>Check the cable condition looking for cable breaks. Check the condition of the connectors (on chassis as well as the cable). Check the range of the data logger; signal can be negative (this could be out of range) or the amplitude could be out of range. Check the data acquisition by applying a 1 x 10⁻⁶ V source to it in the 1 x 10⁻⁶ V range. Look at the output. Check if the output is as expected.</p> <p>Check the data acquisition by short circuiting the data acquisition input with a 100 Ω resistor. Look at the output. Check if the output is close to 0 W/m².</p>
---	---

The sensor signal shows unexpected variations	<p>Check the presence of strong sources of electromagnetic radiation (radar, radio)</p> <p>Check the condition of the shielding.</p> <p>Check the condition of the sensor cable.</p> <p>Check if the cable is not moving during the measurement</p> <p>Check the condition of the connectors (on chassis as well as the cable)</p>
---	--

The dome shows internal condensation Arrange to send the sensor back to Hukseflux for diagnosis.

7.3 Calibration and checks in the field

Recalibration of field pyranometers is typically done by comparison in the field to a reference pyranometer. The applicable standard is ISO 9847 "International Standard-Solar Energy- calibration of field pyranometers by comparison to a reference pyranometer". At Hukseflux an indoor calibration according to the same standard is used.

Hukseflux recommendation for re-calibration:

if possible, perform calibration indoor by comparison to an identical reference instrument, under normal incidence conditions. The recommended calibration interval of pyranometers is 2 years.

In case of field comparison; ISO recommends field calibration to a higher class pyranometer. Hukseflux suggests also allowing use of sensors of the same model and class, because intercomparisons of similar instruments have the advantage that they suffer from the same offsets. It is therefore just as good to compare to pyranometers of the same brand and type as to compare to an instrument of a higher class. ISO recommends to perform field calibration during several days; 2 to 3 days under cloudless conditions, 10 days under cloudy conditions. In general this is not achievable. In order to shorten the calibration process Hukseflux suggests to allow calibration at normal incidence, using hourly totals near solar noon.

Hukseflux main recommendations for field intercomparisons are:

- 1) to take normal incidence as a reference and not the entire day.
- 2) to take a reference of the same brand and type as the field pyranometer or a pyranometer of a higher class, and
- 3) to connect both to the same electronics, so that electronics errors (also offsets) are eliminated.
- 4) to mount all instruments on the same platform, so that they have the same body temperature.
- 5) assuming that the electronics are independently calibrated, to analyse radiation values at normal incidence radiation (possibly tilting the radiometers to approximately normal incidence), if this is not possible to compare 1 hour totals around solar noon for horizontally mounted instruments.
- 6) for second class radiometers, to correct deviations of more than $\pm 10 \%$. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.
- 7) for first class pyranometers, to correct deviations of more than $\pm 5 \%$. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

8) for secondary standard instruments, to correct deviations of more than $\pm 3\%$. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

7.4 Data quality assurance

Quality assurance can be done by:

- analysing trends in solar irradiance signal
- plotting the measured irradiance against mathematically generated expected values
- comparing irradiance measurements between sites
- analysis of night time signals

The main idea is that one should look out for any unrealistic values. There are programs on the market that can semi-automatically perform data screening. See for more information on such a program: www.dqms.com.

8 Appendices

8.1 Appendix on cable extension / replacement

The sensor cable of SR05-A1 is equipped with a M12-A straight connector. In case of cable replacement, it is recommended to purchase a new cable with connector at Hukseflux. In case of cable extension, it is recommended to purchase an extension cable with connector pairs at Hukseflux. Please note that Hukseflux does not provide support for Do-It-Yourself connector- and cable assembly.

SR05-A1 is equipped with one cable. Keep the distance between data logger or amplifier and sensor as short as possible. Cables act as a source of distortion by picking up capacitive noise. In an electrically "quiet" environment the SR05-A1 cable can however be extended without problem to 100 metres. If done properly, the sensor signal, although small, will not significantly degrade because the sensor resistance is very low (so good immunity to external sources) and because there is no current flowing (so no resistive losses).

Connector and cable specifications are summarised on the next page.



Figure 8.1.1 *On the left the SR05-A1 cable with M12-A female connector on sensor end. The cable is non-stripped on the other end. Its length is 3 metres standard and available in 10 and 20 metres too. On the right Hukseflux extension cable with connector pairs, with male and female M12-A connectors, available in 10 and 20 metres.*

Table 8.1.1 *Specifications for SR05-A1 cable replacement and extension*

General replacement	please order a new cable with connector at Hukseflux
General cable extension	please order an extension cable with connector pairs at Hukseflux
Connectors used	chassis: M12-A straight male connector, male thread, 5-pole manufacturer: Binder cable: M12-A straight female connector, female thread, 5-pole manufacturer: Binder The shield is electrically connected to the connector
Cable	5-wire, shielded manufacturer: Binder
Length	cables should be kept as short as possible
Outer sheath	with specifications for outdoor use (for good stability in outdoor applications)

8.2 Appendix on tools for SR05-A1

Table 8.2.1 *Specifications of tools for SR05-A1*

CONFIGURATION	TOOLS	INCLUDED
tooling required for mounting SR05 without ball levelling	two M5 bolts applicable screwdriver	no no
tooling required for mounting SR05 with ball levelling	hex key 4 mm wrench size 8 mm for M5 nuts	yes no
tooling required for mounting SR05 with tube mount	hex key 4 mm	yes
tooling required for levelling SR05 with ball levelling and tube mount	hex key 4 mm	yes
tooling required for tipping the aluminium shim out of SR05's bottom panel position	screwdriver blade width 2 to 4 mm	no

8.3 Appendix on spare parts for SR05-A1

- SR05-A1 cable with female M12-A connector on sensor end, non-stripped on other end (3, 10, 20 m). Specify cable length
- SR05-A1 extension cable with connector pair, with male and female M12-A connectors, (10, 20 m). Specify extension cable length
- Ball levelling (order number BL01)
- Tube mount (order number TM01)
- Tube mount with ball levelling (order number TMBL01)
- Shim for ball levelling mount
- Countersunk set screw for ball levelling mount
- 2 x M5x40 mounting bolt
- 2 x M5x30 mounting bolt
- 2 x M5x20 mounting bolt with 2 x M5 nut
- Desiccant (silica gel, 1.0 g, in a HDPE bag)

NOTE: Dome, level and sensor of SR05 cannot be supplied as spare parts

8.4 Appendix on standards for classification and calibration

Both ISO and ASTM have standards on instrument classification and methods of calibration. The World Meteorological Organisation (WMO) has largely adopted the ISO classification system.

Table 8.4.1 *Pyranometer standardisation in ISO and ASTM.*

STANDARDS ON INSTRUMENT CLASSIFICATION AND CALIBRATION	
ISO STANDARD	EQUIVALENT ASTM STANDARD
ISO 9060:1990 Solar energy -- Specification and classification of instruments for measuring hemispherical solar and direct solar radiation	not available Comment: work is in progress on a new ASTM equivalent standard
Comment: a standard "Solar energy --Methods for testing pyranometer and pyrhelimeter characteristics" has been announced in ISO 9060 but is not yet implemented.	not available
ISO 9846:1993 Solar energy -- Calibration of a pyranometer using a pyrhelimeter	ASTM G167-05 Standard Test Method for Calibration of a Pyranometer Using a Pyrhelimeter
ISO 9847:1992 Solar energy -- Calibration of field pyranometers by comparison to a reference pyranometer	ASTM E 824-10 Standard Test Method for Transfer of Calibration from Reference to Field Radiometers ASTM G207-11 Standard Test Method for Indoor Transfer of Calibration from Reference to Field Pyranometers
ISO 9059:1990 Solar energy -- Calibration of field pyrhelimeters by comparison to a reference pyrhelimeter	ASTM E 816 Standard Test Method for Calibration of Pyrhelimeters by Comparison to Reference Pyrhelimeters
not available	ASTM G213-17 Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrhelimeters

8.5 Appendix on calibration hierarchy

The World Radiometric Reference (WRR) is the measurement standard representing the SI unit of irradiance. Use of WRR is mandatory when working according to the standards of both WMO and ISO. ISO9874 states under paragraph 1.3: the methods of calibration specified are traceable to the WRR. The WMO manual states under paragraph 7.1.2.2: the WRR is accepted as representing the physical units of total irradiance.

The worldwide homogeneity of the meteorological radiation measurements is guaranteed by the World Radiation Center in Davos Switzerland, by maintaining the World Standard Group (WSG) which materialises the World Radiometric Reference.

See www.pmodwrc.ch

The Hukseflux standard is traceable to an outdoor WRR calibration. Some small corrections are made to transfer this calibration to the Hukseflux standard conditions: sun at zenith and 1000 W/m² irradiance level. During the outdoor calibration the sun is typically at 20 to 40° zenith angle, and the total irradiance at a 700 W/m² level.

Table 8.5.1 Calibration hierarchy for pyranometers

WORKING STANDARD CALIBRATION AT PMOD / WRC DAVOS

Calibration of working standard pyranometers:

Method: ISO 9846, type 1 outdoor. This working standard has an uncertainty "uncertainty of standard". The working standard has been calibrated under certain "test conditions of the standard". The working standard has traceability to WRR world radiometric reference.

CORRECTION OF (WORKING) STANDARD CALIBRATION TO STANDARDISED REFERENCE CONDITIONS

Correction from "test conditions of the standard" to "reference conditions" i.e. to normal incidence and 20 °C:

Using known (working) standard pyranometer properties: directional, non linearity, offsets, temperature dependence). This correction has an uncertainty; "uncertainty of correction".

At Hukseflux we also call the working standard pyranometer "standard".

INDOOR PRODUCT CALIBRATION

Calibration of products, i.e. pyranometers:

Method: according to ISO 9847, Type IIc, which is an indoor calibration.

This calibration has an uncertainty associated with the method.

(In some cases like the BSRN network the product calibration is with a different method; for example again type 1 outdoor)

CALIBRATION UNCERTAINTY CALCULATION

ISO 98-3 Guide to the Expression of Uncertainty in Measurement, GUM Determination of combined expanded uncertainty of calibration of the product, including uncertainty of the working standard, uncertainty of correction, uncertainty of the method (transfer error). The coverage factor must be determined; at Hukseflux we work with a coverage factor $k = 2$.

8.6 Appendix on meteorological radiation quantities

A pyranometer measures irradiance. The time integrated total is called radiant exposure. In solar energy radiant exposure is often given in $W \cdot h/m^2$.

Table 8.6.1 Meteorological radiation quantities as recommended by WMO (additional symbols by Hukseflux Thermal Sensor). POA stands for Plane of Array irradiance. The term originates from ASTM and IEC standards.

SYMBOL	DESCRIPTION	CALCULATION	UNITS	ALTERNATIVE EXPRESSION	
E_{\downarrow}	downward irradiance	$E_{\downarrow} = E_{g\downarrow} + E_{l\downarrow}$	W/m^2		
H_{\downarrow}	downward radiant exposure for a specified time interval	$H_{\downarrow} = H_{g\downarrow} + H_{l\downarrow}$	J/m^2		
E_{\uparrow}	upward irradiance	$E_{\uparrow} = E_{g\uparrow} + E_{l\uparrow}$	W/m^2		
H_{\uparrow}	upward radiant exposure for a specified time interval	$H_{\uparrow} = H_{g\uparrow} + H_{l\uparrow}$	J/m^2	$W \cdot h/m^2$	Change of units
E	direct solar irradiance normal to the apparent solar zenith angle		W/m^2	DNI	Direct Normal Irradiance
E_0	solar constant		W/m^2		
$E_{g\downarrow h}$	global irradiance; hemispherical irradiance on a specified, in this case horizontal surface.*	$E_{g\downarrow} = E \cos \theta_h + E_{d\downarrow}$	W/m^2	GHI	Global Horizontal Irradiance
$E_{g\downarrow t}$	global irradiance; hemispherical irradiance on a specified, in this case tilted surface.*	$E_{g\downarrow} = E \cdot \cos \theta_t + E_{d\downarrow t} + E_{r\uparrow t}$ ***	W/m^2	POA	Plane of Array
$E_{d\downarrow}$	downward diffuse solar radiation		W/m^2	DHI	Diffuse Horizontal Irradiance
$E_{l\uparrow}, E_{l\downarrow}$	upward / downward long-wave irradiance		W/m^2		
$E_{r\uparrow}$	reflected solar irradiance		W/m^2		
E^*	net irradiance	$E^* = E_{\downarrow} - E_{\uparrow}$	W/m^2		
T_{\downarrow}	apparent surface temperature**		$^{\circ}C$ or K		
T_{\uparrow}	apparent sky temperature**		$^{\circ}C$ or K		
SD	sunshine duration		h		

θ is the apparent solar zenith angle θ_h relative to horizontal, θ_t relative to a tilted surface
 g = global, l = long wave, t = tilted *, h = horizontal*
 * distinction horizontal and tilted from Hukseflux,
 ** T symbols introduced by Hukseflux,
 *** contributions of $E_{d\downarrow t}$ and $E_{r\uparrow t}$ are $E_{d\downarrow}$ and $E_{r\uparrow}$ both corrected for the tilt angle of the surface

8.7 Appendix on ISO and WMO classification tables

Table 8.7.1 Classification table for pyranometers per ISO 9060 and WMO.

NOTE: WMO specification of spectral selectivity is different from that of ISO. Hukseflux conforms to the ISO limits. WMO also specifies expected accuracies. ISO finds this not to be a part of the classification system because it also involves calibration. Please note that WMO achievable accuracies are for clear days at mid latitudes and that the uncertainty estimate does not include uncertainty due to calibration*.

ISO CLASSIFICATION** TABLE			
ISO CLASS	SECONDARY STANDARD	FIRST CLASS	SECOND CLASS
Specification limit			
Response time (95 %)	15 s	30 s	60 s
Zero offset a (response to 200 W/m ² net thermal radiation)	+ 7 W/m ²	+ 15 W/m ²	+ 30 W/m ²
Zero offset b (response to 5 K/h in ambient temperature)	± 2 W/m ²	± 4 W/m ²	± 8 W/m ²
Non-stability (change per year)	± 0.8 %	± 1.5 %	± 3 %
Non-linearity (100 to 1000 W/m ²)	± 0.5 %	± 1 %	± 3 %
Directional response	± 10 W/m ²	± 20 W/m ²	± 30 W/m ²
Spectral selectivity (350 to 1 500 x 10 ⁻⁹ m) (WMO 300 to 3 000 x 10 ⁻⁹ m)	± 3 %	± 5 %	± 10 %
Temperature response (interval of 50 K)**	2 %	4 %	8 %
Tilt response (0 to 90 ° at 1000 W/m ²)	± 0.5 %	± 2 %	± 5 %
ADDITIONAL WMO SPECIFICATIONS			
WMO CLASS	HIGH QUALITY	GOOD QUALITY	MODERATE QUALITY
WMO: achievable accuracy for daily sums*	2 %	5 %	10 %
WMO: achievable accuracy for hourly sums*	3 %	8 %	20 %
WMO: achievable accuracy for minute sums*	not specified	not specified	not specified
WMO: resolution (smallest detectable change)	1 W/m ²	5 W/m ²	10 W/m ²
CONFORMITY TESTING***			
ISO 9060	individual instrument only: all specs must comply	group compliance	group compliance

* WMO 7.2.1: The estimated uncertainties are based on the following assumptions: (a) instruments are well-maintained, correctly aligned and clean; (b) 1 min and 1 h figures are for clear-sky irradiances at solar noon; (c) daily exposure values are for clear days at mid-latitudes. WMO 7.3.2.5: Table 7.5 lists the expected maximum deviation from the true value, excluding calibration errors.

** At Hukseflux the expression ± 1 % is used instead of a range of 2 %.

*** an instrument is subject to conformity testing of its specifications. Depending on the classification, conformity compliance can be proven either by group- or individual compliance. A specification is fulfilled if the mean value of the respective test result does not exceed the corresponding limiting value of the specification for the specific category of instrument.

8.8 Appendix on definition of pyranometer specifications

Table 8.8.1 Definition of pyranometer specifications

SPECIFICATION	DEFINITION	SOURCE
Response time (95 %)	time for 95 % response. The time interval between the instant when a stimulus is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits around its final steady value. The response time is a measure of the thermal inertia inherent in the stabilization period for a final reading.	ISO 9060-1990 WMO 1.6.3
Zero offset a: (200 W/m ² net thermal radiation)	response to 200 W/m ² net thermal radiation (ventilated). Hukseflux assumes that unventilated instruments have to specify the zero-offset in unventilated – worst case – conditions. Zero offsets are a measure of the stability of the zero-point. Zero offset a is visible at night as a negative offset, the instrument dome irradiates in the far infra red to the relatively cold sky. This causes the dome to cool down. The pyranometer sensor irradiates to the relatively cool dome, causing a negative offset. Zero offset a is also assumed to be present during daytime.	ISO 9060-1990
Zero offset b: (5 K/h in ambient temperature)	response to 5 K/h change in ambient temperature. Zero offsets are a measure of the stability of the zero-point.	ISO 9060-1990
Non-stability (change per year)	percentage change in sensitivity per year. The dependence of sensitivity resulting from ageing effects which is a measure of the long-term stability.	ISO 9060-1990
Non-linearity (100 to 1000 W/m ²)	percentage deviation from the sensitivity at 500 W/m ² due to the change in irradiance within the range of 100 W/m ² to 1000 W/m ² . Non-linearity has an overlap with directional response, and therefore should be handled with care in uncertainty evaluation.	ISO 9060-1990
Directional response	the range of errors caused by assuming that the normal incidence sensitivity is valid for all directions when measuring from any direction a beam radiation whose normal incidence irradiance is 1000 W/m ² . Directional response is a measure of the deviations from the ideal "cosine behaviour" and its azimuthal variation.	ISO 9060-1990
Spectral selectivity (350 to 1500 x 10 ⁻⁹ m) (WMO 300 to 3000 x 10 ⁻⁹ m)	percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 350 x 10 ⁻⁹ m to 1500 x 10 ⁻⁹ m and the spectral distribution of irradiance. Spectral selectivity is a measure of the spectral selectivity of the sensitivity.	ISO 9060-1990
Temperature response (interval of 50 K)	percentage deviation of the sensitivity due to change in ambient temperature within an interval of 50 K the temperature of the pyranometer body.	ISO 9060-1990
Tilt response (0° to 90° at 1000 W/m ²)	percentage deviation from the sensitivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000 W/m ² irradiance. Tilt response describes changes of the sensitivity due to changes of the tilt angle of the receiving surface.	ISO 9060-1990
Sensitivity	the change in the response of a measuring instrument divided by the corresponding change in the stimulus.	WMO 1.6.3
Spectral range	the spectral range of radiation to which the instrument is sensitive. For a normal pyranometer this should be in the 0.3 to 3 x 10 ⁻⁶ m range. Some pyranometers with coloured glass domes have a limited spectral range.	Hukseflux

8.9 Appendix on terminology / glossary

Table 8.9.1 Definitions and references of used terms

TERM	DEFINITION (REFERENCE)
Solar energy or solar radiation	solar energy is the electromagnetic energy emitted by the sun. Solar energy is also called solar radiation and shortwave radiation. The solar radiation incident on the top of the terrestrial atmosphere is called extra-terrestrial solar radiation; 97 % of which is confined to the spectral range of 290 to $3\,000 \times 10^{-9}$ m. Part of the extra-terrestrial solar radiation penetrates the atmosphere and directly reaches the earth's surface, while part of it is scattered and / or absorbed by the gas molecules, aerosol particles, cloud droplets and cloud crystals in the atmosphere. The former is the direct component, the latter is the diffuse component of the solar radiation. (ref: WMO, Hukseflux)
Hemispherical solar radiation	solar radiation received by a plane surface from a 180° field of view angle (solid angle of 2π sr).(ref: ISO 9060)
Global solar radiation	the solar radiation received from a 180° field of view angle on a horizontal surface is referred to as global radiation. Also called GHI. This includes radiation received directly from the solid angle of the sun's disc, as well as diffuse sky radiation that has been scattered in traversing the atmosphere. (ref: WMO) Hemispherical solar radiation received by a horizontal plane surface. (ref: ISO 9060)
Plane-of-array irradiance	also POA: hemispherical solar irradiance in the plane of a PV array. (ref: ASTM E2848-11 / IEC 61724)
Direct solar radiation	radiation received from a small solid angle centred on the sun's disc, on a given plane. (ref: ISO 9060)
Terrestrial or Longwave radiation	radiation not of solar origin but of terrestrial and atmospheric origin and having longer wavelengths ($3\,000$ to $100\,000 \times 10^{-9}$ m). In case of downwelling E_{\downarrow} also the background radiation from the universe is involved, passing through the "atmospheric window". In case of upwelling E_{\uparrow} , composed of long-wave electromagnetic energy emitted by the earth's surface and by the gases, aerosols and clouds of the atmosphere; it is also partly absorbed within the atmosphere. For a temperature of 300 K, 99.99 % of the power of the terrestrial radiation has a wavelength longer than $3\,000 \times 10^{-9}$ m and about 99 per cent longer than $5\,000 \times 10^{-9}$ m. For lower temperatures, the spectrum shifts to longer wavelengths. (ref: WMO)
World Radiometric Reference (WRR)	measurement standard representing the SI unit of irradiance with an uncertainty of less than ± 0.3 % (see the WMO Guide to Meteorological Instruments and Methods of Observation, 1983, subclause 9.1.3). The reference was adopted by the World Meteorological Organization (WMO) and has been in effect since 1 July 1980. (ref: ISO 9060)
Albedo	ratio of reflected and incoming solar radiation. Dimensionless number that varies between 0 and 1. Typical albedo values are: < 0.1 for water, from 0.1 for wet soils to 0.5 for dry sand, from 0.1 to 0.4 for vegetation, up to 0.9 for fresh snow.
Angle of incidence	angle of radiation relative to the sensor measured from normal incidence (varies from 0° to 90°).
Zenith angle	angle of incidence of radiation, relative to zenith. Equals angle of incidence for horizontally mounted instruments
Azimuth angle	angle of incidence of radiation, projected in the plane of the sensor surface. Varies from 0° to 360° . 0 is by definition the cable exit direction, also called north, east is $+90^\circ$. (ASTM G113-09)
Sunshine duration	sunshine duration during a given period is defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 W/m ² . (ref: WMO)

8.10 EU declaration of conformity



We, Hukseflux Thermal Sensors B.V.
Delftechpark 31
2628 XJ Delft
The Netherlands

in accordance with the requirements of the following directive:

2014/30/EU The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model: SR05-A1
Product type: Pyranometer

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission: EN 61326-1 (2006)
Immunity: EN 61326-1 (2006)
Emission: EN 61000-3-2 (2006)
Emission: EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)
Report: 08C01340RPT01, 06 January 2009



Kees VAN DEN BOS
Director
Delft
18 August, 2017

