LP02

Solar Radiation sensor Compliant with ISO and WMO standards

LP02 manual version 0609

Hukseflux Thermal Sensors
http://www.hukseflux.com
e-mail: info@hukseflux.com

Hukseflux
Thermal Sensors

Warning:

Warnings and safety issues

LP02 is a passive sensor, and does not need any power.

Putting more than 12 Volt across LP02 sensor wiring can lead to permanent damage to the sensor.

Contents

List of symbols

Voltage output	U	μV
Sensitivity of the LP02	E	$\mu V/Wm^{-2}$
Time	t	s
Response time	τ	s
Temperature	T	°C
Differential temperature	ΔT	K
Electrical resistance / impedance	R_e	Ω
Solar irradiance	Φ	W/m^2
Wavelength of radiation	n	nm
Radiation sum	S	J/m^2
Directional error	-	%

Subscripts

sen	sensor property
sh	shunt resistor
new	property after modification

Introduction

LP02 is a solar radiation sensor that can be applied for most common solar radiation observations. It complies with the latest ISO and WMO standards. The scientific name of this instrument is pyranometer. LP02 is a modern alternative for the so-called “star” or “black and white” pyranometers overcoming the problem of poor stability of the white reflective paint.

LP02 serves to measure the solar radiation flux that is incident on a plane surface in W/m^2 from a 180 degrees field of view (also called global solar radiation). Working completely passive, using a thermopile sensor, LP02 generates a small output voltage proportional to this flux. Contrary to photodiode-based and “black and white” instruments LP02 has a spectrally flat response across the full solar spectrum.
Using LP02 is easy. For readout one only needs an accurate voltmeter that works in the millivolt range. To calculate the radiation level, the voltage, U, must be divided by the sensitivity; a constant, E, that is supplied with each individual instrument.

$$\Phi = U / E \qquad 0.1$$

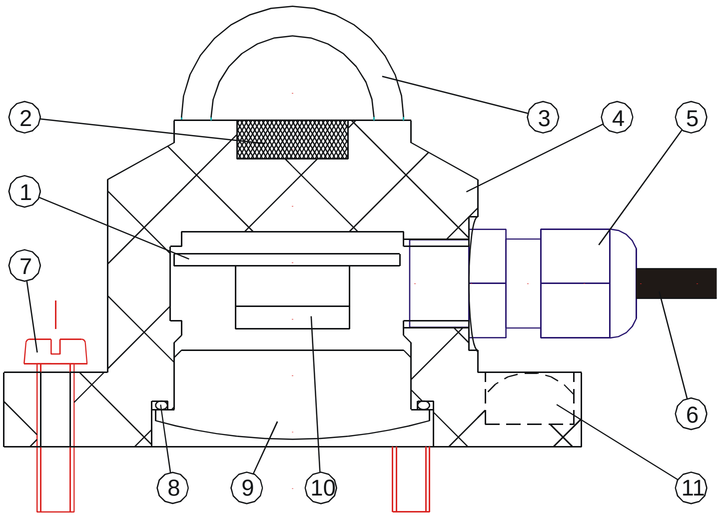

Figure 0.1 *LP02 solar radiation sensor: (1) printed circuit board, (2) sensor, (3) glass dome, (6) cable, standard length 5 m, (10) screwed cable connection, (9) access for cable connection/ replacement.*

LP02 can directly be connected to most commonly used datalogging systems. The instrument is weatherproof and complies with the CE directives.

LP02 is typically used for general meteorological observations, building physics and solar collector testing.

A common application is for outdoor solar radiation measurements as part of a meteorological station.

Apart from these most common applications, LP02 can also be used for testing of artificial light sources such as lamps emitting in the visual and near infra-red range. In addition, because of its flat spectral range it can be used under leaf canopies, or for measurement of reflected radiation using the same sensitivity figure. This application requires horizontal levelling; levelling feet (7) and a level (11) are included.

Although the most common position is horizontal, tilted or inverted mounting is also allowed.

Cable can be installed / replaced by the user using the gland (5), and screwed cable connection (10).

As an option, it is possible to adapt the sensitivity of LP02 by using so called shunt resistors. If this is necessary, the LP02 must be ordered with “trimming” option. In that case soldering pins are put on the printed circuit board. Using shunt resistors, the instrument can be “trimmed” to a certain new (always lower) sensitivity. Details are given in a special paragraph on the subject.

Applicable standards are ISO 9060 and 9847, WMO (World Meteorological Organisation), and ASTM E824-94. LP02 can also be used for stability estimations according to EPA (EPA-454/R-99-005).

Recommendation for use can be found in ISO Technical Report TR 9901 “Solar Engergy-Field pyranometers-Recommended practice for use”.

1 Checking at delivery

Arriving at the customer, the delivery should include:

- pyranometer LP02
- cable of the length as ordered
- calibration certificate matching the instrument serial number
- any other options as ordered

It is recommended to store the certificate in a safe place.

Testing the instrument can be performed by using a simple hand held multimeter.

1 Check the impedance of the sensor between the green (-) and white (+) wire. Use a multimeter at the 200 ohms range. Measure at the sensor output first with one polarity, than reverse polarity. Take the average value. The typical impedance of the wiring is 0.1 ohm/m. Typical impedance should be the typical sensor impedance of 40-60 ohms plus 1.5 ohm for the total resistance of two wires (back and forth) of each 5 meters. Infinite indicates a broken circuit; zero indicates a short circuit.
2 Check if the sensor reacts to light: put the multimeter at its most sensitive range of DC voltage measurement, typically 100 microvolt range or lower.
3 expose the sensor to strong light source, for instance a 100 Watt light bulb at 10 centimeter distance. The signal should read several millivolts now
4 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 zero mV.

More detailed installation directions and trouble shooting directions can be found in the following chapters

The programming of data loggers is the responsibility of the user. Please contact the supplier to see if directions for use with your system are available.

2 Instrument principle

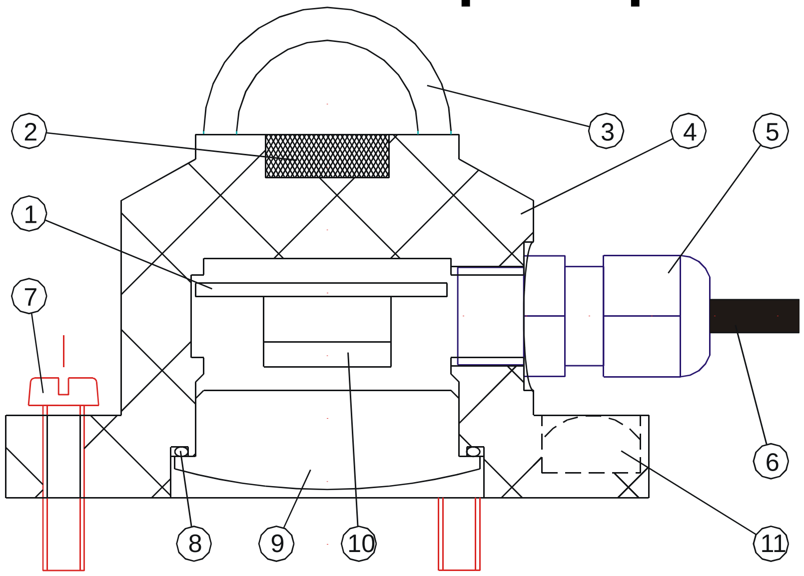

Figure 2.1: *Copy of Figure 0.1 LP02 solar radiation sensor:*

(1) printed circuit board,
(2) thermopile sensor with black coating
(3) glass dome,
(4) housing
(5) cable gland
(6) cable, standard length 5 m,
(7) levelling feet,
(8) rubber O-ring,
(9) access for cable connection/ replacement,
(10) screwed cable connection / connector block
(11) level

LP02's scientific name is pyranometer. A pyranometer is supposed to measure the solar radiation flux from a field of view of 180 degrees.
The solar radiation spectrum extends roughly from 300 to 2800 nm. It follows that a pyranometer should cover that spectrum with a spectral sensitivity that is as "flat" as possible.

For a flux measurement it is required by definition that the response to "beam" radiation varies with the cosine of the angle of incidence; i.e. full response at when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 degrees angle of incidence), zero response when the sun is at the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and 0.5 at 60 degrees angle of incidence.

It follows from the definition that a pyranometer should have a so-called “directional response” or “cosine response” that is close to the ideal cosine characteristic.

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

1 a thermopile sensor with a black coating. This sensor absorbs all solar radiation, has a flat spectrum covering the 300 to 50000 nanometer range, and has a near-perfect cosine response.
2 a glass dome. This dome limits the spectral response from 300 to 2800 nanometers (cutting off the part above 2800 nm), while preserving the 180 degrees field of view. Another function of the dome is that it shields the thermopile sensor from convection.

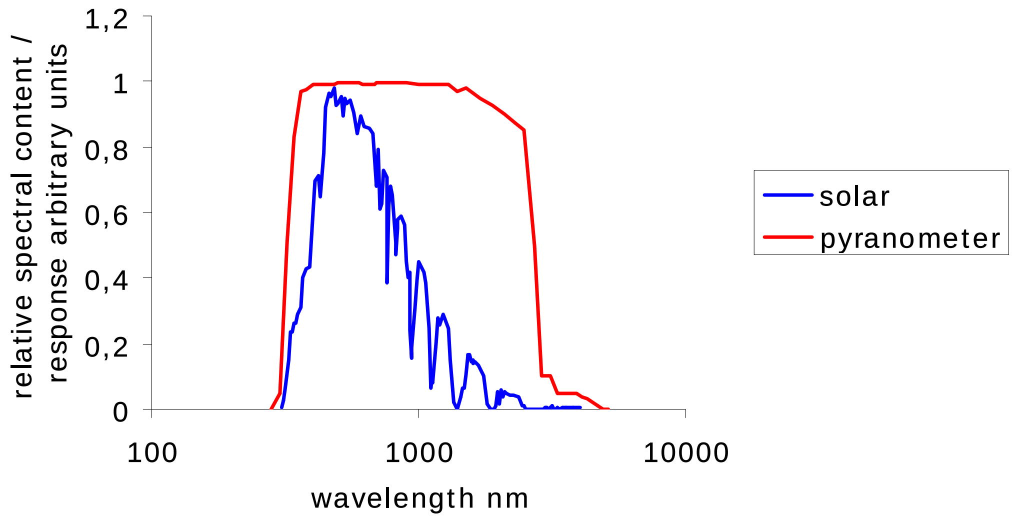

Figure 2.2 *spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum*

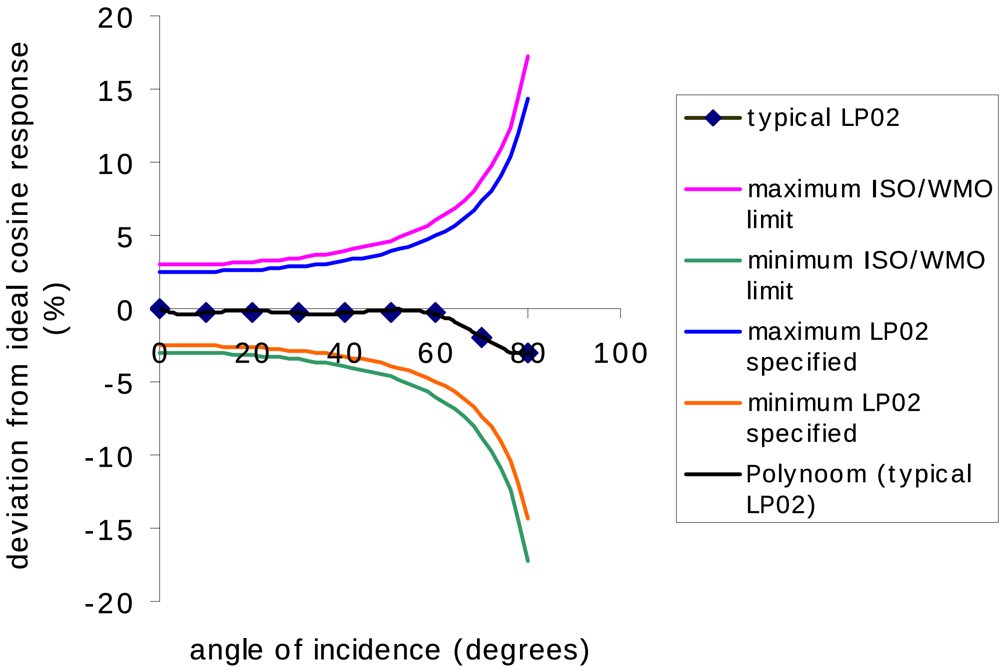

Figure 2.3 *cosine response of a typical LP02 compared to the limits allowed for second class pyranometers in the ISO 9060 standard and to the maximum tolerance as specified for LP02*

The black coating on the thermopile sensor absorbs the solar radiation. This radiation is converted to heat. The heat flows through the sensor to the LP02 housing. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.

3 Specifications of LP02

LP02 serves to measure the solar radiation flux that is incident on a plane surface in W/m^2 from a 180 degrees field of view (also called global solar radiation). Working completely passive, using a thermopile sensor, LP02 generates a small output voltage proportional to this flux. It can only be used in combination with a suitable measurement system.

LP02 ISO / WMO Specifications	
Overall classification according to ISO 9060 / WMO	Second class pyranometer
Response time for 95 % response	18 s
Zero offset a (response to 200 W/m^2 net thermal radiation)	< 15 W/m^2
Zero offset b (response to 5 k/h change in ambient temperature)	<4 W/m^2
Non-stability	< 1% change per year
Non-Linearity	< +/- 2.5%
Directional response for beam radiation:	Within +/- 25 W/m^2
Spectral selectivity	+/- 5% (305 to 2000 nm)
Temperature response (within an interval of 50 degrees C)	Within 6% (-10 to +40 degrees C)
Tilt response	Within +/- 2%

Table 3.1 *Specifications of LP02 (continued on the next page)*

LP02 ADDITIONAL MEASUREMENT SPECIFICATIONS	
Sensitivity	10-40 μV/Wm^{-2}
Expected voltage output	Application with natural solar radiation: -0.1 to + 50 mV
Operating temperature	-40 to +80 °C
Sensor resistance	Between 40 and 60 Ohms (without trimming)
Power required	Zero (passive sensor)
Standard cable length / diameter	5 meters / 5 mm
Cable gland	Accepts cable diameter from 3 to 6.5 mm
Range	To 2000 Wm^{-2}
Cable replacement	Cable can be removed and installed by the user
Spectral range	305 to 2800 nm (50% transmission points)
Required readout:	1 differential voltage channel or 1 single ended voltage channel
Levelling	Level and levelling feet included
Required programming	$\Phi = U / E$
Expected accuracy for daily sums	+/- 10%
Weight including 5 m cable	0.3 kg
CALIBRATION	
Calibration traceability	To WRR, procedure according to ISO 9847
Recommended recalibration interval	Every 2 years
OPTIONS	
Sensitivity adaptation	With soldering pins As an option the circuit board inside LP02 can be delivered with soldering pins, making it possible to add trimming resistors to adapt the LP02 sensitivity
Cable extension	Longer cables can be supplied on request. Specify additional cable length x meters (add to 5 m)
Albdometer Fixture	AMF01
Amplifiers	AC100 and AC 420
Hand Held Readout	LI18

Table 3.1 *Specifications of LP02 (started on the previous page)*

4 Installation

4.1 Installation

LP02 is usually installed horizontally, but can also be installed on a tiled plane or even in an inverted position.

In all cases it will measure the flux that is incident on the surface that is parallel to the sensor surface.

Mechanical mounting	Preferably use holes in the flange
Radiation detection	It should be avoided that there are objects between the course of the sun and the instrument, casting shadows on the instrument.
Levelling	Use the included level if mounted horizontally
Orientation	By convention with the wiring to the nearest pole (so north in the northern hemisphere, south in the southern hemisphere)
Height of installation	In case of inverted installation, a height of 1.5 meters above ground is recommended by WMO (to get good spatial averaging)

Table 4.1.1 *recommendations for installation of LP02*

In case that refelcetd radiation needs to be measured, a tyical setup is drawn in the figure below.

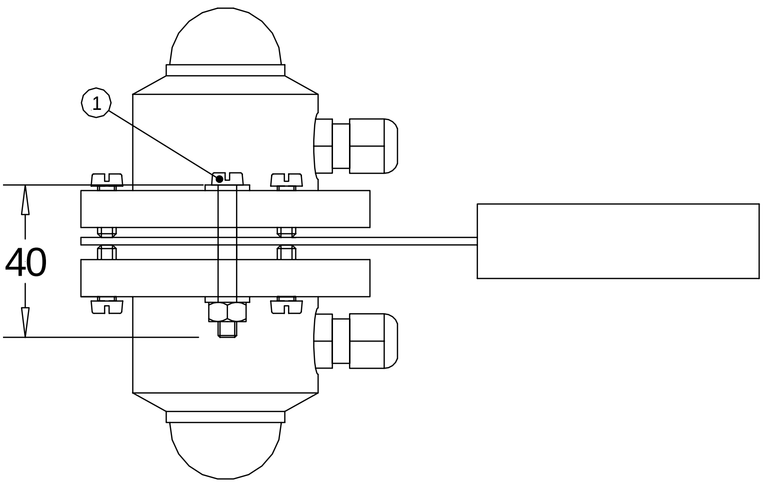

Figure 4.1.1 *LP02's mounted back to back for measurement of reflected radiation. Setscrew (1) and Fixing bolt M5 x 40 (2).*

Electrical connection

In order to operate, LP02 should be connected to a measurement system, typically a so-called datalogger.
LP02 is a passive sensor that does not need any power.
Cables generally act as a source of distortion, by picking up capacitive noise. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. For cable extension, see the appendix on this subject.

Wire	Colour	Measurement system
Sensor output +	White	Voltage input +
Sensor output -	Green	Voltage input - or ground
Shield		Analogue ground

Table 4.2.1 *The electrical connection of LP02.*

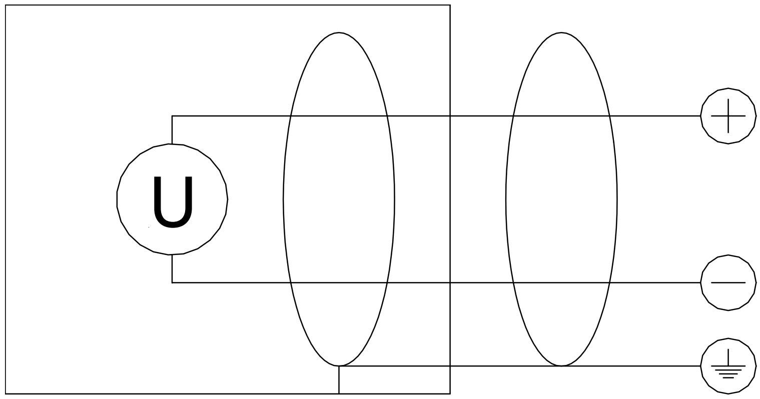

Figure 4.2.1 *Electrical diagram of LP02.*

Sensor	Printed Circuit	Colour code wire
Plus (+)	+	White
Minus (-)	-	Green
Shield	SH	Wire shield
	TR	Not connected

Table 4.2.2 *Standard internal connection of LP02 at the connector block.*

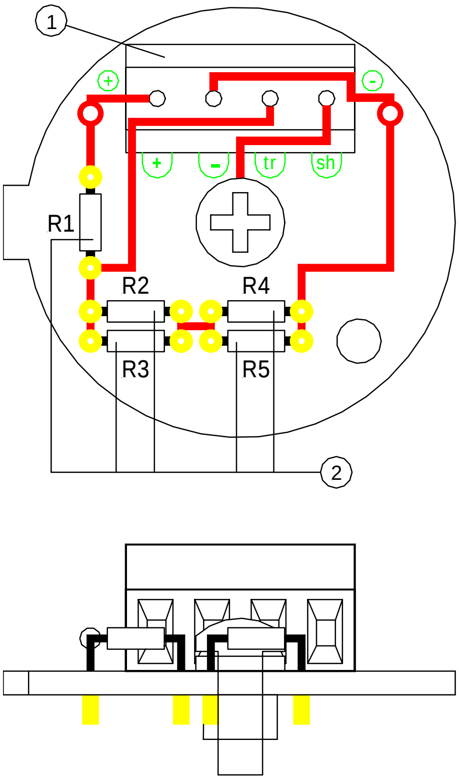

Figure 4.2.2 *Printed circuit board inside LP02; in the normal configuration only +, – and SH are connected to the wiring via the connector block (1). Normally the shunt resistors for trimming (2) are not used.*

4.2 Optional trimming

In case the option "with soldering pins" was ordered, the LP02 sensitivity can be trimmed.

IMPORTANT NOTE: the connection of the wiring on the internal connector block must now be changed.

Sensor	Printed Circuit	Colour code wire
Plus (+)	TR	White
Minus (-)	-	Green
Shield	SH	Wire shield
	+	Not connected

Table 4.3.1 *After trimming: internal connection of LP02 at the connector block.*

Assuming a sensitivity E and no shunt resistors installed, the sensitivity can be changed to E_{new} by installing shunt resistors. This process is called trimming.

1 Measure the LP02 sensor resistance $R_{e\ sen}$. It is suggested to perform this measurement between the + and – of the connector block. The measurement should be performed with dual polarity, taking the average (this is done because some ohmmeters can be confused by the sensor output signal)

The required shunt resistance $R_{e\ sh}$ for trimming to a new value of E, E_{new} , should be chosen according to:

$$R_{e\ sh} = R_{e\ sen}\ ((E_{new}\ /(\ E_{new} - E)) \qquad 4.3.1$$

For building $R_{e\ sh}$ all the connection points R2 to R5 can be used.
R1 is typically connected with a wire.
In case R4 and R5 are not used, R4 should be shunted with a wire.
After soldering in the wiring can be reconnected using the schedule of 4.3.1.

To establish if the procedure and installation of resistors was correct, the resistance between the + and – wires can be checked:

This should be

$$R_{e\ sen\ new} = 1/((1/\ R_{e\ sen}) + (1/\ R_{e\ sh})) \qquad 4.3.2$$

Finally a recalibration should be performed.

5 Dimensions

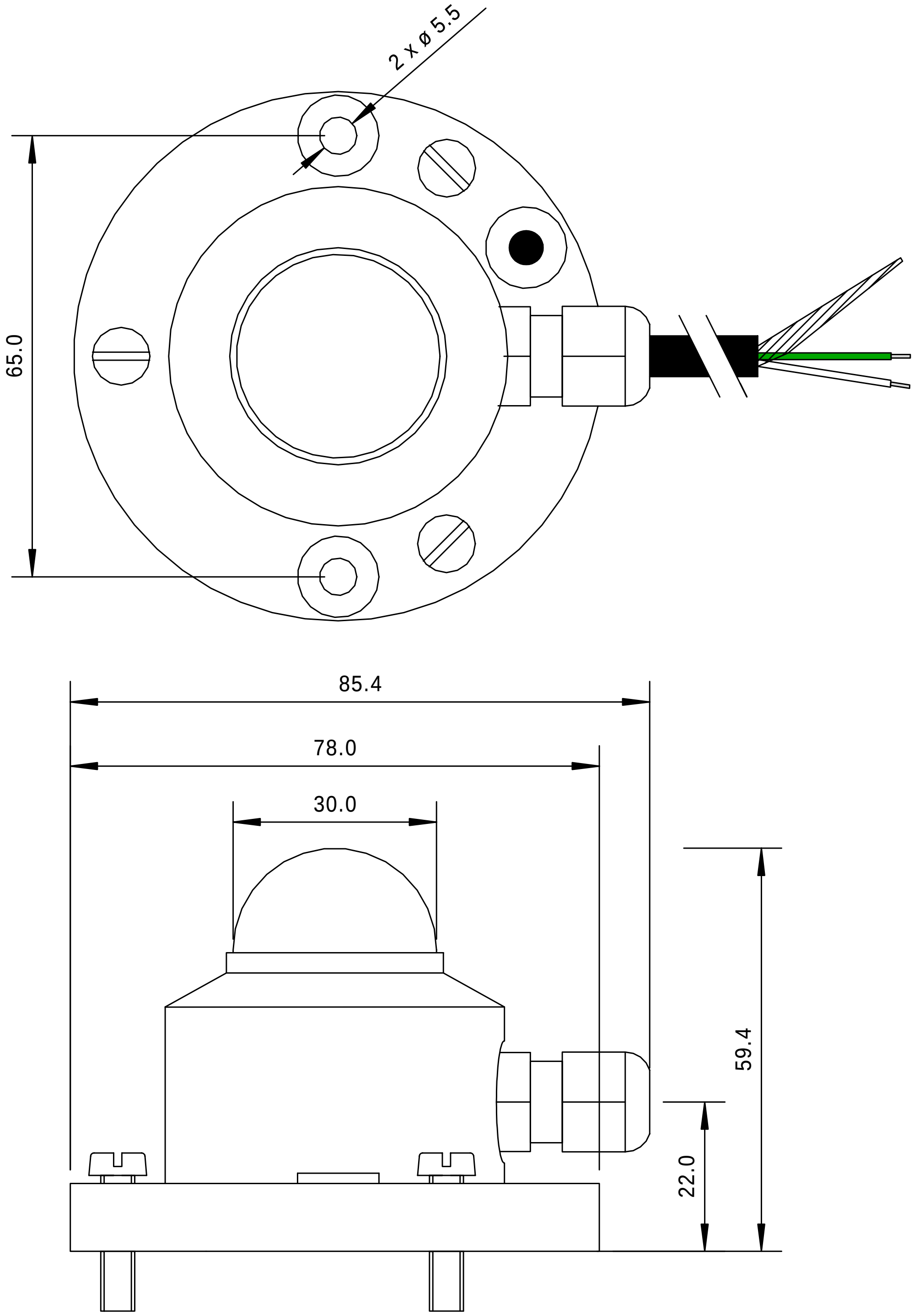

Figure 5.1 *Dimensions of LP02 in mm.*

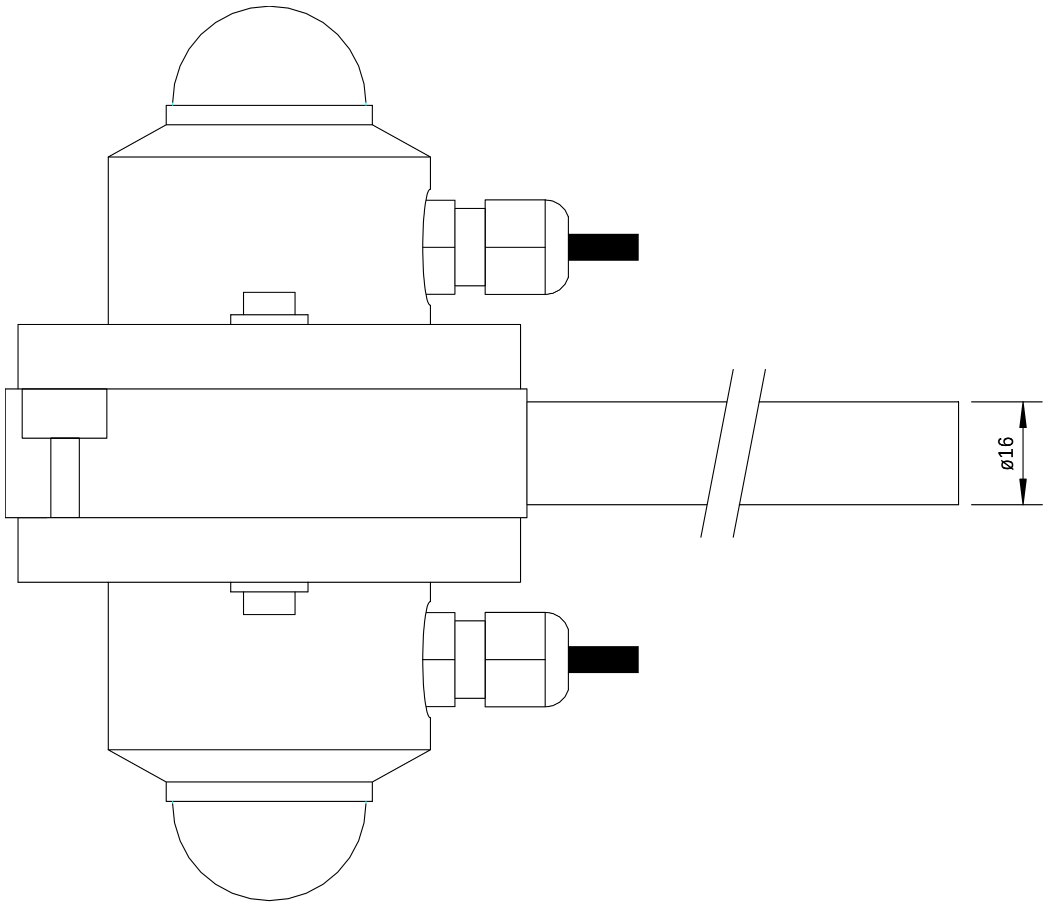

Figure 5.2 *Dimensions including albedometer fixture AMF01*

6 Maintenance and troubleshooting

6.1 Maintenance

Once installed LP02 is essentially maintenance free. Usually errors in functionality will appear as unreasonably large or small measured values.
As a general rule, this means that a critical review of the measured data is the best form of maintenance.

At regular intervals the quality of the cables can be checked.

On a 2 yearly interval the calibration can be checked in an indoor facility.

Critical review of data
Cleaning of dome by water or alcohol
Inspection of dome interior; no condensation
Inspection of cables for open connections
Recalibration: suggested every 2 years, typically by intercomparison with a higher standard in the field.

Table 6.1.1 *LP02 recommendations for maintenance*

6.2 Trouble shooting

This paragraph contains information that can be used to make a diagnosis whenever the sensor does not function.

The sensor does not give any signal	Measure the impedance across the sensor wires. This should be around 100 ohms plus cable resistance (typically 0.1 ohm/m). If it is closer to zero there is a short circuit (check the wiring). If it is infinite, there is a broken contact (check the wiring). This check can be done even when the sensor is buried. Check if the sensor reacts to an enforced heat flux. In order enforce a flux, it is suggested to use a lamp as a thermal source. A 100 Watt lamp mounted at 10 cm distance should give a definite reaction. Check the data acquisition by applying a mV source to it in the 1 mV range.
The sensor signal is unrealistically high or low.	Check if the right calibration factor is entered into the algorithm. Please note that each sensor has its own individual calibration factor. Check if the voltage reading is divided by the calibration factor by review of the algorithm. Check the condition of the leads at the logger. Check the cabling condition looking for cable breaks. Check the range of the data logger; heat flux can be negative (this could be out of range) or the amplitude could be out of range. Check the data acquisition by applying a mV source to it in the 1 mV range.
The sensor signal shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio etc.) Check the condition of the shielding. Check the condition of the sensor cable.

Table 6.2.1 *Trouble shooting for LP02.*

7 Requirements for data acquisition / amplification

Capability to measure microvolt signals	Preferably: 5 microvolt accuracy Minimum requirement: 20 microvolt accuracy (both across the entire expected temperature range of the acquisition / amplification equipment)
Capability for the data logger or the software	To store data, and to perform division by the sensitivity to calculate the solar irradiance.

Table 7.1 *Requirements for data acquisition and amplification equipment.*

8 Appendices

8.1 Appendix on cable extension / replacement

LP02 is equipped with one cable. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. Cables generally act as a source of distortion, by picking up capacitive noise. LP02 cable can however be extended without any problem to 100 meters. If done properly, the sensor signal, although small, will not significantly degrade because the sensor impedance is very low. Cable and connection specifications are summarised below.

Cable	2-wire shielded, copper core (at Hukseflux 3 wire shielded cable is used, of which only 2 wires are used)
Core resistance	0.1 Ω/m or lower
Outer diameter	(preferred) 5 mm
Outer sheet	(preferred) polyurethane (for good stability in outdoor applications).
Connection	Either solder the new cable core and shield to the original sensor cable, and make a waterproof connection using cable shrink, or use gold plated waterproof connectors.

Table 8.1.1 *Specifications for cable extension of LP02.*

8.2 Appendix on calibration

The World Radiometric Reference (WRR) is the measurement standard representing the SI unit of irradiance. It was introduced in order to ensure world-wide homogeneity of solar radiation measurements and is in use since 1980.
The WRR was determined from the weighted mean of the measurements of a group of 15 absolute cavity radiometers which were fully characterized. It has an estimated accuracy of 0.3%. The WMO introduced its mandatory use in its status in 1979.

The world-wide homogeneity of the meteorological radiation measurements is guaranteed by the World Radiation Centre in Davos Switzerland, by maintaining the World Standard Group (WSG) which materializes the World Radiometric Reference.

http://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 500 W/m^2 irradiance level. (during the outdoor calibration the sun is typically at 20-40 degrees zenith angle, and the total irradiance at a 700 W/m^2 level.

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 Engergy- calibration of field pyranometers by comparison to a reference pyranometer”.
At Hukseflux an indoor calibration according to the same standard is used (described in Appendix A of the ISO 9060 standard).

Ther main Hukseflux recommendation for re-calibration is if possible to do it indoor by comparison to an identical reference instrument, under normal incidence conditions.

In case of field comparison; The ISO recommends field calibration to a higher class pyranometer. Hukseflux does not agree with this because in practice this leads to variable errors, due to the conditions of the moment. For second class pyranometers in particular the Far-Infra-Red offset is the dominating error source. This error however varies strongly with the solar elevation and amount of blue sky.
It is therefore safer to compare to pyranometers of the same brand and type.

Secondly, the ISO recommends to perform field calibration during several days; 2-3 days under cloudless conditions, 10 days under cloudy conditions. In general this is not achievable.

Hukseflux main recommendations for field intercomparison are:
1 to take a reference of he same brand and type as the field pyranometer, and
2 to connect both to the same electonics, so that electronics errors (also offsets) are eliminated.
3 Preferaboy both instruments should be mounted on the same platform, so that they have the same body temperature.
4 Assuming that the electronics is independently calibrated, it is suggested:
4.1 of possible to look either at radiation values at normal incidence radiation (possibly tilting the radiometers).
4.2 if this is not possible to compare 1 hour or daily totals.
4.3 to take 10 minute average values, and determine the relative calibration by using the correlation between the two signals, assuming the signals to be both zero at zero irradiance.
5 In general for second class radiometers, deviations of more than +/- 10 % should be corrected. Lower deviations should be interpreted as acceptable.
6 For first class pyranometers, the limit could be set at +/- 5%. Lower deviations should be interpreted as acceptable.
7 For secondary standard instumens, provided that they are well cleaned and venilated, the limit could be set at +/- 2%.

8.3 Appendix on sensor coating

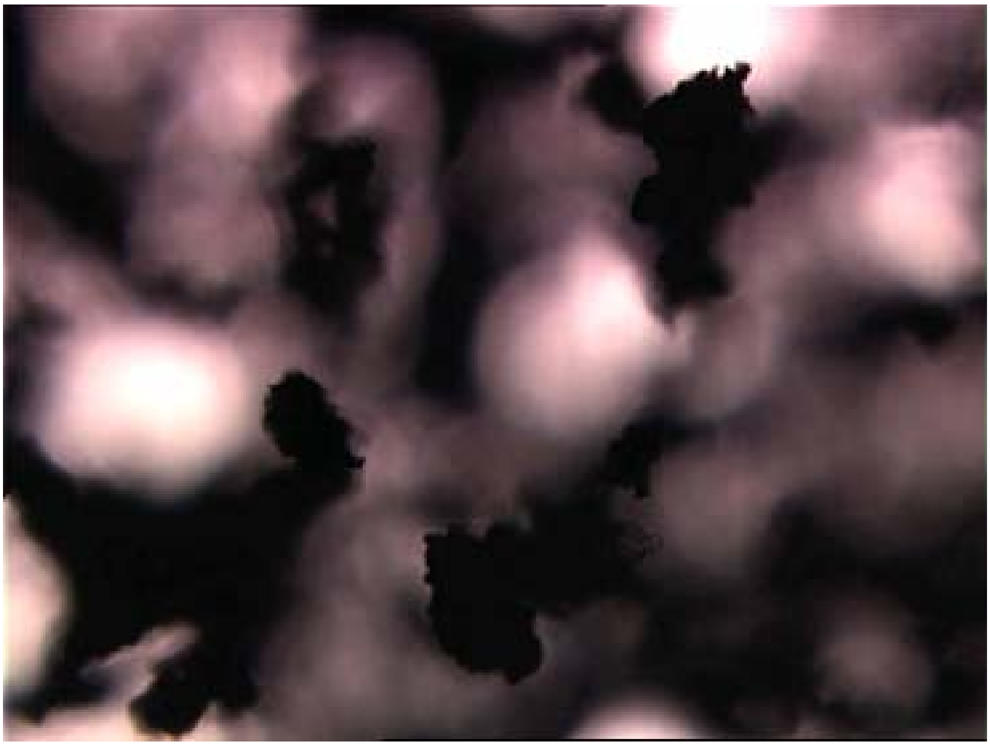

Figure 8.3.1 *Top of the Hukseflux sensor coating on a glass substrate under a confocal laser microscope. The carbon based coating is highly porous, and every element acts as a light trap. The end result is a coating of very high absorption. The ends of carbon particles are in-focus, the outlines of the underlying layers can be seen out-of focus.*

8.4 Declaration of conformity CE

According to EC guidelines 89/336/EEC,

We: Hukseflux Thermal Sensors

Declare that the product: LP02

Is in conformity with the following standards:

Emissions:

Radiated:	EN 55022: 1987	Class A
Conducted:	EN 55022: 1987	Class B

Immunity:

ESD	IEC 801-2; 1984	8kV air discharge
RF	IEC 808-3; 1984	3 V/m, 27-500 MHz
EFT	IEC 801-4; 1988	1 kV mains, 500V other

Delft
August 2006