

CM 121
Shadow Ring

Instruction Manual

IMPORTANT USER INFORMATION

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



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

Kipp & Zonen B.V.
Delftechpark 36
2628 XH Delft Holland
P.O. Box 507 2600 AM Delft Holland
Phone +31 (0)15 2755210
Fax +31 (0)15 2620351
Email info@kippzonen.com
Web www.kippzonen.com

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1. INTRODUCTION

The combination of a CM 121 shadow ring and a pyranometer offers a simple solution for the measurement of the diffuse solar radiation.

Specific advantages of this type of shadowing are that it is suitable for installation anywhere on earth (contrary to designs that require the specification of a particular latitude), that it can be combined with a ventilation unit, and that it has a special U-profile ring which simplifies the mathematical correction for intercepted diffuse radiation.

The shadow ring will keep the pyranometer in the shade during the entire day, preventing the direct solar radiation to reach the sensor. As a result only the diffuse solar radiation is measured. A regular schedule of maintenance would require manual adjustment of the sliding bars (that are connected to the actual shadow ring) every two days. This adjustment is necessary because the elevation of the solar course changes slightly from day to day. For proper setting of the sliding bars, the table of "correction factors and the sliding bar setting" can be consulted.

The CM 121 can be installed everywhere on earth. Normally the pyranometer will be in the horizontal position, alternatively it can be mounted in tilted positions along the north-south axis.

The ring itself is equipped with a special U-profile so that it has a nearly constant view angle during the year. A stable stand is guaranteed even at high winds.

Naturally, the shadow ring intercepts also a proportion of the diffuse sky radiation. A correction factor for this effect is recommended to be used as a refinement of the measurement. A table of correction factors is combined with the table for sliding bar setting.

The CM 121 can be used with Kipp & Zonen pyranometers. Typical use is with CM 11, CM 6B or CM 21. Pyranometer CM 3, although not recommended, can be fitted using the additional levelling fixture type CLF 1 for mounting on CM 121.

Use with SP-Lite is not recommended because of spectral and cosine errors.

There are two types CM 121:

The **CM 121B** is for use without a ventilation unit.

The **CM 121C** is for using in combination with the ventilation unit CV 2. For mounting instructions see chapter 2.2. With the exception of chapter 2 all other instructions apply to both CM 121B and CM 121C.

2. UNPACKING AND ASSEMBLING

2.1 CM 121B

Packed in the CM 121B transport box are separate items:

- Base with crossbar, pyranometer support and sector with sight
- The pillar with thread and 1 nut
- Shadow ring
- Sliding bars with 1 screw each for mounting the sliding bars on the shadow ring
- Two bolts for mounting the pyranometer on the sector
- This manual
- A socket head wrench

After removing the ties with which the items are connected to the transport box, the shadow ring can easily be assembled.

- Place the pillar in between the base and the crossbar, using the thread
- Place the shadow ring on its sliding bars using two screws
- Insert the sliding bars in the crossbar. The correct way is when the pyranometer sensor can be positioned along the axis of the ring

Caution: Please note that the screw that connects the pyranometer support with the crossbar must never be touched because it defines the position of the pyranometer sector relative to the sliding bars and the shadow ring. The sector must be in the center of the ring and this is adjusted in the factory. The particular screw is protected by a cap.

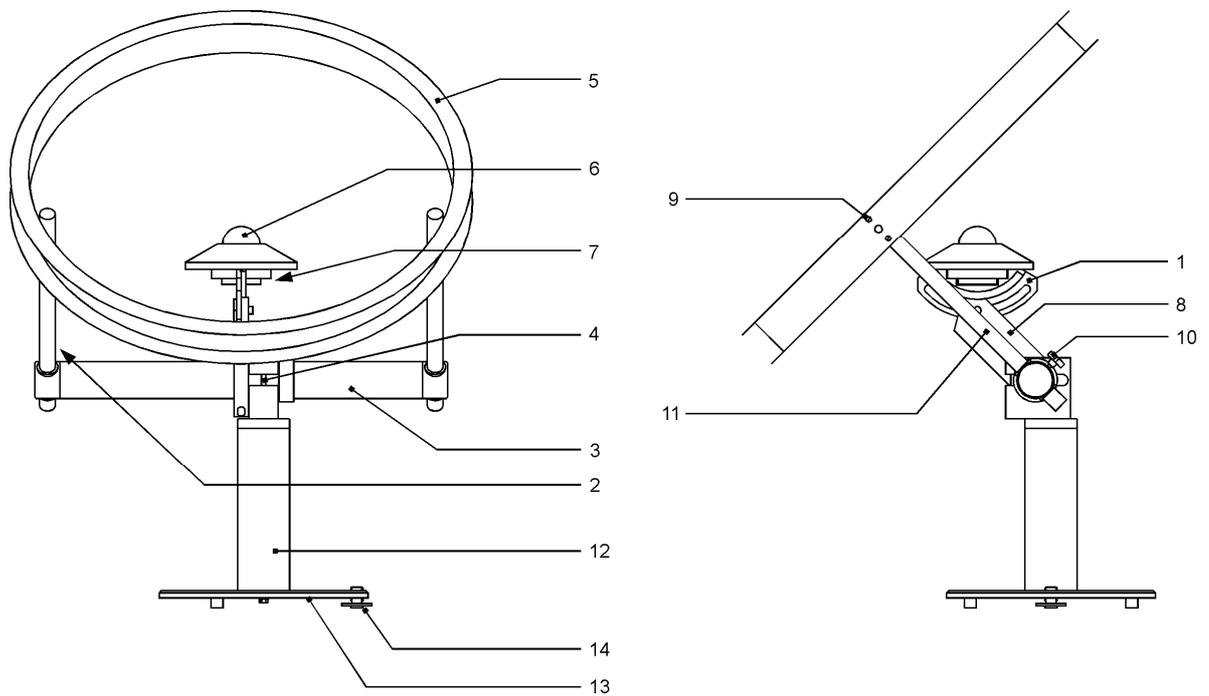


figure 1. the different parts of the shadow ring CM 121B

- 1 sector (including sight)
- 2 scale on the sliding bar (point of readout is indicated)
- 3 crossbar
- 4 securing bolt for the crossbar to the pyranometer support
- 5 shadow ring
- 6 pyranometer (normally not included in delivery)
- 7 spirit level of the pyranometer
- 8 pyranometer support
- 9 screws for attachment of the sliding bar to the shadow ring
- 10 fixing screws for the sliding bars
- 11 sliding bar
- 12 pillar
- 13 base
- 14 leveling screw for the base

2.2 CM 121C

Packed in the CM 121C transport box are the same items as with the CM 121B plus:

- CV 2 adapter
- Two spacers
- Two cap screws M6 x 10
- Two cap screws M5 x 16

After removing the ties with which the items are connected to the transport box, the shadow ring can easily be assembled.

- Place the pillar in between the base and the crossbar, using the thread
- Place the CV 2 adapter (see figure 1.2)
- Place the shadow ring on its sliding bars using two screws
- Insert the sliding bars in the crossbar. The correct way is when the pyranometer sensor with CV 2 can be positioned along the axis of the ring

Caution before you start mounting the CM 121C you have to secure the base a surface otherwise the CM 121C can fall over.

Caution: Please note that the screw that connects the pyranometer support with the crossbar must never be touched because it defines the position of the pyranometer sector relative to the sliding bars and the shadow ring. The sector must be in the center of the ring and this is adjusted in the factory. The particular screw is protected by a cap.

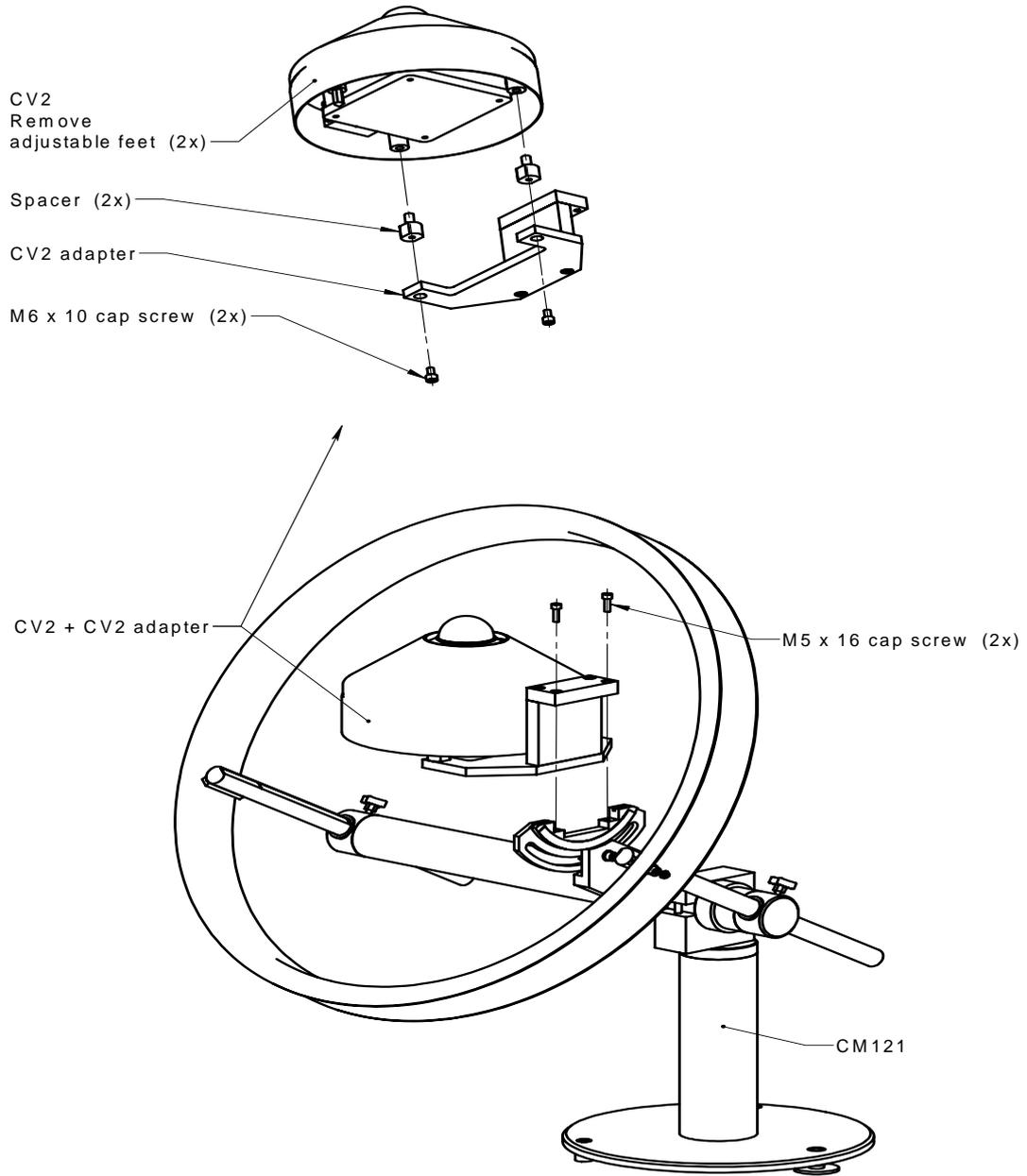


figure 1.2 the extra parts for the CM 121C and mounting instructions

3. PRINCIPLES & SPECIFICATIONS

3.1 Theory

The objective of the shadow ring is to intercept the direct radiation coming to the pyranometer from the sun during the whole day without readjustment. Therefore the shadow ring must satisfy the following requirements. See also the schematic representation (fig. 2).

- Once installed, the axis of the shadow ring must be always parallel to the polar-axis. In consequence the angle between shadow ring axis and horizontal should be equal to the latitude of the observation site.
- The shadow ring must be able to shift along the shadow ring axis relative to the pyranometer and in this way be adjusted to the sun's changes in declination during the year.
- Within the shadow ring construction the pyranometer must be positioned with its sensor on the shadow ring axis.

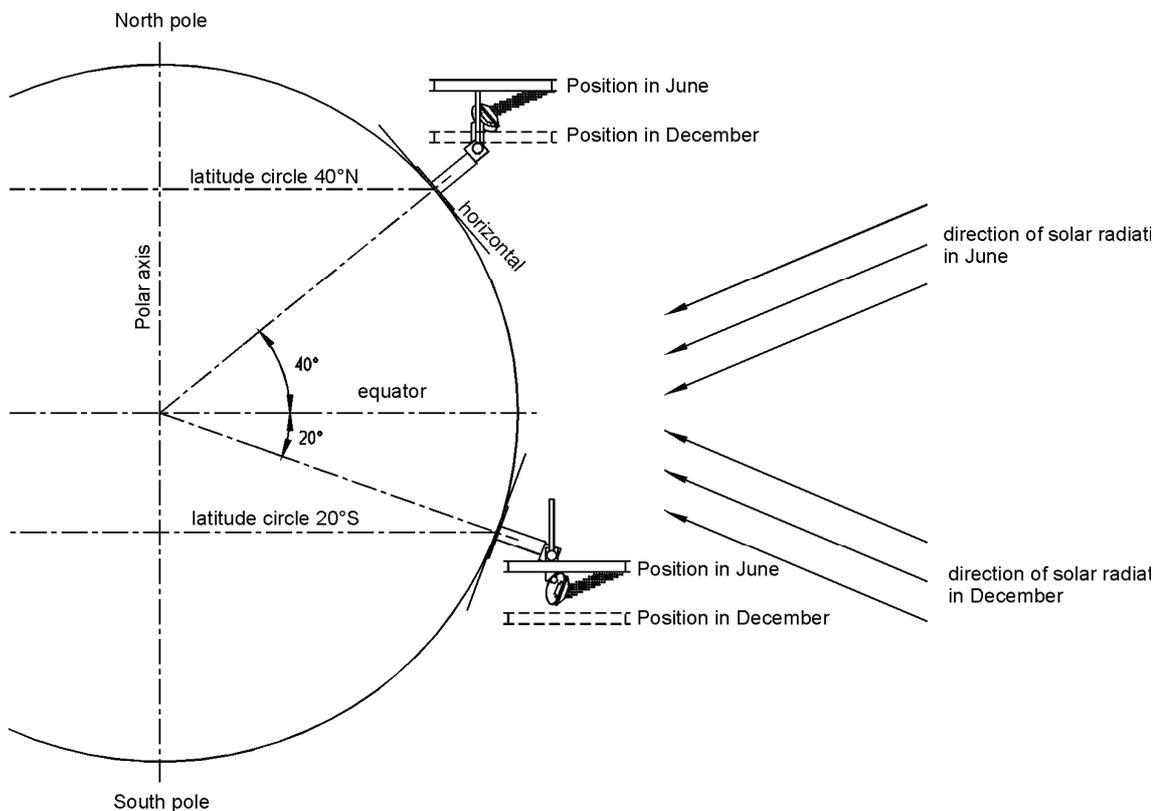


figure 2 *schematic representation of the CM 121B on earth. Also it is shown that the sliding bar setting is a function of the solar declination.*

3.2 Construction

The crossbar is one of the main parts of CM 121B. By rotating the crossbar the angle between shadow ring axis and horizontal earth surface can be set for the particular location. This is an operation that needs to be performed only once for installation at a certain location. The pyranometer support is fixed to the crossbar, so the sensor stays in the center of the ring no matter the tilt angle of the ring. For getting the pyranometer in the horizontal position, the so-called sector can be rotated. See fig. 1.

With the sliding bars the shadow ring can shift along its axis. For this the fixing screws need temporarily to be unscrewed.

The normal situation is that the pyranometer is placed in the horizontal position. However, the sector allows the pyranometer to rotate while keeping the sensor on the same position relative to the ring, so that it is possible to mount the pyranometer in a tilted position along the north south axis.

Measurement of the diffuse radiation on a plane tilted to the south or north is now possible, a feature especially attractive in the application of solar collector testing.

For a site on latitude B the tilt range is B degrees to the equator and 90-B degrees to the nearest pole.

3.3 Specifications

Material	Anodized Aluminum of seawater proof quality, Stainless steel
Weight incl. pyranometer CM 11	5.8 kg
Mounting base	See figure 5
Ring outer diameter	620 mm.
Ring width	55 mm.
Ring width/ring radius ratio	0.185
View angle (The apparent width of the ring as seen from the pyranometer)	10.6°
U-profile shadow ring	defines the accuracy of the view angle constant within $\pm 2\%$

4. MOUNTING AND ALIGNMENT

4.1 Introduction

The CM 121B can be mounted on any surface that is within one degree horizontal. It can also be mounted on a tilted plane, if that plane faces south or north within 1/4 degree.

As explained in the previous chapter, the CM 121B has to be aligned north-south and the sliding bars must be tilted and brought parallel to the polar axis. These two steps are described below. Please mind that it is necessary to perform the north south alignment before the tilting of the sliding bars, because it might be necessary to change the tilting during the north south alignment.

4.2 North-south alignment (one time installation)

The shadow ring has to be aligned to the north south axis. The preferred method to set the orientation is by observing the sun at 12.00 True Solar Time (= Local Apparent Time). This is the moment when the sun is exactly south or north, a quite different time than 12.00 local clock or civil time. The True Solar Time can be obtained from an astronomic observatory or taking the time in between sunrise and sunset from the newspaper. For orienting the CM 121B at the sun, there is a groove made in two separate metal sections of the sector. The sector can be oriented such that this groove is aimed at the sun. The groove can be used as a sight (see fig.4). When the solar beam that passes the first groove can also pass the second groove, the CM 121 is supposed to be aligned with the sun. It is realized that close to the equator, this method loses its validity, and one has to rely more on geographic orientation.

Caution: Please mind that for proper positioning of the pyranometer relative to the ring, the sector is supposed to be fixed with its lower curved surface in direct contact with the upper curved surface of the pyranometer support.

- Wait for a moment that the sun is shining.
- Direct the CM 121B roughly north-south using a map or compass. If possible it can be recommended to use the sight for optimal orientation. Please note that if the sliding bar angle is approximately correct (see next paragraph), the highest point of the ring should be pointing south if the site is on the northern hemisphere, it should be pointing north if the site is in the southern hemisphere. (see figure 4). Please note that close to the equator the orientation by compass and subsequent correction by looking at sunrise and sunset performance can be preferred.
- Now start the real alignment procedure:
- Unscrew the fixing screws of the sliding bars
- Put the shadow ring in a low position so that the sector is not shaded.
- Set the base of the CM 121B horizontal using a level. Do not fasten it.
- Loosen the pyranometer sector so that it can be rotated, changing its tilt angle, loosen the securing bolt of the crossbar.
- Wait for solar noon.
- At solar noon, aim the sight on the pyranometer support exactly at the sun, keeping the CM 121B base in the horizontal position, if necessary turning the CM 121B around its pillar axis, turning the pyranometer sector and the crossbar in the north-south plane, changing its tilt angle. The sight for doing the exact positioning consists of two grooves in the sector (see above or fig.4).
- Rotate the sector and the whole CM 121 until the sights coincide with the centre of the sun disc at 12.00 True Solar Time. Mind that the sun disc is moving 1/4 degree per minute along the sky. The sun disc itself subtends half a degree.
- Fix the shadow ring base
- Install the pyranometer. Please note that installation of the pyranometer requires removal of the levelling screws of the pyranometer. One can let the fixed foot stay on the pyranometer.
- Please mind that for proper positioning of the pyranometer relative to the ring, the sector is supposed to be fixed with its lower curved surface in direct contact with the upper curved surface of the pyranometer support.
- Perform the procedure for tilting of the sliding bars (paragraph 4.3)
- Elevate the shadow ring along the sliding bars so that it shades the pyranometer sensor
- Check if the elevation is conforming the sliding bar scale pointer as indicated in the table

- Check the next sunrise and sunset if the dome is still shaded. If not, note if the change between sunrise and sunset is symmetrical, and make corrections.
- For permanent installation it is recommended to secure the position of the shadow ring by connecting its base to a solid underground. Figure 5 can be used for finding the proper position for clamps or bolts.

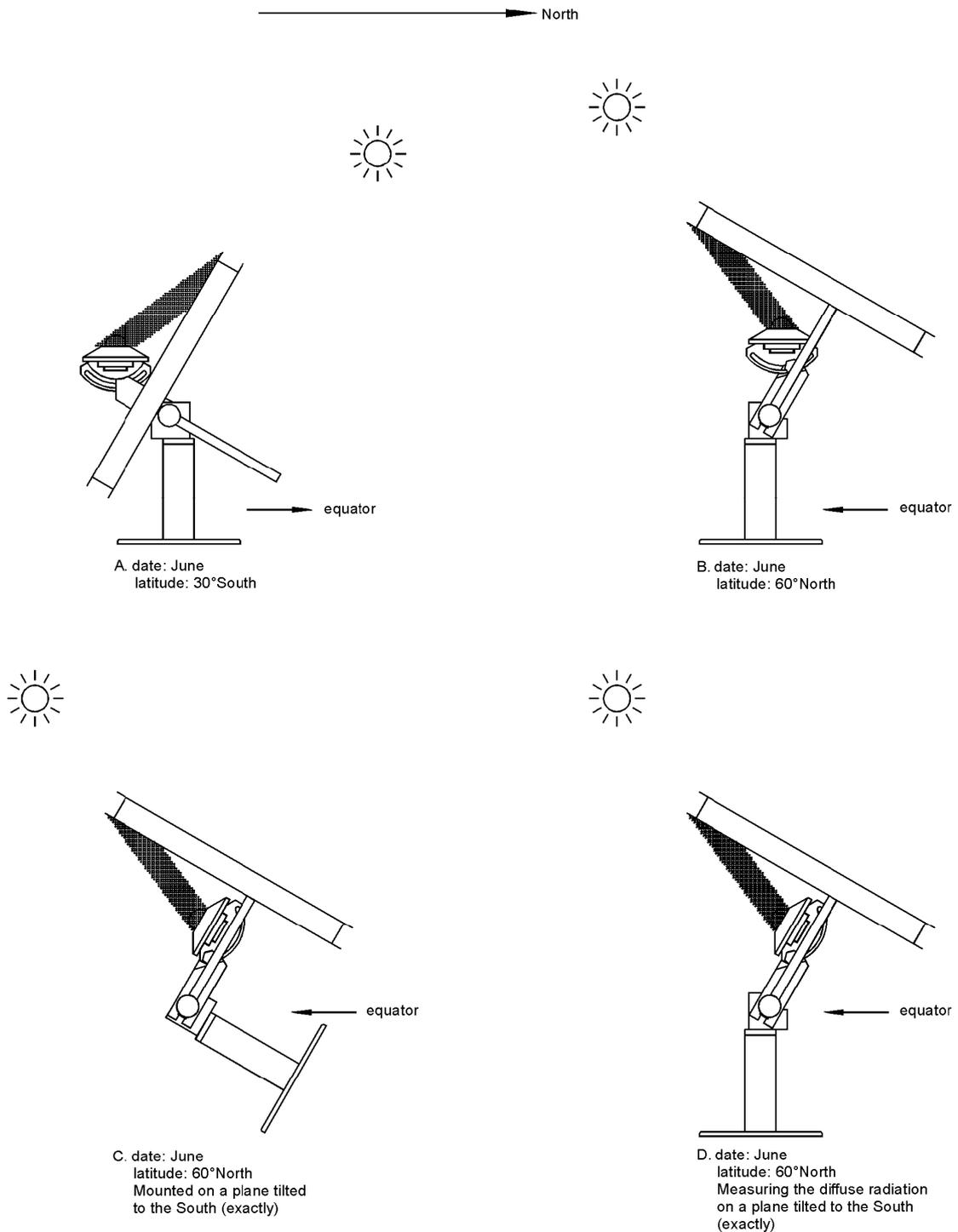


figure 3. schematic view of the installation of CM 121B in several situations

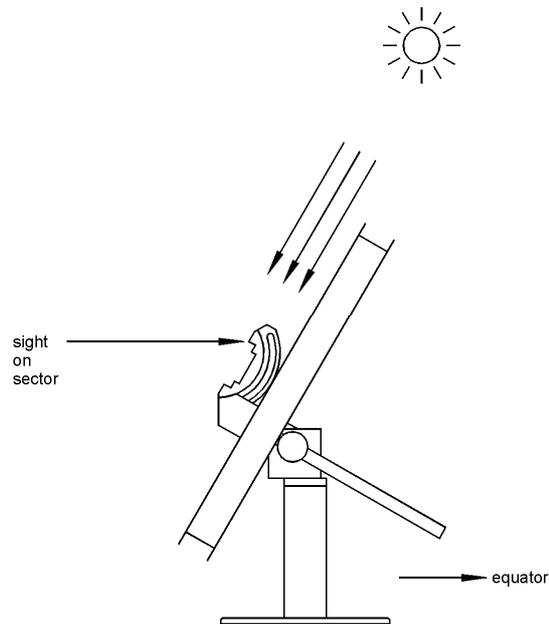


figure 4. set up to align the sight in the sector with the sun at 12.00 True Solar Time

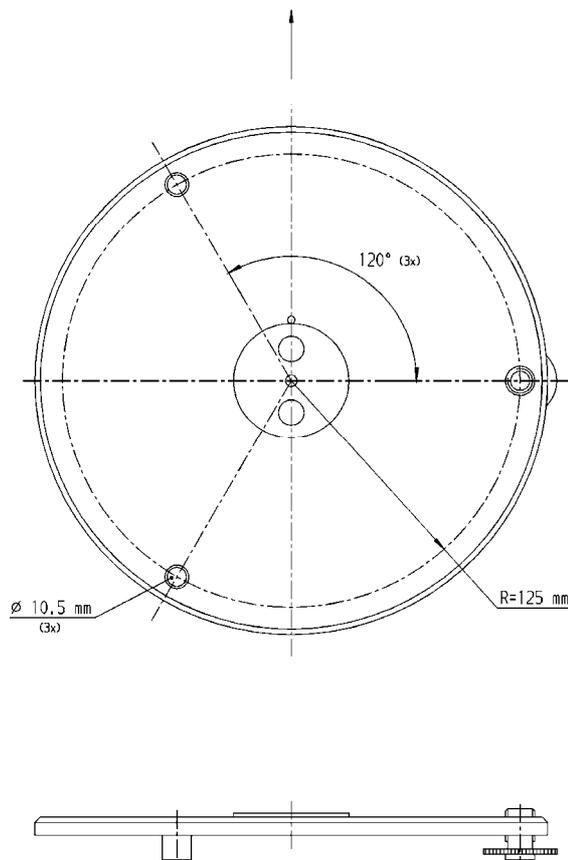


figure 5. dimensions of the CM 121B base

4.3 Tilting of the sliding bars (one time installation)

The purpose of this step is to bring the sliding bars parallel to the polar axis. This can be done by rotating the crossbar after having unscrewed the securing bolt and relocking it in the required tilted position.

When correctly aligned the angle between sliding bars and the horizontal should equal the geographical latitude. See figure 2. This procedure has to be performed only once, because it depends only on the latitude of the site.

An accuracy of 1/4 degree is sufficient.

- Establish the latitude of the site
- Rotate the sector until the scale on the sector indicates the latitude of the observation site
- Secure the sector by tightening the bolt
- Unlock the securing bolt of the crossbar
- Install the pyranometer
- Please mind that for proper positioning of the pyranometer relative to the ring, the sector is supposed to be fixed with its lower curved surface in direct contact with the upper curved surface of the pyranometer support.
- Rotate the crossbar until the pyranometer is horizontal again (look at the spirit level of the pyranometer). By this rotation and by adjustment of the levelling screw at the foot, the bubble of the spirit level can be completely leveled.
- Tighten the securing bolt of the crossbar again and fasten the foot to the foundation.

Caution. Never unscrew the pyranometer support from the crossbar. In case such unscrewing should have occurred, the support has to be aligned again in the following way. Set the sector in position 90° . Set the ring horizontal with a level. Turn the support around the crossbar until the pyranometer is in horizontal position as well (look at spirit level). Fix the support to the crossbar.

4.4 Setting of the shadow ring sliding bars (regular servicing procedure)

The correct shadow ring position is a function of the declination of the sun and it varies across the year.

The only thing that needs to be done to readjust the position of the ring is to set the sliding bars. A readjustment is necessary only after a few days. A regular schedule would require readjustment every two days. However, in most seasons a longer time interval between adjustments is possible. This can be seen in the table in 5.2.

- Unscrew the fixing screws of the sliding bars.
- Set the sliding bars using the sun or the table of 5.2. On clear days the setting of the ring can be done by observing the shadow of the ring on the pyranometer. If correctly aligned the outer dome of the pyranometer must be completely shaded. (The dome shadow on the white screen is covered by the ring shadow.) On cloudy days the ring can be set according to the date with the aid of the scale on the sliding bars and the table of settings. See table 1 of 5.2 lowest row. The relevant figure must be read off at upper side of the crossbar, see figure 1. Please mind that the scale has two sections, centered around zero. At positive declinations of the sun (21 March-23 Sept.) the part of the scale that is used must be in the southern or lower part of the scale. At negative declinations of the sun (23 Sept.-21 March) the part of the scale that is used must be in the northern or higher part of the scale. See figure 2. The figures for the sliding bar adjustment in this row are derived with the formula $L = 297 \tan (D)$, in which D is the declination of the sun. The values of declination and sliding bar setting correspond with the date intervals in the same table.
- Relock the fixing screws

5. MEASUREMENT OF THE DIFFUSE SKY RADIATION

5.1. The shadow ring correction

A pyranometer equipped with a shadow ring is measuring the downward diffuse solar radiation as received by a horizontal surface from a solid angle of 2π with the exception of the solid angle subtended by the shadow ring.

To obtain an estimation of the radiation that would be received from the whole hemisphere if the ring were not present, a correction must be introduced. Such a correction factor is a function of the solid angle subtended by the ring part and the sliding bars of the CM 121B and their altitude above the pyranometer horizon.

The special U-profile of the shadow ring offers the advantage that the intercepted circumsolar part of the sky is far more constant during the year compared to an I-profile (flat) shadow band. (Compare formula 6.8 and 6.9).

The correction presented here is for the case of uniform sky radiation. The intercepted part can easily be calculated. A list with correction factors is supplied. See table 1 in 5.2. It is possible to use more refined models, assuming a more realistic distribution of the radiation across the sky, however it is difficult to indicate how much improvement can be attained doing this as these models tend to depend on empirically obtained data. A brief discussion concerning this problem is found on page 429 of the International Geophysical Year instruction manual 1958, Pergamon Press, London, Paris, New York.

The table is arranged so that the correction factors for particular latitude are in one row. The factors are computed for declinations of -24° to $+24^{\circ}$ with intervals of two degrees. The declination and the date are related to each other. On the top and the bottom of the table there is a row with the corresponding date intervals, the upper row for increasing declination, the lower one for decreasing declination.

5.3 Diffuse sky radiation on a tilted plane

The correction factors are only valid for a pyranometer in the horizontal position. However, for a pyranometer tilted T degrees to the south and on latitude B , the configuration of ring and pyranometer is the same as for a horizontal pyranometer at latitude $(B - T)$ degrees. You can derive a list of correction factors for a tilted pyranometer from table 1 in 5.2, taking into account that only part of the hemisphere is 'seen' by the pyranometer. However, this correction does not take the effect of ground-reflected radiation into account. The correction for this is very much dependant on local conditions and might vary throughout the day as a function of the solar position, and throughout the year as a function of ground properties. Therefore this is the responsibility of the customer.

6. APPENDIX

6.1 Theoretical derivation of the correction factor, for uniform sky radiation

The relation between the correction factor C and the intercepted part S of the downward component of the sky radiation is

$$C = 1 / (1 - S) \quad (6.1)$$

S can be expressed in the view angle V of the ring, the sun's declination D and the latitude B of the observation site.

Let U_0 be the angle between the sun at sunrise (or at sunset) and the sun at true noon in the plane of the ring.

U_0 is computed with the formula:

$$\cos U_0 = -\tan B \cdot \tan D \quad (6.2)$$

Let us consider a part of the ring subtending a solid angle $V \cdot dU$ as seen from point M, the center of the ring, and as seen from the pyranometer of

$$V \cdot \cos D \cdot dU \quad (6.3)$$

V is assumed to be constant within the range of D, due to the special U-profile shadow ring.

Not every part of the ring equally affects the total downward component of the sky. This is because this component is proportional with the cosine of its zenith angle Z. Radiation with a zenith angle Z within this solid angle causes a downward component

$$L \cdot V \cdot \cos D \cdot \cos Z \cdot dU \quad (6.4)$$

L is the radiance (= brightness) of the sky in W/m² sr. L is assumed to be uniform over the complete sky. So the complete ring part above the horizon intercepts a downward component

$$2L \cdot V \cdot \cos D \cdot \int_0^{U_0} \cos Z \cdot dU \quad (6.5)$$

Z can be expressed in the declination D, latitude B and time (by the hour angle U) with the formula

$$\cos Z = \sin B \cdot \sin D + \cos B \cdot \cos D \cdot \cos U \quad (6.6)$$

After integrating we find the total intercepted downward radiation to be

$$2L \cdot V \cdot \cos D \cdot (U_0 \cdot \sin B \cdot \sin D + \sin U_0 \cdot \cos B \cdot \cos D) \quad (6.7)$$

The total irradiance of a horizontal surface by a sky with radiance L (W/m² sr) is L (W/m²). The intercepted part S of the sky radiation therefore is

$$S = 2V \cdot \cos D \cdot (U_0 \cdot \sin B \cdot \sin D + \sin U_0 \cdot \cos B \cdot \cos D) / \pi \quad (6.8)$$

From this formula the list of correction factors is computed taking into account formula (6.2) and (6.1) and $V = 0.185$ rad. Mind that U_0 is in radians.

Actually V varies within 2% in dependence of the declination D but this gives only rise to an error less than $\pm 0.5\%$ in the calculated correction factors.

The influence of the sliding bar parts rising above the horizon is neglected.
To compare: the formula for a flat shadow band is

$$S = 2W \cdot \cos^3 D \cdot (U_0 \cdot \sin B \cdot \sin D + \sin U_0 \cdot \cos B \cdot \cos D) / \pi \cdot R \quad (6.9)$$

W is the ring width and R is the ring radius. A comparison is shown in figure 6.

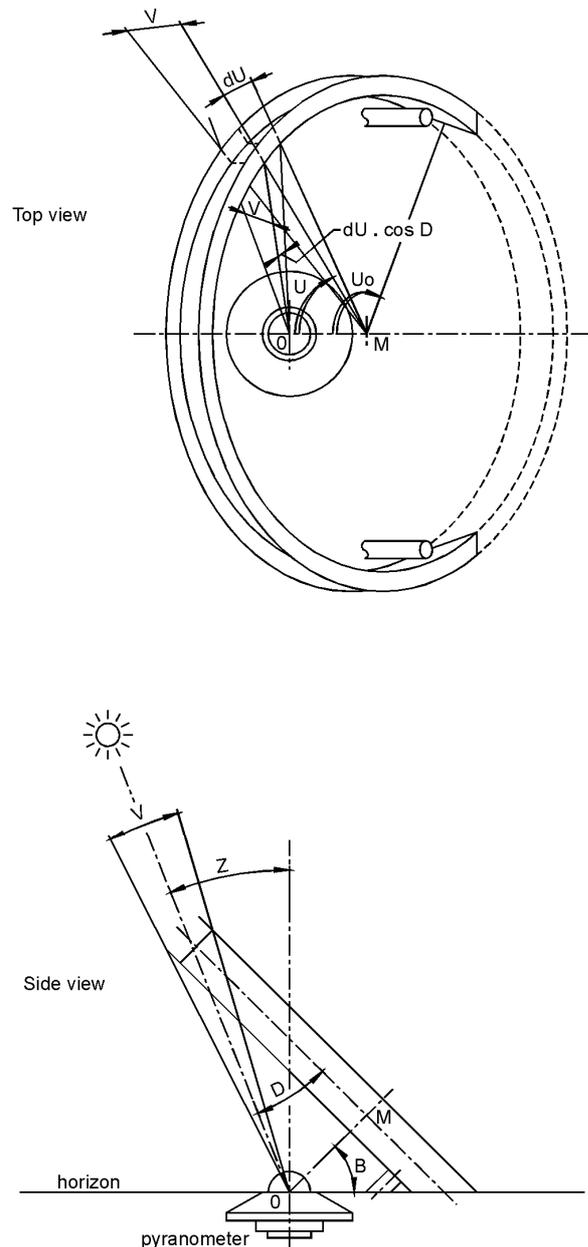


figure 6 the view angle of the U-profile shadow ring as a function of the solar declination, in comparison to a conventional flat shadow band. It is shown that the CM 121B has superior performance, as a result less seasonally variation of errors.



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HEAD OFFICE

Kipp & Zonen B.V.

Delftechpark 36, 2628 XH Delft
P.O. Box 507, 2600 AM Delft
The Netherlands

T: +31 (0) 15 2755 210

F: +31 (0) 15 2620 351

info@kippzonen.com

SALES OFFICES

Kipp & Zonen France S.A.R.L.

7 Avenue Clément Ader
ZA Ponroy - Bâtiment M
94420 Le Plessis Tréville
France

T: +33 (0) 1 49 62 41 04

F: +33 (0) 1 49 62 41 02

kipp.france@kippzonen.com

Kipp & Zonen Asia Pacific Pte. Ltd.

81 Clemenceau Avenue
#04-15/16 UE Square
Singapore 239917

T: +65 (0) 6735 5033

F: +65 (0) 6735 8019

kipp.singapore@kippzonen.com

Kipp & Zonen USA Inc.

125 Wilbur Place
Bohemia
NY 11716
United States of America

T: +1 (0) 631 589 2065

F: +1 (0) 631 589 2068

kipp.usa@kippzonen.com

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