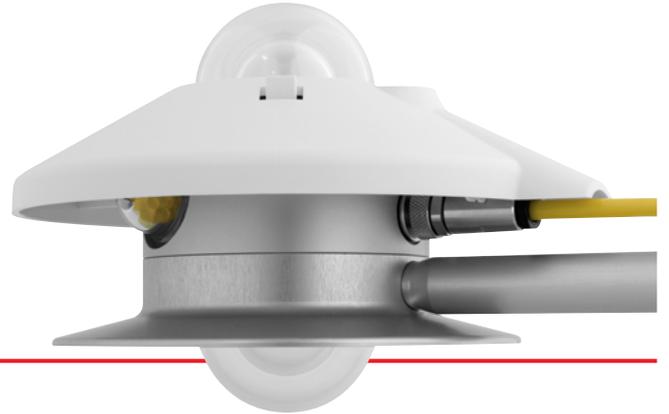




**KIPP &
ZONEN**
SINCE 1830

CMA series

Albedometer



CMP series

Pyranometer



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:

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Manual version: 0806



Declaration of Conformity

According to EC guideline 89/336/EEC 73/23/EEC

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

Declare under our sole responsibility that the products

Type: **CMP 3 / CMP 6 / CMP 11 / CMP 21 / CMP 22**

Name: **Pyranometer**

and

Type: **CMA 6 / CMA 11**

Name: **Albedometer**

to which this declaration relates are in conformity with the following standards

Imissions EN 50082-1 Group standard

Emissions EN 50081-1 Group standard
 EN 55022

Safety standard IEC 1010-1

Following the provisions of the directive.

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

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1. 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 pyranometer or albedometer.

A CMP series pyranometer or CMA series albedometer is a high quality radiometer designed for measuring short-wave irradiance on a plane surface (radiant flux, W/m^2) which results from the sum of direct solar radiation and the diffuse radiation incident from the hemisphere above the instrument.

According to International Standard ISO 9060 and the World Meteorological Organisation (WMO) a pyranometer is the designated type of instrument for the measurement of global or diffuse solar radiation. All pyranometers and albedometers within the CMP/CMA series are compliant with one of the classes 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 CMP/CMA series. Note that the smaller CMP 3 pyranometer with a single glass dome is largely excluded from this manual due to the different construction. However, the general definitions and principles also apply to this model.

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

2. Installation and operation

2.1. 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.

Contents of delivery:

1. Radiometer
2. Sun shield
3. Cable with connector
4. Test reports
5. Instruction sheet
6. Radiometer fixing kit
7. 2 x desiccant bags
8. Product documentation CD

Although all CMP/CMA radiometers are 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.

2.2. Mechanical installation

The mechanical installation of the radiometer depends upon the measuring purpose. Different measuring methods will be explained in the next paragraphs.

2.2.1. Installation for measurement of global radiation

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

1. Desiccant

Check the condition of the desiccant and replace if necessary, for example after a long storage period.

2. Location

Ideally the site for the radiometer should be free from any obstructions to the horizon above 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. 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%. The radiometer should be readily accessible for cleaning the outer dome and inspecting the desiccant

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 or ventilation ducts). Note that hot exhaust gas ($> 100^\circ\text{C}$) 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.

3. Mounting

The CMP pyranometer is provided with two holes for 5 mm bolts. Two each of stainless steel bolts, washers, nuts and nylon insulation rings are provided in the fixing kit. The pyranometer should first be secured lightly with the bolts to a solid and stable mounting stand or platform as shown in Figure 1. After recalibration the nylon insulators must be replaced with new ones to prevent corrosion.

The mounting stand temperature can 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 levelling screws. Ensure that there is a good electrical contact with earth to conduct away currents in the cable shield induced by lightning.

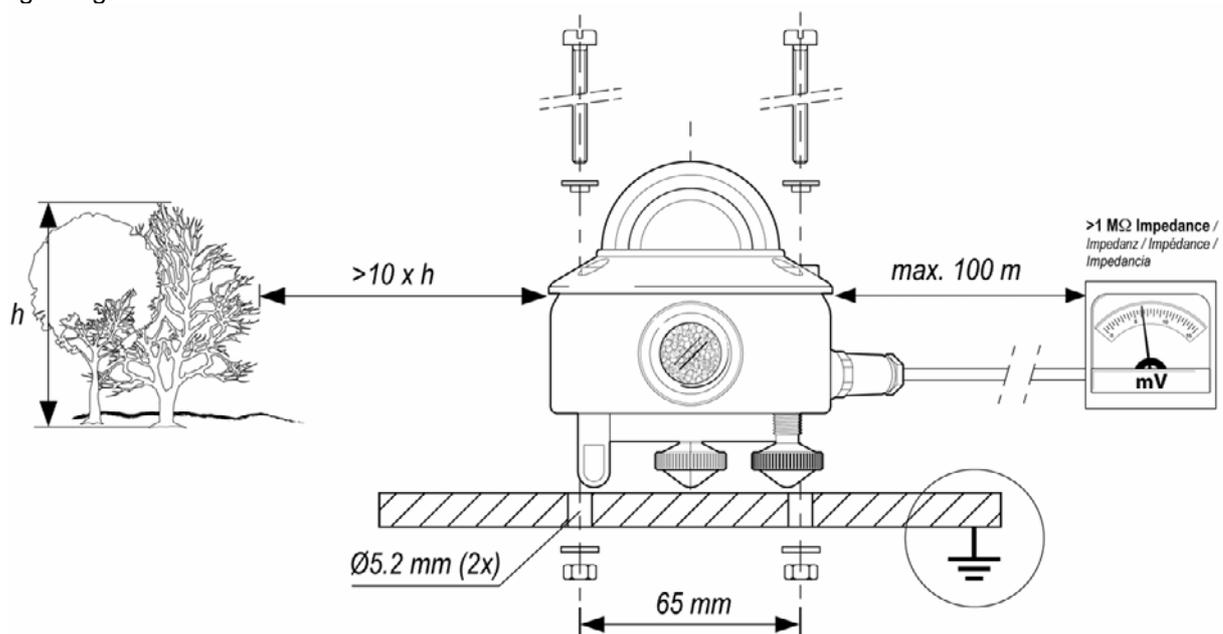


Figure 1 Pyranometer installation

Note: After recalibration and/or reinstallation the nylon insulators must be replaced with new ones to maintain durability.

4. Orientation

In principle no special orientation of the instrument is required, although the World Meteorological Organisation (WMO) recommends that the signal lead is pointed towards the nearest pole, to minimise heating of the electrical connections.

5. Level pyranometer

Accurate measurement of the global radiation requires proper levelling of the thermopile surface. Level the instrument by turning the two levelling screws 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. When the pyranometer is placed horizontally using the bubble level, or when it is mounted with its base directly on a horizontal plane, the thermopile is horizontal within 0.1° .

6. Secure pyranometer

Secure the pyranometer tightly with the two stainless steel bolts. Ensure that the pyranometer maintains the correct levelled position!

7. Fit cable and sun shield

Locate the cable plug correctly in the radiometer socket (it only fits one way) and screw the plug locking ring hand-tight. 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.

2.2.2. Installation for measurement of radiation on inclined surfaces

It is advised to pre-adjust the levelling screws on a horizontal surface for easy orientation of the instrument parallel to the inclined surface. Because the temperature of the mounting stand is expected to rise considerably (more than 10°C above air temperature), the body must be thermally isolated by the levelling screws from the stand. This will promote a thermal equilibrium between domes and body and decrease zero offset signals.

2.2.3. Installation for measurement of reflected radiation

In the inverted position the pyranometer measures reflected global radiation. According to the WMO the height should be 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 upper plate prevents excessive heating of the pyranometer body by the solar radiation and, if large enough, it keeps the lower screen free of precipitation. The lower glare screen prevents direct illumination of the domes by the sun at sunrise and sunset and is available as an accessory kit for the CMP series.

Offset signals generated in the pyranometer by thermal effects are a factor of 5 more significant in the measurement of reflected radiation due to the lower irradiance level. The mast shown in Figure 2 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 .

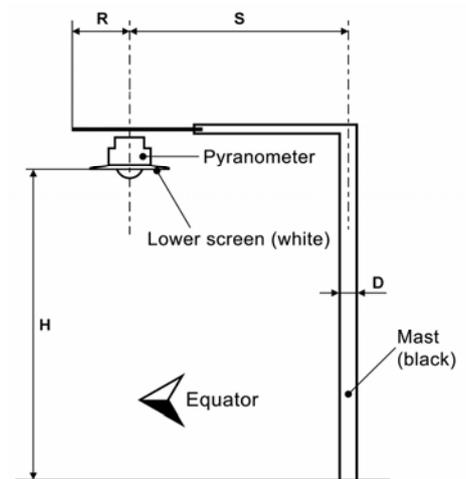


Figure 2 Mast construction

A rule of thumb is:

A black shadow with radius = $0.1 H$ on the field below decreases the signal by 1% and 99% of the signal will originate from an area with radius $10 H$.

2.2.4. Installation for measurement of diffuse radiation

For measuring sky radiation, the direct solar radiation is intercepted by a small disk or sphere. The shadow of the disk must cover the pyranometer domes completely. However, to follow the sun's apparent motion, a power-driven tracking device is necessary as shown in Figure 3.

This can be done using a Kipp & Zonen sun tracker, such as the model 2 AP, designed to track the sun accurately under all weather conditions. More information about the combination of pyranometer and tracker is given in the sun tracker manual.

Alternatively, a static shadow ring can be used to intercept the direct solar radiation; but it is less accurate and may require periodic manual adjustment. At times the shadow ring also intercepts a proportion of the diffuse sky radiation. Therefore, corrections for this to the recorded data are necessary.

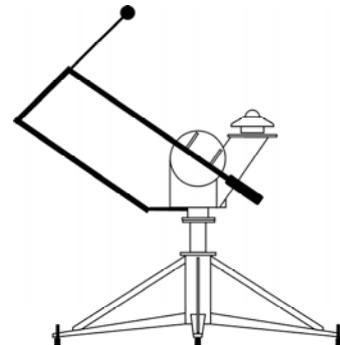


Figure 3 2AP Sun Tracker with shaded pyranometer

Kipp & Zonen produces a universal shadow ring, model CM 121, which is suitable for use at all latitudes. In the CM 121 manual, installation instructions and correction factors are given.

2.2.5. Installation for measurement of albedo

An albedometer measures both the global solar radiation and the reflected radiation from the surface below. It can be configured from two CMP series pyranometers and a suitable mounting plate, or by using a CMA series integrated albedometer.

The requirements for installation of the upper and lower pyranometers are the same as in paragraphs 2.2.1 and 2.2.3 for global and reflected radiation. A typical arrangement is shown in Figure 4. According to the WMO the height should be 1 m to 2 m above a uniform surface covered by short grass.

Installation of the CMA series differs slightly because there are no levelling screws. The integrated mounting rod is fixed to the mast. CMA has an integrated lower glare screen to prevent direct illumination of the domes by the sun at sunrise and sunset.

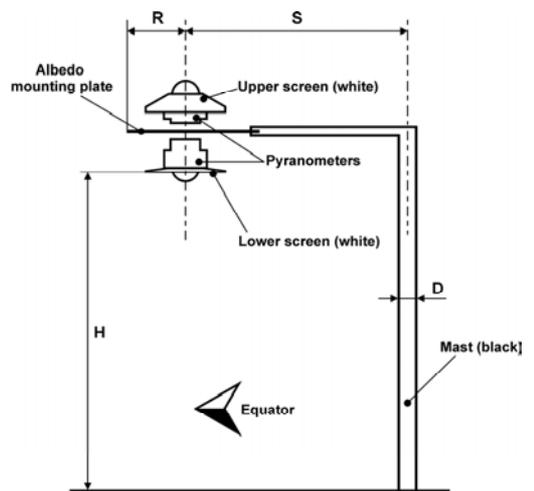


Figure 4 Albedo configuration

The mast shown intercepts a fraction $D/2\pi S$ of the radiation that is 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 .

2.2.6. Underwater use

The CMP/CMA radiometers are in principle watertight according to the IP 67 standard. However, the hemispherical air cavity under the dome(s) acts as a negative lens. The parallel beam of direct solar radiation becomes divergent after the passage of the outer dome. Consequently the intensity at the sensor is lower than outside the dome(s). The calibrated sensitivity figure is not valid in this case and must be derived empirically.

2.3. Electrical installation

As standard the CMP/CMA 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 radiometer 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.

Preferably, secure the radiometer with its levelling screws or mounting rod to a metal support with a good connection to earth (e.g. by using a lightning conductor).

The shield of the cable is connected to the aluminium 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 pyranometer and data logger.

Kipp & Zonen pyranometer 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 minimise 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 pyranometer. The sensitivity is affected more than 0.1% when the load resistance is less than 100 k Ω . For this reason we recommend the use of readout equipment with an input impedance of 1 M Ω 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 pyranometer and cable. The zero offset can be verified by replacing the pyranometer impedance at the readout equipment input terminals with a resistor.

The pyranometer 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 pyranometers exhibit offsets up to ± 2 W/m² due to lack of thermal equilibrium.

For amplification of the pyranometer signal Kipp & Zonen offers the AMPBOX signal amplifier. This amplifier will convert the micro-Volt output from the pyranometer 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. The CMA series have two independent signal outputs, so two AMPBOX amplifiers are required.

2.4. Operation

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

The irradiance value ($E_{\downarrow Solar}$) can be simply calculated by dividing the output signal (U_{emf}) of the pyranometer by its sensitivity ($S_{sensitivity}$) as shown in Formula 1.

For calculation of the solar irradiance (global or reflected) the following formula must be applied:

$$E_{\downarrow Solar} = \frac{U_{emf}}{S_{sensitivity}} \quad \text{Formula 1}$$

$E_{\downarrow Solar}$	= Solar radiation	[W/m ²]
U_{emf}	= Output of radiometer	[μV]
$S_{sensitivity}$	= Sensitivity of radiometer	[μV/W/m ²]

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.

2.5. Measurement uncertainty

When a pyranometer is in operation, the performance of it is correlated to a number of parameters, such as temperature, level of irradiance, angle of incidence, 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 secondary standard instrument (the highest quality) 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 CMP 22 pyranometer. 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 CV 2 ventilation unit is recommended to minimise this small remaining error.

For the CMP 22 the effect of each parameter on the sensitivity can be shown separately.

The non-linearity error, the sensitivity variation with irradiance, is the same for any CMP 22 and is shown in Figure 5 for a range from 0 to 1000 W/m² referred to the calibration at 500 W/m².

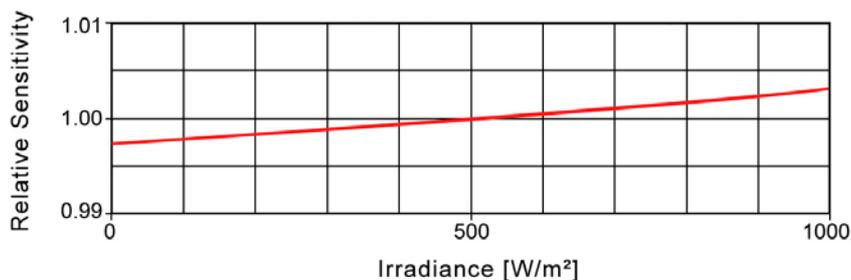


Figure 5 Non-linearity sensitivity variation of a CMP 22

The temperature dependence of the sensitivity is a function of the individual CMP 22. For a given CMP 22 the response lies in the region between the curved lines in Figure 6. The temperature dependence of each CMP 21 and CMP 22 pyranometer is characterised and supplied with the instrument. Each CMP 21 and CMP 22 has a built-in temperature sensor to allow corrections to be applied if required.

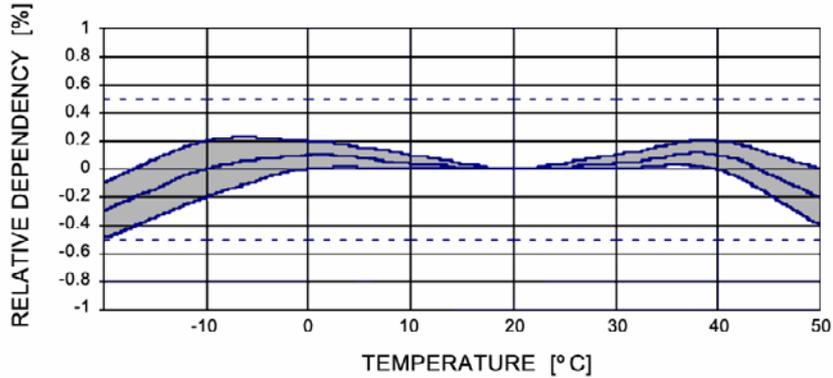


Figure 6 Typical temperature dependency of a CMP 22

The directional error is the summation of the azimuth and zenith error and is commonly given in %. Figure 7 shows the maximum relative zenith error in any azimuth direction for the CMP 22. The directional error of each CMP 21 and CMP 22 pyranometer is characterised and supplied with the instrument.

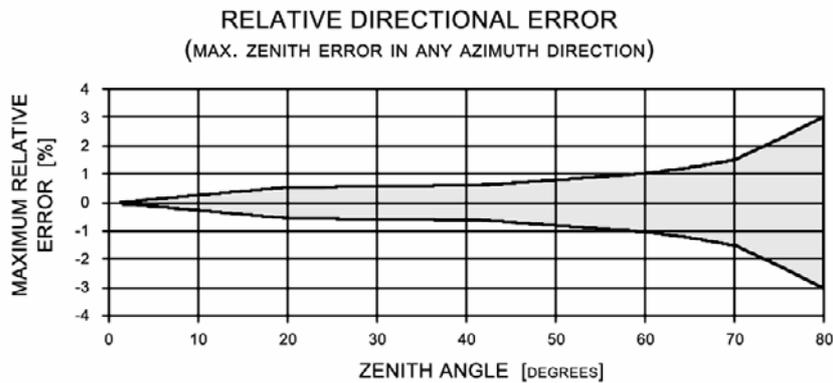


Figure 7 Relative directional error of a CMP 22

2.6. Maintenance

Once installed the radiometer needs little maintenance. The outer dome(s) must be cleaned and inspected regularly, ideally every morning. 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). In this case dew, glazed frost or hoar frost can be precipitated on the top of the outer dome and can stay there for several hours in the morning. An ice cap on the dome is a strong diffuser and increases the pyranometer signal drastically, up to 50% in the first hours after sunrise. Hoar frost disappears due to solar radiation during the morning, but should be wiped of as soon as possible manually.

The dome of the pyranometer can be ventilated continuously by a heated blower to keep the dome above dew point temperature. The need for heating strongly depends upon local climatological circumstances. Generally, heating is advised during cold seasons when frost and dew can be expected. The Kipp & Zonen CV 2 ventilation unit is specially designed for unattended operation under most weather conditions and has a choice of heating levels.

Note that the CMA albedometers and the CMP 3 pyranometer cannot be used with the CV 2 ventilation unit.

A periodic check is to ensure that the radiometer is level and that the silica gel desiccant is still coloured orange. When the orange 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 dessicant:

- 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.

3. Principle components of pyranometers

The detector of the Kipp & Zonen CMP/CMA series pyranometer is based on a passive thermal sensing element called a thermopile. Although the detector construction differs from model to model, the fundamental working principle is applicable to all CMP/CMA series radiometers.

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 pyranometer 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.

The rise of temperature is easily affected by wind, rain and thermal radiation losses to the environment ('cold' sky). Therefore the detector is shielded by two domes (the entry-level CMP 3 has only one dome to reduce size and cost). These domes allow equal transmittance of the direct solar component for every position of the sun on the celestial sphere. A drying cartridge (dessicator) in the radiometer housing is filled with silica gel and prevents dew on the inner sides of the domes, which can cool down considerably on clear windless nights.

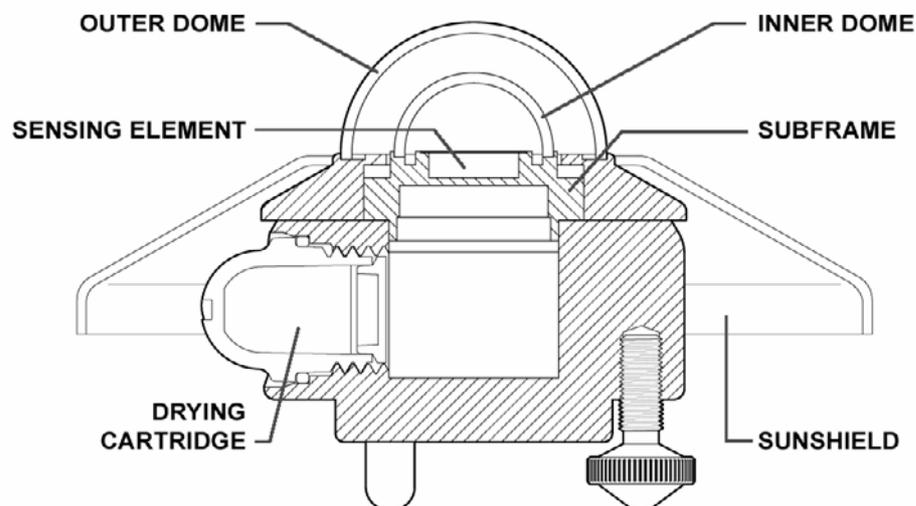


Figure 8 Construction details of a pyranometer

3.1. Dome

The dome material of the radiometer defines the spectral measurement range of the instrument. In general about 97 – 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.

CMP/CMA series radiometers, except the CMP/CM 3, have two high optical grade hemispherical domes, one inner dome and one outer dome. In the chapter 'pyranometer physical properties' the physical relation between dome and pyranometer performance will be explained.

For each particular model the specific dome material and spectral range is shown in the chapter containing the instrument specifications.

3.2. 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 pyranometer 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 pyranometer, 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 pyranometer. Kipp & Zonen black paint gives the best possible stability over a long period of time under all meteorological circumstances.

3.3. Housing

The radiometer housing accommodates all fundamental pyranometer parts. The anodized Aluminium parts are light weight and give a high mechanical and thermal stability to the instrument. Due to its fine mechanical construction all pyranometers are virtually sealed and comply to the international standard IP 67. Each pyranometer model can be leveled by using the bubble level and two leveling feet. For ease of maintenance the bubble level is situated next to the dome of the instrument and due to the special shape of the sun shield it is visible from above. The sun shield acts to protect all the external parts from radiation and to reduce solar heating of the housing.

3.4. Drying cartridge

In case moisture enters the radiometer body the silica-gel desiccant regulates the humidity level inside the pyranometer. 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.

3.5. Cable and connector

For ease of installation and replacement during recalibration of the radiometer, the CMP/CMA series are 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.

4. Pyranometer physical properties

4.1. 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 glass dome and black absorber paint, Kipp & Zonen CMP/CMA series radiometers are equally sensitive in a wide spectral range. 97-98% of the total energy will be absorbed by the thermal detector. The CMP 22 pyranometer has a wider spectral range due to the quartz domes used in its construction.

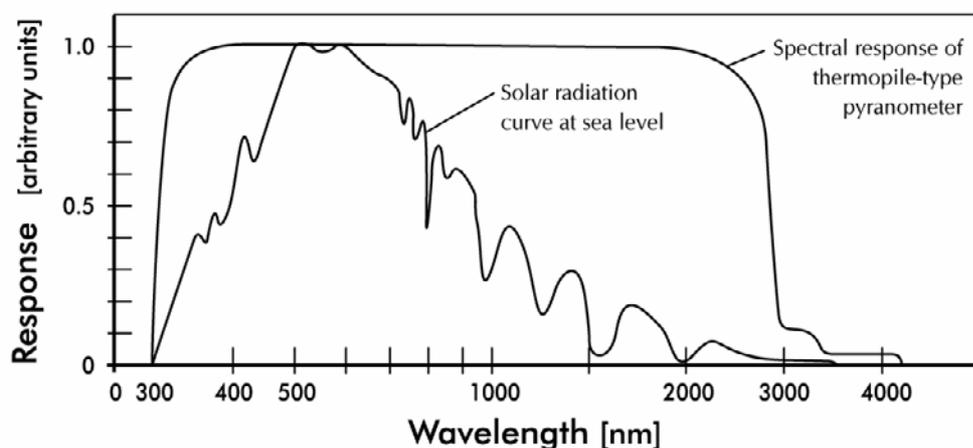


Figure 9 Solar irradiance spectrum at the Earth's surface and pyranometer response

4.2. 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.

4.3. 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.

4.4. 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. CMP/CMA series radiometers have a fast response, which makes them suitable for measuring solar radiation under variable weather conditions.

4.5. Non-linearity

The non-linearity of a radiometer is the percentage deviation in the sensitivity over an irradiance range from 0 to 1000 W·m⁻² compared to the sensitivity calibration irradiance of 500 W·m⁻². The non-linearity effect is due to convective and radiative heat losses at the black absorber surface which make the conditional thermal equilibrium of the radiometer non-linear.

4.6. Temperature dependence

The sensitivity change of the radiometer with ambient temperature change is related to the thermodynamics of the radiometer construction. The temperature dependence is given as percent deviation with respect to the calibrated sensitivity at +20°C. Some of the CMP/CMA series radiometer models have passive electrical compensation circuits to minimise this effect. Each CMP 21 and CMP 22 pyranometer is supplied with an individual test certificate stating the temperature dependency in the range from -20°C to +50°C, at 10°C intervals. The CMP 21 and CMP 22 are fitted as standard with an internal temperature sensor to allow sensitivity corrections to be applied if desired.

4.7. Tilt error

This is the deviation from the sensitivity at 0° tilt (exactly horizontal) over the range from 0° to 90° tilt under 1000 W·m⁻² normal incidence irradiance. The tilt response is proportional to the incident radiation. The error could be corrected for, in applications where it is necessary to install the pyranometer on an inclined surface, but is usually insignificant.

4.8. Zero offset 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 and the instrument housing will generate a small negative output signal which is commonly called Zero Offset type A. This effect is minimized by using an inner dome. This inner dome acts as a 'radiation buffer'. The above is illustrated in Figure 10.

This effect can be minimized by applying appropriate ventilation of the instrument. The CV 2 ventilation unit is specially designed for the CMP series, except CMP 3.

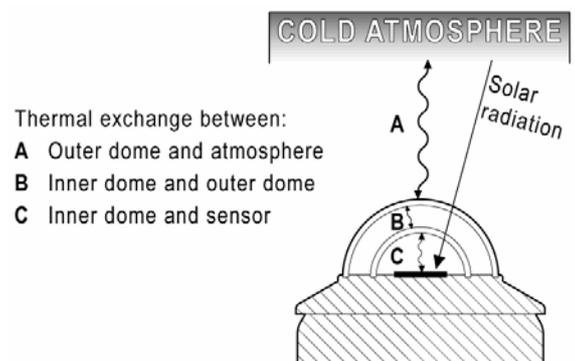


Figure 10 Zero Offset type A

4.9. 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.

4.10. 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 distributor for further information regarding operation in unusually harsh temperature conditions.

4.11. Field of view

The field of view is defined as the unobstructed open viewing angle of the 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.

4.12. Directional response

Radiation incident on a flat horizontal surface originating from a point source with a defined zenith position 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 in figure 11.

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 quality, dimensions and construction of the domes. 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°).

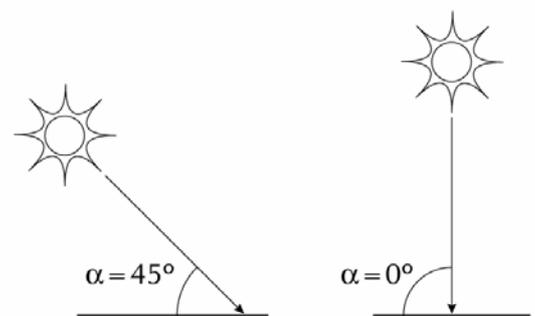


Figure 11 Solar zenith angle

4.13. Maximum irradiance

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

4.14. 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 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 pyranometers for more information.

4.15. Spectral selectivity

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

4.16. Environmental

The CMP/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.

4.17. Uncertainty

The measurement uncertainty 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 determine uncertainty figures based on many years of field measurements.

5. Calibration

5.1. Calibration principle

An ideal radiometer gives voltage output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called 'sensitivity' ($S_{\text{sensitivity}}$).

The sensitivity figure of a particular radiometer is unique. It is determined in the manufacturer's laboratory by comparison against a reference radiometer of similar type. The reference radiometer 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 radiometers have the same black coating and domes.

The supplied sensitivity figure is valid for the following conditions:

- An ambient temperature of +20°C.
- For a horizontal radiometer and for a tilted radiometer.
- Normal incident radiation of 500 W/m².

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.

5.2. Calibration procedure at Kipp & Zonen

5.2.1. The calibration facility

The indoor calibration procedure, according to ISO 9847 Appendix III, is based on a side-by-side comparison with a reference radiometer under a stable artificial sun. Kipp & Zonen uses a 150 W Metal-Halide high-pressure gas discharge lamp with voltage stabilisation. Behind the lamp is a reflector with a diameter of 16.2 cm. The reflector is 110 cm above the radiometers producing a vertical beam. The irradiance at the radiometers is approximately 500 W/m².

To minimise stray light from the walls and the operator, the light is restricted to a small cone around the two radiometers. The unknown radiometer 'a' and the reference radiometer 'b' are placed side by side on a small table. The table can rotate to interchange the positions (1 and 2) of the radiometers. The lamp is centred on the rotating axis of this table. Actually there is no normal incidence of the radiation, but the angle of incidence is the same for both radiometers (3°) so this cannot give rise to errors. The two radiometers are not levelled with the screws, but placed on their bases. The effect of the small beam tilt is negligible (compare $\cos. 3^\circ = 0.9986$ and $\cos. 4^\circ = 0.9976$).

5.2.2. Calibration procedure

After illuminating for 30 seconds, the output voltages of both radiometers are integrated over 30 seconds. Next, both radiometers are covered. After 30 seconds the zero offset signals of both radiometers are integrated, again over a period of 30 seconds. The irradiance at position 1 (radiometer 'a') may be slightly different from that at position 2 (radiometer 'b') due to asymmetry in the lamp optics, etc. Therefore the radiometers are interchanged by rotating the table and the whole procedure is repeated.

5.2.3. Calculation

The sensitivity of the unknown pyranometer is calculated with formula 2:

$$S_a = \frac{A + A'}{B + B'} \cdot S_b \quad \text{Formula 2}$$

- S_b = Sensitivity of the reference radiometer at +20 °C.
- A = Output of test radiometer at position 1
- A' = Output of test radiometer at position 2
- B = Output of reference radiometer at position 2
- B' = Output of reference radiometer at position 1
- S_a = Sensitivity of the test radiometer at +20 °C.

Output = mean value at 100% response minus zero offset signal

5.2.4. Zero offset

The lamp housing and beam restrictors heat up and emit long-wave infrared radiation, which heats up the outer glass dome and, indirectly, the inner one. When the radiometers are shaded, there still remains a small signal of up to +20 µV due to long-wave infrared radiation from the inner dome to the sensor. This zero offset is decreasing with a time constant (1/e) of several minutes.

A zero offset is also embodied in the response due to illumination. To correct for this unwanted response, the zero offset read after 60 seconds of shading is subtracted.

5.3. Traceability to World Radiometric Reference

Reference radiometers, 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.

5.4. 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.

There are several procedures for transferring calibration from a narrow field of view instrument (pyrheliometer) to a wide field of view instrument (pyranometer). For example the direct component of the solar radiation is eliminated temporarily from the pyranometer by shading the whole outer dome of the instrument with a disk. There is however no thermal equilibrium with this method and some pyranometer models show zero-offset drift.

There is another procedure, during which the unknown pyranometer remains in its normal operating condition. This 'component' method involves measuring the direct component with a pyrheliometer and the diffuse component with a disk shaded pyranometer. As, during a clear day, the diffuse radiation is only about 10% of the global radiation, the sensitivity of the second pyranometer does not need to be known very accurately. Both procedures are suitable to obtain a working standard pyranometer. The latter is extensively described in international standard ISO 9846.

Transfer from the working standard pyranometer to other pyranometers can be done in sunlight. The pyranometers must be mounted side by side so that each views the same sky dome. It is desirable to integrate, or average, the outputs over a period of time and then compute the calibration constants on the basis of these averages. This reduces the errors due to changing parameters during the day.

Transfer from another pyranometer in the laboratory is only possible when both pyranometers are of the same type and have the same glass domes and optical coatings. Kipp & Zonen can recalibrate pyranometers according to this method.

6. CMP/CMA models

The CMP series offers 5 different models in the range from CMP 3 up to CMP 22. The mechanical construction of the CMP 3 differs from the others in that it has a single dome, smaller housing dimensions and no drying cartridge (the housing is completely sealed). Features and specification of the double dome pyranometers in the range from CMP 6 to CMP 22 are specified in this chapter. The CMP/CMA series is designed for measuring the irradiance (radiant-flux, W/m^2) on a plane surface, which results from the direct solar irradiance and from the diffuse radiation incident from the hemisphere above.

A CMP/CMA radiometer includes an integrated bubble level, refillable drying cartridge, white snap-on sun shield, and a shielded signal output cable with connector. In addition, the CMA series albedometers also have an integrated conical lower glare shield to prevent illumination of the lower glass dome at sunrise and sunset. The albedometers are equipped with a mounting rod for attachment to a mast. All albedometers are supplied with a calibration certificate indicating both the upper and lower sensor sensitivities.

The CMP series (except CMP 3) can be used in conjunction with the Kipp & Zonen CV 2 ventilation unit for enhanced measurement performance and overall reduced instrument maintenance.

For measuring the diffuse component of solar radiation only, the direct solar component can be shielded statically from the CMP pyranometers by the Kipp & Zonen shadow ring CM 121, and fully automatically by the 2 AP sun tracker with shading system.

6.1. CMP 6 / CMA 6

Fully compliant with all ISO-9060 specification criteria for an ISO First Class pyranometer, the CMP/CMA 6 features a sixty-four junction (connected in series) thermocouple sensing element. The sensing element is coated with a highly stable carbon based inorganic coating, which delivers excellent spectral absorption and long-term stability characteristics. The detector is housed under two concentric glass domes which are 2 mm thick.

The albedo version is constructed around two CMP 6 pyranometer sensors and also complies with the ISO classification. Both sensors are contained in a single housing and have individual sensitivities.

6.2. CMP 11 / CMA 11

Fully compliant with all ISO-9060 specification criteria for an ISO Secondary Standard pyranometer, the CMP 11 features a 32 junction (connected in series) thermocouple sensing element which has faster response than the CMP 6 / CMA 6. Passive temperature compensation is included for improved temperature dependence of sensitivity and non-linearity is reduced. The sensing element is housed under two higher quality concentric glass domes which are 2 mm thick and provide improved directional error. The radiometric leveling is more accurate than in CMP 6 / CMA 6.

CMA 11 is constructed around two CMP 11 pyranometer sensors. Both sensors are contained in a single housing and have individual sensitivities.

6.3. CMP 21

CMP 21 is a high precision scientific pyranometer based upon the CMP 11 but with individual optimisation and characterisation and an integrated housing temperature sensor. CMP exceeds the ISO-9060 specification criteria for an ISO Secondary Standard pyranometer

The special features of the CMP 21 are:

- Individually optimised and characterised temperature dependence.
- Individually characterised directional response.
- Integrated housing temperature sensor.

6.4. CMP 22

CMP 22 is a high precision scientific pyranometer base upon the CMP 21 but with strictly selected quartz domes which are 4 mm thick. CMP 22 has an extended spectral range to match pyrhemometers with quartz windows. Because of the high optical quality and higher refractive index of the quartz domes the directional error is reduced to less than 5 W/m².

The zero offset behaviour is fundamentally improved in two ways:

The zero offset caused by changing instrument temperature is negligible, because of the very well balanced thermopile construction.

The zero offset due to the difference between sensor and dome temperature (e.g. Far Infrared Radiation absorption or emission by the outer dome) is minimised using an improved thermal coupling of sensor and top of dome. Thicker domes, both of 4mm, and the 50% higher thermal conductivity of quartz, compared to glass, improve this thermal coupling.

CMP 22 features are:

- Negligible thermal gradient zero-offset.
- Lowest zero-offset due to FIR radiation.
- Broadened spectral range 200 – 3600 nm.
- Directional error < 5 W/m².
- Lowest temperature dependency of sensitivity.

Like the CMP 11 and CMP 21 pyranometers, the CMP 22 complies with the specifications for the best of three classes of pyranometer, 'High quality', as defined in the 'Guide to meteorological Instruments and Methods of Observation', sixth edition, 1996, of the World Meteorological Organisation (*WMO) Geneva, Switzerland. Most specifications of the CMP 22 are twice as good as required.

** The WMO classification is adapted from the international standard ISO 9060 (1990). Herein 'high quality' class is referred to as 'secondary standard'.*

6.5. CMP / CMA series performance specifications

Specification	Unit	CMP 6/ CMA 6	CMP 11 / CMA 11	CMP 21	CMP 22	Definition
Spectral range	μm	310 - 2800	310 - 2800	310 - 2800	200 - 3600	50 % response point
Sensitivity	μV/W/m ²	5 to 18	7 to 14	7 to 14	7 to 14	Signal output for 1 W/m ² irradiance
Impedance	Ω	20 to 200	10 to 100	10 to 100	10 to 100	At instrument housing connector
Response time	s	< 18	< 5	< 5	< 5	95% of final value
		< 6	< 1.7	< 1.7	< 1.7	63 % of final value
Non-linearity	%	< 1	< 0.2	< 0.2	< 0.2	From 0 to 1000 W/m ² irradiance
Temperature dependence of sensitivity	%	< 4	< 1	< 1*	< 0.5*	Variation in range - 10 °C to + 40 °C from value at + 20 °C *(- 20 °C to + 50 °C)
Tilt error	%	< 1	< 0.2	< 0.2	< 0.2	Deviation when facing downwards
Zero offset A	W/m ²	< 15	< 7	< 7	< 3	At 0 to - 200 W/m ² of IR net radiation
Zero offset B	W/m ²	< 4	< 2	< 2	< 1	At 5 K/h temperature change rate
Operating temperature	°C	-40 to +80	-40 to +80	-40 to +80	-40 to +80	Storage temperature is the same
Field of view		180°	180°	180°	180°	Hemispherical
Directional error	W/m ²	< 20	< 10	< 10	< 5	At 80° with 1000 W/m ² irradiance
Maximum irradiance	W/m ²	2000	4000	4000	4000	Level above which damage may occur
Non-stability	%	< 1	< 0.5	< 0.5	< 0.5	Variation in sensitivity per year
Humidity	% RH	0 - 100	0 - 100	0 - 100	0 - 100	Relative Humidity
Uncertainty in daily total	%	< 5	< 2	< 2	< 1	95 % confidence level

6.6.CMP / CMA series general specifications

Construction	Unit	CMP 6 / CMA 6	CMP 11 / CMA 11	CMP 21	CMP 22
Temperature sensor		N/A	N/A	Thermistor (standard): YSI 44031 10k@25°C Thermistor ±0.2°C Pt-100 (optional) DIN IEC 751. Class A	Thermistor (standard): YSI 44031 10k@25°C Thermistor ±0.2°C Pt-100 (optional) DIN IEC 751. Class A
Descicant		Silica gel (replaceable)	Silica gel (replaceable)	Silica gel (replaceable)	Silica gel (replaceable)
Housing		Anodized Aluminium body	Anodized Aluminium body	Anodized Aluminium body	Anodized Aluminium body
Cable Connector		Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)
Chassis connector		Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)	Shell : CuZn (Brass, Nickel plated)
		Contacts : CuZn, (Nickel, gold plated)	Contacts : CuZn, (Nickel, gold plated)	Contacts : CuZn, (Nickel, gold plated)	Contacts : CuZn, (Nickel, gold plated)
Cable		Colour Yellow (RAL 1021), Polyurethane, Halogen free, UV blocking	Colour Yellow (RAL 1021), Polyurethane, Halogen free, UV blocking	Colour Yellow (RAL 1021), Polyurethane, Halogen free, UV blocking	Colour Yellow (RAL 1021), Polyurethane, Halogen free, UV blocking
Cable length	m	10 (standard), 25, 50 (optional)	10 (standard), 25, 50 (optional)	10 (standard), 25, 50 (optional)	10 (standard), 25, 50 (optional)
Cable wires	Pin 1	Red (+)	Red (+)	Red (+)	Red (+)
	Pin 2	Blue (-)	Blue (-)	Blue (-)	Blue (-)
	Pin 3	Green (+) Albedo sensor facing downward	Green (+) Albedo sensor facing downward	Green (10 K thermistor) (Pt-100, with Gray)	Green (10 K thermistor) (Pt-100, with Gray)
	Pin 4	Yellow (-) Albedo sensor facing downward	Yellow (-) Albedo sensor facing downward	Yellow (10 K thermistor) (Pt-100, with Brown)	Yellow (10 K thermistor) (Pt-100, with Brown)
	Pin 5			Gray (Pt-100)	Gray (Pt-100)
	Pin 6			Brown (Pt-100)	Brown (Pt-100)
Bubble level sensitivity	°	0.1 (bubble inside ring)	0.1 (bubble inside ring)	0.1 (bubble inside ring)	0.1 (bubble inside ring)
Total weight	kg	0.6 (without cable)	0.6 (without cable)	0.6 (without cable)	0.6 (without cable)
		0.9 (with 10 m cable)	0.9 (with 10 m cable)	0.9 (with 10 m cable)	0.9 (with 10 m cable)
		0.9 (without cable)(Albedometer)	0.9 (without cable)(Albedometer)		
		1.2 (with 10 m cable)(Albedometer)	1.2 (with 10 m cable)(Albedometer)		
Outer dimensions	mm	79 x 92.5 (WxH), sun shield Ø 150	79 x 92.5 (WxH), sun shield Ø 150	79 x 92.5 (WxH), sun shield Ø 150	79 x 92.5 (WxH), sun shield Ø 150
		128 x 114 (WxH), sun shield Ø 150 (Albedometer)	128 x 114 (WxH), sun shield Ø 150 (Albedometer)		
Mounting		2 bolts M5 with 65 mm centres. Integral anodized Aluminium tube Ø 16 mm x 350 mm long (Albedometer)	2 bolts M5 with 65 mm centres. Integral anodized Aluminium tube Ø 16 mm x 350 mm long (Albedometer)	2 bolts M5 with 65 mm centres.	2 bolts M5 with 65 mm centres.
Sensor height	mm	68	68	68	68
International standards	WMO	Good quality	High quality	High quality	High quality
	ISO	First Class	Secondary standard	Secondary standard	Secondary standard
	Shock/Vibration	IEC 721-3-2-2m2	IEC 721-3-2-2m2	IEC 721-3-2-2m2	IEC 721-3-2-2m2
	CE	According to EC guideline 89/336/EEC 73/23/EEC	According to EC guideline 89/336/EEC 73/23/EEC	According to EC guideline 89/336/EEC 73/23/EEC	According to EC guideline 89/336/EEC 73/23/EEC
	Protection	IP 67	IP 67	IP 67	IP 67
Instrument calibration		Indoors, side by side against reference CM(P) 6 pyranometer, according to ISO 9047:1992 annex A.3.1	Indoors, side by side against reference CM(P) 11 pyranometer, according to ISO 9047:1992 annex A.3.1	Indoors, side by side against reference CM(P) 21 pyranometer, according to ISO 9047:1992 annex A.3.1	Indoors, side by side against reference CM(P) 22 pyranometer, according to ISO 9047:1992 annex A.3.1
Measurement certificates		Sensitivity calibration certificate	Sensitivity calibration certificate	Sensitivity calibration certificate, temperature dependence test report, directional error test report	Sensitivity calibration certificate, temperature dependence test report, directional error test report

7. Frequently asked questions

The most frequently asked questions are listed below. For an update refer to the Kipp & Zonen website at www.kippzonen.com

Negative output during night-time measurements?

This error 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. Practically 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).

The emitted heat is attracted from the body (by conduction in the dome), from the air (by wind) and from the inner dome (through infrared radiation). The inner dome is cooling down too and will attract heat from the body by conduction and from the sensor by the net infrared radiation. The latter heat flow is opposite to the heat flow from absorbed solar radiation and causes the well-known zero depression at night. This negative zero offset is also present on a clear day but is hidden in the solar radiation signal.

Zero Offset type A can be checked by placing a light and IR reflecting cap over the pyranometer. The response to solar radiation will decay with a time constant ($1/e$) of 1 second, but the dome temperature will go to equilibrium with a time constant of several minutes. So after half a minute the remaining signal represents mainly Zero Offset type A.

Good ventilation of domes and body is the solution to minimising zero offsets. Kipp & Zonen advises the CV 2 ventilation unit for optimal ventilation and suppression of zero offset type A. Using the CV 2 zero offset type A will decrease by $\sim 50\%$.

Maximum and minimum irradiation quantities?

Due to possible reflection from clouds the global irradiance at sea level can rise above the extra-terrestrial direct irradiance of 1367 W/m^2 at the top of the atmosphere. 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.

What is the primary entry point for humidity?

The drying cartridge seal and the silicon glue of the domes are not fully airtight.

Is the pyranometer sensitivity affected by the length of the signal cable?

With longer cable lengths the impedance increases, however it does not affect the radiometer sensitivity for the following reason. The impedance of the voltage measurement device is at least 10000 times more than the impedance of the pyranometer plus cable. Therefore the current that goes through the readout cable is negligible and won't generate an offset. However, the loading may affect the temperature compensation circuit to some extent.

8. Trouble shooting

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

Trouble shooting:

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 instrument by blocking the direct sun during some part of the day?
- Check the dome, 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.
- Check levelling (bubble inside ring)

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

Appendix II 10k thermistor specifications

YSI Thermistor 44031 - Resistance versus Temperature in °C

Thermistor (10 kΩ @ 25°C)

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

$\alpha : 1.03 \cdot 10^{-3}$
 $\beta : 2.38 \cdot 10^{-4}$
 $\gamma : 1.59 \cdot 10^{-7}$

$T [^{\circ}\text{C}]$ = Temperature $R [\Omega]$ = Resistance

YSI 44031 Temperature vs. Resistance											
Temperature			Resistance			Temperature			Resistance		
[°C]	[°F]	[Ohm]	[°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	43,110	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			

Appendix III Pt-100 specifications

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

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

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

T [°C] = Temperature

R [Ω] = Resistance

Pt-100 Temperature vs. Resistance								
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	110.3	59	138.2	122.9

Appendix IV classification According to WMO Guide 1996

Characteristics	CMP 22	CMP 21	CMP 11 CMA 11	CMP 6 CMA 6	High quality	Good quality	Moderate quality
ISO 9060 classification	Secondary standard	Secondary standard	Secondary standard	First class	Secondary standard	First class	Second class
Response time (95 percent response)	5 s	5 s	5 s	18 s	< 15 s	< 30 s	< 60 s
Zero offset:							
(a) Response to 200 W/m ² net thermal radiation (ventilated)	± 3 W/m ²	± 7 W/m ²	± 7 W/m ²	± 15 W/m ²	± 7 W/m ²	± 15 W/m ²	± 30 W/m ²
(b) Response 5 K/h change in ambient temperature	± 1 W/m ²	± 2 W/m ²	± 2 W/m ²	± 4 W/m ²	± 2 W/m ²	± 4 W/m ²	± 8 W/m ²
Resolution (smallest detectable change)	± 1 W/m ²	± 1 W/m ²	± 1 W/m ²	± 1 W/m ²	± 1 W/m ²	± 5 W/m ²	± 10 W/m ²
Stability (change per year, percentage of full scale)	< 0.5	< 0.5	< 0.5	< 1	± 0.8	± 1.5	± 3.0
Directional response of 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 radiation whose normal incidence irradiance is 1000 W/m ²)	± 5 W/m ²	± 10 W/m ²	± 10 W/m ²	± 20 W/m ²	± 10 W/m ²	± 20 W/m ²	± 30 W/m ²
Temperature response (percentage of maximum due to any change of ambient temperature within an interval of 50 K)	± 0.5 -20°C+50°C	± 1 -20°C+50°C	± 1 -10°C+40°C	± 4 -10°C+40°C	± 2	± 4	± 8
Non-linearity (percentage deviation from the responsivity at 500 W/m ² due to any change of irradiance within the range 100 to 1000 W/m ²)	± 0.2	± 0.2	± 0.2	± 1	± 0.5	± 1	± 3
Spectral sensitivity (percentage of deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within the range of 0.3 to 3 µm)					± 2	± 5	± 10
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)	± 0.2	± 0.2	± 0.2	± 1	± 0.5	± 2	± 5
Achievable uncertainty, 95 percent confidence level							
Hourly totals	1 %	2 %	2 %	5 %	3%	8%	20%
Daily totals					2%	5%	10%

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

Pyranometers, 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.



**KIPP &
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SINCE 1830

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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