Hukseflux
Thermal Sensors

USER MANUAL
SR05-D1A3-PV

Digital second class pyranometer – alternative for PV reference cell

Hukseflux
Thermal Sensors

Warning statements

⚠ Putting more than 30 Volt across the sensor wiring of the main power supply can lead to permanent damage to the sensor.

⚠ Keep the voltage on the RS-485 data wiring of SR05-D1A3-PV between -7 and +12 V to avoid permanent damage.

⚠ For proper instrument grounding: use SR05 with its original factory-made SR05 cable.

⚠ Using the same Modbus address for more than one device will lead to irregular behaviour of the entire network.

⚠ Disconnect power while performing service or maintenance.

⚠ Locally connect the cable shield to ground if SR05-D1A3-PV is not connected to ground through the installation platform.

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Contents

List of symbols

Quantities	Symbol	Unit
Voltage output	U	V
Sensitivity	S	V/(W/m^2)
Solar irradiance	E	W/m^2
Output of 0-1 V	U	V
Transmitted range of 0-1 V	r	W/m^2

(see also appendix 9.6 on meteorological quantities)

Subscripts

Not applicable

Notation	Example
Decimal numbers are indicated without prefix	30
Hexadecimal numbers are indicated with a 0x prefix	0x1E

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Introduction

SR05 series is the most affordable range of pyranometers meeting ISO 9060 requirements. These sensors are ideal for general solar radiation measurements and popular for monitoring photovoltaic (PV) systems. Model SR05-D1A3–PV is made as a perfect alternative to PV reference cells. It offers the same Modbus interface as the most common PV reference cell model for easy compatibility. Relative to PV reference cells, SR05-D1A3-PV has the advantage of higher stability, independence of the PV cell type or anti-reflection coating, and better availability and price of recalibration.

SR05 series is an economical range of ISO 9060 second class pyranometers for measurement of solar radiation received by a plane surface, in W/m^2, from a 180 ° field of view angle. SR05 is perfect for predicting generated power and monitoring the overall efficiency of PV power plants. Different mounting options are available, allowing SR05 to be mounted in virtually any situation. The combination of easy installation and its low cost makes SR05 the preferred solution for commercial scale PV systems.

There are several versions of SR05 series:

* 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

and:
* Version SR05-D1A3-PV: digital sensor with Modbus over RS-485, alternative for PV reference cell

This user manual covers use of SR05-D1A3-PV. Specifications of this version differ from those of the other digital and analogue sensors in the SR05 series range. For use of SR05-D1A3 or SR05-D2A2, consult the separate SR05-D1A3 & SR05-D2A2 user manual. For use of SR05-A1, offering analogue millivolt output, consult the separate SR05-A1 user manual.

Figure 0.1 *SR05-D1A3-PV digital second class pyranometer seen from above*

Model SR05-D1A3-PV has a digital output that is identical to the most commonly used photovoltaic reference cell with Modbus over RS-485 output. This allows for easy installation in existing PV monitoring systems, without the need to make major modifications to data logging software, instrument libraries and infrastructure.

Compared to silicon reference cells, pyranometers offer several advantages such as a perfect (cosine) directional response and a flat spectral response over a wide range. Pyranometers therefore measure *the maximum available resource* and are suitable to act as a reference for all types (for example amorphous, crystalline or thin-film) of photovoltaic cells both with and without anti-reflection coating. See also our Application note *"pyranometers versus PV reference cells".* Moreover, since the working principle of a pyranometer is different from a solar cell, the pyranometer offers a truly independent measurement of the irradiance.

PV system performance monitoring: compliant with IEC 61724-1, Class C

IEC 61724-1: Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis – suggests to use pyranometers for PV monitoring; SR05 complies with IEC 61724-1 class C system requirements.

Features and benefits of SR05-D1A3-PV

- higher stability than PV reference cells
- independent of PV cell type
- affordable calibration
- register structure and content identical to most common reference cells for easy exchangeability
- easy implementation and servicing
- easy mounting and levelling
- pricing: affordable second class pyranometers

Figure 0.2 *Two SR05-D1A3-PV digital second class pyranometers, of which one measuring in Plane of Array, replacing PV reference cells*

SR05-D1A3-PV design

SR05 pyranometers employ a thermopile sensor with black coated surface, one dome and an anodised aluminium body with visible bubble level. Optionally the sensor can be delivered with a unique ball levelling mechanism and tube mount or dedicated mounting fixture, for easy installation. SR05-D1A3-PV has an industry standard digital output: Modbus RTU over half-duplex RS-485, that allows multiple sensors to be installed on a single network. In addition, SR05-D1A3-PV has analogue 0 to 1 V output.

Figure 0.3 *On the left SR05-D1A3-PV pyranometer with bubble level and M12-A cable connector in its standard configuration (3 metre cable standard included); on the right SR05 with optional ball levelling, for easy mounting and levelling on (non-)horizontal surfaces (included mounting bolts not displayed)*

Figure 0.4 *SR05-D1A3-PV digital second class pyranometer with optional ball levelling and tube mount for easy mounting and levelling on a tube (tube not included)*

Communication with a PC: Hukseflux Sensor Manager Software

For communication between a PC and SR05-D1A3-PV('s), the Hukseflux Sensor Manager software can be used. It is available for download on our website. The software allows the user to quickly configure SR05-D1A3-PV Modbus address and serial communication settings (baud rate, parity and stopbits) and to plot and export data. Also, the digital outputs may be viewed for sensor diagnostics.
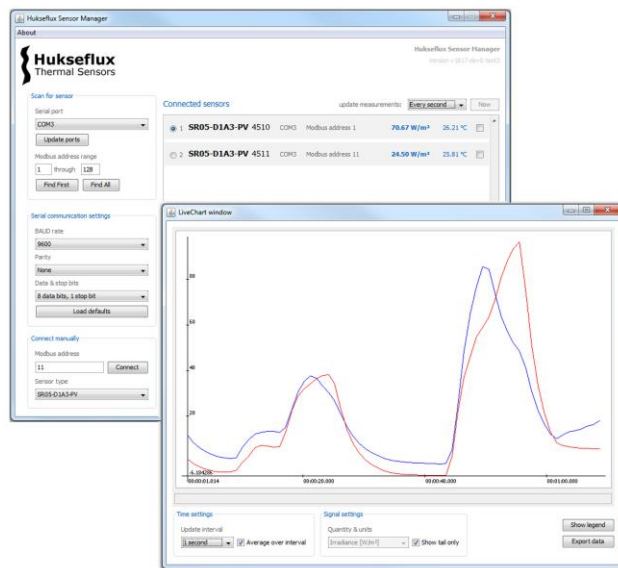
Figure 0.5 *User interface of the Hukseflux Sensor Manager*

Compatibility

SR05-D1A3-PV's Modbus interface is exchangeable with IMT-Solar Si-RS485TC-T-MB PV reference cell's interface. Other reference cells upon request.

Suggested use for SR05-D1A3-PV

- replacement of PV reference cells
- measuring global tilted irradiance (GTI) in the Plane of Array (PoA) of solar panels
- measuring global horizontal irradiance (GHI)

SR05-D1A3-PV is suited for use in SCADA (Supervisory Control And Data Acquisition) systems, supporting Modbus RTU (Remote Terminal Unit) protocol over RS-485. In these networks the sensor operates as a slave. Using SR05-D1A3-PV in a network is easy. Once it has the correct Modbus address and communication settings and is connected to a power supply, the instrument can be used in RS-485 networks. A typical network will request the irradiance (either register 0x0000 or registers 0x1002 + 0x1003) and temperature data (either register 0x0007 or register 0x1006) every 1 second, and eventually store the averages every 60 seconds. How to issue a request, process the register content and convert it to useful data is described in the paragraphs about network communication. The user should have sound knowledge of the Modbus communication protocol when installing sensors in a network. When using the analogue 0 to 1 V output provided by SR05-D1A3-PV, the instrument can be connected directly to commonly used datalogging systems capable of handling a 0 to 1 V signal.

The recommended calibration interval of pyranometers is 2 years. The registers containing the applied sensitivity and the calibration history of the digital versions of SR05 are accessible for users with a password. This allows the user to choose his own local calibration service. The same register access may also be used for remotely controlled re-calibration of pyranometers in the field. Ask Hukseflux for information on this feature and on ISO and ASTM standardised procedures for field calibration.

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 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 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.

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

See also
- view our complete range of sensors
- PMF01 pyranometer mounting fixture, compatible with SR05 ball levelling

1 Ordering and checking at delivery

1.1 Ordering SR05-D1A3-PV

SR05-D1A3-PV second class pyranometer has a digital output that is identical to the most commonly used photovoltaic reference cell with Modbus over RS-485 output.

Besides SR05-D1A3-PV, SR05 series offers several other versions with industry standard outputs, both digital and analogue. Each version offers multiple mounting options and various cable lengths:

- SR05-D1A3 digital second class sensor, with Modbus over RS-485 and 0-1 V output[1]
- SR05-D2A2 digital second class sensor, with Modbus over TTL and 4-20 mA output
- SR05-A1 analogue second class pyranometer with millivolt output

[1] This is our standard Modbus model which is not directly exchangeable with the commonly used PV reference cells.

For an overview of all versions and options, and how to order, please take a look at Table 1.1.1 on the next page.

The standard configuration of SR05-D1A3-PV is with 3 metres cable length.
Common options for SR05-D1A3-PV are:

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

Ball levelling and tube mount are suited for retrofitting.

SR05-D1A3-PV's Modbus interface is exchangeable with IMT-Solar Si-RS485TC-T-MB PV reference cell's interface. Other reference cells upon request.

Table 1.1.1 *Ordering codes for the versions of model SR05*

VERSIONS OF SR05 (part numbers), without cable	
SR05-D1A3-PV	digital second class pyranometer, with Modbus over RS-485 output, alternative for PV reference cell
SR05-D1A3-PV-BL	digital second class pyranometer, with Modbus over RS-485 output, alternative for PV reference cell, with ball levelling
SR05-D1A3-PV-TMBL	digital second class pyranometer, with Modbus over RS-485 output, alternative for PV reference cell, with tube mount on ball levelling
SR05-D1A3	digital second class pyranometer, with Modbus over RS-485 and 0-1 V output
SR05-D1A3-BL	digital second class pyranometer, with Modbus over RS-485 and 0-1 V output, with ball levelling
SR05-D1A3-TMBL	digital second class pyranometer, with Modbus over RS-485 and 0-1 V output, with tube mount on ball levelling
SR05-D2A2	digital second class pyranometer, with Modbus over TTL and 4-20 mA output
SR05-D2A2-BL	digital second class pyranometer, with Modbus over TTL and 4-20 mA output, with ball levelling
SR05-D2A2-TMBL	digital second class pyranometer, with Modbus over TTL and 4-20 mA output, with tube mount on ball levelling
SR05-A1	analogue second class pyranometer, with millivolt output
SR05-A1-BL	analogue second class pyranometer, with millivolt output, with ball levelling
SR05-A1-TMBL	analogue second class pyranometer, with millivolt output, with tube mount on ball levelling

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

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-D1A3-PV
- cable of the length as ordered
- product certificate matching the instrument serial number

For SR05-D1A3-PV-BL, also
- ball levelling
- 4 mm hex key
- 1 x shim
- 2 x M5x20 bolts
- 2 x M5 nuts

For SR05-D1A3-PV-TMBL, also
- 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

Please store the certificate in a safe place.
The Hukseflux Sensor Manager can be downloaded via www.hukseflux.com/downloads

| SR05-D1A3-PV | SR05-D1A3-PV-BL | SR05-D1A3-PV-TMBL |

Figure 1.2.1 *From left to right: SR05-D1A3-PV, SR05-D1A3-PV-BL and SR05-D1A3-PV-TMBL (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 connecting it to a PC and installing the Sensor Manager software. See the chapters on installation and PC communication for directions.

1. At power–up the signal may have a temporary output level different from zero; an offset. Let this offset settle down.
2. Check if the sensor reacts to light: expose the sensor to a strong light source, for instance a 100 W light bulb at 0.1 m distance. The signal should read > 100 W/m^2 now. Darken the sensor either by putting something over it or switching off the light. The instrument irradiance output should go down and within one minute approach 0 W/m^2.
3. Inspect the bubble level.
4. Inspect the instrument for any damage.
5. Check the instrument serial number as indicated by the software against the label on the instrument and against the certificates provided with the instrument.

2   Instrument principle and theory
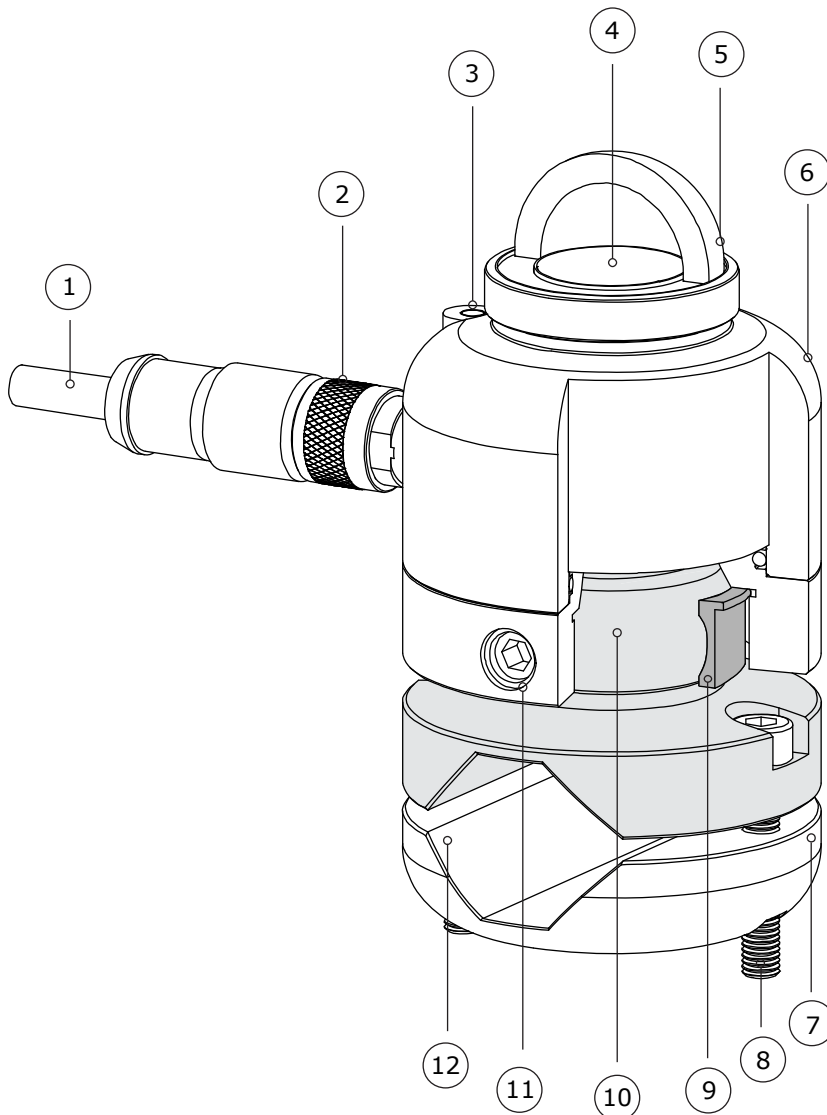
Figure 2.1 *Overview of SR05:*
shaded areas in exploded view show ball levelling mount and shim

(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 (optional)
(8)   mounting screw (included with ball levelling and tube mount; requires 4 mm hex key)
(9)   shim (included with and needed for ball levelling mount)
(10)   ball levelling mount (optional)
(11)   countersunk set screw for levelling adjustment (included with ball levelling mount; requires 4 mm hex key)
(12)   opening for Ø 25 to Ø 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 x 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 x 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 x 10^{-9} m (cutting off the part above 3000 x 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).

- The digital versions of model SR05 have a high-end 24-bit A/D converter, which is used by SR05 to convert the analogue thermopile voltage to a digital signal. SR05-D1A3-PV has a digital output that is identical to the most commonly used photovoltaic reference cell with Modbus over RS-485 output for easy exchangeability.

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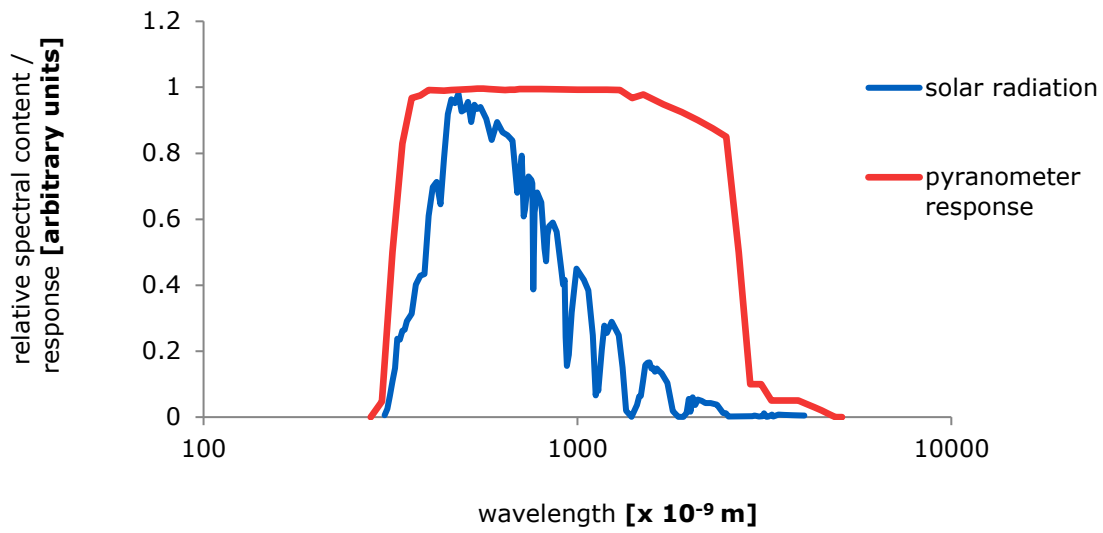
Figure 2.2 *Spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum.*

3 Specifications of SR05-D1A3-PV

3.1 Specifications of SR05-D1A3-PV

SR05 pyranometers measure 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.

SR05-D1A3-PV offers irradiance in W/m^2 as a digital output and as a 0-1 V output. It must be used in combination with suitable power supply and a data acquisition system which uses the Modbus communication protocol over RS-485 or one that is capable of handling a 0-1 V signal.

This user manual covers use of SR05-D1A3-PV. Specifications of this version differ from those of the other digital and analogue sensors in the SR05 series range. For use of SR05-D1A3 or SR05-D2A2, consult the separate SR05-D1A3 & SR05-D2A2 user manual. For use of SR05-A1, offering analogue millivolt output, consult the separate SR05-A1 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-D1A3-PV (continued on next pages)*

SR05-D1A3-PV 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-D1A3-PV (continued)*

SR05-D1A3-PV ADDITIONAL SPECIFICATIONS

Measurand	global irradiance (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
Spectral range (20 % transmission points)	285 to 3000 x 10^{-9} m
Rated operating temperature range	-40 to +80 °C
Output definition	running average over 4 last measurements, measurement every 0.1 s
Recommended data request interval	1 s, storing 60 s averages
Measurement function / optional programming for sunshine duration	programming according to WMO guide paragraph 8.2.2
Measurand	instrument body temperature
Temperature sensor	Solid state System on Chip (SoC) silicon bandgap temperature sensor
measurand in SI units	temperature in °C
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
Cable conductor cross-section	0.25 x 10^{-6} m^2 (24 AWG)
Chassis connector	M12-A straight male connector, male thread, 5-pole
Cable connector	M12-A straight female connector, female thread, 5-pole
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 including 3 m cable	0.45 kg excluding optional accessories
Net weight including 3 m cable	0.35 kg excluding optional accessories
Packaging	box of (170 x 100 x 80) mm
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
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.

Table 3.1.1 *Specifications of SR05-D1A3-PV (started on previous pages)*

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 %
Irradiance resolution	0.1 W/m² (register address 0x0000) 0.01 W/m² (register address 0x1002 + 0x1003)
Instrument body temperature resolution	0.1 °C (register address 0x0007) 0.01 °C (register address 0x1006)
Instrument body temperature accuracy	± 0.5 °C

SR05-D1A3-PV

Rated operating voltage range	5 to 30 VDC
Recommended operating voltage	12 VDC
Power consumption	< 48 x 10⁻³ W at 12 VDC

SR05-D1A3-PV: DIGITAL

Digital output	irradiance in W/m² instrument body temperature in °C
Communication protocol	Modbus over 2-wire RS-485
Transmission mode	RTU
RS-485 transceiver common mode range	-7 to +12 V
RS-485 transceiver type	2-wire, non-isolated
System requirements for use with PC	Windows 7 and later, USB or RS-232 (COM) port and connector, RS-485 / USB converter or RS-485 / RS-232 converter
Software requirements for use with PC	Java Runtime Environment 8 – latest version available free of charge at http://www.java.com, Hukseflux Sensor Manager - software version v1817 or higher
User interface on PC	Hukseflux Sensor Manager v1817 or higher software downloadable: to download and for available software updates, see http://www.hukseflux.com/page/downloads

SR05-D1A3-PV: ANALOGUE 0 TO 1 V

0 to 1 V output	irradiance in W/m²
Transmitted range	0 to 1600 W/m²
Output signal	0 to 1 V
Standard setting (see options)	0 V at 0 W/m² and 1 V at 1600 W/m²

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

Table 3.1.1 *Specifications of SR05-D1A3-PV (started on previous pages)*

Ball levelling	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 option code = BL
Tube mount with ball levelling	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 option code = TMBL
Alternative pyranometer mounting fixture	for mounting any Hukseflux pyranometer on horizontal and vertical tubes, on platforms, both horizontal and in Plane of Array order code = PMF01 PMF01 is compatible with SR05 ball levelling
Adapted transmitted range 0 to 1 V	can be adjusted at the factory upon request

3.2 Dimensions of SR05
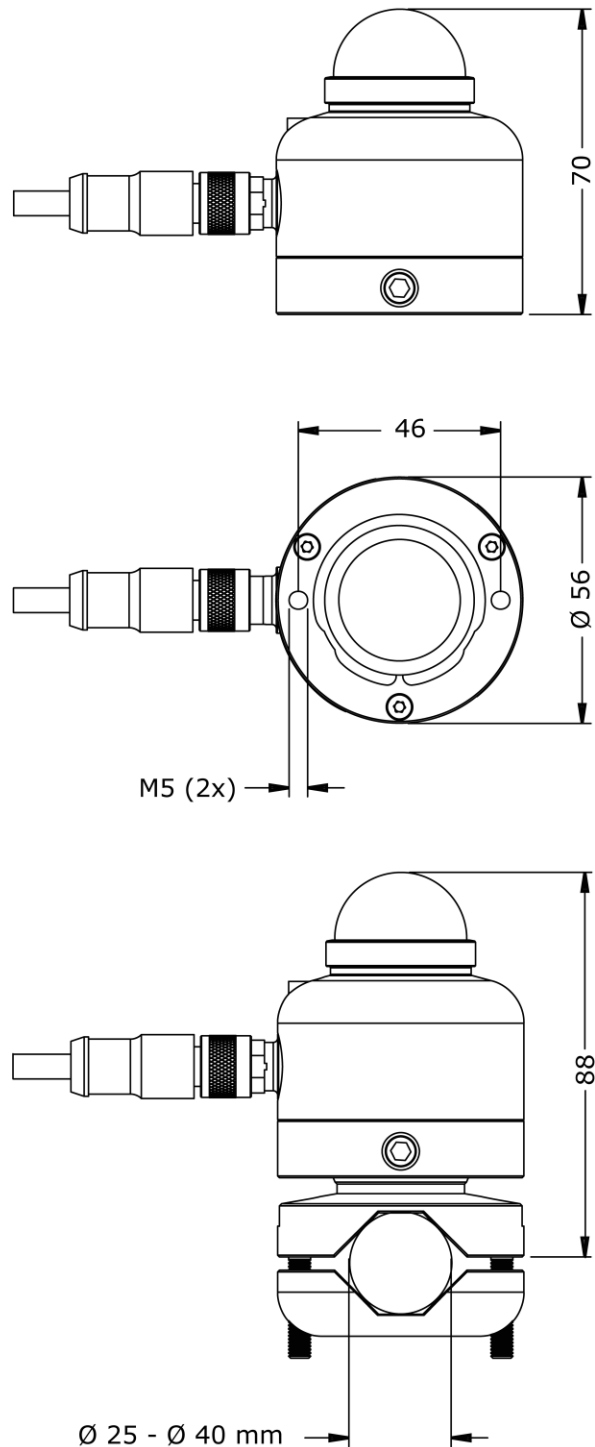
Figure 3.2.1 *Dimensions of SR05 in x 10^{-3} m. The bottom drawing shows the height of SR05 combined with its optional ball levelling mount and the tube diameter required for use with SR05's optional tube mount. M5 mounting bolts and the countersunk set screw require a 4 mm hex key for mounting and 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/m^2.

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 series is applicable in outdoor PV system performance testing. See also Hukseflux model SR15-D1 "digital first class pyranometer" and SR30-D1 "digital 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

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 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	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. with 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. with 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.
Performing a representative measurement	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. 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.
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 is recommended. Ball levelling offers:

- easy levelling
- easy cable orientation
- easy instrument exchange
- easy mounting (mounting bolts 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 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.

SR05   SR05-BL   SR05-TMBL

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 bolts 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 bolt 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 ball levelling option. These are to be used to mount SR05 with its ball levelling to a (non-)horizontal surface.

Two M5x30 bolts and two M5x40 bolts are included with SR05's tube mount with ball levelling. These bolts 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 attached to SR05. In that case follow steps 1 to 7 below to mount and level SR05. Make sure the glass dome is protected at all times.

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. See chapter 5.5 for placing SR05's ball levelling shim. When ordering SR05 combined with ball levelling, the shim is already positioned in its place in the factory.
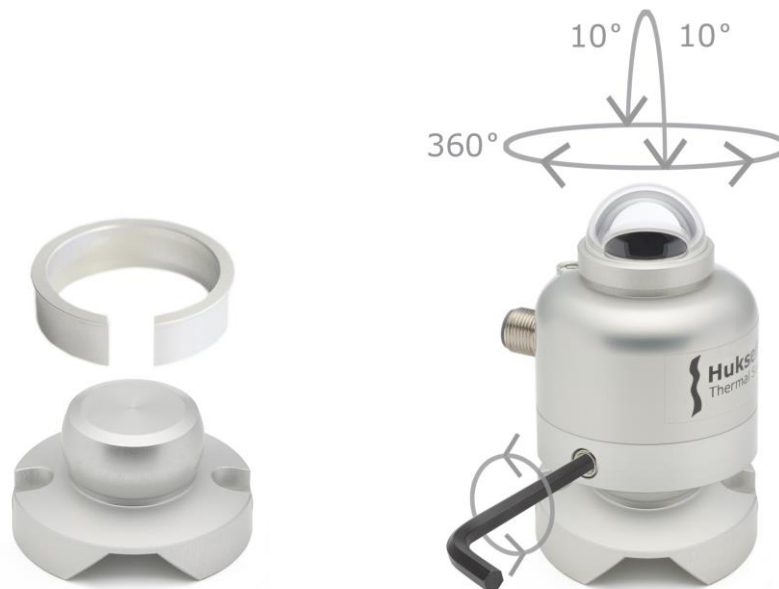
Figure 5.4.1 *On the left SR05's ball levelling including shim (mounting bolts not displayed) and on the right SR05 placed on the ball levelling mount. Loosen the countersunk set screw on SR05's side to unlock, allowing placement of the ball head and SR05 levelling, and tighten it to lock the ball head 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.*

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.

4)   Mount the ball levelling to a surface or platform with its M5 bolts and nuts. See chapter on tooling required.

5)   Place SR05 on the ball levelling mount by gently pushing the sensor onto the ball head until it clicks.

6)   SR05 can now be rotated 360 ° on its ball head by hand. This rotation allows easy cable orientation adjustment. It can be tilted up to 10 °. This allows angle compensation on non-horizontal surfaces up to 10 °.

7)   When SR05 is mounted and levelled, judging by its bubble level, lock the ball head mechanism by turning the set screw clockwise with the 4 mm hex key until it is tightened. SR05 is now locked in its position.

A similar approach is followed when levelling SR05 on its tube mount in the field:
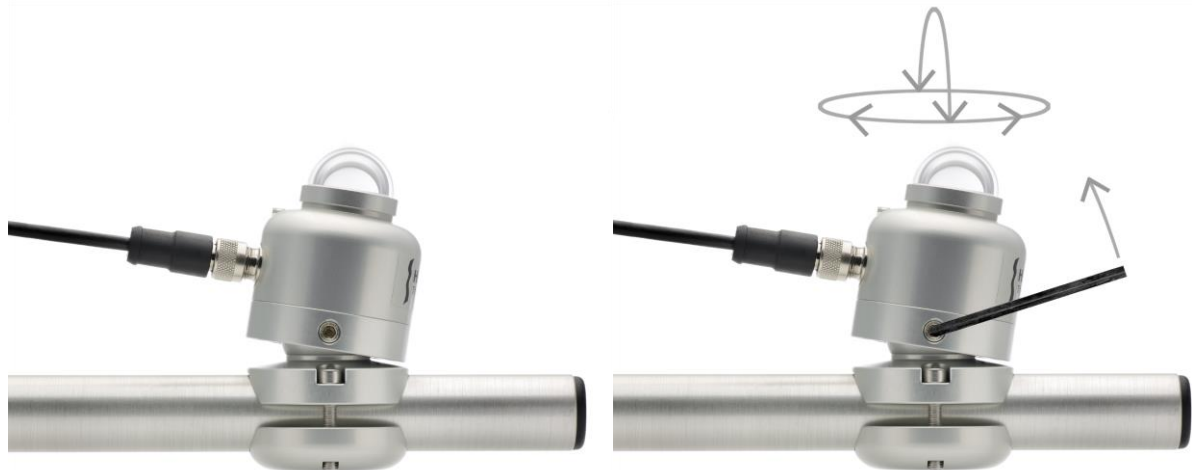
1) judge bubble level and cable orientation 2) loosen set screw to tilt and rotate SR05
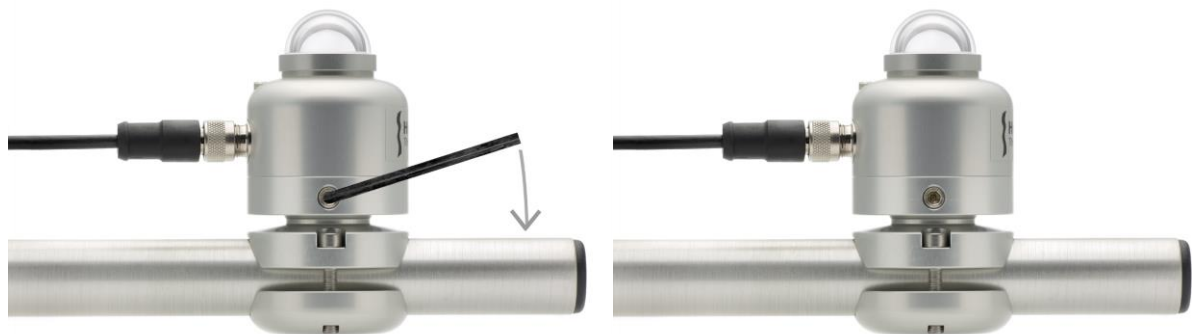
3) tighten set screw to lock ball levelling   4) SR05 is mounted and levelled

Figure 5.4.2 *Levelling steps for SR05 when mounted on tube mount with ball levelling*

When retrofitting SR05 or when ordering SR05 pyranometer and its optional ball levelling in separate orders, the user has to ensure a shim is placed properly in the centre of the bottom plate of SR05. The shim allows smooth levelling. Read the following chapter on placing and removing the shim. When ordering SR05 combined with ball levelling, the shim is already positioned in its place in the factory.

5.5 Placing and removing SR05's ball levelling shim

Only when ordering SR05 pyranometer and its optional ball levelling separately 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. When ordering SR05 combined with ball levelling the shim is already positioned in its place in the factory. 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 ball levelling mount separately.
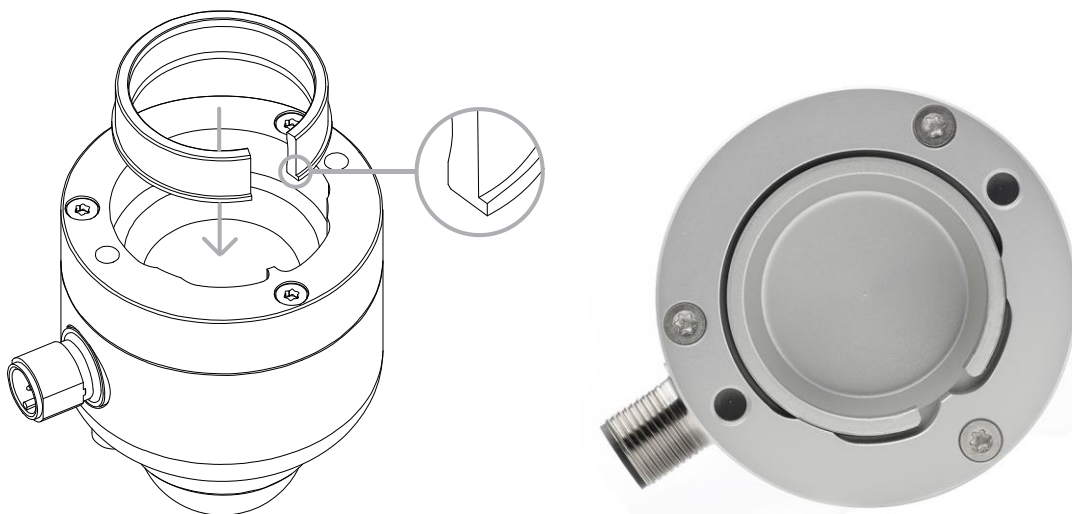
Figure 5.5.1 *Line drawing indicating placement of the aluminium shim and photo showing the shim properly positioned in the centre of SR05's bottom plate. Note the position of the protruding ledge when placing the shim.*

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. For mounting and levelling, continue with the following steps:

6)   Mount the ball levelling with its mounting bolts.

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).

When the 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.

5.6 Electrical connection of SR05-D1A3-PV: wiring diagram

The instrument must be powered by an external power supply, providing an operating voltage in the range from 5 to 30 VDC. SR05-D1A3-PV offers irradiance in W/m^2 as a digital output (Modbus over RS-485) and as an analogue 0 to 1 V output.

This user manual covers use of SR05-D1A3-PV. Specifications of this version differ from those of the other digital and analogue sensors in the SR05 series range. For use of SR05-D1A3 or SR05-D2A2, consult the separate SR05-D1A3 & SR05-D2A2 user manual. For use of SR05-A1, offering analogue millivolt output, consult the separate SR05-A1 user manual.

Table 5.6.1 *Wiring diagram of SR05-D1A3-PV*

PIN	WIRE	SR05-D1A3-PV Modbus over RS-485	SR05-D1A3-PV 0 to 1 V output
1	Brown	VDC [+]	VDC [+]
4	Black	VDC [−]	VDC [−]
3	Blue	not connected	0 to 1 V output
2	White	RS-485 B / B' [+]	not connected
5	Grey	RS-485 A / A' [−]	not connected
	Yellow	shield	shield

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

5.7 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 bolted 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 earth ground at the cable end. This is typically the ground or low voltage of the power supply or the common of the network. 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.

5.8 Using SR05-D1A3-PV's digital output

SR05-D1A3-PV can be read out either via its digital output or via its analogue output. When opting for the analogue output, please refer to the next section. This section describes how to use the digital output. When using SR05's digital output, SR05-D1A3-PV can be connected to an RS-485 network. How to communicate with SR05, and the Modbus protocol, is described in chapter 6.

5.8.1 Connecting SR05-D1A3-PV to an RS-485 network

SR05-D1A3-PV is suited for a two-wire (half-duplex) RS-485 network. In such a network SR05-D1A3-PV acts as a slave, receiving data requests from the master. An example of the topology of an RS-485 two-wire network is shown in the figure below. SR05-D1A3-PV is powered from 5 to 30 VDC. The power supply is not shown in the figure. The VDC [-] power supply ground must be connected to the common line of the network.
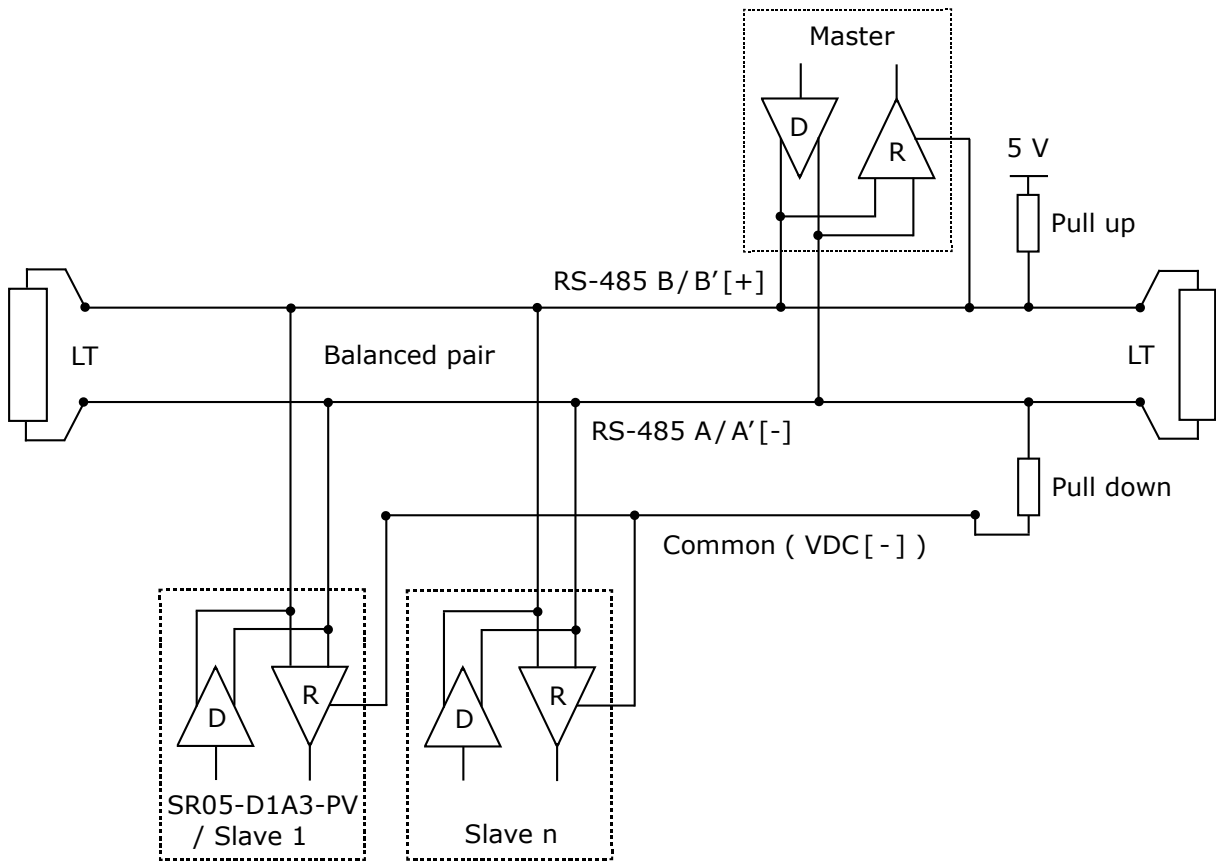
Figure 5.8.1.1 *Typical topology of a two-wire RS-485 network, figure adapted from: Modbus over serial line specification and implementation guide V1.02 (www.modbus.org). The power supply is not shown in this figure.*

After the last nodes in the network, on both sides, line termination resistors (LT) are required to eliminate reflections in the network. According to the EIA/TIA-485 standard, these LT have a typical value of 120 to 150 Ω. Never place more than two LT on the network and never place the LT on a derivation cable. To keep the RS-485 bus in a well

defined state when no transmission is occurring, a pull up and pull down resistor are recommended. Typical values for both resistors are in the range from 650 to 850 Ω.
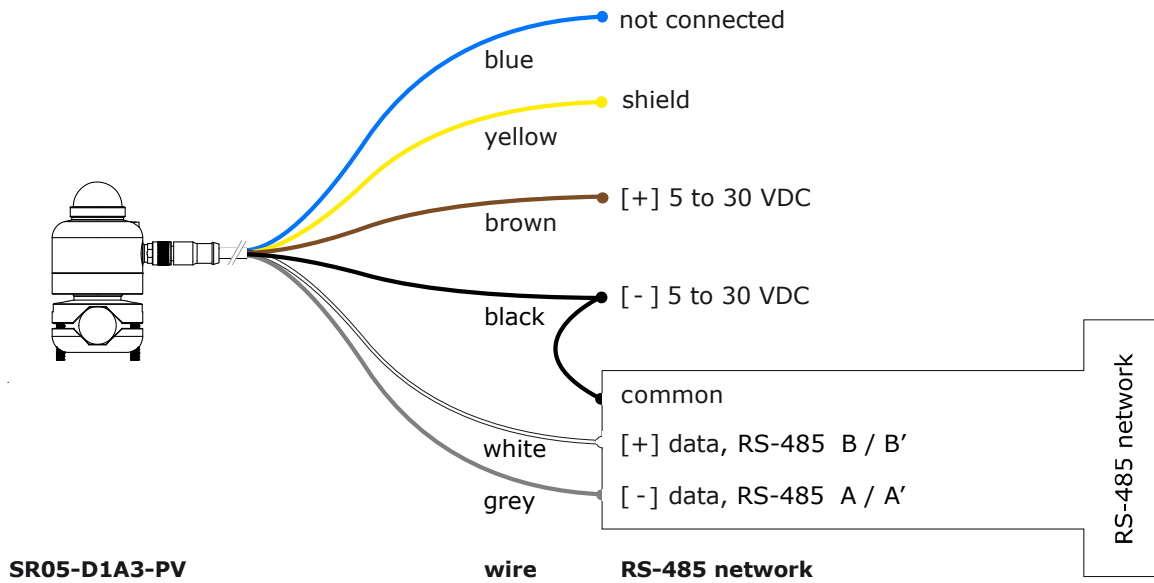
Figure 5.8.1.2 *Connection of SR05-D1A3-PV to an RS-485 network. SR05-D1A3-PV is powered by an external power supply of 5 to 30 VDC.*

5.8.2 Connecting SR05-D1A3-PV to a PC

SR05-D1A3-PV can be accessed via a PC. In that case communication with the sensor can be done via the user interface offered by the Sensor Manager software (see the next chapters) or by any other Modbus testing tool.

Depending on the available ports on the PC, either an RS-485 to USB converter or an RS-485 to RS-232 converter is used. The figure below shows how connections are made. The converter must have galvanic isolation between signal input and output to prevent static electricity or other high-voltage surges to enter the data lines. An external power supply is required to power the SR05-D1A3-PV (5 to 30 VDC). An RS-485 to USB converter is usually powered via the USB interface in which case no external power is needed to feed the converter. If an RS-485 to RS-232 converter is used the converter may need an external power source. This may be the same supply used for the SR05-D1A3-PV.
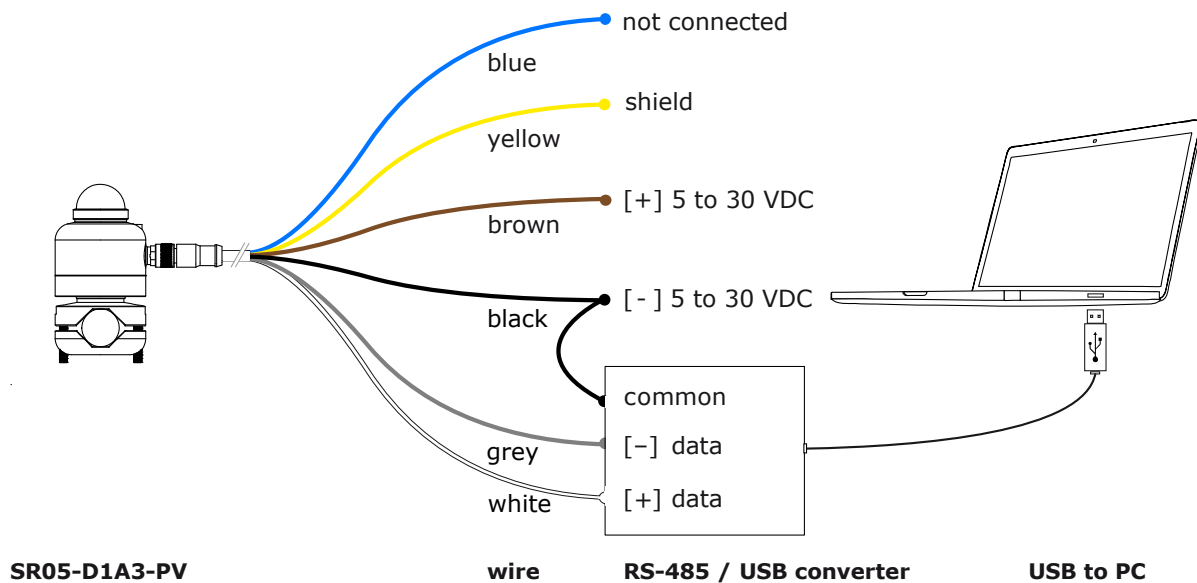
Figure 5.8.2.1 *Connecting SR05-D1A3-PV to an RS-485 to USB converter and a PC*

5.9   Using SR05-D1A3-PV's analogue 0 to 1 V output

SR05-D1A3-PV gives users the option to use 0 to 1 V output instead of its digital output. This section explains how to use the 0 to 1 V output. When opting solely for SR05-D1A3-PV's digital output, please refer to section 5.8.

Using the 0 to 1 V output provided by SR05-D1A3-PV is easy. The instrument can be connected directly to commonly used datalogging systems. The irradiance, E, in W/m^2 is calculated by measuring the SR05-D1A3-PV output, a voltage U, in V, and then multiplying by the transmitted range r. The transmitted range is provided with SR05-D1A3-PV on its product certificate. By convention 0 W/m^2 irradiance corresponds with 0 V transmitter output voltage. The transmitted range, which is the irradiance at output voltage of 1 V, and is typically 1600 W/m^2. The transmitted range can be adjusted at the factory upon request.

The central equation governing SR05-D1A3-PV is:

E = r·U   (Formula 5.9.1)

The standard setting is: E = 1600·U. See chapter 5.5 and the diagram below for electrical connections to voltmeters, when using SR05-D1A3-PV's 0 to 1 V output.
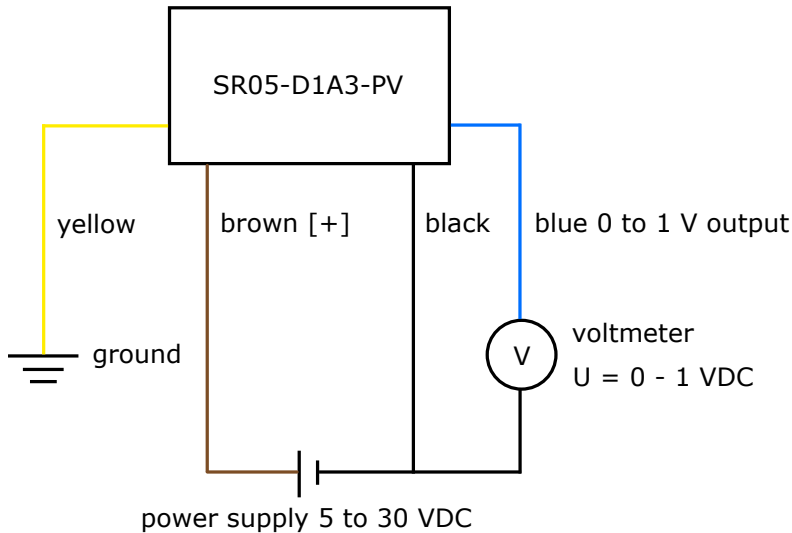
Figure 5.9.1 *Electrical diagram of the connection of SR05-D1A3-PV to a typical voltmeter or datalogger with the capacity to measure voltage signals. SR05-D1A3-PV operates on a supply voltage of 5 to 30 VDC.*

6 Communication with SR05

SR05-D1A3-PV has a Modbus output that is compatible with the IMT-Solar Si-RS485-TC-T-MB silicon reference cell: most of the Modbus functionality of the silicon reference cell is also supported by SR05-D1A3-PV. This makes it easy to install SR05-D1A3-PV in existing photovoltaic monitoring systems without the need to make major modifications to the datalogging software or infrastructure.

In addition to the silicon reference cell compatible Modbus output, our standard Hukseflux Modbus registers are available with an offset in the register address.

6.1 PC communication: Sensor Manager software

The digital SR05 series can be accessed via a PC. In that case the communication with the sensor is done via the user interface offered by the Hukseflux Sensor Manager software or by another Modbus testing tool. The Sensor Manager can be downloaded by the user via www.hukseflux.com/downloads. Alternatively, there are links to testing tools, paid or freeware, available at www.modbus.org.
This chapter describes the functionality of the Sensor Manager only.

The Hukseflux Sensor Manager software provides a user interface for communication between a PC and SR05. It allows the user to locate, configure and test one or more SR05's and to perform simple laboratory measurements using a PC. The Sensor Manager's most common use is for initial functionality testing and modification of the SR05 Modbus address and communication settings. It is not intended for long-term continuous measurement purposes. For available software updates of the Sensor Manager, please check www.hukseflux.com/downloads.

6.1.1 Installing the Sensor Manager

Running the Sensor Manager requires installation of the latest version of Java Runtime Environment software. Java Runtime Environment may be obtained free of charge from www.java.com. The SR05 specifications overview (Table 3.1.1) shows the system and software requirements for using a PC to communicate with SR05.

1) Download the Hukseflux Sensor Manager via www.hukseflux.com/downloads.

2) Unzip the downloaded files and copy the folder "Hukseflux Sensor Manager" to a folder on a PC. For proper installation the user should have writing rights for this file location.

3) Double-click "Hukseflux_Sensor_Manager.jar" in the folder "Hukseflux Sensor Manager". This will start up the Sensor Manager.

6.1.2 Trouble shooting during Sensor Manager installation

- When Java Runtime Environment software is not installed, a Windows message comes up, displaying "the file "Hukseflux_Sensor_Manager.jar" could not be opened". The solution is to install Java Runtime Environment on the PC and try again. Sensor Manager: main window

6.1.3 Sensor Manager: main window
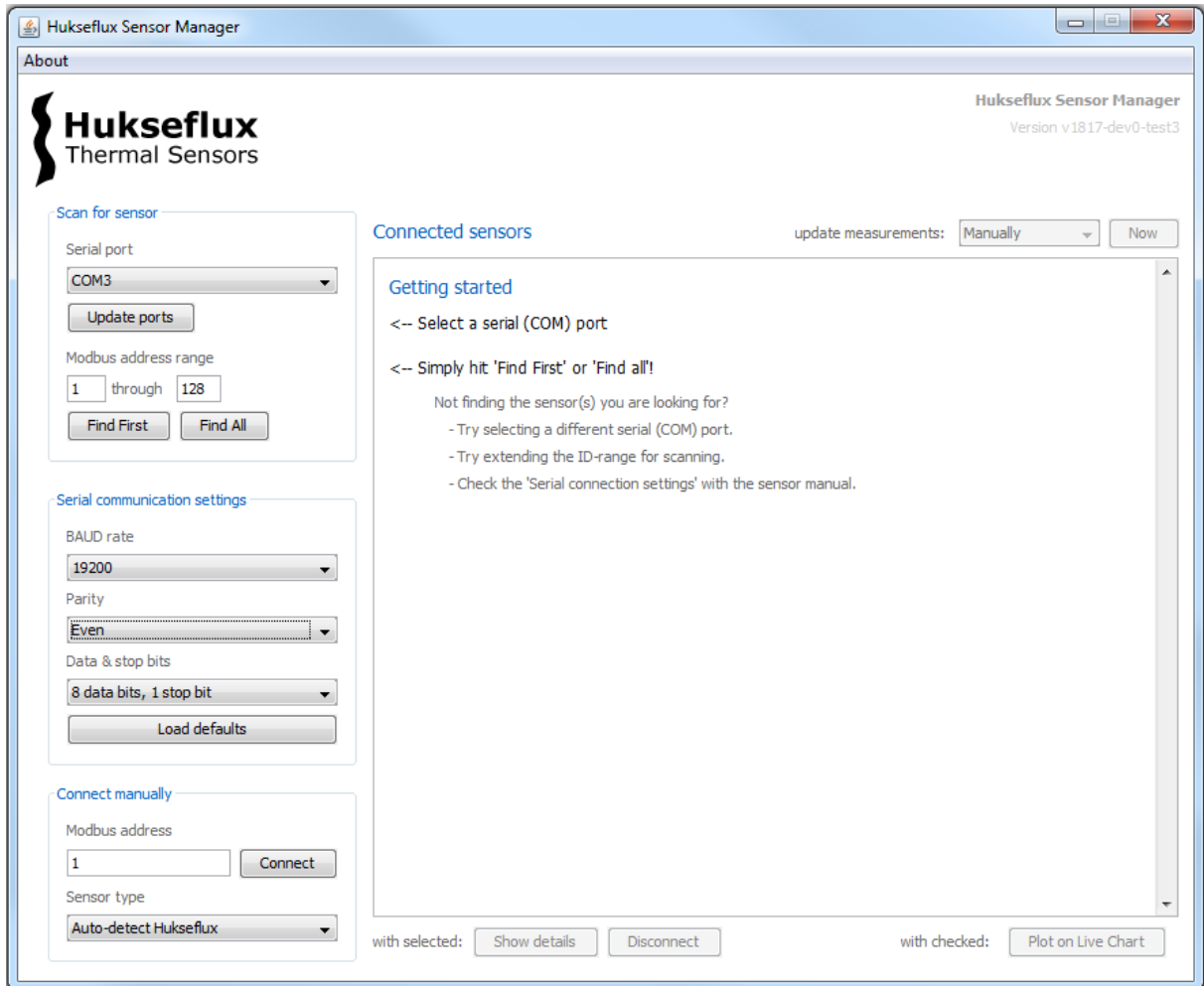
Figure 6.1.3.1 *Main window of the Sensor Manager.*

When the Sensor Manager is started and a digital SR05 is connected to the PC, the user can communicate with the instrument.

In the "Sensor type" drop down box, select model "SR05-D1A3-PV". In the "Serial communication settings" box, select the pyranometer's BAUD rate, parity and data and stop bits. In the "Modbus address" field, key in the instrument's Modbus address. Once the Modbus address is set, click "Connect" to establish contact with the instrument.

Note: the "Auto-detect Hukseflux" option in the "Sensor type" drop down box, the "Find First" button and the "Find All" button only work for standard Hukseflux sensors and will not work for model SR05-D1A3-PV.
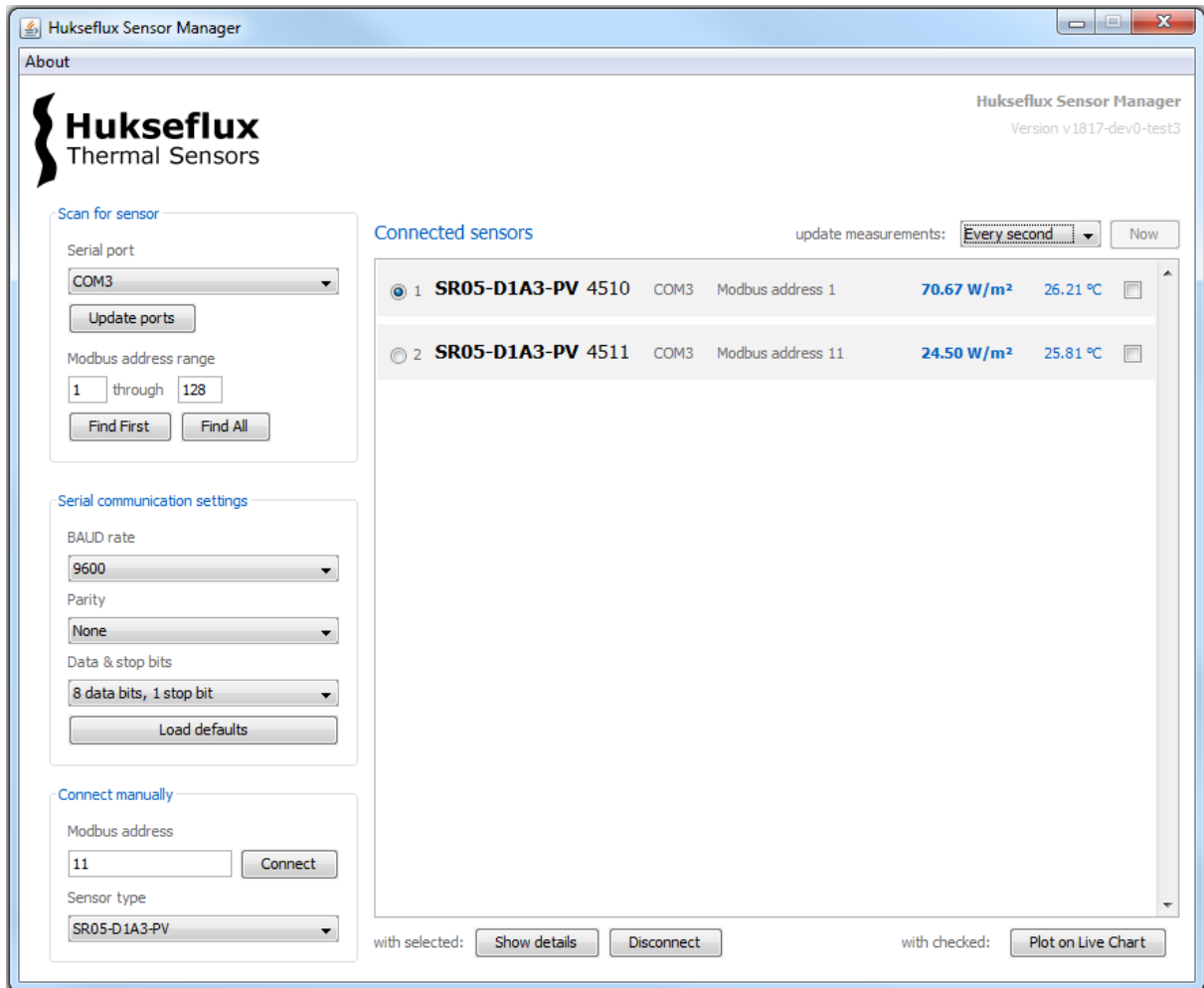
Figure 6.1.3.2 *Sensor Manager main window with two connected SR05's.*

When an instrument is found, temperature and irradiance data are displayed. Updates are done manually or automatically. Automatic updates can be made every second, every 5 seconds or every minute.

6.1.4 Sensor Manager: plotting data

When the "Plot on Live Chart" button in the lower right corner is clicked the "Plot window" opens. A live graph is shown of the measurement with the selected instrument. The x-axis, time, is scaled automatically to display data of the complete measurement period. After checking the box "Show tail only", only the last minutes of measured data are displayed. When the "update interval" is 1 second, the "Show tail only" function is

available after around 10 minutes of data collection. The y-axis displays the measured irradiance in W/m². The Y-axis automatically scales to display the full measured range.
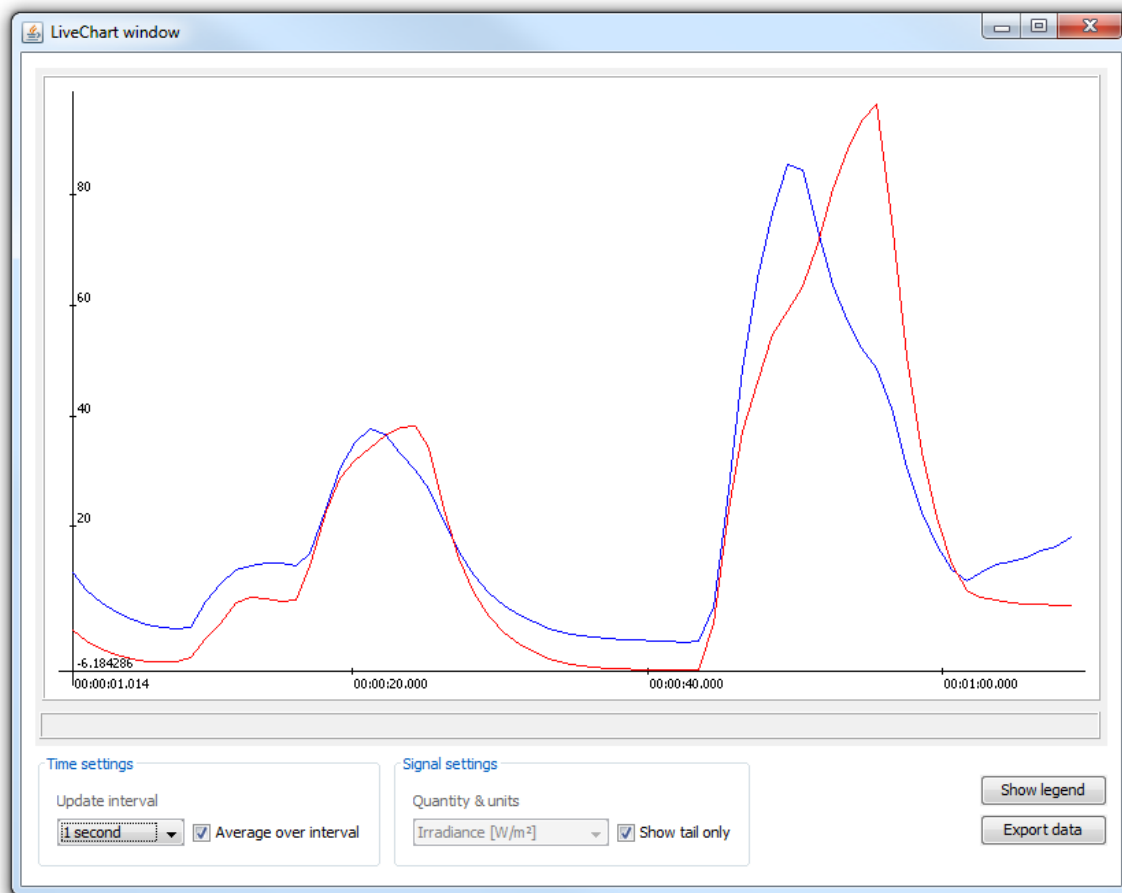
Figure 6.1.4.1 *Example of an SR05 irradiance plot in the Sensor Manager.*

6.1.5 Sensor Manager: information about the instrument

The main window shows the "Show details" button, giving access to the "Sensor details" window. This window displays calibration results and calibration history, temperature coefficients and other properties of the selected instrument, as shown on the next page. The sensor serial number and all calibration information should match the information on the instrument label and on the product certificate.
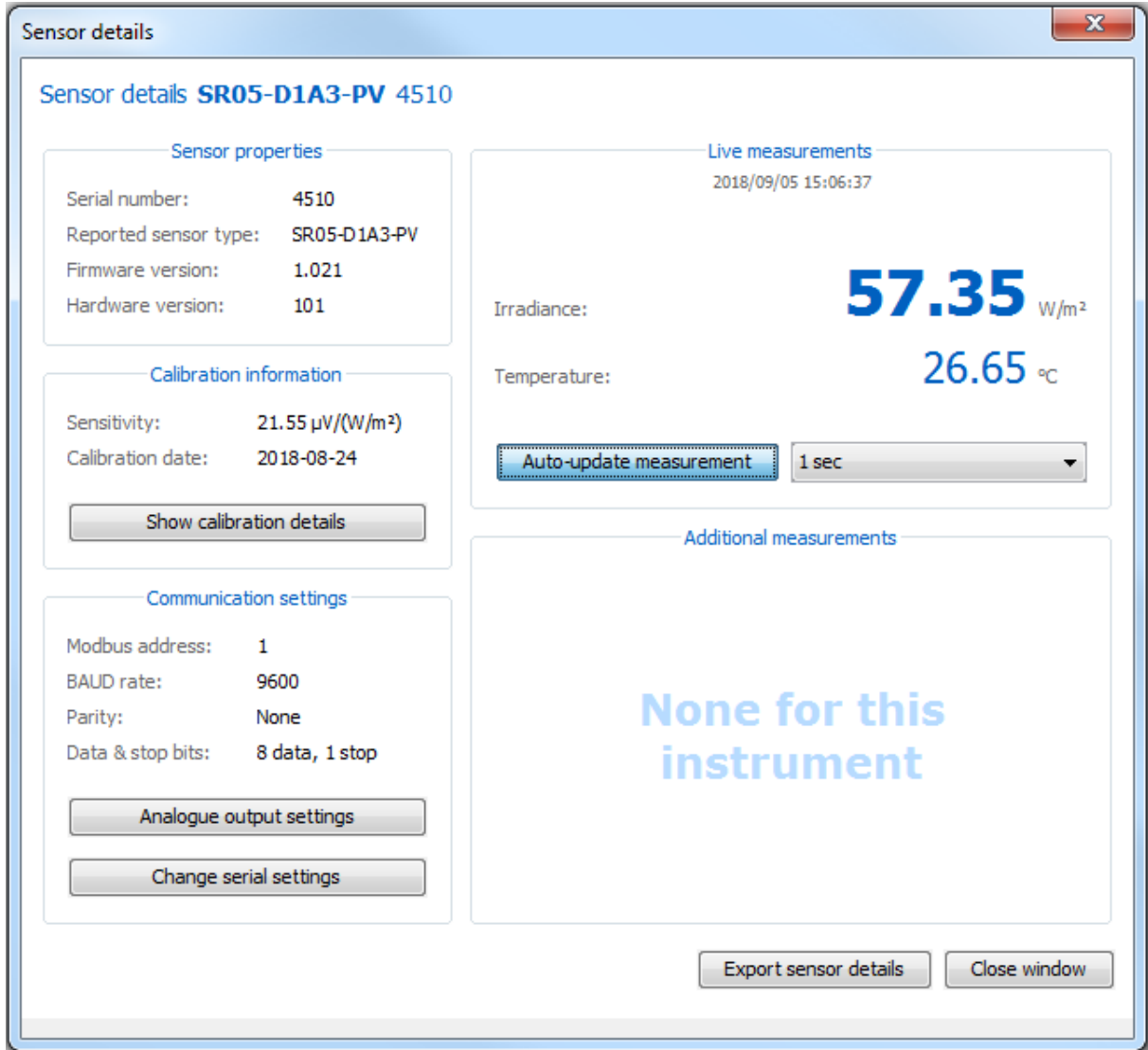
Figure 6.1.5.1 *Sensor details window in the Sensor Manager.*

6.1.6 Sensor Manager: changing Modbus address and communication settings

In the "Sensor details" window the "Change serial settings" function opens the "Change serial communication settings" window, as shown in the figure below.
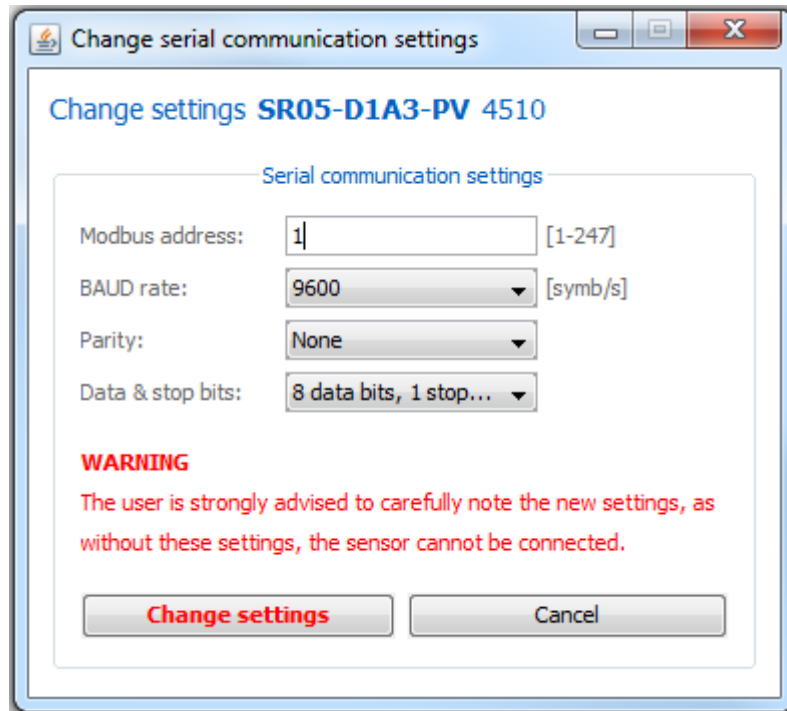
Figure 6.1.6.1 *Change serial communication settings window in the Sensor Manager*

When new communication settings or a new Modbus address are entered, these need to be confirmed by clicking "Change settings". The instrument will then automatically restart. In case the "Change settings" function is not activated, the original settings remain valid. If the Modbus address is changed, the Sensor Manager will automatically reconnect with the instrument using the new address after restart.

6.1.7 Sensor Manager: adjustment of the sensitivity by power users

The Sensor Manager does not allow a "standard user" to change any settings that have a direct impact on the instrument output, i.e. the irradiance in W/m^2. However, in case the instrument is recalibrated it is common practice that the sensitivity is adjusted, and that the latest result is added to the calibration history records. This can be done after obtaining a password and becoming a "power user". Please contact the factory to obtain the password and to get directions to become a "power user".

Example: During a calibration experiment, the result might be that SR05 has an irradiance output in W/m^2 that is 990, whereas the standard indicates it should be 970. The SR05 output is in this example 2.06 % too high. The original sensitivity of 16.15×10^{-6} V/(W/m^2) ought to be changed to 16.48, using registers 0x1029 + 0x102A. The old calibration result is recorded in the calibration history file. In case there are still older results these are moved over to higher register numbers 0x103F to 0x1051.

6.2 Network communication: function codes, registers, coils

Warning: Using the same Modbus address for more than one device will lead to irregular behaviour of the entire network. This chapter describes function codes, data model and registers used in the SR05-D1A3-PV firmware. Communication is organised according to the specifications provided by the Modbus Organization. These specifications are explained in the documents "Modbus application protocol v1.1b" and "Modbus over serial line v1.02". These documents can be acquired free of charge at www.modbus.org.

Table 6.2.1 *Supported Modbus function codes*

SUPPORTED MODBUS FUNCTION CODES	
FUNCTION CODE (HEX)	**DESCRIPTION**
0x01	Read Coils
0x02	Read Discrete Inputs
0x03	Read Holding Registers
0x04	Read Input Register
0x05	Write Single Coil
0x06	Write Single Holding Register
0x08	Diagnostics
0x0F	Write Multiple Coils
0x10	Write Multiple Registers
0x46	Communication Parameter

Note: In accordance with the Modbus application protocol specification function codes 0x01 to 0x06, 0x08, 0x0F and 0x10 belong to the category of public function codes, whereas function code 0x46 belongs to the category of user defined function codes. User defined function codes are non standard. The usage of function code 0x46 is explained in detail in section 6.3.3.

Table 6.2.2 *Modbus data model*

MODBUS DATA MODEL		
PRIMARY TABLES	**OBJECT TYPE**	**TYPE OF**
Discrete input	Single bit	R
Coil	Single bit	R/W
Input register	16 bit word	R
Holding register	16 bit word	R/W

R = read only, W = write only, R/W = read / write

The instrument does not distinguish between *discrete input* and *coil;* neither between *input register* and *holding register.*

Table 6.2.3 *Format of data*

FORMAT OF DATA	DESCRIPTION
U16	Unsigned 16 bit integer
S16	Signed 16 bit integer
U32	Unsigned 32 bit integer
S32	Signed 32 bit integer
Float	IEEE 754 32 bit floating point format
String	A string of ASCII characters

The data format includes *signed* and *unsigned* integers. The difference between these types is that a *signed* integer passes on negative values, which reduces the range of the integer by half. Up to five 16 bit registers can be requested in one request; if requesting six or more registers, multiple requests should be used.

If the format of data is a signed or an unsigned 32 bit integer, the first register received is the most significant word (MSW) and the second register is the least significant word (LSW). This way two 16 bit registers are reserved for a 32 bit integer. If the format of data is *float*, it is a 32 bit floating point operator and two 16 bit registers are reserved as well. Most network managing programs have standard menus performing this type of conversion. In case manual conversion is required, see the appendix on conversion of a floating point number to a decimal number. MSW and LSW should be read together in one request. This is necessary to make sure both registers contain the data of one internal voltage measurement. Reading out the registers with two different instructions may lead to the combination of LSW and MSW of two measurements at different points in time.

An Unsigned 32 bit integer can be calculated by the formula: $(MSW \times 2^{16}) + LSW = U32$. An example of such a calculation is available in the paragraph "Network communication: example master request to SR05".

⚠ Your data request may need an offset of +1 for each SR05 register number, depending on processing by the network master. Example: SR05 register number 7 + master offset = 7 + 1 = master register number 8. Consult the manual of the device acting as the local master.

6.3 Silicon Reference Cell compatible Modbus output

SR05-D1A3-PV has an IMT-Solar Si-RS485TC-T-MB silicon reference cell compatible Modbus output. The corresponding input registers, diagnostic function and serial communication settings are explained below.

6.3.1 Input registers (0x04)

Table 6.3.1.1 *PV reference cell compatible input registers.*

MODBUS REGISTERS 0x0000-0x0008				
REGISTER ADDRESS (HEX)	PARAMETER	DESCRIPTION OF CONTENT	TYPE OF (R/W)	FORMAT OF DATA
0x0000	Irradiance (W/m^2)	Irradiance = value/10	R	U16
0x0001	Cell temperature (˚C)	Temperature = (value-250)/10	R	U16
0x0002	External temperature (˚C)	Not available, always returns 0	R	U16
0x0003	Wind speed (m/s)	Not available, always returns 0	R	U16
0x0004	Factory use only	-	-	-
0x0005	Cell temperature (˚C)	Temperature = (value-1000)/10	R	U16
0x0006	External temperature (˚C)	Not available, always returns 0	R	U16
0x0007	Cell temperature (˚C)	Temperature = value/10	R	S16
0x0008	External temperature (˚C)	Not available, always returns 0	R	S16

6.3.2 Diagnostics (0x08)

Diagnostic subfunction codes supported by SR05-D1A3-PV are listed in Table 6.3.2.1

Table 6.3.2.1 *Diagnostic subfunction codes supported by SR05-D1A3-PV*

DIAGNOSTIC SUBFUNCTION CODES			
SUB FUNCTION CODE	NAME	DATA	COMMENT
0x0000	Return query data	Any	
0x0001	Restart communications option	0x0000 or 0xFF00	
0x0004	Force listen only mode	0x0000	
0x000A	Clear counters	0x0000	
0x000B	Bus message count	0x0000	Only counts messages for this device
0x000C	Checksum error count	0x0000	
0x000D	Error exception count	0x0000	
0x000E	Slave message count	0x0000	
0x000F	Slave no response count	0x0000	Not available, always returns 0
0x0010	Slave NAK count	0x0000	Not available, always returns 0
0x0011	Slave busy count	0x0000	Not available, always returns 0
0x0012	Bus overrun count	0x0000	

6.3.3 Serial communication settings (0x46)

Function code 0x46 allows the user to set the device address and to read and write the serial settings. This section gives a description of the usage of function code 0x46 with sub function codes 0x04, 0x05 and 0x06.

Sub function 0x04: write device address
Sub function code 0x04 is used to change the device address. Upon sending the Modbus request SR05-D1A3-PV will echo the Modbus request. Note that the new device address will only take effect after the device has been reset (see diagnostic function code 0x08, sub function 0x01).

Modbus request:
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x04
New device address	1 Byte	1 to 247
Checksum	2 Byte	CRC16

Reply
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x04
New device address	1 Byte	1 to 247
Checksum	2 Byte	CRC16

Sub function 0x05: read serial communication settings
Sub function code 0x05 is used to read the serial communication settings such as the baud rate and the bit frame.

Modbus request:
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x05
Checksum	2 Byte	CRC16

Reply
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x05
Baud rate	1 Byte	0 to 4, see table 6.3.3.1
Bit frame	1 Byte	0 to 3, see table 6.3.3.2
Checksum	2 Byte	CRC16

Subfunction 0x06: write serial communication settings
Sub function code 0x06 is used to write the serial communication settings such as the baud rate and the bit frame. Upon sending the Modbus request SR05-D1A3-PV will echo the Modbus request. Note that the new serial communication settings will only take effect after the device has been reset (see diagnostic function code 0x08, sub function 0x01).

Modbus request:
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x06
Baud rate	1 Byte	0 to 4, see table 6.3.3.1
Bit frame	1 Byte	0 to 3, see table 6.3.3.2
Checksum	2 Byte	CRC16

Reply:
Device address	1 Byte	1 to 247
Function code	1 Byte	0x46
Sub function code	1 Byte	0x05
Baud rate	1 Byte	0 to 4, see table 6.3.3.1
Bit frame	1 Byte	0 to 3, see table 6.3.3.2
Checksum	2 Byte	CRC16

Table 6.3.3.1 *Baud rate values for function code 0x46, sub function code 0x05 and 0x06*

COMMUNICATION SETTINGS: BAUD RATES	
Value	**Baud rate**
0	1200
1	2400
2	9600
3	19200
4	38400

Table 6.3.3.2 *Bit frame values for function code 0x46, sub function code 0x05 and 0x06*

COMMUNICATION SETTINGS: BIT FRAME	
Value	**Bit frame (data bits/parity bits/stop bits)**
0	8N1
1	8N2
2	8E1
3	8O1

6.4 Standard Hukseflux Modbus Output

In addition to the IMT-Solar Si-RS485TC-T-MB silicon reference cell compatible Modbus output, SR05-D1A3-PV supports the standard Hukseflux Modbus output, but with an offset of 0x1000 in the register address as compared to SR05-D1A3:

SR05-D1A3-PV register address = SR05-D1A3 register address + 0x1000

Table 6.4.1 *Modbus registers 0x1000 to 0x100B. For basic operation, Hukseflux recommends to read out registers 0x1002 + 0x1003 for solar radiation, register 0x1006 for instrument body temperature and register 0x1028 for the sensor serial number.*

MODBUS REGISTERS 0x1000-0x100B				
REGISTER ADDRESS (HEX)	PARAMETER	DESCRIPTION OF CONTENT	TYPE OF (R/W)	FORMAT OF DATA
0x1000	Modbus address	Sensor address in Modbus network, default = 1	R/W	U16
0x1001	Serial communication settings	Sets the serial communication, default = 1	R/W	U16
0x1002 + 0x1003	Irradiance	signal in x 0.01 W/m²	R	S32
0x1004 + 0x1005	Factory use only			
0x1006	Sensor body temperature	In x 0.01 ˚C	R	S16
0x1007	Sensor electrical resistance	In x 0.1 Ω	R	U16
0x1008	Scaling factor irradiance	Default = 100	R	U16
0x1009	Scaling factor temperature	Default = 100	R	U16
0x100A + 0x100B	Sensor voltage output	In x 10^{-9} V	R	S32
0x100C to 0X101F	Factory use only			

Register 0x1000, *Modbus address,* contains the Modbus address of the sensor. This allows the Modbus master to detect the slave, SR05-D1A3-PV, in its network. The address can be changed; the value of the address must be between 1 and 247. The default Modbus address is 1.
Note: The sensor needs to be restarted before changes become effective.

Register 0x1001, *Serial communication settings*, is used to enter the settings for baud rate and the framing of the serial data transfer. Default setting is setting number 1: *9600 baud, 8 data bits, none parity and 1 stop bit*. Setting options are shown in the table below.
Note: The sensor needs to be restarted before changes become effective.

Table 6.4.2 *Serial communication setting options of register 0x1001*

SETTING OPTIONS				
SETTING NUMBER	**BAUD RATE**	**DATABITS**	**STOPBITS**	**PARITY**
1 (= default)	9600	8	1	none
2	9600	8	1	even
3	9600	8	1	odd
4	19200	8	1	none
5	19200	8	1	even
6	19200	8	1	odd
7	38400	8	1	none
8	38400	8	1	even
9	38400	8	1	odd
10	115200	8	1	none
11	115200	8	1	even
12	115200	8	1	odd
13	1200	8	1	none
14	1200	8	1	even
15	1200	8	1	odd
16	2400	8	1	none
17	2400	8	1	even
18	2400	8	1	odd
19	9600	8	2	none
22	19200	8	2	none
25	38400	8	2	none
28	115200	8	2	none
31	1200	8	2	none
34	2400	8	2	none

Register 0x1002 + 0x1003, *Irradiance,* provides the solar radiation output in 0.01 W/m². The value given must be divided by 100 to get the value in W/m². MSW and LSW should be read together in one request.

Register 0x1006, *Instrument body temperature*, provides the temperature of the instrument body in 0.01 °C. The data must be divided by 100 to achieve the value in °C.

Register 0x1007, *Sensor electrical resistance*, sensor resistance in 0.1 Ω. The data needs to be divided by 10 to get the value in Ω. This register returns a 0 by default. To read the resistance, first a measurement has to be performed. This can be done by writing 0xFF00 to coil 2. Hukseflux recommends to use this function only when necessary for diagnostics in case of sensor failure.

Register 0x1008, *Scaling factor irradiance*, default scaling factor is 100

Register 0x1009, *Scaling factor temperature*, default scaling factor is 100.

Register 0x100A + 0x100B, *Sensor voltage output*, sensor voltage output signal of the thermopile in x 10^{-9} V.

Table 6.4.3 *Modbus registers 0x1020 to 0x103E, sensor and calibration information*

MODBUS REGISTERS 0x1020-0x103E				
REGISTER ADDRESS (HEX)	PARAMETER	DESCRIPTION OF CONTENT	TYPE OF (R/W)	FORMAT OF DATA
0x1020 to 0x1023	Sensor model	Part one of sensor description	R	String
0x1024 to 0x1027	Sensor model	Part two of sensor description	R	String
0x1028	Sensor serial number		R	U16
0x1029 + 0x102A	Sensor sensitivity	In x 10^{-6} V/(W/m^2)	R	Float
0x102B	Response time	In x 0.1 s	R	U16
0x102C	Sensor resistance	In x 0.1 Ω	R	U16
0x102D	Reserved	Always 0	R	U16
0x102E + 0x102F	Sensor calibration date	Calibration date of the sensor in YYYYMMDD	R	U32
0x1030 to 0x103C	Factory use			
0x103D	Firmware version		R	U16
0x103E	Hardware version		R	U16

Registers 0x1020 to 0x1027, *Sensor model*, String of 16 characters. There are 8 registers with two ASCII encoded characters per register containing the sensor model name. The decoding is explained in Appendix 9.12 of this manual.

Register 0x1028, *Sensor serial number.*

Register 0x1029 + 0x102A, *Sensor sensitivity,* the sensitivity of the sensor in x 10^{-6} V/(W/m²). Format of data is *float.*

Register 0x102B, *Response time,* the response time of the sensor as measured in the factory in x 0.1 s. The value must be divided by 10 to get the value in s.

Register 0x102C, *Sensor electrical resistance,* returns the electrical resistance measured during the sensor calibration. The resistance is in x 0.1 Ω and must be divided by 10 to get the value in Ω.

Register 0x102E + 0x102F, *Sensor calibration date*, last sensor calibration date, from which the sensitivity in register 41 and 42 was found, in YYYYMMDD.

Register 0x103D, *Firmware version*.

Register 0x103E, *Hardware version*.

Table 6.4.4 *Modbus registers 0x103F to 0x1052, calibration history*

MODBUS REGISTERS 0x103F-0x1052				
REGISTER ADDRESS (HEX)	**PARAMETER**	**DESCRIPTION OF CONTENT**	**TYPE OF (R/W)**	**FORMAT OF DATA**
0x103F + 0x1040	Sensor sensitivity history 1	In x 10^{-6} V/(W/m^2) Default value is 0	R	Float
0x1041 + 0x1042	Calibration date history 1	Former calibration date of the sensor in YYYYMMDD Default value is 0	R	U32
0x1043 + 0x1044	Sensor sensitivity history 2	See register 0x103F + 0x1040	R	Float
0x1045 + 0x1046	Calibration date history 2	See register 0x1041 + 0x1042	R	U32
0x1047 + 0x1048	Sensor sensitivity history 3	See register 0x103F + 0x1040	R	Float
0x1049 + 0x104A	Calibration date history 3	See register 0x1041 + 0x1042	R	U32
0x104B + 0x104C	Sensor sensitivity history 4	See register 0x103F + 0x1040	R	Float
0x104D + 0x104E	Calibration date history 4	See register 0x1041 + 0x1042	R	U32
0x104F + 0x1050	Sensor sensitivity history 5	See register 0x103F + 0x1040	R	Float
0x1051 + 0x1052	Calibration date history 5	See register 0x1041 + 0x1042	R	U32

Register 0x103F to 0x1052: Only accessible for writing by Sensor Manager *power users*: *power users* can write calibration history to registers 0x103F to 0x1052. If default values are returned, no re-calibration has been written. Last calibration sensitivity and calibration date are available in register 0x1029 + 0x102A and 0x102E + 0x102F respectively.

> Please note that if your data request needs an offset of +1 for each SR05 register number, depending on processing by the network master, this offset applies to coils as well. Consult the manual of the device acting as the local master.

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Table 6.4.5 *Coils*

COILS				
COIL	**PARAMETER**	**DESCRIPTION**	**TYPE OF**	**OBJECT TYPE**
0	Restart	Restart the sensor	W	Single bit
1	Reserved			
2	Check	Measure sensor electrical resistance	W	Single bit

Coil 0, *Restart*, when 0xFF00 is written to this coil the sensor will restart. If applied, a new Modbus address or new serial settings will become effective.

Coil 2, *Check*, when 0xFF00 is written to this coil the internal electronics will measure the electrical resistance of the thermopile. After the measurement, a new value will be written into register 7. Requesting to write this coil with a high repetition rate will result in irregular behaviour of the sensor; the check must be executed as an exceptional diagnostics routine only.

6.5 Network communication: getting started

Once it has the correct Modbus address and communication settings, SR05-D1A3-PV can be connected directly to an RS-485 network and a power supply. How to physically connect a sensor as a slave in a Modbus network is shown in section 5.11: Connecting a SR05-D1A3-PV to an RS-485 network. In such a connection the sensor is powered via an external power supply of 5 to 30 VDC. When the sensor is bolted onto a grounded mounting plate, which is usually the case, the shield is not connected to ground at the cable end.

Installing a SR05-D1A3-PV in the network also requires configuring the communication for this new Modbus device. This usually consists of defining a request that can be broadcast by the master. If the SR05-D1A3-PV is not already defined as a standard sensor type on the network, contact the supplier of the network equipment to see if a library file for the SR05-D1A3-PV is available.

Typical operation requires the master to make a request of irradiance data in registers 0x1002 + 0x1003, sensor temperature in register 0x1006, and the sensor serial number in register 0x1028 every 1 second, and store the 60 second averages. The data format of register 0x1002 + 0x1003 is a signed 32 bit integer and the temperature in register 0x1006 is a signed 16 bit integer.

Up to five 16 bit registers can be requested in one request. In case six or more registers are requested in just one request, SR05-D1A3-PV will not respond. If requesting six or more registers, multiple requests should be used: SR05-D1A3-PV will respond as expected.

6.5.1 Adapting Modbus address and communication settings

Setting the instrument address and baud rate can be done in different ways:
- by connecting the sensor to the PC and using the Sensor Manager;
- by connecting the sensor to the PC and using another Modbus testing tool. There are links to different solutions available at www.modbus.org;
- by using the available network user interface software.

The Modbus address is stored in register 0x1000 and has a default value of 1. A user may change the address to a value in the range of 1 to 247. The address value must be unique in the network. The communication settings are stored in register 0x1001. The default setting is setting number 1 representing a communication with 9600 baud, no parity bit, 8 data bits and 1 stop bit. After a new address or communication setting is written the sensor must be restarted. This can be done by writing 0XFF00 to coil 0.

6.6   Network communication: example master request to SR05

Normal sensor operation consists of requesting the output of registers 0x1002 + 0x1003; the temperature compensated solar radiation. For quality assurance also the sensor serial number, register 0x1028 and the temperature in register 0x1006, are useful.

In this example a SR05-D1A3-PV has address 64. The example requests the solar radiation (temperature compensated) register 0x1002 + 0x1003, sensor serial number, register 0x1028, and the temperature of the instrument register 0x1006. The values are represented in hexadecimals.

Note: 32 bit data are represented in 2 registers. MSW and LSW should be read together in one request.

Request for solar radiation, register 2 + 3:

> Master Request:
> 0x40 0x03 0x1000 0x0004 0x4FD8
>
> 0x40 = Modbus slave address, decimal equivalent = 64
> 0x03 = Modbus function code: 0x03 Read holding registers
> 0x1000 = Starting register, the master requests data starting from register 0x1000.
> 0x0004 = Length, the number of registers the master wants to read. 4 registers
> 0x4FD8 = CRC, the checksum of the transmitted data
>
> Sensor response:
> 0x40 0x03 0x08 0x0040 0x0005 0x0001 0x7C4F 0x79DA
>
> 0x40 = Modbus slave address, decimal equivalent = 64
> 0x03 = Modbus function
> 0x08 = Number of bytes returned by the sensor. 8 bytes transmitted by the sensor
> 0x0040 = Register 0x1000; Modbus address
>   0x0005 = Register 0x1001; Serial settings, 19200 baud, 8 data bits, even parity bit, 1 stop bit
>   0x0001 = Register 0x1002; Temperature compensated signal, Most Significant Word (MSW). Decimal equivalent = 1
>   0x7C4F = Register 0x1003; Temperature compensated signal, Least Significant Word (LSW) = Decimal equivalent = 31823
>   0x79DA = CRC, the checksum of the transmitted data
>
> Together, register 0x1002 and 0x1003 are representing the temperature compensated solar radiation output measured by the SR05-D1A3-PV. The MSW is in register 0x1002 and the LSW in 0x1003. The output has to be calculated by the formula: $((MSW \times 2^{16}) + LSW)/100$. In this example the result is: $((2^{16} \times 1) + 31823)/100 = 973.59$ W/m²

Request for body temperature, register 0x1006:

Master Request:
0x40 0x03 0x1006 0x0001 0x6FDA

0x40 = Modbus Slave address
0x03 = Modbus function
0x1006 = Start register
0x0001 = Number of registers
0x6FDA = CRC

Sensor response:
0x40 0x03 0x02 0x08B1 0x43FF

0x40 = Modbus Slave address
0x03 = Modbus function
0x02 = Number of bytes
0x08B1 = Content of register 0x1006, decimal equivalent = 2225
0x43FF = CRC

Temperature = Register 0x1006 x 0.01 = 2225 x 0.01 = 22.25 °C

Register 0x1006 represents the sensors body temperature. The received data
needs to be divided by 100 to represent the correct outcome. In this example the
result is: 2225 x 0.01 = 22.25 °C

Request for serial number, register 0x1028:

Master Request:
0x40 0x03 0x1028 0x0001 0x0FD3

0x40 = Modbus slave address
0x30 = Modbus function
0x1028 = Start register
0x0001 = Number of registers
0x0FD3 = CRC

Sensor response:
0x40 0x03 0x02 0x0A 0x29 0x43 0x35

0x40 = Modbus Slave address
0x03 = Modbus function
0x02 = Number of bytes
0x0A29 = Content of register 40, decimal equivalent = 2601
0x4335 = CRC

Register 0x1028 represents the sensors serial number. In this example the serial
number is 2601.

7 Making a dependable measurement

7.1 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.

7.2 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.

7.3   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:

- 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.

7.4   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).

7.4.1 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 pyrheliometers 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 pyrheliometers: 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 pyrheliometers because it is already taken into account in the calibration process.

Table 7.4.1.1 *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 %

7.4.2 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.

8 Maintenance and trouble shooting

8.1 Recommended maintenance and quality assurance

SR05 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 8.1.1 *Recommended maintenance of SR05. If possible the data analysis and cleaning (1 and 2) should be done on a daily basis. (continued on next page)*

	INTERVAL	SUBJECT	ACTION
	MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE		
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 request "power user" status and a password at the factory permitting to write to registers holding the sensitivity and the calibration history data via the Sensor Manager
6		lifetime assessment	judge if the instrument should be reliable for another 2 years, or if it should be replaced

MINIMUM RECOMMENDED PYRANOMETER MAINTENANCE (continued)

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
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

8.2 Trouble shooting

Table 8.2.1 *Trouble shooting for SR05 (continued on next page)*

General	Inspect the instrument for any damage. Inspect if the connector is properly attached. Check the condition of the connectors (on chassis as well as the cable). Inspect if the sensor receives DC voltage power in the range of 5 to 30 VDC. Inspect the connection of the shield (typically not connected at the network side). Inspect the connection of the sensor power supply, typically the negative is connected to the network *common*.
Prepare for indoor testing	Install the Sensor Manager software on a PC. Equip the PC with RS-485 for communication with SR05-D1A3-PV. Put DC voltage power to the sensor and establish communication with the sensor. At power–up the signal may have a temporary output level different from zero; an offset. Let this offset settle down.
The sensor does not give any signal	Check if the sensor reacts to light: expose the sensor to a strong light source, for instance a 100 W light bulb at 0.1 m distance. The signal should read > 100 W/m^2 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 W/m^2. Check the data acquisition by replacing the sensor with a spare sensor with the same address.
Not able to communicate with the sensor	Check all physical connections to the sensor and try connecting to the sensor again. If communicating is not possible, try to figure out if the address and communication settings are correct. Analyse the cable performance by measuring resistance from pins to cable ends. The electrical resistance should be < 10 Ω. In case of doubt, try a new cable. Connect sensor to a PC and perform the "Find" and "Find all" operation with the Sensor Manager to locate the sensor and verify the communication settings. If all physical connections are correct, and the sensor still cannot be found, please contact the factory to send the sensor to the manufacturer for diagnosis and service.
SR05 does not respond to a request for 6 or more registers	It is not possible to request more than five 16 bit registers in one request. In case of requesting six or more registers in just one request, the sensor will not respond. If requesting six or more registers, use multiple requests: the sensor will respond as expected.
The sensor signal is unrealistically	Note that night-time signals may be negative (down to -5 W/m^2 on clear windless nights), due to zero offset a. Check if the pyranometer has a clean dome.

high or low	Check the location of the pyranometer; are there any obstructions that could explain the measurement result. Check the orientation / levelling of the pyranometer. Check the cable condition looking for cable breaks. Check the condition of the connectors (on chassis as well as the cable).
The sensor signal shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio). Check the condition and connection of the shield. Check the condition of the sensor cable. Check if the cable is not moving during the measurement. Check the condition of the connectors (on chassis as well as the cable)
The dome shows internal condensation	Arrange to send the sensor back to Hukseflux for diagnosis.

8.3 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. The registers containing the applied sensitivity and the calibration history of SR05 are accessible for users. This allows the user to choose his own local calibration service. The same feature may be used for remotely controlled re-calibration of pyranometers in the field. Ask Hukseflux for information on ISO and ASTM standardised procedures for field calibration. Request "power user" status and a password at the factory permitting to write to registers holding the sensitivity and the calibration history data via the Sensor Manager.

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 ± 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 ± 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 ± 3 %. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

8.4 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.

9   Appendices

9.1   Appendix on cable extension / replacement

The sensor cable of the SR05 series 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 is equipped with one cable. Maximum length of the sensor cable is recommended to be 40 metres. It is good practice to keep the length of the instrument as short as possible to avoid inference of the signal and keep noise at acceptable levels.

Do not use SR05's original factory-made cables with a total length of more than 40 metres.

Connector and cable specifications are summarised on the next page.

Connector and cable specifications are summarised on the next page.

Figure 9.1.1 *On the left the SR05 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 9.1.1 *Specifications for SR05 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 housing
Cable	5-wire, shielded manufacturer: Binder
Length	cables should be kept as short as possible; total cable length should be less than 40 m
Outer sheath	with specifications for outdoor use (for good stability in outdoor applications)

9.2   Appendix on tools for SR05

Table 9.2.1 *Specifications of tools for SR05*

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

9.3   Appendix on spare parts for SR05

- SR05 cable with female M12-A connector on sensor end, non-stripped on other end (3, 10, 20 m). Specify cable length
- SR05 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 bolts
- 2 x M5x30 mounting bolts
- 2 x M5x20 mounting bolts with 2 x M5 nuts
- Desiccant (silica gel, 1.0 g, in a HDPE bag)

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

9.4 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 9.4.1 *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 pyrheliometer 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 pyrheliometer	ASTM G167 - 05 Standard Test Method for Calibration of a Pyranometer Using a Pyrheliometer
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 pyrheliometers by comparison to a reference pyrheliometer	ASTM E 816 Standard Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers

9.5 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/m^2 irradiance level. During the outdoor calibration the sun is typically at 20 to 40° zenith angle, and the total irradiance at a 700 W/m^2 level.

Table 9.5.1 *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.

9.6 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 9.6.1 *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**		ºC or K		
$T\uparrow$	apparent sky temperature**		ºC 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

9.7 Appendix on ISO and WMO classification tables

Table 9.7.1 *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/m² net thermal radiation)	+ 7 W/m²	+ 15 W/m²	+ 30 W/m²
Zero offset b (response to 5 K/h in ambient temperature)	± 2 W/m²	± 4 W/m²	± 8 W/m²
Non-stability (change per year)	± 0.8 %	± 1.5 %	± 3 %
Non-linearity (100 to 1000 W/m²)	± 0.5 %	± 1 %	± 3 %
Directional response	± 10 W/m²	± 20 W/m²	± 30 W/m²
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/m²)	± 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/m²	5 W/m²	10 W/m²

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.

9.8 Appendix on definition of pyranometer specifications

Table 9.8.1 *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/m² net thermal radiation)	response to 200 W/m² 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/m²)	percentage deviation from the sensitivity at 500 W/m² due to the change in irradiance within the range of 100 W/m² to 1000 W/m². 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/m². 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 350×10^{-9} m to 1500×10^{-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/m²)	percentage deviation from the sensitivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000 W/m² 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 $\times 10^{-6}$ m range. Some pyranometers with coloured glass domes have a limited spectral range.	Hukseflux

9.9 Appendix on terminology / glossary

Table 9.9.1 *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 x 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 2 π 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 x 10^{-9} m). In case of downwelling $E_l \downarrow$ also the background radiation from the universe is involved, passing through the "atmospheric window". In case of upwelling $E_l \uparrow$, 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 x 10^{-9} m and about 99 per cent longer than 5 000 x 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 °. (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)

9.10 Appendix on floating point format conversion

For efficient use of microcontroller capacity some registers in the SR05 contain data in a *float or floating point* format. In fact, a floating point is an approximation of a real number represented by a number of significant digits (*mantissa*) and an exponent. For implementation of the floating point numbers, Hukseflux follows the IEEE 754 standard. In this example the floating point of register 0x1029 and 0x102A is converted to the decimal value it represents. In the Sensor Manager software and other Modbus tools, floating point data will be converted to decimal data automatically.

Example of the calculation of register 0x1029 + 0x102A representing a floating point for the sensitivity of the sensor, which is 15.14:

Data in register 0x1029, 16754 (MSW)
Data in register 0x102A, 15729 (LSW)
Double word:
$(MSW \times 2^{16}) + LSW$ so: $(16754 \times 2^{16}) + 15729 = 1098005873$

According to IEEE 754:
Sign bit:
$1098005873 < 2147483647$ so: sign bit = 1;
The number 2147483647 is defined by IEEE 754

Exponent:
$1098005873 / 2^{23} = 130$ (digits after the decimal point are ignored)
$130 - 127 = 3$ so: exponent = 3;
The number 127 is a constant defined by IEEE 754

Mantissa:
$130 \times 2^{23} = 1090519040$
$1098005873 - 1090519040 = 7486833$
$7486833 / 2^{23} = 0.8925$
According to IEEE 754, 1 has to be added to get mantissa
$0.8925 + 1 = 1.8925$ so: mantissa = 1.8925

Calculation of floating point:
float = sign bit x mantissa x $(2^{exponent})$ = $1 \times 1.8925 \times 2^{3} = 15.14$
so: floating point = 15.14

9.11 Appendix on function codes, register and coil overview

Table 9.11.1 *Supported Modbus function codes*

SUPPORTED MODBUS FUNCTION CODES	
FUNCTION CODE (HEX)	**DESCRIPTION**
0x01	Read Coils
0x02	Read Discrete Inputs
0x03	Read Holding Registers
0x04	Read Input Register
0x05	Write Single Coil
0x06	Write Single Holding Register
0x08	Diagnostics
0x0F	Write Multiple Coils
0x10	Write Multiple Registers
0x46	Serial communication settings

⚠️ Your data request may need an offset of +1 for each SR05 register number, depending on processing by the network master. Example: SR05 register number 7 + master offset = 7 + 1 = master register number 8. Consult the manual of the device acting as the local master.

Table 9.11.2 Modbus registers 0x0000 to 0x0008

MODBUS REGISTERS 0x0000-0x0008				
REGISTER ADDRESS (HEX)	**PARAMETER**	**DESCRIPTION OF CONTENT**	**TYPE OF (R/W)**	**FORMAT OF DATA**
0x0000	Irradiance (W/m^2)	Irradiance = value/10	R	U16
0x0001	Cell temperature (˚C)	Temperature = (value-250)/10	R	U16
0x0002	External temperature (˚C)	Not available, always returns 0	R	U16
0x0003	Wind speed (m/s)	Not available, always returns 0	R	U16
0x0004	Factory use only	-	-	-
0x0005	Cell temperature (˚C)	Temperature = (value-1000)/10	R	U16
0x0006	External temperature (˚C)	Not available, always returns 0	R	U16
0x0007	Cell temperature (˚C)	Temperature = value/10	R	S16
0x0008	External temperature (˚C)	Not available, always returns 0	R	S16

Table 9.11.3 *Modbus registers 0x1000 to 0x1052*

MODBUS REGISTERS 0x1000 – 0x1052				
REGISTER ADDRESS (HEX)	**PARAMETER**	**DESCRIPTION OF CONTENT**	**TYPE OF (R/W)**	**FORMAT OF DATA**
0x1000	Modbus address	Sensor address in Modbus network, default = 1	R/W	U16
0x1001	Serial communication settings	Sets the serial communication, default = 1	R/W	U16
0x1002 + 0x1003	Irradiance	signal in x 0.01 W/m²	R	S32
0x1004 + 0x1005	Factory use only			
0x1006	Sensor body temperature	In x 0.01 ˚C	R	S16
0x1007	Sensor electrical resistance	In x 0.1 Ω	R	U16
0x1008	Scaling factor irradiance	Default = 100	R	U16
0x1009	Scaling factor temperature	Default = 100	R	U16
0x100A + 0x100B	Sensor voltage output	In x 10^{-9} V	R	S32
0x100C to 0x101F	Factory use only			
0x1020 to 0x1023	Sensor model	Part one of sensor description	R	String
0x1024 to 0x1027	Sensor model	Part two of sensor description	R	String

MODBUS REGISTERS 0x1000 – 0x1052, continued

REGISTER ADDRESS (HEX)	PARAMETER	DESCRIPTION OF CONTENT	TYPE OF (R/W)	FORMAT OF DATA
0x1028	Sensor serial number		R	U16
0x1029 + 0x102A	Sensor sensitivity	In x 10^{-6} V/(W/m^2)	R	Float
0x102B	Response time	In x 0.1 s	R	U16
0x102C	Sensor resistance	In x 0.1 Ω	R	U16
0x102D	Reserved	Always 0	R	U16
0x102E + 0x102F	Sensor calibration date	Calibration date of the sensor in YYYYMMDD	R	U32
0x1030 to 0x103C	Factory use			
0x103D	Firmware version		R	U16
0x103E	Hardware version		R	U16
0x103F + 0x1040	Sensor sensitivity history 1	In x 10^{-6} V/(W/m^2) Default value is 0	R	Float
0x1041 + 0x1042	Calibration date history 1	Former calibration date of the sensor in YYYYMMDD Default value is 0	R	U32
0x1043 + 0x1044	Sensor sensitivity history 2	See register 0x103F + 0x1040	R	Float
0x1045 + 0x1046	Calibration date history 2	See register 0x1041 + 0x1042	R	U32
0x1047 + 0x1048	Sensor sensitivity history 3	See register 0x103F + 0x1040	R	Float
0x1049 + 0x104A	Calibration date history 3	See register 0x1041 + 0x1042	R	U32
0x104B + 0x104C	Sensor sensitivity history 4	See register 0x103F + 0x1040	R	Float
0x104D + 0x104E	Calibration date history 4	See register 0x1041 + 0x1042	R	U32
0x104F + 0x1050	Sensor sensitivity history 5	See register 0x103F + 0x1040	R	Float
0x1051 + 0x1052	Calibration date history 5	See register 0x1041 + 0x1042	R	U32

Note 1:   Up to five 16 bit registers can be requested in one request. If requesting six or more registers, use multiple requests.

⚠️ Please note that if your data request needs an offset of +1 for each SR05 register number, depending on processing by the network master, this offset applies to coils as well. Consult the manual of the device acting as the local master.

Table 9.11.4 *Coils*

COILS				
COIL	**PARAMETER**	**DESCRIPTION**	**TYPE OF**	**OBJECT TYPE**
0	Restart	Restart the sensor	W	Single bit
1	Reserved			
2	Check	Measure sensor electrical resistance	W	Single bit

9.12 Appendix on the sensor model name in the register

Table 9.12.1 *Modbus registers 0x1020 to 0x1027, sensor model name*

MODBUS REGISTERS 0x1020-0x1027				
REGISTER ADDRESS	**PARAMETER**	**DESCRIPTION OF CONTENT**	**TYPE OF**	**FORMAT OF DATA**
0x1020 to 0x1023	Sensor model	Part one of sensor description	R	String
0x1024 to 0x1027	Sensor model	Part two of sensor description	R	String

Registers 32 to 39 will return 8 numbers which can be decoded to find the sensor model name. These 8 numbers (16 bit word or two bytes) are translated to ASCII characters in the following manner. The least significant byte (LSB) of each number corresponds to the first ASCII character and the most significant byte (MSB) corresponds to the first ASCII character in this register location. The following table illustrates this encoding:

Table 9.12.1 Sensor model name encoding for SR05-D1A3-PV

REGISTER ADDRESS	0x1020	0x1021	0x1022	0x1023	0x1024	0x1025	0x1026	0x1027
Register content	0x5253	0x3530	0x442D	0x4131	0x2D33	0x5650	0x0000	0x0000
MSB	0x52	0x35	0x44	0x41	0x2D	0x56	0x00	0x00
LSB	0x53	0x30	0x2D	0x31	0x33	0x50	0x00	0x00
ASCII	SR	05	-D	1A	3-	PV		

Hukseflux
Thermal Sensors

9.13 EU declaration of conformity

$C\epsilon$

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

in accordance with the requirements of the following directive:

2011/65/EU   The Restriction of Hazardous Substances Directive
2014/30/EU   The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model: SR05-D1A3-PV
Product type: Pyranometer

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

Emission: IEC/EN 61000-6-1, Class B, RF emission requirements, IEC CISPR11
                 and EN 55011 Class B requirements
Immunity: IEC/EN 61000-6-2 and IEC 61326 requirements

Report: "EMC test SR05-DA1 v04122015.pdf", 04 December, 2015

Eric HOEKSEMA
Director
Delft
07 August, 2018