



Instruction Manual

CMP series • Pyranometer
CMA series • Albedometer

Important User Information

Dear customer, thank you for purchasing a Kipp & Zonen instrument. It is essential that you read this manual completely for a full understanding of the proper and safe installation, use, maintenance and operation of your new CMP series pyranometer or CMA series albedometer.

We understand that no instruction manual is perfect, so should you have any comments regarding this manual we will be pleased to receive them at:

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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 incurred, arising from the incorrect use of the product.

Modifications made by the user may affect the instrument performance, void the warranty, or affect the validity of the CE declaration or other approvals and compliances to applicable International Standards.

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**KIPP &
ZONEN**
SINCE 1830

EC Declaration of Conformity



Kipp & Zonen B.V.

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declares under our sole responsibility that the product

CMP 3, CMP 6, CMP10, CMP 11, CMP 21 and CMP 22 Pyranometer
and
CMA 6 and CMA 11 Albedometer

to which this declaration relates is in conformity with European Harmonised Standards as published in
Official Journal of the EC, issue: **C321/1 23-10-2012**

The compliance of the product has been based on the following standard

EN 61326-1:2006 [EMC - Emissions]

EN 61326-1:2006 [EMC - Immunity]

following the provisions of the directives

EMC-directive **2004/108/EC**

Delft, 1st January 2015

Dr. F. Kuik - CEO
Kipp & Zonen B.V.

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1. Introduction

Throughout this manual the following symbols are used to indicate to the user important information.



General warning about conditions, other than those caused by high voltage electricity, which may result in physical injury and/or damage to the equipment or cause the equipment to not operate correctly.

Note Useful information for the user

1.1 Product overview

According to International Standard ISO 9060:1990 and the World Meteorological Organisation (WMO) a pyranometer is the designated type of instrument for the measurement of hemispherical (global or diffuse) solar radiation integrated over the wavelength range from 0.3 to 3 μm (300 to 3000 nm). All pyranometers within the CMP series are compliant with one of the classes specified by the international standard.

The albedo of a surface is the extent to which it diffusely reflects short-wave radiation from the sun in the wavelength range from 300 to 3000 nm. It is the ratio of the reflected radiation to the incoming radiation and varies from 0 (dark) to 1 (bright). As an indication, albedo is about 0.15 for grass, 0.5 for dry sand and 0.8 for fresh snow.

CMA series albedometers consist of two pyranometers. The upper measures incoming global solar radiation and the lower measures solar radiation reflected from the surface below. When the two signal outputs have been converted to irradiance in W/m^2 , the albedo can be simply calculated.

This manual, together with the instruction sheets, provide information related to the installation, maintenance, calibration, product specifications and applications of the CMP series pyranometers and CMA series albedometers.

If any questions should remain, please contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: support@kipzonen.com

Please go to www.kipzonen.com for information about other Kipp & Zonen products, or to check for any updates to this manual.

1.1.1 The pyranometer and albedometer

The CMP series instruments are high quality radiometers designed for measuring short-wave irradiance on a plane surface (radiant flux, W/m^2) which results from the sum of the direct solar radiation and the diffuse sky radiation incident from the hemisphere above the instrument. The CMA series also measures the amount of the incoming radiation which is reflected by the surface below.

There are six models in the CMP series; CMP 3, CMP 6, CMP10, CMP 11, CMP 21 and CMP 22; and two models in the CMA series, CMA 6 and CMA 11.

To achieve the required spectral and directional characteristics CMP series pyranometers and CMA series albedometers use thermopile detectors and glass domes. They have built-in bubble levels and the pyranometers have adjustable levelling feet. Snap-on sun shields reduce solar heating of the housings. Albedometers have a mounting rod fitted and an integral glare-shield to prevent direct sunlight from below the horizon entering the lower pyranometer. The waterproof connectors have gold-plated contacts.

The instruments are normally delivered with a waterproof plug pre-wired to a high quality signal cable, typically this is 10 m long but other lengths are available. The instruments can also be ordered with a plug only, for the user to fit their own cable.

CMP pyranometers and CMA albedometers do not require power to operate. Radiation falling onto the sensing element produces a small analogue output voltage.

CMP 3 is smaller and lighter than the other CMP series pyranometers. It features a 64-junction thermopile sensing element with a highly absorptive and spectrally flat black coating to capture incoming radiation and convert it to an electrical signal. This detector is protected by a high quality glass dome which is 4 mm thick. The housing is completely sealed.

CMP 6 uses the same sensing element as CMP 3 but has improved performance due to the double glass dome construction and the increased thermal mass of the larger housing. The glass used has better transmission of ultraviolet radiation than the CMP 3 glass. The two high quality concentric domes, 2 mm thick, reduce directional error and improve thermal isolation. The radiometric levelling is more accurate and CMP 6 has a drying cartridge with replaceable desiccant.

CMP10 and CMP 11 have a 32-junction thermopile sensing element which features faster response, better linearity and a wider measurement range than the CMP 3 and CMP 6. CMP10 and CMP 11 have built-in temperature compensation. The CMP10 has internal desiccant that lasts for 10 years and the CMP 11 has a removable drying cartridge.

CMP 21 is similar to the CMP 11 but has individually optimised temperature compensation and a sensor is fitted to monitor the housing temperature. Each instrument is supplied with its own temperature and directional response for post-processing of recorded data by the user. A Pt-100 temperature sensor can be ordered instead of the standard 10 k Ω thermistor.

CMP 22 has all the features of CMP 21 but uses two 4 mm thick very high quality quartz domes for a wider spectral range and reduced thermal offsets. Because of the high optical quality and refractive index of these domes the directional error is greatly reduced.

CMA 6 is an albedometer comprised of two CMP 6 sensing element and dome assemblies in a single housing with two signal outputs on one signal connector.

CMA 11 uses two of the same sensing elements as fitted to the CMP 11 pyranometer, for similarly improved performance over the CMA 6.

Features and specifications of the CMP and CMA instruments are explained later in this manual.

1.1.2 International Standards

CMP 3 exceeds the requirements of ISO 9060:1990 for a Second Class Pyranometer.

CMP 6 and **CMA 6** are fully compliant with the requirements of ISO 9060:1990 for a First Class Pyranometer.

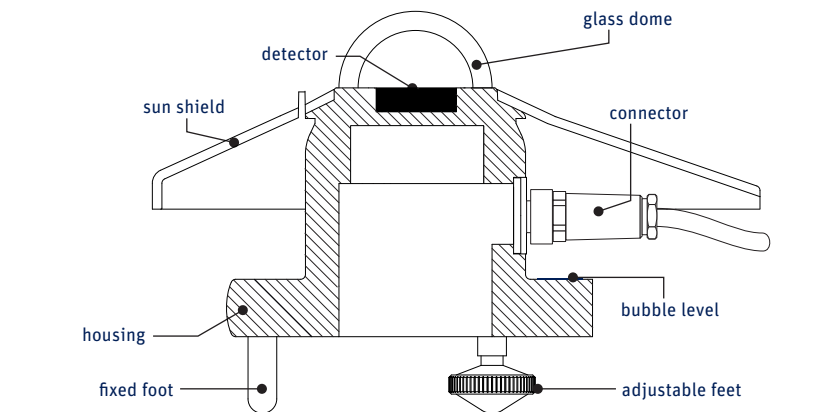
CMP10, CMP 11 and **CMA 11** are fully compliant with the requirements of ISO 9060:1990 for a Secondary Standard Pyranometer.

CMP 21 and **CMP 22** significantly exceed the requirements of ISO 9060:1990 for a Secondary Standard Pyranometer.

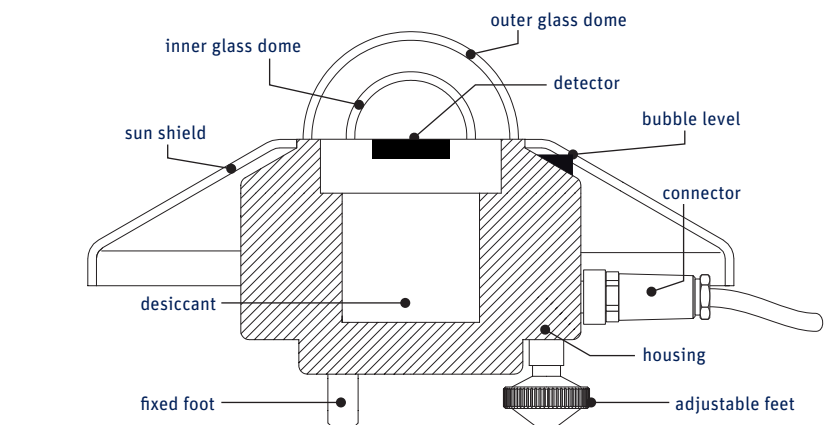
CMP series pyranometers and CMA series albedometers are calibrated in accordance with Annex A.3 of ISO 9847 'Calibration of Field Pyranometers by Comparison to a Reference Pyranometer'. Annex A.3 refers to 'Calibration Devices Using Artificial Sources'. Calibrations are traceable to the World Radiometric Reference (WRR) in Davos, Switzerland.

CMP series pyranometers comply with IEC 60904-1 'Photovoltaic devices - Part 1: Measurement of Photovoltaic Current-Voltage Characteristics'.

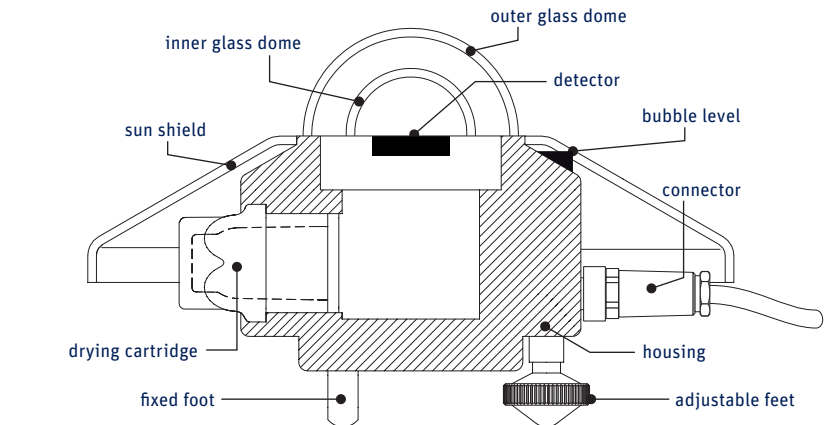
1.2 The CMP 3 pyranometer



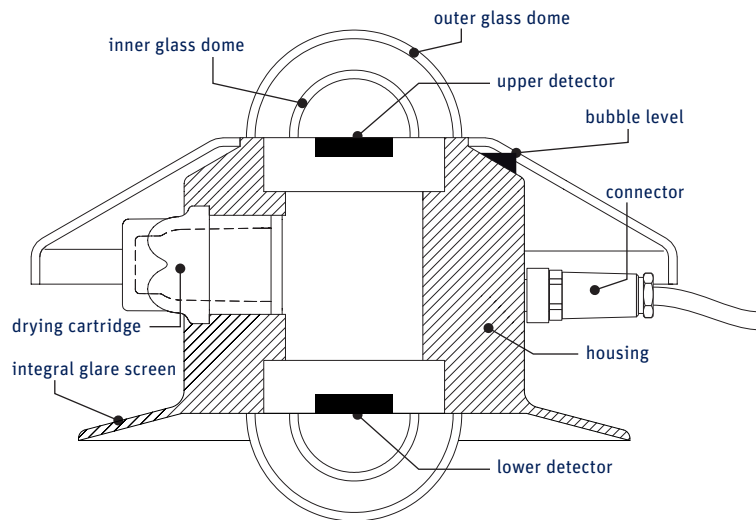
1.3 The CMP10 pyranometer



1.4 The CMP 6, CMP 11, CMP 21 and CMP 22 pyranometers



1.5 The CMA 6 and CMA 11 albedometers



2. Installation

Please follow the instructions in this section carefully, and also refer to the instruction sheets, for the correct mechanical and electrical installation of the CMP and CMA series radiometers.

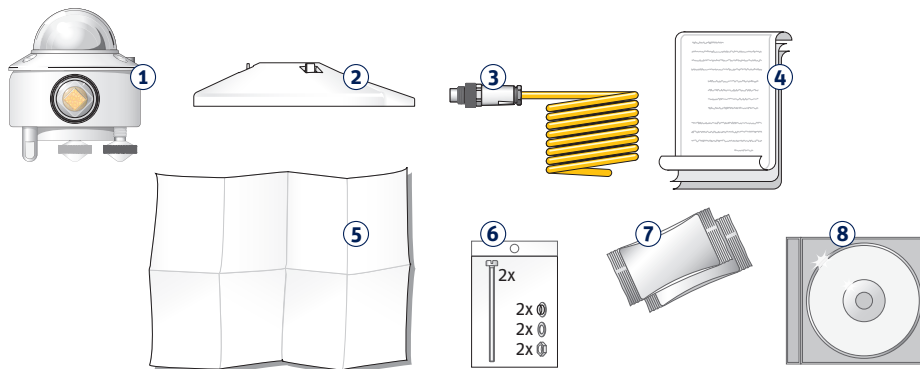
2.1 Included with the product

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 the case of damage and/or the contents are incomplete, contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: support@kippzonen.com

Although all CMP and CMA radiometers are weather-proof and suitable for use in 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.

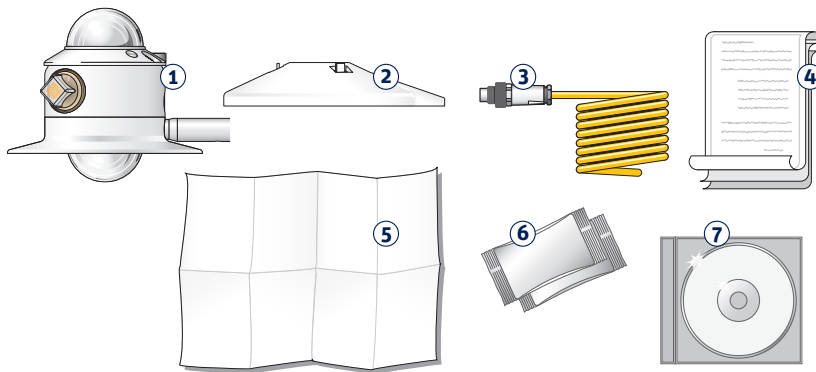
The following items are included with CMP series pyranometers:

- ① Pyranometer
- ② Sun shield
- ③ Cable, pre-wired with connector (2, 4 or 8 pins) or connector only for customer cable
- ④ Calibration certificate (with temperature response and directional response for CMP 21 and CMP 22)
- ⑤ Instruction sheet
- ⑥ Pyranometer fixing kit CMP 3; 2 each of stainless steel M5 x 30, M5 x 40 and M5 x 50 mm screws, nut, flat washer
Pyranometer fixing kit CMP 6, CMP10, CMP 11, CMP 21 and CMP 22; 2 each of stainless steel M5 x 80 mm screw, nut, flat washer, nylon insulation ring
- ⑦ 2 Dessiccant bags, except for CMP 3 (which is sealed) and CMP10 (desiccant lasts for 10 years, will be renewed every factory re-calibration)
- ⑧ CD-ROM with product documentation



The following items are included with CMA series albedometers:

- ① Albedometer with permanently fitted mounting rod
- ② Sun shield
- ③ Cable, pre-wired with connector (4 pins) or connector only for customer cable
- ④ Calibration certificate
- ⑤ Instruction sheet
- ⑥ 2 Dessicant bags
- ⑦ CD-ROM with product documentation



2.2 Tools required

The tools required to fit a CMP series pyranometer to a support are a 4 mm (M5 socket head screw) Allen key and an 8 mm (M5 nut) wrench/spanner. Tools required for the CMA series albedometers depend upon how the mounting rod will be attached to a mast or wall (fittings are not included). Normally, the drying cartridge should be hand-tight, but a 16 mm or 5/8" open-ended wrench/spanner can be used to loosen it.

2.3 Location and support

The Instruction sheets contain all the outline information necessary for the correct installation of the radiometers. Further details for specific types of installation and application are given later in this section.

Check the condition of the desiccant and replace before installation, if necessary; for example after a long storage period. Not required for CMP 3. The CMP10 internal desiccant is operational 10 years after the last calibration date as mentioned on the instrument label and calibration certificate.

2.4 Installation for measurement of horizontal global irradiance

The following steps must be carefully taken for optimal performance of the instrument.

2.4.1 Location

Ideally, the site for the radiometer should be free from any obstructions to the hemispherical view from the plane of the sensing element. If this is not possible, the site should be chosen in such a way that any obstruction over the azimuth range between earliest sunrise and latest sunset should have an elevation not exceeding 5° (the apparent sun diameter is 0.5°)

This is important for an accurate measurement of the direct solar radiation component. The diffuse solar radiation is less influenced by obstructions near the horizon. For instance, an obstruction with an elevation of 5° over the whole azimuth range of 360° decreases the downward diffuse solar radiation by only 0.8%.

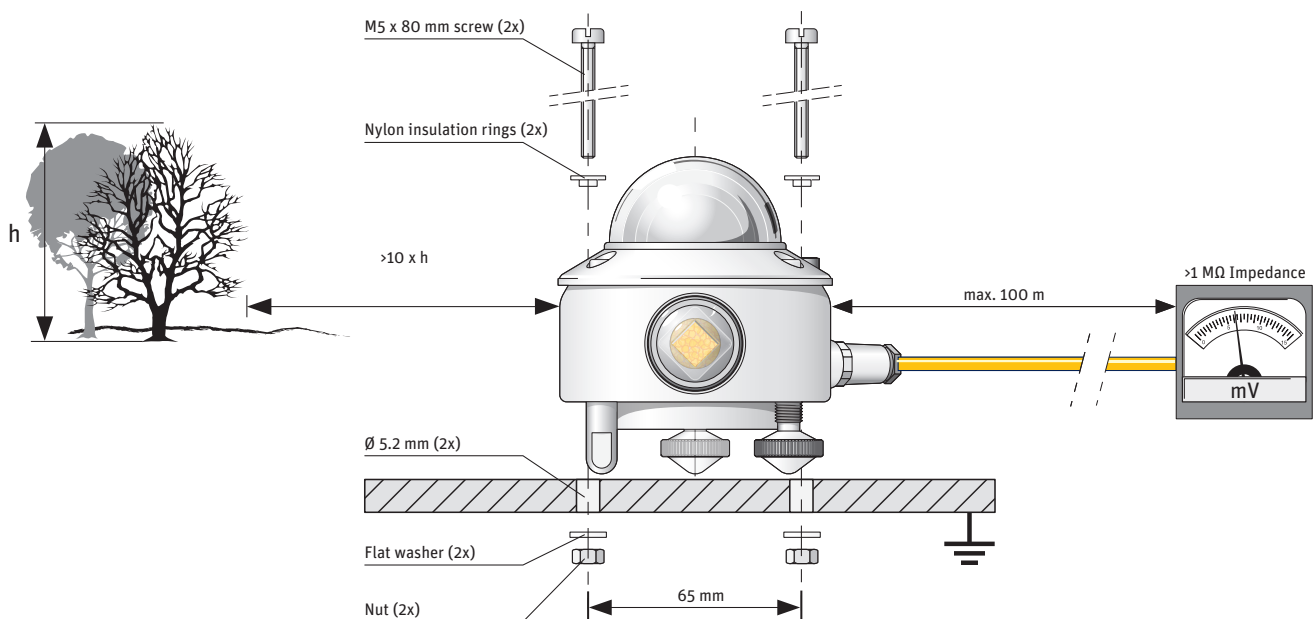
It is evident that the radiometer should be located in such a way that a shadow will not be cast upon it at any time (for example by masts). Note that hot exhaust gas ($> 100^\circ\text{C}$) from ventilation ducts will produce some radiation in the spectral range of the radiometer and cause an offset in the measurements. The radiometer should be distant from light-coloured walls or other objects likely to reflect sunlight onto it, or emitting short-wave radiation.

The radiometer should be readily accessible for cleaning the outer dome, checking that it is level and inspecting the desiccant.

2.4.2 Mounting

The CMP pyranometer is provided with two holes for 5 mm screws. Two each of stainless steel screws, washers and nuts are provided in the fixing kit, and two nylon insulation rings (except for CMP 3). The pyranometer should first be secured lightly with the screws to a solid and stable mounting stand or platform, as shown below. The nylon insulators are important to prevent corrosion between the stainless steel screws and the aluminium pyranometer housing (they are not supplied with CMP 3, where mounting through the base flange is less critical).

The mounting stand temperature may vary over a wider range than the air temperature. Temperature fluctuations of the pyranometer body can produce offset signals, therefore it is recommended to isolate the pyranometer thermally from the mounting stand by placing it on its three feet. However, ensure that there is a good electrical contact with the ground to conduct away currents in the cable shield induced by lightning.



Note After recalibration and/or reinstallation ensure that the nylon insulators are refitted.

CMA albedometers are fitted with a mounting rod with a flat on the top surface that is pre-aligned with the horizontal axis of the radiometer. The rod is 16 mm diameter and extends approximately 300 mm beyond the sun shield. The CMB 1 mounting bracket can be used for fixing the mounting rod to a mast, pole or wall. Also refer to the requirements in 2.6 and 2.7 for the measurement of reflected radiation and albedo.

CMP 3 has an accessory mounting rod which screws into the base flange of the pyranometer. The rod is 12 mm diameter and 300 mm long and can be used with the CMB 1 mounting bracket.

CMF 1 and CMF4 mounting fixtures for unventilated or ventilated (respectively) CMP series pyranometers have similar mounting rods to the albedometers and can also be used with the CMB 1.

2.4.3 Orientation

In principle no special orientation of the instrument is required, although the World Meteorological Organisation (WMO) recommends that the signal lead (connector) is pointed towards the nearest pole, to minimise heating of the electrical connections. This is also where any mounting pole, or other support, should be located in order that shadows do not fall on the instrument.

2.4.4 Levelling

Accurate measurement of the global radiation requires proper levelling of the detector surface. Level the instrument by turning the two adjustable feet to bring the bubble of the spirit level centrally within the marked ring. For easy levelling, first use the screw nearest to the spirit level.

Note It is ideal that the bubble should be completely within the marked ring. However, in fact, the pyranometer is level within the specified accuracy when the bubble is at least half within the ring.

2.4.5 Securing

Fix the pyranometer tightly with the two stainless steel bolts. For albedometers tighten the mounting rod fixings. Ensure that the radiometer maintains the correct levelled position when it is secured.

2.4.6 Fitting the connector and cable

Locate the plug correctly in the radiometer socket, it only fits one way, and push it in. Screw the plug locking ring hand-tight. Over-tightening may damage the waterproof seal. Secure the cable so that it cannot blow in the wind or cause a shadow on the instrument.

Note The cable should be arranged with a curve below the instrument so that water drips off, rather than running along the cable up to the connector.

2.4.7 Fitting the sun shield

Finally, clip on the sun shield to prevent excessive heating of the radiometer body. The bubble level is visible through the top of the sun shield for routine checks and the shield 'tail' helps to protect the connector.

2.5 Installation for measurement of tilted global irradiance

When a pyranometer is mounted on a large flat tilted surface the temperature of this surface can rise considerably (more than 10 °C) above air temperature. It improves the measurement accuracy when the body is thermally isolated by its feet from the surface. This promotes thermal equilibrium between the dome(s) and the housing and decreases zero offsets. It is advised to pre-adjust the levelling feet on a horizontal surface for easy mounting of the instrument parallel to the inclined surface.

For accurately and securely fixing a pyranometer at an angle to a surface an adjustable tilt mounting kit is available. See Accessories in chapter 3.

2.6 Installation for measurement of reflected global irradiance

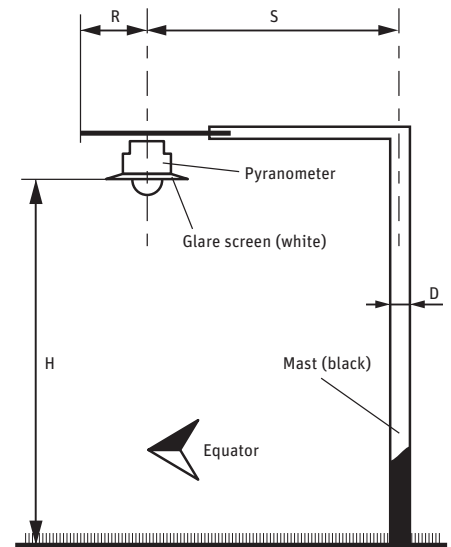
In the inverted position the pyranometer measures reflected global radiation. The height above the surface (H) depends upon its roughness. The WMO recommends a height of 1 m to 2 m above a uniform surface covered by short grass.

The mounting device should not interfere significantly with the field of view of the instrument. The mounting plate above the pyranometer prevents excessive heating of the housing by downwards solar radiation. CMF 1 or CMF4 mounting fixtures can be used. The accessory glare screen kit has an angle of 5° and is fitted to the pyranometer to prevent direct illumination of the domes by the sun at sunrise and sunset. It does not fit the CMP 3.

Thermal offset signals generated in the pyranometer are 5 times more significant in the measurement of reflected radiation due to the lower irradiance level.

The mast shown intercepts a fraction $D/2\pi S$ of the radiation coming from the ground. In the most unfavourable situation (sun at zenith) the pyranometer shadow decreases the signal by a factor R^2/H^2 .

As a guide, a black shadow below the pyranometer with a radius of $0.1 \times H$ decreases the signal by 1%, and 99% of the signal will originate from an area with a radius of $10 \times H$.



2.7 Installation for measurement of albedo

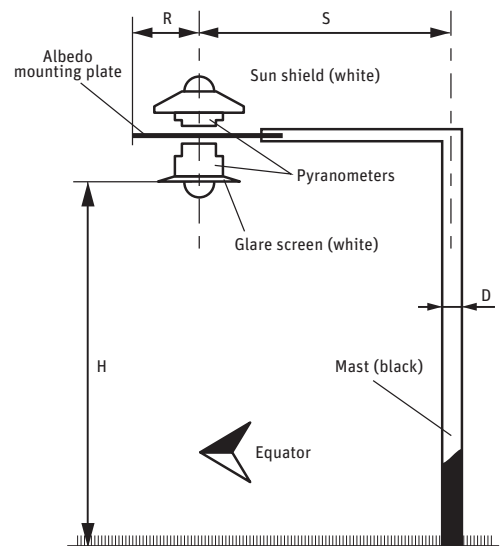
An albedometer consists of two identical pyranometers that measure the incoming global solar radiation and the radiation reflected from the surface below. Albedo is the ratio of the two irradiances, and varies from 0 (dark) to 1 (bright).

Two CMP 3's can be mounted back to back with the standard fixing kit, and the accessory mounting rod screwed into one of them, to make a second class albedometer.

For two of the larger CMP pyranometers a mounting fixture is required. The CMF 1 is used for unventilated pyranometers and the CMF4 for ventilated instruments. The glare screen kit should be fitted to the lower pyranometer.

The requirements for installation of the upper pyranometer are the same as for horizontal global irradiance. The requirements for installation of the lower pyranometer are the same as for reflected global irradiance.

The same principles apply to the CMA 6 and CMA 11 albedometers, which already have an upper sun shield and an integrated lower glare screen and mounting rod.



2.8 Installation for measurement of horizontal diffuse irradiance

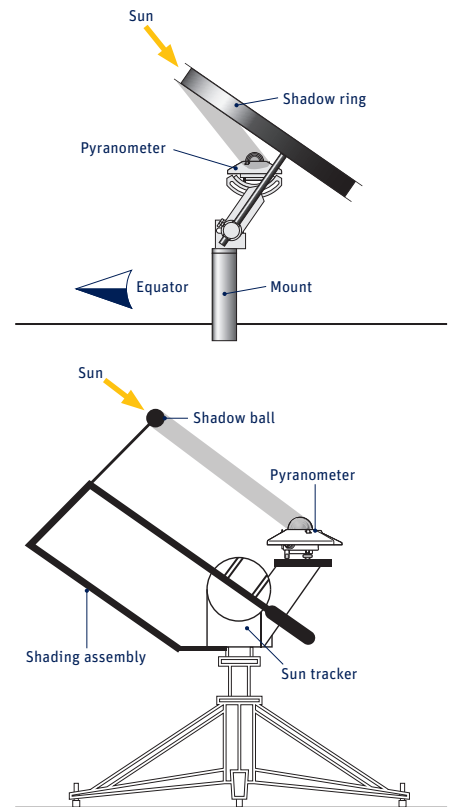
For measuring the diffuse radiation from the sky, the direct solar radiation must be blocked from the pyranometer dome(s).

A static shadow ring can be used to intercept the direct solar radiation. This requires frequent manual adjustment as the sun's arc in the sky changes. At times the shadow ring also intercepts a significant proportion of the diffuse sky radiation. Therefore, post-processing of the recorded data is necessary to correct for this.

Kipp & Zonen produces a universal shadow ring, model CM 121, which is suitable for use at all latitudes.

The alternative to a shadow ring is to use a two-axis automatic sun tracker, such as one of the Kipp & Zonen SOLYS 2 or 2AP. The sun tracker uses location and time information to calculate the position of the sun and point at it accurately under all weather conditions.

The sun tracker can be fitted with a small sphere mounted on an articulated shading assembly. The shadow of the sphere is adjusted to cover the pyranometer dome(s) completely and it will then be shaded correctly throughout the year without adjustment.



2.9 Electrical connections

As standard CMP pyranometers and CMA albedometers are supplied with a waterproof connector pre-wired to 10 m of high quality yellow cable with 2, 4 or 8 wires and a shield covered with a black sleeve. Longer cables of 25 m and 50 m length are available as options and 100 m on special request. The colour code of the wires and the connector pin numbers are shown below and on the instruction sheets.

Note Where the cable needs to be longer than 50 m, the AMBOX 4 to 20 mA signal amplifier is recommended.

2.9.1 Pyranometer connections

CMP 3, CMP 6, CMP10 and CMP 11 are fitted with a 2-pin connector and 2-wire shielded cable. CMP 21 and CMP 22 are fitted with a 4-pin connector and 4-wire shielded cable, the 2 extra connections are for the standard 10 kΩ thermistor temperature sensor signal. CMP 21 and CMP 22 with the optional Pt-100 temperature sensor are fitted with an 8-pin connector and 8-wire shielded cable, two wires are not used.

Radiation Signal			
Wire	Function	Connect with	
1	Red	+	+ (Hi)
2	Blue	-	- (Lo)
	Shield	Housing	⏏ Ground

Thermistor (CMP 21 and CMP 22)			
3		Green	Thermistor
4		Yellow	
Pt-100 (Optional for CMP 21 and CMP 22)			
4		Yellow	Combined
6		Brown	
3		Green	Combined
5		Grey	

2.9.2 Albedometer connections

CMA 6 and CMA 11 are fitted with a 4-pin connector and 4-wire shielded cable.

Radiation Signal		
Wire	Function	Connect with
1 Red	Upper	+ (Hi)
2 Blue		- (Lo)
3 Green	Lower	+ (Hi)
4 Yellow		- (Lo)
Shield	Housing	⏚ Ground

2.9.3 Grounding



The shield of the cable is connected to the aluminium radiometer housing through the connector body. Preferably, secure the radiometer with its levelling screws to a metal support with a good connection to ground (e.g. by using a lightning conductor) and do not connect the cable shield.



If there is no good ground connection at the pyranometer, the shield at the cable end should be connected to ground at the readout equipment. Lightning can induce high voltages in the shield but these will be led off at the pyranometer or readout equipment.

2.9.4 Radiation signal output

The radiometers produce a low-level analogue voltage output. Each radiometer (each 'half' of an albedometer) has a unique sensitivity, which is given on the serial number label on the instrument and on the calibration certificate.

The sensitivity is in the range of 5 to 20 $\mu\text{V}/\text{W}/\text{m}^2$.

Therefore, to accurately measure changes in irradiance of 1 W/m^2 the data logger or data acquisition system requires a total input measurement uncertainty (error) of 5 μV , or less; including noise, offsets, resolution, temperature effects, etc.

The maximum irradiance under natural sunlight is unlikely to exceed 1500 W/m^2 .

The signal output can be connected to a single-ended or differential measurement system input.

Note The input impedance of the readout equipment should be $> 1 \text{ M}\Omega$.

Note The output signal can be negative at night-time. This is normal and is not a fault (see section 7.2).

2.9.5 Temperature signal output

The CMP 21 and CMP 22 are fitted with an internal temperature sensor close to the cold-junction of the thermopile sensing element. Recording this signal allows post-processing of the radiation signal data to remove the small effect of temperature changes not compensated for by the internal circuit. The individual temperature response of each CMP 21 and CMP 22 is provided with the calibration certificate.

For the standard 10 k Ω thermistor temperature sensor the conversion from resistance to temperature is given in Appendix C.

For the optional Pt-100 temperature sensor the conversion from resistance to temperature is given in Appendix D.

3. Accessories

Below is a brief description of the accessories available for CMP series pyranometers. Detailed information can be found on our website, where the brochures and manuals for these accessories can be viewed and downloaded. The only accessories available for the CMA series albedometers are the CMB 1 mounting bracket and the AMPBOX 4 to 20 mA signal amplifier (two amplifiers are required).

3.1 Diffuse radiation measurement

For measuring diffuse radiation a shading device is required. Kipp & Zonen can offer several options for CMP pyranometers:

Shadow ring CM 121B for a CMP 3 or an unventilated CMP 6, CMP10, CMP 11, CMP 21 or CMP 22

Shadow ring CM 121C for a ventilated CMP 6, CMP10, CMP 11, CMP 21 or CMP 22

This shadow ring needs to be adjusted manually every 3-5 days and corrections made for the part of the sky obscured by the ring.

An automated and more accurate way to measure diffuse radiation is to use an automatic sun tracker fitted with a shading mechanism:

2AP sun tracker + shading ball assembly

SOLYS 2 sun tracker + shading ball assembly

3.2 Ventilation

To further improve measurement accuracy of the CMP 6, CMP10, CMP 11, CMP 21 or CMP 22 pyranometers the CVF4 ventilation unit can be used. CVF4 operates from 12 VDC, has a tachometer pulse output to monitor the fan speed, and both 5 Watt and 10 Watt heaters.

The advantages of a CVF4 are:

Lower thermal offsets

No precipitation or condensation on the dome

Less dirt on the dome

Frost, snow or ice can be melted

Less frequent cleaning required

No ventilation unit is available for the CMP 3 pyranometer or the CMA 6 and CMA 11 albedometers.

3.3 Mountings

For mounting pyranometers the following plates and brackets are available:

Mounting rod for CMP 3

CMF 1 mounting fixture with rod for mounting one or two unventilated CMP 6, CMP10, CMP 11, CMP 21 or CMP 22

CMF4 mounting plate with rod for mounting one or two ventilated CMP 6, CMP10, CMP 11, CMP 21 or CMP 22

CMB 1 mounting bracket to fix and adjust a mounting rod to a mast, pole or wall

Adjustable tilt mounting kit allows tilting of a CMP pyranometer (e.g. in the same plane as a PV panel), It has a clear scale for setting the desired angle.

3.4 Glare screen kit

When a CMP 6, CMP10, CMP 11, CMP 21 or CMP 22 pyranometer is mounted looking downwards, to measure reflected radiation, it should be fitted with the glare screen kit. The screen blocks radiation coming from the 5° below the horizon of the pyranometer, to prevent direct illumination of the domes by the sun at sunrise and sunset. CMA albedometers have an integral glare screen.

3.5 Cables

As standard a 10 m long cable with a pre-wired waterproof connector plug is supplied. Optional longer cables are available, or a loose connector only for you to fit to your own cable.

10 m cable with connector (standard)

25 m cable with connector

50 m cable with connector

Loose connector without cable

100 m cable with connector (on special request)

Note 100 m is the maximum length of cable that does not significantly affect the radiometer sensitivity and other characteristics.

3.6 AMPBOX

For customers who require an industry standard output, or to use long cables, the AMPBOX signal amplifier converts the low level radiometer voltage output to a 4 to 20 mA current loop signal. For a CMA albedometer, two AMPBOX units are required.

When supplied with a new pyranometer or albedometer the AMPBOX is adjusted such that the radiometer/AMPBOX pair gives an output where 4 to 20 mA represents 0 to 1600 W/m².

4. Operation and measurement

CMP series pyranometers and CMA albedometers only require a suitable source of radiation (light) to operate and make measurements, no power is required. However, it is necessary to connect them to some sort of readout or data storage device in order to save the measurements, there is no internal data memory.

4.1 Data collection

An optimal setting for the data interval is to sample every second and store one minute averages. For setting up the combination of radiometer and data storage please refer to the manual of the data collection device.

Take care to match the output range of the pyranometer to the input range of the data collection device to maximise the available resolution and minimise noise.

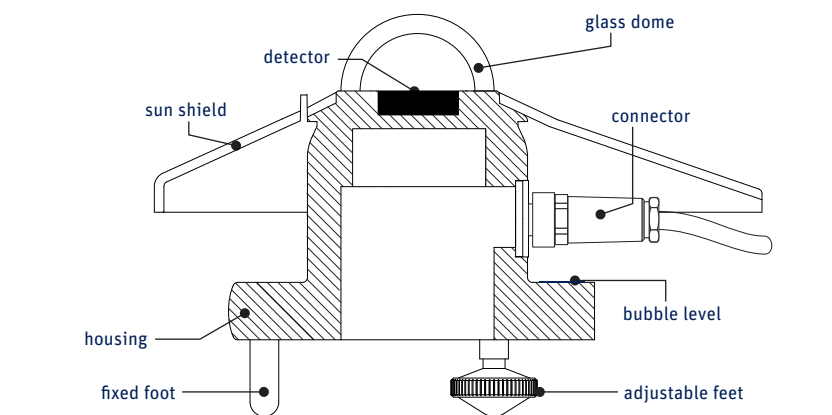
This can be done by determining the maximum expected analogue output of the pyranometer in your application and taking the minimum input range of your data collection device that can just handle that signal. Also refer to section 2.9.4.

4.2 Key parts of CMP and CMA series radiometers

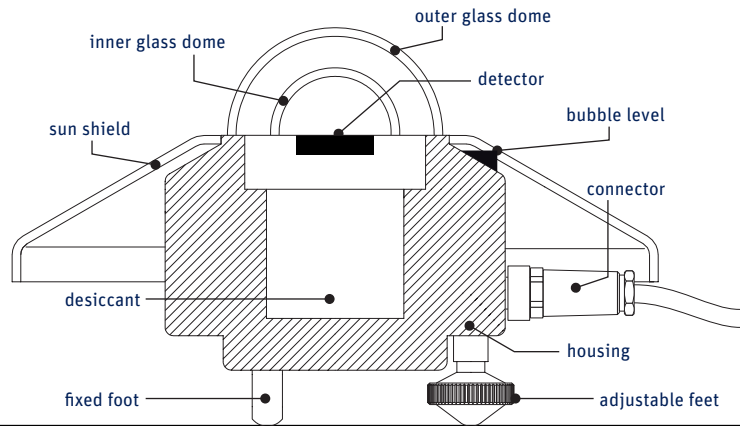
The detectors of the radiometers are based on a passive thermal sensing element called a thermopile. Although the detector construction differs between models, the fundamental working principle is applicable to all the radiometers.

The thermopile responds to the total energy absorbed by a unique black surface coating developed by Kipp & Zonen, which is spectrally non-selective. The thermopile warms up and the heat generated flows through a thermal resistance to a heat-sink, the pyranometer housing. The temperature difference across the thermal resistance of the detector is converted into a small voltage as a function of the absorbed irradiance.

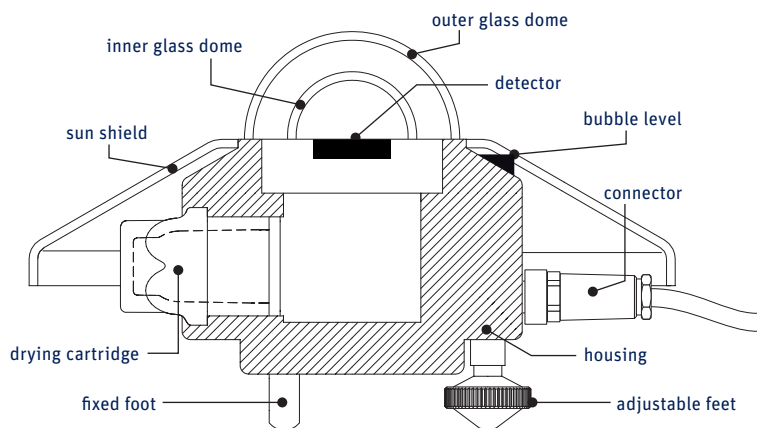
The rise of temperature in the thermopile is easily affected by wind, rain and thermal radiation losses to the environment (for example, a 'cold' sky) and the delicate black coating must be protected. Therefore the detector is shielded by two domes (except for the entry-level CMP 3, which has only one dome to reduce size and cost). These domes allow equal transmittance of the direct solar radiation component for every position of the sun in the hemisphere above the detector.



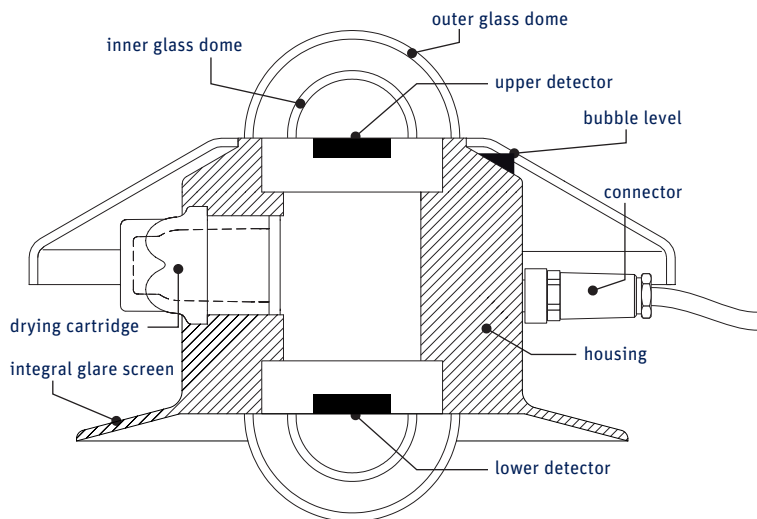
Key parts of the CMP 3 pyranometer



Key parts of the CMP10 pyranometer



Key parts of the CMP 6, CMP 11, CMP 21 and CMP 22 pyranometers



Key parts of the CMA 6 and CMA 11 albedometers

A drying cartridge in the radiometer housing is filled with replaceable silica gel and prevents condensation on the inner sides of the domes, which can cool down considerably on clear windless nights. The CMP 3 has a sealed construction with a non-replaceable internal drying cartridge. The CMP10 has an internal desiccant that lasts for 10 years.

4.2.1 Dome(s)

The material of the radiometer dome(s) defines the spectral measurement range of the instrument. In general 97 to 98 % of the solar radiation spectrum will be transmitted through the domes and will be absorbed by the detector. The solar irradiance can come from any direction within the hemisphere above the radiometer and therefore the domes are designed to minimize errors in measurement at all incident angles (the directional response).

CMP 3 pyranometers have a single 4 mm thick optical quality glass dome. CMP 6, CMP10, CMP 11 and CMP 21 have one inner dome and one outer dome. Each is 2 mm thick and of higher quality glass, with a broader spectral range and finer finishing and tolerances than the CMP 3. CMP 22 has two 4 mm thick domes of very high quality optical quartz.

4.2.2 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 radiometer depends on the individual physical properties of the thermopile and its construction. The sensitivity of each thermopile is unique and therefore each radiometer has an individual calibration factor. This sensitivity is given in the calibration certificate and is on the serial number label attached to the instrument.

The unique black coating on the top surface of the thermopile has a rough structure that effectively 'traps' more than 97% of the incident radiation and heats up the hot junctions. The black-coated thermopile forms the detector, which has a spectral selectivity of less than 2%. This means that within the spectral range of the pyranometer, the absorption for each wavelength is equal to within 2%. The black absorptive coating is one of the most crucial and delicate parts of the pyranometer, Kipp & Zonen's provides the best possible stability over a long period of time under all meteorological circumstances.

4.2.3 Housing

The instrument housing accommodates all the key parts of a radiometer. The anodized aluminium parts are light weight and give high mechanical and thermal stability to the instrument. The stainless steel fixings are isolated where necessary to prevent electrolytic corrosion.

Due to fine mechanical construction, Kipp & Zonen pyranometers and albedometers are virtually sealed and comply with international standard IP 67. Pyranometers have one fixed foot and two adjustable feet and can be levelled using the integral bubble level. For all except the CMP 3, the bubble level is visible from above without removing the snap-on white sun shield (CMP 3 has the bubble level in the base flange). The sun shield acts to protect all the external parts and to reduce solar heating of the housing.

4.2.4 Drying Cartridge

The entry-level CMP 3 has a sealed construction with a non-replaceable internal drying cartridge. However, this also makes it non-serviceable. For serviceability of the higher performance radiometers the construction cannot be completely sealed. In this case, over time, water vapour can 'breathe' into the housing, mainly due to temperature and pressure changes.

To keep the detector and electrical components dry and to prevent condensation forming inside the domes with temperature changes a self-indicating silica-gel desiccant is used to absorb humidity within the radiometer. When fresh the desiccant has an orange colour. After some time absorbing moisture the colour will change to clear (transparent). At this time the silica gel is not fully saturated, but should be replaced with fresh orange desiccant as soon as possible. Two packs of replacement desiccant are supplied with the radiometer. Further packs are available through Kipp & Zonen representatives. The CMP10 has a special sealing and internal desiccant that needs replacement after 10 years. This is done with every factory re-calibration.

4.2.5 Cable and Connector

For ease of installation of the radiometer, and replacement during re-calibration, the CMP and CMA series are provided with a waterproof connector socket fitted to the pyranometer housing. The matching waterproof plug is normally supplied pre-wired to a very high quality yellow cable selected for low noise, very wide temperature range and UV resistance.

Cables are supplied pre-wired to the connector plug in a range of lengths, 10 m is standard. 25 m, 50 m and 100 m lengths are also available. The connector plug can also be supplied loose for the user to fit to their own cable.

5. Maintenance and Re-calibration

CMP pyranometers and CMA albedometers are simple to maintain and do not require any special tools or training. There are no service items requiring scheduled replacement.

5.1 Daily maintenance

On clear windless nights the outer dome temperature of horizontally placed radiometers will decrease, even to the dew point temperature of the air, due to infrared radiation exchange with the cold sky. The effective sky temperature can be 30 °C lower than the ground temperature.

Depending upon the weather conditions; dew, glazed frost or hoar frost can be precipitated on the top of the dome and can stay there for several hours in the morning. An ice cap on the dome is a strong diffuser and decreases the pyranometer signal drastically, up to 50% in the first hours after sunrise. Snow may completely cover the dome.

The frequency of cleaning is highly dependent upon the local weather and environmental conditions, such as dust, airborne pollutants, or salt spray in marine locations. Ideally, the dome of the pyranometer should be cleaned every morning before sunrise. The frequency of cleaning can be reduced by the use of a ventilation unit (not available for the CMP 3, CMA 6 and CMA 11), with the heaters switched on when necessary.

Note Clean the dome using pure alcohol or distilled water and a lint-free cloth. Ensure that no smears or deposits are left on the dome.

5.2 Monthly maintenance

Check the desiccant in the drying cartridge. This is a non-toxic self-indicating silica-gel. When it requires replacement the colour changes from orange to clear (transparent).

To replace the desiccant unscrew the cartridge from the radiometer housing, if it is tight a 16 mm or 5/8" open-ended wrench/spanner can be used to loosen it. Remove the cap from the end of the cartridge and safely dispose of the used silica-gel. Refill with fresh desiccant, and refit the end cap to the cartridge. Make sure that the o-ring seal and its seat in the housing are clean and grease the seal with Vaseline if it is dry.

Note Screw in the drying cartridge hand-tight only, to avoid distorting the o-ring seal.

Desiccant refill packs are available from Kipp & Zonen. One pack is sufficient for one complete refill.

Check that the pyranometer is level and adjust if necessary.

Check that the sun shield is firmly clipped on.

5.3 Yearly maintenance

Check all the electrical connections. Unscrew the plugs, clean if necessary and then reconnect.

Check cables for damage caused by accident or by rodents.

Check the instrument mountings and any base supports are secure.

5.4 Calibration

An ideal radiometer gives an output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called 'sensitivity'. CMP and CMA series radiometers are very stable instruments, but they do change very slightly with time. This is largely due to exposure of the black detector coating to UV solar radiation. Re-calibration is recommended every two years. Normally this is carried out at the Kipp & Zonen factory or at an authorised calibration facility.

5.4.1 Calibration principle

At the Kipp & Zonen factory pyranometers are calibrated, or re-calibrated, in our laboratory according to ISO 9847:1992 'Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer', Annex A 'Calibration devices using artificial sources'. The specific method is given in Annex A.3.1 and is described in the standard as the 'Kipp & Zonen (calibration) device and procedure'.

This is based on a side-by-side comparison of the test pyranometer with a reference pyranometer of the same type under a stable artificial sun. Kipp & Zonen uses a Metal-Halide high-pressure gas discharge lamp with precise voltage stabilisation. The irradiance at the radiometers is approximately 500 W/m².

The reference pyranometers are regularly calibrated outdoors at the World Radiation Centre (WRC) in 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 the reference and test radiometers have the same characteristics.

To minimise stray light from the walls and the operator, the light is restricted to a small cone around the two radiometers. The test radiometer and the reference radiometer are placed side by side on a small rotating table. The lamp is centred on the axis of this table. The table is used to interchange the positions of the pyranometers to allow for inhomogeneity of the light field.

The pyranometers are illuminated and after time for the output to stabilise the readings of both radiometers are integrated over a measurement period. The lamp housing and beam restrictors heat up and emit long-wave infrared radiation which warms up the pyranometer dome(s) slightly. This causes a small offset that is embodied in the pyranometer response under illumination. To determine this offset both radiometers are shaded, and after time to stabilise, the signals of both radiometers are integrated over a period.

The radiometer positions are interchanged by rotating the table and the whole procedure is repeated.

The sensitivity of the test pyranometer is calculated by comparison to the reference pyranometer readings and the calibration certificate is produced. At Kipp & Zonen the complete process is automated under computer control.

Kipp & Zonen produces the CFR Calibration Facility for Radiometers for customers to make their own pyranometer calibrations to ISO 9847, Annex A.3.1. CMA albedometers are calibrated twice, once for the upper pyranometer and once for the lower. An adapter is available to mount a CMA albedometer on the CFR turntable.

5.4.2 Calibration traceability to the WRR

Our reference pyranometers are calibrated at the World Radiation Centre (WRC) in Davos, Switzerland by comparison to the World Radiometric Reference (WRR). They are also fully characterized for linearity, temperature dependence and directional response to enable transfer of the sensitivity under the measurement conditions in Davos to our calibration laboratory conditions.

Kipp & Zonen keeps at least two reference instruments for each pyranometer model. These reference instruments are sent alternate years to the WRC for calibration, so that production and calibration in Delft can continue without interruption.

Kipp & Zonen calibration certificates include an overview of the calibration method, details of the reference pyranometer used, traceability to the WRR, and the uncertainty in the calibration chain from the WRR to the pyranometer being calibrated.

6. Specifications

Kipp & Zonen reserves the right to make changes to specifications and other product documentation without prior notice.

6.1 Optical and electrical

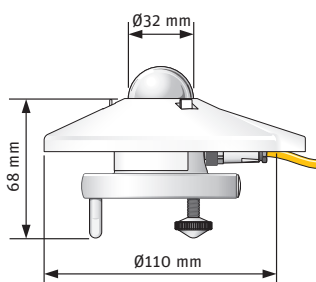
Specifications	CMP 3	CMP 6	CMP10 & CMP 11	CMP 21	CMP 22
Classification to ISO 9060:1990	Second Class	First Class	Secondary Standard	Secondary Standard	Secondary Standard
Spectral range (50% points)	300 to 2800 nm	285 to 2800 nm	285 to 2800 nm	285 to 2800 nm	200 to 3600 nm
Sensitivity	5 to 20 $\mu\text{V}/\text{W}/\text{m}^2$	5 to 20 $\mu\text{V}/\text{W}/\text{m}^2$	7 to 14 $\mu\text{V}/\text{W}/\text{m}^2$	7 to 14 $\mu\text{V}/\text{W}/\text{m}^2$	7 to 14 $\mu\text{V}/\text{W}/\text{m}^2$
Impedance	20 to 200 Ω	20 to 200 Ω	10 to 100 Ω	10 to 100 Ω	10 to 100 Ω
Expected output range (0 to 1500 W/m^2)	0 to 30 mV	0 to 30 mV	0 to 20 mV	0 to 20 mV	0 to 20 mV
Maximum operational irradiance	2000 W/m^2	2000 W/m^2	4000 W/m^2	4000 W/m^2	4000 W/m^2
Response time (63%)	< 6 s	< 6 s	< 1.7 s	< 1.7 s	< 1.7 s
Response time (95%)	< 18 s	< 18 s	< 5 s	< 5 s	< 5 s
Zero offsets					
(a) thermal radiation (at 200 W/m^2)	< 15 W/m^2	< 12 W/m^2	< 7 W/m^2	< 7 W/m^2	< 3 W/m^2
(b) temperature change (5 K/h)	< 5 W/m^2	< 4 W/m^2	< 2 W/m^2	< 2 W/m^2	< 1 W/m^2
Non-stability (change/year)	< 1%	< 1%	< 0.5%	< 0.5%	< 0.5%
Non-linearity (100 to 1000 W/m^2)	< 1.5%	< 1%	< 0.2%	< 0.2%	< 0.2%
Directional response (up to 80° with 1000 W/m^2 beam)	< 20 W/m^2	< 20 W/m^2	< 10 W/m^2	< 10 W/m^2	< 5 W/m^2
Spectral selectivity (350 to 1500 nm)	< 3%	< 3%	< 3%	< 3%	< 3%
Temperature response	< 5% (-10°C to +40°C)	< 4% (-10°C to +40°C)	< 1% (-10°C to +40°C)	< 1% (-20°C to +50°C)	< 0.5% (-20°C to +50°C)
Tilt response (0° to 90° at 1000 W/m^2)	< 1%	< 1%	< 0.2%	< 0.2%	< 0.2%
Field of view	180°	180°	180°	180°	180°
Accuracy of bubble level	< 0.2°	< 0.1°	< 0.1°	< 0.1°	< 0.1°
Temperature sensor output				10 K Thermistor (optional Pt-100)	10 K Thermistor (optional Pt-100)
Detector type	Thermopile	Thermopile	Thermopile	Thermopile	Thermopile
Operational temperature range	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C
Storage temperature range	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C	-40°C to +80°C
Humidity range	0 to 100% non-condensing	0 to 100% non-condensing	0 to 100% non-condensing	0 to 100% non-condensing	0 to 100% non-condensing
Ingress Protection (IP) rating	67	67	67	67	67
Recommended applications	Economical solution for routine measurements in weather stations, field testing	Good quality measurements for hydrology networks, greenhouse climate control	Meteorological networks, PV panel and thermal collector testing, materials testing	Meteorological networks, reference measurements in extreme climates, polar or arid	Scientific research requiring the highest level of measurement accuracy and reliability

Note: The performance specifications quoted are worst-case and/or maximum values

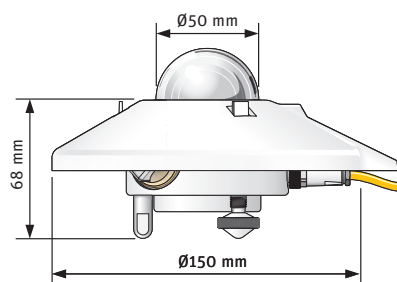
Standard 10 k Thermistor or optional Pt-100 temperature sensor with CMP 21 and CMP 22

Individual directional response and temperature dependence test data with CMP 21 and CMP 22

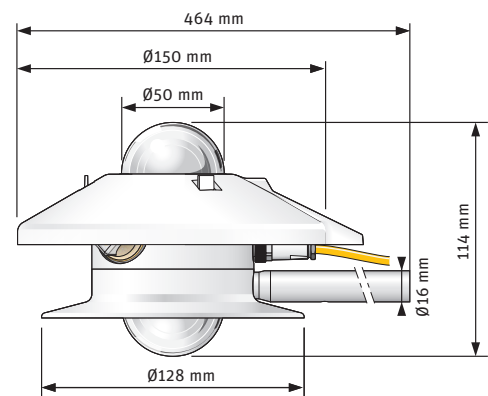
6.2 Dimensions and weight



CMP 3
Weight without cable: 0.3 kg



CMP 6, CMP10, CMP 11, CMP 21 and CMP 22
Weight without cable: 0.6 kg



CMA 6 and CMA 11
Weight without cable: 1.2 kg

7 . Trouble shooting

Note There are no user-serviceable parts within the CMP pyranometers and CMA albedometers. They must not be opened without the agreement and instruction of Kipp & Zonen.

7.1 Output signal not present or incorrect

The following contains a procedure for checking the instrument in case it appears that it does not function correctly:

1. Check the radiometer cable wires are properly connected to the readout equipment.
2. Check the instrument location. Are there any obstructions that cast a shadow on the instrument by blocking the direct sun during some part of the day?
3. Check the dome, it should be clear and clean. If condensation 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 and then replace the cartridge with new desiccant. It may take several days for the sensitivity to fully recover to the original value.
4. Check the data logger or readout offset by connecting a dummy load (100 Ohm resistor). This should give a 'zero' reading.
5. Check levelling. The bubble should be at least half inside the marked ring of the level.
6. If water, frost or ice is deposited on the dome, clean it. Usually, water droplets will evaporate in less than one hour under sunlight.

Any malfunction or visible damage should be reported to your Kipp & Zonen representative, who will suggest the appropriate action.

7.2 Frequently asked questions

The most frequently asked questions are listed below. For an update or further information refer to our website at www.kippzonen.com.

Q: Negative output during night-time measurements?

A: This effect is related to Zero Offset Type A. Normally this zero offset is present when the (inner) dome has a different temperature from the cold junctions of the sensor (the instrument housing). In practice, this is always the case when there is a clear sky. Because of the low effective sky temperature ($< 0^{\circ}\text{C}$) the Earth's surface emits roughly 100 W/m^2 of long-wave infrared radiation upwards. The (outer) glass dome of a pyranometer also has this emission and is cooling down several degrees below air temperature (the emissivity of glass for the particular wavelength region is nearly 1).

Heat is emitted from the body by conduction in the domes, by wind, and from the domes through infrared radiation. The heat flow is opposite to the heat flow when absorbing solar radiation and causes the well-known zero depression at night. This negative zero offset is also present in day-time with a clear sky but is hidden within the solar radiation signal.

Zero Offset Type A can be checked by placing a light and infrared reflecting cap over the pyranometer. The response to solar radiation will decay with the response time of the instrument, but the dome temperature will go to equilibrium with a time constant of several minutes. So after about half a minute the remaining signal is mainly Zero Offset Type A.

Good ventilation of the domes and housing minimises zero offsets and increases stability. Using the Kipp & Zonen CVF4 ventilation unit can reduce Zero Offset Type A by about 50%.

Q: Maximum and minimum irradiation quantities?

A: Due to reflection from certain types of clouds the global irradiance at sea level can rise above the extra-terrestrial direct irradiance (the Solar Constant) of 1367 W/m^2 at the top of the atmosphere (WMO 1982). Values up to 1500 W/m^2 have been reported.

Because the clouds move, this irradiance value mostly appears as short events of a few minutes duration.

Q: What is the primary entry point for humidity?

A: The CMP 3 is fully sealed, but this also means that it is not serviceable. The construction of the other CMP and CMA radiometers allows servicing, such as dome replacement. However, this means that there are seals in the construction that are waterproof, but not gas-tight. Therefore, water vapour can slowly enter due to temperature and pressure changes. The CMP10 has a special sealing that makes the internal desiccant last for 10 years.

Q: Is the pyranometer calibration affected by the length of the signal cable?

A: With longer cable lengths the impedance increases, however it does not affect the radiometer sensitivity for the following reason.

The maximum output impedance of a radiometer with 100 m of Kipp & Zonen cable ($R = 75 \Omega/\text{km}$) is about 200Ω . If the input impedance of the voltage measurement (readout) device is at least $1 \text{ M}\Omega$ (as recommended) this represents only 0.02%. Therefore, the current through the signal cable, and any signal reduction, is a similar percentage and is negligible.

The loading will slightly affect the passive temperature compensation circuit of the CMP10, CMP 11, CMP 21 and CMP 22, but this is also negligible.

When the body temperature of the CMP 21 and CMP 22 is measured with the standard $10 \text{ k}\Omega$ thermistor temperature sensor, the nominal resistance at $+50^\circ\text{C}$ is 3893Ω and 100 m of Kipp & Zonen cable adds 15Ω ($2 \times 7.5 \Omega$). Therefore, the error is 0.4% compared to the nominal temperature sensor uncertainty of 0.1%. The optional Pt-100 temperature sensor used in 4-wire mode compensates for the cable resistance and no additional errors occur.

8. Customer support

If you require any support for your Kipp & Zonen product please contact your local representative in the first instance. The information can be found in the 'Contact' section of our website at www.kippzonen.com

Alternatively, you can contact us directly at www.kippzonen.com/support

Please include the following information:

- Instrument model
- Instrument serial number
- Details of the fault or problem
- Examples of data files
- Readout device or data acquisition system
- Interfaces and power supplies
- History of any previous repairs or modifications
- Pictures of the installation
- Overview of the local environment conditions

Kipp & Zonen guarantees that your information will not be shared with other organisations.

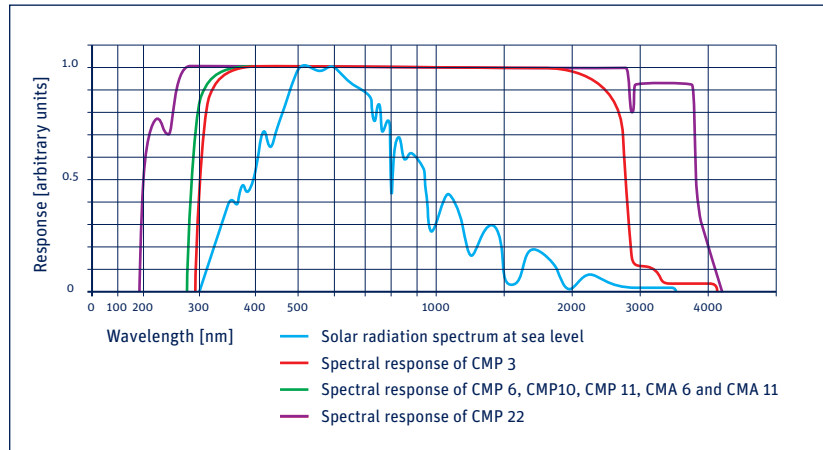
9. Keyword index

Term	Explanation
Albedo	The portion of incoming radiation which is reflected by a surface
Azimuth angle	Angle in horizontal direction (0 to 360°) normally referred to North
Cosine response	Radiometer directional response according to the cosine of the zenith angle
Diffuse horizontal irradiance	Solar radiation, scattered by water vapour, dust and other particles as it passes through the atmosphere, falling onto a horizontal plane surface (DHI)
Direct normal irradiance	Radiation that has travelled in a straight path from the sun falling onto a plane surface normal to the beam (DNI)
Global horizontal irradiance	Total irradiance falling onto a horizontal plane surface (GHI) Global = Diffuse + (Direct x cos α); α is the solar zenith angle
Irradiance	Radiant flux density (W/m ²)
Long-wave radiation	Radiation with wavelengths from 4 μm to more than 40 μm
Pyranometer	Radiometer for measuring short-wave global radiation
Pyrgometer	Radiometer for measuring long-wave radiation
Pyrheliometer	Radiometer for measuring direct short-wave radiation
Short-wave radiation	Radiation with wavelengths from approximately 300 nm to 4000 nm (4 μm)
Thermopile	Thermal detector made up of many thermocouple junctions
WMO	World Meteorological Organisation, Geneva, Switzerland
WRC	World Radiation Centre, Davos, Switzerland
WRR	World Radiometric Reference (standard radiation scale) at WRC
WSG	World Standard Group of radiometers at WRC
Zenith angle	Angle from zenith (0° is vertical, 90° is horizontal)

Appendix A. Pyranometer physical properties

A.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). Due to the excellent physical properties of the glass dome(s) and black absorber paint, Kipp & Zonen CMP and CMA series radiometers are equally sensitive in a wide spectral range. 97 - 98% of the total energy will be absorbed by the thermal detector.



A.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. The sensitivity is determined under standard conditions, and compared with a reference, that are stated on the calibration certificate.

A.3 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 changes in the incident radiation. The response time is normally quoted as the time for the output to reach 95% (sometimes $1/e$, 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.

A.4 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, connections, and passive electronics within the radiometer.

A.5 Non-linearity

The non-linearity of a pyranometer is defined in ISO 9060:1990 as the percentage deviation in the sensitivity over an irradiance range from 100 to 1000 W/m² compared to the sensitivity at the calibration irradiance of 500 W/m². The non-linear effect is largely due to convective and radiative heat losses at the black absorber surface which make the conditional thermal equilibrium of the radiometer non-linear.

A.6 Temperature dependence

The sensitivity change of a radiometer with ambient temperature change is related to the thermo-dynamics of the radiometer construction. This is given as percentage deviation with respect to the calibrated sensitivity at +20 °C.

CMP 3, CMP 6 and CMA 6 do not have any built-in temperature compensation.

CMP10, CMP 11 and CMA 11 have a passive temperature compensation circuit with a standardised linear function.

CMP 21 and CMP 22 have individually optimised linear temperature compensation. As the temperature dependence is not linear, the compensation cannot be exact. Therefore these instruments are supplied with the individual data for the (small) residual temperature dependence. The internal temperature can be monitored with the integrated sensor and the irradiance data can then be post-processed to minimise any remaining errors.

A.7 Tilt error

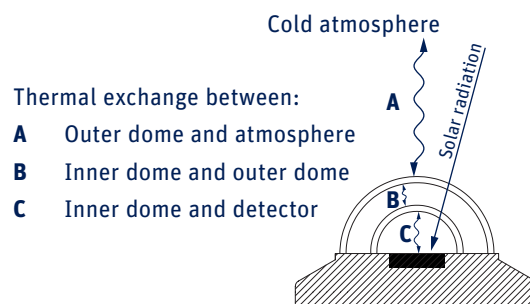
This is the deviation from the sensitivity at 0° tilt (exactly horizontal) over the range from 0° to 90° tilt (vertical) under 1000 W/m² of normal incidence irradiance. The tilt response is proportional to the incident radiation. The error can be corrected in applications where it is necessary to install the pyranometer on an inclined surface, but is usually insignificant.

A.8 Zero offset type A

By physical laws any object having a certain temperature will exchange radiation with its surroundings. The domes of upward facing radiometers will exchange radiation primarily with the relatively cold atmosphere. In general, the atmosphere will be cooler than the ambient temperature at the Earth's surface. For example, a clear sky can have an effective temperature up to 50 °C cooler, whereas an overcast sky will have roughly the same temperature as the Earth's surface.

Due to this, the pyranometer domes will 'lose' energy to the colder atmosphere by means of radiative transfer. This causes the dome to become cooler than the rest of the instrument. This temperature difference between the detector 'view' and the instrument housing will generate a small negative output signal which is commonly called Zero Offset Type A. This effect is reduced by using an inner dome. This inner dome acts as a 'radiation buffer'. Also see section 7.2.

This offset can be minimized by applying appropriate ventilation of the instrument. No ventilation unit is available for the CMP 3, CMA 6 or CMA 11. The CVF4 ventilation unit can be used with the CMP 6, CMP10, CMP 11, CMP 21 and CMP 22.



A.9 Zero offset type B

Proportionally to the ambient temperature the instrument temperature varies and causes thermal currents inside the instrument. This will cause an offset commonly called Zero Offset Type B. It is quantified in ISO 9060:1990 as the response in W/m^2 to a 5 K/hr change in ambient temperature.

A.10 Operating temperature

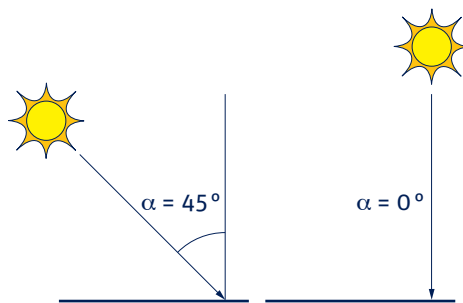
The operating temperature range of the radiometer is determined by the physical properties of the individual parts. Within the specified temperature range Kipp & Zonen radiometers can be operated safely. Outside this temperature range special precautions should be taken to prevent any physical damage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

A.11 Field of view

The field of view is defined as the unobstructed open viewing angle of a radiometer. ISO and WMO require that a pyranometer for the measurement of global solar radiation has a field of view of 180° in all directions (i.e. a hemisphere). The inherent field of view of the instrument should not be confused with the clear field of view of the installation location.

A.12 Directional response

Radiation incident on a flat horizontal surface originating from a point source with a defined zenith position (such as the sun) will have an intensity value proportional to the cosine of the zenith angle of incidence. This is sometimes called the 'cosine-law' or 'cosine-response' and is illustrated below. α is the zenith angle, where 0° is vertical and 90° is horizontal.



Ideally a pyranometer has a directional response which is exactly the same as the cosine-law. However, in a pyranometer the directional response is influenced by the detector and by the quality, dimensions and construction of the dome(s). The maximum deviation from the ideal cosine-response of the pyranometer is given up to 80° angle of incidence with respect to $1000 W/m^2$ irradiance at normal incidence (0° zenith angle).

A.13 Maximum irradiance

The maximum irradiance is defined as the total irradiance level beyond which physical damage may occur to the instrument.

A.14 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 coating on the thermopile 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 pyranometers for more information.

A.15 Spectral selectivity

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

A.16 Environmental

The CMP and CMA series are intended 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.

For use in harsh marine environments, such as offshore; the CMP 6, CMP10, CMP 11, CMP 21 and CMP 22 are available to special order in stainless steel construction - at extra cost, and subject to a minimum order quantity.

A.17 Uncertainty

The measurement uncertainty of a pyranometer can be described as the maximum expected hourly or daily uncertainty with respect to the 'absolute truth'. The confidence level is 95%, which means that 95% of the data-points lie within the given uncertainty interval representing the absolute value. Kipp & Zonen empirically determines uncertainty figures based on many years of field measurements for typical operating conditions.

When a pyranometer is in operation, the performance is correlated to a number of parameters, such as; temperature, level of irradiance, angle of incidence, etc. If the operating conditions differ significantly from the calibration conditions, uncertainty in the calculated irradiances must be expected.

For a 'High Quality' pyranometer the WMO expects maximum uncertainty in the hourly radiation totals of 3%. In the daily total an uncertainty of 2% is expected; because some response variations cancel each other out if the integration period is long. See the WMO 'Guide to Meteorological Instruments and Methods of Observation' Seventh Edition, 2008. ISO 9060:1990 does not refer to hourly or daily uncertainties.

Many years of experience has shown that pyranometer performance can be improved concerning zero offset type A by using a well-designed ventilation system. The Kipp & Zonen CVF4 ventilation unit is recommended for the CMP 6, CMP10, CMP 11, CMP 21 and CMP 22 to minimise this small remaining error.

Appendix B. Pyranometer classification to ISO 9060:1990(E)

Reference number and Specification	
1	Response time (95%)
2	Zero offsets (a) Response to 200 W/m ² net thermal radiation (ventilated) (b) Response 5 K/hr change in ambient temperature
3a	Non-stability percentage change in responsivity per year
3b	Non-linearity percentage deviation from the responsivity at 500 W/m ² due to the change of irradiance within the range 100 W/m ² to 1000 W/m ²
3c	Directional response (for beam radiation) the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction a beam of radiation whose normal incidence irradiance is 1000 W/m ²
3d	Spectral selectivity percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 0.35 μm and 1.5 μm
3e	Temperature response percentage deviation due to change in ambient temperature within an interval of 50 K
3f	Tilt response percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000 W/m ² irradiance

Reference number	ISO Pyranometer Categories			CMP 3	CMP 6/CMA 6	CMP10, 11/CMA 11	CMP 21	CMP 22
	Second Class	First Class	Secondary Standard	Second Class	First Class	Secondary Standard	Secondary Standard	Secondary Standard
1 Response time (95%)	< 60 s	< 30 s	< 15 s	< 18 s	< 18 s	< 5 s	< 5 s	< 5 s
2 Zero offsets (a) (b)	± 30 W/m ² ± 8 W/m ²	± 15 W/m ² ± 4 W/m ²	± 7 W/m ² ± 2 W/m ²	< 15 W/m ² ⁽¹⁾ < 5 W/m ²	< 15 W/m ² ⁽¹⁾ < 4 W/m ²	< 7 W/m ² ⁽¹⁾ < 2 W/m ²	< 7 W/m ² ⁽¹⁾ < 2 W/m ²	< 3 W/m ² ⁽¹⁾ < 1 W/m ²
3a Non-stability	± 3.0%	± 1.5%	± 0.8%	< 1%	< 1%	< 0.5%	< 0.5%	< 0.5%
3b Non-linearity	± 3%	± 1%	± 0.5%	< 1%	< 1%	< 0.2%	< 0.2%	< 0.2%
3c Directional response (for beam radiation)	± 30 W/m ²	± 20 W/m ²	± 10 W/m ²	< 20 W/m ² up to 80° zenith angle	< 20 W/m ² up to 80° zenith angle	< 10 W/m ² up to 80° zenith angle	< 10 W/m ² up to 80° zenith angle	< 5 W/m ² up to 80° zenith angle
3d Spectral selectivity	± 10%	± 5%	± 3%	< 3%	< 3%	< 3%	< 3%	< 3%
3e Temperature response	8%	4%	2%	< 5% (-10°C to +40°C) interval of 50 K	< 4% (-10°C to +40°C) interval of 50 K	< 1% (-10°C to +40°C) interval of 50 K	< 1% (-20°C to +50°C) interval of 70 K	< 0.5% (-20°C to +50°C) interval of 70 K
3f Tilt response	± 5%	± 2%	± 0.5%	< 1%	< 1%	< 0.2%	< 0.2%	< 0.2%

⁽¹⁾ without ventilation

Appendix C. 10kΩ Thermistor specifications

Thermistor (10 kΩ @ 25 °C)	
$T = \left(\alpha + \left[\beta \cdot (\ln(R)) + \gamma \cdot (\ln(R))^3 \right] \right)^{-1} - 273.15$	
$\alpha : 1.03 \cdot 10^{-3} \quad \beta : 2.38 \cdot 10^4 \quad \gamma : 1.59 \cdot 10^{-7}$	

T [°C] = Temperature

R [Ω] = Resistance

YSI Thermistor 44031 - Resistance versus Temperature in °C and °F								
Temperature		Resistance	Temperature		Resistance	Temperature		Resistance
[°C]	[°F]	[Ohm]	[°C]	[°F]	[Ohm]	[°C]	[°F]	[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	43,100	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

Appendix D. Pt-100 specifications

Pt-100 (100 Ω @ 0°C)

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

$\alpha : 3.9083 \cdot 10^{-3} \quad \beta : -5.8019 \cdot 10^{-7}$

T [°C] = Temperature

R [Ω] = Resistance

Pt-100 - Resistance versus Temperature in °C and °F								
Temperature		Resistance	Temperature		Resistance	Temperature		Resistance
[°C]	[°F]	[Ohm]	[°C]	[°F]	[Ohm]	[°C]	[°F]	[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	111.3	59	138.2	122.9



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