8.2 Field Instruments

Mainly two different types of instruments are used referring to the radiation incident from the total hemisphere (solid angle 2π) or radiation coming only from the direction of the sun (direct normal radiation).

8.2.1 Global Radiation

Global radiation is the hemispherical solar radiation, i. e. the radiation received by a plane surface from the solid angle 2π steradian. Instruments measuring hemispherical solar radiation are called *pyranometer*.

Global radiation is measured by a pyranometer. Modern pyranometer using wirewound plated thermopiles, can be one of two types: With a black sensor protected by two precision ground, polished hemispheres or with a black and white "star" sensor that is protected by a single polished hemisphere.

Over the years, there have been efforts to increase the linearity of response, durability, the adherence to the Lambert cosine response law and independence from ambient temperature effects.

Transformation of radiative energy to heat
→ temperature of the receiving surface is raised
→ steady state equilibrium is attained by heat losses to thermal sinks (instrument body, ambient air)
→ constant voltage

The main parts of a pyranometer are:
- thermal sensor (black painted surface)
- glass domes (protection, minimizing exchange of thermal radiation, IR-shield)
- instrument body

The required pyranometer accuracy can only be realized with detectors of the thermoelectric type. The temperature of the absorber is measured by a thermopile (series of thermocouples), whose active junctions are in contact with the absorber surface (Moll-Gorczynski-type). The passive junctions are connected to the instrument body, which therefore has to be shielded against the radiation. A remaining temperature dependence has to be compensated by an auxiliary thermistor circuitry.

differences in temperature by diff. paintings (black & white), diff. thermal insulation (CM 11), diff. radiation exposure (PSP)

sensor types: Eppley PSP, Kipp & Zonen CM 11, CM 21, Schenk

spectral sensitivity: nearly uniform in range 300–2800 nm (governed by glass dome absorption)

response time!

Plot: typical pyranometer data (K&Z data sheet)

Characteristics of Pyranometer. The values in parentheses give the specifications for first class pyranometer according to the WMO classification.

Response Time i.e. the time for reaching a certain percentage of the final measuring value due to the thermal inertia of the instrument (95 % value: $<$ 30 sec)

Zero offset due to thermal radiation ($<$ 15 $\mathrm{Wm^{-2}}$ for 200 $\mathrm{Wm^{-2}}$ net thermal radiation, ventilated)

Non-stationarity caused by the ageing of the absorber surface ($< \pm 1$ % per year).

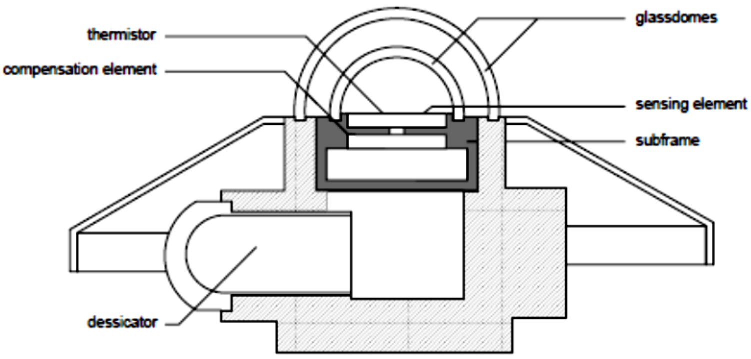

Fig. 8.1. Schematic construction of Kipp & Zonen CM 11 pyranometer.

Non-linearity The change in responsivity with irradiance level ($< \pm 1$ % from measured value at 500 Wm^{-2} over full range).

Cosine response The deviation in responsivity from the proportionality to the cosine of the angle of incidence ($\pm$ 2 % at 60 ° angle of incidence, $\pm$ 5 % maximum deviation withim 60 °–80 °.

Azimuth response The azimuthal variation of the deviation in responsivity from the cosine response ($\pm$ 5 % deviation from mean at 80 ° angle of incidence).

Spectral selectivity governed by the glass dome and the absorber coating ($\pm$ 5 % maximum deviation in $\alpha\tau$ from average within the spectral range 0.35–1.5 μm).

Temperature response due to the changing ambient temperature (4 % deviation for a change of ambient temperature within an interval of 50 K).

Tilt response when the pyranometer is operated in an inclined position ($\pm$ 2 % deviation for vertical mounting and 1000 Wm^{-2}).

8.2.2 Direct Radiation

Direct radiation is measured by use of a pyrheliometer, which measures radiation at normal incidence. The pyrheliometer consists of a wirewound thermopile at the base of a tube, the aperture of which bears a ratio to its length of 1 to 10, subtending an angle of 543'30" (Eppley NIP). This limits the radiation that the thermopile receives to direct solar radiation only. The pyrheliometer is mounted on a solar tracker for continuous readings.

From small solid angle centered at the sun's disk
$\rightarrow$ direct normal radiation
angular diameter of sun's disk: 0.5°.

instruments measuring direct solar irradiance are called *pyrheliometer*. Usually of thermoelectric type.

Components:
- thermal sensor (blackened surface, black cavity)
- (diaphragm) tube
- tracking device

typically full angle of view: 5–6°.

8.2.3 Diffuse Radiation

Diffuse radiation can either be derived from the direct radiation and the global radiation or measured by shading a pyranometer from the direct radiation so that the thermopile is only receiving the diffuse radiation.

The direct measurement of the diffuse radiation is performed by using a pyranometer which is shielded from direct solar radiation by a circular disk or a fixed shade ring (shadow band). A shading disk must be tracked to follow the suns path and therefore requires a huge amount of maintenance. Therefore operational stations are usually equipped with shade ring devices, which have to be adjusted to only follow the solar declination 1–2 times a week.

Because the shade ring covers parts of the diffuse sky instead of only the sun disk, a shading correction has to be applied. The correction factor depends on the pyranometer type, the geometry of the shade ring, the geographical latitude and the actual anisotropy of the sky radiance distribution. According to Drummond (1956) and Dehne (1984), isotropic and anisotropic correction factors are introduced through the empirical formulas, respectively:

$$f_{is} = \frac{1}{1 - KF}, \tag{8.1}$$

where $K = (b/r)\cos^3\delta$, $F = (2/\pi)(\omega_0 \sin\phi \sin\delta + \sin\omega_0 \cos\phi \cos\delta)$ and $\omega_0 = \arccos(-\tan\phi\tan\delta)$ is the sunset hour angle. b and r are the width and the radius of the shading ring, respectively. δ is the declination of the sun and ϕ the geographical latitude.

The anisotropic correction factor is expressed as a function of the uncorrected diffuse radiation $G_{d,uncorr}$, the global radiation G and the declination of the sun δ:

$$f_{an} = 1.064 - 0.067\left(\frac{G_{d,uncorr}}{G}\right)^3 - 0.001\delta. \tag{8.2}$$

The corrected value of the diffuse radiation thus can be written:

$$G_{d,corr} = f_{is} f_{an} G_{d,uncorr}. \tag{8.3}$$

An indirect method of measuring the diffuse radiation is the simultaneous measurement of the global radiation G and the direct normal radiation $G_{b,n}$ using a pyranometer and a pyrheliometer. The diffuse radiation then is calculated using the relationship

$$G_d = G - G_{b,n}\cos\theta_z. \tag{8.4}$$

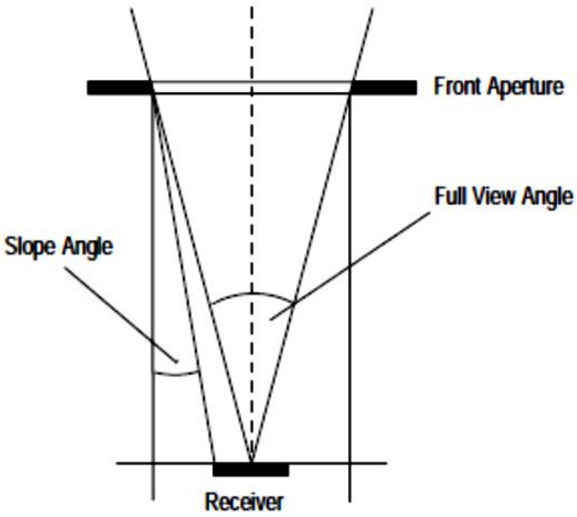

Fig. 8.2. View limiting geometry of a pyrheliometer.