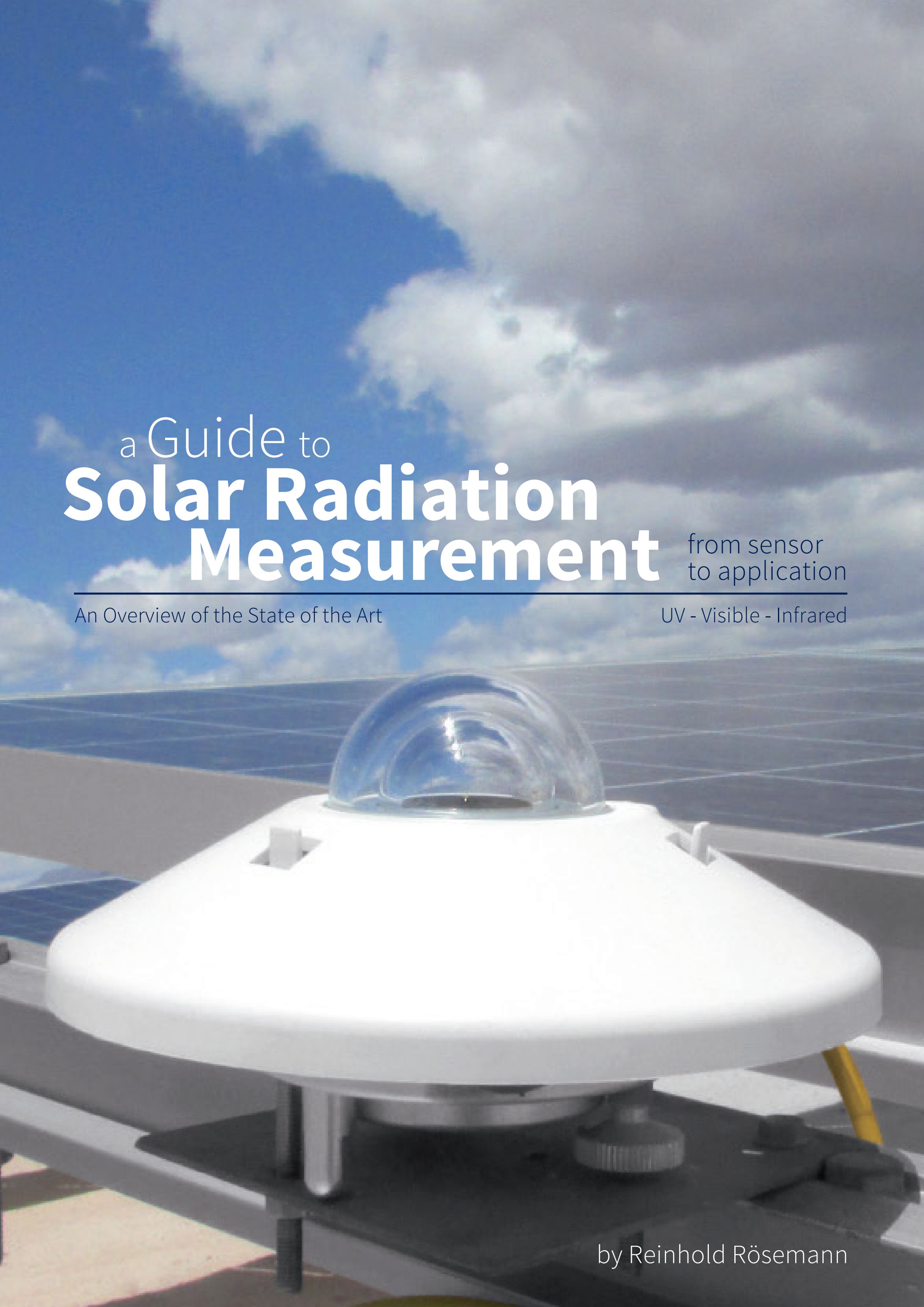

a Guide to
Solar Radiation Measurement

from sensor to application

An Overview of the State of the Art

UV - Visible - Infrared

by Reinhold Rösemann

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1. Preface

Those who deal with the subject of solar radiation sensors and measuring methods for meteorological purposes will find that there is a great deal of literature on special topics, but with a confusing mass of detail and scientific profundity. Often the information is overloaded with formulae and sometimes even do-it-yourself building instructions for individual sensors, which is of little interest to the typical user.

Somebody from a different area of specialization looking into these matters could easily get confused just searching for the right sensor for their measuring application. On the other hand, it is necessary to provide as much information on a sensor and its application as possible, in order to obtain an idea of the different issues of the task and their relative importance.

This is why few formulae or construction details are mentioned in this book. The reader will simply receive a general overview of this special field from the application and measuring viewpoint.

More specific information can be found in the individual data sheets and operating manuals provided by manufacturers, which should be available from the company websites. To increase one's knowledge of this subject it is recommended to cross-refer this book to the respective technical literature.

At this point I would like to thank all those who have supported me in so many ways in the accomplishment of both the original book and this updated third edition.

Reinhold Rösemann

2. Introduction

It is very complex to answer the question:

‘What effect does solar radiation have on us and our world?’

First, we have to take into account the kind of radiation that the sun emits and which parts of that radiation reach the earth. Furthermore, the effects of radiation need to be looked upon separately as direct and indirect effects.

Examples of direct effects are the cosy warmth that we feel when laying in the sun at the beach or the sunburn that we can experience from too much exposure. The effects can be beneficial in some circumstances but harmful in others.

Visible light and a certain amount of ultraviolet radiation are vital for our health. This includes the activation of the D-provitamins in our skin. A lack of vitamin D results in rickets. UV-radiation is necessary for our skin and it can be used to treat skin diseases, such as psoriasis and acne.

However, the human body reacts very sensitively when the radiation exceeds a certain limit. The most common negative effect is sunburn but excessive exposure to ultraviolet radiation may also cause skin cancer, melanoma or eye problems.

There are many more direct effects which are not so obvious.

Humans, animals, plants and our environment experience not only the direct effects of radiation but also the indirect ones. The indirect effects are so numerous that we first of all have to realize that our life on this planet would be absolutely impossible without solar radiation. Through the food that we eat, the water we drink and the air that we breathe we experience the indirect effects.

Solar radiation influences the weather substantially. ‘Weather’ generally defines a short-term physical condition of our atmosphere. However, the weather is determined by very complex and interacting phenomena that also influence the local climate, and that of the whole planet, over long periods of time.

To understand and predict climate changes requires measurements of high precision and reliability over long periods of time to quantify small and slow, but significant, trends.

Weather observation and weather forecasting are absolutely vital to our modern civilisation and its technical progress. Transport and commerce by land, sea and air could not be maintained without continuous measurement and collection of weather data. Safeguarding human lives by prediction of avalanches, black ice and other dangers would not be possible without continuous monitoring of solar radiation.

The power of the sun is increasingly being harnessed to provide a source of clean and renewable energy without a carbon footprint or greenhouse gas emissions. Solar energy can be used to generate electricity and to provide heat, but of course this is also heavily dependent upon the climate and weather.

The sun is a major driver in agriculture and hydrology and measurement of solar radiation is a key to food and water resource management.

It continues to be necessary to develop specific sensors to manage a complicated range of measurements for these purposes. There are also a variety of methodologies needed to acquire the necessary measurement data. This book is intended to provide an overview of the sensors presently available on the market and their fields of application.

3. The Sun

The sun is the centre of gravity of our solar system and it is the energy supply for our planet. It is the energy emitted by the sun that allows, directly or indirectly, the existence of life on earth. The sun consists of 71% Hydrogen, 27% Helium and 2% solid matter. Near its centre the temperature is around 16 million degrees and the nuclear reaction area in its core takes up almost one quarter of its whole diameter, which is approximately 1,392,000 km. The mass of the sun is around 332,000 x the mass of the earth.

The energy emitted by the sun is 3.72 X 1020 MW, which equates to a radiative power of 63 MW per m^2 of its surface. At the mean distance between earth and sun of approximately 150 million kilometres (1 Astronomical Unit, AU) the irradiance reaching the outside of the earth's atmosphere, normally to the sun's beams, is known as the Solar Constant (Eo). The 1982 value used in many older publications is 1,367 W/m^2. The current value, obtained by NASA from extra-terrestrial measurements in 2008, is 1,360.8 ± 0.5 W/m^2.

Actually, it is not constant. The earth's elliptical orbit reaches the point nearest to the sun (Perihelion - 147.5 million kilometres) around January 4^{th}. After 6 months, around the 4^{th} of July, it reaches the farthest distance from the sun (Aphelion - 152.6 million kilometres). This means that the direct solar radiation reaching the earth's atmosphere is 6.6 % more intense in January than it is in July (see figure 1).

Also the total energy emitted by the sun changes by up to 0.1 %, depending upon solar activity. The sun spot activity cycle of nominally 11 years may be between 9 and 12 years and varies in intensity. The sun's outermost and relatively thin 400 km layer is called the Photosphere and has a temperature of approximately 5,770 Kelvin. This is the layer that emits the spectrum of radiation which is visible to the human eye and is termed 'light'. Electro-magnetic radiation, including light, takes approximately 8.3 minutes to reach the earth.

Note that figure 1 shows the dates for the Winter and Summer Solstices (shortest day and longest day respectively, in the Northern Hemisphere). These do not correspond to Perihelion and Aphelion because the earth's axis of rotation is tilted by 23.5°, which is the latitude of the Tropics of Cancer (North) and Capricorn (South). Between the Solstices are the Spring and Autumn Equinoxes.

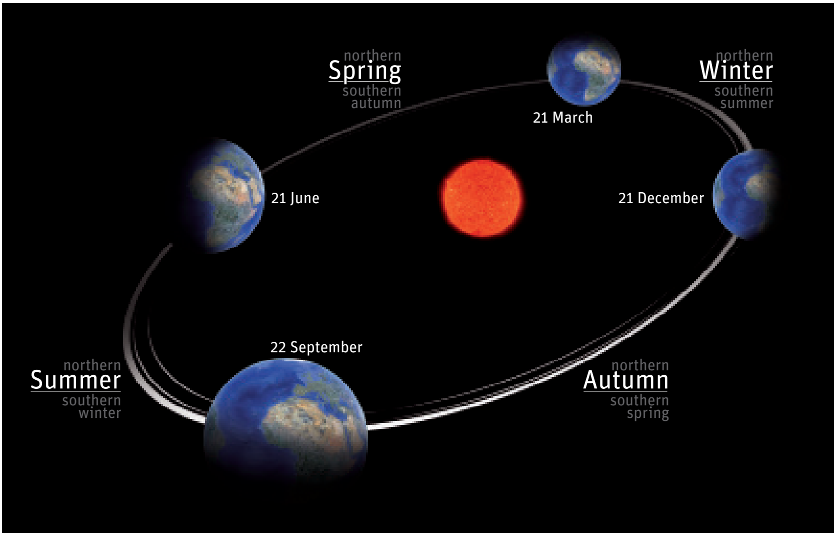


figure 1: the Earth's orbit around the Sun

The average temperature of the whole earth is about 2.3°C higher at aphelion than at perihelion, even although it is further away from the sun. This is due to the axial tilt and the distribution of land and sea on the earth's surface.

The sun has been in its present stage of development for approximately 4.5 billion years. There is still enough fuel (Hydrogen) in it to power the nuclear fusion reaction that produces the sun's energy for another 4.5 billion years in this stage of the star's life cycle.

4. The Atmosphere

The earth's atmosphere has a considerable influence on the intensity of solar radiation reaching the ground. Its height is approximately 70 to 80 km and it mainly consists of Nitrogen (~78 %) and Oxygen (~21 %). About a dozen other gases plus water vapour together make up only 1% but can have a large effect on climate and the environment, for instance 'greenhouse gasses' such as Methane and Carbon Dioxide.

The individual layers of our atmosphere differ from each other and are therefore classified by specific terms as shown in figure 2.

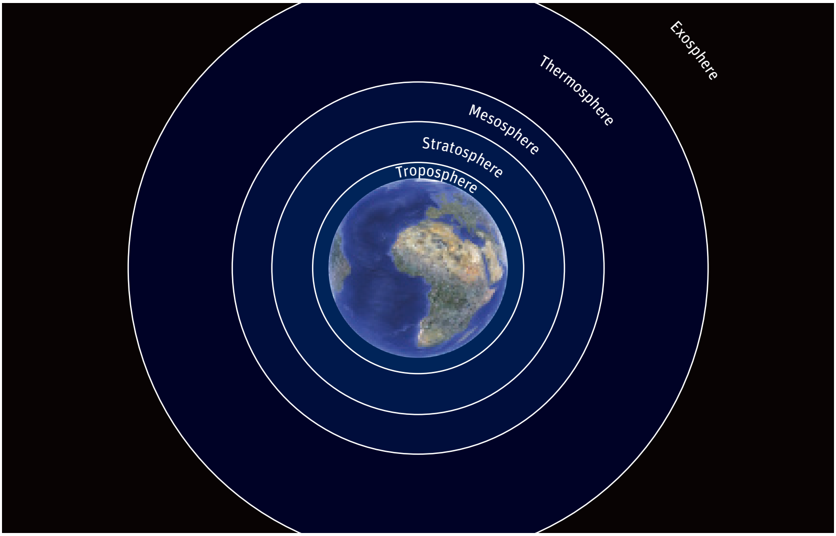


figure 2: the atmosphere

The bottom layer is named the Troposphere. It is the cloudiest layer and reaches up to the Tropopause. The Tropopause is the boundary between the Troposphere and the Stratosphere. It is at heights between 11 km and 16 km, depending on the location above the earth and the atmospheric conditions.

The Stratosphere is nearly cloudless due to its very low humidity. Above the Stratosphere is the Mesosphere, beginning at a height of approximately 50 km above the ground surface. Above the Mesosphere is the Ionosphere, which is also known as the Thermosphere, and reaches up to height of around 640 km. Beyond the Ionosphere begins the Exosphere which is the outer boundary and reaches up to 9,600 km. Beyond this is inter-planetary space.

Half of the complete mass of our atmosphere is situated in the first 5 to 6 km above the ground surface. The planetary boundary layer (PBL), also known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with the earth's surface. Depending upon the location and conditions, the thickness of the boundary layer can be from 50 m to 2,000 m although typically it is in the range of 200 to 500 m.

When passing through the atmosphere extra-terrestrial solar radiation is reduced by scattering and absorption caused by air molecules, aerosol particles, water droplets and ice crystals in clouds.

Gaseous molecules and aerosols cause most of the absorption of solar radiation.

Scattering of solar radiation takes place within the whole spectral range. However, there are different ways in which the scattering can occur:

- Scattering by water droplets and/or ice crystals in clouds relatively evenly across the whole spectral range;
- Scattering by molecules (Rayleigh-Scattering), predominantly of radiation at shorter wavelengths;
- Scattering by aerosol particles (Mie-Scattering) at wavelengths dependent upon the particle size and distribution.

Scattering and absorption in the atmosphere have a large effect on the spectrum of the solar radiation reaching the ground.

Figure 3 shows the variation in the spectrum of solar radiation at sea level under different atmospheric conditions from a clear sky to completely clouded.

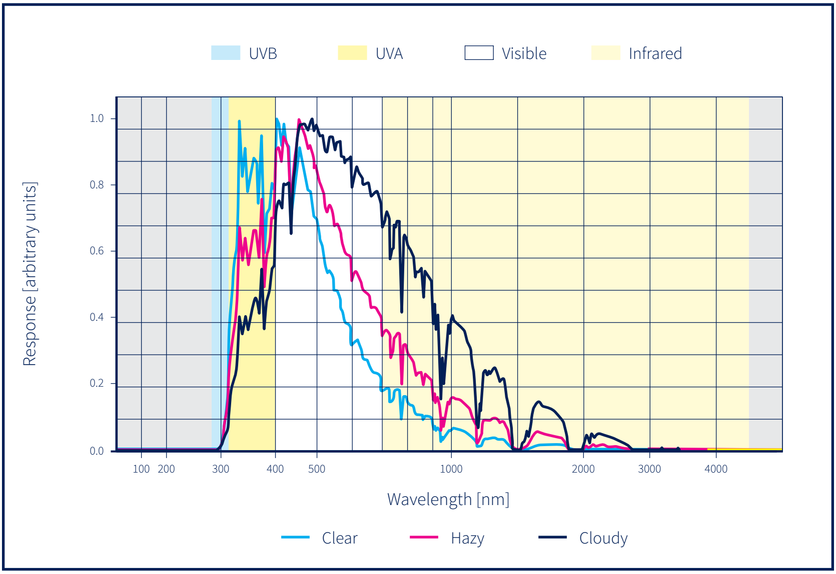


figure 3: spectral shift in diffuse irradiance with sky type

Variations of air pressure and temperature within the atmosphere influence absorption and therefore affect the spectrum at sea level and at different heights above sea level.

The spectrum of solar radiation received on top of a mountain in a remote region can differ markedly from the spectrum received in an industrial or urban area near sea level.

Wavelength is shown in μm (micrometres, or microns, 10^{-6} m).

5. The Earth

The earth's equator has a diameter of 12,756 km and a circumference of 40,076 km. 70.8 % of the earth's surface is covered by water.

The sun provides over 99.98 % of all energy to the earth's surface, the rest is from internal geothermal sources. This results in an average surface temperature of 14 °C, although extreme variations may occur locally and temporally. The highest temperature recorded was 57.3 °C at El Azizia, Libya on 13th September 1922. The lowest was -89.2 °C at the Russian Vostok Station in Antarctica on 21st July 1983.

The angle of incidence of the solar radiation is changing continually as the earth is circling around the sun and also spinning around its own axis. The ratio of radiation intensity and angle of incidence may be described as a cosine function, which is also called Lambert's Law (see figure 4).

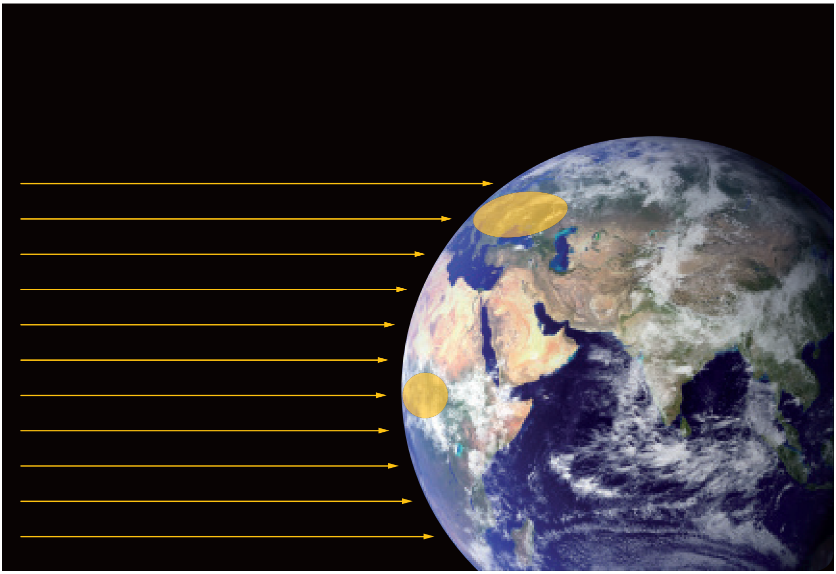


figure 4: angle of incidence of solar radiation

The amount and type of radiation falling on the surface also depends upon the changing characteristics of the atmosphere.

A crucial factor for the amount of radiation being absorbed by the earth, or reflected from it, is the composition of the surface.

The 23.5° inclination of the earth's axis also has an influence on the radiation received at a location, as can be seen from figure 5.

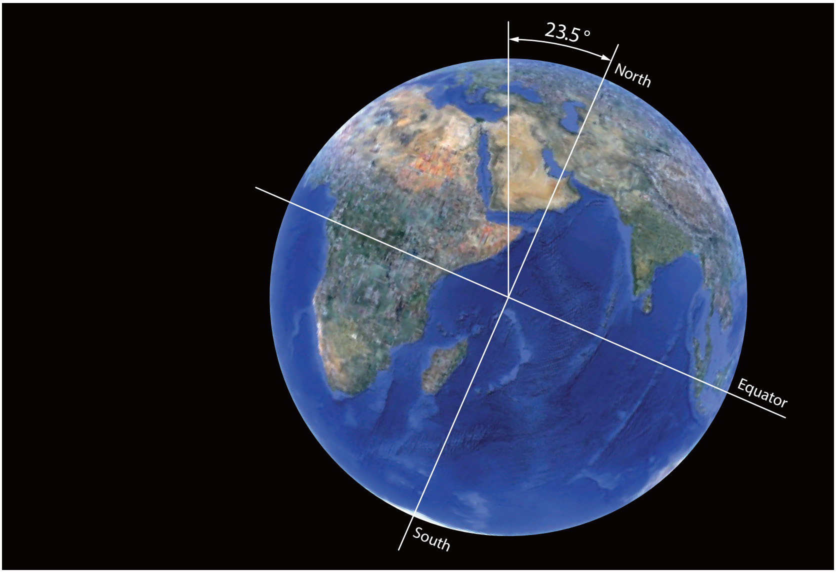


figure 5: inclination of the Earth's axis

The earth is almost spherical in shape and gravitational force binds the atmosphere like a shell. The intensity of the solar radiation at a point on the surface is therefore influenced by the curvature of the surface and the effective thickness of the atmosphere.

The solar radiation reaches its highest intensity when the sun is directly overhead at a 'solar zenith angle' (θ) of 0° and the thickness of the atmosphere is at its minimum. The lower the sun's position is in the sky, the more atmosphere the radiation must pass through, and so more radiation is scattered and absorbed. Less radiation reaches the earth's surface and the spectrum of the radiation also changes.

When the sun is directly overhead the atmospheric depth/thickness is at a minimum, and is defined as having a Relative Air Mass of 1.0 for that location. As the sun moves down towards the horizon, the air mass increases following a cosine function where Air Mass = 1/Cos θ (Solar Zenith Angle).

At a solar zenith angle 85° the atmospheric thickness is approximately 11.4 times larger than at the shortest path (solar zenith angle 0°). See figure 6.

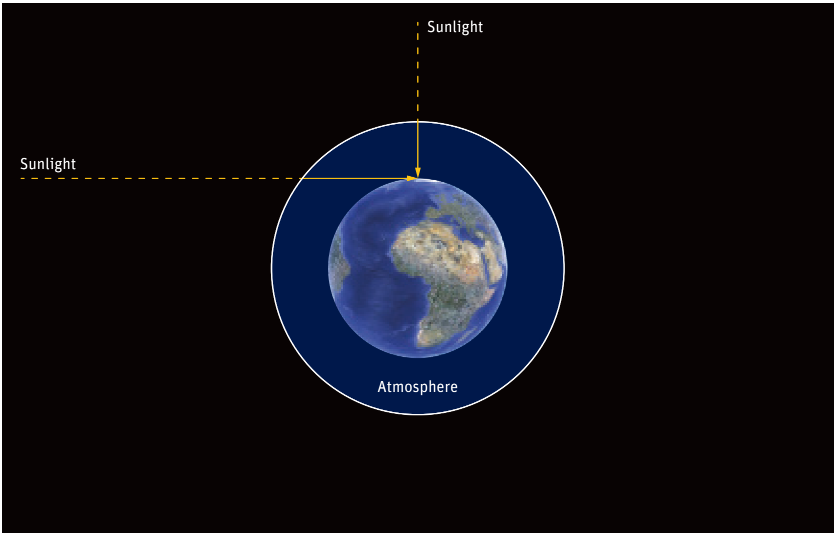


figure 6: atmospheric depth

The effects of solar radiation are also influenced by the composition of the surface that it is incident upon. It is not difficult to understand that a surface covered with snow reflects more radiation than one covered with trees or with dark rock. The fraction of the incident solar radiation that is reflected by the surface is called the Albedo.

A less reflective surface has a lower Albedo and will absorb more radiation and therefore heat up more. In general, this is why land tends to heat up more quickly than oceans.

6. Solar Radiation

The sun appears to us to be distant and small (it subtends an angle of 32 minutes of arc). Therefore the beam of radiation arriving at the earth's surface is almost parallel.

This radiation is a continuum over a wide range of wavelengths at varying intensities. The electro-magnetic solar radiation impinging on the upper edge of the atmosphere is called extra-terrestrial radiation. The mean integral for the complete spectrum is 1,360.8 W/m^2 (the Solar Constant).

Electromagnetic radiation (EMR) is a form of energy exhibiting wave-like behavior as it travels through space. EMR has both electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. See figure 7.

EM radiation carries both energy and momentum and exhibits both wave properties and particle properties at the same time (wave-particle duality). For example, radiation from electrons is released as photons, which are bundles of energy that travel at the speed of light as quantized harmonic waves.

These electric and magnetic waves have certain characteristics, including amplitude, wavelength, and frequency. This energy is grouped into categories, based on wavelength, to form the electro-magnetic spectrum.

Shorter wavelength means higher frequency, and higher frequency means greater energy. Shorter wavelength waves, such as x-rays, carry energy levels that can be hazardous to our health and protection may be needed.

Wavelength (**λ**) is the distance of one full cycle of the oscillation. For example, if you are on a boat, it is the distance between two wave peaks in the water. See figure 7.

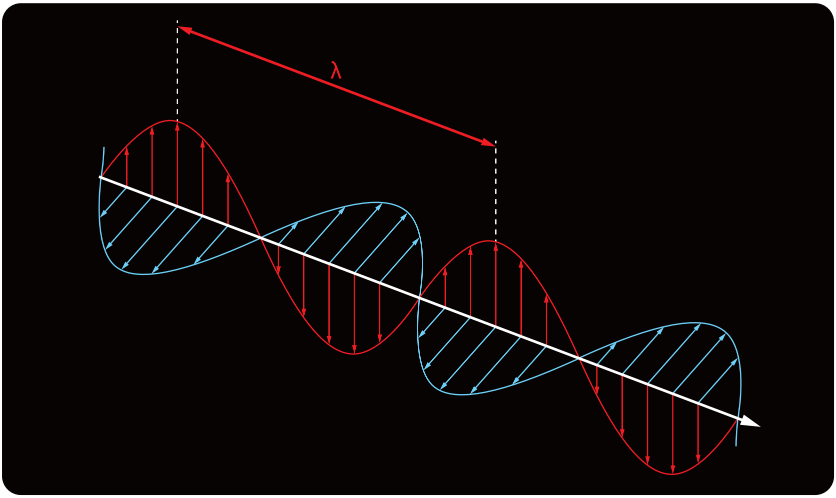


figure 7: wavelength of electro-magnetic radiation

The normal measurement of the wavelength of solar and atmospheric radiation is the nanometre (nm, 10^{-9} m) and for infrared radiation is the micrometre (μm, 10^{-6} m). The range is shown in table 1. In astronomy and older books you may see wavelengths in Ångström (Å, 10^{-10} m).

Wavelengths of Solar & Atmospheric Radiation			
Short-wave	UV-C	200 to 280 nm	Emitted from the sun, totally absorbed by the earth's atmosphere before reaching the ground.
	UV-B	280 to 315 nm	Emitted from the sun, 90 % absorbed by the earth's atmosphere, biologically very active, causes sunburn.
	UV-A	315 to 400 nm	Emitted from the sun, most reaches the ground, not biologically very active.
	Vis	400 to 700 nm	Visible light from violet to red (coulors of the rainbow).
	NIR	700 to 3,000 nm	Heat radiation from the sun.
Long-wave (infrared)	FIR	3,000 to 50,000 nm	Heat radiation from the atmosphere, clouds, earth and surroundings.

table 1: wavelengths of solar & atmospheric radiation

The radiation significant for processes on earth extends from 280 to 3,000 nm (short-wave radiation) and from 3 μm to >40 μm (long-wave radiation). The maximum intensity of the solar spectrum at the earth's surface occurs between 400 and 500 nm (depending upon the sky conditions), towards the blue end of the visible.

The complete spectrum comprises the ultraviolet (UV), visible (Vis), and infrared (IR) wavebands. However, these wavelength ranges need to be sub-divided depending on the individual application field. Best known are the prismatic colours of visible light, the colours of the rainbow, from violet to red.

UV is normally sub-divided into UVA, UVB and UVC radiation. Approximately 6% of the total solar radiation falling on the earth is ultraviolet. These shorter wavelengths (higher frequency) have higher energy, thus increasing the effect on biological and chemical systems.

IR is split into near infrared (NIR) and far infrared (FIR). FIR from the sun is not received at the earth's surface, it comes from the sky; atmosphere and clouds absorb short-wave radiation, warm up, and re-emit radiation in the far infrared as heat; and from the earth's surface. FIR is also emitted by the earth's surface due to warming by energy from the sun and atmosphere (and a small amount of geothermal heat).

The attenuation of solar radiation passing through our atmosphere is due to the following processes:

ultraviolet

Scattering by molecules and aerosols, absorption by Ozone (O_3), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2) and trace gases.

visible

Scattering by molecules and aerosols, but little absorption. Shorter wavelengths are scattered most, so the sky normally looks blue.

infrared

Absorption by water vapour and aerosols but little scattering.

Molecular Ozone in the upper layers of our atmosphere functions as a filter for ultraviolet radiation and the effect increases with shorter wavelengths. Whereas almost all UVA radiation reaches the surface, nearly 90% of the UVB radiation is absorbed by the Ozone, and all of the UVC.

A decreasing Ozone layer means increasing UVB radiation reaching the surface with detrimental effects upon people and the biosphere.

Solar radiation is the driver for many chemical, biological and physical phenomena in the atmosphere, on the ground and in the seas.

A major effect of solar radiation reaching the earth's surface is that it warms it up, which is vital for our existence. 30 % of the extra-terrestrial radiation solar radiation (yellow in figure 8) is reflected back into space but approximately 51 % is absorbed by land and water and another 19 % is absorbed by the clouds and atmosphere.

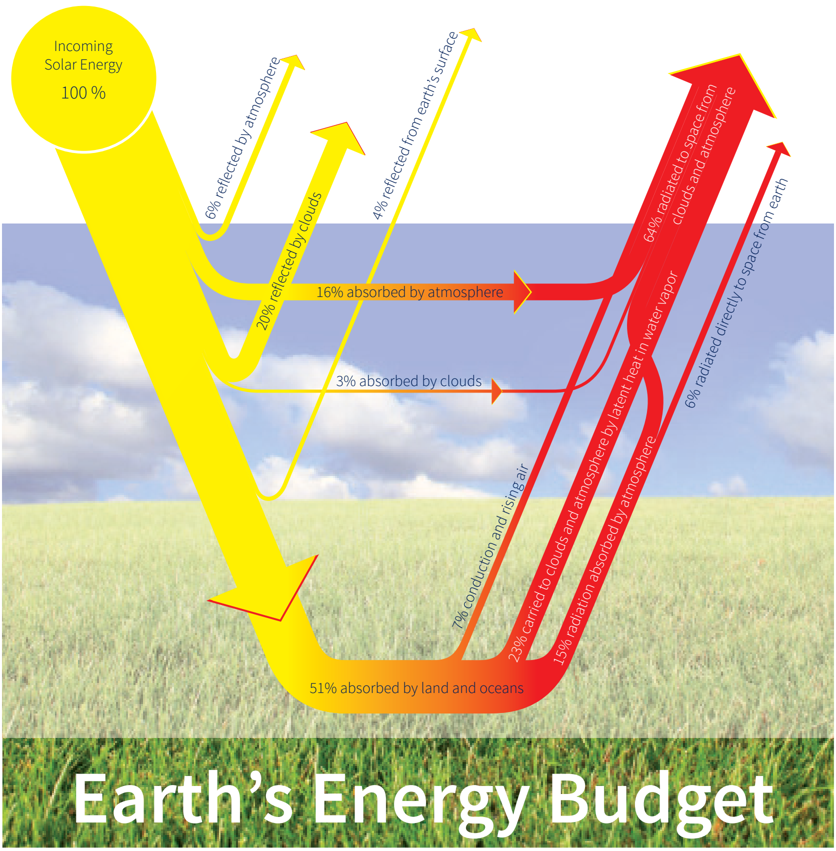


figure 8: the Earth's radiation energy budget

Long-wave far infrared radiation (FIR) is shown in red and is mostly transformed short-wave energy; that is re-radiated from the land, water, clouds and atmosphere. Only a small amount of the total energy remains on the earth but this is enough to maintain all the biological processes on our planet and to drive the weather systems.

Variations in the reflected and re-radiated energy do, of course, influence the energy balance between ground and atmosphere. This energy balance, in turn, influences meteorological conditions and other processes, for example the growth of plants.

Rising concern for the survival of our environment and our way of life, together with the desire for higher crop yields, makes it necessary to have available precise information on incoming and reflected radiation. In this respect the distribution of the radiation intensity at different wavelengths can be of the utmost importance.

Nowadays, measuring solar radiation is extremely important in many different fields of application, such as climatology, meteorology, hydrology, pollution forecasting, solar energy, agriculture and material testing.

Solar radiation measurement for climatology and weather forecasting is an important part of many of the daily activities of our world, which we can no longer do without. For example, the data obtained are essential for shipping and aviation.

During recent years, measuring of solar radiation has also become more and more important in the field of material testing, in which, for example, the UV radiation resistance of products and finishes has come to the fore.

Accurate solar radiation data is critical to the solar energy industry. In research and development, choosing the optimum locations and system types, efficiency monitoring, and maintenance scheduling.

7. Measured Meteorology Parameters

Meteorological observations for weather forecasting have been carried out on a regular basis for centuries. However, the data acquired can only be evaluated and interpreted after having recorded medium-term and long-term atmospheric conditions with a good statistical level of quality and verification.

Nowadays, transport and communications such as ground, air and sea traffic could not be maintained without real-time data, which are mainly being collected from measurements and observations in the atmosphere close to the ground (the Boundary Layer). The main meteorological parameters in this field are:

- Wind speed and direction
- Air temperature
- Air pressure
- Air humidity
- Precipitation
- Visibility
- Solar, atmospheric and terrestrial radiation

These parameters are also significant for such issues as air pollution, avalanche warning, the renewable energy industry, agriculture, forestry, water supply, town and regional planning, disaster management - and many more. For example, the evaluation and interpretation of gas emission measurements is only possible in comparison with meteorological data acquired concurrently.

The structure of the atmosphere close to the ground is extremely important for the local environmental conditions. Knowing the solar radiation as well as the air humidity and air temperature is necessary to evaluate chemical reactions of pollutants in the air.

All meteorological parameters are subject to short-term variations, normally caused by turbulences within the atmosphere, and these are influenced by solar radiation, directly or indirectly. These variations result in typical daily or yearly trends.

In order to be able to evaluate these typical trends it is necessary to compute the mean values from the actual ones measured over a specific period. For some meteorological parameters it is quite easy to understand their daily cycle. For example, the temperature cycle is normally a simple curve with a minimum value shortly after sunrise and a maximum in the early afternoon.

The yearly cycle of a meteorological parameter can be determined by making daily measurements. The average yearly cycle within a climatic region is normally determined by making measurements over a minimum of 30 years.

For large areas the spatial distribution of meteorological parameters can be taken from a climatic database but local peculiarities normally have to be measured separately. This means that the sensors and associated electronics must be designed to withstand the local climatic conditions, which may be extreme, from deserts to Antarctica.

Within the atmosphere close to the ground the temporal and spatial characteristics of radiation values are influenced by the characteristics of the ground surface. The most influential factors affecting the received radiation at any particular location are:

• Location on the earth
• Date and time
• Precipitation (cloud, fog, rain, snow)
• Constriction of the horizon (field of view)
• Air pollution (aerosols and gasses)
• Albedo

Due to the physical effects mentioned above it is sometimes not sufficient for many application fields to just measure the 'Global Radiation' coming from all around the measurement location. It may also be necessary to measure the 'Direct Radiation' coming only from the sun and/or the 'Diffuse Radiation' (not coming directly from the sun). The 'Radiation Balance' of incoming to outgoing radiation in the short-wave and long-wave may also be required.

As already mentioned, before reaching the ground the solar radiation is influenced by our atmosphere and its physical characteristics and an essential parameter is the absorption in different wavelength ranges. Albedo is affected by surfaces with different reflection characteristics, such as water, ice, snow, stone, grass, crops or woodland.

The different wavelength ranges as well as the properties of the atmosphere and the ground surface must be taken into consideration and this makes it necessary to develop special sensors suitable for individual measuring tasks.

In order to be able to develop the proper sensor, it is necessary beforehand to determine which meteorological value shall be measured and how it is defined. The symbols below are those given in the World Meteorological Organisation (WMO) Guide to Meteorological Instruments and Methods of Observation, 7th Edition 2008.

Note: These parameters are for Irradiance in W/m^2. Further explanations can be found in the glossary.

The parameters within the short-wave spectral range are:

Direct Solar Irradiance	E
Solar Zenith Angle	θ (0° = vertical, 90° = horizontal)
Diffuse Sky Irradiance	$Ed_{\downarrow}$
Global Irradiance	$Eg_{\downarrow} = E\cos\theta + Ed_{\downarrow}$
Reflected Global Irradiance	$Er\uparrow$
Albedo	$A = Er\uparrow / Eg_{\downarrow}$
Short-wave Net Irradiance	$E^*g = Eg_{\downarrow} - Er\uparrow$

The parameters within the long-wave spectral range are:

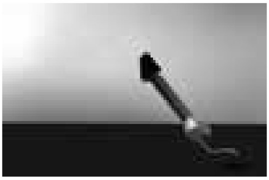
Downward Atmospheric Irradiance	$El_{\downarrow}$
Upward Ground Irradiance	$El\uparrow$
Long-Wave Net Irradiance	$E^*l = El_{\downarrow} - El\uparrow$

Consequently, the radiation balance over the complete spectrum is the difference between received and returned radiation:

Total Net Irradiance $E^* = E^*g + E^*l$

These parameters represent the most important solar radiation factors, for which the following sensors have been developed.

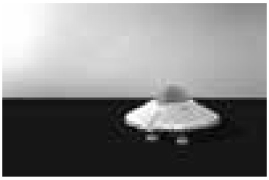
Direct Solar Radiation



Sensor:	Pyrheliometer
Spectral Range:	300 to 3,000 nm
Field of View:	<5°
Necessary Accessory:	Sun Tracker

Measures radiation coming directly from the sun and its aureole. Sun tracker keeps pyrheliometer aligned on the sun throughout daylight period. A key parameter for solar energy applications.

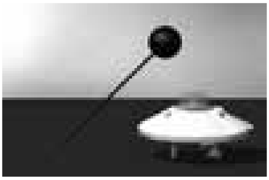
Global Radiation



Sensor:	Pyranometer
Spectral Range:	300 to 3,000 nm
Field of View:	180°
Necessary Accessory:	None
Optional Accessory:	Ventilation Unit

The basic measurement for most applications but has offsets caused by direct sun heating of the dome(s).

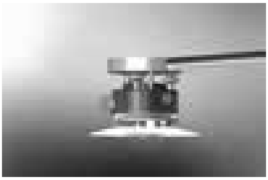
Diffuse Sky Radiation



Sensor:	Pyranometer
Spectral Range:	300 to 3,000 nm
Field of View:	180°
Necessary Accessory:	Shading Device:
	Shadow Ring
	Sun Tracker / Shading Ball

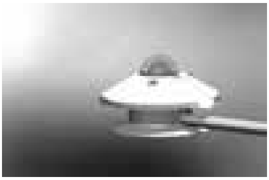
The pyranometer is shaded from the direct solar radiation to avoid heating offsets. Global radiation can be accurately calculated from direct and diffuse radiation and the solar zenith angle: $Eg_{\downarrow} = E\cos\theta + Ed_{\downarrow}$.

Reflected Global Radiation



Sensor:	Pyranometer
Spectral Range:	300 to 3,000 nm
Field of View:	180°
Necessary Accessory:	Glare Shield to keep out low-angle non-reflected radiation
Optional Accessory:	Ventilation Uni

Albedo / Net Short-wave Radiation

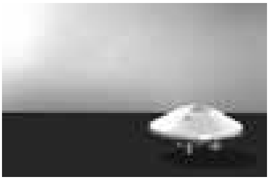


Sensor:	Albedometer (single housing containing 2 Pyranometers)
Spectral Range:	300 to 3,000 nm
Field of View:	180°
Necessary Accessory:	None

Integral Glare Shield to keep out low-angle non-reflected radiation. Albedo and short-wave net irradiance can be calculated: $A = Er\uparrow / Eg_{\downarrow}$; $E^*g = Eg_{\downarrow} - Er\uparrow$

Albedometers can also be assembled using two separate Pyranometers, a Mounting Plate and a Glare Shield for the down-ward facing sensor to keep out low-angle non-reflected radiation.

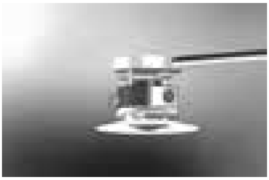
Downward Atmospheric Radiation



Sensor:	Pyrgeometer
Spectral Range:	4.5 to >40 μm
Field of View:	At least 150°, ideally 180°
Necessary Accessory:	With the exception of the Kipp & Zonen CGR4, all pyrgeometers on the market require shading from direct solar radiation which causes thermal dome offsets: Shadow Ring Sun Tracker / Shading Ball
Optional Accessory:	Ventilation Unit

Measures the downward far infrared radiation from the sky. An internal temperature sensor is necessary to correct the readings for the instrument temperature.

Upward Ground Radiation



Sensor:	Pyrgeometer
Spectral Range:	4.5 to >40 μm
Field of View:	At least 150°
Necessary Accessory:	Glare Shield to keep out low-angle non-reflected radiation
Optional Accessory:	Ventilation Unit

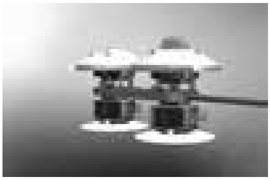
Measures the upward far infrared radiation from the surface. An internal temperature sensor is necessary to correct the readings for the instrument temperature.

Net Long-wave Radiation

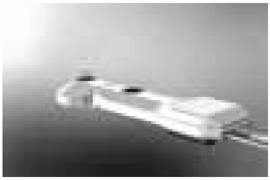
Sensor:	2 Pyrgeometers
Spectral Range:	4.5 to >40 µm
Field of View:	At least 150°, ideally 180°
Necessary Accessory:	Mounting Plate and a Glare Shield for the lower sensor to keep out low-angle non-reflected radiation

Long-wave net irradiance can be calculated: $E^*l = El_{\downarrow} - El^{\uparrow}$.
Internal temperature sensors are necessary to correct the readings for the instrument temperatures.

Total Radiation Balance



Sensor:	2 x Pyranometers and 2 x Pyrgeometers or an integrated 4-component net radiometer
Spectral Range:	300 to >40 µm
Field of View:	180 ° / 150 °, ideally 180 °
Necessary Accessory:	Mounting Plate and Glare Shields for the down-ward facing sensors to keep out low-angle non-reflected radiation
Optional Accessory:	Ventilation Units



Internal temperature sensors are necessary to correct the pyrgeometer readings for the instrument temperatures. The upwards facing sensors measure the total incoming radiation. The downwards facing sensors measure the total outgoing radiation. All four components of the radiation balance are measured. The total net irradiance can be calculated: $E^* = E^*g + E^*l$

Combinations of these measurements are necessary for weather forecasts, climatology, solar energy and other applications previously mentioned.

Manufacturers offer instruments of the above types at a range of price, performance and quality levels and the choice of models will depend upon the task, the accuracy required, installation and operating costs, and the budget available.

Direct Solar Irradiance measured on a plane at 90 ° to the incident beam is termed Direct Normal Irradiance (DNI).
Diffuse Sky Irradiance measured on a horizontal plane is termed Diffuse Horizontal Irradiance (DHI).
Global Irradiance measured on a horizontal plane is termed Global Horizontal Irradiance (GHI).
The relationship is GHI = DHI*Cos θ + DHI.

A typical high quality solar monitoring station will comprise an automatic sun tracker fitted with the instruments to measure the direct, diffuse and global radiation. Depending upon the application, long-wave radiation and reflected short-wave radiation may be added to provide the total radiation balance. Ultraviolet radiation and other measurements may also be made.

A further field of application for solar sensors is environmental simulation where the effect on materials is tested under 'artificial suns' in special climatic test chambers. In order to cut down the testing time, very high intensity artificial radiation sources are often used that far exceed the maximum natural levels.

Sensors that are used for these monitoring purposes should have measuring ranges that allow for radiation levels in the range up to 4,000 W/m^2 and they are often required to work at high temperatures of >100 °C. Environmental test measurement outdoors and environmental simulation are increasing markets for solar radiation sensors.

For most applications it is not only the momentary value of the parameter being measured that is important. Variations in the amount of energy received over a period of time, and the effects to be expected as a result, are extremely important. It is usual to measure and record meteorological parameters during the diurnal cycle (daily course) in order to make predictions about the future weather conditions.

The diurnal variations of global irradiance (Eg↓), diffuse irradiance (Ed↓), direct irradiance (E) and atmospheric far infrared thermal irradiance (El↓) measured over two consecutive days can be seen from figures 9 and 10 provided by the Meteorological Observatory Lindenberg of the Deutscher Wetterdienst. The Observatory location is at Latitude 52.21 °N, Longitude 14.12 °E.

The global and diffuse solar radiation were measured with CM22 pyranometers, the direct radiation with a CH1 pyrheliometer, and the thermal radiation of the atmosphere with a CG4 pyrgeometer - all fitted to a model 2AP automatic sun tracker. The instruments are manufactured by Kipp & Zonen B.V., The Netherlands.

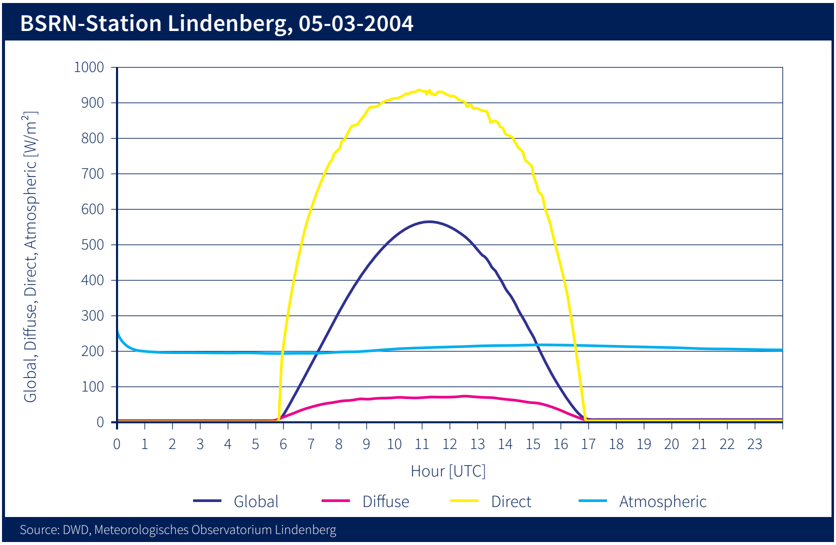


figure 9: diurnal variation of irradiance on 05-03-2004

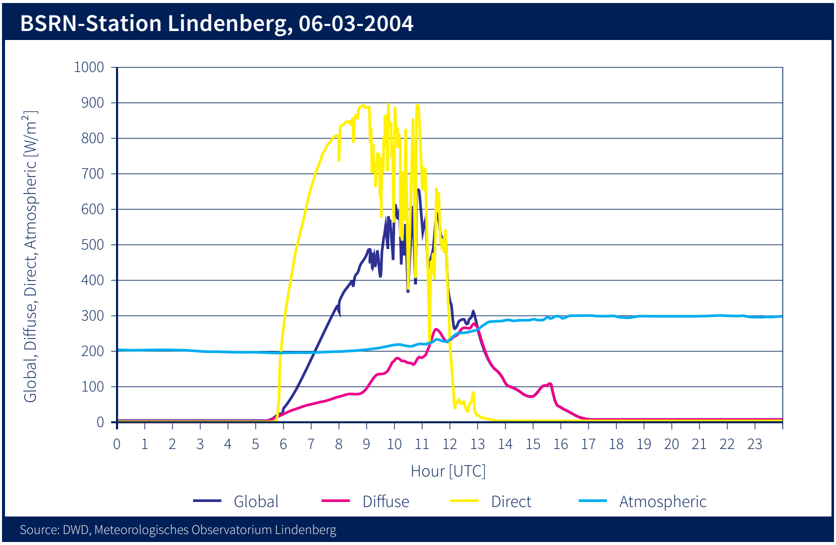


figure 10: diurnal variation of irradiance on 06-03-2004

8. Measuring Principles

Before looking at the measurement parameters in detail it is necessary to be aware of the procedure of measuring itself.

This procedure comprises:

1. Acquisition and presentation of physical values
2. Comparison of the measured values to a standard unit

There are two main prerequisites:

1. The parameter to be measured must be clearly specified
2. The standard quantity and unit must be established by agreement

Standard quantities and units are normally established by international conventions. The International System of Units (SI) defines seven 'base units' for seven 'base quantities' that are assumed to be mutually independent, as follows:

Base Quantity	Base Unit	Symbol
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electric Current	Ampere	A
Thermodynamic Temperature	Kelvin	K
Amount of Substance	Mole	mol
Luminous Intensity	Candela	cd

In addition there are two 'supplementary' quantities and units:

Supplementary Quantity	Unit	Symbol
Plane Angle	Radian	rad
Solid Angle	Steradian	sr

All other measurement quantities and units can be derived from these basic and supplementary quantities and units.

Thus, the measuring process can be described as inter-relating a measured value with the respective standard unit.

Only one base unit has a physical representation and this is the kilogram, it is equal to the mass of the international prototype of the kilogram preserved in a vault in Sèvres, France. Since its installation in 1889 it has only been brought out 3 times to be cleaned and weighed. The last time the cylinders were removed and cleaned (between 1988 and 1992) there was found to be a variation of 23 µg, due to microscopic surface contamination and abrasion. Now the race is on to find a suitable replacement definition based on fundamental or atomic constants.

Eighty copies of 'the kilogram' exist, of which only 6 are 'official' and these are held by national standards organisations as 'working' or 'reference' standards. However, the comparison of such measures as temperature (the Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water) to a working or reference standard is not practical. In such cases it is only possible to compare with defined bench marks related to the technical features of bodies or materials.

This becomes even more difficult when looking at radiation, as references representing the quantity 'global radiation' do not exist. Therefore, the subject of 'calibration' in the field of radiation measurement is even more challenging because here, there are no primary standards available for the sensor manufacturers.

In most cases the sun, under clear and unpolluted sky conditions, can be used as a reference for meteorological measurements. However, in order to be independent from the sun for calibrations most of the sensor manufacturers use calibrated radiation sources, such as lamps, projectors, etc. However, the use of these calibration sources makes it necessary to consider the ambient conditions very thoroughly in order to avoid any disturbing effects. The precautionary measures that have to be taken in this regard should not be underestimated.

Within modern sensors the physical parameter measured must primarily be represented as an electrical signal from which the actual measurement value can be determined. However, optical radiation parameters can be transformed into different physical ones, such as infrared radiation converted into a heating effect. See table 2.

Transformation of Solar Radiation		
Output	Physical Effect	Application
Thermal	Absorption producing temperature increase	Pyranometer Pyrheliometer Pyrgeometer
Electrical	Photo effect (i.e. photo-diode)	Lux Meter PAR Sensor Silicon Pyranometer UV Sensor Sunshine Duration Sensor
Optical	Wavelength conversion by fluorescent elements	UV Sensors
Molecular	Chemical change in emulsion	Photographic Paper

table 2: transformation of solar radiation

The following terms help with understanding the measuring principle and together with the respective component specifications can be used to define the measuring procedure:

Indicator

Values on analogue devices are indicated by a pointer on a scale. Digital indicators show values as numbers in a display.

Indication Range

The indication range is the minimum and maximum values that can be read from the indicator.

Measurement Facility / Measurement System

Complete set of components, such as sensor, signal amplifier and indicator, necessary to determine the measurement value.

Measuring Error

Difference between indicated and real value. The real value would be the one shown by an absolutely error-free measuring system.

Measuring Principle

The physical basis of the measurement.

Measurement Range

The range of indicated values in which measuring errors do not exceed specified limits.

Measurement Signal

Output value (normally an electrical signal) of a sensor.

Measurement Value

Value shown on the indicator or determined from the output signal.

Method of Measurement

The procedure for making a measurement using the measuring principle.

Parameter

Physical quantity, the value of which can be determined by measuring.

Sensors and measurement systems should measure physical quantities with as few errors and as little interference to the physical quantity as possible. The concept and development of the different types of sensors plays a significant part here but also the choice, application and maintenance of the sensors and systems under all kinds of environmental conditions influence the results considerably.

The differentiation and designation of sensors for the measurement of solar and atmospheric radiation intensity has been defined by the World Meteorological Organization (WMO). This differentiation by, application, spectral range and view angle can be seen in table 3.

In addition there are defined procedures (standards) for determining the performance of the sensors and 'quality' classifications based upon the performance. There are also standards or guidelines for the calibration, installation, operation and maintenance of solar radiation sensors.

Sensors for the Measurement of Irradiance			
Sensor Type	Application	Spectral Range	Field of view
Pyrheliometer	Direct solar radiation, mounted on a sun tracker	At least 300 to 3,000 nm	5°
Pyranometer	Global, diffuse and reflected solar radiation	At least 300 to 3,000 nm	180°
Pyrgeometer	Far Infrared radiation from sky or surface	At least 4.5 to >40 µm	At least 150° ideally 180°
Net short-wave radiation and Albedo sensor	One upward pyranometer and one downward pyranometer	At least 300 to 3,000 nm	180° each
Net long-wave radiation sensor	One upward pyrgeometer and one downward pyrgeometer	At least 4.5 to >40 µm	At least 150° ideally 180° each

table 3: important types of sensors for measuring irradiance

The sensors listed in table 3 provide measurement signals that can be converted to irradiance in units of W/m^2 by use of the individual sensor calibration factor.

There are other sensor types that use similar functional principles and these will be introduced later in this book. The main exceptions to these principles are sensors for sunshine duration measurement and ultraviolet sensors.

9. Radiation Sensor Principles

Thermoelectric Principle

Most broad-band sensors transform the parameter solar radiation into an electrical signal. Normally the short-wave and long-wave radiation are converted into thermal energy by absorption in a horizontal, blackened surface. The absorption of these black surfaces over a very wide wavelength range is almost 99 % for high-quality sensors.

This enables measurement of the incoming radiation with almost no dependence upon its wavelength. The resulting increase of temperature (ΔT) is in the order of 1 to 10 Kelvin.

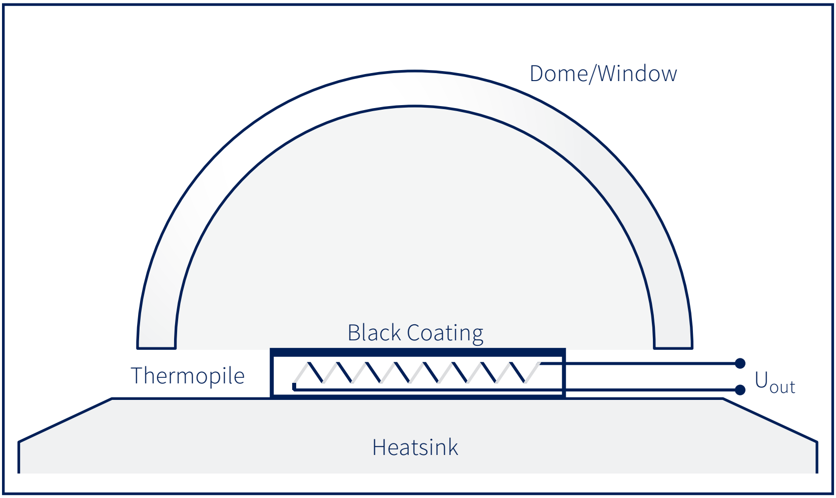


figure 11: sensor based on the thermoelectric principle

The temperature increase is measured via thermocouples. A thermocouple is a junction between two different metals that produces a voltage related to a temperature difference (the Seebeck effect). Many thermocouples can be connected in series or series-parallel to make a thermopile.

The active (hot) junctions (see figure 11) are located either centrally or equally spaced-out directly beneath the blackened receiver surface and are heated by the radiation absorbed in the black coating.

The passive (cold) junctions of the thermopile are located outside the black receiver surface and are attached in such a way that they maintain the same temperature as the sensor housing, which serves as a heat-sink. A typical construction is shown in figure 12.

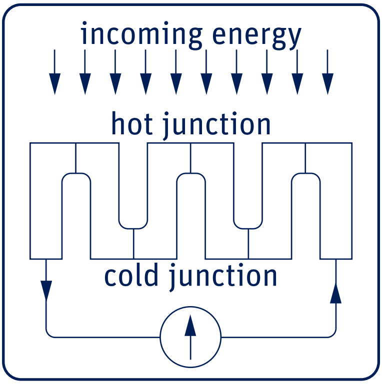


figure 12: thermopile construction

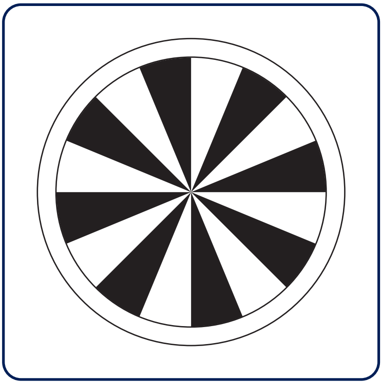


figure 13: black/white coating

Thermopile sensors with a black receiver surface are the most commonly used type. However, another construction principle also includes thermoelectric sensors but uses the differential absorptivity of colour variations over the receiver elements.

These black and white sensors (see figure 13) consist of alternating black and white segments, whereby the hot junctions are located underneath the black segments and the cold ones are underneath the white segments. Their advantage is that the mass of the housing does not have to be used as a direct summing point.

The disadvantage of this design is that the white segments become yellow in the course of time due to the solar radiation and their sensitivity therefore declines. Due to this reduced stability it is necessary to recalibrate these sensors at shorter intervals resulting in higher costs for maintenance.

Another method similar to the thermopile principle that is becoming more and more important is based upon Peltier elements (see figure 14). These sensors are also thermoelectric and generate an active output voltage signal.

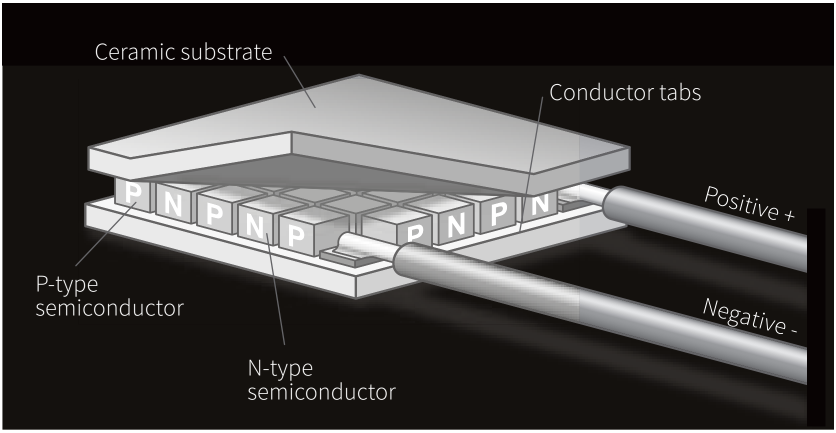


figure 14: Peltier element construction

This type of sensor tends to be more stable than conventional thermopiles and have better characteristics for response, time, linearity, and changes in ambient temperature, but they are more expensive.

Bolometric Principle

Solar radiation can also be transformed into an electrical signal with a temperature-dependent chain of resistors. In this bolometric principle, several resistors are mounted centrally beneath the black receiver element and others are mounted to maintain the same temperature as the housing.

These resistors can be connected to form a 'Wheatstone' measuring bridge in order to produce a voltage proportional to the temperature increase, as shown in figure 15.

This kind of transformation of a parameter offers many possibilities to build precise sensors. In this case the resistors change their values but no active voltage is being produced, so it is termed a passive principle. However, these types of sensors need an external power supply for the Wheatstone measuring bridge.

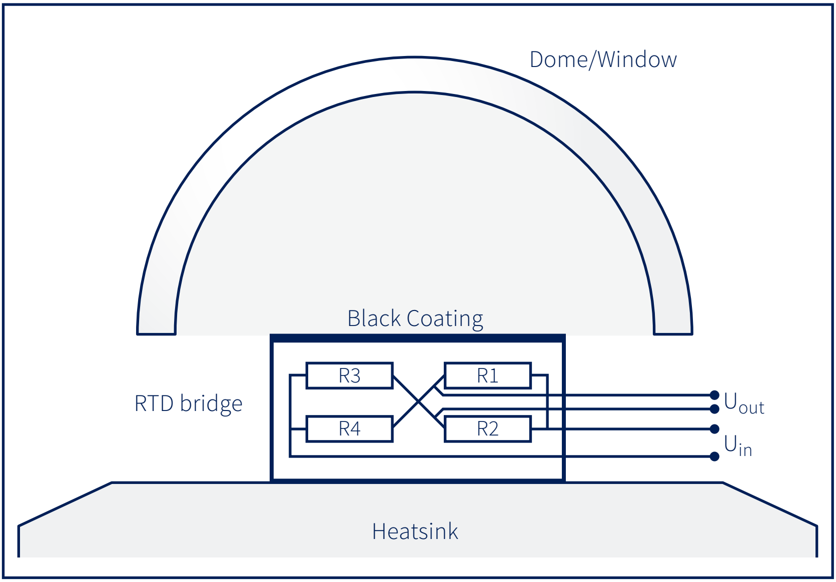


figure 15: sensor based on the bolometric principle

Most of the time, in the field application, the power has to be provided through very long supply lines or by batteries or solar panels. Therefore, the thermoelectric principle, which does not require an auxiliary power source, is often preferred to bolometric sensors.

The principle of absorbing incoming radiation and transforming it into electrical voltage requires sufficient energy to achieve an increase of temperature that can then be measured accurately. Limitations in resolution are usually due to the rest of the measurement system, rather than the sensor.

The sensors described above must be protected from environmental influences that could disturb the temperature changes caused by the radiation absorbed, or affect the absorptivity of the black coating.

The normal solution is to equip these sensors with protective domes or windows that can also be used to select the spectral range to which the sensor responds, depending upon the optical materials used.

Photoelectric Principle

Sensors for which a constant sensitivity over the whole spectral range is not necessary or not desired, such as sensors for measuring specific spectral ranges, are usually equipped with a photodiode as the sensing element. Advantages of photodiodes are the ready availability, small size and relatively high output signal.

The absorption of electromagnetic radiation by semi-conductors leads to the photoelectric effect, which can be used for the measurement of radiation. Thermoelectric forces do not have any influence here, so photodiodes have a very fast response time independent of thermal mass.

The achievable output voltages are dependent upon the materials of the semi-conductors as well as the internal structure and the load resistance (the shunt shown in figure 18). Generally the depletion layer in the photodiodes (the p-n junction) serves as the receiving element for the radiation.

figure 16: typical photodiode

The sensitivity of photodiodes varies with wavelength and different types are suitable for different spectral ranges. A simple photodiode is often used for measurements of radiation in the range of 400 to 1,100 nm, encompassing the visible and some near infrared. This is sometimes referred to as a 'silicon pyranometer'.

In order to collect radiation from a complete hemisphere and provide a good directional response the diode is normally mounted behind a diffuser. The diffuser may be of a type resistant to environmental effects that can be used outdoors without further protection, as shown in figure 17.

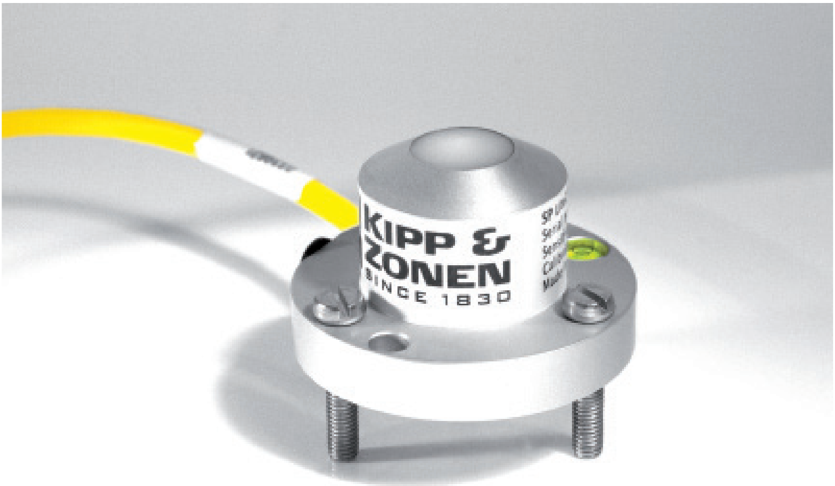


figure 17: silicon pyranometer with all-weather construction

Some types of photoelectric sensor have diffuser materials that require protection.

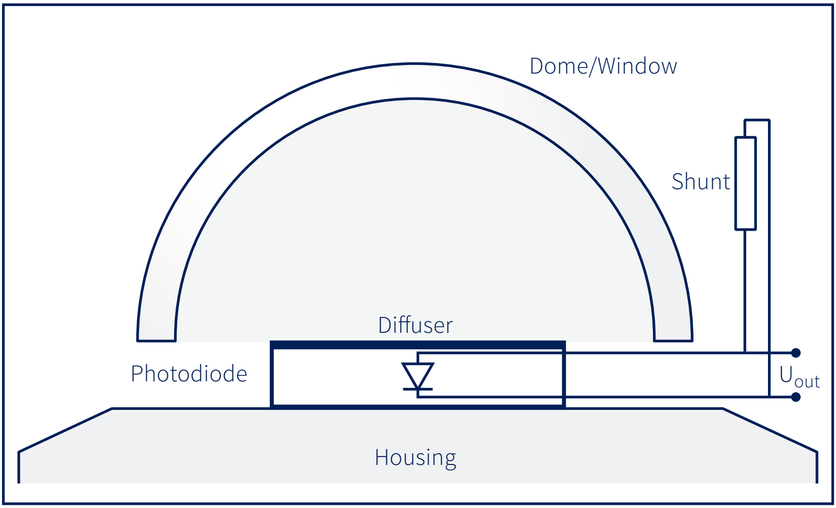


figure 18: sensor based on the photoelectric principle

Specific types of photodiodes are used in combination with optical filters to produce a tailored spectral response. Examples are PAR (Photo-synthetically Active Radiation, affecting Chlorophyll production in plants), Lux (human eye response) and UV sensors.

Thermomechanical Principle

Sometimes it is required to both measure and record radiation with instruments that do not need any electrical power supply. For this purpose some instruments with sensors use the thermomechanical principle.

The basis for such sensors is bimetallic elements which consist of two materials mechanically connected together that have different coefficients of thermal expansion. One side of the bimetallic element is blackened with an absorptive coating and exposed to the solar radiation, the other side is not.

This causes a difference in temperature of the two materials and the bimetallic element bends in proportion to the radiation intensity. This bending movement is transmitted to a pointer or writing device via a system of levers. The sensitive black surface is covered with a glass dome for protection.

An example of this type of instrument is the 'Aktinograph' manufactured by Thies Clima of Göttingen, Germany.

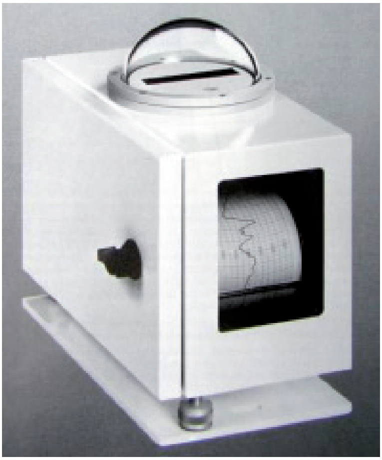


figure 19: Aktinograph by Thies Clima

10. Optical Filters

The spectral response of sensors can be modified by using a coloured glass, which absorbs light of certain wavelengths, or by applying specialised coatings to optical surfaces. These are known as thin-film optical coatings, or interference filters. Most people have seen these as 'anti-reflection' coatings on camera lenses.

An interference filter consists of multiple thin layers of metallic reflecting materials separated by dielectric material spacer layers. Depending on the materials and their spacing the filter can be designed to transmit only specific wavebands of electro-magnetic radiation. The layers are vapour-deposited in a vacuum chamber onto a stable and rigid substrate material.

There are four basic types of optical filter:

Neutral density filter
This is designed for equal absorption at all the wavelengths within a specific spectral range in order to reduce the intensity of radiation. Usually this is to avoid overloading a detector.

Band-pass filter
Radiation outside a certain spectral range is blocked so that only the wavelengths that it is desired to measure are passed through. The transmission 'curve' may be designed to match a specific response, such as PAR or Lux.

Short-pass filter
Transmission blocked at wavelengths longer than a specified value.

Long-pass filter
Transmission blocked at wavelengths shorter than a specified value, the simplest form is a coloured glass.

The choice of filters for specific products is determined by the manufacturer and may be constrained by international standards. The spectral response of an instrument is a combination of the characteristics of the optical materials and filters, detector, and diffuser (if used).

Besides the transmittance of the filter, the transmission cut-on and cut-off characteristics and the reflection losses occurring at the surfaces must be considered. A significant factor is the quality of the polishing of the surfaces.

Glass substrates are suitable for almost any kind of filter within the short-wave solar radiation spectral range of 300 to 3,000 nm. For applications in the ultraviolet range or in the near infrared a quartz substrate is normally used.

Glass is not suitable for sensors measuring long-wave radiation. The substrates need to have good transmission in the infrared and are mainly metallic or semiconductor materials, such as Silicon.

Coloured glass filters for the separation of defined spectral ranges of solar radiation have often been used to measure changes in atmospheric turbidity caused by aerosols. The wavelengths are specified by WMO and others. The best known manufacturer of these filters is Schott AG of Mainz, Germany.

Normally the measurement is made by a set of four pyranometers, three with different coloured glass windows plus one with a standard quartz window. A cheaper option is a single pyrheliometer with a rotating filter wheel, but the measurements are not simultaneous.

Coloured glass filters are well understood and the long-wave transmission limit is governed by the characteristics of the glass itself. The short-wave limit is determined by the colouring of the glass but is not very precise and is temperature dependant. Coloured glasses also have a limited life in moderate to severe climates.

In recent years low-cost, compact and rugged solid-state spectrometers and detector arrays have become available which make sun photometers a viable alternative to this method. They measure a spectrum of the solar radiation in one instrument, simultaneously at all the wavelengths, and provide more information about the atmosphere. However, the spectral range is limited compared to the pyrheliometer and filter method.

11. Domes and Windows

It is necessary to protect black sensor coatings and some types of diffuser against external influences, which may affect the measurement; such as precipitation, dirt and wind.

Pyrheliometers for measuring the direct irradiance have a flat window that is normally made of UV grade Quartz to transmit all the short-wave radiation from below 200 to beyond 4,000 nm.

Nearly all pyranometers use an optical quality glass for their hemispherical single or double domes. Depending upon the glass type the transmission is from 300 nm, or less, to about 3,000 nm. Double domes give better stability under dynamically changing conditions by further 'insulating' the sensor surface from environmental effects such as wind and rapid temperature fluctuations.

The shape of the dome, and the refractive index of the material, improves the response of the sensor when the sun is close to the horizon, 'bending' the incoming radiation beam.

The highest specification pyranometers use Quartz domes for a wider spectral response. The higher refractive index further improves the directional response and better thermal conductivity than glass provides other performance benefits. However, Quartz domes are considerably more expensive than glass.

Pyrgeometers have a flat window that gives a 150° field of view or a dome (hemispherical or meniscus type) that gives a 180° field of view. The material is usually a specific type of Silicon that has good long-wave far infrared transmission. However, it does not block all the short-wave radiation, so a 'solar-blind' filter is applied to the inside surface, ensuring that only the FIR is transmitted.

High quality Ultraviolet sensors use UV grade Quartz for their domes. However, lower performance sensors may use a special glass with enhanced UV transmission, which has a more limited spectral range, but is considerably cheaper.

If it is intended to design a sensor to measure both short-wave and long-wave radiation it will be necessary to use windows or domes of synthetic material. Often polyethylene film of about 0.25 mm thickness is used. The best known example was the Q7.1 manufactured by Radiation and Energy Balance Systems Inc. of Belleville, Washington, USA, that is shown in figure 20.

However, the domes are not rigid and to maintain their shape they could optionally be pressurised by an air pump, which added complexity and the need for power. The domes are also very soft and are easily damaged, often by birds, and have to be replaced by new ones on a regular basis. For these reasons this type of sensor has lost popularity and is being replaced by more modern, lower maintenance designs (see the Net Radiometer section).

figure 20: REBS Q7.1 net radiometer with polyethylene domes

12. Sensor Properties

Sensors and their measuring properties are defined by the relationship of input values to output values, and in consideration of the different internal and external influences. Regarding sensors for measuring radiation intensity the following characteristics related to the input values are important:

Sensitivity
Response Time
Non-stability
Non-linearity
Directional Response
Spectral Range
Spectral Selectivity
Temperature Response
Tilt Response
Field of View
Resolution
Zero Offsets

The individual sensor characteristics should be listed on the manufacturers' data sheets in accordance with the standardised international guidelines. This will allow the comparison of the technical data of sensors because for many measurements it is essential to be able to appraise possible measurement uncertainties.

The International Standards Organisation (ISO) refers to most of these characteristics in ISO 9060:1990 'Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation' ISO defines classifications for these types of solar radiation sensors with minimum requirements for the sensor performance.

Similar requirements can be found in the World Meteorological Organisation (WMO) Guide to Meteorological Instruments and Methods of Observation, currently at the 7th Edition, 2008.

Most well-known manufacturers of solar radiation sensors publish their product information based on these requirements.

Please note that it is no longer encouraged to use terms such as ‘accuracy’ or ‘error’, except in the most general sense, for measurement performance. These are poorly defined terms.

The term ‘uncertainty’ should be used where appropriate. The International Standards Organisation (ISO) Guide to the Expression of Uncertainty Measurement (GUM) provides a standard method for the determination of uncertainty in measurement.

Sensitivity

This is the relationship of the electrical output signal to the input value of the measured parameter. The sensitivity of a solar radiation sensor is normally the mean value over a defined spectral range under defined measurement conditions and is determined by the manufacturer during calibration. It may also be called ‘responsivity’.

For short-wave solar radiation sensors the sensitivity is normally quoted for a typical mid-range irradiance of approximately 500 W/m^2. The sensitivity should have a linear behaviour with received radiation intensity, although in practice small deviations occur which are specified as ‘non-linearity’.

Changes of the sensitivity due to temperature variations are probable and indicated on data sheets as ‘temperature dependency’ or ‘temperature response’.

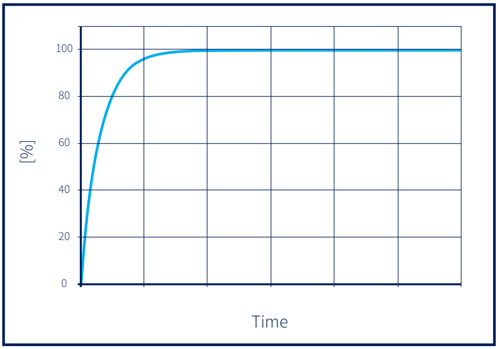
For solar radiation sensors without amplification the sensitivity is usually quoted in microvolts of signal output for 1 watt per square metre of incident irradiance, $\mu V/W/m^2$.

Response Time

The response time of a sensor is determined by internal features, and is defined by ISO 9060 as the time for the sensor output value to reach 95% of the incoming radiation value after a step-change in radiation.

However, some manufacturers of solar radiation sensors specify the 63% point, which appears to be faster.

Thermoelectric sensors have response times from a few seconds to more than 30 seconds, depending upon the design. Sensors based on the photoelectric principle (photodiode) have a response time of <1 second.



Response times faster than 1 second have little benefit in measuring solar radiation. The output signal of the sensor is usually not sampled at faster than 1 second intervals, and the values are normally integrated over a time period of between 10 and 60 seconds.

Non-Stability

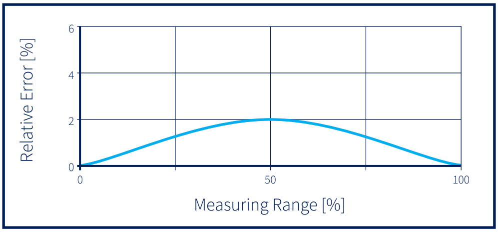
Information on stability is needed for the evaluation of the long-term constancy of the sensitivity and the zero point of a sensor, which is often an important consideration for certain applications. The main factors in sensitivity drift with time are the type and design of the detector and exposure to solar radiation.

Non-stability is usually quoted as the change in sensitivity over 1 year of operation. Thermoelectric sensors do not normally change if kept in the dark in appropriate storage conditions.

Significant factors in ensuring a sensor's stability during operation are maintenance and recalibration at regular intervals. These intervals are normally prescribed by the manufacturer (if this is not the case, recalibration every two years is strongly recommended).

Non-linearity

Non-linearity is the deviation of the measured value from the ideal linear behaviour of the sensor within the measuring range. The values mentioned on data sheets are a result of the sensor characteristics and are constant within specified limits.

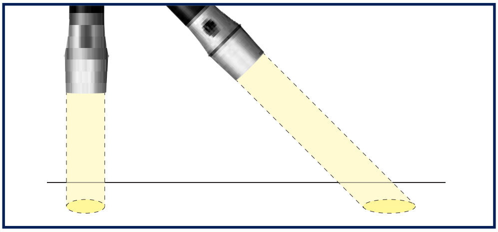


The deviation is normally quoted over a typical useful measurement range with respect to a mid-range value. ISO 9060 specifies non-linearity from 100 W/m^2 to 1,000 W/m^2 with respect to 500 W/m^2.

Directional Response

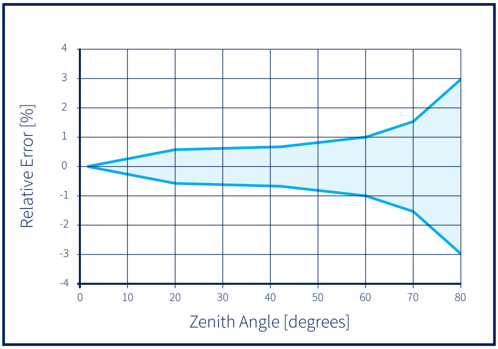
The relative deviation of measuring values from the ideal values, depending upon the angle of incidence of the solar radiation. Ideally a sensor for measuring radiation from the complete hemisphere should have equal response to radiation coming from all solar zenith angles and all azimuth directions.

When the Sun is directly overhead, its light (and energy) is concentrated upon the smallest possible surface area of the ground that it can strike (and be absorbed by). However, when the Sun is lower in the sky, its beams strike the ground obliquely, and are thus spread out over a larger area. The amount of energy per unit area is thus reduced as the sun moves lower in the sky.



Radiation at a defined zenith position will have an intensity value proportional to the cosine of the zenith angle of incidence. This is sometimes called the 'cosine-response'. The directional response of a sensor is influenced by the quality, dimensions and construction of the dome(s) and/or diffuser and the detector position.

The deviation from the ideal cosine response is usually given by manufacturers with respect to 1000 W/m^2 of direct beam irradiance, as specified in ISO 9060. This is normally for up to 80° angle of incidence. Beyond 85° solar zenith angle the cosine relationship starts to break down and the deviation at 90° is not meaningful because half of the solar disk is below the horizon or below the view of the sensor.

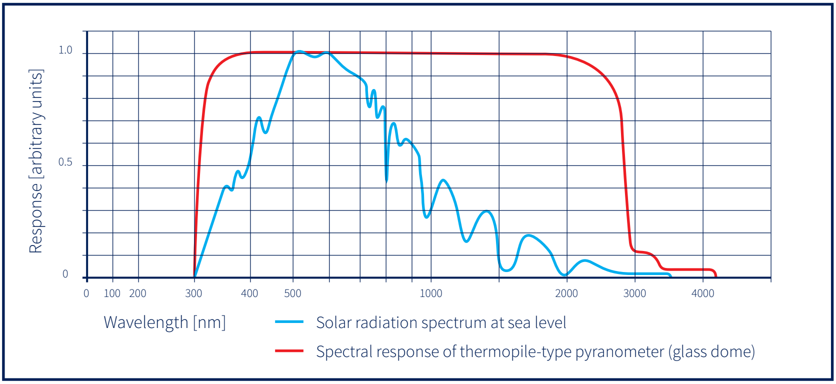


The directional response may also vary depending on the azimuth angle of the incident radiation. This is largely due to variations in the concentricity of the dome inner and outer surfaces, inner and outer dome positions, and the centre of the detector.

Directional error is quoted in W/m^2 with reference to a direct irradiance of 1,000 W/m^2. Cosine error is usually given as a percentage.

Spectral Range

The spectrum of the solar radiation reaching the Earth's surface is in the wavelength range between 280 nm and 4000 nm, extending from the ultraviolet (UV) to the far infrared (FIR) and is shown in the graph below.



The black absorber of a thermoelectric sensor is equally sensitive over a very wide range of wavelengths, so the spectral range is largely defined by the optical characteristic of the protective domes and windows used. The response of a typical thermoelectric sensor with a glass dome is shown in the graph.

For other types of sensors the spectral range is defined not only by the domes and windows, but also by the type of detector, optical filters and diffusers.

Most manufacturers of quality solar radiation sensors define their spectral range by the 50% points. These are the low and high wavelengths at which the sensitivity of the instrument is reduced to 50% of the mean over most of the range. Some manufacturers specify spectral range at the limits of measurement (5% sensitivity or less), which seems more impressive but is not particularly useful.

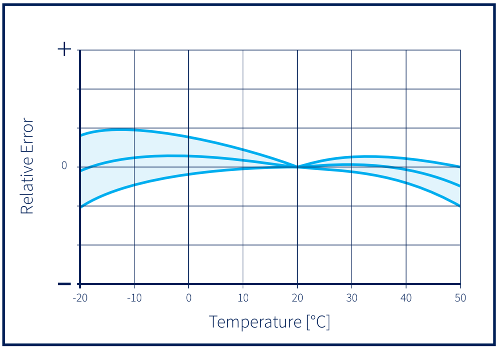
Spectral Selectivity

Spectral selectivity is the percentage deviation of a sensor's response over a specified wavelength range from its mean value over that range. For pyranometers and pyrheliometers ISO 9060 specifies the range as from 350 to 1,500 nm and is appropriate to glass domes and windows.

Temperature Response

The influence of relatively slow ambient temperature variations on the measurement results, where the sensor has time to reach equilibrium with its environment.

The temperature response of a sensor is normally kept to a minimum by its construction. This means that errors due to ambient temperature fluctuations stay within certain limits. However, at the margins of the defined temperature range the influence of temperature changes will increase and the effect may be non-linear.



Low end solar radiation sensors do not normally have any internal correction for this temperature dependency of the sensitivity. Higher performance sensors usually have internal compensation circuitry (active or passive).

The best sensors also have the output of an internal temperature sensor available and individual temperature response data measured during calibration. This enables the user to post-correct the data for the highest accuracy.

Tilt Response

The dependency of the measuring sensitivity and/or the zero point of a sensor on the tilt angle referred to a horizontal surface. For solar radiation sensors this is normally the deviation from the sensitivity at 0° tilt (exactly horizontal) over the range up to 90° (vertical) under 1000 W/m^2 of normal incidence irradiance.

Tilt response mainly applies to thermoelectric sensors and the deviation is caused by changes in convection effects over the black absorber surface compared with the horizontal calibration position. The error could be corrected for in applications where it is necessary to install the pyranometer on an inclined surface, but is usually insignificant.

Field of View

This is the included angle of a cone, centred on the sensor, within which it can receive and measure radiation. This is typically 5° for a pyrheliometer measuring direct solar radiation and 180° (a hemisphere) for a pyranometer.

The field of view for other types of instrument may depend upon the application or accepted standards and conventions.

Resolution

Resolution is the smallest change of a parameter that can be measured by a sensor. Most solar radiation sensors have analogue outputs directly from the detector. Resolution is usually limited by the performance of the rest of the measurement chain and electrical noise in the environment, which can be minimised by careful shielding of cables and grounding of sensors.

Zero Offsets

Thermoelectric solar radiation sensors have zero offsets that are a result of their measuring principle. Other types of sensor do not experience these effects.

Due to their thermal mass, thermoelectric sensors take time to reach equilibrium with their environment after rapid temperature changes, for example caused by wind or evaporative cooling. During this period an offset in the measurement will occur.

This 'Zero Offset Type B' is defined by ISO 9060 as the offset in W/m^2 caused by a temperature change of 5 K per hour. This is the rate that can occur on the morning of a fine sunny day.

The other main offset, 'Zero Offset Type A' affects pyranometers and is caused largely by differences between the temperature of the sensor and the sky above. For example, if the sensor housing is at +30 °C and a cold clear sky is at -10 °C, the output of the sensor is the net radiation exchange between the sensor and the sky, largely through the domes. This exchange is 200 W/m^2 and there is a small negative offset within the measured radiation value.

Zero Offset A is specified by ISO 9060 in W/m^2 for 200 W/m^2 of net thermal (far infrared) radiation. In general, thermal offsets can be reduced by applying ventilation and heating to the sensor to stabilise the effects.

There are also circumstances where the direct solar radiation can cause offsets due to differential heating of parts of the sensor, for example in pyrgeometers where the silicon window or dome blocks much of the short-wave radiation by absorption. The silicon therefore heats up and radiates a 'false' far infrared radiation to the thermoelectric detector, causing an offset.

For this reason, all pyrgeometers on the market, except the Kipp & Zonen CGR4 model, require shading from direct solar radiation which causes thermal dome or window offsets.

Sensors with built-in amplification, or other electronics, may have an inherent zero offset in their outputs resulting from their circuitry.

13. Pyranometers

Pyranometers are, as defined by international standard ISO 9060, instruments for the measurement of hemispherical (global) solar radiation in a spectral range of 300 to 3,000 nm. This range also comprises part of the ultraviolet and infrared radiation.

Temperature, air pressure, wind speed and direction, humidity and quantity of rain are the most frequently measured meteorological values, but they are mainly dependent on the radiation reaching our atmosphere and the earth's surface.

Pyranometers are widely used for meteorological and climatology measurements and are becoming increasingly common as a standard component of automatic weather stations (AWS). They are also used in hydrology, environmental and materials testing, greenhouse control, building automation and are essential to solar energy applications.

figure 21: pyranometer with sun screen

Accurate and, above all, widely comparable measuring values are of the utmost importance in order to be able to analyse data consistently world-wide. The reason why the sensor specifications are defined by the WMO and international standards is to achieve this world-wide comparability.

These specifications mean that, at present, the required data can only be acquired by using thermoelectric sensors with their almost flat non-selective spectral response.

Instruments not complying with these specifications cannot be classified as pyranometers and must use a different name, for example, the 'silicon pyranometer'.

The main pyranometer components are shown in figure 22.

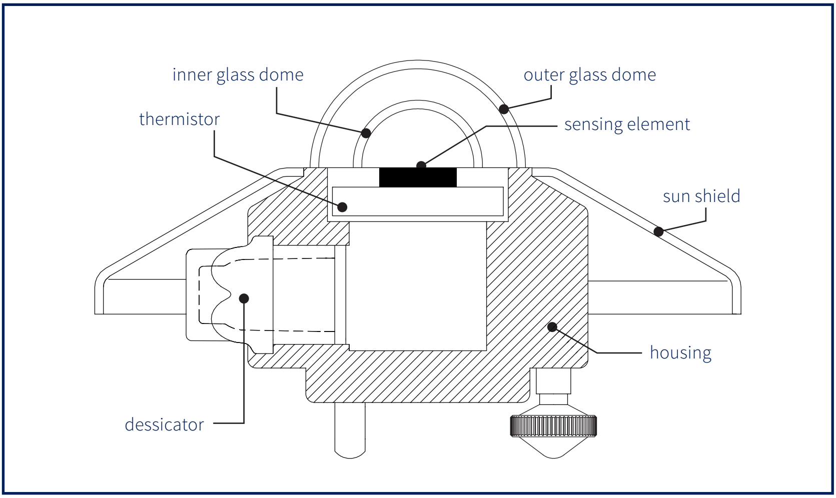


figure 22: pyranometer construction

Thermoelectric sensing element - the detector with black, or black and white, coating.

Hemispherical dome(s) - (one or two), protecting the receiver surface.

Housing - functions as the sensor thermal reference and is often protected by a removable white sun screen.

Desiccator - a container filed with a desiccant to keep the pyranometer dry internally, so that condensation cannot form on the detector surface or on the insides of the domes. The drying agent is normally self-indicating silica gel that changes colour when replacement is necessary. Some newer pyranometer designs have a sealed construction with a long-life internal desiccant to reduce maintenance, so that periodic inspection and replacement of the drying agent is not necessary

Thermistor - higher performance pyranometers usually have a thermistor fitted close to the detector cold junctions as part of an internal temperature compensation circuit. A second temperature sensor may be fitted to provide a signal that can be recorded externally.

Classification of Pyranometers

Pyranometers are classified by their accuracy such that there are scientific precision sensors as well as sensors for routine measurements. According to ISO (International Standards Organisation) 9060:1990 there are three categories, as shown in table 4:

Secondary Standard

First Class

Second Class

Pyranometer specification list

Ref. no.	Specification	Pyranometer category Secondary standard	 first class	 second class
1	Response time (time for 95% response)	< 15 s	< 30 s	< 60 s
2	Zero offsets response to 200 W/m² net thermal radiation response to 5 K/hr temperature change	< 7 W/m² < 2 W/m²	< 15 W/m² < 4 W/m²	< 30 W/m² < 8 W/m²
3a	Non-stability (percentage change in responsitivity per year)	< 0.8 %	< 1.5 %	< 3 %
3b	Non-linearity (due to change in irradiance within 100 to 1000 W/m²)	< 0.5 %	< 1 %	< 3 %
3c	Directional response	< 10 W/m²	< 20 W/m²	< 30 W/m²
3d	Spectral selectivity	< 3 %	< 5 %	< 10 %
3e	Temperature response	< 2 %	< 4 %	< 8 %
3f	Tilt response	< 0.5 %	< 2 %	< 5 %

table 4: ISO 9060:1990 pyranometer specifications

It should be borne in mind that these are the minimum performance requirements for each category and that many pyranometers exceed these.

Second Class and First Class pyranometers are designed for network field applications and routine monitoring with a balance of technical specifications and cost.

Secondary Standard instruments are normally used as reference standards in laboratories and institutes, in scientific monitoring stations for climate research and for solar energy applications. All are measurement areas where data of high accuracy is required.

Some of the pyranometers on the market, such as the Kipp & Zonen CMP22 with Quartz domes, significantly exceed the Secondary Standard performance requirements.

Sensors for calibration purposes should not be used in the field in order to preserve their performance and calibration accuracy.

There is no Primary Standard pyranometer. In effect this is the reference group of direct and diffuse solar radiation instruments at the World Radiation Centre in Davos, Switzerland; from which global radiation is derived.

Black Surface Thermoelectric Pyranometers

The basic design of a pyranometer can be seen from figure 22. It is for the measurement of global solar radiation with a field of view of almost a complete hemisphere. Global radiation consists of direct solar radiation and diffuse sky radiation and the electrical signal output should be proportional to the intensity.

The majority of available pyranometers transfer the radiation energy incident upon their black receiver surface into thermal energy by absorption. The special black coating has an absorption factor of nearly 1 over the whole spectral range.

This thermal energy causes a measurable rise of temperature. Thermoelectric sensors with blackened receiver surfaces usually meet the standards with regard to the spectral and directional requirements.

The temperature increase is normally determined by measuring the difference between the temperature of the receiver surface and that of a heat sink, for example the housing of the sensor.

Recording the temperature difference is usually done by a thermopile or a Peltier element (see figures 12 and 14). The thermopile contains a large number of thermocouples which are electrically connected in series or series-parallel. The Peltier element has a different construction, but the principle is similar.

The thermopile or Peltier element supports the homogeneous distribution of the 'hot' (active) junctions underneath the receiver surface, which leads to a constant measuring sensitivity over the measuring area. The 'cold' junctions are thermally connected to the sensor housing.

No power is required to operate a passive pyranometer; an output voltage is generated by the detector in proportion to the incident radiation. There are two output signal connections, typically designated 'high' and 'low' or '+' and '-'. The signal cable is normally provided with a shield (screen) which is connected to the sensor housing.

High quality pyranometers have internal passive temperature compensation components to correct for the changes in sensitivity of the sensing element with variations in ambient temperature.

Some pyranometers have the option of built-in amplification to suit data acquisition systems which cannot accept very low signal levels, or to work with long cables (greater than 100 m length).

The latest designs have internal analogue-to-digital conversion and microprocessors, which can perform more precise temperature correction and provide serial data communication over long distances.

Black & White Thermoelectric Pyranometers

Pyranometers with a black and white segmented surface are based on a different construction principle. The thermopile is arranged so that the ‘cold’ thermocouple junctions are positioned underneath the white segments and the ‘hot’ junctions are below the black portions. See figure 13.

The black segments absorb most of the incoming radiation energy whilst the white segments reflect most of the energy within the specified spectral range. Therefore, the black segments heat up more than the white segments. The differential output voltage of the thermopile then represents the amount of incoming radiation. In principle this design has lower thermal offsets than the all-black surface type of thermopile.

Black and white pyranometers have been on the market as First Class and Second Class instruments for many years, but there are no Secondary Standard sensors. This is mainly due to a specific characteristic, yellowing of the white segments, resulting in lesser long-term stability and making it necessary to recalibrate them more frequently. The manufacturers of these instruments sometimes recommend recalibration every 3 months, compared with 2 years or more for the all-black sensors.

Bolometric Pyranometers

The measurement of temperature differences by temperature-dependent resistors (the bolometric principle) can also be used for pyranometers. Two, measuring resistors are in thermal contact with a black measuring surface and two more are in contact with a heat-sink. These resistors are electrically connected to form a Wheatstone measuring bridge, with the output proportional to the temperature difference.

This type of pyranometer is not very common because it requires power, careful matching of the four measuring resistors, and usually has a long response time.

Features of Pyranometers

The thermoelectric principles described previously are the most common ones for pyranometers. However, the output voltage of the sensor is generated in relation to the temperature of the heat sink. Therefore, the ‘real’ value representing the incoming radiation is only reached when there is a thermal equilibrium of incoming and outgoing energy.

The receiver surfaces are covered by quartz or glass domes in order to protect them from external weather influences and dirt. The actual sensor element receives global radiation within a spectral range which is largely determined by the spectral transmittance of the dome(s) and the absorption factor of the receiver surface.

It should be noted that the dome also gets heated up by the incoming radiation and therefore emits thermal radiation towards the receiver which creates a ‘false’ signal, termed Zero Offset Type A. The detector surface would, in this case, receive more infrared radiation than coming in from the sun or sky.

Therefore, the higher accuracy pyranometers are equipped with two domes to reduce this effect. Furthermore, there is convection within the pyranometer measuring volume which may influence the performance when tilting the pyranometer from horizontal.

Silicon Photoelectric Pyranometers

‘Silicon Pyranometers’ with photodiode detectors are suitable for simpler measuring tasks and lower cost applications. They do not meet ISO classifications or WMO requirements with regard to spectral range and selectivity. However, under clear sky conditions and at high solar elevations the measurements can be close to those of Second Class thermoelectic pyranometers as specified in ISO 9060.

A diffuser is placed above the photodiode to provide good directional response to radiation from all angles. The sensor shown in figure 23 has a conical diffuser so that precipitation rolls off easily and it tends to be self-cleaning in rain. The construction is shown in figure 24.

figure 23: silicon pyranometer

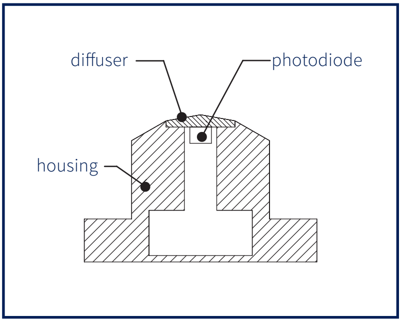


figure 24: silicon pyranometer construction

The typical spectral sensitivity of a silicon pyranometer can be seen in figure 25. It is sufficient for use in greenhouses and for similar applications involving the control of light and climate. Silicon pyranometers are also widely used with entry level agricultural and hydrological weather stations.

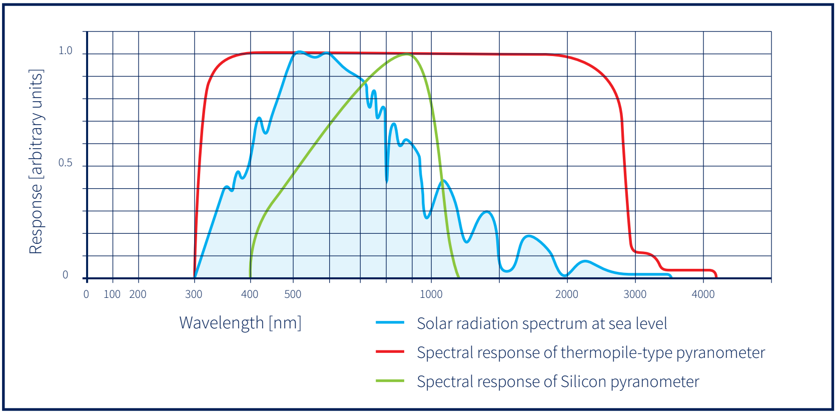


figure 25: silicon pyranometer (spectral response)

Calibration of Pyranometers

The objective of a calibration is to determine the relation between input value and output value of a sensor. Thermoelectric pyranometers are usually calibrated in W/m^2 and produce an output voltage in the region of 5 to 20 µV (microvolts) per W/m^2 of irradiance. The measuring range is usually up to 2,000 W/m^2 for natural sunlight and 4,000 W/m^2 for simulated solar radiation.

ISO (International Standards Organisation) 9846:1993 describes how to calibrate pyranometers using a reference pyrheliometer (usually an 'absolute cavity') under natural sunlight and with a clear sky. A 'sun and shade' method is employed.

It is assumed for that the global radiation, $Eg_{\downarrow}$, is composed of direct sun radiation, E, (with respect to the solar zenith angle, θ) and diffuse sky radiation, $Ed_{\downarrow}$. In principle the difference between the shaded and unshaded measurements of the pyranometer should equal the cosine-corrected direct measurement of the pyrheliometer.

$$Eg_{\downarrow} = E\cos\theta + Ed_{\downarrow}$$

The pyranometer to be calibrated is exposed to diffuse radiation (with a shading device) or global radiation, for predefined time periods whilst measurements are taken. The domes must be accurately shaded from direct radiation at all solar elevations to avoid thermal offsets, but not exclude part of the diffuse sky.

This calibration methodology requires fine weather conditions and a reference pyrheliometer and therefore is normally only done by institutes with the appropriate instrumentation.

Manufacturers of pyranometers prefer a calibration method independent of atmospheric and environmental conditions. Calibration is carried out in a laboratory by comparison to a reference pyranometer, as described in ISO 9847:1992 'Calibration of Field Pyranometers by Comparison to a Reference Pyranometer'. Annex A.3 refers to 'Calibration Devices Using Artificial Sources'.

For users with a large network of pyranometers it may be more cost and time effective to purchase their own calibration facility than to return instruments to the manufacturer every two years, with shipping and calibration costs and downtime. An example is shown in figure 26.

figure 26: calibration facility for pyranometers

Until recently, the light sources embodied Tungsten Halogen lamps but are now being replaced by metal-halide high-pressure gas discharge lamps. These have a spectrum that is a more realistic match to that of the sun and much lower infrared emission, so heating of the pyranometers is greatly reduced. Metal-halide lamps have a useful life of thousands of hours, compared to tens of hours for the Tungsten Halogen lamps.

The accuracy, stability and traceability of the reference pyranometer must meet certain requirements and it must be of the same generic type as the test pyranometer. The light source must be very stable and the physical arrangement of the calibration equipment must also meet specific requirements.

The procedure is normally carried out manually, but a large-scale manufacturer of pyranometers may have an automated system that carries out the procedure under computer control, stores the calibration data, and generates the calibration certificates.

The lamp is placed vertically above the pyranometers to provide an irradiance of approximately 500 W/m^2, about half the typical outdoor measurement range. A shade and unshade method is used to determine thermal zero offsets. The positions of the test and reference pyranometers are interchanged to take into account inhomogeneity in the light pattern. The lamp stability is monitored and the environmental conditions are kept constant.

The procedure is illustrated in figure 27 below.

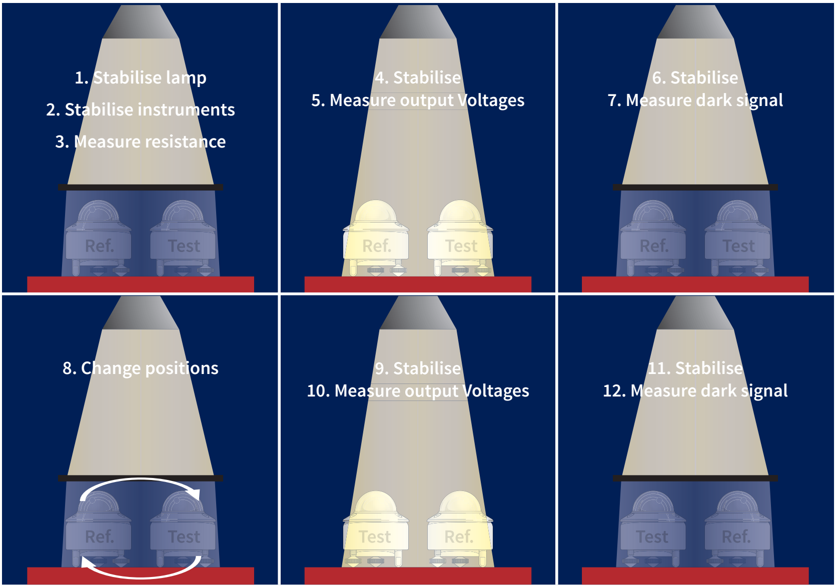


figure 27: illustration of ISO 9847:1992, A.3 calibration procedure

During this side-by-side comparison the sensitivity of the reference instrument is transferred to the test instrument. The sensitivity of the reference pyranometer must be recent and traceable to the World Radiometric Reference in Davos, Switzerland.

The calibration certificate should detail the full traceability, and the calculated uncertainties, of the calibration procedure.

External Influences

On clear, windless nights the outer dome temperature of pyranometers may decrease, even to the dew point temperature of the air. This is due to the infrared radiation emitted to the cold sky. In this case, dew, glazed frost or hoar frost can be deposited on the glass domes and remain there for several hours in the morning.

Such a frost cap on the dome is a strong diffuser and attenuator of light thus decreasing the output signal of the sensor drastically, by up to 50 %, during the first few hours after sunrise. In order to reduce this problem, or to melt snow deposits, ventilation units with heaters should be used.

The measurement of incoming solar radiation is strongly dependent on the angle of incidence of the direct beam; therefore pyranometers must be securely mounted to remain level in all environmental conditions. If the sensors are to be used on aircraft or ships it will be necessary to take the influences of roll and pitch into account when processing the data.

Electrical Connection

The signal cable is normally provided with a shield (screen) which is connected to the sensor housing. For maximum protection from lightning it is recommended to ground the sensor housing and not connect the shield to the data acquisition system ground.

However, often the pyranometer mounting is not grounded, in which case the cable shield should be grounded at the data acquisition system Protective Earth (not the 0 V input or power supply). This also reduces the pick-up of external electrical interference (noise) on the signal wires and is particularly important for instruments with internal electronics. In any case, it is strongly recommended to follow the instructions in the sensor product documentation.

In general, the maximum recommended signal cable length for an unamplified pyranometer is 100 m of high quality, low-loss cable. Refer to the manufacturer's information for maximum cable length. Extending the cable further may affect the sensitivity and other characteristics of the sensor.

The signal cable may also include wires for connection of an internal temperature sensor. This is usually a 10K thermistor or Pt-100 Platinum RTD. The most suitable type is usually determined by the input characteristics of the data acquisition system. However, for cable lengths of more than 25 m it is recommended to use a 4-wire Pt-100 configuration to avoid errors due to the cable resistance. Some pyranometers have the option of a built-in amplifier, or a microprocessor with serial data communication, so the cable may also have DC power connection wires.

On many sensors the output cable is held into the sensor housing by a compression gland fitting. However, these are difficult to make air-tight and not very convenient for installation, maintenance and exchange of sensors during recalibration. Therefore, plug and socket connections are becoming more popular for ease of use. These should be of high quality with gold-plated connections and suitable for all the expected operating environments.

The cable supplied with the pyranometer, or used to extend the supplied cable, must be of high quality, low resistance, stay flexible in very low temperatures and be resistant to UV radiation.

Usually, the internal connections to the thermopile detector cause a variation in the azimuth response of the sensor and these are arranged in-line with the signal cable position. The sensor is installed in such a way that the cable is pointing away from the equator. This minimises azimuth response errors and also prevents possible shadows from the cable and mounting devices.

Measurement of Diffuse Sky Radiation

As required by WMO and ISO, pyranometers are equipped with a field of view of 180° for the measurement of global radiation. They may also be used for the measurement of diffuse sky radiation when an appropriate shading device is used to prevent the direct radiation reaching the dome and the receiver surface.

Suitable for this purpose are manual and automatic shading devices. A shadow ring requires periodic manual adjustment of the zenith position every few days; whereas a two-axis automatic sun tracker requires no adjustment, but needs power and is more expensive.

A shadow ring, as shown in figure 28, has a pyranometer mounted horizontally in the centre and the ring. The ring position is adjusted every 2 or 3 days to allow for the changing angle of the solar arc (declination) so that the dome is completely shaded. It should not be over-shaded, which would exclude some of the diffuse sky radiation.

A table gives the adjustment position for latitude and time of year and also gives associated correction factors to allow for the significant part of the whole diffuse sky that is obscured by the ring.

figure 28: pyranometer mounted in a shadow ring

An automatic sun tracker is rarely used to measure diffuse radiation only. Typically it also has an unshaded pyranometer to measure global radiation and a pyrheliometer to measure direct radiation, and often a pyrgeometer to measure the downwards long-wave radiation; as shown in figure 29.

figure 29: automatic sun tracker with shaded pyranometer

Measuring Artificial Radiation Sources

Solar simulation using artificial radiation sources is becoming increasingly important within the areas of environmental measurement and material testing (see figure 30) and in solar energy. Pyranometers are particularly suited to monitoring the intensity and stability of the radiation, but should have temperature compensation because of the wide range of environmental test conditions.

figure 30: environmental testing

In addition 'accelerated testing' is often carried out, using much higher irradiances than occur naturally, up to 4,000 W/m^2. In addition, the temperature may vary from extreme cold to more than 120 °C. One manufacturer has developed a special pyranometer for this application with an operating range from -40 °C to +150 °C and temperature compensated, as shown in figure 31.

figure 31: high temperature pyranometer

14. Pyrheliometers

Pyrheliometers (sometimes called Normal Incidence Pyrheliometers) were originally designed to determine the solar constant. However, this is now done more accurately using satellite instruments operating outside the Earth's atmosphere.

As seen from the earth the sun has a solid angle of approximately 0.5° and according to WMO recommendations, a field of view of 5° and a slope angle of 1° have been determined as the optical configuration for pyrheliometers. Due to this angle, the sensor will detect not only the direct radiation but also part of the circumsolar radiation.

Circumsolar radiation is caused by diffraction of the sun's light due to the condition of the atmosphere, mostly aerosols, and is also influenced by the solar altitude. This is why it is necessary to standardise the aperture angle and other geometrical details in order to achieve comparability of the measuring results between different pyrheliometer types and makes.

Field pyrheliometers usually have a flat quartz window to protect the detector and fore-optic tube and to measure all the short-wave solar radiation in the range from 200 to 4,000 nm (4 µm). Some older instruments may have glass windows, and therefore a more restricted spectral range. There is usually some form of rain-shield to protect the window (see figure 32).

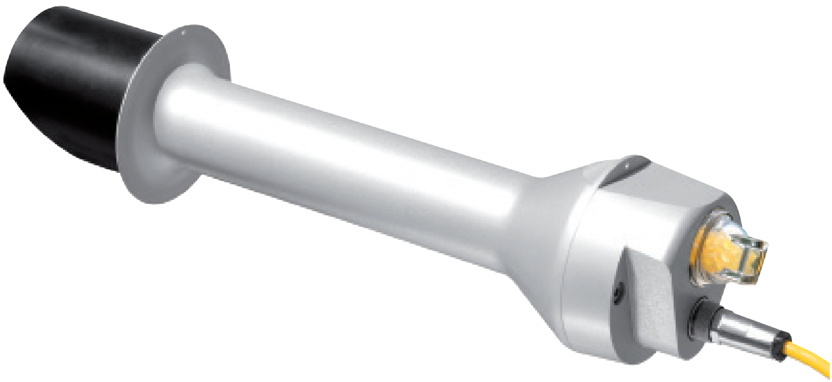


figure 32: pyrheliometer showing rain shield and alignment aids

The pyrheliometer must be aligned with the axis of the sun's direct beam to better than 0.1° and sighting alighting alignment aids are normally included for this purpose (see figures 32 and 34).

A pyrheliometer is normally installed on an automatic two-axis sun tracking system for continuous measurement of the direct solar irradiance as in figure 33.

figure 33: automatic sun tracker with pyrheliometers

Field pyrheliometers consist of the following main components, which are shown in figure 34:

Thermoelectric sensing element

Housing (tube)

Protective window

Aperture rings

Alignment aids

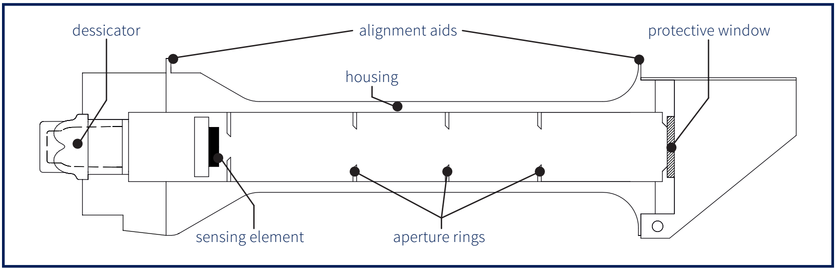


figure 34: pyrheliometer construction

In field pyrheliometers, the measurement is performed by an all-black thermoelectric detector similar to that used in pyranometers because high stability and non-selective radiation absorption over a wide spectral range are required.

The front opening, aperture rings and tube length are constructed in such a way that they define a field of view of 5° and the required 1° slope angle. The internal surfaces are blackened to prevent internal reflections. The fore-optic tube and detector are protected by the flat window previously mentioned.

Better performance pyrheliometers use a dual-tube construction. This is similar in principle to dual domes on a pyranometer and reduces the effects of wind and evaporative cooling on the measurements.

The electrical connection is the same as that for pyranometers. Similarly, the move is away from fixed signal cables to high quality connectors and there may be internal amplifiers or digital electronics. The pyrheliometer housing will probably not have a good ground connection through the sun tracker bearings and so the signal cable shield should be grounded at the data acquisition system Protective Earth.

As the direct solar radiation is a very important parameter the pyrheliometer should incorporate temperature compensation. Like most pyranometers, pyrheliometers have a desiccator to keep the instrument dry inside and prevent condensation.

The original types of pyrheliometer had no protective window so that they could capture all the energy available from the direct sun beam. Although not suitable for continuous unattended operation in all weathers, they can be more accurate than field pyrheliometers. This type of instrument is now termed an Absolute Cavity Radiometer (ACR).

The basic designs of modern black-body cavity pyrheliometers are similar in principle, with an arrangement of two cavities. The active cavity is exposed to the sun, whereas the passive cavity is used for compensation purposes.

The instruments are operating in a ‘chopped’ mode. The active cavity is exposed to sun and heats up. It is then shaded, usually by an electrically operated shutter. Whilst shaded, the temperature difference between the active and passive cavities is reduced to zero by electrically heating the passive cavity. The amount of electrical energy supplied is then directly equivalent to the incoming radiation.

Absolute Cavity Radiometers (ACR) are designed for the highest accuracy. This is mainly achieved through precisely made cavities and expensive electronics for the measuring and control technology, thus increasing the costs. Like other pyrheliometers, an ACR must be mounted on a two-axis automatic sun tracker.

Front aperture windows are not used because they would reduce the accuracy. As a result, an ACR is not suitable for all-weather unattended operation. The instruments are designed for scientific purposes in the fields of meteorology, climatology and solar energy and for the calibration of field pyrheliometers.

The PMO6-CC ACR is designed and manufactured by the Physikalisch-Meteorologisches Observatorium and World Radiation Center (PMOD/WRC) in Davos, Switzerland and is shown in figure 35, without the electronic control unit. This instrument can measure direct solar irradiance with an uncertainty in the region of 0.1 %.

figure 35: PMO6-CC absolute cavity radiometer by pmod/wrc

Classification of Pyrheliometers

As with pyranometers, pyrheliometers are classified by their accuracy such that there are scientific precision sensors as well as sensors for routine measurements. According to ISO (International Standards Organisation) 9060:1990 there are three categories of field pyrheliometer, as shown in table 5:

Secondary Standard

First Class

Second Class

It should be borne in mind that these are the minimum requirements for each category and many sensors exceed these.

Second Class pyrheliometers are rarely used because of their limited accuracy. First Class instruments are normally used for field network field applications and routine monitoring.

An Absolute Cavity Radiometer can be a Primary Standard, given sufficient history of stability and traceability to the WRR, otherwise it would be a Secondary Standard instrument.

An ACR is normally used as a reference for direct irradiance measurements in laboratories and institutes and for the calibration of field pyrheliometers.

Pyrheliometer specification list				
Ref. no.	Specification	Pyrheliometer category		
		Secondary standard	first class	second class
1	Response time (time for 95% response)	< 15 s	< 20 s	< 30 s
2	Zero offsets response to 5 K/hr temperature change	< 1 W/m²	< 3 W/m²	< 6 W/m²
3a	Non-stability (percentage change in responsitivity per year)	< 0.5 %	< 1 %	< 2 %
3b	Non-linearity (due to change in irradiance within 100 to 1000 W/m²)	< 0.2 %	< 0.5 %	< 2 %
3d	Spectral selectivity	< 0.5 %	< 1 %	< 5 %
3e	Temperature response	< 1 %	< 2 %	< 10 %
3f	Tilt response	< 0.2 %	< 0.5 %	< 2 %
4	Traceability (maintained by periodic comparison)	< 0.5 % with primary standard	< 2 % with secondary standard or better	< 5 % with first class or better

table 5: ISO 9060:1990 pyrheliometer specifications

The specifications are similar to those for pyranometers, except that Zero Offset A and Directional Response do not apply.

The Secondary Standard classification is assigned only to individual instruments calibrated against a Primary Standard, whereas First Class and Second Class classifications can also be generically assigned to series produced sensors.

Calibration of Pyrheliometers

The objective of a calibration is to determine the relation between input value and output value of a sensor. Like pyranometers, thermoelectric pyrheliometers are usually calibrated in W/m² and produce an output voltage in the region of 5 to 20 µV (microvolts) per W/m² of irradiance.

Absolute Cavity Radiometers have an electronic control unit with a digital interface for computer operation. The measuring range is up to at least 1,400 W/m².

ISO and WMO recommend a comparison with a higher class pyrheliometer under natural sunlight with a clear sky, meeting the following minimum meteorological requirements:

Radiation intensity higher than 700 W/m^2

Little water vapour

Low wind speed

Separation between sun and clouds of at least 20°

Averaging of at least 10 individual measurements

This is the method preferred by scientific researchers and the reference is usually a Primary Standard Absolute Cavity Radiometer.

As with pyranometers, manufacturers will always prefer a calibration method independent from direct sunlight and weather influences. This is where the calibration is done in a laboratory by comparison to a reference pyrheliometer of similar type to the test sensor, either traceable to a WRC calibration or calibrated directly by WRC on a regular basis.

In this case the calibration light source is a fixed collimated beam from a stabilised Xenon lamp that simulates the direct solar radiation beam. The reference and test pyrheliometers are interchanged in the beam to determine the sensitivity of the test sensor.

It is important that pyrheliometers are maintained and calibrated regularly and that their alignment is regularly checked on the sun tracker to minimise errors.

15. Pyrgeometers

As mentioned in a previous chapter, apart from the short-wave solar radiation emitted by the sun in the spectral range from below 300 to 3,000 nm (3 µm), long-wave thermal radiation is also an important factor at the earth's surface.

Every object which has a temperature above absolute zero (-273.15 °C or 0 Kelvin) emits radiation. The hotter the object the shorter the wavelengths emitted. When dealing with radiation as a result of a body's temperature it is more convenient to express temperature on the absolute Kelvin scale. The relation between Celsius and Kelvin is as follows:

Temperature in Kelvin [K] = Temperature in Celsius [°C] + 273.15

For example, the outer layer of the sun has a temperature of approximately 5770 Kelvin. As a result, the sun emits radiation which reaches the earth's surface with wavelengths as previously shown in figure 3. More than half this solar radiation is absorbed by the land and the oceans, which heat up.

The atmosphere also absorbs some of the sun's energy in discrete wavebands due to the properties of gases and aerosols such as water vapour, Ozone, Carbon Dioxide and Methane (see figure 36).

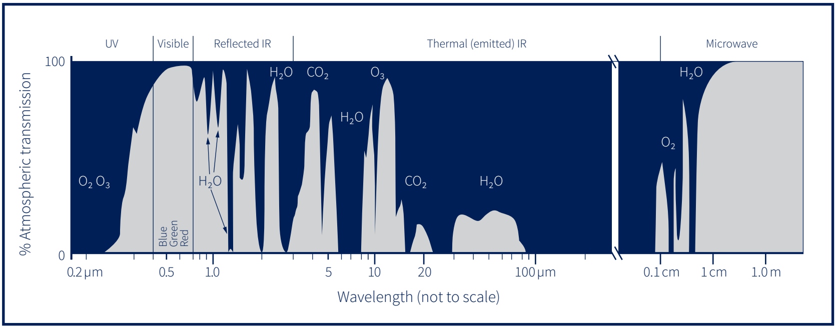


figure 36: absorption bands in the Earth's atmosphere

The earth's surface, the atmosphere and clouds are much cooler than the sun and emit much longer wavelengths, in the Far Infrared (FIR). There are also parts of the spectrum where there is little, or no, absorption and these are known as 'atmospheric windows'. One window is from approximately 3.0 to 4.5 μm, as illustrated in figure 36, and is the 'gap' in spectral measurement between glass dome pyranometers and pyrgeometers.

Pyrgeometers are sensors designed for the measurement of long-wave radiation on a plane surface. They have all-black thermoelectric detectors similar to those used in pyranometers and pyrheliometers. Their spectral range typically reaches from below 4.5 μm to beyond 40 μm. A very high quality pyrgeometer is shown in figure 37 and some of its special features are explained later in this section.

figure 37: pyrgeometer with meniscus dome

Pyrgeometers are used for measuring downward FIR from the sky and upward FIR from the earth's surface. In field measurements they produce an electrical output signal proportional to the net radiation. In effect this is the difference between the sky (looking up) or ground (looking down) temperature and the temperature of the pyrgeometer detector. See figure 38. All these emission sources are treated as being 'black body' radiators.

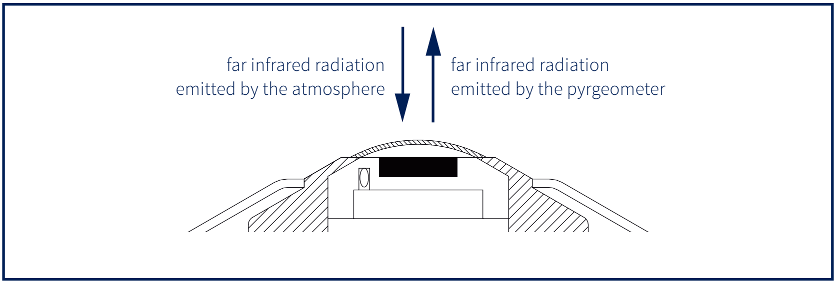


figure 38: atmosphere / pyrgeometer radiation exchange

Because the sensor is usually radiating energy towards a colder sky, the downward FIR signal output is normally negative. On the other hand, the ground is often closer in temperature to the instrument and the output could be positive or negative. The output of the sensor is the net irradiance. Typical values are from 0 to -150 W/m^2 for downward FIR and from -25 to + 25 W/m^2 for upward FIR.

The actual downward or upward irradiance can be calculated, as below, if the temperature of the detector (T in Kelvin) is known:

$$FIR\ (W/m^2) = Net\ FIR\ (W/m^2) + ((5.67 \times 10^{-8}\ W/m^2) \times T^4)$$

The electrical connection is the same as that for pyranometers. Similarly, the move is away from fixed signal cables to high quality connectors.

The signal cable also includes wires for connection of an internal temperature sensor, which must be fitted as standard. This is in addition to components that may be used for internal compensation of the sensor temperature dependence.

The temperature sensor is normally a 10K thermistor or Pt-100 Platinum RTD. The most suitable type is usually determined by the input characteristics of the data acquisition system. However, for cable lengths of more than 25 m it is recommended to use a 4-wire Pt-100 to avoid errors due to the cable resistance.

The housing temperature is monitored close to the cold junction of the thermopile detector and is used in the calculation to convert the net FIR value of the output signal into the actual downward or upward long-wave irradiances. This can be done by post-processing at a later date, or in real-time within the data acquisition system.

The latest versions of the pyrgeometer perform this calculation internally using a microprocessor and digital electronics, after applying the correction for the sensor temperature response.

Pyrgeometers consist of the following main components as shown in figure 39:
Thermoelectric sensing element
Housing
Protective window which blocks short-wave radiation
Temperature sensor for cold junctions of detector

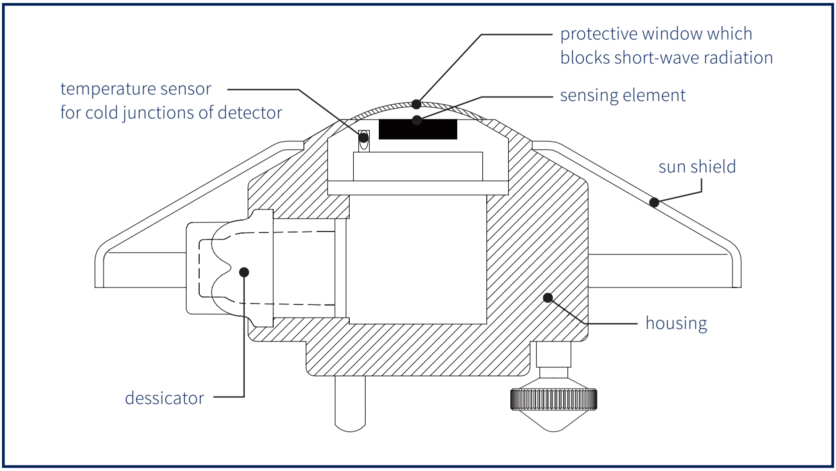


figure 39: pyrgeometer construction

Pyrgeometer technology is based on a silicon window which protects the detector surface. Silicon has good FIR transmission characteristics but also allows through a substantial amount of short-wave radiation. The crucial point about pyrgeometers is that only long-wave radiation should reach the sensor element. A ‘solar-blind’ optical interference filter is applied to the inner side of the window to block the short-wave radiation.

In lower cost pyrgeometers the window is flat, which is relatively inexpensive but limits the field of view to approximately 150°. Higher performance pyrgeometers use a dome to provide a 180° field of view. The dome may be hemispherical, but this is not actually necessary due to the high refractive index of silicon ‘bending’ the light.

The instrument shown in figure 37 uses a low profile meniscus dome and also has a very thin ‘hard-carbon’ (synthetic diamond) surface, which smooths ‘ripples’ in the FIR transmission at wavelengths beyond 20 μm.

A problem is heating of the silicon window or dome caused by absorption of short-wave radiation. This is seen as an offset by the detector. This can be partially corrected by measuring the dome temperature; so some pyrgeometers are equipped with one or more additional temperature sensors in order to make corrective calculations.

Normally it is recommended that pyrgeometers are shaded from the direct solar radiation by a shadow ring or automatic sun tracker to reduce the thermal offsets. However, the pyrgeometer shown in figure 37 has a unique construction with a dome of low thermal mass and a special method of rapidly conducting heat into the housing. This is so effective that there is no significant offset and it is not necessary to shade the dome.

The calibration of pyrgeometers is not simple because all the objects in the field of view have some FIR radiation emission. Calibration can be by comparison with a traceable ‘reference’ pyrgeometer using a ‘black-body’ calibration unit in a laboratory. However, a better calibration is by comparison outdoors under clear skies over a day and night period.

16. Net Radiation Sensors

The combination of short-wave radiation from the sun and long-wave (infrared) radiation from the atmosphere and ground are the driving forces for many of the dynamic atmospheric processes at the Earth's surface. In the short term they directly influence weather systems and in the long term they are key parameters driving the climate systems around the world.

Commonly four separate components are monitored; incoming and reflected short-wave solar radiation, plus downward and upward long-wave radiation. The sum of the incoming and outgoing components is called the net radiation balance (sometimes termed the 'radiation budget'). This balance is often used as a parameter in meteorological, climatological, hydrological and agricultural research.

Separate pyranometers and pyrgeometers can be used to measure these four radiation components, however, for many applications it is desirable that a single dedicated instrument is used. Such instruments are called net radiometers. An albedometer is a net radiometer designed to measure the two components of the net short-wave radiation.

Net Radiometer Configurations

Net radiometers exist in different configurations, depending on their application. The differences between net radiometer models depend upon the level of information that they are required to provide.

A one-component net radiometer is small, light and simple to install and is sensitive to the total solar and atmospheric radiation spectrum. There is a choice of different constructions on the market for this purpose.

Sensors equipped with polyethylene plastic domes are available. However, these are very thin and have poor resistance to mechanical influences (such as pecking birds, hail, etc.) are soft and difficult to clean and deteriorate with solar UV radiation.

Typically these soft domes need replacement every 3-6 months, and may need an air pump to maintain their shape in adverse conditions.

Because of these drawbacks, domeless types of net radiometer have appeared on the market as shown in figure 40. This light and robust construction can be found in many measuring facilities in the agricultural sector, for example to aid water management and optimise crop yields.

The instrument shown has a single thermoelectric detector. On one side the hot junctions are connected to a black absorber, on the other side the cold junctions are connected to another black absorber. In the sensor shown the absorbers are aluminium cones with a special black coating that does not need additional protection from the environment.

The single output is the temperature difference between the two sides of the detector and represents the net balance of short-wave and long-wave radiation.

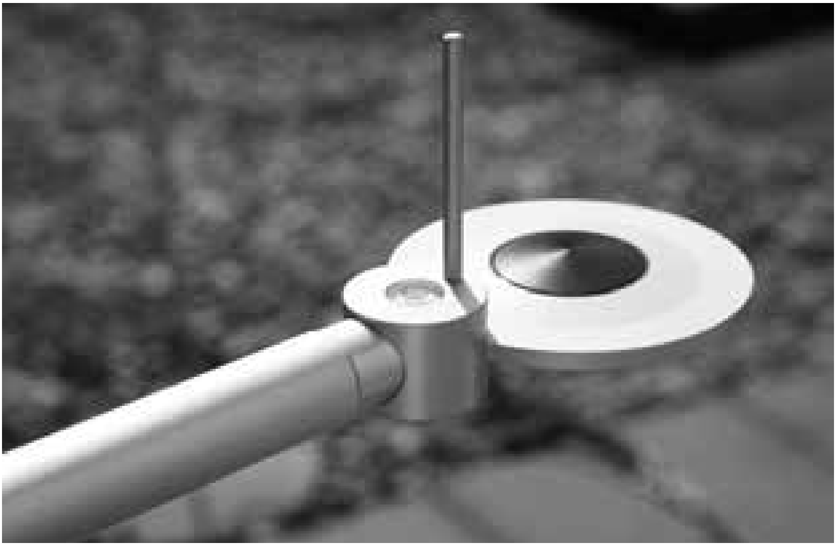


figure 40: one-component net radiometer

The measured values are affected to some extent by wind cooling of the absorbing surfaces, although this can be corrected given wind speed information, which is normally available at the same location.

When a distinction needs to be made between net short-wave and net long-wave radiation a two-component net radiometer is used. In this configuration there are two 'differential' thermoelectric detectors, providing two signal outputs.

One detector has upper and lower glass domes to measure net short-wave radiation. The other has upper and lower silicon windows with solar-blind coatings, to measure net long-wave radiation. An example is shown in figure 41.

figure 41: two-component net radiometer

Finally, all four parameters of the energy balance can be measured separately. The advantages of this type of instrument are that the incoming and outgoing short-wave and long-wave radiation are measured individually and the surface albedo can be calculated. Albedo is defined as the ratio between incoming and reflected short-wave solar radiation.

A light weight integrated four-component net radiometer is illustrated in figure 42. It consists of two pyranometers and two pyrgeometers in a single housing and a temperature sensor for the pyrgeometer compensation.

The instrument shown also has an integrated ventilation unit and heater to keep all four windows and domes free of frost and dew.

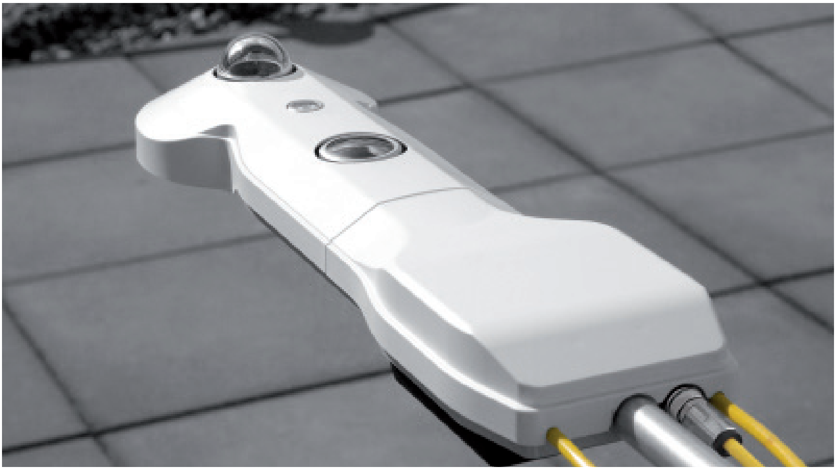


figure 42: four-component net radiometer with ventilation unit

A precision scientific net radiometer can be assembled from individual high performance pyranometers and pyrgeometers as shown in figure 43.

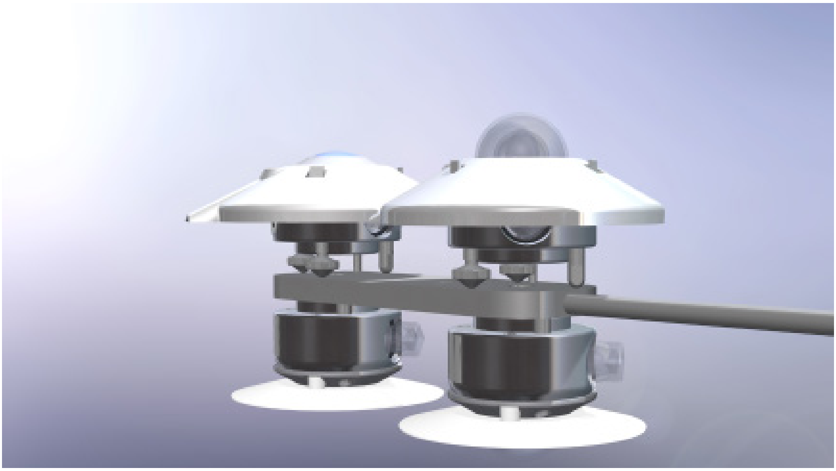


figure 43: four-component scientific net radiometer

Installation of Net Radiometers

In order to measure the surface net radiation components accurately, care must be taken over the method of installation.

Mounting the instrument in a horizontal position is important and this is aided by an integral spirit level. A fixed or detachable rod is often included to aid mounting.

Frequently net radiometers are installed on meteorological towers with additional instrumentation. In order not to obstruct the field of view of the radiometer's detectors, it is often necessary to install the instrument on an arm at a distance from the tower and other instruments.

Net radiometers are often used for field campaigns, mounted at remote sites on collapsible tripod stands. In these situations, low weight, compact, robust design and easy portability are necessary features. The mounting and support should be on the side of the pyranometer away from the equator to avoid casting shadows. Refer to figure 45 in the albedometer section.

The upward and downward facing sensors should ideally be of the same type and it is important that the downward facing sensors have a view of a surface that is representative of the area to be monitored.

The downward facing sensor(s) should also have a glare shield that prevents direct illumination of the domes at sunrise and sunset. Typically this blocks radiation from the 5° below the horizon and may be integrated into the design or a separate accessory, as in figure 43.

Calibration, connections and electrical characteristics are similar to those of individual pyranometers and pyrgeometers.

17. Albedometers

Within meteorology, the albedo is a measure of the reflection of short-wave solar radiation from a diffusely reflecting surface. This is normally from the ground but could be from clouds or the sea when viewed from above (for example from a satellite).

Fresh snow reflects approximately 75% to 95% of short-wave solar radiation whereas short grass typically reflects only about 15%. This corresponds to albedos of 0.75 to 0.95 and 0.15, respectively.

The incoming short-wave global solar irradiance in W/m^2 (Eg↓) is measured by an upward facing pyranometer. The reflected solar irradiance in W/m^2 (Er↑) is measured by a horizontally mounted downward-facing pyranometer. The two pyranometers should be of the same type and the downward unit should be fitted with a glare screen that prevents direct illumination of the domes at sunrise and sunset. Albedo is calculated as A = Er↑ / Eg↓.

An albedometer is a specific form of net radiometer which consists of two identical pyranometers in a single housing with an integrated glare screen and a mounting rod, as in figure 44. These are convenient and easily portable for field experiments.

The surface underneath the sensor can vary enormously. In order to achieve comparable values from different measuring locations it was determined by experiment (e.g. in the WMO guidelines), that albedometers should be installed at a height of 1.5 to 2 meters above short grass and other relatively level surfaces.

For validating satellite data it may be necessary to install at a greater height, so that the surface area viewed by the downwards pyranometer approximates to that of the pixel area of the satellite instrument.

It is important that the mounting construction and other parts do not obstruct the sensors' fields of view, thus distorting the measured values. Necessary support elements and cables should always point to the nearest pole, as shown in figure 45, in order to minimise the casting of shadows onto the sensors. It is possible to calculate the proportion of the field of view that is obscured and to make a correction to the recorded irradiance values.

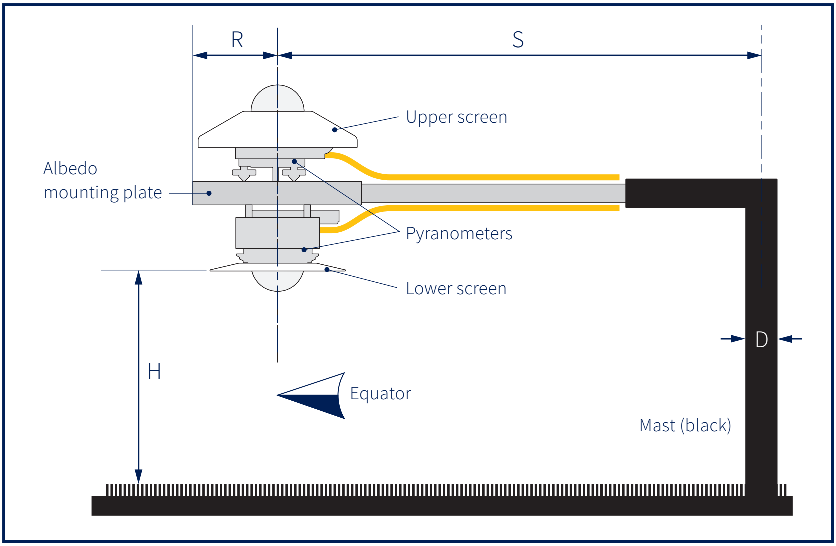


figure 45: mounting an albedometer

The mast shown always intercepts a fraction $D/2\pi S$ of the radiation that is coming from the ground. In the most unfavourable situation, with the sun at zenith, the shadow of the pyranometer/albedometer decreases the signal by a factor R^2/H^2.

18. UV Sensors

Ultraviolet is part of the spectrum of electromagnetic radiation being emitted by the sun. The solar radiation reaching the earth's atmosphere consists of approximately:

50 % visible light (VIS)

40 % near infrared radiation (NIR)

10 % ultraviolet radiation (UV)

The UV radiation consists of:

UVA - 315 to 400 nm, most of which reaches the ground

UVB - 280 to 315 nm, 90% is absorbed by the atmosphere

UVC - 100 to 280 nm, completely absorbed by the atmosphere

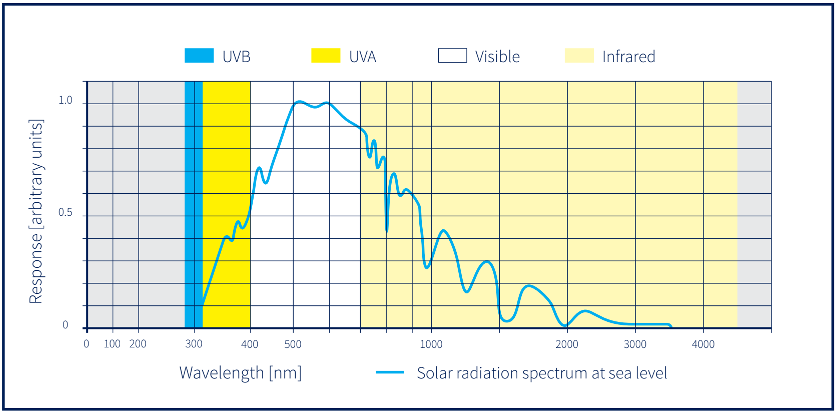


figure 46: solar radiation at sea level

WMO and WHO (the World Health Organisation) define the boundary between UVA and UVB as 315 nm. However, some organisations, particularly in the USA, previously used a boundary definition of 320 nm. This makes a significant difference to the amount of UVB measured and must be taken into account when comparing data from different published information and from different UV sensors.

In the past there have been a number of units of measurement for UV radiation. One commonly used was Minimum Erythemal Dose (MED). Nowadays, UV irradiance should always be measured in W/m^2.

For some applications it is only necessary to monitor the 'Total UV' irradiance, which represents the combined UVA and UVB components. This is most commonly monitored in meteorology stations as an extension to the solar radiation monitoring by pyranometers. It is also used for checking the UV output of light sources and solar simulators and the response of PV materials in renewable energy research.

For many applications, exact information on the proportion of UVA and UVB radiation within the solar spectrum is very important, for example:

Climatology	Determining properties of the ozone layers
Agriculture	UV stress on fauna and flora
Material testing	UV resistance
Public health	UV exposure (dermatology/sunburn)

UV radiation emits more photonic energy than visible light and infrared radiation, thus having a much stronger influence on materials, flora, fauna and people. Shorter wave UVB radiation has more energy per photon than the longer wave UVA radiation and is potentially more harmful.

Monitoring UV radiation is becoming more and more important, especially in view of the continuing changes to processes in the ozone layers of the atmosphere and the consequential effects on the environment and physical health.

However, measuring UV radiation is difficult as the amount of energy is very small compared to the amount of visible radiation reaching the earth at the same time. Further factors are the variations caused by dynamic changes in the ozone concentration of the atmosphere which increase with rising wavelengths in the range of 280 to 320 nm. UV radiation is also influenced by aerosols, clouds and the zenith angle of the sun (air mass).

The influence of surfaces causing multiple reflections, such as areas covered with snow, is also significant.

Climatology

UVB is only a small proportion of the UV energy from the sun reaching the earth's surface, but the amount is highly dependent upon the concentration of Ozone in the stratosphere. 'Holes in the Ozone layer', with large reductions in concentration of 25 % or more, are mainly confined to the North and South Poles. However, areas of up to 10 % Ozone depletion are spread more widely. They are indicators of the general health of the atmosphere, and a reduction in Ozone means that more harmful UV reaches the ground.

To determine the concentration of atmospheric Ozone (not ground level Ozone) the spectrum of the UV radiation from the sun is analysed using a spectrophotometer. These instruments are discussed later in this chapter. In fact, what is measured is 'Total Column Ozone' in the atmosphere between the instrument and the sun in Dobson Units (DU). The global average value is about 300 DU and the boundary of an Ozone hole is normally defined as 220 DU.

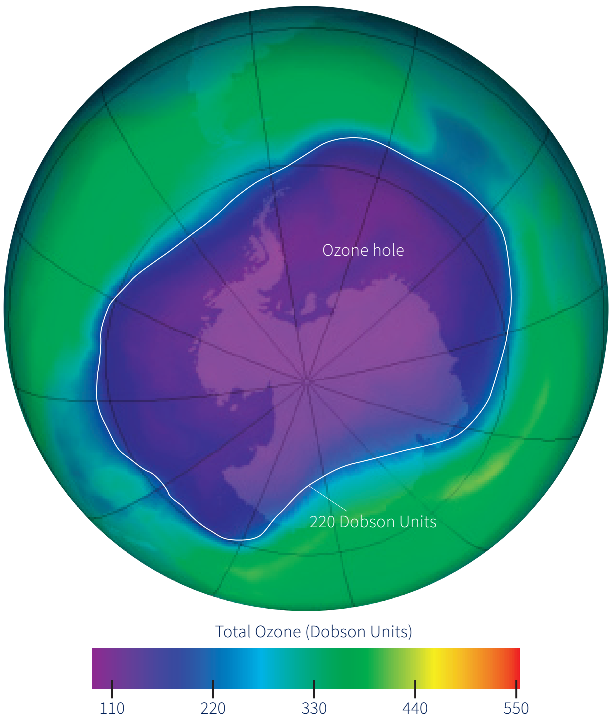


figure 47: ozone hole over Antarctica, 24 September 2006

A network of sophisticated instruments around the world provides information to the World Ozone and Ultraviolet Data Center (WOUDC), which is hosted for WMO by the Meteorological Service of Canada. This is part of the WMO Global Ozone Observing System (GO_3OS) and Global Atmosphere Watch (GAW) programmes. These programmes were launched specifically to monitor changes in the earth's atmosphere over several decades with a high level of accuracy.

Agriculture

UVA and UVB measurements are used to monitor and investigate the effects of solar UV radiation on plants and animals. Animals can suffer some of the same effects as humans, although usually at reduced levels because animals typically have a higher level of skin protection.

UVB particularly affects plant growth, leaf properties, chlorophyll production and crop yield. It can also cause DNA damage that leads to changes in future generations of the plant. There is evidence that increased levels of UVB also affect life in the upper 1-2 metres of the oceans including plankton growth.

Material Testing

In materials testing important issues are the ageing effects of outdoor UV exposure that cause degradation, such as brittleness and discolouration. Measurements are also carried out under controlled conditions in environmental test chambers using artificial UV light sources.

Infrared radiation heats up materials, resulting in softening, whereas visible light tends to cause colour changes and thermal stress. UV radiation causes decomposition, ageing embrittlement and colour changes in materials and also affects the adhesive strength of coatings and bonded joints.

One of the main tasks of material testing is to determine the protective factor of clothing and sun protection products for the human skin.

Public Health

UV radiation has some beneficial effects for people. Vitamin D is important for health and one of the main sources is production within the skin stimulated by UV radiation. UV also helps with skin conditions such as psoriasis and acne and promotes general health.

However, too much UV can burn the skin and cause cancers, melanoma, cataracts and DNA damage. UV radiation measured with a similar response to the human skin is termed Erythemally Active UV irradiance (UVE) and must be used to calculate the Global Solar UV Index (UVI) for public health information.

UVE is monitored for human biology and medical applications, where it is important that the measurement is similar to the erythemal response of the human skin. The data is often used to calculate the UV Index for public health information in weather reports. UVE is also measured in the development of cosmetics, sun blocks and creams, and protective materials for the skin.

The effects of solar UV radiation on human skin have gained increased importance over recent years. The earth's protective Ozone layer has become severely damaged over the last century due to human activity, mainly by chloro-fluoro-carbons (CFCs) released into the atmosphere. This reduces its effectiveness as a filter for UV radiation. Due to international conventions banning CFCs, and some other chemical compounds, the depletion has stabilised but will take decades to recover to 'normal' Ozone concentration levels.

UV intensity increases with altitude because there is less atmosphere to absorb it. Conversely, UV intensity decreases when the sun is low and there is more air mass for the radiation to pass through. UV is reflected well by high albedo surfaces such as snow and calm water, enhancing the effects.

The increase in UV at street level can also increase the amount of ground level Ozone, which can cause photo-chemical smog that is also detrimental to one's health. The balance of Ozone and UV radiation has therefore become of considerable interest.

With regard to the human skin it should be noted that the shorter wave, higher energy UVB radiation is absorbed by the epidermis (the outer layer) whereas the longer wave, lower energy UVA radiation encroaches on the deeper skin (dermis). UV radiation of wavelengths shorter than 300 nm is absorbed by normal window glass and much of the UVB radiation does not pass through.

UV-B radiation causes thickening of the epidermis. The radiation dose exceeding a certain limit will cause sunburn which will be followed by brown pigmentation of the skin by Melanin after two or three days. The Melanin is a reaction to protect the skin from further radiation damage.

A UVE radiometer has a spectral response function that is close to the erythemal (sunburn) action spectrum of the human skin. There have been a number of response functions used in the past. The currently accepted function is that proposed by McKinlay and Diffey in 1987 and adopted as the international standard ISO: 17166:1999 / CIE S 007/E-1998. This function covers the range from 250 to 400 nm and is shown with a logarithmic scale in figure 48.

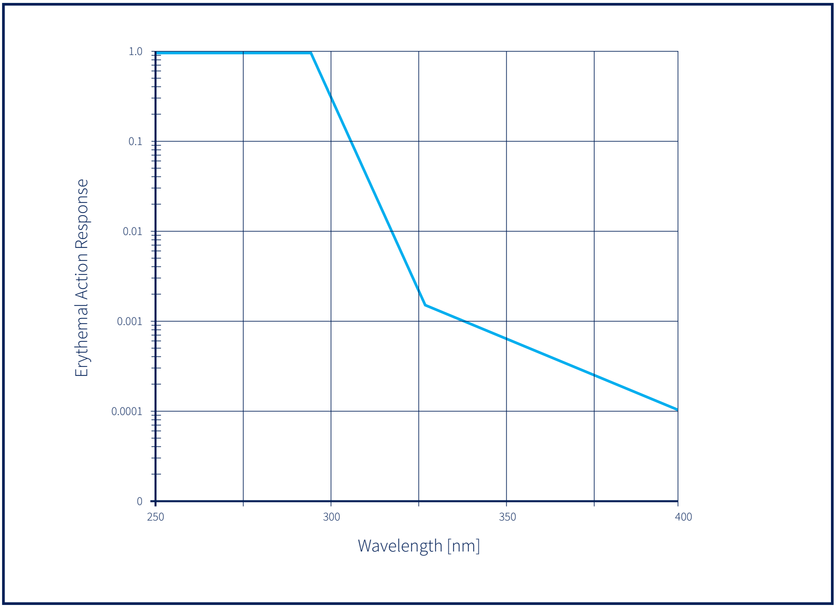


figure 48: erythemal action spectrum function, ISO: 17166:1999 / CIE S 007/E-1998

As can be seen from the spectral function graph, UVE includes some UVA radiation and a response towards the UVC band. For this reason a UVB radiometer should not be used to measure UVE and to calculate the Global Solar UV Index.

The Global Solar UV Index

In order to make it easier to understand the risk of UV exposure the Global Solar UV Index was created under the auspices of the United Nations, World Meteorological Organisation and World Health Organisation. This UV Index is composed of weighted measurement values (erythemal action spectrum as per ISO 17166:1999, CIE/S 007/E-1999) and describes the effects of UV radiation on the human skin, the exposure risk and the protective precautions to be taken depending upon the radiation intensity.

Today, the Global Solar UV Index (UVI) is internationally recognised as a standard for the evaluation of the sunburn risk and runs from UVI of 1 to UVI of 11+, where higher UVI represents higher risk of sunburn and skin damage. The scale is shown in table 6.

Exposure Category	UVI Range
Low	<2
Moderate	3 to 5
High	6 to 7
Very high	8 to 10
Extreme	11+

table 6: radiation exposure categories of Global Solar UV Index

As previously mentioned, UV irradiance is measured in W/m^2. The Global Solar UV Index can be calculated by multiplying the UVE radiation value by 40 m^2/W. For example, 0.25 W/m^2 of UVE represents a UVI of 10 and this is the value used for public health information.

Humans have to be exposed to the sun for quite a while to get sunburn. However, when the skin starts reddening it means that the maximum ultraviolet radiation dose for that skin has been exceeded. This may result in sunburn. The maximum dose depends upon the individual skin type which has been classified in six categories in the UV index, starting from the sensitive type (extremely light-skinned) to the dark-skinned type with natural protection. See table 7.

Skin Type Classification		Burns in the Sun	Tans After Having Been in the Sun
I II	Melano-compromised	Always Usually	Seldom Sometimes
III IV	Melano-competent	Sometimes Seldom	Usually Always
V VI	Melano-protected	Naturally brown skin Naturally black skin	

Because of the variation in the effect of UV radiation on the human skin depending on skin type, altitude, UV spectrum and any protection applied the quoting of 'burn times' is actively discouraged. People who have a tan already may stay in the sun about twice as long as people with no tan at all.

Note that the human skin can protect itself against UV radiation to a certain degree, but the human eye cannot. UV radiation on the human eye may lead to temporary 'snow-blindness', keratitis and even promote cataracts. Eye protection with full UVA and UVB absorption should be worn when necessary.

In general, UV monitoring has not been the historical interest or responsibility of meteorological organisations. As it is largely a public health issue it normally falls within the parameters of environmental protection or pollution monitoring authorities.

UV Sensor Types

Principally, there are three different types of sensors available for the measurement of UV-radiation:

Broadband Sensors often have a response that covers part of the UVA and UVB solar radiation spectrum and this is sometimes (inaccurately) called 'Total UV'. More specialised broadband sensors are designed to monitor specifically UVA, UVB or UVE (Erythemal) radiation and these are becoming the most widely used type of UV sensor.

Narrowband Sensors filter out only a certain very narrow part of the spectrum, normally at one UVA, and one UVB, wavelength defined by WMO. This type of sensor has lost popularity and has been replaced by broadband sensors because the measurements are not good representations of the UVA or UVB irradiance under a range of sky and atmosphere conditions.

Spectrophotometers measure the intensity of the radiation over a spectral range at a large number of discreet wavelengths.

UVA and UVB are the irradiance integrated over a 'rectangular' function between wavelength limits and UVE is a function with three slopes. These responses cannot be replicated by broadband sensors, resulting in a spectral mismatch and associated measurement errors.

However, the desired responses can be achieved by processing the measurement data from a UV spectrophotometer. These instruments provide the most information but are expensive.

Broadband 'Total UV' Sensors

Total UV sensors are mainly used in meteorology stations in addition to the solar radiation monitoring by pyranometers. They are also used for checking the UV output of artificial light sources and solar simulators.

Total UV is increasingly monitored in renewable energy research as the response of PV materials is pushed into the ultraviolet.

The use of Total UV sensors in the field of material testing is becoming more common, both under natural sunlight and in environmental test chambers. Nowadays materials, paints, adhesives, etc., that are destined for industries such as automotive engineering are subject to extensive testing procedures to find out how they degrade under UV radiation.

Because material testing with natural sunlight can take days, weeks or months, artificial radiation sources with a higher intensity and comparable spectrum are often used to achieve significant results in a much shorter period of time. This accelerated testing makes it possible to recognise the effects of UV radiation much earlier.

Total UV sensors use a photoelectric detector. This is normally a type of photodiode with an enhanced response in the ultraviolet. However, the response is far from flat and is further modified by the transmission characteristics of the diffuser material.

A specially designed thin-film optical filter between the diffuser and the photodiode is often used to try and achieve a combined measurement of UVA and UVB. It is not possible to achieve a ‘square’ spectral response from 280 to 400 nm, and therefore there is a considerable spectral mismatch, particularly in the UVB part of the spectrum. A typical construction is shown in figure 49.

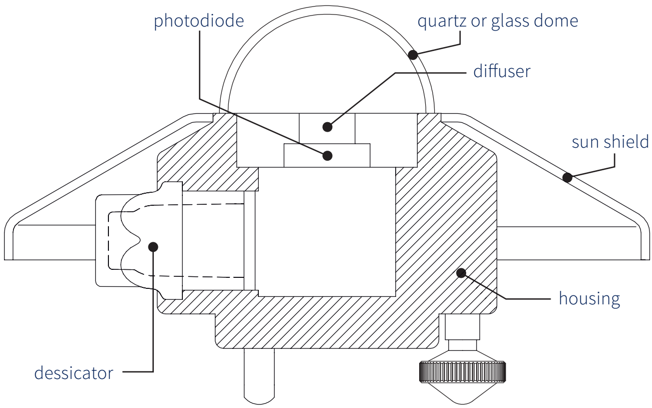


figure 49: total UV sensor construction

Total UV sensors consist of the following main components:

Photodiode sensing element

Housing

Diffuser

Protective quartz or glass dome for diffuser

The diffuser is designed to provide an equal response to UV radiation from all directions but it requires protection from dirt and environmental conditions. Therefore, a dome is fitted as shown in figure 50. In this case the sun shield is not necessary to reduce thermal effects as the detector is photoelectric, but it provides protection for the housing, cable connector and desiccator.

figure 50: a total UV sensor

The dome may be quartz, but because the spectral response of the detection system is limited in the UVB a glass with good UV transmission is often used to reduce costs.

Existing international calibration standards mainly apply to sensors used for monitoring exposure of workers to high levels of UV in industrial processes, such as curing adhesives. There are currently no international standards for the calibration of UV sensors used for environmental monitoring purposes.

Generally the measured output is a voltage signal corresponding to the UV radiation falling onto the sensor's diffuser surface. Since the calibration conditions may vary depending on the manufacturers' individual procedures, it is of utmost importance to pay attention to the manufacturer's calibration details and the spectral response stated in the sensor documentation.

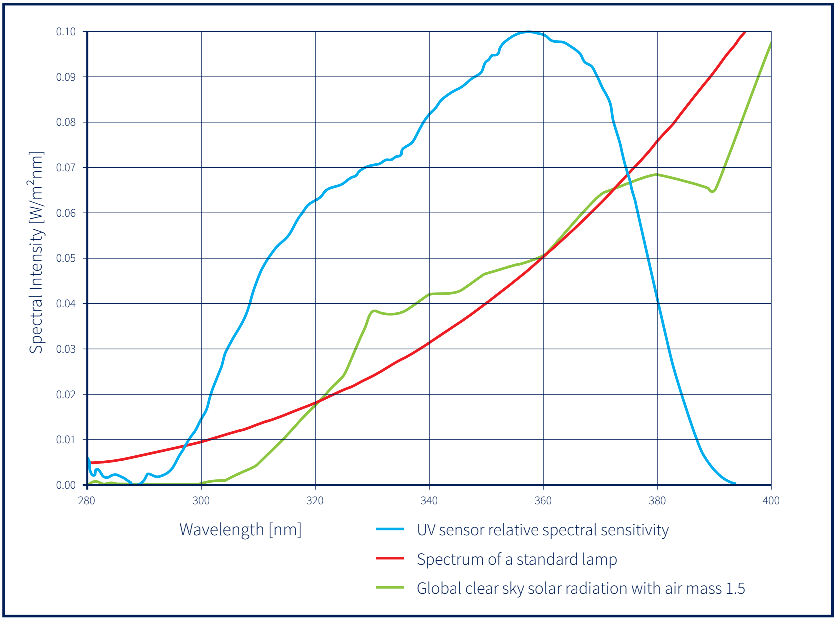


figure 51: typical total UV sensor spectral response

Data sheets normally quote the wavelengths at which the spectral sensitivity is 50% of the maximum. For the response shown in the blue curve of figure 51 the 50% points are 311 nm and 378 nm. Note that some manufacturers may only quote the 'complete' range, which in this case is approximately from 290 to 395 nm.

The UV spectrum received at ground level is significantly affected by clouds, aerosols, particulates, water vapour, gasses in the atmosphere (particularly Ozone) and the solar zenith angle.

However, this affects the UVB much more than the UVA. As the UVA irradiance is typically 15 times greater than the UVB irradiance under natural sunlight most of the spectral mismatch errors are masked in a Total UV sensor and can be reduced by careful calibration procedures.

The electrical circuit of a Total UV sensor is similar to that of a silicon pyranometer. The photodiode emits a voltage proportional to the incoming UV radiation. An electrical resistor (shunt) is connected in parallel with the photodiode. The current emitted by the photodiode causes a proportional voltage across the shunt. This voltage will then be available as the output signal.

Due to non-linearity of the detector response, sensors optimised for measuring natural solar radiation up to 100 W/m^2 are not suitable for high intensity artificial UV sources. However, the latest type using an internal microprocessor and digital electronics, can apply linearisation and temperature correction and is suitable for both applications.

Broadband UV Sensors with Specific Spectral Responses

For the measurement of solar UV radiation it is important to keep in mind that the average degree of scattering due to molecules (Raleigh Scattering) within the atmosphere is approximately 50%. When the sun is high in the sky the scattering is approximately 30%; but when it is only 10° above the horizon it reaches 88%. Therefore, the air mass must be taken into account.

Furthermore, it must not be forgotten that the spectrum of the diffuse UV radiation may differ from that of the direct UV radiation. A further aspect that must not be disregarded is the the effect of total column ozone absorption.

Without making appropriate corrections for the difference between the actual measurement conditions and the conditions under which the sensor was calibrated the errors in the measured values can be large, up to 30% for UVB and UVE.

For measurements with artificial UV radiation sources their spectral characteristics are relevant. Correction on the basis of their spectral data is recommended but is almost always less problematic than making atmospheric measurements.

Broadband sensors are designed to mimic the spectrum of UVA, UVB or UVE (Erythemal) solar radiation and these are becoming the most widely used type of UV sensor.

For providing Global Solar UV Index information only a broadband sensor with the erythemally correct spectral response (see figure 48) or a suitable spectrophotometer can be used.

In a common type of broadband sensor the UV radiation is converted to visible light by stimulating the emission of a fluorescent substance such as a phosphorus-based compound. The conversion into an electrical signal is performed by a photodiode of appropriate chromatic sensitivity. A filter is used to block visible light from entering the sensor.

The individual sensor models differ significantly in detail as the conversion is effected into different colour ranges within the visible light spectrum, depending on the design and make. The spectral response is determined by the characteristics of the fluorescent substance and supplementary optical filters.

The components that mainly determine the functional principle of the sensor are shown in figure 52.

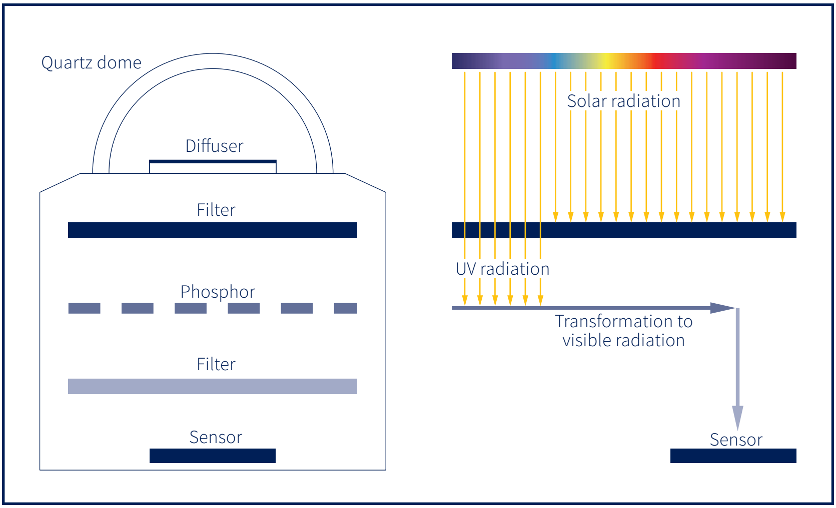


figure 52: conversion of UV radiation to visible light by a phosphor

The quartz dome provides good UV transmission, improves the directional response and protects the diffuser. The first filter(s) blocks visible light and partly determines the spectral response. The phosphor coats a substrate material and converts the received UV radiation into emitted visible light, usually green. A further filter blocks unwanted stray light from reaching the photodiode detector (sensor).

All these components contribute to the overall spectral response of the instrument.

The optical filters phosphor and photodiode are all temperature and humidity sensitive, so for the best performance these parts of the sensor must be controlled at a stable temperature and kept dry. Because outside power is required for this type of sensor there is usually a built-in signal amplifier.

The example shown in figure 53 also has an output to monitor the temperature control and is available in models to measure UVA, UVB or UVE radiation.

figure 53: UV sensor with specific spectral response (UVA, UVB or UVE)

A more recent alternative design does not use phosphors and employs a UV sensitive photodiode with optical interference filters to determine the spectral response. This type also requires temperature stabilisation for good measurement performance.

Broadband UV sensors change sensitivity and spectral response with time due to ageing effects of the spectrally sensitive components. Calibration is normally recommended yearly.

If the spectral response of a sensor is fully characterised during calibration, it is possible to generate a table of correction factors that can be applied to the measured UV irradiance values to correct for the effects of varying air mass and ozone column concentrations. This can improve the measurement accuracy by a factor of two.

Currently only one manufacturer of broadband UV sensors with individually characterised spectral responses provides this information, and the associated software to automatically apply the corrections.

Narrowband UV Sensors

These sensors measure at one very narrow part of the spectrum. This is typically 10 nm bandwidth at 368 nm in the UVA and 2 nm bandwidth at 306 nm in the UVB. However, this is not a good representation of the UVA or UVB irradiance under a range of sky and atmosphere conditions and this type of sensor is no longer in production. They have been replaced by broadband UV sensors.

UV Spectrophotometers

Spectrophotometers are optical instruments which determine the intensity of electromagnetic radiation with respect to its wavelength or frequency. They are used to determine and analyse the spectrum of radiation and to quantify gasses in the atmosphere.

The measured spectrum varies depending upon the individual field of application. The spectral range for atmospheric UV and total column ozone measurement is typically from 290 to 360 nm. The increment of the individual measuring points (spectral resolution) is also highly dependent on the area of application. The individual steps may be as small as 0.5 nm. Due to the functional principle of these instruments several minutes may be required to measure (scan) the whole spectral range, depending on the accuracy required.

Nowadays, the measurement of solar UV radiation is becoming more and more important, especially with respect to its effects on environmental conditions and human health. An additional factor is the increase of UV-B radiation during recent years due to the ozone depletion 'holes' in the stratosphere.

Spectrophotometers are used for special scientific issues such as the world-wide determination of UV and ozone values within the scope of the WMO Global Ozone Observing System (GO_3OS) programme and Global Atmosphere Watch (GAW). These WMO programmes were launched specifically to monitor changes in the earth's atmosphere over several decades with a high level of accuracy.

The Kipp & Zonen Brewer Mk III, shown in figure 54, is the only instrument in current production sanctioned by WMO for making total column ozone measurements.

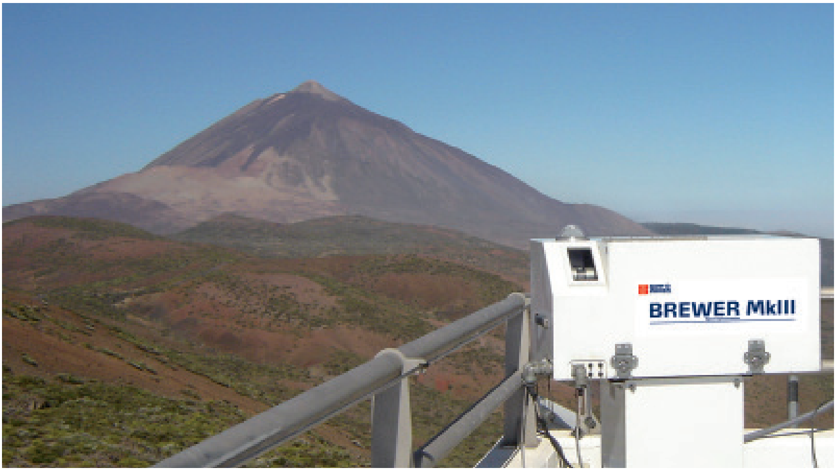


figure 54: the Brewer Mk III spectrophotometer

Especially noteworthy here is the amount of UVB radiation, as this part is the most biologically active and significantly influenced by atmospheric ozone. The erythemal effect on human skin is a key point in this regard. The most suitable instruments for these measurements are spectrophotometers because the measure data can be processed to exactly match UVB and UVE response functions.

However, the low energy of solar UVB radiation compared to that of the visible radiation makes it critical that the instrument filters out the visible radiation very effectively. Spectrophotometers best achieve this by using a double monochromator (two in series) as in the Brewer Mk III. The detector for the monochromator output is a high sensitivity photomultiplier tube.

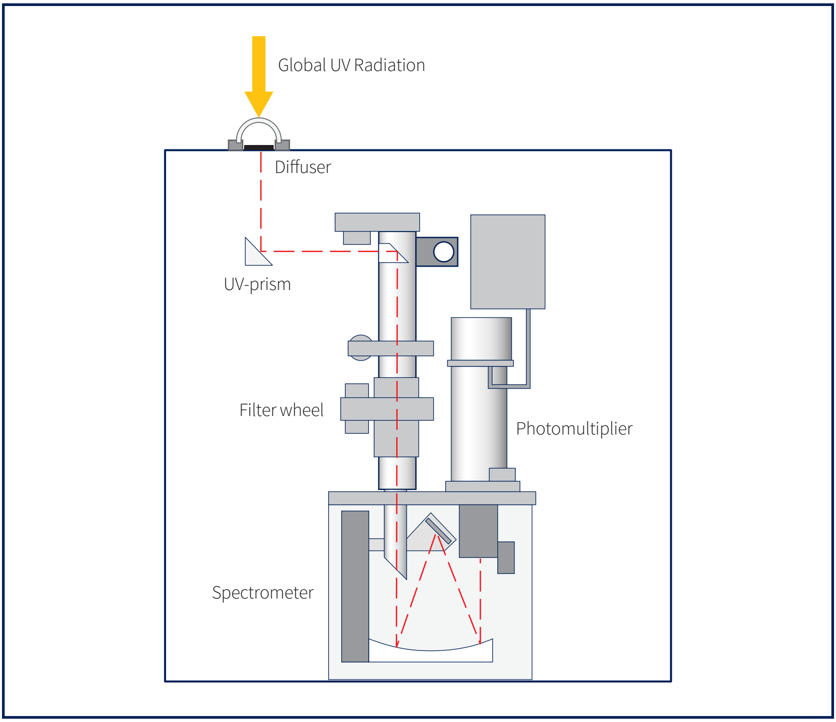


figure 55: Brewer spectrophotometer optical schematic

The Brewer has unique design of self-compensating monochromator that allows it to operate in a wide range of environmental conditions without temperature stabilisation. As shown in figure 55, there is a UV prism that rotates to different positions, enabling the instrument to receive radiation directly from the sun (via an integrated sun tracking system) from the whole sky, or from internal calibration lamps.

Spectrophotometers have a requirement for regular maintenance and service and it must be ensured that the monochromator still reaches the correct individual measuring frequencies. For better monitoring of the instruments and their functions internal reference radiation sources are used to enable regular testing of the stability.

The calibration procedure is quite complex because spectrophotometers are normally calibrated at the location where they have been installed for measuring. UV and ozone calibration in the field requires specialised equipment and a lot of expertise. Ozone is monitored by comparing the irradiance at a number of specific wavelengths.

A special problem in this regard is the radiation source for the calibration, usually the sun for ozone and an artificial source for UV. The solar radiation can be drastically influenced by the changing condition of the atmosphere and the artificial source by its own spectrum, which always differs from that of the sun and in addition has a limited lifetime.

Due to the complexity of the spectrophotometers it is important to thoroughly observe the manufacturers' instructions for maintenance. Calibrations are normally performed by either the manufacturer or an authorised subcontractor.

Less sophisticated 'solid state' instruments without moving parts use a CCD or photodiode array as the detector, which measures the complete spectral range simultaneously. However, these instruments are usually intended for measurement in laboratories with artificial light sources. They do not have the stability, sensitivity or stray light rejection for measuring UVB and UVE accurately outdoors from sunlight.

19. Sunshine Duration Sensors

The parameters to be measured that have been discussed in previous chapters were all well-defined. But, when talking about sunshine, we make a subjective judgement as to whether it is sunny or not and this is difficult to decide with a partially obscured sun within a cloudy and diffuse sky.

The sunshine duration in hours has been measured for a long time by many meteorological institutes with a device specially developed for this purpose, the Campbell-Stokes sunshine recorder. This was invented by John Francis Campbell in 1853 and refined by Sir George Gabriel Stokes in 1879.

Solar radiation falls on a glass sphere and is focussed onto a strip of recording paper. If there is sufficient intensity the paper becomes burnt, leaving a marked trace. An example of the recorder is shown in figure 56.

figure 56: Campbell-Stokes sunshine recorder (image by Thies Clima, Göttingen, Germany)

The recording strip must be manually replaced each day and the position of the strip must be adjusted every few days as the solar arc in the sky changes. The sunshine duration for a day is determined by measuring the length of the burnt trace on the paper.

However, the relevant factor for this procedure is the threshold value at which the tracing starts. This value is supposed to coincide with the changeover point from the status 'not sunny' to the status 'sunny'. Although the simple construction seems to be ideal there are problems with consistency of the measurements from one location, or operator, to another.

The radiation intensity at which the paper strip starts to mark is highly dependent on the ambient humidity, temperature and the type of paper. Deciding whether the strip is burnt, or not, is also quite subjective and if it rains the recording is lost. Despite all these problems the Campbell-Stokes instrument has been used as a standard for many years and was made and sold by several manufacturers. It is still used in some countries today.

However, the instrument does not have an electrical output signal, and does not allow for automated real-time measurement or recording. It requires daily manual intervention and the data quality depends upon the environmental conditions. Many novel instruments were developed in the 19th century to reduce these operational problems, but most of them were quickly forgotten.

In the early 20th century a new concept was developed by the U.S. Weather Bureau that became known as the Marvin Sunshine Recorder and was used, mainly in North America, as a standard for many years. This instrument was successful but required experience and special expertise from the user, so Foster and Foskett (also of the U.S. Weather Bureau) developed a successor in 1953.

This instrument became known as the Foster Sunshine Switch and did have an electrical output. It was equipped with two selenium photocells, which were mounted in such a way that one of them was protected by a shadow ring and received only the diffuse radiation, whilst the other was exposed to the global radiation. Again this was almost exclusively used in the USA and Canada; the Campbell-Stokes remained the favourite in the rest of the world.

Upon the analysis of measurement data from many measuring stations with Campbell-Stokes sunshine recorders and comparison with pyrheliometers it turned out that the threshold value for ‘sunny’ was ranging between 70 W/m^2 and 280 W/m^2 of direct solar irradiance. This is an enormous range of 400% and clearly not a situation that could be allowed to continue.

In 1981 the value of 120 W/m^2 of direct solar irradiance was defined by the World Meteorological Organisation as the threshold value for ‘sunny’. Sunshine Duration refers to the time (usually in decimal hours) for which the irradiance is above this threshold.

Due to increasing labour costs; manual operation, interpretation and recording are no longer acceptable. In addition, instruments are required to be usable at exposed locations and under harsh environmental conditions.

Automatic Weather Stations (AWS) with modern communications, data networks and computer supported information systems require a real-time measurement and this has expedited the development of new concepts. However, long-term comparability of data across measuring systems remains a prerequisite.

Designs from several developers work with a shading method using rotating devices driven by motors and thus having moving components. However, the desire for measuring systems without moving parts is increasing because they provide long-term, reliable, operation with low maintenance.

For scientific purposes the direct solar radiation (and hence the sunshine duration) is normally measured very accurately, to within 1%, with a pyrheliometer mounted on an automatic sun tracker. A sunshine duration sensor is not a substitute for a pyrheliometer to measure direct solar irradiance.

Modern electronic sunshine duration sensors are relatively low cost and the best types provide a real-time sunny / not sunny signal with good reliability, but only a few reach the WMO target uncertainty of $< 10\%$ under all sky conditions. Most do not have an output of the direct irradiance value.

Sunshine duration measurement is often used by national and private weather networks to provide data on the amount of sunshine per day for tourist and resort information.

Figure 57 shows a sunshine duration sensor that is becoming the most commonly used type by weather networks in Europe and is often used to replace Campbell-Stokes instruments.

figure 57: sunshine duration sensor

This instrument was developed by Kipp & Zonen of the Netherlands and is equipped with three photodiode sensors fitted with diffusers and works according to a principle which can be described as follows, with reference to figure 58.

Photodiode D1 receives both the direct and the diffuse radiation. D2 and D3 are arranged and shaded in such a way that the one of them pointing away from the sun detects the diffuse radiation. The internal electronics identify the sensor (D2 or D3) with the smaller measuring signal as the diffuse radiation.

The electronics subtract the smaller signal of either D2 or D3 (diffuse radiation) from the signal of D1 (direct and diffuse radiation) to calculate the direct solar radiation. This is made available as a variable signal output and also controls a switch which changes state from 'low'/'not sunny' to 'high'/'sunny' when the threshold value of 120 W/m^2 is exceeded.

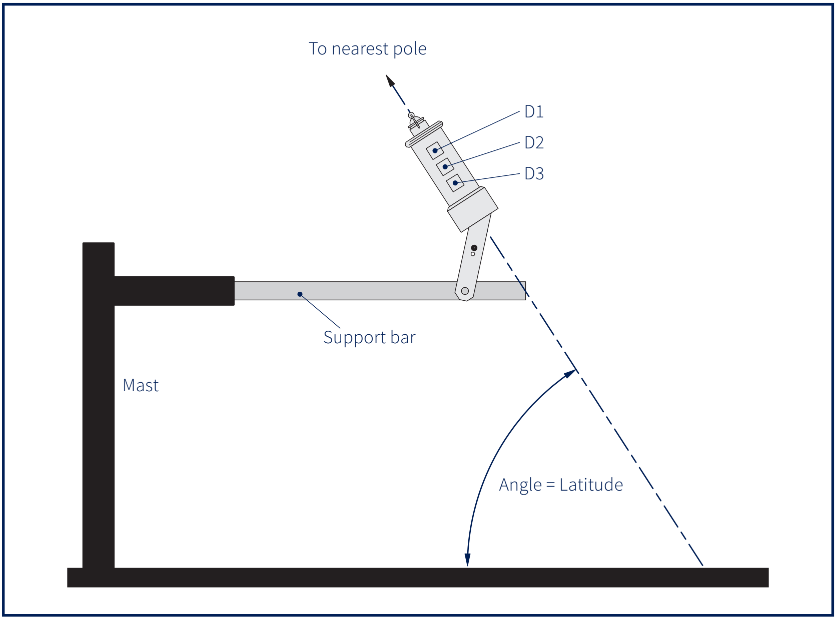


figure 58: sunshine duration sensor design & installation

The instrument is installed in a vertical plane and adjusted so that the tilt angle is the same as the angle of latitude at the installation location and pointing towards the nearest pole.

This sensor can be installed at any location on the globe and a built-in heater can be used to dissipate rain, dew and frost on the glass tube. The instrument must be installed at a location where direct solar radiation can reach it during the whole day without obstructions. An internal indicator shows when the desiccant requires replacement.

The adjustment and correction of the Campbell-Stokes instrument is rather difficult and has to be done regularly at short time intervals. For the original Foster Sunshine Switch four seasonal adjustments are necessary.

The Kipp & Zonen sunshine duration sensor does not need to be adjusted. The design ensures that the sun stays within the view of the detectors throughout the year and corrections are made to compensate for the fact that they do not see the whole sky.

20. Lux Sensors

All the previously mentioned sensors measure irradiance in W/m^2. However, solar radiation contains wavelengths not visible to the human eye and therefore the pyranometer or pyrheliometer output value does not represent the sense of brightness to a person.

The lux sensor is a photometer intended to mimic the human eye response and measures illuminance in accordance with the International Commission on Illumination (CIE) standards and recommendations. When the sensor is combined with a portable read-out device it is often called a Luxmeter.

The spectral sensitivity of the human eye is defined by the CIE ‘Standard Observer Curve’ for daylight conditions, from 400 to 700 nm with a peak at 550 nm, and is shown in figure 59. However, in reality most people’s eyes respond to wavelenghts of light up to 750 nm.

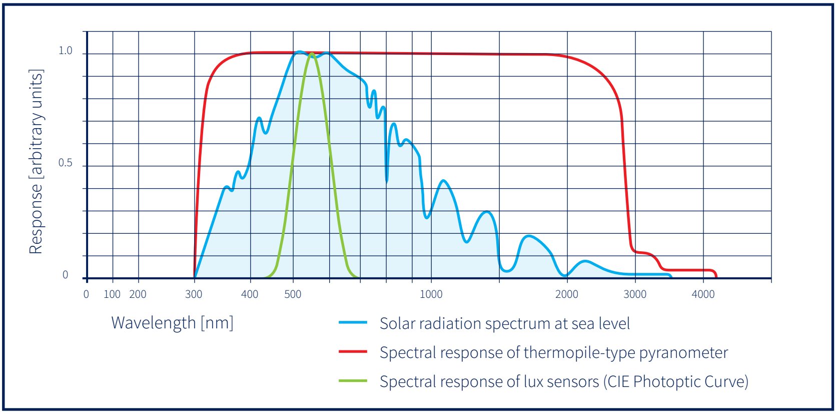


figure 59: Lux sensor spectral response

Lux sensors work according to the photoelectric principle. The detector elements used to be made of selenium but nowadays are silicon photodiodes. However, just a photodiode does not make a functional Lux sensor, as shown in figure 60.

A lux sensor consists of a diffuser for good directional response, optical filter(s) and photodiode detector. It is the combination of these components that determines the sensor's spectral response and the viewing angle of 180°.

Many lux sensors are low cost, low accuracy, units for indoor use in building automation systems to control internal lighting or to switch street lamps and other external illumination on and off at dusk / dawn.

The sensor shown in figure 60 is designed for long-term outside operation with an appropriately robust and resistant housing design, cable and levelling facility. It is intended for measurement of illuminance under all conditions to a good level of accuracy. Installation and connection is similar to a silicon pyranometer.

Lux sensors must be calibrated differently for artificial light sources as the colour temperature and spectrum of the lamp will differ from that of sunlight. A typical measurement range for natural sunlight outdoors is 0 to 100 klux.

figure 60: lux sensor by Skye Instruments

21. PAR Sensors

Exposure to light is essential for the growth of a plant. Under the influence of light from the sun, or from artificial sources, plants convert carbon dioxide and water into glucose and oxygen. This process is called Photosynthesis and occurs mainly under the influence of light in a number of discrete wavebands within the range between 400 nm (blue) and 700 nm (red). Light within this spectral region is referred to as Photosynthetically Active Radiation (PAR) and is measured by a PAR sensor, as shown in figure 61.

However, the PAR sensor's spectral response is different from that of a pyranometer or a Lux sensor and so is the unit of measurement. In the case of studying the effect that light has on plant growth it makes more sense to measure radiation in terms of a flux of light particles or photons.

The reason for this is that Photosynthesis is a chemical process driven by the absorption of light. Each molecule taking part in this process interacts with one absorbed photon. As a result the unit of measurement for PAR sensors is the number of photons per second per square meter, $\mu mol/s.m^2$. This measurement quantity is also referred to as the Photosynthetic Photon Flux (PPF).

figure 61: PAR sensor

Converting Between Radiometric and Photon Units

When converting radiation originally measured in W/m^2 into terms of micromoles one has to be careful because there is not a single conversion factor, which can be applied. Photons of higher frequency (shorter wavelength) have more energy than those of lower frequency (longer wavelength) and the conversion also depends on the spectral composition of the sunlight or artificial light source.

For example, if you would like to express solar radiation in terms of micromoles the following steps need to be taken:

1. Determine the solar radiation intensity at a certain wavelength, for example 1 W/m^2 at 400 nm

   $E_{solar} = 1\ W/m^2$

2. Divide this intensity by the energy of one micromole of photons with a wavelength of 400 nm

   $E_{\mu mol} = (h.c/\lambda)\ \mu mol$

Where:

$E_{\mu mol}$	Energy of 1 µmol of photons at wavelength λ		
h	Planck's constant	6.63×10^{-34}	[J.s]
c	Speed of light	2.99×10^{8}	[m/s]
λ	Wavelength		[m]
µmol	Number of photons	6.02×10^{17}	

3. The result, without showing all the numbers, is

   $E_{solar} / E_{\mu mol} = 3.3\ \mu mol/s.m^2$ at 400 nm wavelength

In order to convert the entire solar spectrum to micromoles these steps need to be repeated for every available wavelength. The end result of this process is shown in figure 62 for a typical global solar spectrum at sea level, where integrating the solar spectrum for both W/m^2 and µmol data yields approximately 1,000 W/m^2 and 6,500 µmol/s.m^2 respectively.

The difference between the irradiance and the photon flux in the PAR region can be clearly seen in the graphs.

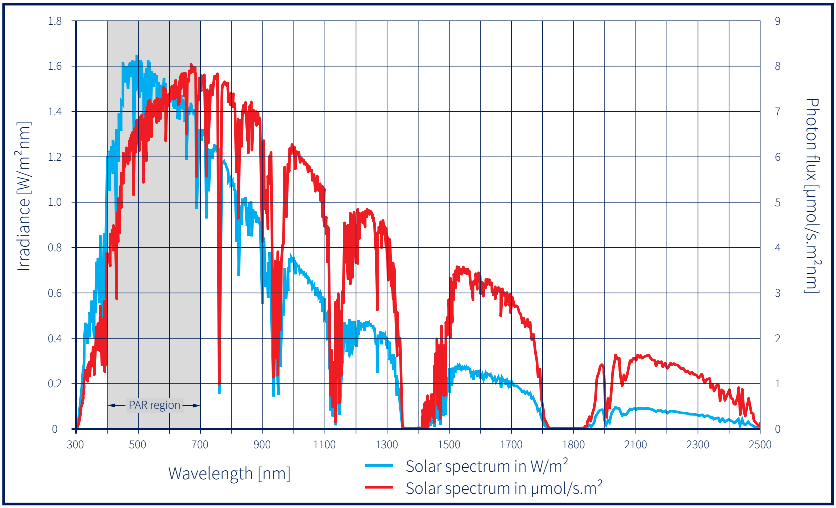


figure 62: typical solar spectrum in W/m² and μmol/s.m² per nm

Since only radiation with wavelengths between 400 and 700 nm is considered to take part in the photosynthesis process, integrating over this wavelength range yields approximately 430 W/m² and 1980 μmol/s.m² for the typical global solar spectrum at sea level.

This method can also be used to convert the output from artificial light sources into micromoles, if the emission spectrum of the source is known.

Response of a PAR Sensor

Since each photon interacts with one molecule a PAR sensor needs to have a response which has equal sensitivity for photons of all wavelengths in the 400 to 700 nm range. This is the quantum response and the instrument may be termed as a PAR Quantum Sensor. The quantum response is shown in figure 63 for a high quality PAR sensor.

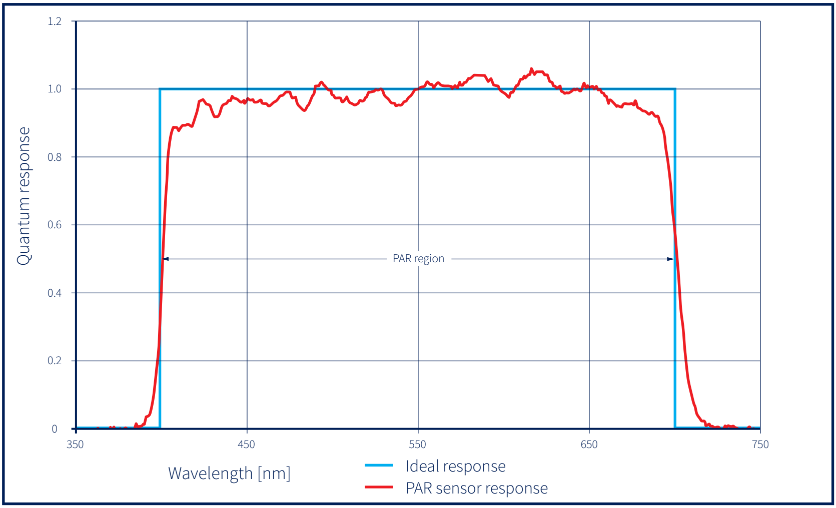


figure 63: PAR sensor quantum response

The quantum response should not be confused with the spectral response, which is tilted as shown in figure 64 because photons of shorter wavelength have higher energy.

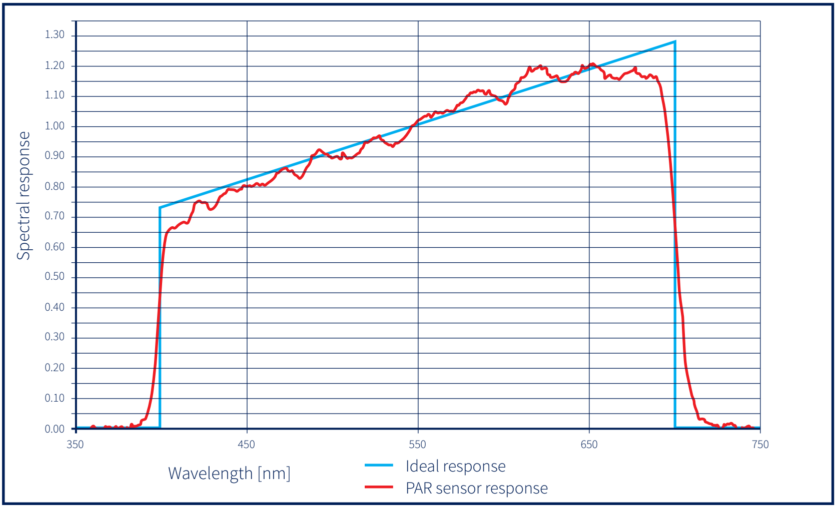


figure 64: PAR sensor spectral response

Construction of a PAR Sensor

The construction of a PAR sensor differs only slightly from that of a Lux sensor. Its diffuser and 180 ° angle of view are the same, but the optical filter(s) and photodiode detector are adapted to provide the desired spectral response.

A PAR sensor is normally used in agriculture and horticulture, both in fields and in greenhouses. In addition to high quality PAR radiation measurement durability is an important factor.

Especially in greenhouses conditions can be very harsh due to high temperature and humidity, artificial lighting, and possibly spraying with pesticides and/or fertilisers. For sensors to operate reliably they must be designed to resist the influences of these conditions.

The internal electrical circuit is identical to that of a Lux sensor, as shown in figure 65, with a shunt resistor across the photodiode.

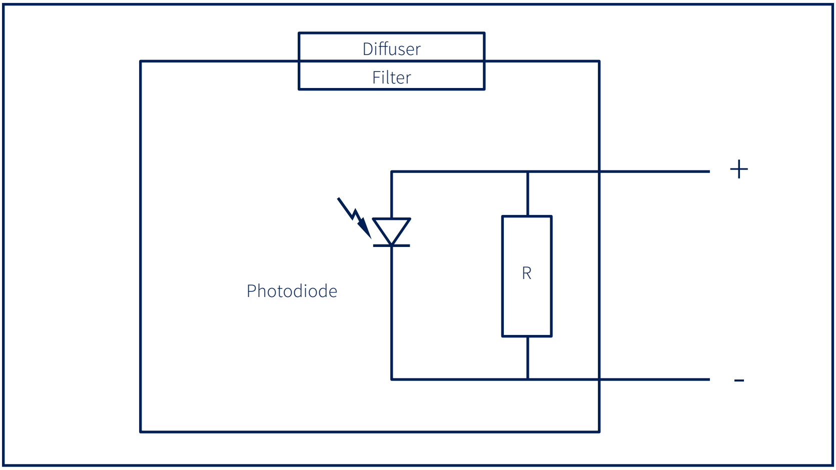


figure 65: schematic of PAR sensor construction

The sensor output is usually a millivolt signal, which is converted to a value in μmol/s.m^2 by applying a calibration factor.

22. Accessories for Sensors

Ventilation Unit

Sensors for solar radiation measurement have to be installed in such a location that they are easily accessible for maintenance and free from any obstructions that might affect their measuring function. However, they are exposed to all kinds of precipitation so that measuring errors may be caused by dew, frost, rain, snow or airborne dust, dirt and pollution.

This means that the domes will need regular cleaning to maintain full performance. For example it may be some hours after sunrise before due is evaporated from the dome and during this period the readings will be inaccurate.

Ventilation of radiometers improves the reliability and accuracy of the measurement by reducing dust, raindrops and dew on the dome, which would otherwise affect the measurement. The frequency of cleaning the domes can be reduced. Normally the fan is run continuously from a DC power supply. An example of a high flow ventilation unit fitted to a pyranometer is shown in figure 66.

figure 66: ventilation units fitted to pyranometers

As pyranometers and pyrgeometers generally have a view angle of 180° it is not easy to ventilate the domes consistently and ventilation units may differ considerably from each other depending on the design and make of the sensor for which they are intended.

It is important that the airstream passing the domes does not affect the sensors' measuring features adversely. A high performance ventilation unit is shown in figure 67.

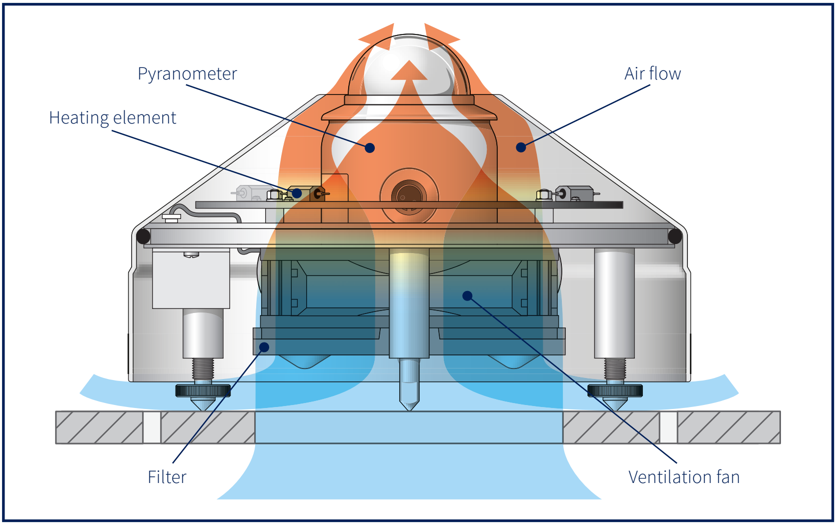


figure 67: ventilation unit construction

A radial fan sucks air through coarse and fine particulate filters and expels a flow of clean air with a slight overpressure (a few mBar). The air swirls inside the cover and exits as an unstable flow over the dome, so that there are no 'dead spots'.

Ventilation units may be equipped with DC heating elements that can be externally switched on that warm up the air to melt frost and snow on the domes. However, the warming must not be too extensive (not over + 1°C) in order to avoid heating up the domes and thus causing measuring errors. The heater power is usually in the range 5 to 10 W.

For thermopile-based instruments ventilation stabilises the temperature of the radiometer near to that of the ambient air and may reduce the thermal offsets which are produced by cooling down of the domes under calm clear sky conditions or by dome heating due to the absorption of solar radiation.

Ventilation units must, of course, be reliable and suitable for outside use in all conditions. They can be equipped with replaceable air filters that keep the air clean and the unit free from deposits. Some units have a pulse output that can be connected to the digital input of a data logger to monitor that the fan speed is correct.

Well-designed ventilation units considerably increase the time during which reliable measurements are available, especially during the early morning hours, and reduce the frequency of dome cleaning.

Shadow Ring

In order to measure the diffuse hemispherical solar radiation with a pyranometer it is necessary to intercept the direct radiation so that it does not reach the detector surface. This shading must be accurate for the course of the whole day without having to make adjustments and it should be applicable everywhere on earth.

For this purpose a pyranometer can be mounted inside a shadow ring that has adjustments to suit any latitude and longitude. The ring made with a special profile to provide an almost constant view angle during the whole year. To maintain optimum shading of the pyranometer as the course of the sun changes it is necessary to adjust the shadow ring every two or three days.

Shadow rings block the direct solar radiation, but also a portion of the diffuse sky, so it is necessary to compensate for this on a daily basis by using the correction tables provided by the manufacturer.

The alternative solution is to use a shading assembly on an automatic sun tracker, as described in a later section. This requires no adjustment or corrections to the readings, but is more expensive and requires power.

A typical shadow ring and its principle are shown in figures 68 and 69.

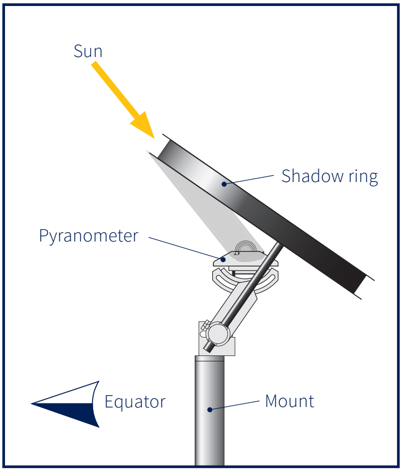


figure 68: shadow ring *figure 69: shadow ring principle*

Shadow ring at Penteli site, National Observatory of Athens, Greece

The following are design prerequisites for a shadow ring:

1. The axis of the shadow ring must be parallel to the axis of the earth; therefore the angle between the axis of the shadow ring and horizontal will be equal to the geographical latitude.
2. It must be possible to move the shadow ring along its axis so that the sun's declination can be tracked.
3. The pyranometer must be positioned in such a way that its receiver surface is horizontal and centred on the ring axis.

As the shadow ring is intended for continuous outside use a rugged design and a stable support are necessary to withstand extreme weather conditions. The mechanical alignment must be carried out thoroughly as instructed by the manufacturer and the north-south alignment must be absolutely accurate.

For the installation and adjustment of the shadow ring the True Solar Time has to be taken into account and it should not be forgotten that the sun is moving by 0.25° degrees per minute.

Sun Trackers

Pyranometers must be shaded to enable measuring of diffuse solar radiation; direct solar radiation must be blocked from reaching the detector. A shadow ring, as described in the previous section, requires manual adjustment very 2-3 days and corrections for the part of the diffuse sky obscured by the ring.

Pyrheliometers and other instruments for the measurement of direct solar radiation must be pointed accurately and continuously at the sun. The pointing accuracy must have a maximum deviation of 0.1° from the solar axis to meet WMO monitoring requirements.

The solution for continuous measurements of direct and diffuse solar radiation without the need for periodic adjustment or corrections is to mount the sensors on a two-axis automatic sun tracker as shown in figure 70. The sun tracker provides a stable mounting for the pyrheliometer and other radiometers and moves horizontally (azimuth) and vertically (zenith) to follow the solar arc.

figure 70: two-axis automatic sun tracker at the Solar Resource Assessment project in Chile by Pontificia Universidad Católica de Chile

Stepping motors controlled by a micro-processor drive through belts or gears to provide movement with the desired torque and accuracy. An on-board programme requires accurate longitude, latitude, altitude, date, and time information for the measurement site. Given this information the sun tracker can calculate the position of the sun throughout the day.

In older types of sun tracker the location and time information is entered manually; using a computer, setup software and a data communication link to the tracker. The most recent designs have an integrated GPS receiver that obtains and updates information automatically.

The pyrheliometer is mounted to the zenith axis of the sun tracker. An optional shading assembly blocks the direct solar radiation from reaching a pyranometer mounted on the tracker so that the diffuse solar radiation from the sky can be measured. An unshaded pyranometer is usually also fitted to measure the global radiation.

A pyrgeometer may be fitted for the measurement of downward far infrared radiation and this may also be shaded from direct short-wave radiation to reduce thermal offsets.

The 'solar monitoring station' shown in in figure 70 includes all the above sensors and shows the pyranometers and pyrgeometer fitted with ventilation units. A sun sensor is shown fitted below the pyrheliometer. A tripod stand with adjustable feet allows levelling of the tracker.

In order for the sun tracker to point the pyrheliometer accurately at the sun within 0.1° the mounting must be very stable and rugged and not move under severe weather conditions. If this is not possible, a sun sensor can be fitted to provide active feedback and correction to the sun tracking algorithm in the case of movement of the tracker mounting.

The shading assembly must be designed to maintain shading of pyranometers of ± 2.5°around the axis of the sun at all solar elevations from the horizon to directly overhead, to match the field of view of pyrheliometers. It must also be sufficiently rigid to resist high winds and severe weather.

A sun tracker for installation in the Antarctic needs to be more powerful and rugged than one for use in a temperate climate, whilst maintaining high accuracy. At night-time a sun tracker is not moving and in cold conditions ice may build up around it. This normally requires the high torque provided by reduction gear drives to break the ice when the tracker 'wakes up' before dawn.

The sun tracker must be suitable for the intended payload typically 10 to 15 kg, and the expected environmental operating conditions.

Some sun trackers have a ‘positioning mode’ whereby they have the capability to accept commands from an external computer to point in any desired direction for special purposes.

Single-axis sun trackers exist, but these are only suitable for use with a pyrheliometer and cannot be used for shading to make diffuse radiation measurements. The tracker rotates at a constant rate to follow the sun’s arc across the sky and this type is often referred to as a ‘clockwork’ sun tracker. Each day it requires resetting and the zenith angle must be changed to keep the pyrheliometer aligned on the sun, and therefore it is not fully automatic.

Fully automatic monitoring stations as shown in figure 70 are widely used in high quality solar radiation and energy balance/flux networks, such as the Baseline Surface Radiation Network (BSRN) of the World Climate Research Programme.

Similar systems, usually without the pyrgeometer, are increasingly used in solar energy applications where high accuracy data is required. This can be in the research and development of materials and technologies, for the assessment of optimum locations for large-scale power generation (solar prospecting) or as a reference for the on-going efficiency monitoring of a solar energy plant.

Mountings

Instruments such as albedometers and net radiometers are often supplied with a mounting rod and other sensors may have a screw-in mounting rod available as an accessory. For instruments without these features mounting fixtures are available which incorporate a plate and a rod. A mounting bracket can be used to attach a mounting rod to a pole, mast or a wall.

A horizontally mounted pyranometer measures the global short-wave radiation from the sun and sky in a way that is easily comparable with other sites, with solar energy database information and with insolation models. However, for fixed angle (non-tracking) photovoltaic panels it is important to know the energy available within the ‘view’ of the panel. This ‘tilted global’ or ‘plane of array’ (POA) radiation is measured using a pyranometer inclined at the same angle as the panel.

The mounting shown in figure 71 can be fixed to a horizontal surface and has a clear scale in degrees, and a secure locking device, for easy adjustment of the angle of a pyranometer between 0 ° and 90 ° solar zenith angle.

figure 71: adjustable tilt pyranometer mounting

23. The Measuring Chain

The Measuring Chain in General

Generally speaking, solar radiation sensors are designed to convert a physical parameter into an electrical measuring signal, which is typically a proportional analogue voltage and due to the conversion methods this signal is usually very small.

As already described in Chapter 8 'Measuring Principles', there are three different principles for the conversion of radiation measuring quantities; thermoelectric, bolometric and photoelectric. The output signals usually range from a few mV to approximately 100 mV for the whole measuring range.

Due to these small sensor output voltages the following aspects have to be taken into consideration:

1. To be able to process the measuring signals additional electronic equipment such as signal amplifiers may be required.

2. The transfer of the measuring signals to the succeeding equipment such as amplifiers, data loggers or indicators needs special attention.

In the beginning, highly sensitive galvanometers were used for the indication and recording of these small sensor output voltages. Later, thermionic vacuum tubes (valves) were used as measuring amplifiers. However, only the development of transistors made it possible to bring sensors with hand-held meters or compact data loggers onto the market for routine measurements.

Today there are companies that specialise in the development, production and distribution of data loggers with high sensitivity inputs suitable for the direct connection of solar radiation sensors. Some sensor manufacturers have also developed electronic measuring equipment especially for field applications to suit the expected environmental conditions.

The combination of different components such as sensors, measuring electronics, indicators, etc., for measuring physical parameters is called the measuring chain, as in figure 72.

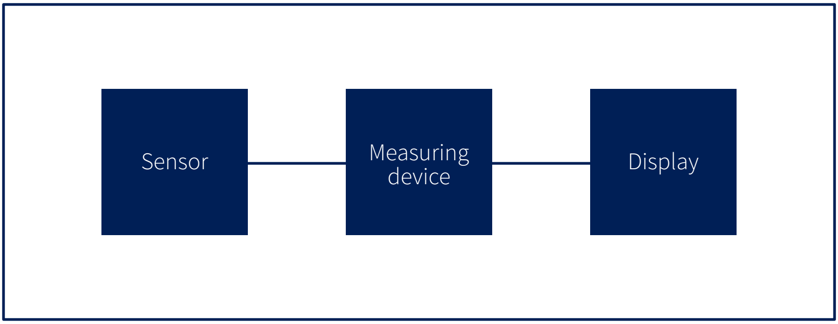


figure 72: the measuring chain

The manufacturers must provide at least the minimum of technical data for each one of these components to enable the user to choose and connect the appropriate products to build a functional measuring chain.

However, it is not only the individual components and their technical specifications that influence the features of a measuring chain. The output characteristics of a component can interact with the input characteristics of the succeeding component.

'A chain is only as strong as its weakest link'

The Sensor

Nowadays the low output voltage of typical solar radiation sensors is not usually a problem. However, the sensors' internal resistance may differ depending on the conversion principle and this has an influence on succeeding resistances, capacitances and inductances.

There are many meteorological data loggers that can accept the sensor inputs directly and highly effective and stable amplifiers are available for increasing the measuring signals.

Depending on the individual configuration of a measuring chain the sensitivity and the frequency characteristics may be influenced by the input and output loads. If the configuration is inappropriate the susceptibility to errors caused by external interfering signals and internal disturbances of the components may increase.

Parasitic voltage sources could, for instance, be caused by the thermal voltages on contacts, galvanic voltages on contacts, fluctuating contact resistances, etc.

Sensors and succeeding electronic systems and instruments must work satisfactorily and dependably in a given electromagnetic ambience which they should not influence, or be influenced by. Electrical components of a measuring chain could:

1. Create or emit variable electromagnetic interference.
2. Be affected by external electromagnetic interference.

This could cause interference in one's own measuring chain and/or affect other systems. Wiring and shielding concepts with a certain electromagnetic compatibility, such as in various CE directives, are used in order to ensure that components of the measuring chain are less susceptible to errors.

When developing a sensor, the manufacturer has already made some decisions regarding its shielding and grounding. However, the effectiveness of these measures can only be guaranteed if the assembly, installation and electrical connection of the sensor are carried out in accordance with the manufacturer's instructions.

One of the first factors is whether the sensor is equipped with an output connector or the measuring cable is fixed to the sensor. The advantage of the connector is, of course, that the user has more flexibility with regards to the installation and servicing of the sensor and so fixed cables are becoming less common.

For long-term stability and reproducible resistance, gold-plated contacts are indispensable and the connectors must be robust, weather-proof and shielded. In order to guarantee correct shielding and signal transfer the manufacturer should supply the correct cable pre-wired to the connector.

It is important that the manufacturer specifies cables with sufficient shielding and which are resistant to moisture, high and low temperatures, UV radiation and flexing in wind; thus providing long-term functionality.

The output resistance of solar radiation sensors can vary significantly, depending on the measured physical parameter and the measuring principle. The output resistance of common sensors ranges from a few Ω up to some kΩ. If the input resistance of the measuring equipment is too low it may affect the performance of the sensor and lead to measuring errors.

This measuring equipment input resistance must be at least 1,000 times the sensor output impedance thus keeping measuring errors (in relation to the expected overall accuracy) to a negligible level. Normally a minimum of 1 MΩ is recommended.

In general the sensor output signals can be regarded as DC. Sensors will not cause interference if they do not contain active electronic circuits.

The Signal Cable

An important part of the measuring transfer is the sensor signal output cable previously mentioned, which is already taken into account in the calibration procedure as a possible source of errors.

Typical shielded signal cables have a line resistance of approximately 8-15Ω per 100 meters of length. Signal cables up to a length of 100 meters are normally satisfactory with unamplified sensors before voltage drop becomes significant.

Care must be taken when a signal cable is extended. The cable must be of the same specification and quality as that supplied with the sensor and the basic cable characteristics and shielding must be carried through any connectors used to extend the cable. Extension connectors must be waterproof if located outdoors.

It is advised to check with the sensor manufacturer whether extending the supplied cable may affect the calibration or other functions of the sensor.

Due to the generally low voltage signals, the measuring cables should be shielded and the choice of appropriate grounding points and avoidance of ground loops is important. As there are different concepts for grounding it is advised to adhere strictly to the manufacturers' instructions.

Electrical machinery or high voltage equipment or communication antennas may be located near the sensors or amplifiers. These may cause considerable interfering signals. The use of mobile power supplies (generators or electronic voltage transformers and inverters) may cause similar problems. The sensor output cable is also subject to parasitic inductance. All these effects can be reduced or avoided by using sufficiently shielded cables. This is particularly important where sensors contain amplifiers or digital electronics.

The specifications of a high quality signal cable are given in table 8 and the construction is illustrated in figure 73.

Cable specification			
	2-wire Li2YD11Y	4-wire Li2YD11Y	8-wire Li2YD11Y
AWG	24	24	26
Number of strands	7x 0.2 mm tinned copper		7x 0.15 mm tinned copper
Wire insulation	PE		
Wire thickness	1.2 mm		0.9 mm
Shield (screen)	Spiral wrap tinned copper 0.15 mm, 95% nominal optical coverage		
Cable insulation	PUR		
Cable thickness	5 mm		
UV resistance	UL 1581 300 Hr Xenon lamp test		
Impendance	~82 Ω/km at 20 °C	~82 Ω/km at 20 °C	~150 Ω/km at 20 °C
Isolation resistance	> 1,000 MΩ/km		
Capacity	~85 nF/km		~100 nF/km

table 8: high quality sensor signal cable specifications

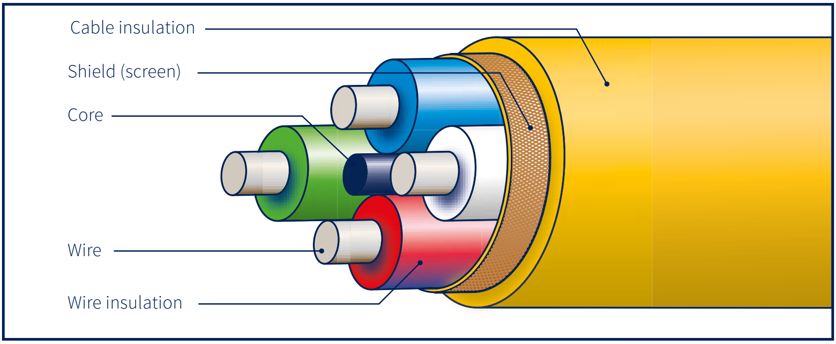


figure 73: high quality sensor signal cable construction

Grounding and Shielding

The metal housing of a sensor provides good protection against physical, chemical and mechanical impacts but it can also protect against electrical and magnetic interference. However, in most solar radiation sensors, this protective effect is not always 100 % perfect. One of the reasons is the glass dome covering the receiver surface cannot keep out electrical and magnetic fields.

Regarding the assignment of the different wires of a measuring cable it can be said that wires of the same circuit should normally be positioned next to each other in pairs. For example, a pair of wires for the measuring signal and another pair for an internal temperature sensor or a supply voltage. This arrangement minimises 'cross-talk' from one circuit to another.

Capacitively coupled interference in a measuring cable can be avoided with good shielding. Ground loops and the currents that they cause may lead to interference in the measuring wires.

Shielding will not be effective unless there is proper grounding. The shield of a measuring cable should only be grounded at one end to avoid ground loops and the associated equalising currents. This is due to the fact that grounding points separated by more than a few metres rarely have the same potential. Even if they do have the same potential double-grounding is not advised.

In general, if it cannot be guaranteed that the sensor housing has a good, low resistance, ground connection it is better to ground the signal cable at the measurement equipment. Note that this must be to a good Protective Earth (PE), not the low/0V input of a data logger or a DC power supply.

The installation of current-carrying cables or high-voltage cables alongside measuring cables over long distances may also lead to inductive interference. Higher quality measuring cables normally have wires twisted together in pairs in order to reduce this effect. Parallel installation over long distances should therefore either be avoided or, at least, the distance between the two cables be kept as great as possible. For extreme applications the measuring cables could be installed in metal conduit tubes or similar.

Where sensors are mounted on towers or roofs of buildings there should be a well-grounded lightning rod nearby to preferentially attract and conduct away any lightning strikes.

The Electronics

In the simplest case the electronics of a measuring chain consist of just one small instrument. This often takes the form of a calibrated amplifier with an integrated indicator displaying the measured value in the correct units. This reduces the danger of misinterpretations and the instrument is often a hand-held unit suitable for field applications.

To minimise additional measuring errors the input resistance of the measuring instrument should be at least a thousand times the output impedance of the sensor, ideally at least 1 MΩ.

A typical example is shown in figure 74. This particular model also has programmable data logging functions which can be accessed and configured by software running on a computer.

figure 74: hand-held irradiance meter and data logger

However, with fixed installations there are often several steps in the chain with different stages of signal processing. Amplifiers mainly transform the small output signal of a sensor into a more easily used signal but can also provide adjustment possibilities, such as zero setting, amplification (gain) setting and filtering.

The measuring chain in figure 75 could represent the sensor connected to an amplifier providing a higher level signal to a data acquisition system, which in turn provides digital data to a computer for display at the control station.

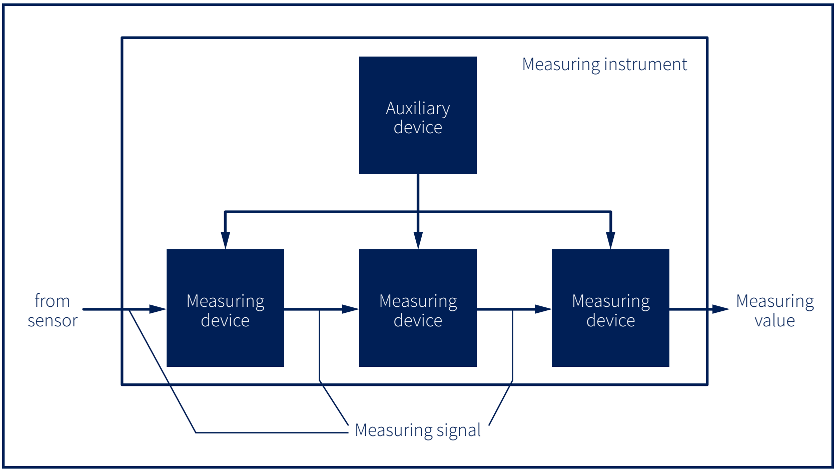


figure 75: fixed measuring equipment schematic

Nowadays, the output values of sensor amplifiers are almost always standardised. For industrial applications analogue output values in the range of 0 to ±1 V, 0 to ±10 V, 0 to ±20 mA and 4 to 20 mA are well established.

These values are high enough to provide a good signal-to-noise ratio thus enabling the undisturbed transmission of signals over long distances. For amplified voltage outputs in the 1 V to 10 V range load resistances up to 500 Ω are often acceptable. On very long signal cables with a higher resistance there will, of course, be a voltage drop. A typical wire resistance is approximately 8 Ω per 100 m of cable.

The characteristics of amplifiers and their auxiliary equipment define the features of a measuring chain. The amplifier design range comprises modular type amplifiers, stand-alone units, system components, plug-in measuring cards for computers, etc. Special amplifiers can meet even the highest demands for accuracy and stability.

The amplifier's capabilities determine the possible fields of application. Ambient temperatures ranging from -40 °C up to +60 °C are within the normal expected environmental conditions for meteorological applications and the amplifier must be weatherproof. An example is shown in figure 76.

figure 76: signal amplifier for all-weather use

The individual measuring chains can differ considerably depending upon the application and some examples are shown in figure 77.

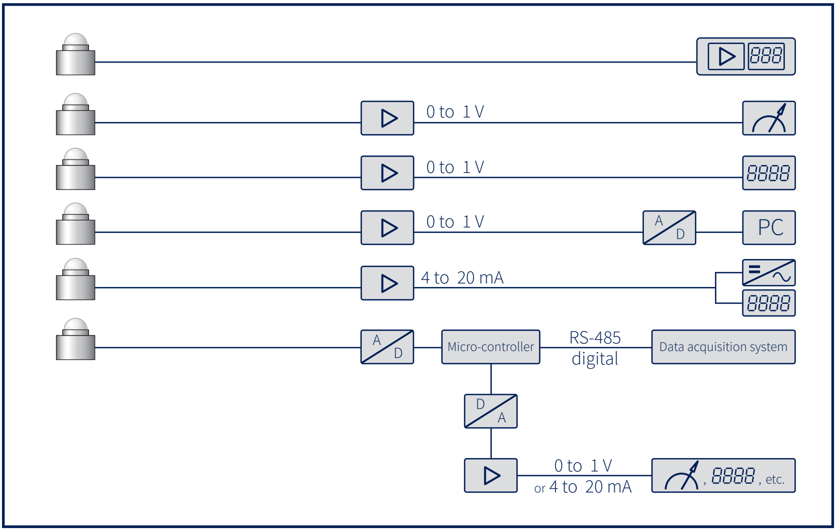


figure 77: measuring chain examples

Amplifier features have a characteristic influence on the signal passed along the measuring chain, including:

• Measuring range
• Input sensitivity
• Signal-to-noise ratio
• Temperature response
• Linearity
• Stability
• Offsets

In general the sensor output signals are DC voltages that change relatively slowly, so features such as frequency response are not of major interest.

For industrial applications, especially in cases where independence from varying cable resistance is required, outputs with a defined current (normally ± 20 mA) are preferred. For this purpose, the amplifier is equipped with a circuit controlling the current flow to be proportional to the measuring value.

Thus, the variable line resistances do not have an effect and cable lengths of hundreds of metres can be used. The input resistance of the indicator or registration device, together with the measuring cable, should not exceed a predetermined value which depends upon the voltage of the current loop supply. For example a loop resistance of 500 Ω with a 20 mA current signal will cause a voltage drop of 10 V.

A popular variant of a defined current is the 4 to 20 mA output. This is normally used where the measuring signal does not create negative values. In this case 4 mA equals a signal value of 'zero' whereas 20 mA equals the maximum signal output.

An advantage of this 'live' zero is that 0 mA indicates a fault or a break in the current loop and can be used to trigger a warning system. This is preferred, or even compulsory, for safety related circuits.

When the measuring value is zero there is still a current flow of 4 mA which may be used as power for amplifiers requiring only a low energy supply.

However, most amplifiers are supplied in separate housings that are installed near to the measurement site and the power is supplied separately. This is shown in figure 78 with a 4 to 20 mA signal amplifier powered by the current loop. In this configuration cable lengths up to 1,000 m can be used.

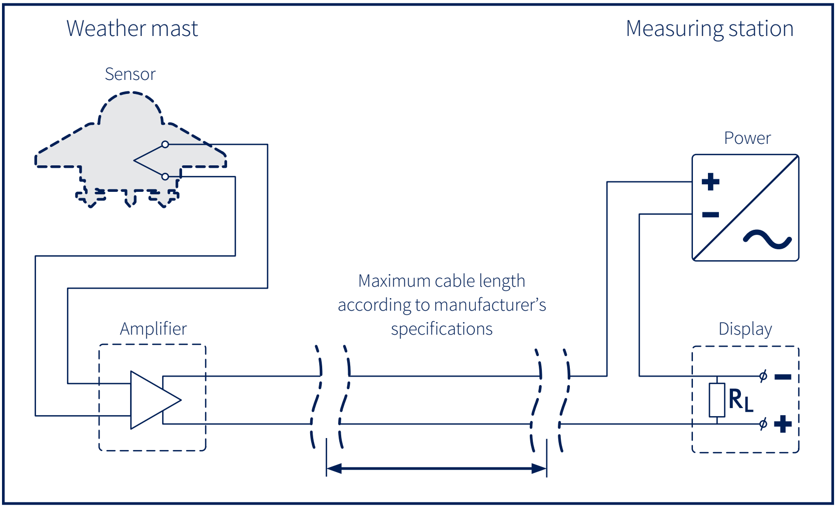


figure 78: measuring chain with 4-20 mA amplifier

It is possible to install an amplifier within the sensor housing, although this might require an increase in size. With thermoelectric or bolometric type sensors extreme care is needed to ensure that the power dissipation of the amplifier does not cause offsets in the detector which will affect the measurement accuracy.

Analogue-to-Digital Converter

Nowadays, digital processing of measuring values is indispensable for many areas of science and technology. As the physical parameters being measured are analogue, transformation of the measuring signal to the digital domain becomes necessary. For this analogue-to-digital conversion higher voltages are usually needed, therefore pre-amplification is almost always necessary and this is often an integrated part of the A/D Converter (ADC).

The pre-amplifier design is critical for many reasons. Amplifying the very low level sensor signal (down to a few µV) must be achieved with sufficient stability and accuracy. Any zero drift or zero offset in the pre-amplification stage would be intensified in the succeeding amplification and further processing, thus possibly invalidating the complete measurement.

The nearer the pre-amplifier is to the sensor, the lower will be the risk of interference affecting the very small sensor signal. As digital data transfers have the potential to be error-free it becomes more and more common to install the pre-amplifier and ADC near the sensor or even to integrate them, but there must be a power supply available at the sensor location.

Meanwhile, many different principles have been developed for A/D conversion. Analogue measuring values tend to change continuously. The faster the changes need to be tracked and analogue values converted into digital ones, the more complex will be the conversion procedure.

For radiation measurements based on the thermoelectric principle these changes happen relatively slowly, within a range of a few seconds, due to the thermal inertia within the sensor. However, for sensors with photodiode detectors the response time is only a few milli-seconds. It is important that the A/D conversion is carried out continuously to detect changes of the measuring signals.

However, even more important is the resolution capability that is reached or desired. Older industrial recommendations and/or standards often mentioned an 8-bit resolution. In reality ADCs with such a low resolution are not in use anymore. Table 9 below shows the notional resolution that can be achieved with commonly available converters:

Analogue-to-Digital Converter Resolution		
Converter type	Conversion Bits	Resolution in W/m² for 1500 W/m² Full Scale
8-bit	256	5.86
10-bit	1024	1.46
12-bit	4096	0.366
14-bit	16384	0.092
16-bit	65536	0.023

table 9: analogue-to-digital converter resolution

It is desirable to be able to record changes of 1 W/m^2, so clearly an 8-bit or 10-bit converter is not sufficient. In reality, ADCs rarely perform to the full resolution, for example a 16-bit converter may be described as having '15-bit accuracy'. Therefore, at least a 12-bit ADC is required.

However, in addition to the resolution of the ADC other considerations are the noise, offsets and input range. The noise may well be equivalent to the resolution and the offset 2-3 times the resolution. This means that, in practice, it is necessary to use a converter with at least 14-bits to achieve a 1 W/m^2 'accuracy'. The input range must be able to accept the maximum expected output signal from the sensor, whilst not being so large that the resolution is degraded. For example, if the input range is equivalent to 0 to 6,000 W/m^2 a 16-bit converter is required.

These ADC characteristics affect how a successive indicator should be interpreted. For example a display might have 8 digits and indicate 1,120 W/m^2 as 001121.79 due to offsets and with the last two digits fluctuating due to the conversion noise.

The transfer of the digitised data to the central measuring station or the data processing centre depends not only on the digital 'accuracy' of the data but also on the features of the digital interface and hardware.

There are a large number of industrial 'bus' systems and standards for the transfer of digital data, but none of these are commonly used in meteorology or environmental monitoring. The most common method is to transfer data as ASCII message strings using RS-232 or RS-485 serial communication. SDI-12 (Serial Data Interface 1200 Baud) by 2-wire RS-485 is a protocol specifically designed for sensors collecting environmental data from sites where low power is required.

RS-232 is limited to a cable length of about 15 m (depending upon the data baud rate), whereas RS-485 (particularly in 4-wire mode) works reliably with cable lengths in excess of 1,000 m.

In the solar energy field Modbus®, using RS-485, has become the preferred protocol for the control and monitoring of equipment and this is being extended to the solar radiation sensors. This can take advantage of the fact that if the sensors are individually addressable they can be connected in a multi-drop configuration to a single RS-485 line, thus saving on cable costs.

24. Installation and Maintenance

The place of installation, how to put into operation and how to maintain solar radiation sensors has to be determined with respect to the individual requirements of the instruments as well as the application field and the measuring task.

The Place of Installation

There are certain rules to be observed, mainly to guarantee the comparability of measuring values for the same physical parameter taken on different sites or by different persons.

Measurements should be done in such a way regarding measuring time, measuring location and measuring height that they can be compared with the measuring values for other physical parameters that are related. For example the correlation of solar radiation values to other meteorological parameters.

For the measurement of meteorological parameters such as temperature, humidity and wind, measuring locations with a short-cut grass surface and a clear area of at least 10 m x 10 m are recommended. The sensor height above the ground may be 1 m for measuring precipitation, 2 m for measuring temperature and humidity, and up to 10 m for wind direction and speed.

Sensors and instruments for the measurement of sunshine duration and solar irradiance should ideally be mounted such that there are no obstructions to the horizon in all directions. In areas with high building density it may be necessary to install them on roof platforms to obtain a clear hemispherical field of view.

The surroundings at the place of installation should not affect the measurement. This is particularly important for pyrgeometers because of their sensitivity to sources of heat.

Any auxiliary equipment necessary for running the system (such as power supply, lightning protection or cables) may need to meet local standards or approvals.

Normally, the place of installation of a solar radiation sensor is intended to be representative of a greater area and should, in any case, fulfil the following requirements:

1. Sensors must be installed in such a way that their horizontal orientation (levelling), or desired tilt angle, can be adjusted and is stable in the long-term and in all weather conditions. This is especially critical for sun trackers.

2. Sensors must be easily accessible for regular maintenance such as cleaning the dome and replacing the desiccant.

3. The sensor's measuring horizon above an angular height of 5° should not be obstructed by any vegetation or buildings in order to avoid any obscuration of the sky, by shadows or reflected radiation. Exceptions are antennas or other slim objects covering an azimuth angle of less than 1°.

4. For pyrgeometers sources of heat must be avoided.

5. If these requirements cannot be fulfilled, a different place will have to be chosen at which the measurements are impeded for as short a part of the day as possible. Unavoidably distorted measuring values should either not be used at all, or corrected after consultation with the manufacturer.

Installation

For the installation of solar radiation sensors it is important to follow the instructions in the operating manual and other product documentation.

Horizontal levelling of the sensor by using the built-in level indicator or, if necessary, a water level, must be carried out thoroughly and the sensor securely fixed to a rigid and stable support.

Any mounting hardware, such as a mast, that might cause shadows must be located on the side away from the equator, towards the nearest pole.

The electrical connections must be weatherproof and cables secured, and if necessary protected against animals, insects and birds. The manufacturer's instructions may give a preferred orientation for the sensors' cable exits, for example directed away from the equator.

In order to minimise dew, dirt, dust and sand deposition it is recommended to install a ventilation unit, with heating activated for frosty conditions.

General Maintenance

All meteorological instruments need regular maintenance and so do solar radiation sensors. The amount and intervals of maintenance services are dependent upon the instrument type and the conditions at the place of installation. However, the manufacturer's maintenance instructions usually comprise the minimum requirements to maintain correct operation and the specified performance and shoul be adhered to.

Every maintenance service incurs costs in materials and labour time. These costs should be considered in the planning phase and during installation. Maintenance work should only be done by qualified personnel because it is important to avoid external damage and accidental shifting of sensors or adjustment devices. This particularly applies to more complex instruments such as sun trackers.

Most solar radiation sensors are rugged designs but they are still sensitive to shock and internal humidity. If they have become damp inside or suffered mechanical shock, even if there is no noticeable external damage, comparative tests with known good sensors should be carried out. If there is any doubt about the correct performance, recalibration should be performed at a recognised facility.

The most important regular maintenance for a solar radiation sensor is to keep the dome or window clean. Dirt, water droplets, frost or any medium that absorbs or scatters solar radiation will affect the accuracy of the measurement. This is why ventilation units are recommended in locations with high precipitation or pollution incidence.

The second most important issue is to make sure that the sensor remains dry internally by regularly checking the condition of the desiccant and replacing it if necessary. This prevents internal condensation when the temperature of the sensor passes through the prevailing dew-point. Internal condensation on the dome or window affects the readings and will eventually cause deterioration of the detector, electrical components and wires.

Some designs of instruments are sealed and have a long-life internal drying agent so that regularly inspection and changing of desiccant is not necessary and maintenance is reduced. The drying agent is usually replaced during recalibration by the manufacturer.

Domes and Windows

Domes and windows should be inspected and cleaned on a regular basis. They must be cleaned of such things as dust, bird droppings, greasy pollution deposits, leaves, etc. The frequency of inspection and cleaning depends upon the local conditions but should be performed regularly, at least during each maintenance visit.

Domes should be cleaned with a soft, clean piece of cloth using distilled water or alcohol. A normal domestic glass cleaner can be used if any residue is thoroughly polished away. Frost, snow or ice can be removed with a warm piece of cloth; scraping off frost or ice is not recommended. A ventilation unit reduces the frequency of cleaning.

The glass domes have a similar hardness to window glass, so in areas prone to strong winds they can become scratched, chipped, or etched by sand and grit. This diffuses radiation and affects the measurements. For this reason the outer dome is usually replaceable and returns the sensor to its original calibrated sensitivity.

Quartz domes are more expensive but are significantly harder and less likely to need replacement. Pyrheliometers normally have quartz windows. The Silicon dome or window of a pyrgeometer is harder than glass but not as resistant as quartz.

Figure 79 shows the typical user-replaceable spares for a solar radiation sensor - the outer dome and the drying cartridge, which is filled with a desiccant that changes colour from the dry to the damp condition.

figure 79: spare dome and drying cartridge with desiccant

Desiccant

Most pyranometers are equipped with drying cartridges, normally filled with self-indicating silica gel. The colour should be checked quarterly. If it has turned from orange to clear (blue to pink on the older cobalt-based type) it is approximately 30 % saturated and should be replaced with fresh desiccant from a sealed package.

Whilst it is possible to regenerate the silica gel by controlled heating for a number of hours, it is not recommended because it affects the water absorption capacity and the humidity point at which the colour change occurs. Ideally fresh desiccant from a sealed package should always be used.

Levelling

The horizontal levelling or the tilt angle of the sensors should be checked quarterly. The sensor fixings should also be checked to ensure that they are secure.

Housing and Sun Shield

Quarterly the housing should be cleaned to prevent corrosion and the sun shield should be cleaned to keep it white and reflective. It can be easily replaced if necessary.

Cables and Connectors

Quarterly the cables and connectors should be cleaned and checked for damage and security of the connections and cable fixings.

Horizon

The horizon of the sensor field of view of should be checked quarterly for obstructions such as changes to the surrounding buildings, trees or vegetation.

Detector Surface

The radiation receiving surface, which is a black absorptive coating or a white diffuser, can be checked every 3 months for signs of condensed water and staining by holding a torch in such a way that its light falls onto the surface with an angle as flat as possible in order to emphasise any defects. If there are any defects repairs and re-calibration will be necessary.

Ventilation Units

Ventilation units should be checked monthly, the white cover cleaned and the inlet air filter cleaned or replaced, as necessary.

Manual Shading Devices

Manual shading devices should be checked every two or three days for correct shading and be re-adjusted if necessary.

Albedometers

An additional check for albedometers is to regularly check the condition of the ground below the downward facing sensor; clean it from brushwood, leaves, etc. and keep grass cut short.

Pyrheliometers

Pyrheliometers with single-axis sun trackers should be readjusted manually every one or two days to follow the seasonal declination of the sun. Pyrheliometers mounted on fully automatic sun trackers should be checked monthly, or after sever weather events, to ensure that the alignment has not changed.

Operating Conditions

Solar radiation sensors should be designed to be used all over the world. However, there are many places that have more extreme environments and these should be borne in mind when selecting sensors. Such extremes could be in temperature, pressure, wind (hurricane season), precipitation (monsoon season), high solar UV radiation, blown sand or corrosive environments (by the sea or industrial sites).

Sensors and auxiliary equipment for permanent outside use should be able to withstand these conditions for at least 5 years.

Sensors and auxiliary equipment for the European market must conform to CE requirements in accordance with the relevant regulations for the type of equipment. This particularly applies to electro-magnetic compatibility and safety issues.

Recalibration of Radiation Sensors

Solar radiation sensors are normally delivered with a certificate supplied by the manufacturer which defines the measurement parameter, the measuring units, the sensitivity and/or the measuring range of the sensor. It should also specify the calibration conditions, date, location, and the reference equipment used. Ideally the calibration certificate should also provide the uncertainty calculations for the complete calibration transfer chain.

The calibration of sensors must be documented by calibration certificates and should be repeated at least every two years as a general recommendation. Recalibration is also necessary after most types of sensor component replacement or repair has been carried out.

25. Glossary

Absorption	Process during which incoming energy is absorbed by an object
Airmass	Ratio of the actual solar radiation path through the atmosphere to the direct vertical path
Albedo	The proportion of incident radiation being reflected by an object or surface
Albedometer	Sensor for measuring incoming and reflected short-wave radiation such that the Albedo can be calculated
Anemometer	Sensor for measuring wind speed
Atmosphere	All the air surrounding the earth
Barometer	General term for sensors measuring the atmospheric air pressure
Calibration	Determination of the relationship between the output value and the measuring value
Celsius	Temperature scale named after the Swedish scientist Anders Celsius. 0 °C represents the freezing point of water, 100 °C represents its boiling point; both under standard conditions
Climate	Statistical characteristics of the weather during a certain time period in a certain region
Condensation	The changeover from the gaseous state to the liquid state
Corona	The coloured ring around the sun or moon caused by the refraction of light through water vapour in the atmosphere
Dew Point	The temperature to which air must cool down to saturate with water vapour
Diffraction	Change in direction of light waves at the edge of objects or through small apertures
Diffuse Radiation	Scattered and reflected solar radiation falling onto a horizontal surface, with the direct radiation excluded
Direct Radiation	Solar radiation falling directly onto a surface normal to the sun, with the diffuse radiation excluded
Dobson Unit	Unit of measurement for the total amount of ozone between the measuring instrument and the sun. 100 DU = 1m column of ozone at ground level under standard atmospheric conditions. The global average is about 300 DU
Drift	Slow temporal change of the measuring value of a sensor
Equinox	The date when day and night have the same length
Far Infrared Radiation	Long-wave radiation in the range from 4.5 to > 40 µm
Global Radiation	Total of direct and diffuse solar radiation from the hemisphere falling onto a horizontal surface
Humidity	The presence of water vapour in the air, usually measured by hygrometers
Irradiance	Instantaneous value of radiation (W/m^2)
Infrared Radiation	Long-wave radiation in the range of 0.7 to > 40 µm
Inversion	When the air temperature rises in relation to the height above ground level instead of falling
Isobar	On meteorological maps, a line connecting locations of equal barometric pressure
Isohel	On meteorological maps, a line connecting locations with the same sunshine duration values

Isorad	On meteorological maps, a line connecting locations with the same solar irradiance
Isotherm	On meteorological maps, a line connecting locations with the same air temperature
Kelvin	Temperature scale named after scientist Lord Kelvin Zero Kelvin equals - 273.15 ° Celsius One degree on the Kelvin scale equals one degree on the Celsius scale
Light (visible)	Electromagnetic radiation visible to the human eye, wavelengths between 400 nm and 700 nm
Lightning	Visible electrical discharge in the atmosphere
Measuring Error	Deviation of a measuring value from the real value
Measuring Range	Range of values in which measuring errors do not exceed certain specified limits
Measuring Instrument	A sensor for measuring a physical parameter
Measuring Chain	Series of components to measure a physical parameter and to transform the measuring signal into the desired output format
Measuring Principle	Physical basis of the measurements
Measuring Signal	Output value of a sensor or measuring device which is directly related to the physical parameter being measured
Measuring Procedure	Application of a measuring principle and a measuring method
Measuring Value	A numerical value in specified units derived from the measuring signal of a sensor
MED	Minimum Erythemal Dose MED/hr is a measure of skin exposure to UV radiation
Mesosphere	A layer of the upper atmosphere located between the stratosphere and the ionosphere
Meteorology	A science that deals with atmospheric phenomena and processes, particularly with respect to weather conditions and forecasting
Method of Measurement	Special modus operandi of measuring independent from the measuring principle
Metrology	The science of determining measuring values of physical parameters
Net Radiation	Difference between incoming and outgoing radiation of the same spectral range
Output	Measuring signal coming out of a sensor
Ozone	Gas naturally occurring in the atmosphere. In higher concentrations it is toxic and corrosive. Its molecules consist of three oxygen atoms and the chemical formula is O_3
Ozone Hole	Term for a decrease of the atmospheric ozone content below 220 DU or a reduction of about 30 % in a defined geographical area
Ozone Layer	The layer in the atmosphere at a height from 20 to 40 km which absorbs a considerable part of the UV radiation coming from the sun
Precipitation	Any form of water falling to earth from the atmosphere including rain, snow, sleet and hail
Pyranometer	Sensor for the measurement of global short-wave solar radiation in a spectral range from 300 to 3,000 nm

Pyrgeometer	Sensor for the measurement of global long-wave atmospheric radiation in a spectral range from 4.5 µm to beyond 40 µm
Pyrheliometer	Sensor for the measurement of direct solar short-wave radiation in a spectral range from 300 to 3,000 nm
Pyrometer	Sensor for remote measurement of temperature
Radiation	Transport of energy by electromagnetic waves. The spectrum extends from very short wavelength cosmic radiation through to X-rays, ultraviolet, visible light, infrared and on to radio waves and very long wavelength microwaves
Radiation Balance	Difference between upward and downward radiation at both short and long wavelengths
Resolution	Smallest difference between two measuring values that can be detected by the sensor or subsequent parts of the measuring chain
Response Time	Time taken for the output value to reach a defined percentage of the input value after a step-change in the input value
Saturation	Condition where the concentration of water vapour in the air has reached its theoretical maximum. This maximum depends on the ambient temperature and pressure
Sensitivity	Change of the output value in relation to the input value
Sky	The hemispherical part of the atmosphere that is directed towards the sun, it causes diffuse radiation. In space there is only direct solar radiation
Solar Constant	Long-term mean solar irradiance outside the earth's atmosphere falling onto a 1 m^2 surface which is oriented normal to the sun's rays whilst the distance between earth and sun is medial. Usually taken as 1368 W/m^2 but recently revised to 1360.8 W/m^2
Spectrophotometer	Sensing instrument for the measurement of radiation over a range of discrete wavelengths
Stratosphere	The stratosphere is a layer in the atmosphere at a height from 10 to 15 km up to 50 km. It is above the troposphere and below the mesosphere. It is nearly cloudless and contains the ozone layer
Threshold	An input value above or below which there is a specific change of the output value
Troposphere	Lowest layer of the atmosphere, where the weather occurs. The troposphere reaches up to a height of 10 to 15 km. Between the troposphere and the stratosphere is the tropopause.
Tropopause	Junction of troposphere and stratosphere, the height varies from 10 km to 15 km depending on location and conditions
Ultraviolet Radiation	Invisible radiation in the spectral range from 100 to 400 nm
UV Index	Global UV Index of UN / WMO / WHO for the evaluation of values of erythemally weighted UV radiation that is harmful to human skin
Weather	Condition of the atmosphere at a certain time and location. The weather is mainly influenced by solar radiation, air temperature, air humidity, precipitation, air pressure and air movement
Wind	Movements of masses of air in the atmosphere. Traditionally regarded as horizontal but nowadays often measured in 3 axes
Zenith Angle	The angle of an object in the sky away from the zenith position (vertically above the observer).

26. List of References

Illustrations and tables that are not otherwise attributed are the property of the author or of Kipp & Zonen B.V. - Delft - The Netherlands.

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27. Technical Terms

English	Deutsch	Français
A		
absorber	Absorber	absorber
absorber plate	Absorberfläche	plaque d'absorption
absorption constant	Absorptionskonstante	constante d'absorption
acceleration	Beschleunigung	accélération
accessories	Zubehör	accessoires
accumulator	Akkumulator	accumulateur
accuracy	Genauigkeit	précision
accuracy class	Genauigkeitsklasse	classe de précision
actuation	Betätigung	commande
adapter	Adapter	adaptateur
adaption	Adaption	adaptation
adjust	justieren	ajuster - régler
adjusting element	Abgleichelement	élément d'ajustement
adjustment	Abgleich	ajustement - réglage
ageing	Alterung	vieillissement
aggressive environment	aggressive Umgebung	environnement agressif
air humidity	Luftfeuchtigkeit	hygrométrie
air mass	Luftmasse	masse d'air
air pressure	Luftdruck	pression atmosphérique
air pressure compensation	Luftdruckausgleich	compensation de la pression atmosphérique
air pressure dependence	Luftdruckabhängigkeit	dépendance de la pression atmosphérique
air pressure variation	Luftdruckschwankung	variation de la pression atmosphérique
alarm	Alarm	alarme
albedo	Albedo	albedo
alert notice	Alarmmeldung	annonce d'alarme
aligning	ausrichten	aligner
alternating	alternierend	alternance
ambient air	Umgebungsluft	air ambiant
amplifier	Verstärker	amplificateur
analog indication	Analoganzeige	indication analogique
analog indicator	Analoganzeiger	indicateur analogique
analog output	Analogausgang	sortie analogique
analog-to digital converter	Analog-Digital-Wandler	convertisseur analogique digital
analog-to-digital converter	Analog-Digital-Konverter	convertisseur analogique digital
analogue	Analog	analogique
anemometer	Windgeschwindigkeitsmesser	anémomètre
aneroid barometer	Barometer	baromètre
angularity	Winkelstellung	angularité
aperture	Blende	ouverture - orifice
aperture plane	Öffnungsebene	angle d'ouverture
aphelion	Sonnen entferntester Punkt	aphelie
application	Einsatz	application
application class	Anwendungsklasse	classe d'utilisation
application potential	Applikationsfähigkeit	potentiel d'application
approval	Zulassung	approbation
approving authority	Zulassungsbehörde	autorité d'approbation
arrangement	Anordnung	arrangement
atmosphere	Atmosphäre	atmosphère
atmospheric conditions	Witterung	conditions atmosphériques
atmospheric depth	atmosphärische Tiefe	profondeur atmosphérique
atmospheric exposure	Witterungseinfluss	exposition atmosphérique
atmospheric layer	atmosphärische Schicht	couche atmosphérique
atmospheric long-wave radiation	atmosphärische langwellige Strahlung	radiation atmosphérique longue onde
attenuation	Dämpfung	atténuation

attenuator	Abschwächer	atténuateur
auxiliary device	Zusatzeinrichtung	outil auxiliaire
average	Durchschnitt	moyenne
average	Mittelwert	moyenne
axial	axial	axial
axle	Achse	axe
azimuth	Scheitelkreis	azimuth

B

back up battery	Pufferbatterie	batterie de sauvegarde
balancing	Ausgleich	compensation
bandwidth	Bandbreite	largeur de la bande
bar	Bar	bar
bar	Stab	bâton
bar	tange	barrre
barometer	Barometer	baromètre
base	Unterteil	partie inférieure
base plate	Grundplatte	plaque de base
battery	Batterie	batterie
battery operation	Batteriebetrieb	fonctionnement de la batterie
battery supply	Batteriespeisung	alimentation batterie
beam	Balken	faisceau
beam	Strahl	rayon
bearing surface	Auflagefläche	surface portante
bending moment	Biegemoment	moment de flexion
bolometric principle	Bolometrisches Prinzip	principe bolométrique
bolt	Bolzen	goujon
breakdown	Versagen	rupture
breaking load	Bruchlast	charge de rupture
bridge balance	Brückenabgleich	équilibrage du pont
bridge circuit	Brückenschaltung	circuit de pont
bridge excitation voltage	Brückenspeisespannung	tension d'alimentation pont
buffer	Stoßfänger	dispositif antichoc

C

cable	Kabel	câble
cable box	Kabelkasten	boite de raccordement
cable break	Kabelbruch	rupture du câble
cable connection	Kabelanschluss	câble de raccordement
cable extension	Kabelverlängerung	extension de câble
cable influence	abeleinfluss	influence du câble
cable jointing sleeve	Kabelverbindungsmuffe	prolongateur de câble
calibrate	eichen	calibrer
calibrate	kalibrieren	étalonner
calibration	Kalibrierung	calibration
calibration certificate	Kalibrierzeugnis	certificat de calibration
calibration curve	Kennlinie	courbe d'étalonnge
calibration signal	Kalibriersignal	signal d'étalonnage
calibration standard	Kalibriernormal	étalon de calibration
calibration tolerance	Kalibriertoleranz	tolérance de calibration
centering	Zentrierung	centrage
centre of gravity	Schwerpunkt	centre de gravité
change in zero signal	Nullsignaländerung	dérive de zéro
checking of operation	Funktionskontrolle	contrôle de fonction
chopper	Wechselrichter	couperet

circuit diagram	Schaltplan	diagramme de circuit
circuit diagram	Stromlaufplan	diagramme de circuit
circular scale	Kreisskale	échelle circulaire
circumsolar radiation	Zirkumsolarstrahlung	radiation circumsolaire
clamp bolt	Spannschraube	boulon de fixation
climate	Klima	climat
climate-controlled cabinet	Klimaschrank	coffret de contrôle climatique
cloud	Wolke	nuage
coating	Auskleidung	enveloppe
collector, parabolic dish	Kollektor, Parabolspiegel	disque parabolique
combined error	Fehler zusammengesetzter	erreur combinée
compensating device	Ausgleichseinrichtung	dispositif de compensation
compensation resistors	Kompensationswiderstände	résistances de compensation
component	Bauteil	composant
concentrator	Konzentrator	concentreur
condition testing	Beschaffenheitsprüfung	contrôle de qualité
connecting terminal	Anschlussklemme	bornier de raccordement
connection	Anschluss	raccordement
connection cable	Verbindungskabel	câble de liaison
connection point	Anschlussstelle	point de connexion
connection wire	Anschlussdraht	câble de connexion
connector	Anschlussstecker	connecteur
construction	Konstruktion	construction
content	Inhalt	contenu
continuous load	Dauerbelastung	charge permanente
contour	Außenlinie	contour
control	Kontrolle	contrôle
control	Steuerung	réglage
control element	Bedienungselement	élément de contróle
copper	Kupfer	cuivre
correction device	Korrektureinrichtung	dispositif de correction
corrosion	Korrosion	corrosion
corrosion resistance	Korrosionsbeständigkeit	résistance à la corrosion
cosine response	Kosinusverhalten	réponse du cosinus
counterbalance weight	Ausgleichsgewicht	contrepoids d'équilibrage
creep error	Kriechfehler	fluage
criterion	Kriterium	critére
cryogenic temperature range	Tieftemperaturbereich	gamme de température cryogénique
curing of defects	Fehlerbeseitigung	élimination des erreurs
current circuit	Stromkreis	circuit électrique
current limitation	Strombegrenzung	limite de courant

D

damage	Beschädigung	dégât
damping	Dämpfung	amortissement
damping characteristics	Dämpfungseigenschaft	propriétés d'amortissement
data archiving	Datenarchivierung	archivage des données
data preparation	Datenaufbereitung	préparation des données
data sheet	Datenblatt	fiche des données
DC amplifier	Gleichspannungs-Messverstärker	amplificateur à courant continu
dead time	Totzeit	temps mort
definition	Definition	définition
deformation	Verformung	déformation
density	Dichte	densité
density test	Dichtheitsprüfung	test de densité
design	Ausführung	construction

design	Bauart	modèle d'instrument de pesage
deviation	Abweichung	déviation
deviation curve	Fehlerkurve	courbe d'erreur
dew point	Taupunkt	point de rosée
diagramme	Diagramm	diagramme
diameter	Durchmesser	diamètre
diffraction	Beugung	diffraction
diffuse solar radiation	diffuse Strahlung	rayonnement solaire diffus
diffusion	Diffusion	diffusion
digital	digital	numérique
dimension	Abmessung	dimension
dimension	Dimension	dimension
dimension	Größe	taille
dimensioning	Bemaßung	dimension
direct solar irradiance	direkte Solarbestrahlung	rayonnement solaire direct
direct solar radiation	direkte Strahlung	radiation solaire directe
directional dependence	Richtungsabhängigkeit	influence de l'inclinaison
disassemble	Demontage	démontage
discontinuous	diskontinuierlich	discontinu
display	anzeigen	afficher
display	Anzeiger	affichage
display unit	Anzeigeeinheit	unité d'affichage
distance	Abstand	distance
drift	Drift	dérive
drift error	Driftfehler	dérive du zéro
dynamic	dynamisch	dynamique
dynamics	Dynamik	Dynamique

E

earth's surface	Erdoberfläche	surface terrestre
eccentric	außermittig	excentrée
effect of temperature	Temperaturgang	effet de température
elasticity	Elastizität	élasticité
emittance	Aussendung	émission
endurance strength	Dauerfestigkeit	force d'endurance
endurance test	Dauerprüfung	essais d'endurance
energy of radiation	Strahlungsenergie	énergie du rayonnement
environment	Umgebung	environnement
environment	Umwelt	environnement
environmental condition	Umweltbedingung	condition environnante
environmental influence	Umwelteinfluss	influence environnante
environmental temperature	Umgebungstemperatur	température environnante
equator	Äquator	équateur
equivalent length	equivalente Länge	longueur équivalente
error	Abweichung	erreur
error	Fehler	erreur
error due to drift	Kriechfehler	erreur de dérive
error of measurement	Messabweichung	erreur de mesure
evaluation	Auswertung	évaluation
evaporation	Verdunstung	évaporation
exchange	auswechseln	changer
excitation voltage	Speisespannung	tension d'alimentation
external heat source	externe Wärmequelle	source de chaleur externe
external pressure	Außendruck	pression extérieure
extraterrestrial solar radiation	extraterrestrische Solarstrahlung	rayonnement extraterrestre solaire

F

fail-safe	ausfallsicher	sécurisé
fastening	Befestigung	fixation
fastening bolt	Befestigungsbolzen	axe de blocage
fastening screw	Befestigungsschraube	vis de fixation
feature	Eigenschaft	qualité
feedback	Rückführung	retour
field of application	Einsatzbereich	domaine d'application
field of operation	Arbeitsfeld	champ d'opération
field of view	Öffnungswinkel	champ de vue
filter	Filter	filtre
fixing screws	Halteschrauben	vis de maintien
flange	anflanschen	brider
formula	Formel	formule
frame	Rahmen	cadre
freedom from bias	Richtigkeit	justesse
freezing point	Gefrierpunkt	point de gel
frequency range	Frequenzbereich	gamme de fréquence
fresnel lens	Fresnellinse	lentille de Fresnel
friction	Reibung	friction
full bridge	Vollbrücke	pont complet
function	Funktion	fonction

G

gain	Vertärkungsfaktor	gain
girder	Träger	support
gland	Stopfbuchse Presse	étoupe
global solar radiation	rahmen	rayonnement solaire global
gravity	Schwerkraft	gravitation
ground	Erde	terre
ground lead	Erdleitung	conducteur de mise à la terre
ground loop	Erdschleife	tresse de mise á la terre
grounding	Erdung	prise de terre

H

hail	Hagel	grêle
hair hygrometer	Haarhygrometer	hygromètre à cheveu
half bridge	Halbbrücke	demi-pont
handling	Handhabung	manutention
heat conductivity	Wärmeleitfähigkeit	conductivité de la chaleur
heat conductivity	Wärmeleitvermögen	conductivité de la chaleur
heat conductor	Wärmeleiter	conducteur de la chaleur
heat dissipation	Wärmeableitung	dissipation de la chaleur
heat exchanger	Wärmetauscher	échangeur thermique
heat of evaporation	Verdampfungswärme	chaleur d'évaporation
heat proof	hitzebeständig r	ésistant à la chaleur
heat pump	Wärmepumpe	pompe de chaleur
heat radiation	Wärmestrahlung	radiation thermique
heating	Heizung	chauffage
height of construction	Bauhöhe	hauteur de construction
heliocentric	heliozentrisch	héliocentrique
heliotype	Lichtdruck	heliotype
hermetic	hermetisch	hermétique
high tension	Hochspannung	haute tension
hook	Haken	crochet

hot	heiß	chaud
hour	Stunde	heure
housing	Gehäuse	boîtier
humidity	Feuchtigkeit	humidité
hygrometer	Feuchtemesser	hygromètre
hysteresis	Hysterese	hystérèsis
hysteresis error	Hysteresefehler	erreur d'hystérésis
hysteresis error	Umkehrspanne	erreur d'hystérésis

I

ice point	Eispunkt	point de glace
identification mark	Identitätszeichen	signe distinctif ou d'identification
illuminance	Beleuchtungsstärke	illuminance
illuminated display	Leuchtbildanzeige	affichage lumineux
illumination	Beleuchtung	luminosité
incident angle	Einfallswinkel	angle d'incidence
indicating range	Anzeigebereich	gamme d'affichage
indication	Anzeige	indication
indication	Bezeichnung	dénomination
indication	Messwert	indication
indication device	Anzeigeeinrichtung	dispositif indicateur
indication error	Anzeigefehler	erreur d'indication
indicator	Anzeigegerät	indicateur
influence	Beeinflussung	influence
influence	Einfluss	influence
influence of measuring lead	Messleitungseinfluss	influence du conducteur
infrared radiation	Infrarot Strahlung	rayonnement infrarouge
infrastructure	Unterwerk	infrastructure
input	Eingang	entrée
input impedance	Eingangswiderstand	resistance d'entrée
input resistance	Eingangswiderstand	resistance d'entrée
input signal	Eingangssignal	signal d'entrée
installation	Installation	installation
installation guidelines	Einbaurichtlinien	conseils de montage
installation instruction	Einbauvorschriften	instructions de montage
insulation	Isolierung	isolation
insulation resistance	Isolationswiderstand	résistance d'isolation
integration	Integration	intégration
integration time	Integrationszeit	temps d'intégration
intensity	Intensität	intensité
interference	Störung	perturbation
interference free	störungsfrei	sans interférence
interference level	Störpegel	degré de perturbation
interference suppression	Störsignalunterdrückung	suppression de l'interférence
interfering signal	Störsignal	signal de perturbation
interfering voltage	Störspannung	tension de perturbation
internal resistance	Innenwiderstand	résistance interne
interruption	Aussetzen	interruption
inversion	Inversion	inversion
irradiance	Bestrahlung	irradiance
irradiation	Strahlungsintensität	irradiation
isobar	Isobar	isobar
isohel	isohel	isohel
isorad	isorad	isorad
isotherm	Isotherm	isotherme

J		
jumper	Kurzschlussbrücke	sauteur
K		
keyboard	Tastatur	clavier
L		
laboratory measurement equipment	Labor-Messgeräte	équipement de mesure de laboratoire
laboratory test	Laborversuch	expérience de laboratoire
lateral load	Querlast	charge latérale
lead	Leitung	conducteur
level	Niveau	niveau
level	nivellieren	niveller
level	Pegel	niveau
level indicator	Libelle	indicateur de niveau
levelling device	Nivelliereinrichtung	dispositif de mise de niveau
lever	Hebel	levier
lever arm	Hebelarm	bras de levier
liability	Haftung	responsabilité
life cycle	Lebensdauer	cycle de vie
light	Licht	lumière
light absorption	Lichtabsorption	absorption de lumière
light beam	Lichtstrahl	rayon de lumière
light cone	Lichtkegel	cône de lumière
light diffusion	Lichtstreuung	diffusion de la lumière
light emitting diode	Leuchtdiode	diode d'émission de lumière
light intensity	Lichtstärke	intensité lumineuse
light scatter	Lichtstreuung	diffusion de la lumière
light source	Lichtquelle	source de lumière
lightning protection	Blitzschutz	protection contre la foudre
lightning strike	Blitzschlag	coup de foudre
limit	Toleranz	tolérance
limit value	Grenzwert	valeur limite
limitation mark	Begrenzungszeichen	indicateur de limitation
limiting temperature range	Grenztemperaturbereich	gamme de limite de température
limits of error	Fehlergrenzen	erreurs maximales tolérées
linearity	Linearität	linéarité
linearity error	Linearitätsfehler	erreur de linéarité
linearizing	Linearisierung	linéarisation
litz wire	Kupferlitze	tresse de cuivre
load	beladen	charger
load	Belastung	charge
load	Last	charge
load capacity	Belastbarkeit	capacité de chargement
loading direction	Belastungsrichtung	direction de la charge
lock nut	Gegenmutter	contre-écrou
lock washer	Unterlegscheibe	rondelle
locking device	Arretiereinrichtung	dispositif de blocage
long term measurement	Langzeitmessung	mesure à longue terme
longitudinal axis	Längsachse	axe longitudinal
long-term drift	Langzeitdrift	dérive à longue terme
long-term stability	Langzeitstabilität	stabilité à longue terme
long-wave radiation	langwellige Strahlung	radiation de longues fréquences
luminance	Leuchtdichte	luminance
luminous numerical display	Leuchtziffernanzeige	écran numérique lumineux

M

main indication	Hauptanzeige	indication principale
maintenance	Wartung	maintenance
male connector	Stecker	connecteur mâle
marking	Aufschrift	marquage
mass	Masse	masse
mass of filling	Füllmenge	quantité de remplissage
material characteristic	Materialeigenschaft	caractéristique du matériau
maximum capacity	Tragfähigkeit	portée maximale
measurable	messbar	mesurable
measure of scatter	Streumaß	mesure de la diffusion
measured quantity	Messgröße	quantité mesurée
measured signal	Messsignal	signal mesurée
measurement	Messung	mesure
measurement accuracy	Messgenauigkeit	précision de mesure
measurement period	Messzeitraum	période de mesure
measurement setup	Messaufbau	établissement de la mesure
measurement site	Messort	site de mesure
measurement uncertainty	Messunsicherheit	incertitude de mesure
measuring area	Messfläche	aire de mesure
measuring cable	Messkabel	câble de mesure
measuring cable	Messleitung	câble de mesure
measuring chain	Messkette	chaîne de mesure
measuring channel	Messkanal	voie de mesure
measuring device	Messgerät	outil de mesure
measuring duration	Messdauer	temps de mesure
measuring electronics	Messelektronik	electronique de mesure
measuring element	Messelement	elément sensible
measuring equipment	Messeinrichtung	équipement de mesure
measuring error	Messfehler	erreur de mesure
measuring junction	Messstelle (eines Thermopaares)	jonction de mesure
measuring method	Messmethode	méthode de mesure
measuring method	Messprinzip	méthode de mesure
measuring point	Messort	point de mesure
measuring procedure	Messverfahren	procédure de mesure
measuring range	Messbereich	plage de mesure
measuring range selector	Messbereichsumschalter	sélecteur de sensibilités
measuring resistor	Messwiderstand	mesure de résistance
measuring result	Messergebnis	résultat de mesure
measuring system	Messsystem	système de mesure
measuring technique	Messtechnik	technique de mesure
measuring time	Messzeit	temps de mesure
measuring value	Messwert	valeur mesurée
measuring value memory	Messwertspeicher	mémoire de la valeur mesurée
medium	Medium	moyen
melting point	Schmelzpunkt	point de fonte
mercury	Quecksilber	mercure
mercury pressure gauge	Quecksilbermanometer	jauge de pression de mercure
meteorology	Meteorologie	météorologie
metric	metrisch	métrique
metrological property	Messtechnische Eigenschaft	propriété métrologiques
micro sensor	Miniaturaufnehmer	micro-capteur
micro technology	Mikrotechnologie	micro-technologie
millimetre of mercury	Millimeter Quecksilbersäule	millimètre mercure
millimetre of water column	Millimeter Wassersäule	colonne d'eau millimètre
minimum distance	Mindestabstand	espace minimum
minimum utilisation range	Mindestanwendungsbereich	gamme d'utilisation minimum

mirror	Spiegel	miroir
misbehaviour	Fehlverhalten	mauvaise conduite
misload	Fehlbelastung	charge d'erreur
mobility	Beweglichkeit	mobilité
Modem (Modulation/Demodulation)	Modem (Modulation/Demodulation)	modem (modulation/démodulation)
modification	Abänderung	modification
modulation	Modulation	modulation
module	Modul	module
moisture	Feuchtigkeit	humidité
moisture protection	Feuchteschutz	protection contre l'humidité
moisture protection	Feuchtigkeitsschutz	protection contre l'humidité
moment	Moment	moment
monitoring	Überwachung	enregistrement
mounting	Montage	montage
mounting advice	Einbauhinweis	conseil de montage
mounting aids	Einbauhilfe	accessoires de montage
mounting assembly	Einbaumodul	Module de montage
mounting example	Einbaubeispiel	exemple de montage
mounting instruction	Montageanleitung	instructions de montage
mounting instruction	Montagehinweis	indications de montage
mounting module	Montagebausatz	set de montage
mounting plate	Befestigungsplatte	lame de fixation
mounting surface	Montagefläche	surface de montage

N

natural frequency	Eigenfrequenz	fréquence propre
noise	Rauschen	bruit
nominal measuring range	Nennmessbereich	gamme de mesure nominale
nominal sensitivity	Nennkennwert	sensibilité nominale
non-conformity of a curve	Kennlinienabweichung	non-conformité d'une courbe
non-linearity	Nichtlinearität	non-linéarité
non-selective surface	unselektive Oberfläche	surface non sélective
NTC resistor	NTC-Widerstand	résistance NTC
numeric display	Digitalanzeiger	affichage numérique
numeric indication	Digitalanzeige	indication numérique

O

obliqueness	Schrägstellung	inclinaison
open system	offenes System	système ouvert
operating manual	Bedienungsanleitung	manuel d'emploi
operation	Betrieb	fonctionnement
operation temperature range	Nenntemperaturbereich	température de fonctionnement
operational fault	Funktionsfehler	panne fonctionnelle
operational reliability	Betriebssicherheit	fiabilité
operator	Bedienungsperson	opérateur
optical axis	optische Achse	axe optique
optical set-up	optischer Aufbau	installation optique
optimization	Optimierung	optimiser
orientation (angle)	Ausrichtung (Winkel)	angle d'orientation
output	Ausgabe	émission
output	Ausgang	sortie
output resistance	Ausgangswiderstand	resistance de sortie
output signal	Ausgangssignal	signal de sortie
overload	Überlast	surchargé
overload	Überlastung	surcharge

ozone	Ozon	ozone
ozone layer	Ozonschicht	couche d'ozone

P

package	Packung	emballage
pair of wires	Aderpaar	paire de conducteurs
parallax	Parallaxe	parallax
parallel connection	Parallelschaltung	branchement en parallèle
parameter	Parameter	paramètre
Peltier effect	Peltiereffekt	effet Peltier
Peltier element	Peltierelement	élément Peltier
percentage scale	Prozentskale	échelle en pourcentage
performance	Leistung	performance
perihelion	sonnennächster Punkt	perihélie
permissible	zulässig	acceptable
photo cell	Photozelle	cellule photo
photo diode	Fotodiode	photodiode
photo semiconductor	Fotohalbleiter	photo semiconducteur
photocell	Fotowiderstandszelle	photocelulle
photoelectric effect	Fotoelektrischer Effekt	effet photoélectrique
photometer	Lichtstärkemesser	photomètre
phototransistor	Fototransistor	phototransistor
pilot plant	Versuchsanlage	usine pilote
pivot	Zapfen	pivot - axe
place of installation	Aufstellungsort	lieu d'installation
place of use	Gebrauchsort	lieu d'utilisation
plane	eben	plane
plane surface	Oberfläche, plane	surface plane
platform	Plattform	plateforme
plug	Stecker	prise
plug connection	Steckeranschluss	connexion
plug connection	Steckverbindung	prise de courrant
pointer	Zeiger	curseur
polarisation characteristics	Polarisationsverhalten	caractéristiques de polarisation
preamplifier	Vorverstärker	préamplificateur
precipitation	Niederschlag	précipitation
precise	genau	précis
precision	Präzision	précision
preparatory measures	vorbereitende Maßnahme	mesures préparatoires
pressure	Druck	pression
pressure direction	Druckrichtung	direction de la pression
pressure load	Druckbelastung	charge de pression
probe tip	Messspitze	sonde
probe tip	Tastspitze	sonde
process	Prozess	procédé
processing device	Auswerteeinrichtung	dispositif processeur
proportionality	Proportionalität	proportionalité
proportioning	dosieren	doser
protection against corrosion	Korrosionsschutz	protection contre la corrosion
protection class	Schutzart	classe de protection
protective ground	Schutzleiter	protection de mise à la terre
PTC resistor	PTC-Widerstand	résistance PTC
pyranometer	Pyranometer	pyranomètre
pyrgeometer	Pyrgeometer	pyrgéomètre
pyrheliometer	Pyrheliometer	pyrhéliomètre
pyrometer	Pyrometer	pyromètre
pyrradiometer	Pyrradiometer	pyrradiomètre

Q

quantity	Menge	quantité
quartz	Quarz	quartz

R

radiant energy	Strahlungsenergie	énergie radiante
radiant flux	Strahlenfluss	flux radiant
radiation	Strahlung	radiation
radiometer	plattform	radiomètre
rain	Regen	pluie
random	Zufall	aléatoire
random error	zufällige Messabweichung	erreur aléatoire
range of use	Verwendungsbereich	domaine d'utilisation
range selection	Bereichsumschaltung	gamme de mesure
rate of change	Änderungsgeschwindigkeit	taux de change
reaction	Rückwirkung	réaction
ready for operation	betriebsbereit	prêt à fonctionner
recalibration	Nachkalibrierung	recalibration
receiver	Empfänger	récepteur
receiving surface	Empfangsfläche	surface de réception
recipe	Rezept	recette
recommended value	Richtwert	valeur recommandée
recording	Registrierung	enregistrement
recording device	Registriergerät	appareil enregistreur
reference	ergleichswert	référence
reference conditions	Referenzbedingungen	conditions de référence
reference element	Referenzelement	élément de référence
reference temperature	Referenztemperatur	température de référence
reflectance	Reflexionsgrad	réflexion
reflection	Reflexion	réflexion
refraction	Brechung	réfraction
relation	Beziehung	relation
relative error of measurement	relative Messabweichung	erreur relative de mesure
relay	Relais	relais
reliability	Zuverlässigkeit	conformité
remote control	Fernsteuerung	commande à distance
remote indication	Fernanzeige	indicateur á distance
repeatability	Wiederholbarkeit	répétabilité
reproducibility	Reproduzierbarkeit	reproductibilité
requirement	Anforderung	exigence
resistor	Widerstand	résistance
resolution	Auflösung	résolution
resonance	Resonanz	résonance
response	Antwort	réponse
response behaviour	Antwortverhalten	comportement de la réponse
response sensivity	Ansprechempfindlichkeit	sensibilité de résponse
response threshold	Ansprechschwelle	seuil de mobilité
response time	Ansprechdauer	temps de réponse
rest position	Ruhelage	position de repos
result	Resultat	résultat
reversible	reversibel	réversible
rise time	Anstiegszeit	temps de montée
rod	Stab	barre
rod	Tragarm	console
rounding error	Rundungsfehler	erreur d'arrondissage

S

scale	Skale	échelle
scale	Teilung	étape
scale division	Skalenteil	échelon
scattering	Streuung	écartement
scattering angle	Streuwinkel	angle d’écartement
scope of delivery	Lieferumfang	étendue de livraison
screw	Schraube	vis
seal	plombieren	plomber
second	Sekunde (Zeit)	seconde
second of arc	Sekunde (Bogen)	seconde (arc)
security	Sicherheit	sécurité
security regulations	Sicherheitsvorschriften	règles de sécurité
selection	Auswahl	sélection
selection device	Umschalteinrichtung	dispositif de sélection
selective surface	selektive Oberfläche	surface sélective
sensing line	Fühlerleitung	détecteur
sensitivity	Empfindlichkeit	sensibilité
sensitivity	Kennwert	sensibilité
sensitivity adjusting device	Empfindlichkeitseinsteller	dispositif de réglage de sensibilité
sensitivity range	Kennwertbereich	gamme de sensibilités
sensitivity tolerance	Kennwerttoleranz	tolérance de la sensibilité
sensor	Sensor	capteur
sensor	Fühler	détecteur
serial interface	serielle Schnittstelle	interface en série
series	Typenreihe	gamme
series resistance	Reihenwiderstand (physikalisch)	résistance séries
series resistor	Reihenwiderstand (Bauelement)	résistance séries
set point	Schaltpunkt	point de tri
set to zero	Nullstellen	mettre á zéro
setting index	Einstellmarke	index de réglage
setting range	Einstellbereich	gamme de réglage
setting value	Einstellwert	valeur de réglage
shade	Schatten	ombre
shading device	Abschattvorrichtung	dispositif d’ombrage
shielded cable	Leitung, abgeschirmt	câble de sécurité
shielding	abschirmen	protection
shielding	Abschirmung	blindage
shock resistance	Stoßfestigkeit	résistance aux chocs
short circuit	Kurzschluss	court-circuit
short-term stability	Kurzzeitstabilität	stabilité court terme
short-term test	Kurzzeitversuch	test de courte durée
short-wave radiation	kurzwellige Strahlung	radiation onde courte
shunt	Nebenschlusswiderstand	résistance de dérivation
side force	Seitenkraft	force latérale
silicagel	Silikagel	silicagel
silicon	Silizium	silicium
skin effect	Hauteffekt	effet sur la peau
sky radiation	Himmelsstrahlung	radiation du ciel
slope angle	Böschungswinkel	angle de la pente
software	Software	logiciel
solar activity	Sonnentätigkeit	activité solaire
solar altitude	Höhenwinkel der Sonne	altitude du soleil
solar azimuth	Azimutwinkel der Sonne	azimuth solaire
solar cell	Solarzelle	cellule solaire
solar constant	Solarkonstante	constante solaire
solar contribution	solare Mitwirkung	contribution solaire

solar declination	Solarneigung	déclinaison solaire
solar eclipse	Sonnenfinsternis	éclipse solaire
solar energy	Solarenergie	énergie solaire
solar flux	Sonnenenergiefluss	flux solaire
solar irradiance simulator	Bestrahlungssimulator	simulateur de l'irradiation solaire
solar irradiation	Sonnenbestrahlung	rayonnement solaire
solar noon	Mittag (auf die Sonne bezogen)	lune solaire
solar radiation	Solarstrahlung	radiation solaire
solar spectrum	Solarspektrum	spectre solaire
solar time	Sonnenzeit	heure solaire
solarimeter	Solarimeter	solarimètre
solstice	Sonnenwende	solstice
spark	Funken	étincelle
spectra	Spektrum	spectre
spectral analysis	Spektralanalyse	analyse spectrale
spectral distribution	spektrale Strahlungsverteilung	distribution spectrale
spectral filter	Farbfilter	filtre spectral
spectral pyranometer	Spektralpyranometer	pyranomètre spectral
spectral radiant intensity	spektrale Strahlungsintensität	intensité du rayonnement spectral
spectral sensitivity	spektrale Empfindlichkeit	sensibilité spectrale
spectro radiometer	Spektroradiometer	spectroradiomètre
speculum	Spiegel	spéculum
speed of light	Lichtgeschwindigkeit	vitesse de la lumière
spirit level	Wasserwaage	niveau à bulle
spot check	Stichprobe	vérification
stability	Messbeständigkeit	stabilité
stability	Stabilität	stabilité
stability of zero	Nullpunktstabilität	stabilité du zéro
stability test	Stabilitätsprüfung	essai de stabilité
stainless steel	Edelstahl	acier inoxydable
stamp	stempeln	marquer
standard	Normal	étalon
standard barometric pressure	barometrischer Standarddruck	pression barométrique standard
standard climate	Normklima	climat normal
standard conditions	Normalbedingungen	conditions normales
standard deviation	Standardabweichung	écart type
standardize	normieren	standardiser
standby condition	Bereitschaftszustand	condition d'attente
start-up time	Vorlaufzeit	temps de course
static	statisch	statique
statistical processing	statistische Bearbeitung	procédé statistique
stiffener	Versteifung	contrefort
storage temperature range	Lagerungstemperaturbereich	température de stockage
storm	Sturm	tempête
strain	Dehnung	tension
stress	Beanspruchung	stress
suitability	Tauglichkeit	convenance
sum	Summe	somme
sun	Sonne	soleil
sun recorder	Heliograph	héliographe
sun-path diagram	Verlauf des Sonnenpfades	diagramme trajectoire du soleil
sunpower	Sonnenenergie	puissance solaire
sunrise	Sonnenaufgang	lever du soleil
sunset	Sonnenuntergang	coucher du soleil
sunshine	Sonnenschein	luminosité solaire
sunshine recorder	Sonnenscheinschreiber	enregistreur de radiation solaire
supply	Speisung	alimentation

support	abstützen	soutenir
support bearing	Lager	palier
support rollers	Tragrollen	rouleaux porteurs
support structure	Unterbau	fondation
supporting force	Auflagekraft	force d'appui
supporting point	Auflagepunkte	point d'appui
surface	Oberfläche	surface
surface temperature	Oberflächentemperatur	température à la surface
surface treatment	Oberflächenbehandlung	traitement de surface
surge arrester	Überspannungsableiter	dispositif d'arrêt de surtension
surroundings	Umgebung	environnement
switch	Schalter	commutateur
switch off	ausschalten	éteindre
symbol of units of measurement	Einheitenzeichen	symbole des unités de mesure
systematic error systematische	Messabweichung	erreur systématique

T

technical data	technische Daten	données techniques
temperate climate	gemäßigtes Klima	climat tempéré
temperature	Temperatur	température
temperature balance	Temperaturausgleich	balance de température
temperature chamber	Temperaturschrank	chambre de température
temperature coefficient	Temperaturkoeffizient	coefficient de température
temperature compensation	Temperaturkompensation	compensation de température
temperature constancy	Temperaturkonstanz	constance de température
temperature dependence	Temperaturabhängigkeit	dépendance de la température
temperature deviation	Temperaturschwankung	deviation de température
temperature drop	Temperaturabfall	goutte
temperature gradient	Temperaturgradient	gradient de température
temperature influence	Temperatureinfluss	influence de la température
temperature inversion	Temperaturumkehr	inversion de température
temperature measurement	Temperaturmessung	mesure de température
temperature range	Temperaturbereich	gamme de température
temperature response	Temperaturverhalten	réponse de température
temperature rise	Temperaturanstieg	hausse de température
temperature sensitive	temperaturempfindlich	sensibilité à la température
temperature sensor	Temperaturfühler	capteur de température
temperature stability	Temperaturbeständigkeit	stabilité de température
temporary	zeitweise	temporaire
tension	Spannung (mechanisch)	tension
terminating resistor	Abschlusswiderstand	résistance
test circuit	Kontrollschaltung	circuit de contrôle
test input	Messeingang	entrée test
test method	Prüfmethode	méthode de test
test piece	Prüfling	unité de test
test program	Prüfprogramm	programme d'essai
test report	Prüfbericht	protocole d'essai
test result	Prüfergebnis	résultat d'essai
test site	Messgelände	site de test
test specification	Prüfvorschrift	spécification de test
test voltage	Prüfspannung	test tension
testing	Prüfen	test
thermal convection	Thermokonvektion	convection thermique
thermal effect	Thermoeffekt (Seebeck-Effekt)	effet thermique
thermistor	Thermistor	thermistance
thermocouple	Thermoelement	thermocouple

thermometer	Thermometer	thermomètre
thermopile	thermoelektrische Säule	thermopile
thread	Gewinde	fil
thread hole	Gewindeloch	taraudage
tightening force (torque)	Anzugsmoment	Couple de démarrage
tilt error	Neigungseinfluss	erreur d'inclinaison
tilt response	Neigungsverhalten	réponse d'inclinaison
time constant	Zeitkonstante	constance de temps
torque	Drehmoment	couple
torsion	Verdrehung	torsion
total error	Gesamtfehler	erreur totale
total incident radiation	gesamt einfallende Strahlung	influence du rayonnement total
traceability	Rückführbarkeit	traçabilité
tracking error	Nachlauffehler	erreur de poursuite
transducer	Aufnehmer	convertisseur
transmitter	Sender	transmetteur
transport locking device	Transportsicherung	dispositif de blocage de transport
turbulence	Turbulenz	turbulence
twilight	Zwielicht	crépuscule
type	Typ	type
type of protection	Schutzart	degré de protection

U

ultraviolet radiation	Ultraviolett Strahlung	rayonnement ultraviolet
uncertainty	Unsicherheit	incertitude
uneven surface	Oberfläche, gekrümmte	surface courbée

V

validity	Gültigkeit	validité
variability	Veränderlichkeit	variabilité
variation	Änderung	variation
ventilation slit	Belüftungsspalt	ouverture de ventilation
ventilation unit	Belüftungseinheit	unité de ventilation
verification certificate	Eichbescheinigung	certificat de vérification
verification device	Eicheinrichtung dispositif	auxiliaire de vérification
verification instruction	Eichanweisung	instruction de vérification
verify	eichen	vérifier
vernier	Nonius	vernier
vibration	Schwingung	vibration
vibration damper	Vibrationsdämpfer	amortisseur
vibration damping	Schwingungsdämpfung	amortissement de vibration
view angle	Gesichtsfeldwinkel	angle de vue
visibility	Sicht	visibilité
visible radiation	sichtbare Strahlung	rayonnement visible
voltage	Spannung (elektrisch)	tension

W

warm up time	Anwärmzeit	temps de préchauffage
warranty	Garantie	garantie
wavelength	Wellenlänge	longueur d'onde
weather	Wetter	temps
weight	Gewicht	poids
Wheatstone bridge	Wheatstone'sche Brücke	pont de Wheatstone
wind	Wind	vent

wind direction	Windrichtung	direction du vent
wind forces	Windkräfte	forces du vent
wind speed	Windgeschwindigkeit	vitesse du vent
wind vane	Windfahne	girouette
wire	Ader	conducteur
wireless transmission	drahtlose Übertragung	transmission sans fil
World Radiometric Reference (WRR)	Welt Strahlungs Referenz	référence radiomètrique mondiale

Z

zenith	Scheitelpunkt	zénith
zenith angle	Sonnenstandswinkel	angle du zénith
zenith angle of sun	Sonnenstand	angle du zénith soleil
zero drift	Nullpunktdrift	déviation du zéro
zero offset	Null-Offset	zéro offset
zero point	Nullpunkt	point zéro
zero position	Nulllage	position zéro
zero setting device	Nullstelleinrichtung	dispositif de mise á zéro
zero signal	Nullsignal	valeur zéro
zone of use	Gebrauchszone	zone d’utilisation

Français	Deutsch	English
A		
absorber	Absorber	absorber
absorption de lumière	Lichtabsorption	light absorption
accélération	Beschleunigung	acceleration
acceptable	zulässig	permissible
accessoires	Zubehör	accessories
accessoires de montage	Einbauhilfe	mounting aids
accumulateur	Akkumulator	accumulator
acier inoxydable	Edelstahl	stainless steel
activité solaire	Sonnentätigkeit	solar activity
adaptateur	Adapter	adapter
adaptation	Adaption	adaption
affichage	Anzeiger	display
affichage lumineux	Leuchtbildanzeige	illuminated display
affichage numérique	Digitalanzeiger	numeric display
afficher	anzeigen	display
air ambiant	Umgebungsluft	ambient air
aire de mesure	Messfläche	measuring area
ajustement - réglage	Abgleich	adjustment
ajuster - régler	justieren	adjust
alarme	Alarm	alarm
albedo	Albedo	albedo
aléatoire	Zufall	random
aligner	ausrichten	aligning
alimentation	Speisung	supply
alimentation batterie	Batteriespeisung	battery supply
alternance	alternierend	alternating
altitude du soleil	Höhenwinkel der Sonne	solar altitude
amortissement	Dämpfung	damping
amortissement de vibration	Schwingungsdämpfung	vibration damping
amortisseur	Vibrationsdämpfer	vibration damper
amplificateur	Verstärker	amplifier
amplificateur à courant continu	Gleichspannungs-Messverstärker	DC amplifier
analogique	Analog	analogue
analyse spectrale	Spektralanalyse	spectral analysis
anémomètre	Windgeschwindigkeitsmesser	anemometer
angle de la pente	Böschungswinkel	slope angle
angle de vue	Gesichtsfeldwinkel	view angle
angle d’écartement	Streuwinkel	scattering angle
angle d’incidence	Einfallswinkel	incident angle
angle d’orientation	Ausrichtung (Winkel)	orientation (angle)
angle d’ouverture	Öffnungsebene	aperture plane
angle du zénith	Sonnenstandswinkel	zenith angle
angle du zénith soleil	Sonnenstand	zenith angle of sun
angularité	Winkelstellung	angularity
annonce d’alarme	Alarmmeldung	alert notice
aphelie Sonnen	entferntester Punkt	aphelion
appareil enregistreur	Registriergerät	recording device
application	Einsatz	application
approbation	Zulassung	approval
archivage des données	Datenarchivierung	data archiving
arrangement	Anordnung	arrangement
atmosphère	Atmosphäre	atmosphere
atténuateur	Abschwächer	attenuator
atténuation	Dämpfung	attenuation

autorité d’approbation	Zulassungsbehörde	approving authority
axe	Achse	axle
axe de blocage	Befestigungsbolzen	fastening bolt
axe longitudinal	Längsachse	longitudinal axis
axe optique	optische Achse	optical axis
axial	axial	axial
azimuth	Scheitelkreis	azimuth
azimuth solaire	Azimutwinkel der Sonne	solar azimuth

B

bar	Bar	bar
baromètre	Barometer aneroid	barometer
baromètre	Barometer	barometer
barre	Stab	bar
barre	Stab	rod
bâton	Stange	bar
batterie	Batterie	battery
batterie de sauvegarde	Pufferbatterie	back up battery
blindage	Abschirmung	shielding
boite de raccordement	Kabelkasten	cable box
boîtier	Gehäuse	housing
bornier de raccordement	Anschlussklemme	connecting terminal
boulon de fixation	Spannschraube	clamp bolt
branchement en parallèle	Parallelschaltung	parallel connection
bras de levier	Hebelarm	lever arm
brider	anflanschen	flange
bruit	Rauschen	noise
brut	brutto	gross

C

câble	Kabel	cable
câble de connexion	Anschlussdraht	connection wire
câble de liaison	Verbindungskabel	connection cable
câble de mesure	Messkabel	measuring cable
câble de raccordement	Kabelanschluss	cable connection
câble de sécurité	Leitung, abgeschirmt	shielded cable
cadre	Rahmen	frame
calibration	Kalibrierung	calibration
calibrer	eichen	calibrate
capacité de chargement	Belastbarkeit	load capacity
capteur	Sensor	sensor
capteur de température	Temperaturfühler	temperature sensor
caractéristique du matériau	Materialeigenschaft	material characteristic
caractéristiques de polarisation	Polarisationsverhalten	polarisation characteristics
cellule photo	Photozelle	photo cell
cellule solaire	Solarzelle	solar cell
centrage	Zentrierung	centering
centre de gravité	Schwerpunkt	centre of gravity
certificat de calibration	Kalibrierzeugnis	calibration certificate
certificat de vérification	Eichbescheinigung	verification certificate
chaîne de mesure	Messkette	measuring chain
chaleur d’évaporation	Verdampfungswärme	heat of evaporation
chambre de température	Temperaturschrank	temperature chamber
champ de vue	Öffnungswinkel	field of view
champ d’opération	Arbeitsfeld	field of operation

changer	auswechseln	exchange
charge	Belastung	load
charge	Last	load
charge de pression	Druckbelastung	pressure load
charge de rupture	Bruchlast	breaking load
Charge d'erreur	Fehlbelastung	misload
charge latérale	Querlast	lateral load
charge permanente	Dauerbelastung	continuous load
charger	beladen	load
chaud	heiß	hot
chauffage	Heizung	heating
circuit de contrôle	Kontrollschaltung	test circuit
circuit de pont	Brückenschaltung	bridge circuit
circuit électrique	Stromkreis	current circuit
classe de précision	Genauigkeitsklasse	accuracy class
classe de protection	Schutzart	protection class
classe d'utilisation	Anwendungsklasse	application class
clavier	Tastatur	keyboard
climat	Klima	climate
climat normal	Normklima	standard climate
climat tempéré	gemäßigtes Klima	temperate climate
coefficient de température	Temperaturkoeffizient	temperature coefficient
coffret de contrôle climatique	Klimaschrank	climate-controlled cabinet
colonne d'eau millimètre	Millimeter Wassersäule	millimetre of water column
commande	Betätigung	actuation
commande à distance	Fernsteuerung	remote control
commutateur	Schalter	switch
compensation	Ausgleich	balancing
compensation de la pression atmosphérique	Luftdruckausgleich	air pressure compensation
compensation de température	Temperaturkompensation	temperature compensation
composant	Bauteil	component
comprtement de la réponse	Antwortverhalten	response behaviour
concentreur	Konzentrator	concentrator
condition d'attente	Bereitschaftszustand	standby condition
condition environnante	Umweltbedingung	environmental condition
conditions atmosphériques	Witterung	atmospheric conditions
conditions de référence	Referenzbedingungen	reference conditions
conditions normales	Normalbedingungen	standard conditions
conducteur	Ader	wire
conducteur	Leitung	lead
conducteur de la chaleur	Wärmeleiter	heat conductor
conducteur de mise à la terre	Erdleitung	ground lead
conductivité de la chaleur	Wärmeleitfähigkeit	heat conductivity
conductivité de la chaleur	Wärmeleitvermögen	heat conductivity
cône de lumière	Lichtkegel	light cone
conformité	Zuverlässigkeit	reliability
connecteur	Anschlussstecker	connector
connecteur mâle	Stecker	male connector
connexion	Steckeranschluss	plug connection
conseil de montage	Einbauhinweis	mounting advice
conseils de montage	Einbaurichtlinien	installation guidelines
console	Tragarm	rod
constance de température	Temperaturkonstanz	temperature constancy
constance de temps	Zeitkonstante	time constant
constante d'absorption	Absorptionskonstante	absorption constant
constante solaire	Solarkonstante	solar constant
construction	Ausführung	design

construction	Konstruktion	construction
contenu	Inhalt	content
contour	Außenlinie	contour
contre-écrou	Gegenmutter	lock nut
contrefort	Versteifung	stiffener
contrepoids d'équilibrage	Ausgleichsgewicht	counterbalance weight
contribution solaire	solare Mitwirkung	solar contribution
contrôle	Kontrolle	control
contrôle de fonction	Funktionskontrolle	checking of operation
contrôle de qualité	Beschaffenheitsprüfung	condition testing
convection thermique	Thermokonvektion	thermal convection
convenance	Tauglichkeit	suitability
convertisseur	Aufnehmer	transducer
convertisseur analogique digital	Analog-Digital-Konverter	analog-digital converter
convertisseur analogique digital	Analog-Digital-Wandler	analog-digital converter
corrosion	Korrosion	corrosion
couche atmosphérique	atmosphärische Schicht	atmospheric layer
couche d'ozone	Ozonschicht	ozone layer
coucher du soleil	Sonnenuntergang	sunset
coup de foudre	Blitzschlag	lightning strike
couperet	Wechselrichter	chopper
couple	Drehmoment	torque
Couple de démarrage	Anzugsmoment	tightening force (torque)
courbe d'erreur	Fehlerkurve	deviation curve
courbe d'étalonnge	Kennlinie	calibration curve
court-circuit	Kurzschluss	short circuit
crépuscule	Zwielicht	twilight
critére	Kriterium	criterion
crochet	Haken	hook
cuivre	Kupfer	copper
curseur	Zeiger	pointer
cycle de vie	Lebensdauer	life cycle

D

déclinaison solaire	Solarneigung	solar declination
définition	Definition	definition
déformation	Verformung	deformation
dégât	Beschädigung	damage
degré de perturbation	Störpegel	interference level
degré de protection	Schutzart	type of protection
demi-pont	Halbbrücke	half bridge
démontage	Demontage	disassemble
dénomination	Bezeichnung	indication
densité	Dichte	density
dépendance de la pression atmosphérique	Luftdruckabhängigkeit	air pressure dependence
dépendance de la température	Temperaturabhängigkeit	temperature dependence
dérive	Drift	drift
dérive à longue terme	Langzeitdrift	long-term drift
dérive de zéro	Nullsignaländerung	change in zero signal
dérive du zéro	Driftfehler	drift error
détecteur	Fühler	sensor
détecteur	Fühlerleitung	sensing line
déviation	Abweichung	deviation
deviation de température	Temperaturschwankung	temperature deviation
déviation du zéro	Nullpunktdrift	zero drift
diagramme	Diagramm	diagramme

diagramme de circuit	Schaltplan	circuit diagram
diagramme de circuit	Stromlaufplan	circuit diagram
diamètre	Durchmesser	diameter
diffraction	Beugung	diffraction
diffusion	Diffusion	diffusion
diffusion de la lumière	Lichtstreuung	light diffusion
diffusion de la lumière	Lichtstreuung	light scatter
dimension	Abmessung	dimension
dimension	Bemaßung	dimensioning
dimension	Dimension	dimension
diode d’émission de lumière	Leuchtdiode	light emitting diode
direction de la charge	Belastungsrichtung	loading direction
direction de la pression	Druckrichtung	pressure direction
direction du vent	Windrichtung	wind direction
discontinu	diskontinuierlich	discontinuous
dispositif antichoc	Stoßfänger	buffer
dispositif auxiliaire de vérification	Eicheinrichtung	verification device
dispositif d’arrêt de surtension	Überspannungsableiter	surge arrester
dispositif de blocage	Arretiereinrichtung	locking device
dispositif de blocage de transport	Transportsicherung transport	locking device
dispositif de compensation	Ausgleichseinrichtung	compensating device
dispositif de correction	Korrektureinrichtung	correction device
dispositif de mise á zéro	Nullstelleinrichtung	zero setting device
dispositif de mise de niveau	Nivelliereinrichtung	levelling device
dispositif de réglage de sensibilité	Empfindlichkeitseinsteller	sensitivity adjusting device
dispositif de sélection	Umschalteinrichtung	selection device
dispositif d’ombrage	Abschattvorrichtung	shading device
dispositif indicateur	Anzeigeeinrichtung	indication device
dispositif processeur	Auswerteeinrichtung	processing device
disque parabolique	Kollektor, Parabolspiegel	collector, parabolic dish
dissipation de la chaleur	Wärmeableitung	heat dissipation
distance	Abstand	distance
distribution spectrale	spektrale Strahlungsverteilung	spectral distribution
domaine d’application	Einsatzbereich	field of application
domaine d’utilisation	Verwendungsbereich	range of use
données techniques	technische Daten	technical data
doser	dosieren	proportioning
Dynamique	Dynamik	dynamics
dynamique	dynamisch	dynamic

E

écart type	Standardabweichung	standard deviation
écartement	Streuung	scattering
échangeur thermique	Wärmetauscher	heat exchanger
échelle	Skale	scale
échelle circulaire	Kreisskale	circular scale
échelle en pourcentage	Prozentskale	percentage scale
échelon	Skalenteil	scale division
éclipse solaire	Sonnenfinsternis	solar eclipse
écran numérique lumineux	Leuchtziffernanzeige	luminous numerical display
effet de température	Temperaturgang	effect of temperature
effet Peltier	Peltiereffekt	Peltier effect
effet photoélectrique	Fotoelektrischer Effekt	photoelectric effect
effet sur la peau	Hauteffekt	skin effect
effet thermique	Thermoeffekt (Seebeck-Effekt)	thermal effect
élasticité	Elastizität	elasticity

electronique de mesure	Messelektronik	measuring electronics
élément d’ajustement	Abgleichelement	adjusting element
élément de contróle	Bedienungselement	control element
élément de référence	Referenzelement	reference element
élément Peltier	Peltierelement	Peltier element
elément sensible	Messelement	measuring element
élimination des erreurs	Fehlerbeseitigung	curing of defects
emballage	Packung	package
émission	Ausgabe	output
émission	Aussendung	emittance
énergie du rayonnement	Strahlungsenergie	energy of radiation
énergie radiante	Strahlungsenergie	radiant energy
énergie solaire	Solarenergie	solar energy
enregistrement	Registrierung	recording
enregistrement	Überwachung	monitoring
enregistreur de radiation solaire	Sonnenscheinschreiber	sunshine recorder
entrée	Eingang	input
entrée test	Messeingang	test input
enveloppe	Auskleidung	coating
environnement	Umgebung	environment
environnement	Umgebung	surroundings
environnement	Umwelt	environment
environnement agressif	aggressive Umgebung	aggressive environment
équateur	Äquator	equator
équilibrage du pont	Brückenabgleich	bridge balance
équipement de mesure	Messeinrichtung	measuring equipment
équipement de mesure de laboratoire	Labor-Messgeräte	laboratory measurement equipment
erreur	Abweichung	error
erreur	Fehler	error
erreur aléatoire	zufällige Messabweichung	random error
erreur combinée	Fehler zusammengesetzter	combined error
erreur d’arrondissage	Rundungsfehler	rounding error
erreur de dérive	Kriechfehler	error due to drift
erreur de linéarité	Linearitätsfehler	linearity error
erreur de mesure	Messabweichung	error of measurement
erreur de mesure	Messfehler	measuring error
erreur de poursuite	Nachlauffehler	tracking error
erreur d’hystérésis	Hysteresefehler	hysteresis error
erreur d’hystérésis	Umkehrspanne	hysteresis error
erreur d’inclinaison	Neigungseinfluss	tilt error
erreur d’indication	Anzeigefehler	indication error
erreur relative de mesure	relative Messabweichung	relative error of measurement
erreur systématique	systematische Messabweichung	systematic error
erreur totale	Gesamtfehler	total error
erreurs maximales tolérées	Fehlergrenzen	limits of error
espace minimum	Mindestabstand	minimum distance
essai de stabilité	Stabilitätsprüfung	stability test
essais d’endurance	Dauerprüfung	endurance test
établissement de la mesure	Messaufbau	measurement setup
étalon	Normal	standard
étalon de calibration	Kalibriernormal	calibration standard
étalonner	kalibrieren	calibrate
étape	Teilung	scale
éteindre	ausschalten	switch off
étendue de livraison	Lieferumfang	scope of delivery
évaluation	Auswertung	evaluation
évaporation	Verdunstung	evaporation

excentrée	außermittig	eccentric
exemple de montage	Einbaubeispiel	mounting example
exigence	Anforderung	requirement
expérience de laboratoire	Laborversuch	laboratory test
extension de câble	Kabelverlängerung	cable extension

F

faisceau	Balken	beam
fiabilité	Betriebssicherheit	operational reliability
fiche des données	Datenblatt	data sheet
fil	Gewinde	thread
filtre	Filter	filter
filtre spectral	Farbfilter	spectral filter
fixation	Befestigung	fastening
fluage	Kriechfehler	creep error
flux radiant	Strahlenfluss	radiant flux
flux solaire	Sonnenenergiefluss	solar flux
fonction	Funktion	function
fonctionnement	Betrieb	operation
fonctionnement de la batterie	Batteriebetrieb	battery operation
fondation	Unterbau	support structure
force d'appui	Auflagekraft	supporting force
force d'endurance	Dauerfestigkeit	endurance strength
force latérale	Seitenkraft	side force
forces du vent	Windkräfte	wind forces
formule	Formel	formula
fréquence propre	Eigenfrequenz	natural frequency
friction	Reibung	friction

G

gain	Vertärkungsfaktor	gain
gamme	Typenreihe	series
gamme d'affichage	Anzeigebereich	indicating range
gamme de fréquence	Frequenzbereich	frequency range
gamme de limite de température	Grenztemperaturbereich	limiting temperature range
gamme de mesure	Bereichsumschaltung	range selection
gamme de mesure nominale	Nennmessbereich	nominal measuring range
gamme de réglage	Einstellbereich	setting range
gamme de sensibilités	Kennwertbereich	sensitivity range
gamme de température	Temperaturbereich	temperature range
gamme de température cryogénique	Tieftemperaturbereich	cryogenic temperature range
gamme d'utilisation minimum	Mindestanwendungsbereich	minimum utilisation range
garantie	Garantie	warranty
girouette	Windfahne	wind vane
goujon	Bolzen	bolt
goutte	Temperaturabfall	temperature drop
gradient de température	Temperaturgradient	temperature gradient
gravitation	Schwerkraft	gravity
grêle	Hagel	hail

H

hausse de température	Temperaturanstieg	temperature rise
haute tension	Hochspannung	high tension
hauteur de construction	Bauhöhe	height of construction

héliocentrique	heliozentrisch	heliocentric
héliographe	Heliograph	sun recorder
heliotype	Lichtdruck	heliotype
hermétique	hermetisch	hermetic
heure	Stunde	hour
heure solaire	Sonnenzeit	solar time
humidité	Feuchtigkeit	humidity
humidité	Feuchtigkeit	moisture
hygromètre	Feuchtemesser	hygrometer
hygromètre à cheveu	Haarhygrometer	hair hygrometer
hygrométrie	Luftfeuchtigkeit	air humidity
hystérèsis	Hysterese	hysteresis

I

illuminance	Beleuchtungsstärke	illuminance
incertitude	Unsicherheit	uncertainty
incertitude de mesure	Messunsicherheit	measurement uncertainty
inclinaison	Schrägstellung	obliqueness
index de réglage	Einstellmarke	setting index
indicateur	Anzeigegerät	indicator
indicateur á distance	Fernanzeige	remote indication
indicateur analogique	Analoganzeiger	analog indicator
indicateur de limitation	Begrenzungszeichen	limitation mark
indicateur de niveau	Libelle	level indicator
indication	Anzeige	indication
indication	Messwert	indication
indication analogique	Analoganzeige	analog indication
indication numérique	Digitalanzeige	numeric indication
indication principale	Hauptanzeige	main indication
indications de montage	Montagehinweis	mounting instruction
influence	Beeinflussung	influence
influence	Einfluss	influence
influence de la température	Temperatureinfluss	temperature influence
influence de l'inclinaison	Richtungsabhängigkeit	directional dependence
influence du câble	Kabeleinfluss	cable influence
influence du conducteur	Messleitungseinfluss	influence of measuring lead
influence du rayonnement total	gesamt einfallende Strahlung	total incident radiation
influence environnante	Umwelteinfluss	environmental influence
infrastructure	Unterwerk	infrastructure
installation	Installation	installation
installation optique	optischer Aufbau	optical set-up
instruction de vérification	Eichanweisung	verification instruction
instructions de montage	Montageanleitung	mounting instruction
instructions de montage	Einbauvorschriften	installation instruction
intégration	Integration	integration
intensité	Intensität	intensity
intensité lumineuse	Lichtstärke	light intensity
interface en série	serielle Schnittstelle	serial interface
interruption	Aussetzen	interruption
inversion	Inversion	inversion
inversion de température	Temperaturumkehr	temperature inversion
irradiance	Bestrahlung	irradiance
irradiation	Strahlungsintensität	irradiation
isobar	Isobar	isobar
isohel	isohel	isohel
isolation	Isolierung	insulation

isorad	isorad	isorad
isotherme	Isotherm	isotherm

J

jauge de pression de mercure	Quecksilbermanometer	mercury pressure gauge
jonction de mesure	Messstelle (eines Thermopaares)	measuring junction
justesse	Richtigkeit	freedom from bias

L

lame de fixation	Befestigungsplatte	mounting plate
largeur de la bande	Bandbreite	bandwidth
lentille de Fresnel	Fresnellinse	fresnel lens
lever du soleil	Sonnenaufgang	sunrise
levier	Hebel	lever
lieu d'installation	Aufstellungsort	place of installation
lieu d'utilisation	Gebrauchsort	place of use
limite de courant	Strombegrenzung	current limitation
linéarisation	Linearisierung	linearizing
linéarité	Linearität	linearity
logiciel	Software	software
longueur d'onde	Wellenlänge	wavelength
longueur équivalente	equivalente Länge	equivalent length
lumière	Licht	light
luminance	Leuchtdichte	luminance
luminosité	Beleuchtung	illumination
luminosité solaire	Sonnenschein	sunshine
lune solaire	Mittag (auf die Sonne bezogen)	solar noon

M

maintenance	Wartung	maintenance
manuel d'emploi	Bedienungsanleitung	operating manual
manutention	Handhabung	handling
marquage	Aufschrift	marking
masse	Masse	mass
masse d'air	Luftmasse	air mass
mauvaise conduite	Fehlverhalten	misbehaviour
mémoire de la valeur mesurée	Messwertspeicher	measuring value memory
mercure	Quecksilber	mercury
mesurable	messbar	measurable
mesure	Messung	measurement
mesure à longue terme	Langzeitmessung	long term measurement
mesure de la diffusion	Streumaß	measure of scatter
mesure de résistance	Messwiderstand	measuring resistor
mesure de température	Temperaturmessung	temperature measurement
mesures préparatoires	vorbereitende Maßnahme	preparatory measures
météorologie	Meteorologie	meteorology
méthode de mesure	Messmethode	measuring method
méthode de mesure	Messprinzip	measuring method
méthode de test	Prüfmethode	test method
métrique	metrisch	metric
mettre á zéro	Nullstellen	set to zero
micro-capteur	Miniaturaufnehmer	micro sensor
micro-technologie	Mikrotechnologie	micro technology
millimètre mercure	Millimeter Quecksilbersäule	millimetre of mercury

miroir	Spiegel	mirror
mobilité	Beweglichkeit	mobility
modèle d'instrument de pesage	Bauart	design
modem (modulation/démodulation)	Modem (Modulation/Demodulation)	Modem (Modulation/Demodulation)
modification	Abänderung	modification
modulation	Modulation	modulation
module	Modul	module
Module de montage	Einbaumodul	mounting assembly
moment	Moment	moment
moment de flexion	Biegemoment	bending moment
montage	Montage	mounting
moyen	Medium	medium
moyenne	Durchschnitt	average
moyenne	Mittelwert	average

N

niveau	Niveau	level
niveau	Pegel	level
niveau à bulle	Wasserwaage	spirit level
niveller	nivellieren	level
non-conformité d'une courbe	Kennlinienabweichung	non-conformity of a curve
non-linéarité	Nichtlinearität	non-linearity
nuage	Wolke	cloud
numérique	digital	digital

O

ombre	Schatten	shade
opérateur	Bedienungsperson	operator
optimiser	Optimierung	optimization
outil auxiliaire	Zusatzeinrichtung	auxiliary device
outil de mesure	Messgerät	measuring device
ouverture - orifice	Blende	aperture
ouverture de ventilation	Belüftungsspalt	ventilation slit
ozone	Ozon	ozone

P

paire de conducteurs	Aderpaar	pair of wires
palier	Lager support	bearing
panne fonctionnelle	Funktionsfehler	operational fault
parallax	Parallaxe	parallax
paramètre	Parameter	parameter
partie inférieure	Unterteil	base
performance	Leistung	performance
perihélie	sonnennächster Punkt	perihelion
période de mesure	Messzeitraum	measurement period
perturbation	Störung	interference
photo semiconducteur	Fotohalbleiter	photo semiconductor
photocelulle	Fotowiderstandszelle	photocell
photodiode	Fotodiode	photo diode
photomètre	Lichtstärkemesser	photometer
phototransistor	Fototransistor	phototransistor
pivot - axe	Zapfen	pivot
plage de mesure	Messbereich	measuring range
plane	eben	plane

plaque d'absorption	Absorberfläche	absorber plate
plaque de base	Grundplatte	base plate
plateforme	Plattform	platform
plomber	plombieren	seal
pluie	Regen	rain
point d'appui	Auflagepunkte	supporting point
point de connexion	Anschlussstelle	connection point
point de fonte	Schmelzpunkt	melting point
point de gel	Gefrierpunkt	freezing point
point de glace	Eispunkt	ice point
point de mesure	Messort	measuring point
point de rosée	Taupunkt	dew point
point de tri	Schaltpunkt	set point
point zéro	Nullpunkt	zero point
pompe de chaleur	Wärmepumpe	heat pump
pont complet	Vollbrücke	full bridge
pont de Wheatstone	Wheatstone'sche Brücke	Wheatstone bridge
portée maximale	Tragfähigkeit	maximum capacity
position de repos	Ruhelage	rest position
position zéro	Nulllage	zero position
potentiel d'application	Applikationsfähigkeit	application potential
préamplificateur	Vorverstärker	preamplifier
précipitation	Niederschlag	precipitation
précis	genau	precise
précision	Genauigkeit	accuracy
précision	Präzision	precision
précision de mesure	Messgenauigkeit	measurement accuracy
préparation des données	Datenaufbereitung	data preparation
Presse étoupe	Stopfbuchse	gland
pression	Druck	pressure
pression atmosphérique	Luftdruck	air pressure
pression barométrique standard	barometrischer Standarddruck	standard barometric pressure
pression extérieure	Außendruck	external pressure
prêt à fonctionner	betriebsbereit	ready for operation
principe bolométrique	Bolometrisches Prinzip	bolometric principle
prise	Stecker	plug
prise de courrant	Steckverbindung	plug connection
prise de terre	Erdung	grounding
procédé	Prozess	process
procédé statistique	statistische Bearbeitung	statistical processing
procédure de mesure	Messverfahren	measuring procedure
profondeur atmosphérique	atmosphärische Tiefe	atmospheric depth
programme d'essai	Prüfprogramm	test program
prolongateur de câble	Kabelverbindungsmuffe	cable jointing sleeve
proportionalité	Proportionalität	proportionality
propriété métrologiques	Messtechnische Eigenschaft	metrological property
propriétés d'amortissement	Dämpfungseigenschaft	damping characteristics
protection	abschirmen	shielding
protection contre la corrosion	Korrosionsschutz	protection against corrosion
protection contre la foudre	Blitzschutz	lightning protection
protection contre l'humidité	Feuchteschutz	moisture protection
protection contre l'humidité	Feuchtigkeitsschutz	moisture protection
protection de mise à la terre	Schutzleiter	protective ground
protocole d'essai	Prüfbericht	test report
puissance solaire	Sonnenenergie	sunpower
pyranomètre	Pyranometer	pyranometer
pyrgéomètre	Pyrgeometer	pyrgeometer

pyrhéliomètre	Pyrheliometer	pyrheliometer
pyromètre	Pyrometer	pyrometer
pyrradiomètre	Pyrradiometer	pyrradiometer

Q

qualité	Eigenschaft	feature
quantité	Menge	quantity
quantité mesurée	Messgröße	measured quantity
quartz	Quarz	quartz

R

raccordement	Anschluss	connection
radiation	Strahlung	radiation
radiation atmosphérique longue onde	atmosphärische langwellige Strahlung	atmospheric long-wave radiation
radiation circumsolaire	Zirkumsolarstrahlung	circumsolar radiation
radiation de longues fréquences	langwellige Strahlung	long-wave radiation
radiation du ciel	Himmelsstrahlung	sky radiation
radiation onde courte	kurzwellige Strahlung	short-wave radiation
radiation solaire	Solarstrahlung	solar radiation
radiation solaire directe	direkte Strahlung	direct solar radiation
radiation thermique	Wärmestrahlung	heat radiation
radiomètre	Radiometer	radiometer
rayon	Strahl	beam
rayon de lumière	Lichtstrahl	light beam
rayonnement extraterrestre solaire	extraterrestrische Solarstrahlung	extraterrestrial solar radiation
rayonnement infrarouge	Infrarot Strahlung	infrared radiation
rayonnement solaire	Sonnenbestrahlung	solar irradiation
rayonnement solaire diffus	diffuse Strahlung	diffuse solar radiation
rayonnement solaire direct	direkte Solarbestrahlung	direct solar irradiance
rayonnement solaire	global rahmen	global solar radiation
rayonnement ultraviolet	Ultraviolett Strahlung	ultraviolet radiation
rayonnement visible	sichtbare Strahlung	visible radiation
réaction	Rückwirkung	reaction
recalibration	Nachkalibrierung	recalibration
récepteur	Empfänger	receiver
référence	Vergleichswert	reference
référence radiomètrique mondiale	Welt Strahlungs Referenz	World Radiometric Reference (WRR)
réflexion	Reflexion	reflection
réflexion	Reflexionsgrad	reflectance
réfraction	Brechung	refraction
réglage	Steuerung	control
règles de sécurité	Sicherheitsvorschriften	security regulations
relais	Relais	relay
relation	Beziehung	relation
répétabilité	Wiederholbarkeit	repeatability
réponse	Antwort	response
réponse de température	Temperaturverhalten	temperature response
réponse d’inclinaison	Neigungsverhalten	tilt response
réponse du cosinus	Kosinusverhalten	cosine response
reproductibilité	Reproduzierbarkeit	reproducibility
résistance	Abschlusswiderstand	terminating resistor
résistance	Widerstand	resistor
résistance à la corrosion	Korrosionsbeständigkeit	corrosion resistance
résistance aux chocs	Stoßfestigkeit	shock resistance
résistance de dérivation	Nebenschlusswiderstand	shunt

resistance de sortie	Ausgangswiderstand	output resistance
resistance d'entrée	Eingangswiderstand	input impedance
resistance d'entrée	Eingangswiderstand	input resistance
résistance d'isolation	Isolationswiderstand	insulation resistance
résistance interne	Innenwiderstand	internal resistance
résistance NTC	NTC-Widerstand	NTC resistor
résistance PTC	PTC-Widerstand	PTC resistor
résistance séries	Reihenwiderstand (Bauelement)	series resistor
résistance séries	Reihenwiderstand (physikalisch)	series resistance
résistances de compensation	Kompensationswiderstände	compensation resistors
résistant à la chaleur	hitzebeständig	heat proof
résolution	Auflösung	resolution
résonance	Resonanz	resonance
responsabilité	Haftung	liability
résultat	Resultat	result
résultat de mesure	Messergebnis	measuring result
résultat d'essai	Prüfergebnis	test result
retour	Rückführung	feedback
réversible	reversibel	reversible
rondelle	Unterlegscheibe	lock washer
rouleaux porteurs	Tragrollen	support rollers
rupture	Versagen	breakdown
rupture du câble	Kabelbruch	cable break

S

sans interférence	störungsfrei	interference free
sauteur	Kurzschlussbrücke	jumper
seconde	Sekunde (Zeit)	second
seconde (arc)	Sekunde (Bogen)	second of arc
sécurisé	ausfallsicher	fail-safe
sécurité	Sicherheit	security
sélecteur de sensibilités	Messbereichsumschalter	measuring range selector
sélection	Auswahl	selection
sensibilité	Empfindlichkeit	sensitivity
sensibilité	Kennwert	sensitivity
sensibilité à la température	temperaturempfindlich	temperature sensitive
sensibilité de réponse	Ansprechempfindlichkeit	response sensivity
sensibilité nominale	Nennkennwert	nominal sensitivity
sensibilité spectrale	spektrale Empfindlichkeit	spectral sensitivity
set de montage	Montagebausatz	mounting module
seuil de mobilité	Ansprechschwelle	response threshold
signal de perturbation	Störsignal	interfering signal
signal de sortie	Ausgangssignal	output signal
signal d'entrée	Eingangssignal	input signal
signal d'étalonnage	Kalibriersignal	calibration signal
signal mesurée	Messsignal	measured signal
signe distinctif ou d'identification	Identitätszeichen	identification mark
silicagel	Silikagel	silicagel
silicium	Silizium	silicon
simulateur de l'irradiation solaire	Bestrahlungssimulator	solar irradiance simulator
site de mesure	Messort	measurement site
site de test	Messgelände	test site
solarimètre	Solarimeter	solarimeter
soleil	Sonne	sun
solstice	Sonnenwende	solstice
somme	Summe	sum

sonde	Messspitze	probe tip
sonde	Tastspitze	probe tip
sortie	Ausgang	output
sortie analogique	Analogausgang	analog output
source de chaleur externe	externe Wärmequelle	external heat source
source de lumière	Lichtquelle	light source
soutenir	abstützen	support
spécification de test	Prüfvorschrift	test specification
spectre	Spektrum	spectra
spectre solaire	Solarspektrum	solar spectrum
spectroradiomètre	Spektroradiometer	spectro radiometer
spéculum	Spiegel	speculum
stabilité	Messbeständigkeit	stability
stabilité	Stabilität	stability
stabilité à longue terme	Langzeitstabilität	long-term stability
stabilité court terme	Kurzzeitstabilität	short-term stability
stabilité de température	Temperaturbeständigkeit	temperature stability
stabilité du zéro	Nullpunktstabilität	stability of zero
standardiser	normieren	standardize
statique	statisch	static
stress	Beanspruchung	stress
support	Träger	girder
suppression de l'interférence	Störsignalunterdrückung	interference suppression
surcharge	Überlastung	overload
surchargé	Überlast	overload
surface	Oberfläche	surface
surface courbée	Oberfläche, gekrümmte	uneven surface
surface de montage	Montagefläche	mounting surface
surface de réception	Empfangsfläche	receiving surface
surface non sélective	unselektive Oberfläche	non-selective surface
surface plane	Oberfläche, plane	plane surface
surface portante	Auflagefläche	bearing surface
surface sélective	selektive Oberfläche	selective surface
surface terrestre	Erdoberfläche	earth's surface
symbole des unités de mesure	Einheitenzeichen	symbol of units of measurement
système de mesure	Messsystem	measuring system
système ouvert	offenes System	open system

T

taille	Größe	dimension
taraudage	Gewindeloch	thread hole
taux de change	Änderungsgeschwindigkeit	rate of change
technique de mesure	Messtechnik	measuring technique
température	Temperatur	temperature
température à la surface	Oberflächentemperatur	surface temperature
température de fonctionnement	Nenntemperaturbereich	operation temperature range
température de référence	Referenztemperatur	reference temperature
température de stockage	Lagerungstemperaturbereich	storage temperature range
température environnante	Umgebungstemperatur	environmental temperature
tempête	Sturm	storm
temporaire	zeitweise	temporary
temps	Wetter	weather
temps de course	Vorlaufzeit	start-up time
temps de mesure	Messdauer	measuring duration
temps de mesure	Messzeit	measuring time
temps de montée	Anstiegszeit	rise time

temps de préchauffage	Anwärmzeit	warm up time
temps de réponse	Ansprechdauer	response time
temps d'intégration	Integrationszeit	integration time
temps mort	Totzeit	dead time
tension	Dehnung	strain
tension	Spannung (elektrisch)	voltage
tension	Spannung (mechanisch)	tension
tension d'alimentation	Speisespannung	excitation voltage
tension d'alimentation pont	Brückenspeisespannung	bridge excitation voltage
tension de perturbation	Störspannung	interfering voltage
terre	Erde	ground
test	Prüfen	testing
test de courte durée	Kurzzeitversuch	short-term test
test de densité	Dichtheitsprüfung	density test
test tension	Prüfspannung	test voltage
thermistance	Thermistor	thermistor
thermocouple	Thermoelement	thermocouple
thermomètre	Thermometer	thermometer
thermopile	thermoelektrische Säule	thermopile
tolérance	Toleranz	limit
tolérance de calibration	Kalibriertoleranz	calibration tolerance
tolérance de la sensibilité	Kennwerttoleranz	sensitivity tolerance
torsion	Verdrehung	torsion
traçabilité	Rückführbarkeit	traceability
traitement de surface	Oberflächenbehandlung	surface treatment
transmetteur	Sender	transmitter
transmission sans fil	drahtlose Übertragung	wireless transmission
tresse de cuivre	Kupferlitze	litz wire
tresse de mise á la terre	Erdschleife	ground loop
turbulence	Turbulenz	turbulence
type	Typ	type

U

unité d'affichage	Anzeigeeinheit	display unit
unité de test	Prüfling	test piece
unité de ventilation	Belüftungseinheit	ventilation unit

V

valeur de réglage	Einstellwert	setting value
valeur limite	Grenzwert	limit value
valeur mesurée	Messwert	measuring value
valeur recommandée	Richtwert	recommended value
valeur zéro	Nullsignal	zero signal
validité	Gültigkeit	validity
variabilité	Veränderlichkeit	variability
variation	Änderung	variation
variation de la pression atmosphérique	Luftdruckschwankung	air pressure variation
vent	wind	Wind
vérification	Stichprobe	spot check
vérifier	eichen	verify
vernier	Nonius	vernier
vibration	Schwingung	vibration
vieillissement	Alterung	ageing
vis	Schraube	screw
vis de fixation	Befestigungsschraube	fastening screw

vis de maintien	Halteschrauben	fixing screws
visibilité	Sicht	visibility
vitesse de la lumière	Lichtgeschwindigkeit	speed of light
vitesse du vent	Windgeschwindigkeit	wind speed
voie de mesure	Messkanal	measuring channel

Z

zénith	Scheitelpunkt	zenith
zéro offset	Null-Offset	zero offset
zone d'utilisation	Gebrauchszone	zone of use

Deutsch	English	Français
A		
Abänderung	modification	modification
Abgleich	adjustment	ajustement - réglage
Abgleichelement	adjusting element	élément d'ajustement
Abmessung	dimension	dimension
Abschattvorrichtung	shading device	dispositif d'ombrage
abschirmen	shielding	protection
Abschirmung	shielding	blindage
Abschlusswiderstand	terminating	resistor résistance
Abschwächer	attenuator	atténuateur
Absorber	absorber	absorber
Absorberfläche	absorber plate	plaque d'absorption
Absorptionskonstante	absorption constant c	onstante d'absorption
Abstand	distance	distance
abstützen	support	soutenir
Abweichung	deviation	déviation
Abweichung	error	erreur
Achse	axle	axe
Adapter	adapter	adaptateur
Adaption	adaption	adaptation
Ader	wire	conducteur
Aderpaar	pair of wires	paire de conducteurs
aggressive Umgebung	aggressive environment	environnement agressif
Akkumulator	accumulator	accumulateur
Alarm	alarm	alarme
Alarmmeldung	alert notice	annonce d'alarme
Albedo	albedo	albedo
alternierend	alternating	alternance
Alterung	ageing	vieillissement
Analog	analogue	analogique
Analoganzeige	analog indication	indication analogique
Analoganzeiger	analog indicator	indicateur analogique
Analogausgang	analog output	sortie analogique
Analog-Digital-Konverter	analog-digital converter	convertisseur analogique digital
Analog-Digital-Wandler	analog-digital converter	convertisseur analogique digital
Änderung	variation	variation
Änderungsgeschwindigkeit	rate of change	taux de change
anflanschen	flange	brider
Anforderung	requirement	exigence
Anordnung	arrangement	arrangement
Anschluss	connection	raccordement
Anschlussdraht	connection wire	câble de connexion
Anschlussklemme	connecting terminal	bornier de raccordement
Anschlussstecker	connector	connecteur
Anschlussstelle	connection point	point de connexion
Ansprechdauer	response time	temps de réponse
Ansprechempfindlichkeit	response sensivity	sensibilité de résponse
Ansprechschwelle	response threshold	seuil de mobilité
Anstiegszeit	rise time	temps de montée
Antwort	response	réponse
Antwortverhalten	response behaviour	comprtement de la réponse
Anwärmzeit	warm up time	temps de préchauffage
Anwendungsklasse	application class	classe d'utilisation
Anzeige	indication	indication
Anzeigebereich	indicating range	gamme d'affichage

Anzeigeeinheit	display unit	unité d'affichage
Anzeigeeinrichtung	indication device	dispositif indicateur
Anzeigefehler	indication error	erreur d'indication
Anzeigegerät	indicator	indicateur
anzeigen	display	afficher
Anzeiger	display	affichage
Anzugsmoment	tightening force (torque)	Couple de démarrage
Applikationsfähigkeit	application potential	potentiel d'application
Äquator	equator	équateur
Arbeitsfeld	field of operation	champ d'opération
Arretiereinrichtung	locking device	dispositif de blocage
Atmosphäre	atmosphere	atmosphère
atmosphärische langwellige Strahlung	atmospheric long-wave radiation	radiation atmosphérique longue onde
atmosphärische Schicht	atmospheric layer	couche atmosphérique
atmosphärische Tiefe	atmospheric depth	profondeur atmosphérique
Auflagefläche	bearing surface	surface portante
Auflagekraft	supporting force	force d'appui
Auflagepunkte	supporting point	point d'appui
Auflösung	resolution	résolution
Aufnehmer	transducer	convertisseur
Aufschrift	marking	marquage
Aufstellungsort	place of installation	lieu d'installation
ausfallsicher	fail-safe	sécurisé
Ausführung	design	construction
Ausgabe	output	émission
Ausgang	output	sortie
Ausgangssignal	output signal	signal de sortie
Ausgangswiderstand	output resistance	resistance de sortie
Ausgleich	balancing	compensation
Ausgleichseinrichtung	compensating device	dispositif de compensation
Ausgleichsgewicht	counterbalance weight	contrepoids d'équilibrage
Auskleidung	coating	enveloppe
ausrichten	aligning	aligner
Ausrichtung (Winkel)	orientation (angle)	angle d'orientation
ausschalten	switch off	éteindre
Außendruck	external pressure	pression extérieure
Aussendung	emittance	émission
Außenlinie	contour	contour
außermittig	eccentric	excentrée
Aussetzen	interruption	interruption
Auswahl	selection	sélection
auswechseln	exchange	changer
Auswerteeinrichtung	processing device	dispositif processeur
Auswertung	evaluation	évaluation
axial	axial	axial
Azimutwinkel der Sonne	solar azimuth	azimuth solaire

B

Balken	beam	faisceau
Bandbreite	bandwidth	largeur de la bande
Bar	bar	bar
Barometer aneroid	barometer	baromètre
Barometer	barometer	baromètre
barometrischer Standarddruck	standard barometric pressure	pression barométrique standard
Batterie	battery	batterie
Batteriebetrieb	battery operation	fonctionnement de la batterie

Batteriespeisung	battery supply	alimentation batterie
Bauart	design	modèle d'instrument de pesage
Bauhöhe	height of construction	hauteur de construction
Bauteil	component	composant
Beanspruchung	stress	stress
Bedienungsanleitung	operating manual	manuel d'emploi
Bedienungselement	control element	élément de contrôle
Bedienungsperson	operator	opérateur
Beeinflussung	influence	influence
Befestigung	fastening	fixation
Befestigungsbolzen	fastening bolt	axe de blocage
Befestigungsplatte	mounting plate	lame de fixation
Befestigungsschraube	fastening screw	vis de fixation
Begrenzungszeichen	limitation mark	indicateur de limitation
beladen	load	charger
Belastbarkeit	load capacity	capacité de chargement
Belastung	load	charge
Belastungsrichtung	loading direction	direction de la charge
Beleuchtung	illumination	luminosité
Beleuchtungsstärke	illuminance	illuminance
Belüftungseinheit	ventilation unit	unité de ventilation
Belüftungsspalt	ventilation slit	ouverture de ventilation
Bemaßung	dimensioning	dimension
Bereichsumschaltung	range selection	gamme de mesure
Bereitschaftszustand	standby condition	condition d'attente
Beschädigung	damage	dégât
Beschaffenheitsprüfung	condition testing	contrôle de qualité
Beschleunigung	acceleration	accélération
Bestrahlung	irradiance	irradiance
Bestrahlungssimulator	solar irradiance simulator	simulateur de l'irradiation solaire
Betätigung	actuation	commande
Betrieb	operation	fonctionnement
betriebsbereit	ready for operation	prêt à fonctionner
Betriebssicherheit	operational reliability	fiabilité
Beugung	diffraction	diffraction
Beweglichkeit	mobility	mobilité
Bezeichnung	indication	dénomination
Beziehung	relation	relation
Biegemoment	bending moment	moment de flexion
Blende	aperture	ouverture - orifice
Blitzschlag	lightning strike	coup de foudre
Blitzschutz	lightning protection protection	contre la foudre
Bolometrisches Prinzip	bolometric principle	principe bolométrique
Bolzen	bolt	goujon
Böschungswinkel	slope angle	angle de la pente
Brechung	refraction	réfraction
Bruchlast	breaking load	charge de rupture
Brückenabgleich	bridge balance	équilibrage du pont
Brückenschaltung	bridge circuit	circuit de pont
Brückenspeisespannung	bridge excitation	voltage tension d'alimentation pont

D

Dämpfung	attenuation	atténuation
Dämpfung	damping	amortissement
Dämpfungseigenschaft	damping characteristics	propriétés d'amortissement
Datenarchivierung	data archiving	archivage des données

Datenaufbereitung	data preparation	préparation des données
Datenblatt	data sheet	fiche des données
Dauerbelastung	continuous load	charge permanente
Dauerfestigkeit	endurance strength	force d'endurance
Dauerprüfung	endurance test	essais d'endurance
Definition	definition	définition
Dehnung	strain	tension
Demontage	disassemble	démontage
Diagramm	diagramme	diagramme
Dichte	density	densité
Dichtheitsprüfung	density test	test de densité
diffuse Strahlung	diffuse solar radiation	rayonnement solaire diffus
Diffusion	diffusion	diffusion
digital	digital	numérique
Digitalanzeige	numeric indication	indication numérique
Digitalanzeiger	numeric display	affichage numérique
Dimension	dimension	dimension
direkte Solarbestrahlung	direct solar irradiance	rayonnement solaire direct
direkte Strahlung	direct solar radiation	radiation solaire directe
diskontinuierlich	discontinuous	discontinu
dosieren	proportioning	doser
drahtlose Übertragung	wireless transmission	transmission sans fil
Drehmoment	torque	couple
Drift	drift	dérive
Driftfehler	drift error	dérive du zéro
Druck	pressure	pression
Druckbelastung	pressure load	charge de pression
Druckrichtung	pressure direction	direction de la pression
Durchmesser	diameter	diamètre
Durchschnitt	average	moyenne
Dynamik	dynamics	Dynamique
dynamisch	dynamic	dynamique

E

eben	plane	plane
Edelstahl	stainless steel	acier inoxydable
Eichanweisung	verification instruction	instruction de vérification
Eichbescheinigung	verification certificate	certificat de vérification
Eicheinrichtung	verification device	dispositif auxiliaire de vérification
eichen	calibrate	calibrer
eichen	verify	vérifier
Eigenfrequenz	natural frequency	fréquence propre
Eigenschaft	feature	qualité
Einbaubeispiel	mounting example	exemple de montage
Einbauhilfe	mounting aids	accessoires de montage
Einbauhinweis	mounting advice	conseil de montage
Einbaumodul	mounting assembly	Module de montage
Einbaurichtlinien	installation guidelines	conseils de montage
Einbauvorschriften	installation instruction	instructions de montage
Einfallswinkel	incident angle	angle d'incidence
Einfluss	influence	influence
Eingang	input	entrée
Eingangssignal	input signal	signal d'entrée
Eingangswiderstand	input impedance	resistance d'entrée
Eingangswiderstand	input resistance	resistance d'entrée
Einheitenzeichen	symbol of units of measurement	symbole des unités de mesure

Einsatz	application	application
Einsatzbereich	field of application	domaine d'application
Einstellbereich	setting range	gamme de réglage
Einstellmarke	setting index	index de réglage
Einstellwert	setting value	valeur de réglage
Eispunkt	ice point	point de glace
Elastizität	elasticity	élasticité
Empfänger	receiver	récepteur
Empfangsfläche	receiving surface	surface de réception
Empfindlichkeit	sensitivity	sensibilité
Empfindlichkeitseinsteller	sensitivity adjusting device	dispositif de réglage de sensibilité
equivalente Länge	equivalent length	longueur équivalente
Erde	ground	terre
Erdleitung	ground lead	conducteur de mise à la terre
Erdoberfläche	earth's surface	surface terrestre
Erdschleife	ground loop	tresse de mise á la terre
Erdung	grounding	prise de terre
externe Wärmequelle	external heat source	source de chaleur externe
extraterrestrische Solarstrahlung	extraterrestrial solar radiation	rayonnement extraterrestre solaire

F

Farbfilter	spectral filter	filtre spectral
Fehlbelastung	misload	Charge d'erreur
Fehler	error	erreur
Fehler zusammengesetzter	combined error	erreur combinée
Fehlerbeseitigung	curing of defects	limination des erreurs
Fehlergrenzen	limits of error	erreurs maximales tolérées
Fehlerkurve	deviation curve	courbe d'erreur
Fehlverhalten	misbehaviour	mauvaise conduite
Fernanzeige	remote indication	indicateur á distance
Fernsteuerung	remote control	commande à distance
Feuchtemesser	hygrometer	hygromètre
Feuchteschutz	moisture protection	protection contre l'humidité
Feuchtigkeit	humidity	humidité
Feuchtigkeit	moisture	humidité
Feuchtigkeitsschutz	moisture protection	protection contre l'humidité
Filter	filter	filtre
Formel	formula	formule
Fotodiode	photo diode	photodiode
Fotoelektrischer Effekt	photoelectric effect	effet photoélectrique
Fotohalbleiter	photo semiconductor	photo semiconducteur
Fototransistor	phototransistor	phototransistor
Fotowiderstandszelle	photocell	photocelulle
Frequenzbereich	frequency range	gamme de fréquence
Fresnellinse	fresnel lens	lentille de Fresnel
Fühler	sensor	détecteur
Fühlerleitung	sensing line	détecteur
Funktion	function	fonction
Funktionsfehler	operational fault	panne fonctionnelle
Funktionskontrolle	checking of operation	contrôle de fonction

G

Garantie	warranty	garantie
Gebrauchsort	place of use	lieu d'utilisation
Gebrauchszone	zone of use	zone d'utilisation

Gefrierpunkt	freezing point	point de gel
Gegenmutter	lock nut	contre-écrou
Gehäuse	housing	boîtier
gemäßigtes Klima	temperate climate	climat tempéré
genau	precise	précis
Genauigkeit	accuracy	précision
Genauigkeitsklasse	accuracy class	classe de précision
gesamt einfallende Strahlung	total incident radiation	influence du rayonnement total
Gesamtfehler	total error	erreur totale
Gesichtsfeldwinkel	view angle	angle de vue
Gewicht	weight	poids
Gewinde	thread	fil
Gewindeloch	thread hole	taraudage
Gleichspannungs-Messverstärker	DC amplifier	amplificateur à courant continu
Grenztemperaturbereich	limiting temperature range	gamme de limite de température
Grenzwert	limit value	valeur limite
Größe	dimension	taille
Grundplatte	base plate	plaque de base
Gültigkeit	validity	validité

H

Haarhygrometer	hair hygrometer	hygromètre à cheveu
Haftung	liability	responsabilité
Hagel	hail	grêle
Haken	hook	crochet
Halbbrücke	half bridge	demi-pont
Halteschrauben	fixing screws	vis de maintien
Handhabung	handling	manutention
Hauptanzeige	main indication	indication principale
Hauteffekt	skin effect	effet sur la peau
Hebel	lever	levier
Hebelarm	lever arm	bras de levier
heiß	hot	chaud
Heizung	heating	chauffage
Heliograph	sun recorder	héliographe
heliozentrisch	heliocentric	héliocentrique
hermetisch	hermetic	hermétique
Himmelsstrahlung	sky radiation	radiation du ciel
hitzebeständig	heat proof	résistant à la chaleur
Hochspannung	high tension	haute tension
Höhenwinkel der Sonne	solar altitude	altitude du soleil
Hysterese	hysteresis	hystérèsis
Hysteresefehler	hysteresis error	erreur d'hystérésis

I

Identitätszeichen	identification mark	signe distinctif ou d'identification
Infrarot Strahlung	infrared radiation	rayonnement infrarouge
Inhalt	content	contenu
Innenwiderstand	internal resistance	résistance interne
Installation	installation	installation
Integration	integration	intégration
Integrationszeit	integration time	temps d'intégration
Intensität	intensity	intensité
Inversion	inversion	inversion
Isobar	isobar	isobar

isohel	isohel	isohel
Isolationswiderstand	insulation resistance	résistance d'isolation
Isolierung	insulation	isolation
isorad	isorad	isorad
Isotherm	isotherm	isotherme

J

justieren	adjust	ajuster - régler

K

Kabel	cable	câble
Kabelanschluss	cable connection	câble de raccordement
Kabelbruch	cable break	rupture du câble
Kabeleinfluss	cable influence	influence du câble
Kabelkasten	cable box	boite de raccordement
Kabelverbindungsmuffe	cable jointing sleeve	prolongateur de câble
Kabelverlängerung	cable extension	extension de câble
kalibrieren	calibrate	étalonner
Kalibriernormal	calibration standard	étalon de calibration
Kalibriersignal	calibration signal	signal d'étalonnage
Kalibriertoleranz	calibration tolerance	tolérance de calibration
Kalibrierung	calibration	calibration
Kalibrierzeugnis	calibration certificate	certificat de calibration
Kennlinie	calibration curve	courbe d'étalonnge
Kennlinienabweichung	non-conformity of a curve	non-conformité d'une courbe
Kennwert	sensitivity	sensibilité
Kennwertbereich	sensitivity range	gamme de sensibilités
Kennwerttoleranz	sensitivity tolerance	tolérance de la sensibilité
Klima	climate	climat
Klimaschrank	climate-controlled cabinet	coffret de contrôle climatique
Kollektor, Parabolspiegel	collector, parabolic dish	disque parabolique
Kompensationswiderstände	compensation resistors	résistances de compensation
Konstruktion	construction	construction
Kontrolle	control	contrôle
Kontrollschaltung	test circuit	circuit de contrôle
Konzentrator	concentrator	concentreur
Korrektureinrichtung	correction device	dispositif de correction
Korrosion	corrosion	corrosion
Korrosionsbeständigkeit	corrosion resistance	résistance à la corrosion
Korrosionsschutz	protection against corrosion	protection contre la corrosion
Kosinusverhalten	cosine response	réponse du cosinus
Kreisskale	circular scale	échelle circulaire
Kriechfehler	creep error	fluage
Kriechfehler	error due to drift	erreur de dérive
Kriterium	criterion	critére
Kupfer	copper	cuivre
Kupferlitze	litz wire	tresse de cuivre
Kurzschluss	short circuit	court-circuit
Kurzschlussbrücke	jumper	sauteur
kurzwellige Strahlung	short-wave radiation	radiation onde courte
Kurzzeitstabilität	short-term stability	stabilité court terme
Kurzzeitversuch	short-term test	test de courte durée

L

Labor-Messgeräte	laboratory measurement equipment	équipement de mesure de laboratoire
Laborversuch	laboratory test	expérience de laboratoire
Lager	support bearing	palier
Lagerungstemperaturbereich	storage temperature range	température de stockage
Längsachse	longitudinal axis	axe longitudinal
langwellige Strahlung	long-wave radiation	radiation de longues fréquences
Langzeitdrift	long-term drift	dérive à longue terme
Langzeitmessung	long-term measurement	mesure à longue terme
Langzeitstabilität	long-term stability	stabilité à longue terme
Last	load	charge
Lebensdauer	life cycle	cycle de vie
Leistung	performance	performance
Leitung	lead	conducteur
Leitung, abgeschirmt	shielded cable	câble de sécurité
Leuchtbildanzeige	illuminated display	affichage lumineux
Leuchtdichte	luminance	luminance
Leuchtdiode	light emitting diode	diode d'émission de lumière
Leuchtziffernanzeige	luminous numerical display	écran numérique lumineux
Libelle	level indicator	indicateur de niveau
Licht	light	lumière
Lichtabsorption	light absorption	absorption de lumière
Lichtdruck	heliotype	heliotype
Lichtgeschwindigkeit	speed of light	vitesse de la lumière
Lichtkegel	light cone c	ône de lumière
Lichtquelle	light source	source de lumière
Lichtstärke	light intensity	intensité lumineuse
Lichtstärkemesser	photometer	photomètre
Lichtstrahl	light beam	rayon de lumière
Lichtstreuung	light diffusion	diffusion de la lumière
Lichtstreuung	light scatter	diffusion de la lumière
Lieferumfang	scope of delivery	étendue de livraison
Linearisierung	linearizing	linéarisation
Linearität	linearity	linéarité
Linearitätsfehler	linearity error	erreur de linéarité
Luftdruck	air pressure	pression atmosphérique
Luftdruckabhängigkeit	air pressure dependence	dépendance de la pression atmosphérique
Luftdruckausgleich	air pressure compensation	compensation de la pression atmosphérique
Luftdruckschwankung	air pressure variation	variation de la pression atmosphérique
Luftfeuchtigkeit	air humidity	hygrométrie
Luftmasse	air mass	masse d'air

M

Masse	mass	masse
Materialeigenschaft	material characteristic	caractéristique du matériau
Medium	medium	moyen
Menge	quantity	quantité
Messabweichung	error of measurement	erreur de mesure
Messaufbau	measurement setup	établissement de la mesure
messbar	measurable	mesurable
Messbereich	measuring range	plage de mesure
Messbereichsumschalter	measuring range selector	sélecteur de sensibilités
Messbeständigkeit	stability	stabilité
Messdauer	measuring duration	temps de mesure
Messeingang	test input	entrée test
Messeinrichtung	measuring equipment	équipement de mesure

Messelektronik	measuring electronics	electronique de mesure
Messelement	measuring element	elément sensible
Messergebnis	measuring result	résultat de mesure
Messfehler	measuring error	erreur de mesure
Messfläche	measuring area	aire de mesure
Messgelände	test site	site de test
Messgenauigkeit	measurement accuracy	précision de mesure
Messgerät	measuring device	outil de mesure
Messgröße	measured quantity	quantité mesurée
Messkabel	measuring cable	câble de mesure
Messkanal	measuring channel	voie de mesure
Messkette	measuring chain	chaîne de mesure
Messleitung	measuring cable	câble de mesure
Messleitungseinfluss	influence of measuring lead	influence du conducteur
Messmethode	measuring method	méthode de mesure
Messort	measurement site	site de mesure
Messort	measuring point	point de mesure
Messprinzip	measuring method	méthode de mesure
Messsignal	measured signal	signal mesurée
Messspitze	probe tip	sonde
Messstelle (eines Thermopaares)	measuring junction	jonction de mesure
Messsystem	measuring system	système de mesure
Messtechnik	measuring technique	technique de mesure
Messtechnische Eigenschaft	metrological property	propriété métrologiques
Messung	measurement	mesure
Messunsicherheit	measurement uncertainty	incertitude de mesure
Messverfahren	measuring procedure	procédure de mesure
Messwert	indication	indication
Messwert	measuring value	valeur mesurée
Messwertspeicher	measuring value memory	mémoire de la valeur mesurée
Messwiderstand	measuring resistor	mesure de résistance
Messzeit	measuring time	temps de mesure
Messzeitraum	measurement period	période de mesure
Meteorologie	meteorology	météorologie
metrisch	metric	métrique
Mikrotechnologie	micro technology	micro-technologie
Millimeter Quecksilbersäule	millimetre of mercury	millimètre mercure
Millimeter Wassersäule	millimetre of water column	colonne d'eau millimètre
Mindestabstand	minimum distance	espace minimum
Mindestanwendungsbereich	minimum utilisation range	gamme d'utilisation minimum
Miniaturaufnehmer	micro sensor	micro-capteur
Mittag (auf die Sonne bezogen)	solar noon	lune solaire
Mittelwert	average	moyenne
Modem (Modulation/Demodulation)	Modem (Modulation/Demodulation)	modem (modulation/démodulation)
Modul	module	module
Modulation	modulation	modulation
Moment	moment	moment
Montage	mounting	montage
Montageanleitung	mounting instruction	instructions de montage
Montagebausatz	mounting module	set de montage
Montagefläche	mounting surface	surface de montage
Montagehinweis	mounting instruction	indications de montage

N

Nachkalibrierung	recalibration	recalibration
Nachlauffehler	tracking error	erreur de poursuite

Nebenschlusswiderstand	shunt	résistance de dérivation
Neigungseinfluss	tilt error	erreur d'inclinaison
Neigungsverhalten	tilt response	réponse d'inclinaison
Nennkennwert	nominal sensitivity	sensibilité nominale
Nennmessbereich	nominal measuring range	gamme de mesure nominale
Nenntemperaturbereich	operation temperature range	température de fonctionnement
Nichtlinearität	non-linearity	non-linéarité
Niederschlag	precipitation	précipitation
Niveau	level	niveau
Nivelliereinrichtung	levelling device	dispositif de mise de niveau
nivellieren	level	niveller
Nonius	vernier	vernier
Normal	standard	étalon
Normalbedingungen	standard conditions	conditions normales
normieren	standardize	standardiser
Normklima	standard climate	climat normal
NTC-Widerstand	NTC resistor	résistance NTC
Nulllage	zero position	position zéro
Null-Offset	zero offset	zéro offset
Nullpunkt	zero point	point zéro
Nullpunktdrift	zero drift	déviation du zéro
Nullpunktstabilität	stability of zero	stabilité du zéro
Nullsignal	zero signal	valeur zéro
Nullsignaländerung	change in zero	signal dérive de zéro
Nullstelleinrichtung	zero setting device	dispositif de mise á zéro
Nullstellen	set to zero	mettre á zéro

O

Oberfläche	surface	surface
Oberfläche, gekrümmte	uneven surface	surface courbée
Oberfläche, plane	plane surface	surface plane
Oberflächenbehandlung	surface treatment	traitement de surface
Oberflächentemperatur	surface temperature	température à la surface
offenes System	open system	système ouvert
Öffnungsebene	aperture plane	angle d'ouverture
Öffnungswinkel	field of view	champ de vue
Optimierung	optimization	optimiser
optische Achse	optical axis	axe optique
optischer Aufbau	optical set-up	installation optique
Ozon	ozone	ozone
Ozonschicht	ozone layer	couche d'ozone

P

Packung	package	emballage
Parallaxe	parallax	parallax
Parallelschaltung	parallel connection	branchement en parallèle
Parameter	parameter	paramètre
Pegel	level	niveau
Peltiereffekt	Peltier effect	effet Peltier
Peltierelement	Peltier element	élément Peltier
Photozelle	photo cell	cellule photo
Plattform	platform	plateforme
plattform	radiometer	radiomètre
plombieren	seal	plomber
Polarisationsverhalten	polarisation characteristics	caractéristiques de polarisation

Präzision	precision	précision
Proportionalität	proportionality	proportionalité
Prozentskale	percentage scale	échelle en pourcentage
Prozess	process	procédé
Prüfbericht	test report	protocole d'essai
Prüfen	testing	test
Prüfergebnis	test result	résultat d'essai
Prüfling	test piece	unité de test
Prüfmethode	test method	méthode de test
Prüfprogramm	test program	programme d'essai
Prüfspannung	test voltage	test tension
Prüfvorschrift	test specification	spécification de test
PTC-Widerstand	PTC resistor	résistance PTC
Pufferbatterie	back up battery	batterie de sauvegarde
Pyranometer	pyranometer	pyranomètre
Pyrgeometer	pyrgeometer	pyrgéomètre
Pyrheliometer	pyrheliometer	pyrhéliomètre
Pyrometer	pyrometer	pyromètre
Pyrradiometer	pyrradiometer	pyrradiomètre

Q

Quarz	quartz	quartz
Quecksilber	mercury	mercure
Quecksilbermanometer	mercury pressure	gauge jauge de pression de mercure
Querlast	lateral load	charge latérale

R

Rahmen	frame	cadre
rahmen global	solar radiation	rayonnement solaire global
Rauschen	noise	bruit
Referenzbedingungen	reference conditions	conditions de référence
Referenzelement	reference element	élément de référence
Referenztemperatur	reference temperature	température de référence
Reflexion	reflection	réflexion
Reflexionsgrad	reflectance	réflexion
Regen	rain	pluie
Registriergerät	recording device	appareil enregistreur
Registrierung	recording	enregistrement
Reibung	friction	friction
Reihenwiderstand (Bauelement)	series resistor	résistance séries
Reihenwiderstand (physikalisch)	series resistance	résistance séries
Relais	relay	relais
relative Messabweichung	relative error of measurement	erreur relative de mesure
Reproduzierbarkeit	reproducibility	reproductibilité
Resonanz	resonance	résonance
Resultat	result	résultat
reversibel	reversible	réversible
Richtigkeit	freedom from bias	justesse
Richtungsabhängigkeit	directional dependence	influence de l'inclinaison
Richtwert	recommended value	valeur recommandée
Rückführbarkeit	traceability	traçabilité
Rückführung	feedback	retour
Rückwirkung	reaction	réaction
Ruhelage	rest position	position de repos
Rundungsfehler	rounding error	erreur d'arrondissage

S

Schalter	switch	commutateur
Schaltplan	circuit diagram	diagramme de circuit
Schaltpunkt	set point	point de tri
Schatten	shade	ombre
Scheitelkreis	azimuth	azimuth
Scheitelpunkt	zenith	zénith
Schmelzpunkt	melting point	point de fonte
Schrägstellung	obliqueness	inclinaison
Schraube	screw	vis
Schutzart	protection class	classe de protection
Schutzart	type of protection	degré de protection
Schutzleiter	protective ground	protection de mise à la terre
Schwerkraft	gravity	gravitation
Schwerpunkt	centre of gravity	centre de gravité
Schwingung	vibration	vibration
Schwingungsdämpfung	vibration damping	amortissement de vibration
Seitenkraft	side force	force latérale
Sekunde (Bogen)	second of arc	seconde (arc)
Sekunde (Zeit)	second	seconde
selektive Oberfläche	selective surface	surface sélective
Sender	transmitter	transmetteur
Sensor	sensor	capteur
serielle Schnittstelle	serial interface	interface en série
Sicherheit	security	sécurité
Sicherheitsvorschriften	security	regulations règles de sécurité
Sicht	visibility	visibilité
sichtbare Strahlung	visible radiation	rayonnement visible
Silikagel	silicagel	silicagel
Silizium	silicon	silicium
Skale	scale	échelle
Skalenteil	scale division	échelon
Software	software	logiciel
solare Mitwirkung	solar contribution	contribution solaire
Solarenergie	solar energy	énergie solaire
Solarimeter	solarimeter	solarimètre
Solarkonstante	solar constant	constante solaire
Solarneigung	solar declination	déclinaison solaire
Solarspektrum	solar spectrum	spectre solaire
Solarstrahlung	solar radiation	radiation solaire
Solarzelle	solar cell	cellule solaire
Sonne	sun	soleil
Sonnen entferntester Punkt	aphelion	aphelie
Sonnenaufgang	sunrise	lever du soleil
Sonnenbestrahlung	solar irradiation	rayonnement solaire
Sonnenenergie	sunpower	puissance solaire
Sonnenenergiefluss	solar flux	flux solaire
Sonnenfinsternis	solar eclipse	éclipse solaire
sonnennächster Punkt	perihelion	perihélie
Sonnenschein	sunshine	luminosité solaire
Sonnenscheinschreiber	sunshine recorder	enregistreur de radiation solaire
Sonnenstand zenith	angle of sun	angle du zénith soleil
Sonnenstandswinkel	zenith angle	angle du zénith
Sonnentätigkeit	solar activity	activité solaire
Sonnenuntergang	sunset	coucher du soleil
Sonnenwende	solstice	solstice
Sonnenzeit	solar time	heure solaire

Spannschraube	clamp bolt	boulon de fixation
Spannung (elektrisch)	voltage	tension
Spannung (mechanisch)	tension	tension
Speisespannung	excitation voltage	tension d'alimentation
Speisung	supply	alimentation
Spektralanalyse	spectral analysis	analyse spectrale
spektrale Empfindlichkeit	spectral sensitivity	sensibilité spectrale
spektrale Strahlungsverteilung	spectral distribution	distribution spectrale
Spektroradiometer	spectro radiometer	spectroradiomètre
Spektrum	spectra	spectre
Spiegel	mirror	miroir
Spiegel	speculum	spéculum
Stab	bar	bâton
Stab	rod	barre
Stabilität	stability	stabilité
Stabilitätsprüfung	stability test	essai de stabilité
Standardabweichung	standard deviation	écart type
Stange	bar	barre
statisch	static	statique
statistische Bearbeitung	statistical processing	procédé statistique
Stecker	male connector	connecteur mâle
Stecker	plug	prise
Steckeranschluss	plug connection	connexion
Steckverbindung	plug connection	prise de courrant
Steuerung	control	réglage
Stichprobe	spot check	vérification
Stopfbuchse	gland	Presse étoupe
Störpegel	interference level	degré de perturbation
Störsignal	interfering signal	signal de perturbation
Störsignalunterdrückung	interference suppression	suppression de l'interférence
Störspannung	interfering voltage	tension de perturbation
Störung	interference	perturbation
störungsfrei	interference free	sans interférence
Stoßfänger	buffer	dispositif antichoc
Stoßfestigkeit	shock resistance	résistance aux chocs
Strahl	beam	rayon
Strahlenfluss	radiant flux	flux radiant
Strahlung	radiation	radiation
Strahlungsenergie	energy of radiation	énergie du rayonnement
Strahlungsenergie	radiant energy	énergie radiante
Strahlungsintensität	irradiation	irradiation
Streumaß	measure of scatter	mesure de la diffusion
Streuung	scattering	écartement
Streuwinkel	scattering angle	angle d'écartement
Strombegrenzung	current limitation	limite de courant
Stromkreis	current circuit	circuit électrique
Stromlaufplan	circuit diagram	diagramme de circuit
Stunde	hour	heure
Sturm	storm	tempête
Summe	sum	somme
systematische Messabweichung	systematic error	erreur systématique

T

Tastatur	keyboard	clavier
Tastspitze	probe tip	sonde
Tauglichkeit	suitability	convenance

Taupunkt	dew point	point de rosée
technische Daten	technical data	données techniques
Teilung	scale	étape
Temperatur	temperature	température
Temperaturabfall	temperature drop	goutte
Temperaturabhängigkeit	temperature dependence	dépendance de la température
Temperaturanstieg	temperature rise	hausse de température
Temperaturbereich	temperature range	gamme de température
Temperaturbeständigkeit	temperature stability	stabilité de température
Temperatureinfluss	temperature influence	influence de la température
temperaturempfindlich	temperature sensitive	sensibilité à la température
Temperaturfühler	temperature sensor	capteur de température
Temperaturgang	effect of temperature	effet de température
Temperaturgradient	temperature gradient	gradient de température
Temperaturkoeffizient	temperature coefficient	coefficient de température
Temperaturkompensation	temperature compensation	compensation de température
Temperaturkonstanz	temperature constancy	constance de température
Temperaturmessung	temperature measurement	mesure de température
Temperaturschrank	temperature chamber	chambre de température
Temperaturschwankung	temperature deviation	deviation de température
Temperaturumkehr	temperature inversion	inversion de température
Temperaturverhalten	temperature response	réponse de température
Thermistor	thermistor	thermistance
Thermoeffekt (Seebeck-Effekt)	thermal effect	effet thermique
thermoelektrische Säule	thermopile	thermopile
Thermoelement	thermocouple	thermocouple
Thermokonvektion	thermal convection	convection thermique
Thermometer	thermometer	thermomètre
Tieftemperaturbereich	cryogenic temperature range	gamme de température cryogénique
Toleranz	limit	tolérance
Totzeit	dead time	temps mort
Tragarm	rod	console
Träger	girder	support
Tragfähigkeit	maximum capacity	portée maximale
Tragrollen	support rollers	rouleaux porteurs
Transportsicherung	transport locking device	dispositif de blocage de transport
Turbulenz	turbulence	turbulence
Typ	type	type
Typenreihe	series	gamme

U

Überlast	overload	surchargé
Überlastung	overload	surcharge
Überspannungsableiter	surge arrester	dispositif d'arrêt de surtension
Überwachung	monitoring	enregistrement
Ultraviolett Strahlung	ultraviolet radiation	rayonnement ultraviolet
Umgebung	environment	environnement
Umgebung	surroundings	environnement
Umgebungsluft	ambient air	air ambiant
Umgebungstemperatur	environmental temperature	température environnante
Umkehrspanne	hysteresis error	erreur d'hystérésis
Umschalteinrichtung	selection device	dispositif de sélection
Umwelt	environment	environnement
Umweltbedingung	environmental condition	condition environnante
Umwelteinfluss	environmental influence	influence environnante
unselektive Oberfläche	non-selective surface	surface non sélective

Unsicherheit	uncertainty	incertitude
Unterbau	support structure	fondation
Unterlegscheibe	lock washer	rondelle
Unterteil	base partie	inférieure
Unterwerk	infrastructure	infrastructure

V

Veränderlichkeit	variability	variabilité
Verbindungskabel	connection cable	câble de liaison
Verdampfungswärme	heat of evaporation	chaleur d'évaporation
Verdrehung	torsion	torsion
Verdunstung	evaporation	évaporation
Verformung	deformation	déformation
Vergleichswert	reference	référence
Versagen	breakdown	rupture
Verstärker	amplifier	amplificateur
Versteifung	stiffener	contrefort
Vertärkungsfaktor	gain	gain
Verwendungsbereich	range of use	domaine d'utilisation
Vibrationsdämpfer	vibration damper	amortisseur
Vollbrücke	full bridge	pont complet
vorbereitende Maßnahme	preparatory measures	mesures préparatoires
Vorlaufzeit	start-up time	temps de course
Vorverstärker	preamplifier	préamplificateur

W

Wärmeableitung	heat dissipation	dissipation de la chaleur
Wärmeleiter	heat conductor	conducteur de la chaleur
Wärmeleitfähigkeit	heat conductivity	conductivité de la chaleur
Wärmeleitvermögen	heat conductivity	conductivité de la chaleur
Wärmepumpe	heat pump	pompe de chaleur
Wärmestrahlung	heat radiation	radiation thermique
Wärmetauscher	heat exchanger	échangeur thermique
Wartung	maintenance	maintenance
Wasserwaage	spirit level	niveau à bulle
Wechselrichter	chopper	couperet
Wellenlänge	wavelength	longueur d'onde
Welt Strahlungs Referenz	World Radiometric Reference (WRR)	référence radiomètrique mondiale
Wetter	weather	temps
Wheatstone'sche	Brücke Wheatstone	bridge pont de Wheatstone
Widerstand	resistor	résistance
Wiederholbarkeit	repeatability	répétabilité
Wind	wind	vent
Windfahne	wind vane	girouette
Windgeschwindigkeit	wind speed	vitesse du vent
Windgeschwindigkeitsmesser	anemometer	anémomètre
Windkräfte	wind forces	forces du vent
Windrichtung	wind direction	direction du vent
Winkelstellung	angularity	angularité
Witterung	atmospheric conditions	conditions atmosphériques
Wolke	cloud	nuage

Z

Zapfen	pivot	pivot - axe
Zeiger	pointer	curseur
Zeitkonstante	time constant	constance de temps
zeitweise	temporary	temporaire
Zentrierung	centering	centrage
Zirkumsolarstrahlung	circumsolar radiation	radiation circumsolaire
Zubehör	accessories	accessoires
Zufall	random	aléatoire
zufällige Messabweichung	random error	erreur aléatoire
zulässig	permissible	acceptable
Zulassung	approval	approbation
Zulassungsbehörde	approving authority	autorité d’approbation
Zusatzeinrichtung	auxiliary device	outil auxiliaire
Zuverlässigkeit	reliability	conformité
Zwielicht	twilight	crépuscule

Solar radiation is one of the biggest factors that influence our daily lives. There is more to it than just the light we see with our eyes; it provides energy for nearly all the life on Earth and drives the weather, climate and water cycle.

In these times of climate change and more extreme and less predictable weather, solar radiation sensors and measurements for meteorological purposes are becoming more and more important. More and better sensors in a wider range of locations are needed to provide inputs to the complex computer programmes which model and forecast climate and weather.

Solar energy is now the fastest growing and evolving application for the accurate measurement of solar radiation, to ensure the best conversion of the sun's power into electricity or heat. Solar radiation is also a key driver in agriculture and water resources; ultraviolet radiation is a public health concern.

Measurement and instrumentation engineering are cross-technologies that draw on many areas of expertise. In order to achieve reliable measuring data, it is necessary to have considerable knowledge of the physical parameters to be measured, sensing techniques, analogue and digital signal processing and data acquisition. However, this broad background is not always part of technical education, which is becoming more focused on narrow specialisations.

The first and second editions of the guide are used as reference books by many students, scientists and researchers around the world who are not familiar with solar radiation, its different components and how to measure them. This third edition contains even more information on the instruments, and the measurement technologies.

The intention is to provide a general overview of the current state of the art in solar radiation sensors and their functional principles. A glossary and a multi-lingual dictionary for technical terms complete the story.