Kipp & Zonen

INSTRUCTION MANUAL

CG 3

PYRGEOMETER

0359 200

IMPORTANT USER INFORMATION

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

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

Kipp & Zonen B.V.		
Röntgenweg 1	2624 BD Delft	Holland
P.O. Box 507	2600 AM Delft	Holland
Phone	+31 (0)15 2698000	
Fax	+31 (0)15 2620351	
Email	info.holland@kippzonen.com	

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

Manual version: 0604

CE

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

Types: **CG 3 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

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

TABLE OF CONTENTS

1 GENERAL INFORMATION

1.1 INTRODUCTION

CG 3 has been designed for meteorological measurements of downward atmospheric longwave-radiation with good reliability and accuracy. For meteorological energy balance studies, a net pyrgeometer (looking both up and down) can be constructed from two CG 3 radiometers, which are mounted on a net pyrgeometers mounting plate. Each radiometer has a separate cable that is fixed along the rod of the mounting plate.

CG 3 provides a voltage that is proportional to the net radiation in the far infrared (FIR). By calculation, downward atmospheric longwave-radiation is derived. For this reason CG 3 embodies an YSI 44031 10 k thermistor or optional Pt-100 sensor to measure the body temperature.

CG 3 uses a specially designed Silicon window. Although the window is flat, CG 3 has a 150 degrees field of view. On the inside a solar-blind filter blocks solar radiation. Although CG 3 does not have the ideal 180 degrees field of view the radiation exchange within 150 degrees is representative of the radiation exchange within the hemisphere. This is because the reference CG 3 is calibrated outdoors with respect to a reference CG 4, which has a 180 degrees field of view.

CG 3 features are:

- Sensitive to infrared radiation in a wavelength range from 5 μm (microns) to approximately 40 μm.
- 150 degrees field of view.

For meteorological energy balance studies, a net pyrgeometer (looking both up and down) should be used, as described above.

1.2 PHYSICAL PRINCIPLES OF THE PYRGEOMETER

The CG 3 pyrgeometer incorporates a thermal detector. The thermal detector is a 64-thermocouple thermopile. The body temperature sensor, either a 10 k thermistor (YSI44031) or Pt-100 (optionally, instead of the 10 k thermistor), is incorporated in the pyrgeometer’s Aluminium housing

A black painted disk absorbs the radiant energy. 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 one side of the Silicon window a coating is deposited. The outer side of the window is just the bare Silicon that protects the detector from environmental influences such as wind and rain. On the inner side an interference filter is deposited that transmits only the long-wave radiation. The Silicon window and coating allow uniform transmittance of the atmospheric long-wave radiation in a range from 4.5 μm (cut-on) to approximately 40 μm. A schematic construction drawing of the CG 3 pyrgeometer is shown in figure 1.1.

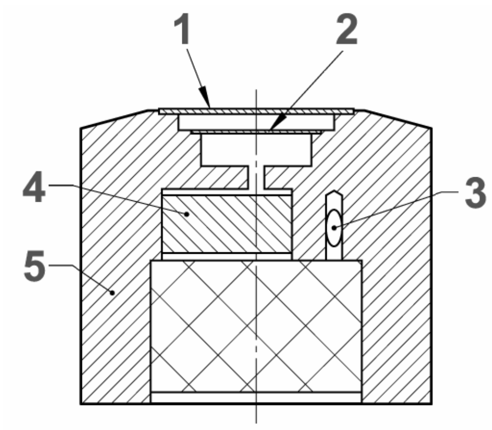

Figure 1.1 Schematic construction of the CG 3 pyrgeometer

1 Silicon window
2 Thermal detector
3 Temperature sensor
4 Desiccant
5 Aluminium housing

1.2.1 Properties of the Silicon window

CG 3 uses a specially designed pure Silicon window. Although the window is not hemispherical, CG 3 has a 150 degrees field of view.

A big advantage of the flat window over the typical spherical window is the ability of the coating supplier to deposit a more uniform coating on the window surface. Deposition of a uniform filter coating on a strongly curved surface is a very difficult process with unpredictable results.

Kipp & Zonen has developed a window with good optical qualities due to the optimal shape and coating uniformity.

In this way, a CG 3 window achieves equal transmittance over the whole window surface.

The solar-blind filter is opaque to radiation shorter than the 4.5 µm cut-on wavelength. This low-pass filter is deposited on the inside of the window and is an interference filter. Currently most pyrgeometers have their cut-on at a lower wavelength. Problems may occur in the case of clear sunny days with low humidity when, in the solar spectrum between 2.5 µm and 5 µm, there can be infrared solar radiation up to 10 W/m^2 that would increase the measured downward infrared radiation significantly. In the CG 3 this unwanted signal is blocked by the filter coating.

The CG 3 window transmittance curve is given in figure 1.2
The transmittance is given at normal incidence.

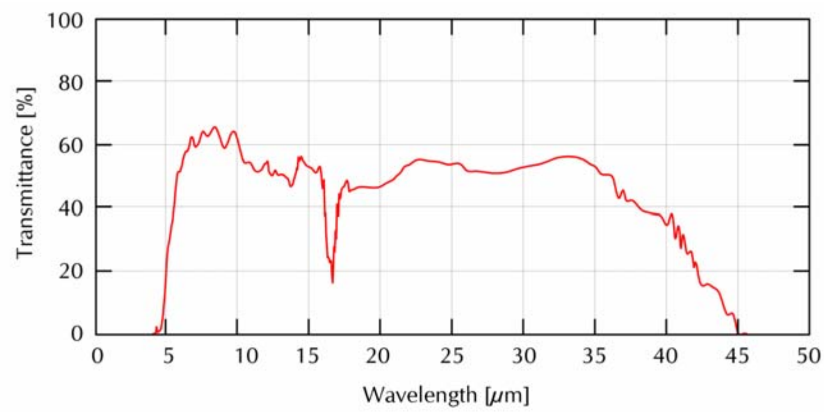

Figure 1.2 Typical transmittance of the CG 3 window.

1.3 DOWNWARD ATMOSPHERIC LONGWAVE-RADIATION

The atmosphere is a gaseous envelope surrounding the earth, held in place by gravity, having its maximum density just above the solid surface and becoming gradually thinner with distance from the ground. Finally it becomes indistinguishable from interplanetary gas.
There is no defined upper limit or “top” to the atmosphere.

As we go away from the surface of the earth, different regions can be defined with widely different properties, being the locations of various physical and chemical phenomena. One such phenomenon is longwave thermal radiation, which is an important, but rather difficult to measure, component of the atmospheric radiation balance.

The atmosphere is transparent to longwave radiation emitted by the Earth’s surface at certain wavelength intervals, particularly within a spectral range of approximately 8 μm 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 amount of the heat gained each day from the sun.

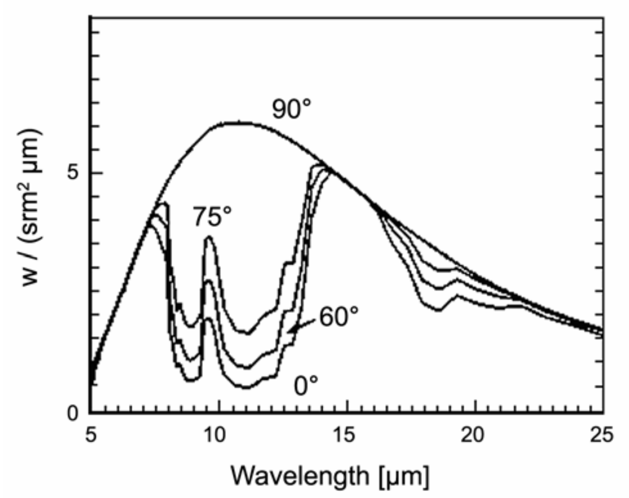

Figure 1.3 Atmospheric radiation (‘window’ at 8 µm to 14 µm)

The sun radiates approximately as a black-body at an equivalent temperature of nearly 5770 K. Almost 99 % of its emitted energy is at wavelengths less than 4 μm and is called short-wave radiation. The equivalent radiant temperature of the Earth's surface is about 275 K. More than 99 % of this energy is emitted at wavelengths more than 5 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 long-wave radiation emitted from the earth by chemical elements in the atmosphere such as Water Vapour (H_2O), Oxygen (O_2), Ozone (O_3), Carbon Dioxide (CO_2), etc. These elements are the main emitters of longwave-radiation in the atmosphere.

The remaining unabsorbed portion of the earth's radiation escapes into 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 black-body is seen in the range 8 μm to 14 μm with a temperature of +14 ºC.

Outside this wavelength range a blackbody of -60 ºC is observed. Under clear sky conditions in the 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 μm to 14 μm. In this range the pyrgeometer also loses its thermal energy upward.

Whereas 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 long-wave radiation emitted from the pyrgeometer.

The downward atmospheric long-wave radiation can be calculated using formula 1 by measuring the thermopile output voltage U_{emf} [μV], the body temperature T_b [K], and taking the instrument calibration factor S [$\mu V/W/m^2$] into account.

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

Formula 1 (provided by 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 3)	[W/m^2]
$5.67 \cdot 10^{-8} \cdot T_b^4$	= Upward irradiance of the CG 3 radiometer	[W/m^2]

Note that the net radiation term (U_{emf} / S) is mostly negative, so the calculated downward atmospheric long-wave radiation is smaller than the instrument'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 with wavelengths less than 1.1 μm within the window material. As a consequence the windows of certain types of pyrgeometers will heat up proportionally 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 value for downward long-wave radiation that is too high.

This offset is not easily reduced by ventilation, which only cools at a maximum rate of 50 $W/m^2/ºC$ whilst solar radiation can be absorbed at a rate of up to 500 W/m^2 on a sunny day.
Certain types of pyrgeometers are equipped with one or more thermistors to measure the absolute temperature of the window that represents the offset. During window temperature measurements a complex calculation must be performed to compensate for the offset.

Window heating can be determined by carrying out the following check.

1.4.1 How to perform the check?

The check must be performed under clear sky conditions. The CG 3 pyrgeometer is operated with thermopile and thermistor outputs recorded for measuring the downward radiation.

To perform the outdoor check, follow the next steps:

1. Stand close behind the pyrgeometer in line with the sun so that the pyrgeometer is illuminated by the solar radiation.
2. Wait without moving for at least 1 minute until the pyrgeometer thermopile output has stabilised (your body contributes to the pyrgeometer signal). Record the readings.
3. Raise your hand in front of the pyrgeometer and in line with the sun so that the pyrgeometer is completely shaded.
4. Wait without moving for at least 1 minute until the pyrgeometer thermopile output has stabilised. Record the readings.
5. The check is completed. The difference between the readings found after steps 2 and 4 gives the amount of window heating.

1.5 LOW TEMPERATURE DEPENDENCY OF SENSITIVITY

The sensitivity is correlated to temperature as a consequence of the physical properties of the thermopile materials. 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 careful thermopile construction the sensitivity drops less than 5 % at -20 °C with respect to the sensitivity at +50 °C.

2 TECHNICAL DATA

2.1 SPECIFICATIONS OF THE CG 3 PYRGEOMETER

Performance

Spectral range:	4.5 µm to 42 µm (50 % points)
Sensitivity:	10 µV/W/m^2 (nominal)
Impedance:	40 Ω to 200 Ω (nominal)
Response time:	25 seconds (95 % response) < 8 seconds (63 % response)
Non-linearity:	1 % (-250 W/m^2 to +250 W/m^2, net radiation)
Temperature dependence of sensitivity:	5 % max (-10 °C ref +40 °C)
Tilt error:	3 % max (facing downwards)
Zero offset due to temperature change:	±4 W/m^2 (5 K/h temperature change)
Operating temperature:	-40 °C to +80 °C
Field of view:	150 degrees
Net-irradiance:	-250 to +250 W/m^2
Non-stability:	1 % (sensitivity change per year)
Spectral selectivity within the range 8 µm to 14 µm:	5 % max.
Window heating offset:	25 W/m^2 max. (1000 W/m^2 normal incidence solar radiation)
Accuracy:	10 % (daily totals)

Estimated inaccuracy of Measurement:	± 20 W/m^2.
Thermistor specifications (for thermistor version):	YSI 44031 (10 k / 25 ºC) (see Appendix II)
Pt-100 specifications (for Pt-100 version):	Heraeus M-GX 1013, DIN IEC 751, Class A (see appendix III)

Construction

Detector paint:	Carbon Black
Window:	Silicon with internal solar-blind filter
Desiccant:	silica gel (non-replaceable)
Housing materials:	Anodised aluminium body
Weight	CG 3: 650 g
Cable length:	10 m
Dimensions in mm:	See figures 2.1 and 2.2

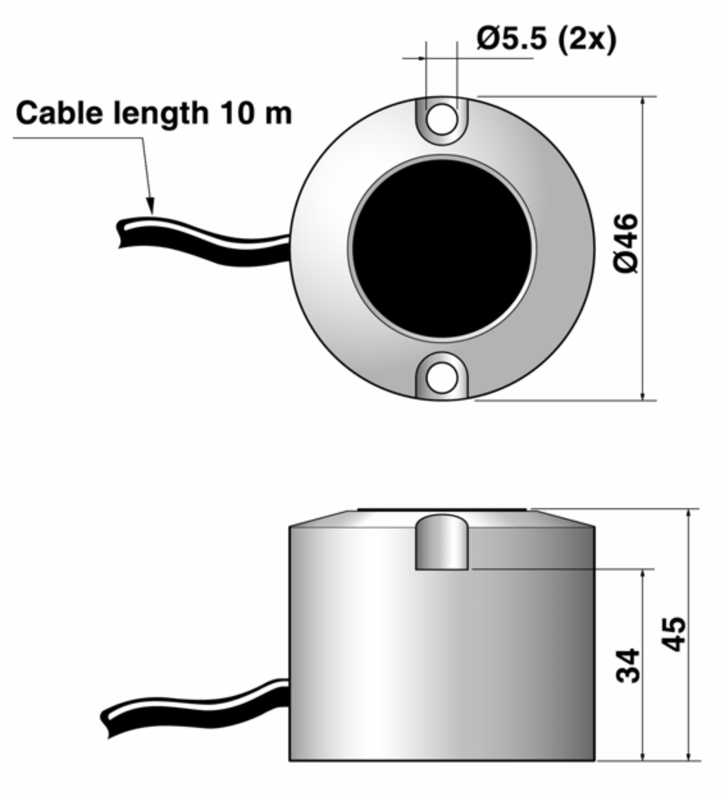

Figure 2.1 CG 3 pyrgeometer outline dimensions in mm.

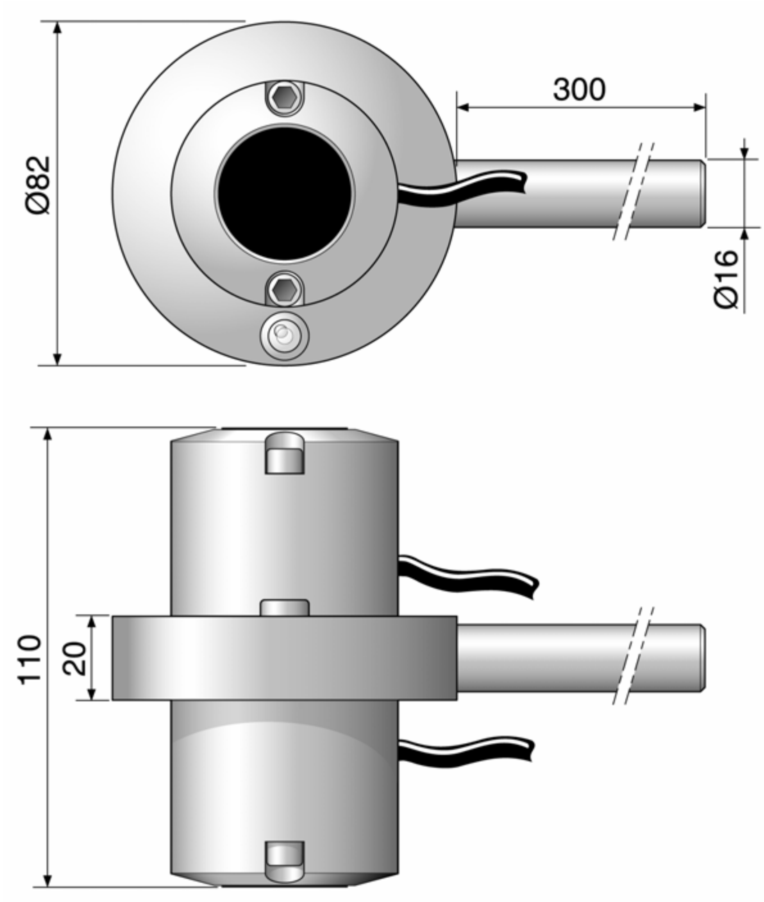

Figure 2.2 *CG 3 Net pyrgeometer outline dimensions in mm (2 x CG 3 + Net Pyrgeometer Mounting Plate)*

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 irradiance. However, if the measurement conditions differ significantly from the calibration conditions the 'actual' sensitivity will be different from that supplied and errors in the calculated irradiances must be expected.

These errors can be corrected because the 'actual' sensitivity can be calculated when it is a well-known function of simply measured parameters (sometimes called the transfer function or the sensitivity function). This is especially convenient in connection with a programmable data acquisition system.

For the CG 3 the effect of each parameter on the sensitivity can be shown separately, because the parameters exhibit little interaction. The non-linearity error (the variation in sensitivity with irradiance) is similar for all CG 3 instruments. See figure 2.3.

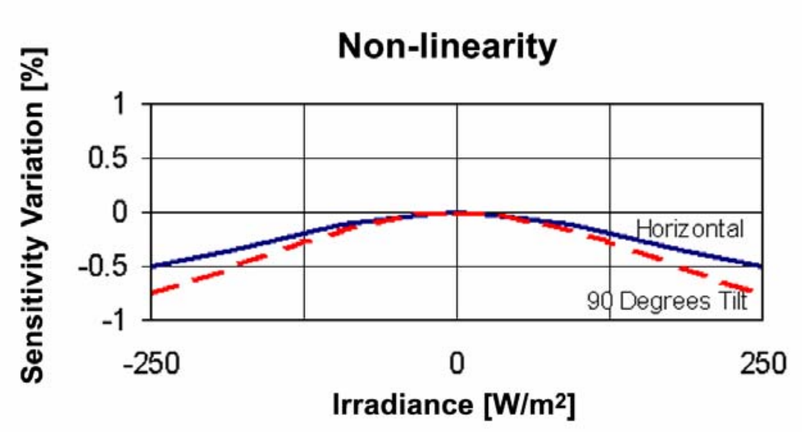

Figure 2.3 *Non-linear sensitivity variation with irradiance of the CG 3 pyrgeometer when horizontal and when mounted at 90°.*

The temperature dependence of the sensitivity varies slightly between instruments. For any given CG 3 the variation curve lies in the region between the limit lines in figure 2.4

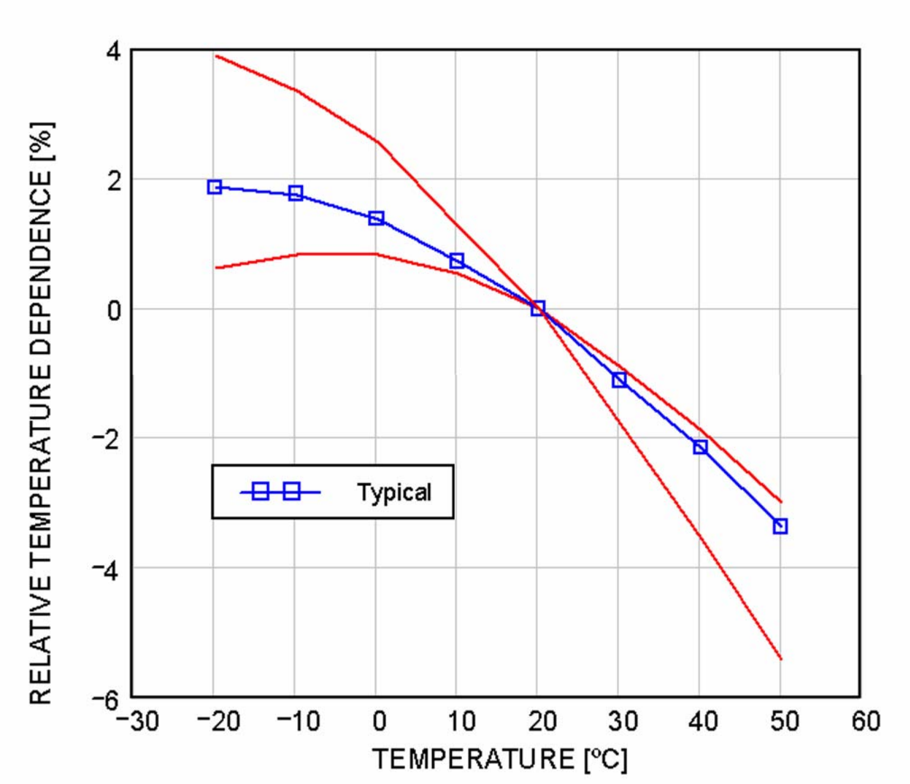

Figure 2.4 *Curves of relative sensitivity variation with instrument temperature of CG 3 pyrgeometers.*

3 INSTALLATION

Reading these instructions before installation is essential.

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 3 pyrgeometer delivery will include the following items:

1 CG 3 pyrgeometer
2 Calibration certificate
3 Instruction manual

Unpacking

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

Although all Kipp & Zonen radiometers are weatherproof and suitable for harsh ambient conditions, they contain delicate parts. It is recommended to use the original shipment packaging to safely transport the instrument to the measurement site.

3.2 MECHANICAL INSTALLATION

The mechanical installation of the pyrgeometer depends upon the application. Different measuring methods are explained in chapter 4.

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 also be readily accessible to clean the window.

Obstructions on the horizon with an elevation of less than 15 º are outside the field of view of the CG 3 and not relevant.

In principle no special orientation of the instrument is required. However, The World Meteorological Organisation (WMO) recommends that the instrument leads be pointed towards the nearest terrestrial pole, to minimise heating of the electrical connections.

3.2.2 Mounting

The CG 3 pyrgeometer is provided with two holes for M5 cap screws.

Although the instrument doesn't have any levelling feet, ensure that the pyrgeometer is in a properly levelled position!

Ensure that the pyrgeometer body makes a good electrical contact with earth to lead off currents in the cable induced by lightning.

3.2.3 Mounting of net pyrgeometer CG 3

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

For CG 3's a Net Pyrgeometer Mounting Plate with a 300 mm mounting rod is available.
.
Typical is a height of 2 m above short homogeneous vegetation, such as grass. The mast on which the rod is clamped can block the downwelling or upward radiation with a maximum fraction $D / 2 \cdot \pi \cdot S$, in which D is the diameter of the mast and S the distance of the radiometer from the mast. The mast itself also emits infrared radiation, so ensure that the mast and CG 3 temperatures are similar, or that the emissivity of the mast is low (reflecting).

3.3 ELECTRICAL CONNECTION

CG 3 is supplied as standard with a two wire thermistor for temperature measurement.

As an option this can be replaced by a Pt-100 sensor.

Thermistor YSI 44031

Red	: Thermopile (plus)
Blue	: Thermopile (minus)
Yellow	: Thermistor
Green	: Thermistor
Shield	: Connected to body

Pt-100 version

The wire colour code is:

Red	: Thermopile (plus)
Blue	: Thermopile (minus)
Yellow	: Pt-100 (combined with green)
Green	: Pt-100 (combined with yellow)
White	: Pt-100 (combined with black)
Black	: Pt-100 (combined with white)
Shield	: Connected to body

Circuit diagram of CG 3 is shown in figures 3.1.

Important characteristics for signal amplification are zero-offset and sensitivity per bit. The typical sensitivity of a pyrgeometer is 10 μV/Wm^2. Therefore a zero offset greater than 10 μV will produce an offset of more than 1 W/m^2.

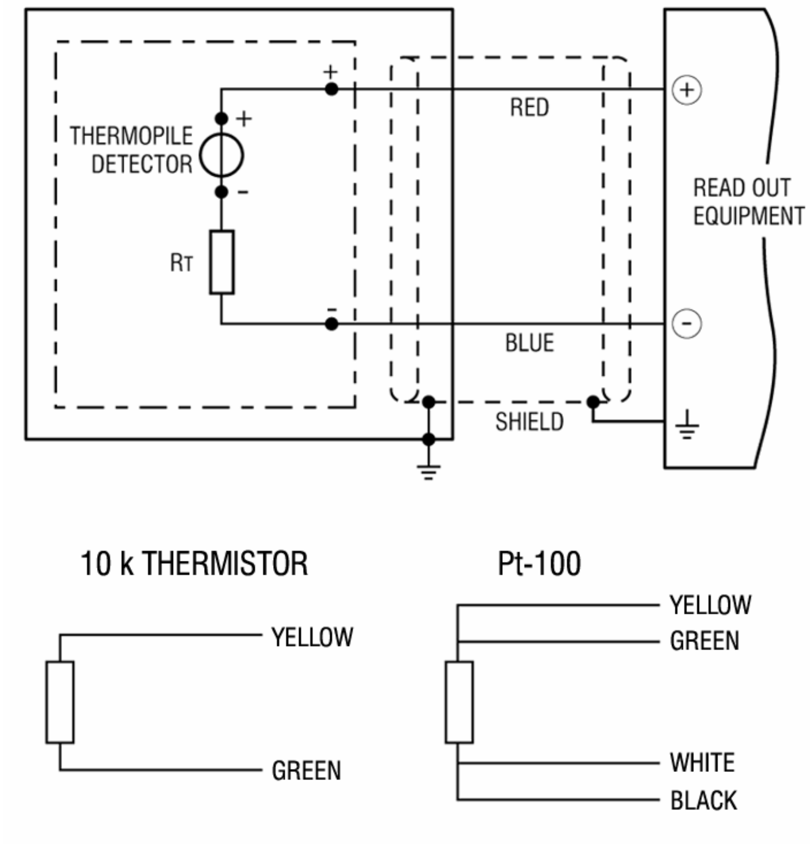

Figure 3.1 *Circuit diagram of the CG 3 pyrgeometer with a 10 k thermistor or with a Pt-100 temperature sensor.*

If a resolution of 1 W/m^2 is required, a readout resolution of 10 μV per bit is necessary.

The cable shield is connected to the case. The shield 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 a 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 any 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 3.1, it is clear that the impedance of the readout equipment is loading the thermopile.
The sensitivity is affected more than 0.1% when the load resistance is less than 100 kΩ. For this reason we recommend the use of readout equipment with input impedance's of 1 MΩ or more, such as potentiometric recorders, digital voltmeters, etc.

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 100 m, which are coupled by waterproof connectors to the CG 3 cable. The lead resistance is 8 Ω / 100 m.

A considerable input bias current of the readout equipment could 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/D converter must be available for the thermopile readout. The span and resolution of the A/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. Figure 3.2 shows the thermistor connections to a Campbell data logger.
The connection of the Pt-100 is shown in figure 3.3.

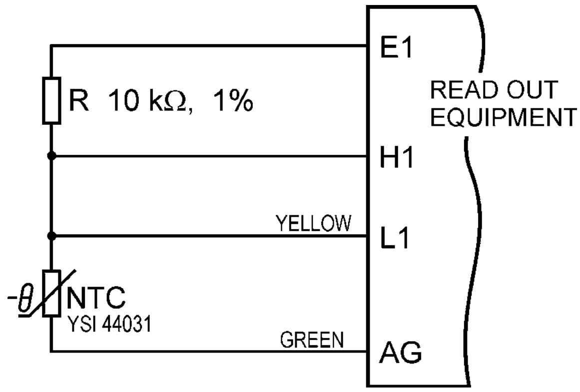

Figure 3.2 *Example of CG 3 with thermistor connected to a Campbell data logger.*

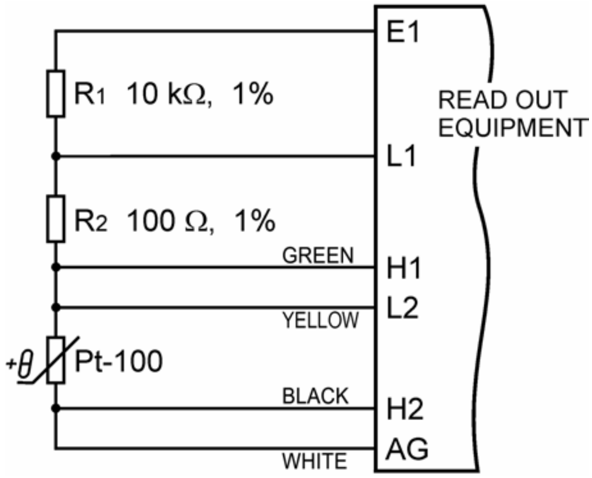

Figure 3.3 *Example of CG 3 with Pt-100 connected to a Campbell data logger.*

For amplification of the pyrgeometer signal, the Kipp & Zonen amplifier is recommended, which converts the output voltage from the pyrgeometer into a standard 4 – 20 mA output current. In order to allow negative values from the CG 3 to be transmitted the zero setting of the amplifier (normally 4 mA) can be adjusted up to 8 mA.

4 OPERATION

After completing the installation the pyrgeometer will be ready for operation. At the end of this section 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 (provided by 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 3)	[W/m^2]
$5.67 \cdot 10^{-8} \cdot T_b^4$	= Upward irradiance of the CG 3 radiometer	[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 instrument's upward irradiance $(5.67 \cdot 10^{-8} \cdot T_b^4)$

Note: Temperature Tb is given in Kelvin [K]. This unit can easily be converted into degrees Celsius by subtracting 273.15 K from the original value.

4.1.1 Example

During field measurements the pyrgeometer is exposed to varying atmospheric conditions with typical radiating properties. The most common are a cloudy overcast sky and a 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).

With higher clouds the thermopile output shows a little negative voltage (a few W/m^2), due to a small heat exchange between the relatively warm pyrgeometer and the colder sky. In this case the calculated atmospheric long-wave radiation (L_d) shows a relatively large positive value.

In the case of rain or mist, the thermopile output will read zero, because water deposited on the pyrgeometer window is a perfect infrared absorber. Figure 4.1A illustrates a cloudy overcast sky.

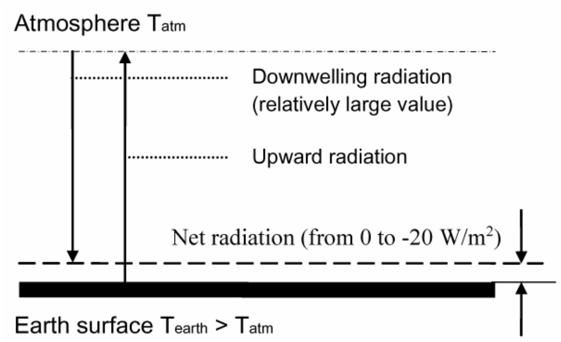

Figure 4.1A Cloudy overcast sky condition.

4.1.3 Clear sky conditions

Clear sky conditions differ in that there is a relative large heat loss caused by the atmospheric window. Therefore the amount of radiation re-emitted by a clear sky is smaller than the cloudy overcast sky condition. Because of the heat lost in the upward direction, the sensor's hot junctions will cool down and show a relatively 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 relatively small positive value. A clear sky condition is illustrated in figure 4.1B.

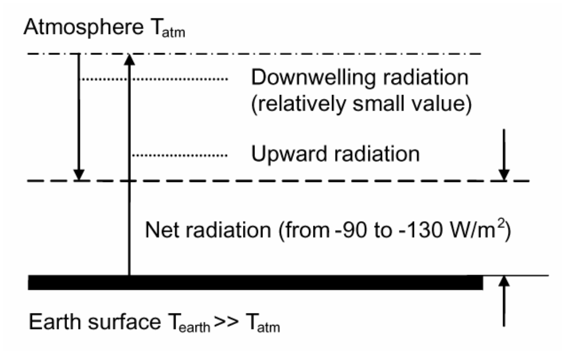

Figure 4.1B Clear sky condition.

4.1.4 Measurements during a sunny day

CG 3 only provides accurate day-time measurements on sunny days when used with a moving shading device. Without this precaution solar radiation up to 1000 W/m^2 results in a window heating offset which affects the overall calculated downward radiation by up to +25 W/m^2.

Formula 1 can be applied with the following provision:
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), altitude of the CG 3 and solar declination angle. The graph in figure 4.2 indicates the possible infrared radiation in the solar spectrum in the case of low water content in the atmosphere.

The amount of solar infrared radiation at the CG 3 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 can be affected more (0 – 10 W/m^2).

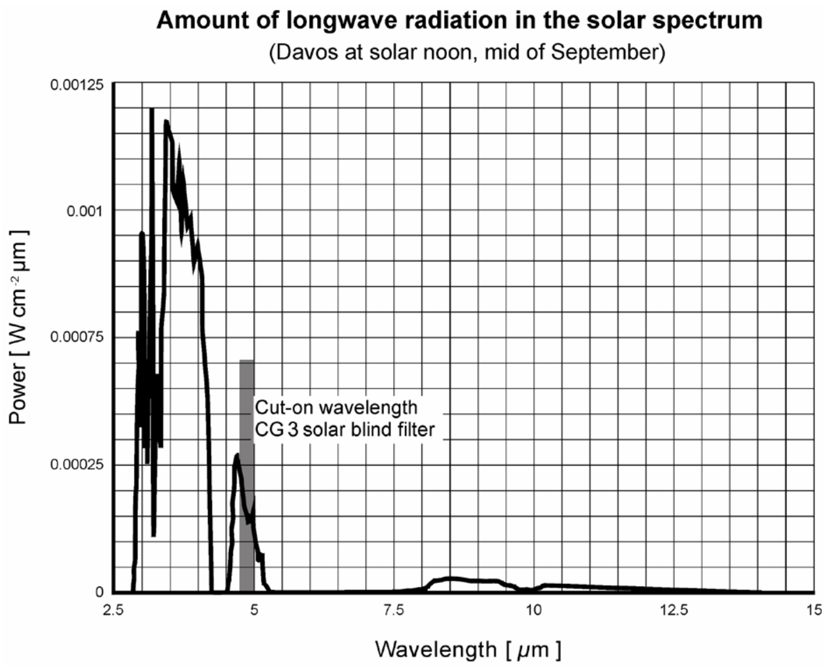

Figure 4.2 Direct solar irradiance, noon, mid-September, Davos.

4.1.5 Calculating the effective sky temperature

The long wave radiation emitted by the atmosphere is related to its temperature according to Stefan-Boltzman's law. The quantity of long wave radiation measured with an upward facing pyrgeometer can be used to determine the effective sky temperature. Since Ld is considered as the longwave downwelling radiation, the effective sky temperature can be calculated according to formula 2 below.

$$T_{eff,sky} = \left(\frac{Ld_{CG3}}{\varepsilon \cdot \sigma} \right)^{\frac{1}{4}}$$ *Formula [2]*

$T_{eff,sky}$	= The effective sky temperature	[K]
Ld_{CG3}	= Long wave radiation measured with CG 3	[W/m²]
σ	= $5.67 \cdot 10^{-8}$	[$W/M^2 \cdot K^4$]
ε	= Emissivity constant of sky	[-]

4.2 Measuring net radiation with two pyrgeometers

With two CG 3's mounted as a net-pyrgeometer, the long-wave radiation balance (also called the net long-wave radiation) can be measured. This balance, combined with the information from an albedometer, gives the net total radiation. A mounting plate with 300 mm rod for 2 instruments is available (see chapter 10).

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

The combination of a net pyrgeometer (two CG 3'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 and separate information on solar and long-wave radiation is available.

4.2.1 Calculating the surface temperature

The long-wave radiation emitted by the surface is related to its temperature according to Stefan-Boltzman's law. A downward facing pyrgeometer can be used to determine the effective temperature of a surface.

Since Ld is considered as the long-wave upwelling radiation, the effective surface temperature can be calculated according to formula 3 below.

$$T_{eff,sur} = \left(\frac{Ld_{CG3}}{\varepsilon \cdot \sigma} \right)^{\frac{1}{4}}$$ *Formula* [3]

$T_{eff,\,sur}$	= The effective surface temperature	[K]
Ld_{CG3}	= Long wave radiation measured with CG 3	[W/m²]
σ	= $5.67 \cdot 10^{-8}$	[$W/M^2 \cdot K^4$]
ε	= Emissivity constant of surface	[-]

The emissivity ε depends on atmospheric conditions or the surface type. Table 1 shows some typical emissivity values. Please note that the values listed are approximations.

Table1: Typical constants of material emissivity

Material	Emissivity [ε]
Brick	0.80 to .95
Concrete	0.94 to .95
Sand	0.90
Snow	0.85
Soil	0.90 to .98
Water	0.93
Wood	0.89 to .95

5 MAINTENANCE

Once installed the pyrgeometer needs little maintenance.

The Silicon window must be inspected at regular intervals and cleaned regularly.

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 ºC 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. Hoar frost disappears due to solar radiation during the morning, but should be wiped off manually as soon as possible.

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

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 3 is calibrated in a side-by-side comparison against a reference pyrgeometer. This method can be applied either indoors or outdoors. Outdoor calibration is preferable above any conventional indoor side-by-side calibration method.

6.2.1 The indoor procedure

The reference CG 3 pyrgeometer and test pyrgeometers are mounted horizontally on a table under a large area warm plate stabilised at 67 ºC. The table can rotate to exchange the positions of the two instruments. The net irradiance at the pyrgeometers is approximately 150 W/m^2. The indoor procedure is based on a sequence of simultaneous readings.

After 60 seconds exposure to the warm plate, the output voltages of both pyrgeometers are integrated for 30 seconds. Next, both are covered by a blackened “shutter” with a stable “room temperature” and after 60 seconds both signals are integrated again. These two “zero” signals are subtracted from the “warm” signals to produce comparable responses. In this way temperature differences between the two pyrgeometers are compensated.

Next, the pyrgeometer positions are interchanged by rotation of the table and the procedure is repeated. The means of the former and latter responses are compared to derive the sensitivity figure of the test pyrgeometer. In this way asymmetry in the warm plate and in infrared radiation within the test environment is cancelled out.

6.2.2 The outdoor procedure

The CG 3 is calibrated outdoors at Kipp & Zonen under a mainly clear sky during night-time. The instrument is installed side-by-side next to a reference CG 4 pyrgeometer. For a period of 6 hours the pyrgeometer thermopile output (Uemf) and body temperature (T_b) is measured.

Afterwards the downward radiation (L_d) is determined for each instrument by using the formula given in chapter 4. For the CG 3 a preliminary sensitivity of S = 10 $\mu V/W/m^2$ is used. The calculated resulting curve of L_d shows a different response from the CG 4 reference curve.

By changing the sensitivity (S) of the reference CG 3 an optimal curve fit with the CG 4 reference finally yields the exact calibration factor (S). The fitting is best made for the periods with high Infrared exchange (clear sky) but under cloud fields with a lower signal the curves can still fit within ±2 %.

By this procedure the effect of the restricted field of view of the reference CG 3 is “calibrated out” for clear sky conditions. With the indoor procedure the outdoor sensitivity of the reference CG 3 is “transferred” to the test CG 3’s. Therefore the test CG 3 sensitivity equates to the clear sky calibration conditions for the reference CG 3. However, tolerances in the spectral response of the reference and test CG 3’s limit the accuracy of the transfer because the black-body radiation spectrum of the hot plate differs significantly from the atmospheric window solar spectrum.

6.2.3 Traceability to the World Radiometric reference

On a yearly base the reference CG 4 pyrgeometer is calibrated outdoors against the standard group of radiometers at the PMOD WRC in Davos.

The CG 4 is calibrated by an outdoor comparison on the roof platform of PMOD/WRC to the reference pyrgeometer PIR 31463F3 of the World Radiation Centre. The comparison is made during nighttime and clear sky conditions on several days. The thermopile signal and dome temperature signal are recorded on the same data logger as the reference pyrgeometer. Body and dome temperatures are determined using the Steinhart and Hart equation and the YSI coefficient of the YSI 44031 thermistor. From the measurement the sensitivity factor C is determined by using a simple relation, which involves the pyrgeometer signal Uemf, and the body temperature Tb of the pyrgeometer. The dome temperature however is not involved in the evaluation, and no dome correction has been made. The long wave downward irradiance E is calculated using the equation
$E = Uemf/C + \sigma Tb^4$

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	**Cloudy 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 thermopile connection wires may be crossed over.

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 on the window, clean it.

Malfunction	Possible cause	Check
No signal or noisey signal	Broken leads	Cover sensor, Impedance across red and blue wire should be within specification
	Window is wet, dirty or dusty	Clean window using soft lens cleaner
	Unwanted Infrared radiation sources near the instrument	Check the site for exhaust vents and/or heat reflecting objects
	Malfunction readout equipment	Check readout device
	Broken leads inside sensor	Check signal at sensor, no repair possible
No temperature signal	Broken leads	Check impedance
Stained window	Persistent dirt	Clean window using alcohol with a soft cloth or tissue

9 DELIVERY

Delivery of CG 3

- Pyrgeometer CG 3
- Calibration certificate
- Manual CG 3

The CG 3 can be delivered in two configurations:

• CG 3 + Thermistor (YSI 44031, 10 k / 25 ºC)	0359900
• CG 3 + Pt-100	0359901

10 PART NUMBERS / SPARE PARTS / OPTIONS

Description	Part no.
Manual CG 3 pyrgeometer	0359200
CT 24 Signal amplifier 4 – 20 mA	0305710
Levelling fixture CLF 1	0338700
CG 3 Net Pyrgeometer Mounting Plate	0359700
Indoor recalibration	0999700
Outdoor recalibration	0999701

APPENDIX I WORLD RADIATION CENTRE INFORMATION

The World Radiation Centre capable of Pyrgeometer calibration is:

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

APPENDIX II 10 K 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 ºC

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 Radiometers, Pyrgeometers &
Sunshine Duration Meters**

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 have added three fax forms at the end of this manual to enable you to schedule the recalibration of your instrument(s) at Kipp & Zonen.

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

☐ **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 +31-15-262-0351

or mail to:

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

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

☐ **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 +31-15-262-0351

or mail to:

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

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

☐ **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 +31-15-262-0351

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 :

Holland **Kipp & Zonen B.V.**
Röntgenweg 1
2624 BD DELFT
T +31 15 269 8000
F +31 15 262 0351
E kipp.holland@kippzonen.com

UK **Kipp & Zonen Ltd.**
P.O. Box 819,
LINCOLN, Lincolnshire LN6 0WY
T +44 1522 695 403
F +44 1522 696 598
E kipp.uk@kippzonen.com

Germany **Gengenbach Messtechnik**
Heinrich-Otto-Strasse 3
D-73262 REICHENBACH/FILS
T +49 7153 9258 0
F +49 7153 9258 160
E info@rg-messtechnik.de

USA **Kipp & Zonen USA Inc.**
125, Wilbur Place
BOHEMIA/NY 11716
T +1 631 589 2065
F +1 631 589 2068
E kipp.usa@kippzonen.com

France **Kipp & Zonen S.A.R.L.**
7, avenue Clément Ader
ZA Ponroy - Bât. M
F-94420 LE PLESSIS TREVISE
T +33 1 49 62 4104
F +33 1 49 62 4102
E kipp.france@kippzonen.com

Kipp & Zonen

WWW.KIPPZONEN.COM