Kipp & Zonen

INSTRUCTION MANUAL

CG4

PYRGEOMETER

0345 200

IMPORTANT USER INFORMATION

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

The exclamation mark within an equilateral triangle is intended to alert the user to the presence of important operating and maintenance instructions in the literature accompanying the instrument.

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

Kipp & Zonen B.V.

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

WARRANTY AND LIABILITY

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

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

Manual version: 0304

DECLARATION OF CONFORMITY

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

We **Kipp & Zonen B.V.**
Röntgenweg 1
2624 BD Delft

Declare under our sole responsibility that the product

Type: **CG 4**
Name: **Pyrgeometer**

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

Imissions	EN 50082-1	Group standard
Emissions	EN 50081-1 EN 55022	Group standard
Safety standard	IEC 1010-1	

Following the provisions of the directive

R.E. Ringoir
Product management
KIPP & ZONEN B.V.

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1 GENERAL INFORMATION

1.1 INTRODUCTION

Pyrgeometers are recommended by the BSRN (Baseline Surface Radiation Network) as the best means of measuring the upward and downward components of long wave atmospheric radiation.

CG 4 has been designed for meteorological measurements of downward atmospheric long wave radiation with extreme high reliability and accuracy. A second CG 4 can be used to measure the upward component of the radiation.

Outdoors CG 4 provides a voltage that is proportional to the net radiation in the far infrared (FIR). By calculation, downward atmospheric long wave radiation is derived. For this reason CG 4 embodies a thermistor to measure the body temperature.

CG 4 uses a specially designed silicon window. Although the window is not hemispherical, CG 4 has a 180° field of view with good cosine response. A diamond-like coating protects the outer surface of the window. On the inside a solar blind filter blocks all solar radiation.

The solar radiation absorbed by the window is conducted away very effectively by a unique construction. Even in full sunlight the window heating effect is very low compared to that of other pyrgeometers on the market. This allows accurate daytime measurements without the need for a tracking shading disc. It also eliminates the need for window heating compensation by using the correction formula.

CG 4 features are:

- Sensitive to infrared radiation in a wavelength range from 4.5 to approx. 40 μm.
- Low window heating offset.
- 180 ° field of view with good cosine response.
- Diamond like coating for optimal protection against environmental influences.
- Low temperature dependence of sensitivity

1.2 PHYSICAL PRINCIPLES OF THE PYRGEOMETER

The CG 4 pyrgeometer is provided with a thermal detector. The thermal detector is a 64-thermocouple thermopile. The body temperature sensor, either a thermistor (YSI44031) or Pt-100 (optional), is built-in at the edge of the thermal detector, at the cold junctions.

The radiant energy is absorbed by a black painted disk. The heat generated flows through a thermal resistance to the heatsink (the pyrgeometer body). The temperature difference across the thermal resistance of the detector is converted into a voltage. The thermopile output can be easily affected by wind and rain. Therefore a Silicon window shields the detector.

On both sides of the Silicon window a coating is deposited. The outer side of the window is protected with a diamond-like layer against environmental influences such as wind and rain. On the inner side an interference filter is deposited for passing the long wave radiation only. The Silicon window allows equal transmittance of the atmospheric long wave radiation in a range from 4.5 (cut-on) to approx. 40 μm. A construction drawing of the CG 4 pyrgeometer is shown in figure 1.1

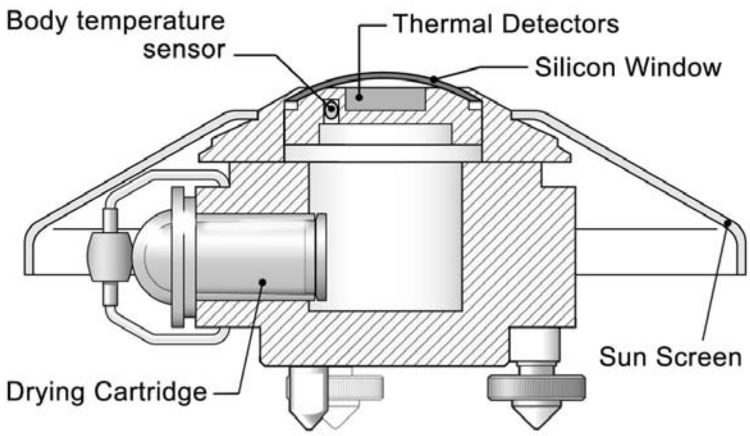


Figure 1.1 Schematic construction of the CG 4 pyrgeometer.

1.2.1 Properties of the Silicon window

CG 4 uses a specially designed pure silicon window. Although the window isn't hemispherical, CG 4 has a 180° field of view with good cosine response.

A big advantage of the meniscus shaped window over the typical spherical window is the ability of the coating manufacturer to deposit a more uniform coating on the window surface. Deposition of a uniform filter coating on a strongly curved surface is a rather difficult, possibly impossible process.
With that knowledge Kipp & Zonen developed a window with a good optical quality due to an optimal shape and coating uniformity.

In this way a CG 4 window allows equal dome transmittance over the whole window surface.

The diamond-like coating also called " Hardcarbon coating " is a carbon layer of a few microns thickness, with the main purpose of providing optimal protection against environmental influences.
An additional advantage is that the hardcarbon acts as an anti-reflection coating, which leads to a transmittance increase.

The solar blind filter is opaque for radiation under the 4.5 µm known as the cut-on wavelength. The low-pass filter deposited at the inside of the window is an interference filter. Currently most pyrgeometers have their cut-on at a lower wavelength. Problems may occur in case of clear sunny days with low humidity. In the solar spectrum between 2.5 and 4.5 µm, there can be still an amount of infrared solar radiation up to 10 W/m^2. This unwanted fraction would increase the amount of downward radiation unavoidable. In the CG 4 this signal is blocked by the filter coating.

The CG 4 window transmittance curve is given in figure 1.2
The transmittance is given at normal incidence.

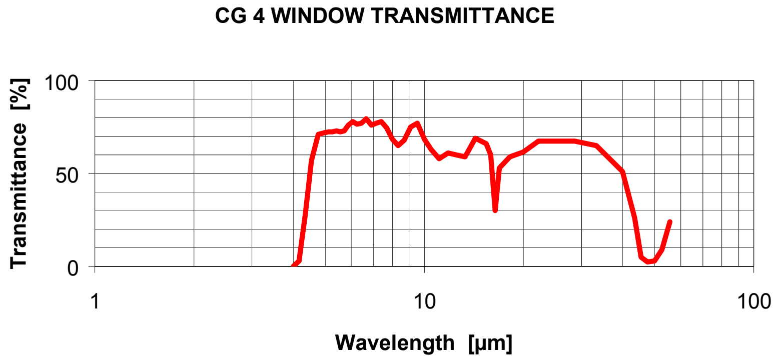


Figure 1.2 Typical transmittance of a CG 4 window.

1.3 DOWNWARD ATMOSPHERIC LONG WAVE RADIATION

The atmosphere is a gaseous envelope surrounding the earth, held by gravity, having its maximum density just above the solid surface and becoming gradually thinner with distance from the ground, until it finally becomes indistinguishable from the interplanetary gas.
There is, therefore, no defined upper limit or “top” of the atmosphere. As we go away from the surface of the earth, different regions can be defined, with widely different properties, being the seats of a great variety of physical and chemical phenomena. One of these fascinating phenomena is the thermal or long wave radiation.
An important, but rather difficult to measure, component of the radiation budget is the atmospheric long wave radiation balance.
The atmosphere is transparent to long wave radiation emitted by the Earth’s surface in certain wavelength intervals, particular within a spectral range of approximately 8 to 14 µm, which is called the atmospheric window (see figure 1.3).

Within this spectral range the earth is able to maintain an equilibrium temperature by losing a certain quantity of heat gained each day from the sun.
The sun radiates approximately as a blackbody at an equivalent temperature of nearly 5770K. Almost 99% of its emitted energy are contained in wavelengths less than 4μm and are called short-wave radiation. The equivalent radiant temperature of the Earth's surface is about 275K. More than 99% of this energy is emitted at wavelengths more than 3 μm and is called long-wave, thermal, or infrared radiation.

Downward long wave radiation is a result of atmospheric re-emission. Re-emission is the reversible effect of absorption of earthly emitted long wave radiation by chemical elements like water (H_2O), Oxygen (O_2), Ozone (O_3), Carbon dioxide (CO_2) *etc.* These elements are the main emitters of long wave radiation in the atmosphere.
The remaining unabsorbed portion of the earth's radiation escapes into the outer space. Under clear skies an object can be cooled below ambient air temperature by radiative heat loss to the sky. Observing the earth from outer space, a blackbody is seen in a range of 8 to 14 μm with a temperature of 14 °C and outside this wavelength range a blackbody of -60 °C. Under clear sky conditions in a reverse direction, outer space can be observed in the same spectral range. The long wave radiation exchange mainly occurs in the spectral range of 8 to 14μm. In this range the pyrgeometer also loses its thermal energy upward.

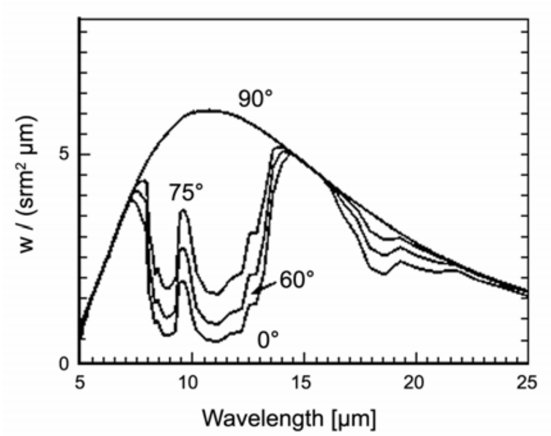


Figure 1.3 Atmospheric radiation (atmospheric window 8 to 14 µm)

Where as a pyranometer only receives solar radiation, pyrgeometers can emit their own radiation by losing energy to a relatively cold sky. The pyrgeometer signal therefore is the difference between the downward long wave radiation emitted from the atmosphere and the upward emitted radiation from the pyrgeometer.

The downward atmospheric long wave radiation can be calculated with formula 1 by measuring the thermopile output voltage Uemf [µV], the body temperature T_b [K], and taking the calibration factor S [µV/W/m^2] into account.

$$L_d = \frac{Uemf}{S} + 5.67 \cdot 10^{-8} \cdot T_b^4$$ *(formula 1)*

This formula is given by the WMO, 1996

L_d = Downward atmospheric long wave radiation [W/m^2]

$\frac{Uemf}{S}$ = Net - radiation (Difference between the downward long wave radiation emitted from the atmosphere and the upward irradiance of the CG 4 sensor) [W/m^2]

$5.67 \cdot 10^{-8} \cdot T_b^4$ = Upward irradiance of the CG 4 sensor [W/m^2]

Note that the net radiation term (Uemf / S) is mostly negative, so the calculated downward atmospheric long wave radiation is smaller than the sensor's upward irradiance ($5.67 \cdot 10^{-8} \cdot T_b^4$).

1.4 WINDOW HEATING EFFECT

Currently the major source of error concerning common pyrgeometer measurements is caused by window heating. When a pyrgeometer is exposed to the sun, window heating occurs due to absorption of solar radiation in the window material. As a consequence the windows of certain types of pyrgeometers will heat up proportional to the amount of solar radiation.

The resulting temperature difference between window and thermopile will cause heat transfer by radiation and convection to the sensor. This affects the net thermal radiation as measured by the thermopile. This error is commonly referred to as the "Window heating offset", and results in the measurement of a too high value for downward long wave radiation.

This offset is not easily reduced by (for example) ventilation; ventilation only cools off 50 W/m^2/°C at maximum while solar radiation can be absorbed at a rate of about 500 W/m^2 on a sunny day. Currently, certain types of pyrgeometers are equipped with one or more window thermistors to measure the windows absolute temperature that represents the appearing offset. During window temperature measurements a complex calculation must be performed to eliminate the offset.

Arguments against a thermistor to measure window temperature are:

- *The thermistor contacts a part of the window, it is a blackbody radiator and heat source itself and its material and adhesive increases the mean emission coefficient of the inner window surface. Its presence increases the window-heating offset.*

- *The window thermistor should be carefully matched with the body thermistor because calculations must be done using the temperature difference of the two thermistors.*

- *The customer needs at least one extra data logger channel for thermistor input.*

Because of the possible problems caused by window thermistors Kipp & Zonen developed the revolutionary CG 4 pyrgeometer.
In the CG 4, window heating is strongly suppressed by a unique construction that is conducting away the absorbed heat very effectively. In this way, CG 4 temperature variations between window and sensor are less than 0.3 degrees Celsius, compared to 2.0 or even 3.0 degrees Celsius for other types of pyrgeometers. Temperature variations in this small range represent a window heating offset less than 4 W/m^2. This allows accurate daytime measurements, even in full sunlight, without the need for a tracking shading disc.

Window heating can be checked by doing the following experiment. The experiment is illustrated with an example.

1.4.1 How to perform the check?

The check must be performed under clear sky conditions. The CG 4 pyrgeometer is operated with thermopile and thermistor readout for measuring the downward radiation.

To perform the outdoor check, follow next steps:

1. Stand in line with the sun and the pyrgeometer under the condition that the pyrgeometer is still illuminated by solar radiation.
2. Wait for at least 1 minute until the pyrgeometer thermopile output is stabilised (your body contributes to the pyrgeometer signal) record the reading.
3. Raise your hand in line with the sun and pyrgeometer so that the pyrgeometer is shaded completely.Wait for at least 1 minute until the pyrgeometer thermopile output is stabilised, record the reading.
4. Check performed, data can be interpreted. The difference in readings found after steps 2 and 4 gives the amount of window heating.

1.4.2 Example

Experiment to show the window heating offset of the CG 4 pyrgeometer.

On a sunny day (irradiance ≈ 750 W/m^2) the instrument was shaded for about 3 minutes (shown in figure 1.4).
During shading and unshading the CG 4 shows a dynamic change in the amount of calculated downward radiation. One minute after shading the calculated downward radiation settles. The window heating offset of

CG 4 stabilises at < 3 W/m^2. The experiment shows that for most practical purposes, CG 4 does not need compensation for window heating offset.

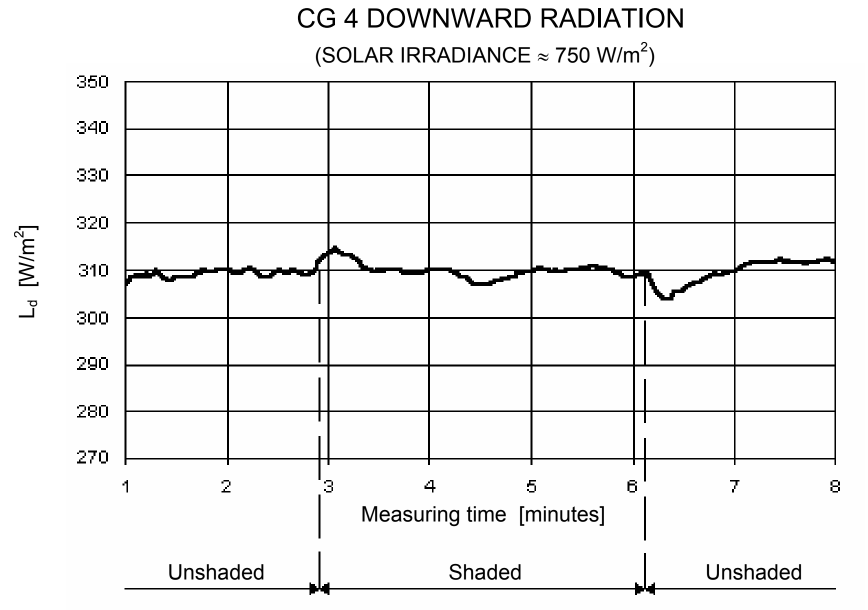


Figure 1.4 CG 4 calculated downward radiation (L_d)

1.5 LOW TEMPERATURE DEPENDENCY OF SENSITIVITY

The sensitivity is correlated to the temperature as a consequence of typical physical material properties of the thermopile. For a given heat flow the sensitivity of the pyrgeometer is a function of the thermal conductivity of the sensor materials and of the thermo-electric power of the sensor material. Both physical parameters show temperature dependency.

Due to the thermopile construction and applied thermistor compensation circuit the temperature response is suppressed to below 1%, between -20 °C and +50 °C.

During manufacturing each CG 4 pyrgeometer is checked for its temperature dependency specifications.

2 TECHNICAL DATA

2.1 SPECIFICATIONS OF THE CG 4 PYRGEOMETER

Performance

Spectral range:	4.5 to 42 µm, 50% points.
Sensitivity:	10 µV/W/m² (nominal).
Impedance:	40 to 200 Ω (nominal).
Response time:	25 s (95% response). < 8 s (63% response).
Non-linearity:	<± 1% (at -250 to +250 W/m² irradiance).
Temperature dependence of sensitivity:	Max. ±1 % (-20 °C to +50 °C).
Tilt error:	Max. 1% deviation when facing downwards.
Zero offset due to temperature changes:	< 2 W/m² offset at 5 K/h temp. change.
Operating temperature:	-40 °C to +80 °C.
Field of view:	180 ° (2 π sr).
Irradiance:	-250 to +250 W/m².
Non-stability:	<±1% sensitivity change per year.
Spectral selectivity within the range 8 to 14 µm:	Max. approx. ±5 %.
Window heating offset:	Max. 4 W/m² (1000 W/m² normal incidence solar radiation).
Accuracy	3% for daily totals

Estimated inaccuracy of measurement:	< 7.5 W/m^2.
Thermistor specifications (only for thermistor version):	Type YSI 44031. See Appendix II.
Pt-100 specifications (only for Pt-100 version):	Type Heraeus M-GX 1013, DIN IEC 751. Class A. See appendix III.

Construction

Receiver paint:	Carbon Black.
Window:	Silicon with solar blind filter and diamond-like coating.
Desiccant:	Silica gel.
Spirit level:	Sensitivity of 0.5 ° (bubble half out of the ring) Coincide with base of the instrument.
Materials:	Anodised aluminium case. Stainless steel screws etc. White plastic screen of ASA. Drying cartridge PMMA.
Shock/vibration	IEC 721-3-2-2-m2
Weight:	1050 g.
Cable length:	10 m.
Dimensions in mm:	W x H 150 x 76.5 See figure 2.1

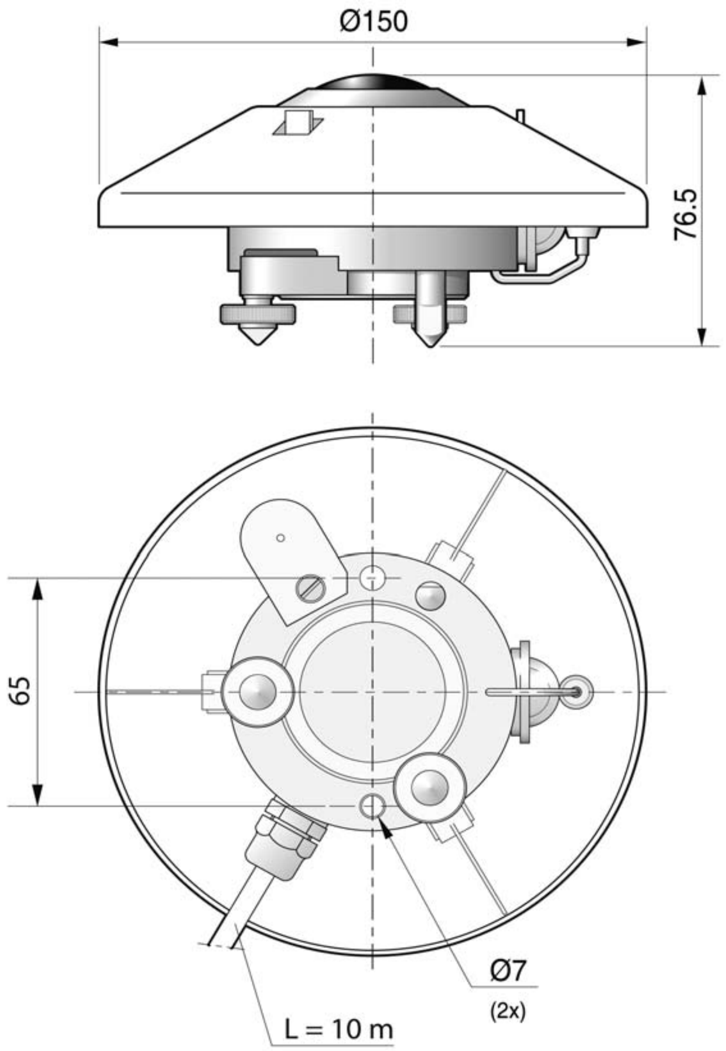


Figure 2.1 CG 4 pyrgeometer outline dimensions

2.2 ACCURACY

As listed in paragraph 2.1 the sensitivity is cross-correlated to a number of parameters such as temperature and level of irradiance.

Normally, the supplied sensitivity figure is used to calculate the irradiances. If the conditions differ from the calibration conditions, errors in the calculated irradiances must be expected.

These remaining errors can be reduced if the actual sensitivity of the pyrgeometer is used by the conversion of voltage to irradiance. The actual sensitivity can be calculated when it is a well-known function of simply measured parameters (sometimes called transfer function or sensitivity function). This is especially convenient in connection with a programmable data acquisition system.

For the CG 4 the effect of each parameter on the sensitivity can be shown separately, because the parameters exhibit less interaction. The non-linearity error, the sensitivity variation with irradiance, is similar for any CG 4. See figure 2.2

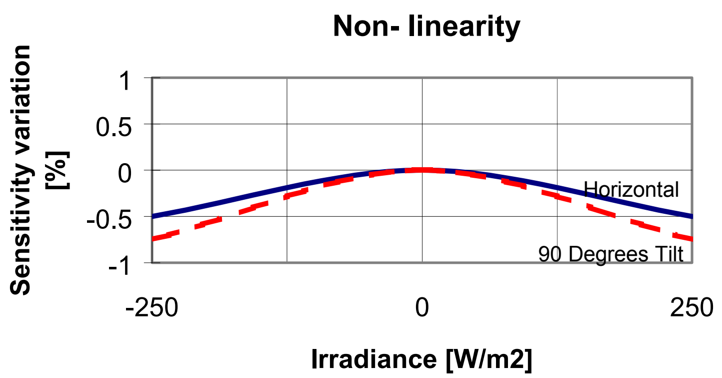


Figure 2.2 Non linear sensitivity variation with irradiance of the CG 4 pyrgeometer.

The temperature dependence of the sensitivity is an individual function. For any given CG 4 the curve lies in the region between the (1 %) limit lines in figure 2.3

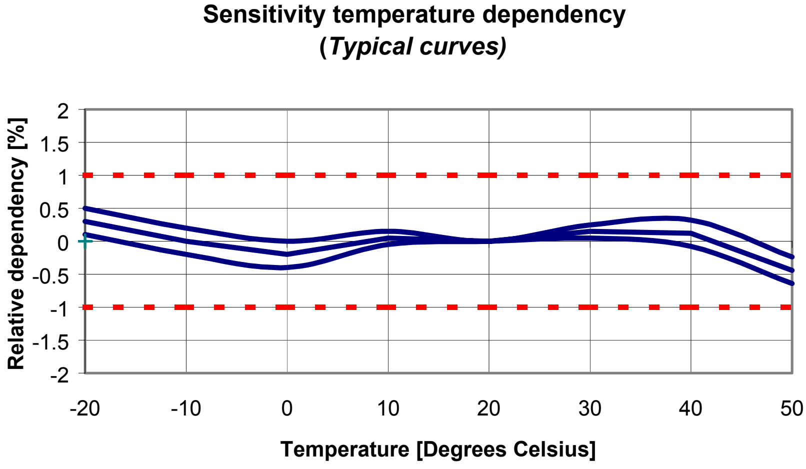


Figure 2.3 The curve of relative sensitivity variation with instrument temperature of a CG 4 pyrgeometer lies in the ±1 % region. Typical curves are shown.

3 INSTALLATION

Reading these instructions before installation is recommended.

3.1 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 not complete, your dealer should be notified in order to facilitate the repair or replacement of the instrument.

The CG 4 pyrgeometer delivery will include the following items:

1	CG 4 pyrgeometer
2	White sun screen
3	2 x Mounting bolts
4	2 x Nylon insulators
5	Calibration certificate
6	This manual

Unpacking

Keep the original packaging for later shipments (e.g. recalibration) !

Although all sensors are weatherproof and suitable for harsh ambient conditions, they do partially consist of delicate mechanical parts. It is recommended to use the original shipment packaging to safely transport the equipment to the measurement site.

3.2 MECHANICAL INSTALLATION

The mechanical installation of the pyrgeometer must be carried out depending on the application. Different measuring methods will be explained in chapter 4.

Generally for measuring downward atmospheric long wave radiation the following steps must be carefully considered for optimal performance of the instrument:

3.2.1 Location

Ideally the site for the pyrgeometer should be free from any obstructions above the plane of the sensing element, and at the same time the pyrgeometer should be readily accessible to clean the window and inspect the dessicator.

Obstructions on the horizon with angular height less than 10° are mostly no problem, unless they are hot (exhaust vents etc.)

In principle no special orientation of the instrument is required.
The World Meteorological Organisation recommends that the emerging leads are pointed to the north, to minimise heating of the electrical connections.

3.2.2 Mounting

The CG 4 pyrgeometer is provided with two holes for 5 mm bolts.
Two stainless steel bolts and two nylon rings are provided. The pyrgeometer should first be secured lightly with the bolts to a mounting stand or platform (Shown in figure 3.1). The nylon insulators must be placed under the bolt heads to avoid electrolytic corrosion between bolt and body.

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

The mounting stand temperature can vary over a wider range than the air temperature. Temperature fluctuations of the pyrgeometer body can produce offset signals. It is recommended to isolate the pyrgeometer thermally from the mounting stand,

e.g. by placing it on its levelling screws. But keep an electric contact with earth to lead off currents in the cable induced by lightning.

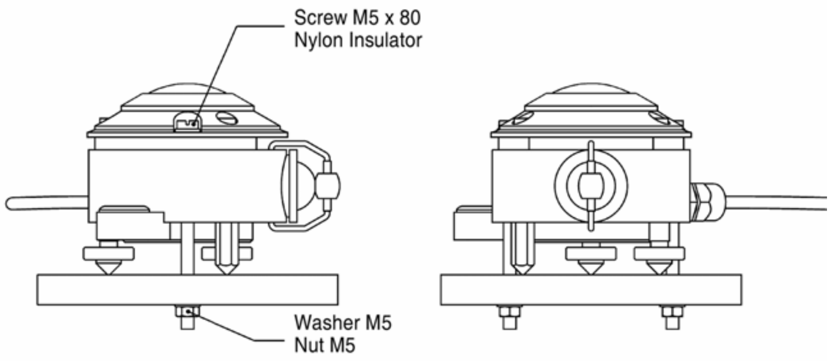


Figure 3.1 Mounting the CG 4 pyrgeometer

3.2.3 Levelling

Accurate measurement of the downward atmospheric long wave radiation requires the proper levelling of the thermopile surface. Level the instrument by turning the levelling screws to bring the bubble of the spirit level within the marked ring (For easy levelling first use the screw nearest to the spirit level).
When the CG 4 is placed horizontally with the spirit level, or when it is mounted with its base parallel to a horizontal plane, the thermopile is horizontal within 0.5 °.

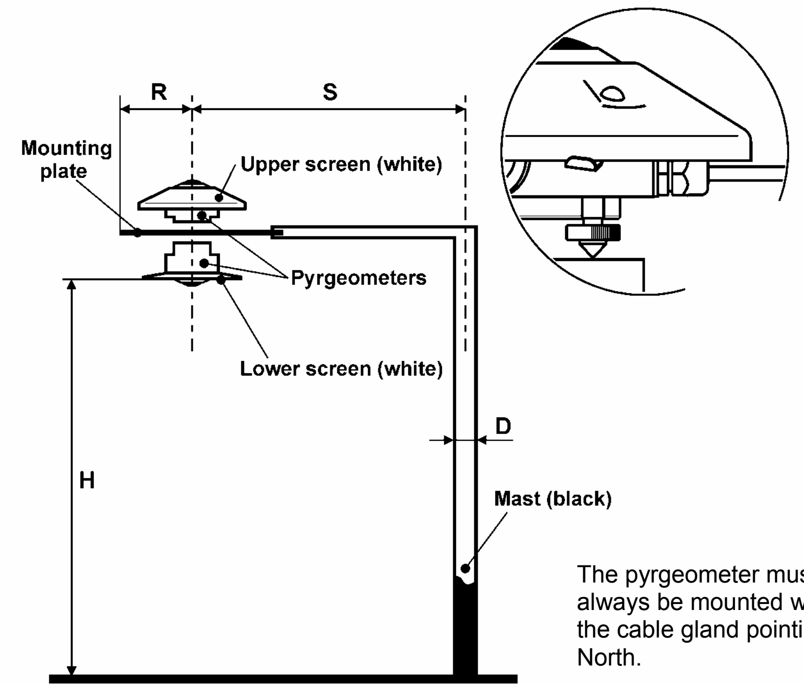
The pyrgeometer should be secured tightly with the two stainless steel bolts. Ensure that the pyrgeometer maintains the proper levelled position!

3.2.4 Mounting of two CG 4's as net pyrgeometer

As with all net radiation measurements, a location that is representative for the whole area of study should be found.

For the two, possible ventilated, CG 4's a mounting plate with a 500 mm rod is available (see chapter 9).

Typical is a height of 2 m above short homogeneous vegetation. The mast on which the rod is clamped can block the down welling or upward radiation with a fraction of max. $(D / 2 \cdot \pi \cdot S)$, in which D is the diameter of the mast and S the distance of sensor to mast. The mast itself also emits infrared radiation, so keep the mast and CG 4 temperatures close to each other or the emissivity low (reflecting mast).



The pyrgeometer must always be mounted with the cable gland pointing North.

Figure 3.2 Mounting of two pyrgeometers.

3.3 ELECTRICAL CONNECTION

The CG 4 is provided with a 10 m, 6 wire shielded cable (8 wire for the Pt-100 version). The following colour code is used:

Red	: Plus thermopile
Blue	: Minus thermopile
White	: Case
Black	: Shield

Thermistor
Yellow
Green

Pt-100 (optional)

Yellow	: Pt 100	(combined with brown)
Brown	: Pt 100	(combined with yellow)
Green	: Pt 100	(combined with grey)
Grey	: Pt 100	(combined with green)

A surge arrester is installed to lead off induced lightning currents to the case. It is recommended to ground the case for this reason. The surge arrester is noble gas filled, has infinite impedance and recovers after breakdown. Breakdown voltage is 90 V. Peak pulse current is 10 kA.

The shield is isolated from the case, so no shield-current can exist. Shield and white lead may be connected to the same ground at the readout equipment. The cable must be firmly secured to minimise spurious response during stormy weather (deforming standard cable produces voltage spikes, a tribo electric effect and capacitance effect). Kipp & Zonen pyrgeometer cables are of low noise type, however take care that the terminals '+' and '-' at a connection box have the same temperature, to prevent thermal EMF's.
A junction box or connector with a metal outer case is advised.

Looking at the circuit diagram of figure 3.3, it is clear that the impedance of the readout equipment is loading the thermistor circuit and the thermopile.

The sensitivity is affected more than 0.1% when the load resistance is under 100 kΩ. For this reason we recommend the use of readout equipment with input impedance's of 1 MΩ or more such as potentiometric recorders, digital voltmeters, etc.

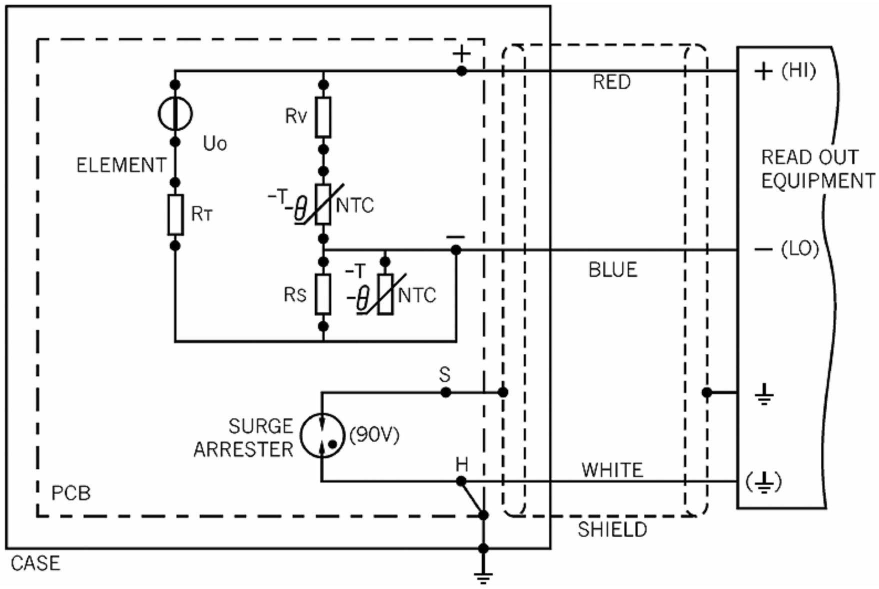


Figure 3.3 Circuit diagram of the CG 4 pyrgeometer and the connection to the readout equipment.

The data loggers and chart recorders manufactured by Kipp & Zonen meet these requirements. Longer cables may be applied, but the cable resistance must be less than 0.1% of the impedance of the readout equipment.

Kipp & Zonen supplies shielded low-noise extension cables up to lengths of 200 m which are coupled by waterproof connectors to the CG 4 cable. The lead resistance is 8 Ohm/100 m.

A considerable input bias current of the readout equipment can produce a voltage of several micro Volts across the impedance of the pyrgeometer. The correct measured zero signal can be verified with a resistance replacing the pyrgeometer impedance at the input terminals.

The pyrgeometer can also be connected to a computer or data acquisition system. A low voltage analogue input module with A to D converter must be available for thermopile readout. The span and resolution of the A to D converter in the module must allow a system sensitivity of about 1 bit per W/m^2. For calculation of the downward radiation, temperature data has to be converted to absolute body temperatures in Kelvin units. A thermistor connection to the Campbell data logger is shown in figure 3.4
The connection of the Pt-100 is shown in figure 3.5

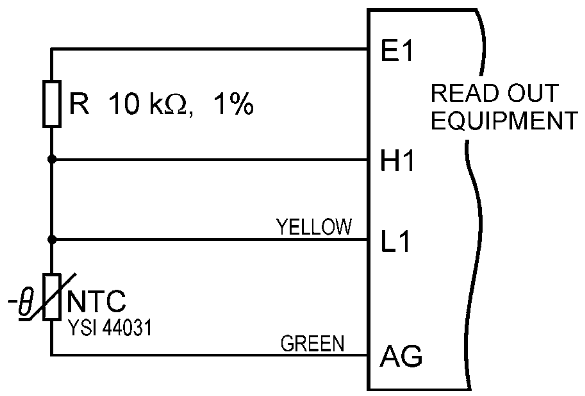


Figure 3.4 Example of a CG 4 with a thermistor connected to a Campbell data logger

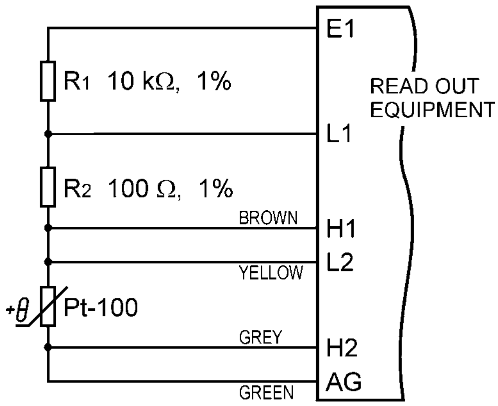


Figure 3.5 *Example of a CG 4 with a Pt-100 connected to a Campbell data logger*

For amplification of the pyrgeometer signal, Kipp & Zonen recommends the CT 24 amplifier, available from Kipp & Zonen.
This amplifier will convert the output voltage from the pyrgeometer into a standard 4 – 20 mA output current. Voltage output and/or amplification adjustment to the pyrgeometers calibration factor are also possible.
In order to allow negative values for the CG 4, the zero of the CT 24 (normally 4 mA) will be shifted to 8 mA.

4 OPERATION

After completing the installation the pyrgeometer will be ready for operation. At the end of the paragraph an example is given to illustrate a downward atmospheric long wave radiation measurement under two different atmospheric conditions.

4.1 CALCULATING THE DOWNWARD RADIATION

The downward atmospheric long wave radiation can be calculated with formula 1 by measuring the thermopile output voltage Uemf [μV], the body temperature T_b [K], and taking the calibration factor S [μV/W/m^2] into account.

$$L_d = \frac{Uemf}{S} + 5.67 \cdot 10^{-8} \cdot T_b^4$$ *(formula 1)*

L_d	= Downward atmospheric long wave radiation	[W/m^2]
$\frac{Uemf}{S}$	= Net - radiation (Difference between the downward long wave radiation emitted from the atmosphere and the upward irradiance of the CG 4 sensor)	[W/m^2]
$5.67 \cdot 10^{-8} \cdot T_b^4$	= Upward irradiance of the CG 4 sensor	[W/m^2]

Mind that the net radiation term (Uemf / S) is mostly negative, so the calculated downward atmospheric long wave radiation is smaller than the sensor's upward irradiance ($5.67 \cdot 10^{-8} \cdot T_b^4$).

In the BSRN manual (WMO/TD-No.897) an extended formula is described. This formula corrects for window heating and so called “solar radiation leakage”. Due to the low window heating offset and proper cut-on frequency, these corrections are not necessary for the CG 4.

4.1.1 Example

During field measurements the pyrgeometer is exposed to varying atmospheric conditions with typical radiating properties. Therefore we define the two most common conditions known as, cloudy overcast sky and clear sky.

4.1.2 Cloudy overcast sky

Typical for a cloudy overcast sky is that radiation emitted by the earth is absorbed 100%. Therefore the overcast sky will re-emit the radiation (L_d) 100%.
In theory the net radiation (Uemf / S) will be zero, so the pyrgeometer thermopile output voltage (Uemf) will be zero. Practically the thermopile output shows a little negative voltage (a few Watts per meter square), due to a small heat exchange between a relatively warm pyrgeometer and a colder sky.
In this case the calculated atmospheric long wave radiation (L_d) shows a relatively large positive value. In the case of rain, the thermopile output will read zero, because water deposited at the pyrgeometer window is a perfect infrared absorber. A cloudy overcast sky condition is illustrated in figure 4.1A

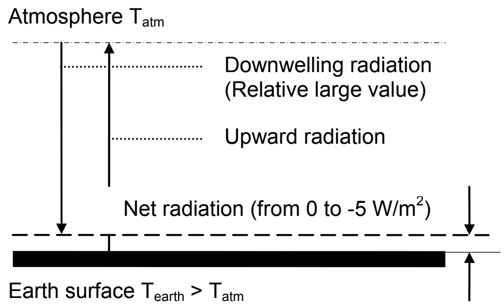


Figure 4.1A Cloudy overcast sky condition

4.1.3 Clear sky conditions

Clear sky conditions differ in the way that there is a relative large heat loss caused by the atmospheric window. In this way the amount of re-emitted radiation by a clear sky is smaller compared to the cloud overcast sky condition. Because of the heat-lost in upward direction, the sensors hot junctions will cool-down and show a relative large negative net radiation value (from -90 to -130 W/m^2). In this case the calculated atmospheric long wave radiation (L_d) shows a relative small positive value. A clear sky condition is illustrated in figure 4.1B

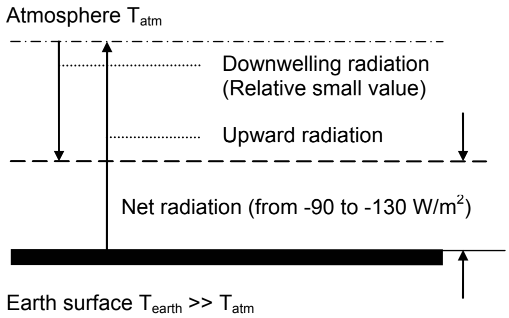


Figure 4.1B Clear sky condition

4.1.4 Measurements during a sunny day

CG 4 allows accurate daytime measurements on sunny days without the need for a moving shading device. Despite solar radiation up to 1000 W/m^2 the window heating will be less than 4 W/m^2 in the overall calculated downward radiation.

Formula 1 can be applied without any problems with the following exception: One must take note of the amount of Infrared radiation in the solar spectrum. The amount of solar infrared radiation depends on many parameters, for example the water vapour content in the atmosphere (Humidity), location of the CG 4 at a certain altitude and

the suns declination angle. The following curve indicates the possible infrared radiation in the solar spectrum in the case of low water content in the atmosphere.
The amount of solar infrared at the CG 4 sensor is expected to be very low (0 to 3 W/m^2) because of the filter cut-on at 4.5 μm. Other types of pyrgeometers could be affected more (0 – 10 W/m^2).

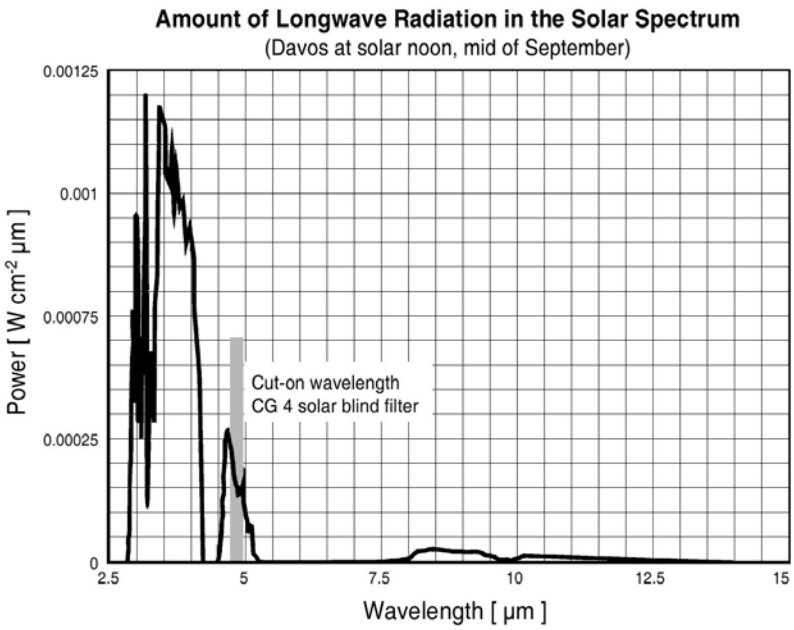


Figure 4.2 Direct solar irradiance in Davos at solar noon, mid of September.

4.2 MEASURING NET RADIATION WITH TWO PYRGEOMETERS

With two CG 4's as a net-pyrgeometer, the long wave radiation balance (also called net long wave radiation) can also be measured. This balance, combined with the information from an albedometer, gives the net total radiation. A mounting plate with 500 mm rod for 4 possibly ventilated sensors is available (see chapter 9).

When determining the net-long wave radiation, it is not strictly necessary to measure sensor temperatures.
Assuming that the temperatures of upper and lower sensor are equal, it can be cancelled from the equation for net-radiation.

The combination of a net pyrgeometer (two CG 4's) and a CM 7B or CM 14 albedometer for measuring net total radiation has many advantages over conventional net total radiation sensors with plastic (polyethylene) windows. Robustness and maintainability are better, separate information on solar and long wave radiation is offered. Problems with dew deposition are minimised with the Kipp & Zonen CV 2 ventilation unit by ventilating and optional heating of the pyrgeometer.

4.3 THERMAL STRESS STUDIES

The CG 4 pyrgeometer is suitable for use in building research for thermal stress studies. It may be necessary to keep the CG 4 body at a known temperature, e.g. the human skin temperature, to get reproducible results.

5 MAINTENANCE

Once installed the pyrgeometer needs little maintenance.
The Silicon window must be inspected at regular intervals and cleaned regularly, e.g. every morning. On clear windless nights the window temperature of horizontally placed pyrgeometers will decrease, even to the dew point temperature of the air, due to IR 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 window and can stay there for several hours in the morning. An ice cap on the window is a strong infrared absorber and increases the pyrgeometer signal drastically up to 0 μV in the first hours after sunrise. Hoar frost disappears due to solar radiation during the morning, but should be wiped off manually as soon as possible.

Another periodic check should ensure that the instrument is level and that the silica gel is still coloured blue. When the blue silica gel in the drying cartridge is turned completely pink (normally after several months), it must be replaced by active material. Pink silica gel can be activated again by heating in an oven at 130°C for several hours.

In some networks, the exposed window of the pyrgeometer is ventilated continuously by a blower to keep the window above the dew point temperature. Preheating of the air is not necessary in principle.

The Kipp & Zonen CV 2 ventilation unit is specially designed to maintain accurate unattended operation under most weather conditions. CV 2 is able to prevent dew deposition and will remove water droplets much quicker.

Note: During maintenance or operation be aware that everything emits thermal radiation, so hot gasses, persons, birds can affect the signal if they subtend a considerable angle in the field of view.

It is normal in humid areas to replace the desiccant twice a year.
The exchange interval is affected by humidity, change in air pressure and the frequency of temperature changes.
Apart from that it is good to visit the site regularly to check the condition of the pyrgeometer (desiccant, dirt on window, levelling of instrument and condition of the cabling).
Water transport through the cable is possible when the open end of the cable and the connected device are in a humid environment.

Some tips when changing the desiccant:

A Make sure the surfaces of the pyrgeometer and the cartridge, that touch the rubber ring, are clean (corrosion can do a lot of harm here, and dirt in combination with water can cause this).

B The rubber ring is normally coated with a silicon grease (Vaseline will also do) to make the seal even better. If the rubber ring looks dry apply some grease to it.

C Check that the metal spring that retains the drying cartridge applies enough force. It is normal that you have to use two hands to open and close it.

It is very difficult to make the pyrgeometers hermetically sealed. The only way to do this properly is to put the inside of the instrument under pressure (> 1.0 Bar), but this has to be checked at yearly intervals.
So, due to pressure differences inside and outside the instrument there will always be some exchange of (humid) air.

6 CALIBRATION

6.1 THE CALIBRATION FACTOR

The ideal pyrgeometer should always have a constant ratio of voltage output to irradiance level (outside the instrument in the plane of the sensing element). This ratio is called sensitivity (S) or responsivity. The sensitivity figure of a particular pyrgeometer is unique.

6.2 CALIBRATION PROCEDURE AT KIPP & ZONEN

The CG 4 is calibrated outdoors in a side-by-side comparison against a reference CG 4 pyrgeometer. This method of outdoor calibration is preferable above any conventional indoor side-by-side calibration method.

6.2.1 The outdoor procedure

The CG 4's are calibrated outdoors at Kipp & Zonen under a mainly clear sky during nighttime. The instruments are installed side by side next to the reference pyrgeometer. Both the pyrgeometers thermopile outputs (Uemf) and body temperatures (T_b) are measured each second and compressed to one minute averages. Afterwards the downward radiation (L_d) on the reference pyrgeometer is calculated using the formula:

$$L_d = \frac{Uemf}{S} + 5.67 \cdot 10^{-8} \cdot T_b^4$$

For the other "test" CG 4's a one minute average sensitivity is calculated using the formula:

$$S_t = U_t / (L_d - 5.67 \cdot 10^{-8} \cdot T_b^4)$$

A final St is determined only from one minute St's determined in periods with net IR-exchange = $L_d - 5.67 \cdot 10^{-8} \cdot T_b^4 > 40$ W/m² (Clear sky).
The sum of all periods must be at least 6 hours.

6.2.2 Traceability to the World Radiometric reference

The reference CG 4 pyrgeometer is calibrated in principle the year before during the summer by an outdoor comparison on the roof platform of the PMOD/WRC to the reference pyrgeometers of the World Radiation Center. (See www.pmodwrc.ch).

6.3 RECALIBRATION

Pyrgeometer sensitivity changes with time and with exposure to radiation. Periodic calibration (at least every two years) is advised. Accurate calibrations can be done outdoors under clear sky conditions by comparison to a reference pyrgeometer.

7 FREQUENTLY ASKED QUESTIONS (FAQ's)

The most frequently asked questions are listed below.
For an update, please refer to the Kipp & Zonen website:
http://www.kippzonen.com

1. What are typical values for downwelling atmospheric long wave radiation?

Ambient temperature	**Clouded sky** (Lnet = 0 W/m^2)	**Clear sky** (Lnet = -150 W/m^2)
	L_d in W/m^2	
-20 °C	230	80
0 °C	315	165
+30 °C	480	330

2. The values calculated with the formula, given in chapter 4, show a very strange value. What could be the reason?

- Check whether the (instrument) temperature (T_b) is given in Kelvin.
- Check that the net radiation (Uemf / S) is a negative value, if not, the wires are possibly interchanged.

3. What is the primary entry point for humidity?

The desiccant cartridge and cable gland have equal chances to transport some moisture, but also the silicon glue of the window is not fully watertight. However, normally the cable gland is never touched while the cartridge is removed frequently. So when no care is taken, one can easily make the desiccant cartridge the primary entry point.

Note: Water transport through the cable is also possible when the open end of the cable and the connected device are in a humid environment.

8 TROUBLE SHOOTING

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

The following contains a procedure for checking the instrument in case it does not function as it should.
If water or ice is deposited to the outside, clean the outside. Probably water droplets will evaporate in less than one hour.

Malfunction	Possible cause	Check
None or disturbed signal	Broken leads	Cover sensor, Impedance over red and blue wire should be within specs.
	Window is wet or dusty	Clean window using soft lens cleaner
	Unwanted IR sources near the instrument	Check the site for exhaust vents and/or heat reflecting objects
	Malfunction readout equipment	Check device
	Broken leads inside sensor	Signal at sensor print. No repair possible
No temperature signal	Broken leads	Impedance
Stained window	Persistent dirt	Clean window using alcohol with a soft cloth or tissue

9 PART NUMBERS / SPARE PARTS / OPTIONS

Description	Part no.
Upper sunscreen (plastic)	0305-166
Lower sunscreen (metal)	0012-053
Levelling screw (2 required per pyrgeometer)	0012-117
Fixed foot	0012-116
Complete drying cartridge consisting of:	
Clamp-Spring	0305-165
Drying cartridge (without cover)	9012-106
Cover for cartridge	9012-107
Rubber ring	2132-153
Silica gel container (1kg)	2643 943
Manual CG 4 pyrgeometer	0345 200
CV 2 ventilation unit	0349 900
CV 2 ventilation unit with heater	0349 901
CT 24 solar sensor 4 – 20 mA amplifier	0305 710

Mounting plates with a 500 mm rod to install radiometers for net radiation measurements:

Mounting plate for 4 sensors, all 4 can be ventilated (2 upper and 2 lower)	0012 067
Mounting plate for 2 possibly ventilated sensors (1 upper and 1 lower)	0012 069

Description	Part no.
Mounting plate for 4 unventilated sensors (2 upper and 2 lower)	0012 092
10 meters cable extension and connectors	0305 666
15 meters cable extension and connectors	0305 631
20 meters cable extension and connectors	0305 632
25 meters cable extension and connectors	0305 633
30 meters cable extension and connectors	0305 634
50 meters cable extension and connectors	0305 635
75 meters cable extension and connectors	0305 636
100 meters cable extension and connectors	0305 637
200 meters cable extension and connectors	0305 638

APPENDIX I WORLD RADIATION CENTRE INFORMATION

The World Radiation Centre capable of Pyrgeometer calibration is:

Physikalisch-Meterologisches Observatorium
Dorfstrasse 33 CH-7260
Davos Dorf Switzerland.
Website: www.pmodwrc.ch

APPENDIX II THERMISTOR SPECIFICATIONS

YSI thermistor 44031 Resistance versus Temperature in °C

Temperature [°C]	Resistance [Ω]	Temperature [°C]	Resistance [Ω]	Temperature [°C]	Resistance [Ω]
-30	135200	0	29490	30	8194
-29	127900	1	28150	31	7880
-28	121100	2	26890	32	7579
-27	114600	3	25690	33	7291
-26	108600	4	24550	34	7016
-25	102900	5	23460	35	6752
-24	97490	6	22430	36	6500
-23	92430	7	21450	37	6258
-22	87660	8	20520	38	6026
-21	83160	9	19630	39	5805
-20	78910	10	18790	40	5592
-19	74910	11	17980	41	5389
-18	71130	12	17220	42	5193
-17	67570	13	16490	43	5006
-16	64200	14	15790	44	4827
-15	61020	15	15130	45	4655
-14	58010	16	14500	46	4489
-13	55170	17	13900	47	4331
-12	52480	18	13330	48	4179
-11	49940	19	12790	49	4033
-10	47540	20	12260	50	3893
-9	45270	21	11770	51	3758
-8	43110	22	11290	52	3629
-7	41070	23	10840	53	3504
-6	39140	24	10410	54	3385
-5	37310	25	10000	55	3270
-4	35570	26	9605	56	3160
-3	33930	27	9227	57	3054
-2	32370	28	8867	58	2952
-1	30890	29	8523	59	2854

APPENDIX III Pt-100 SPECIFICATIONS

Pt-100 Resistance versus Temperature in °C

Temperature [°C]	Resistance [Ω]	Temperature [°C]	Resistance [Ω]	Temperature [°C]	Resistance [Ω]
-30	88.22	0	100.00	30	111.67
-29	88.62	1	100.39	31	112.06
-28	89.01	2	100.78	32	112.45
-27	89.40	3	101.17	33	112.83
-26	89.80	4	101.56	34	113.22
-25	90.19	5	101.95	35	113.61
-24	90.59	6	102.34	36	113.99
-23	90.98	7	102.73	37	114.38
-22	91.37	8	103.12	38	114.77
-21	91.77	9	103.51	39	115.15
-20	92.16	10	103.90	40	115.54
-19	92.55	11	104.29	41	115.93
-18	92.95	12	104.68	42	116.31
-17	93.34	13	105.07	43	116.70
-16	93.73	14	105.46	44	117.08
-15	94.12	15	105.85	45	117.47
-14	94.52	16	106.24	46	117.85
-13	94.91	17	106.63	47	118.24
-12	95.30	18	107.02	48	118.62
-11	95.69	19	107.40	49	119.01
-10	96.09	20	107.79	50	119.40
-9	96.48	21	108.18	51	119.78
-8	96.87	22	108.57	52	120.16
-7	97.26	23	108.96	53	120.55
-6	97.65	24	109.35	54	120.93
-5	98.04	25	109.73	55	121.32
-4	98.44	26	110.12	56	121.70
-3	98.83	27	110.51	57	122.09
-2	99.22	28	110.90	58	122.47
-1	99.61	29	110.28	59	122.86

APPENDIX IV   RECALIBRATION SERVICE

Pyranometers, UV-meters, Pyrgeometers &
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 at least 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 your convenience we added three fax forms to schedule the recalibration of your instrument(s) at Kipp & Zonen.

NAME :
COMPANY/INSTITUTE :
ADDRESS :
POSTCODE +CITY :
COUNTRY :
PHONE :
FAX :

☐ **I would like to receive a price list for recalibration**

☐ **I would like to submit my instruments for recalibration**

Type/Model:	**Qty:**	**Requested delivery time**
		I intend to send the instruments to Kipp & Zonen on: . . . . . ./. . . . . ./. . . . . .
		I would like to receive the instrument(s) back on: . . . . . ./. . . . . ./. . . . . .

Conformation by Kipp & Zonen
☐ Yes, the dates are acceptable to us ☐ No, unfortunately the dates do not fit into our calibration schedule. We suggest the following dates: . . . . . ./. . . . . ./. . . . ./. . . . . ./. . . . . .

Fax +31-15-2620351

or mail to:

Kipp & Zonen P.O. Box 507 2600AM
Delft The Netherlands

NAME :
COMPANY/INSTITUTE :
ADDRESS :
POSTCODE +CITY :
COUNTRY :
PHONE :
FAX :

☐ **I would like to receive a price list for recalibration**

☐ **I would like to submit my instruments for recalibration**

Type/Model:	**Qty:**	**Requested delivery time**
		I intend to send the instruments to Kipp & Zonen on: . . . . . ./. . . . . ./. . . . . .
		I would like to receive the instrument(s) back on: . . . . . ./. . . . . ./. . . . . .

Conformation by Kipp & Zonen
☐ Yes, the dates are acceptable to us ☐ No, unfortunately the dates do not fit into our calibration schedule. We suggest the following dates: . . . . . ./. . . . . ./. . . . ./. . . . . ./. . . . . .

Fax +31-15-2620351

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Type/Model:	Qty:	Requested delivery time
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		I would like to receive the instrument(s) back on: . . . . . ./. . . . . ./. . . . . .

Conformation by Kipp & Zonen
☐ Yes, the dates are acceptable to us ☐ No, unfortunately the dates do not fit into our calibration schedule. We suggest the following dates: . . . . . ./. . . . . ./. . . . ./. . . . . ./. . . . . .

Fax +31-15-2620351

or mail to:

Kipp & Zonen P.O. Box 507 2600AM
Delft The Netherlands

Customer Support

Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares. The address is as follows:

Für Servicearbeiten und Kalibrierung, Verbrauchs-material und Ersatzteile steht Ihnen unsere Customer Support Abteilung unter folgender Adresse 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. Leur adresse est la suivante :

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