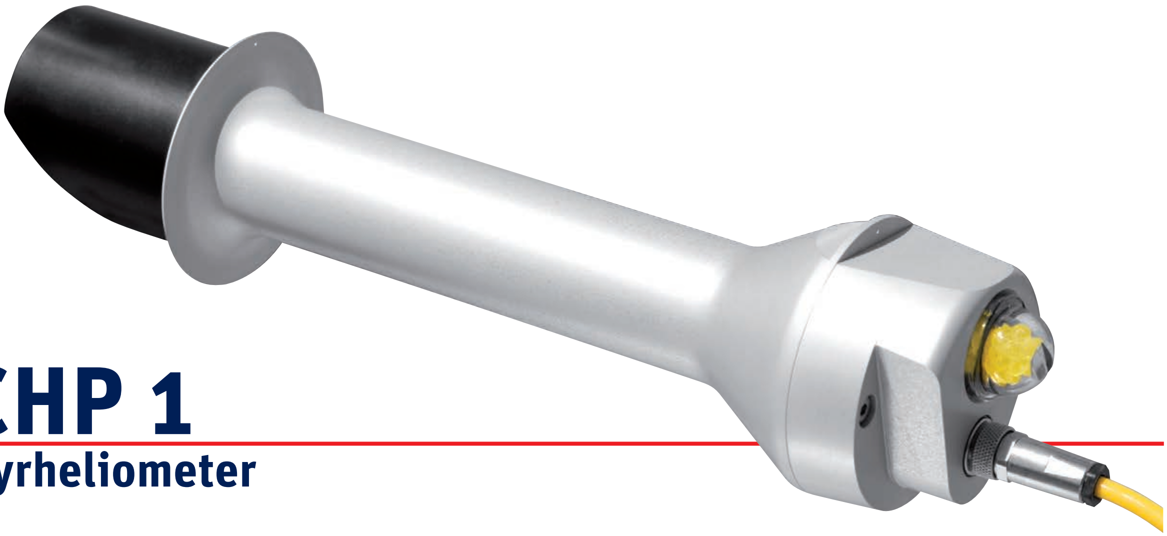

CHP 1

Pyrheliometer

Instruction Manual

IMPORTANT USER INFORMATION

Reading this entire manual is recommended for full understanding of the use of this product.

Should you have any comments on this manual we will be pleased to receive them at:

Kipp & Zonen B.V.
Delftechpark 36, 2628 XH Delft, the Netherlands
or P.O. Box 507, 2600 AM Delft, the Netherlands

T: +31 (0)15 2755 210
F: +31 (0)15 2620 351
info@kippzonen.com
www.kippzonen.com

Kipp & Zonen reserves the right to make changes to the specifications without prior notice.

WARRANTY AND LIABILITY

Kipp & Zonen guarantees that the product delivered has been thoroughly tested to ensure that it meets its published specifications. The warranty included in the conditions of delivery is valid only if the product has been installed and used according to the instructions supplied by Kipp & Zonen.

Kipp & Zonen shall in no event be liable for incidental or consequential damages, including without limitation, lost profits, loss of income, loss of business opportunities, loss of use and other related exposures, however used, rising from the faulty and incorrect use of the product. User made modifications can affect the validity of the CE declaration.

Manual version: 0811

KIPP & ZONEN
SINCE 1830

DECLARATION OF CONFORMITY

According to EC guideline 89/336/EEC

We Kipp & Zonen B.V.
Delftechpark 36
2628 XH Delft
The Netherlands

Declare under our sole responsibility that the product

Type: CHP 1
Name: Pyrheliometer

To which this declaration relates is in conformity with the following standards

Imissions	EN 50082-1	Group standard
IEC 100-4-2	IEC 801-2	8 kV
IEC 100-4-3	IEC 801-3	3 V/m
IEC 100-4-4	IEC 801-4	1 kV
Emissions	EN 50081-1	Group standard
EN 55022		

Following the provisions of the directive:

B.A.H. Dieterink
President
KIPP & ZONEN B.V.

TABLE OF CONTENTS

INTRODUCTION

Dear customer, thank you for purchasing a Kipp & Zonen instrument. Please read this manual and the separate instruction sheet for a full understanding of the use of your pyrheliometer.

The pyrheliometer CHP 1 is designed to measure the irradiance which results from the radiant flux from a solid angle of 5 °.

According to International Standard ISO 9060 and the World Meteorological Organization (WMO) a pyrheliometer is the designated type of instrument for the measurement of direct solar radiation. The CHP 1 pyrheliometer is compliant with the "First Class" class specified by the international standards.

This manual, together with the instruction sheet, gives information related to installation, maintenance, calibration, product specifications and applications of the CHP 1 pyrheliometer.

If any questions should remain, please feel free to contact your Kipp & Zonen dealer or e-mail info@kippzonen.com

For information about other Kipp & Zonen products or to check for any update of this manual, go to www.kippzonen.com

1 INSTALLATION AND OPERATION

1.1 Delivery

Check the contents of the shipment for completeness (see below) and note whether any damage has occurred during transport. If there is damage, a claim should be filed with the carrier immediately. In this case, or if the contents are incomplete, your dealer should be notified in order to facilitate the repair or replacement of the instrument.

1.2 Contents of delivery

Pyrheliometer
Rain screen
Cable with connector
Test reports
Instruction sheet
2x Desiccant bags
Product documentation CD

Although the CHP 1 is weatherproof and suitable for harsh environmental conditions, they have some delicate mechanical parts. Please keep the original packaging for safe transport of the radiometer to the measurement site or for use when returning the radiometer for calibration.

The calibration certificate supplied with the instrument is valid for 1 year from the date of first use by the customer, subject to the variations in performance due to specific operating conditions that are given in the instrument specifications. The calibration certificate is dated relative to the time of manufacture, or recalibration, but the instrument does not undergo any sensitivity changes when kept in the original packing and not exposed to light. From the moment the instrument is taken from its packaging and exposed to irradiance the sensitivity will deviate slightly with time. See the 'non-stability' performance (maximum sensitivity change per year) given in the radiometer specification list.

1.3 Mechanical installation

The mechanical installation will be explained in the next paragraphs.

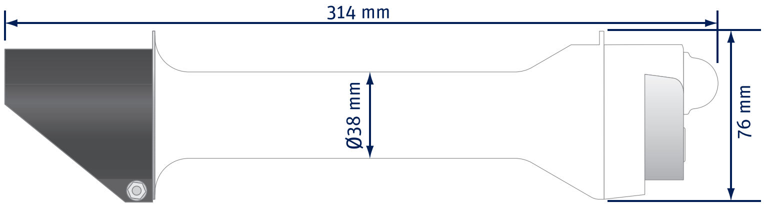

Figure 1: Dimensional drawing CHP 1

For installation on the Kipp & Zonen trackers 2AP and Solys2, please consult the manual of the tracker.

1.4 Electrical installation

As standard the CHP 1 is supplied with a waterproof connector pre-wired to 10 m cable with a number of leads and a shield covered with a black sleeve. The number of connector pins and cable leads depends upon the model of pyrheliometer and whether a temperature sensor is fitted (and which type). The colour code of the wires and the connector pin numbers are shown on the instruction sheet. Longer cables are available as options.

PYRHELIOMETER CONNECTION
ANSCHLUSS • RACCORDEMENT • CONEXIÓN

	Wire Kabel Fil Cable	Function Funktion Fonction Función	Connect with Anschluss an Relier à Conectar con
1	Red Rot • Rouge • Rojo	+	+ Hi
2	Blue Blau • Bleu • Azul	–	– Lo
4	Yellow Gelb • Jaune • Amarillo	Combined Kombiniert Combiné Combinado	Pt-100
6	Brown Braun • Brun • Marrón		
3	Green Grün • Vert • Verde	Combined Kombiniert Combiné Combinado	Pt-100
5	Grey Grau • Gris • Gris		
7	Black Schwarz • Noir • Negro	Combined Kombiniert Combiné Combinado	Thermistor
8	White Weiss • Blanc • Blanco		
	Shield Abschirmung Protection Malla	Housing Gehäuse Boîte Cubierta	Ground * Erde Terre Tierra

Pin Layout
Steckerbelegung • Schéma des connexions • Diagrama de conexiones
1 Red • Rot • Rouge • Rojo
2 Blue • Blau • Bleu • Azul
3 Green • Grün • Vert • Verde
4 Yellow • Gelb • Jaune • Amarillo
5 Grey • Grau • Gris • Gris
6 Brown • Braun • Brun • Marrón
7 Black • Schwarz • Noir • Negro
8 White • Weiss • Blanc • Blanco

* Connect to ground if Radiometer not grounded
Mit Erde verbinden, wenn das Radiometer nicht geerdet ist
Reliez à la terre si le Radiomètre n'est pas connecté
Conectar a tierra si el Radiómetro no lo está

The shield of the cable is connected to the aluminum radiometer housing through the connector body. The shield at the cable end may be connected to ground at the readout equipment. Lightning can induce high voltages in the shield but these will be led off at the pyrheliometer and data logger.

Kipp & Zonen pyrheliometer cables are of low noise type, but bending the cable produces small voltage spikes, a tribo-electric and capacitance effect. Therefore, the cable must be firmly secured to minimize spurious responses during stormy weather.

The impedance of the readout equipment loads the temperature compensation circuit and the thermopile. It can increase the temperature dependency of the pyrheliometer. The sensitivity is affected more than 0.1 % when the load resistance is less than 100 kΩ. For this reason we recommend the use of readout equipment with an input impedance of 1 MΩ or more. The solar integrators, data loggers and chart recorders from Kipp & Zonen meet these requirements.

Long cables may be used, but the cable resistance must be smaller than 0.1 % of the impedance of the readout equipment. It is evident that the use of attenuator circuits to modify the calibration factor is not recommended because the temperature response will also be affected.

A high input bias current at the readout equipment can produce several micro-Volts across the impedance of the pyrheliometer and cable. The zero offset can be verified by replacing the pyrheliometer impedance at the readout equipment input terminals with a resistor.

The pyrheliometer can also be connected to a computer or data acquisition system. A low voltage analogue input must be available. The resolution of the Analogue-to-Digital Converter (ADC) must allow a system sensitivity of about 1 bit per W/m². More resolution is not necessary during outdoor solar radiation measurements, because pyrheliometers exhibit offsets up to ± 2 W/m² due to lack of thermal equilibrium.

For amplification of the pyrheliometer signal Kipp & Zonen offers the AMPBOX signal amplifier. This amplifier will convert the micro-Volt output from the pyrheliometer into a standard 4 – 20 mA signal. The use of the AMPBOX amplifier is recommended for applications with long cables (> 100 m), electrically noisy environments or data loggers with a current-loop input. The AMPBOX can be factory adjusted to suit the sensitivity of an individual radiometer to produce a defined range, typically 4 – 20 mA represents 0 – 1600 W/m².

2 OPERATION

2.1 Measurement of direct solar radiation

After completing the installation the pyrheliometer will be ready for operation.

The irradiance value (E↓Solar) can be simply calculated by dividing the output signal (Uemf) of the pyrheliometer by its sensitivity (Sensitivity) as shown in Equation 1. For calculation of the direct solar irradiance the following formula must be applied:

$$E_{DirectSolar} = \frac{U_{emf}}{S}$$

Equation 1: Calculation of solar radiation

Where:

$E_{DirectSolar}$	= Solar radiation	[W/m²]
U_{emf}	= Output of radiometer	[µV]
S	= Sensitivity of radiometer	[µV/W/m²]

To be certain that the quality of the data is of a high standard, care must be taken with daily maintenance of the radiometer. Once a voltage measurement is taken, nothing can be done to retrospectively improve the quality of that measurement.

2.2 Measurement of instrument temperature

Inside the detector assembly a Pt-100 (Class A) and 10kΩ thermistor are placed to provide the detector temperature. The location of these temperature sensors is shown in Figure 2.

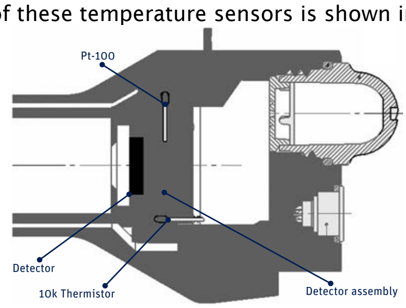

Figure 2: Position of temperature sensors inside the CHP 1 detector assembly

The temperature of the Pt-100 and 10kΩ thermistor can be derived using Equation 2 and Equation 3

Thermistor (10 kΩ @ 25ºC)

$$T = \left(\alpha + \left[\beta \cdot (\ln(R)) + \gamma \cdot (\ln(R))^3\right]\right)^{-1} - 273.15$$

$\alpha: 1.0295 \cdot 10^{-3}$ $\beta: 2.391 \cdot 10^{-4}$ $\gamma: 1.568 \cdot 10^{-7}$

T ["C] = Temperature R [Ω] = Resistance

Equation 2: Temperature vs Thermistor Resistance

Pt-100 (100 Ω @ 0°C)

$$T = \frac{-\alpha + \sqrt{\alpha^2 - 4 \cdot \beta \cdot \left(\frac{-R}{100} + 1\right)}}{2 \cdot \beta}$$

$\alpha: 3.9080 \cdot 10^{-3}$ $\beta: -5.8019 \cdot 10^{-7}$

Equation 3: Temperature vs Pt-100 resistance

3 MAINTENANCE

Once installed the pyrheliometer needs little maintenance. The window must be cleaned and inspected regularly, ideally every morning.

A periodic check is to ensure that the silica gel desiccant is still coloured orange. When the yellow silica gel in the drying cartridge is turned completely transparent (normally after several months), it must be replaced by fresh silica gel as supplied in the small refill packs. The content of one pack is sufficient for one complete refill. At the same time check that the radiometer mounting is secure and that the cable is in good condition.

Some tips when changing the desiccant:

Make sure the surfaces of the radiometer and the drying cartridge that touch the rubber o-ring are clean (corrosion can do a lot of harm here and dirt, in combination with water, can cause this);
The rubber o-ring is coated with a silicon grease to improve the seal. If the rubber o-ring looks dry apply some grease to it (Vaseline will also do);
Check that the drying cartridge is tightly threaded into the radiometer body.

It is very difficult to make the radiometers hermetically sealed; so, due to pressure differences between the inside and the outside of the instrument, there will always be some exchange of (humid) air.

The radiometer sensitivity changes with time and with exposure to radiation. Calibration every two years is advised. Further information about Kipp & Zonen recalibration services can be found in Appendix VI.

4 PRINCIPLE COMPONENTS OF PYRHELIOMETERS

The detector of the Kipp & Zonen CHP 1 pyrheliometer is based on a passive thermal sensing element called a thermopile.

The thermopile responds to the total power absorbed by the black surface coating, which is a non-spectrally selective paint, and warm up. The heat generated flows through a thermal resistance to the heat-sink (the pyrheliometer body). The temperature difference across the thermal resistance of the detector is converted into a voltage as a linear function of the absorbed solar irradiance.

A drying cartridge (dessicator) in the radiometer housing is filled with silica gel and prevents dew on the inner sides of the windows, which can cool down considerably on clear windless nights.

4.1 Window

The window material of the pyrheliometer defines the spectral measurement range of the instrument. In general about 97 – 98 % of the solar radiation spectrum will be transmitted through the window and will be absorbed by the detector.

4.2 Detector

The thermopile sensing element is made up of a large number of thermocouple junction pairs connected electrically in series. The absorption of thermal radiation by one of the thermocouple junctions, called the active (or ‘hot’) junction, increases its temperature. The differential temperature between the active junction and a reference (‘cold’) junction kept at a fixed temperature produces an electromotive force directly proportional to the differential temperature created. This is a thermoelectric effect. The sensitivity of a pyrheliometer depends on the individual physical properties of the thermopile and construction. The sensitivity of each thermopile is unique and therefore each radiometer has unique calibration factor, even with the same radiometer model.

On the top surface of the sensor a black paint is deposited which has a very rough structure containing many micro-cavities that effectively ‘’trap’’ more than 97 % of the incident radiation in a broad spectral range. Furthermore, the spectral selectivity is less than 2 %. This means that within the spectral range of the pyrheliometer, the absorption for each wavelength is equal to within 2 %. The black painted sensing element forms the detector. Considering the long-term stability of the instrument, the black paint is one of the most crucial and delicate parts of the pyrheliometer. Kipp & Zonen black paint gives the best possible stability over a long period of time under all meteorological circumstances.

4.3 Housing

The radiometer housing accommodates all fundamental pyrheliometer parts. The anodized Aluminum parts are light weight and give a high mechanical and thermal stability to the instrument. Due to its fine mechanical construction all pyrheliometers are virtually sealed and comply with the international standard IP 67.

4.4 Drying cartridge

In case moisture enters the radiometer body the silica-gel desiccant regulates the humidity level inside the pyrheliometer. Initially the desiccant will have an orange color. After some time it becomes saturated with moisture and the colour will change to become clear (transparent). At this time the contents of the drying cartridge should be replaced with fresh, unsaturated orange colored desiccant as soon as possible. Replacement desiccant is available through Kipp & Zonen distributors.

4.5 Cable and connector

For ease of installation and replacement during recalibration of the radiometer, the CHP 1 is provided with a weather proof signal cable connector.

Kipp & Zonen radiometers use a custom-made cable that is selected as a low noise type particularly suited to handle the low voltage output of the thermopile or of a temperature sensor.

The shield of the cable is connected to the metal body of the connector and preferably should be connected to ground at the readout equipment. Cables come pre-wired to the connector plug in a range of lengths.

5 PYRHELIOMETER PHYSICAL PROPERTIES

In this chapter the principal physical characteristics of the CHP 1 pyrheliometer are given.

5.1 Spectral range

The spectrum of the solar radiation reaching the Earth's surface is in the wavelength range between 280 nm and 4000 nm, extending from ultraviolet (UV) to the far infrared (FIR) as shown in Figure 9. Due to the excellent physical properties of the quartz window and black absorber paint, the Kipp & Zonen CHP 1 pyrheliometer is equally sensitive in a wide spectral range. 97-98 % of the total energy will be absorbed by the thermal detector.

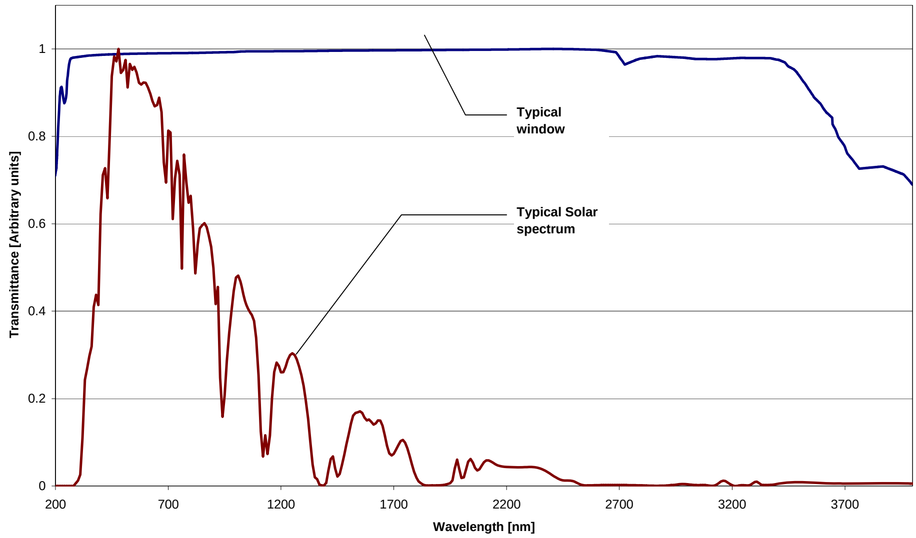

Figure 3: Solar irradiance spectrum at the Earth's surface and pyrheliometer response

5.2 Sensitivity

The radiometer thermopile sensitivity is mainly determined by the physical properties of the detector itself. The thermoelectric power, thermal conductivity of the junctions and the overall dimensions of the sensing element are related to its sensitivity.

5.3 Impedance

The radiometer impedance is defined as the total electrical impedance at the radiometer output connector fitted to the housing. It arises from the electrical resistance in the thermal junctions, wires and passive electronics within the radiometer.

5.4 Response time

Any measuring device requires a certain time to react to a change in the parameter being measured. The radiometer requires time to respond to change in the incident radiation. The response time is normally quoted as the time for the output to reach 95 % (sometimes 63 %) of the final value following a step-change in irradiance. It is determined by the physical properties of the thermopile and the radiometer construction. The CHP 1 has a fast response, which makes them suitable for measuring solar radiation under variable weather conditions.

5.5 Operating temperature

The operating temperature range of the radiometer is determined by the physical properties of the individual parts. Within the specified temperature range Kipp & Zonen radiometers can be operated safely. Outside this temperature range special precautions should be taken to prevent any physical damage or performance loss of the radiometer. Please contact your distributor for further information regarding operation in unusually harsh temperature conditions.

5.6 Field of view

Figure 4 shows the pyrheliometers optical construction.

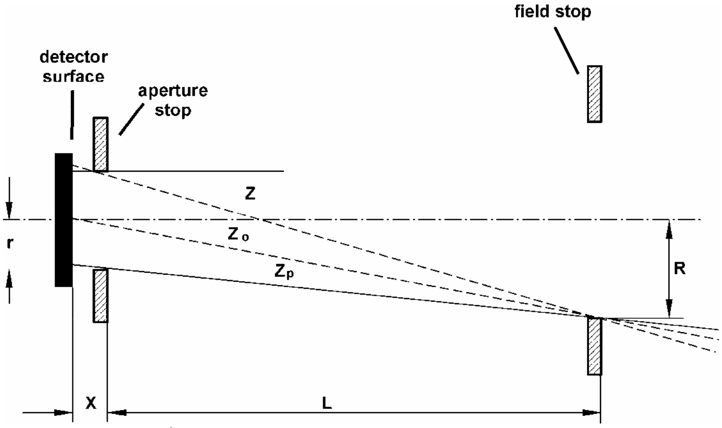

Figure 4: Optical construction

The beam of light that reaches the detector is limited by the field and aperture stop. The slope, opening and limit angles are determined by R, r and L. The distance x is negligible.

For the CHP 1 the full opening angle is 5 °, the slope angle is 1 °. The sun, as seen from the detector, occupies a solid angle of 0.5 °. A 100 % response can be expected only if the sun is entirely within the slope angle. This is the case when tracking accuracy is better than slope angle minus half the solar angle.

Concluding, tracking accuracy should be within 0.75 ° of ideal.

5.7 Environmental

The CHP 1 pyrheliometer is designed for outdoor use under all expected weather conditions. The radiometers comply with IP 67 and their solid mechanical construction is suitable to be used under all environmental conditions within the specified ranges.

6 MEASUREMENT ACCURACY

When a pyrheliometer is in operation, its performance is correlated to a number of parameters, such as temperature, level of irradiance etc. Normally, the supplied sensitivity figure is used to calculate the irradiances. If the conditions differ significantly from calibration conditions, uncertainty in the calculated irradiances must be expected.

For a first class pyrheliometer the WMO expects maximum errors in the hourly radiation totals of 3 %. In the daily total an error of 2 % is expected, because some response variations cancel each other out if the integration period is long. Kipp & Zonen expects maximum uncertainty of 2 % for hourly totals and 1% for daily totals for the CHP 1 pyrheliometer.

For the CHP 1 the effect of each parameter on the sensitivity can be shown separately.

6.1 Non linearity

The non-linearity error, the sensitivity variation with irradiance is shown in Figure 5 for a range from 0 to 1000 W/m^2 referred to the calibration at 500 W/m^2.

Figure 5: Non-linearity sensitivity variation of a CHP 1

6.2 Temperature dependence

The temperature dependence of the sensitivity is a function of the individual CHP 1. For a given instrument the response lies in the region between the curved lines in Figure 6. The temperature dependence of each pyrheliometer is characterized and supplied with the instrument. Each CHP 1 has built-in temperature sensors to allow corrections to be applied if required.

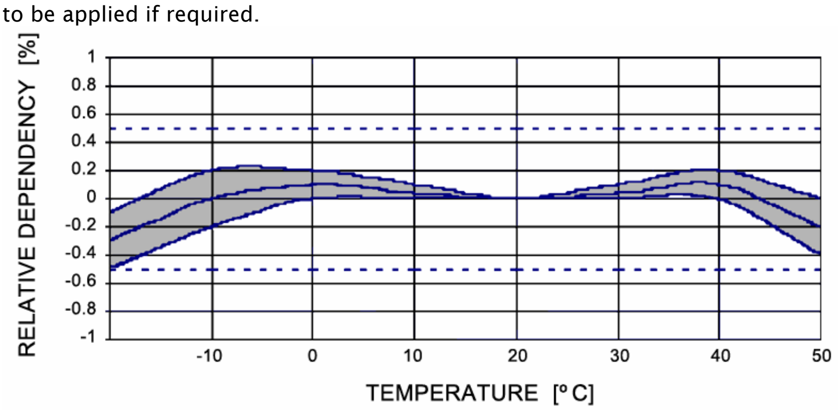

Figure 6: Typical temperature dependency of a CHP 1

6.3 Zero offset B

Proportionally to the ambient temperature the instrument temperature varies and causes heat currents inside the instrument. This will cause an offset commonly called Zero Offset type B. It is quantified as the response in W/m^2 to a 5 K/hr change in ambient temperature.

6.4 Non-stability

This is the percentage change in sensitivity over a period of one year. This effect is mostly due to degradation by UV radiation of the black absorber paint on the sensing element surface. Kipp & Zonen recommends recalibration every two years. However, for quality assurance purposes some institutes, companies or networks may require more or less frequent recalibration. Please read the chapter on the calibration procedure for pyrheliometers for more information.

6.5 Spectral selectivity

Spectral selectivity is the variation of the window transmittance and absorption coefficient of the black detector paint with wavelength and is commonly specified as a % of the mean value.

7 CALIBRATION

7.1 Calibration principle

An ideal pyrheliometer gives voltage output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called ‘sensitivity’ (Sensitivity).

The sensitivity figure of a particular pyrheliometer is unique. It is determined in the manufacturer's laboratory by comparison against a reference pyrheliometer of similar type. The reference pyrheliometer is calibrated outdoors regularly at the World Radiation Centre (WRC) at Davos, Switzerland. The spectral content of the laboratory calibration lamp differs from the outdoor solar spectrum at the World Radiation Centre. However, this has no consequences for the transfer of calibration, because standard and test pyrheliometers have the same black coating and windows.

The supplied sensitivity figure is valid for the following conditions:

An ambient temperature of +20 °C.
Normal incident radiation of 500 W/m^2.

For any other condition the sensitivity figure can be used within uncertainty bands given in the specifications for each model.

A summary of calibration methods is also found in the WMO guide of 1996.

7.2 Calibration procedure at Kipp & Zonen

At Kipp & Zonen, calibration is performed by indoor comparison with a reference instrument. The reference is not of a higher standard classification. The comparison is made under a xenon lamp at an irradiance level of approximately 500 W/m^2. The reference has been calibrated at the World Radiation Centre. The accuracy of this calibration is ± 0.5 %. ISO requests that each pyrheliometer, in order to obtain its classification, must periodically be compared to a higher standard.

7.3 Traceability to world radiometric reference

Reference pyrheliometers, which are calibrated annually by the World Radiation Centre in Davos, are used for the calibration of radiometers manufactured by Kipp & Zonen. The reference radiometers are fully characterized, i.e. linearity, temperature dependence and directional response are recorded.

Kipp & Zonen keeps two reference radiometers for each radiometer model. These reference radiometers are sent alternate years to WRC for calibration, so production and calibration in Delft can carry on without interruption.

8 RECALIBRATION

Radiometer sensitivity changes with time and with exposure to radiation. Periodic calibration every two years is advised.

Accurate calibrations can be done outdoors under clear conditions by comparison with a reference pyrheliometer. Many national or regional weather services have calibration facilities. Their standard pyrheliometer is compared with the World Radiometric Reference at Davos, Switzerland. This embodies several absolute cavity (black body) pyrheliometers. Information about regional calibration centres can be found in appendix V.

9 FREQUENTLY ASKED QUESTIONS

The most frequently asked questions are listed in the FAQ section of our website at www.kippzonen.com

10 TROUBLE SHOOTING

The following contains a procedure for checking the instrument in case it appears that it does not function as it should.

Output signal fails or shows improbable results:

- Check the wires are properly connected to the readout equipment.
- Check the instrument location. Are there any obstructions that cast a shadow on the window by blocking the direct sun during some part of the day?

- Check the window, it should be clear and clean. If water is deposited on the inside, please change the desiccant. If too much water is deposited internally the drying cartridge should be removed and the instrument warmed to dry it.
- Check instrument impedance (see specifications for expected values).
- Check data logger or integrator offset by connecting a dummy load (100 Ohm resistor). This should give a “zero” reading.

- If water or ice is deposited on the window, clean it. Probably water droplets will evaporate in less than one hour under sunlight.

Any visible damage or malfunction should be reported to your distributor, who will suggest appropriate action.

APPENDIX I RADIOMETRIC TERMINOLOGY

Term	Explanation
Albedo	The portion of incoming radiation which is reflected by a surface
Azimuth angle	Angle in horizontal direction (0-360 °)
Angle of incidence	Incident angle from zenith (vertical)
Cosine response	Detector response according to the cosine law
Diffuse solar irradiance	Solar radiation, scattered by water vapor, dust and other particles as it passes through the atmosphere
Direct solar irradiance	Radiation that has traveled a straight path from the sun
Global solar irradiance	Total irradiance falling on a horizontal surface (Diffuse + Direct $\cdot$ cos α)
Irradiance	Radiant flux density (W/m^2)
Long-wave radiation	Radiation with wavelengths > 4 µm and < 100 µm
Pyrheliometer	Radiometer suitable to measure short-wave global radiation
Pyrgeometer	Radiometer suitable to measure downward long-wave radiation
Pyrheliometer	Radiometer suitable to measure direct irradiance
Short-wave radiation	Radiation with wavelengths > 280 nm and < 4 µm
Thermopile	Thermal detector made up of many thermocouple junctions
WMO	World Meteorological Organisation
WRC	World Radiation Center (in Davos, Switzerland)
WRR	World Radiation Reference (standard radiation scale)
WSG	World Standard Group (radiometer standards maintained in Davos)
Zenith angle	Angle from zenith (0 °, vertical)

APPENDIX II 10K THERMISTOR SPECIFICATIONS

YSI Thermistor 44031 - Resistance versus Temperature in ˚C

Thermistor (10 kΩ @ 25ºC)

$$T = \left(\alpha + \left[\beta \bullet (\ln(R)) + \gamma \bullet (\ln(R))^3\right]\right)^{-1} - 273.15$$

$\alpha: 1.0295 \bullet 10^{-3}$ $\beta: 2.391 \bullet 10^{-4}$ $\gamma: 1.568 \bullet 10^{-7}$

T [°C] = Temperature R [Ω] = Resistance

YSI 44031 Temperature vs. Resistance

Temperature [˚C]	Temperature [˚F]	Resistance [Ohm]	Temperature [˚C]	Temperature [˚F]	Resistance [Ohm]	Temperature [˚C]	Temperature [˚F]	Resistance [Ohm]
-30	-22.0	135,200	0	32.0	29,490	30	86.0	8,194
-29	-20.2	127,900	1	33.8	28,150	31	87.8	7,880
-28	-18.4	121,100	2	35.6	26,890	32	89.6	7,579
-27	-16.6	114,600	3	37.4	25,690	33	91.4	7,291
-26	-14.8	108,600	4	39.2	24,550	34	93.2	7,016
-25	-13.0	102,900	5	41.0	23,460	35	95.0	6,752
-24	-11.2	97,490	6	42.8	22,430	36	96.8	6,500
-23	-9.4	92,430	7	44.6	21,450	37	98.6	6,258
-22	-7.6	87,660	8	46.4	20,520	38	100.4	6,026
-21	-5.8	83,160	9	48.2	19,630	39	102.2	5,805
-20	-4.0	78,910	10	50.0	18,790	40	104.0	5,592
-19	-2.2	74,910	11	51.8	17,980	41	105.8	5,389
-18	-0.4	71,130	12	53.6	17,220	42	107.6	5,193
-17	1.4	67,570	13	55.4	16,490	43	109.4	5,006
-16	3.2	64,200	14	57.2	15,790	44	111.2	4,827
-15	5.0	61,020	15	59.0	15,130	45	113.0	4,655
-14	6.8	58,010	16	60.8	14,500	46	114.8	4,489
-13	8.6	55,170	17	62.6	13,900	47	116.6	4,331
-12	10.4	52,480	18	64.4	13,330	48	118.4	4,179
-11	12.2	49,940	19	66.2	12,790	49	120.2	4,033
-10	14.0	47,540	20	68.0	12,260	50	122.0	3,893
-9	15.8	45,270	21	69.8	11,770	51	123.8	3,758
-8	17.6	43,110	22	71.6	11,290	52	125.6	3,629
-7	19.4	41,070	23	73.4	10,840	53	127.4	3,504
-6	21.2	39,140	24	75.2	10,410	54	129.2	3,385
-5	23.0	37,310	25	77.0	10,000	55	131.0	3,270
-4	24.8	35,570	26	78.8	9,605	56	132.8	3,160
-3	26.6	33,930	27	80.6	9,227	57	134.6	3,054
-2	28.4	32,370	28	82.4	8,867	58	136.4	2,952
-1	30.2	30,890	29	84.2	8,523	59	138.2	2,854

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APPENDIX III PT-100 SPECIFICATIONS

Pt-100 - Resistance versus Temperature in °C and °F

Pt-100 (100 Ω @ 0°C)

$$T = \frac{-\alpha + \sqrt{\alpha^2 - 4 \cdot \beta \cdot \left(\frac{-R}{100} + 1\right)}}{2 \cdot \beta}$$

α : $3.9080 \cdot 10^{-3}$ β : $-5.8019 \cdot 10^{-7}$

T ["C] = Temperature

R [Ω] = Resistance

Pt-100 Temperature vs. Resistance

Temperature [˚C]	[˚F]	Resistance [Ohm]	Temperature [˚C]	[˚F]	Resistance [Ohm]	Temperature [˚C]	[˚F]	Resistance [Ohm]
-30	-22.0	88.2	0	32.0	100.0	30	86.0	111.7
-29	-20.2	88.6	1	33.8	100.4	31	87.8	112.1
-28	-18.4	89.0	2	35.6	100.8	32	89.6	112.5
-27	-16.6	89.4	3	37.4	101.2	33	91.4	112.8
-26	-14.8	89.8	4	39.2	101.6	34	93.2	113.2
-25	-13.0	90.2	5	41.0	102.0	35	95.0	113.6
-24	-11.2	90.6	6	42.8	102.3	36	96.8	114.0
-23	-9.4	91.0	7	44.6	102.7	37	98.6	114.4
-22	-7.6	91.4	8	46.4	103.1	38	100.4	114.8
-21	-5.8	91.8	9	48.2	103.5	39	102.2	115.2
-20	-4.0	92.2	10	50.0	103.9	40	104.0	115.5
-19	-2.2	92.6	11	51.8	104.3	41	105.8	115.9
-18	-0.4	93.0	12	53.6	104.7	42	107.6	116.3
-17	1.4	93.3	13	55.4	105.1	43	109.4	116.7
-16	3.2	93.7	14	57.2	105.5	44	111.2	117.1
-15	5.0	94.1	15	59.0	105.9	45	113.0	117.5
-14	6.8	94.5	16	60.8	106.2	46	114.8	117.9
-13	8.6	94.9	17	62.6	106.6	47	116.6	118.2
-12	10.4	95.3	18	64.4	107.0	48	118.4	118.6
-11	12.2	95.7	19	66.2	107.4	49	120.2	119.0
-10	14.0	96.1	20	68.0	107.8	50	122.0	119.4
-9	15.8	96.5	21	69.8	108.2	51	123.8	119.8
-8	17.6	96.9	22	71.6	108.6	52	125.6	120.2
-7	19.4	97.3	23	73.4	109.0	53	127.4	120.6
-6	21.2	97.7	24	75.2	109.4	54	129.2	120.9
-5	23.0	98.0	25	77.0	109.7	55	131.0	121.3
-4	24.8	98.4	26	78.8	110.1	56	132.8	121.7
-3	26.6	98.8	27	80.6	110.5	57	134.6	122.1
-2	28.4	99.2	28	82.4	110.9	58	136.4	122.5
-1	30.2	99.6	29	84.2	110.3	59	138.2	122.9

APPENDIX IV MAIN SPECIFICATIONS

Specifications	
ISO classification	First Class
Response time (95 %)	5 s
Zero offsets due to temperature change (5 K/hr)	± 1 W/m²
Non-stability (change/year)	± 0.5 %
Non-linearity (0 to 1000 W/m²)	± 0.2 %
Temperature dependence of sensitivity	± 0.5 % (-20 to +50 °C)
Sensitivity	7 to 14 μV/W/m²
Impedance	10 to 100 Ω
Operating temperature	-40 to +80 °C
Spectral range (50 % points)	200 to 4000 nm
Typical signal output for atmospheric applications	0 to 15 mV
Maximum irradiance	4000 W/m²
Expected daily uncertainty	± 1 %
Full opening view angle	5 ° ± 0.2 °
Slope angle	1 ° ± 0.2 °
Required tracking accuracy	± 0.5 ° from ideal
Weight (excluding cable)	0.9 kg

APPENDIX V LIST OF WORLD AND REGIONAL RADIATION CENTRES

World Radiation Centres

Davos (Switzerland)
St. Petersburg (Russia) (data centre only)

Region I (Africa)
- Cairo (Egypt)
- Khartoum (Sudan)
- Kinshasa (Dem. Rep. of the Congo)
- Lagos (Nigeria)
- Tamanrasset (Algeria)
- Tunis (Tunisia)

Region II (Asia)
- Pune (India)
- Tokyo (Japan)

Region III (South America)
- Buenos Aires (Argentina)
- Lima (Peru)
- Santiago (Chile)

Region IV (North and Central America)
- Toronto (Canada)
- Boulder (United States)
- Mexico City (Mexico)

Region V (South-West Pacific)
- Melbourne (Australia)

Region VI (Europe)
- Budapest (Hungary)
- Davos (Switzerland)
- St. Petersburg (Russian Federation)
- Norrköping (Sweden)
- Trappes/Carpentras (France)
- Uccle (Belgium)
- Lindenberg (Germany)

APPENDIX VI RECALIBRATION SERVICE

Pyrheliometers, Albedometers, Pyrgeometers, UV-Radiometers & Sunshine Duration Sensors

Kipp & Zonen solar radiation measurement instruments comply with the most demanding international standards. In order to maintain the specified performance of these instruments, Kipp & Zonen recommends calibration of their instruments every two years.

This can be done at the Kipp & Zonen factory. Here, recalibration to the highest standards can be performed at low cost. Recalibration can usually be performed within four weeks. If required, urgent recalibration can be accomplished in three weeks or less (subject to scheduling restrictions). Kipp & Zonen will confirm the duration of recalibration at all times. Please note that special quantity recalibration discounts are available for instruments of the same type.

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Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares.

Für Servicearbeiten und Kalibrierung, Verbrauchsmaterial und Ersatzteile steht Ihnen unsere Customer Support Abteilung zur Verfügung.

Notre service 'Support Clientèle' reste à votre entière disposition pour tout problème de maintenance, réparation ou d'étalonnage ainsi que pour les accessoires et pièces de rechange.

Nuestro apoyo del cliente se queda a su disposición para cualquier mantenimiento o la reparación, la calibración, los suministros y reserva.

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