KIPP & ZONEN

# The benefits of accurately measuring solar irradiance

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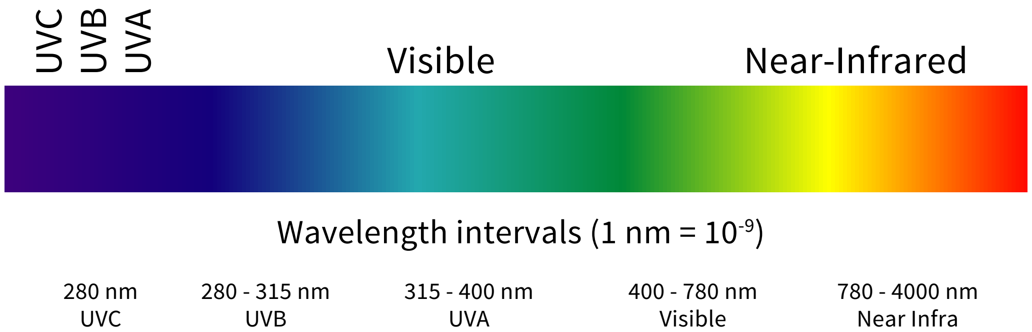
# 1. What is solar irradiance?




The sun provides 99.97% of the energy at the earth's surface (the rest is geothermal) and it is responsible, directly or indirectly, for the existence of life on Earth. The energy emitted by the sun is approximately 63 MW for every $m^2$ of its surface, about 3.72 x $10^{20}$ MW in total.

The unit for the measurement of irradiance (radiative flux) is Watts per square metre ($W/m^2$). At the mean distance between Earth and sun of 150 million kilometres, the flux of the solar radiation reaching the Earth's atmosphere is 1,360.8 ± 0.5 $W/m^2$ (NASA, 2008). This quantity is named the Solar Constant.

However, it is not actually constant. The Earth is closest to the sun in January and the radiation at the edge of the atmosphere is 6.6% higher than in June, when we are furthest away. There are various processes inside the sun and at its surface, such as the cycle that controls sun spot and solar flare activity, that cause fluctuations in the emitted radiation – but these are not more than 0.1%.

The surface of the sun is very hot and the layer emitting most of the radiation, the Photosphere, is at about 5770 Kelvin. This means that there is a lot of short-wave radiation, ultraviolet and visible, and it takes approximately 8.3 minutes to reach the earth.

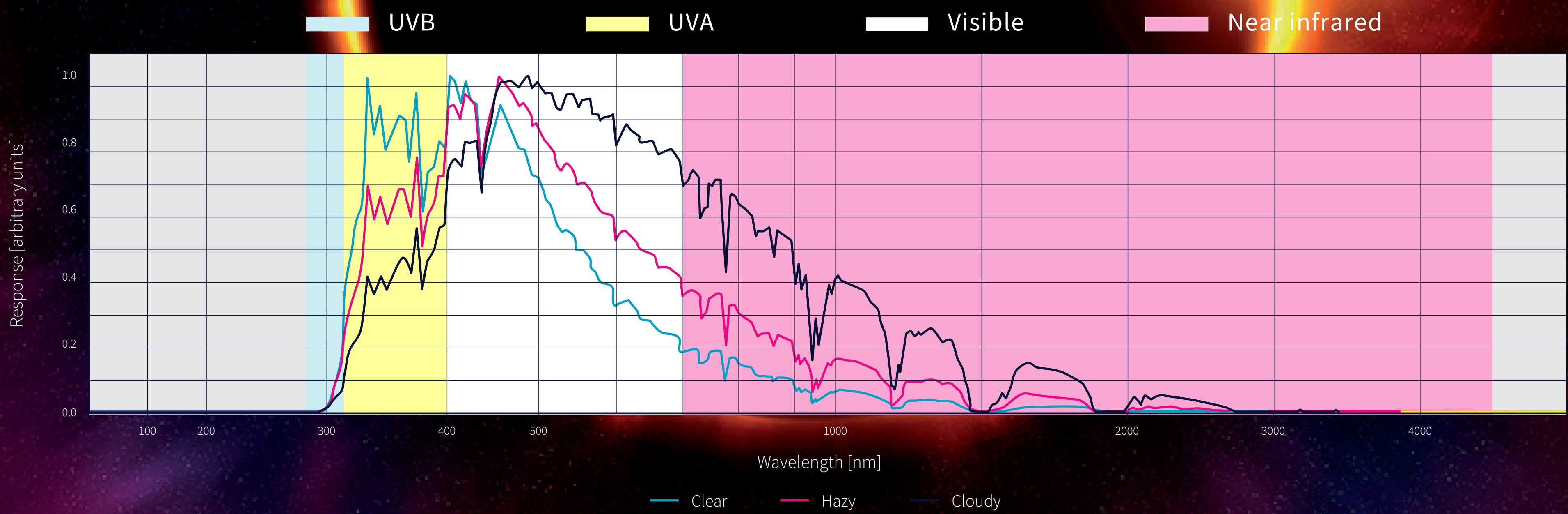
When passing through the atmosphere some solar radiation reaches the Earth's surface as a direct beam and some is scattered or absorbed by the atmosphere, aerosols (fine solid particles and liquid droplets), clouds and ice in aircraft contrails. Gaseous molecules, aerosols and clouds cause most of the absorption, heating up the atmosphere. All of the UVC and most of the UVB is absorbed by Oxygen and Ozone in the stratosphere.

Scattering of solar radiation by water droplets and ice crystals takes place over the whole spectral range, whereas gas molecules predominantly scatter short (blue) wavelengths and particles mainly scatter longer (red) wavelengths.

When the sun is directly overhead (at zenith) the atmosphere is thinnest 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 to approximately 11 times larger and the effects of absorption and scattering are correspondingly greater. This is why a clear sky near solar noon is blue, but shifts to red when the sun is near the horizon.

These processes, particularly clouds, significantly affect the spectrum of radiation that reaches the Earth's surface.

The Standard Test Conditions (STC) for PV modules refer to a reference spectrum of radiation at sea level with an air mass of 1.5 and under specific atmospheric conditions. Up to 99 % of the hemispherical solar radiation incident at the earth's surface is contained within the wavelength range from 300 nm in the UVB to 3,000 nm in the near infrared.



# 2. The components of solar radiation

Energy from the sun reaches the Earth's atmosphere as a direct beam of radiation, but as it passes through the atmosphere some of it is scattered in all directions and is termed 'diffuse' radiation. On a day with a clear sky the total irradiance reaching the Earth's surface is typically in the range from 700 to 1,300 W/m$^2$ at local solar noon; depending on the latitude, altitude and time of year.

**Direct Normal Irradiance (DNI)**
When the direct radiation from the sun falls on a plane surface at 90° (normal) to the beam the radiative flux is the direct normal irradiance. On a clear day up to 95% of the energy received at the Earth's surface is DNI, but on a cloudy day it is close to zero.

DNI is of most importance to solar energy technologies that rely on focusing the light from the sun; Concentrating Solar Power (CSP) thermal systems and Concentrating Photovoltaic (CPV). It is measured with a pyrheliometer that has a field of view of 5° and is mounted on an automatic sun tracker that moves to keep the instrument pointed accurately at the sun from sunrise to sunset.



**Diffuse Horizontal Irradiance (DHI)**
The solar radiation scattered by the atmosphere is generally taken to be diffuse and of approximately equal distribution across the sky above the measurement location. On a clear day it is about 5% of the total energy received at the Earth's surface, but almost 100% on a cloudy day. PV panels respond to light from a wide range of incident angles, so they can utilize this diffuse radiation to produce energy on cloudy days.

When the diffuse radiation from the hemisphere of sky falls on a horizontal plane surface the radiative flux is the diffuse horizontal irradiance. DHI is measured with a horizontal pyrometer mounted on a sun tracker and continuously shaded from the direct sun beam throughout the day. The 5° of sky that is obscured matches the 5° seen by a pyrheliometer.


**Global Horizontal Irradiance (GHI)**
When all the radiation from the sun (DNI) and sky (DHI) falls on a horizontal plane surface the radiative flux is the global (total) horizontal irradiance. However, GHI is not simply DHI + DNI.

If the sun is directly overhead it makes a circular beam on the horizontal surface, but as it moves down in the sky the beam spreads out into an ellipse – in the same way that shadows get longer in the evening. The DNI is the same in $W/m^2$, but spread over a larger area so the irradiance on the horizontal surface decreases.

The relationship is a cosine function: $GHI = DHI + DNI*\cos(\theta)$

$\theta$ is the solar zenith angle (SZA) where vertically above the location is 0° and horizontal is 90°.

So, GHI = DHI + DNI only occurs at solar noon and if the sun is at 0° SZA (which never happens outside the tropics).

GHI is important because it is the parameter measured in weather and climate networks, derived from satellite instruments and calculated with clear sky energy models. It is measured with a horizontal pyranometer.

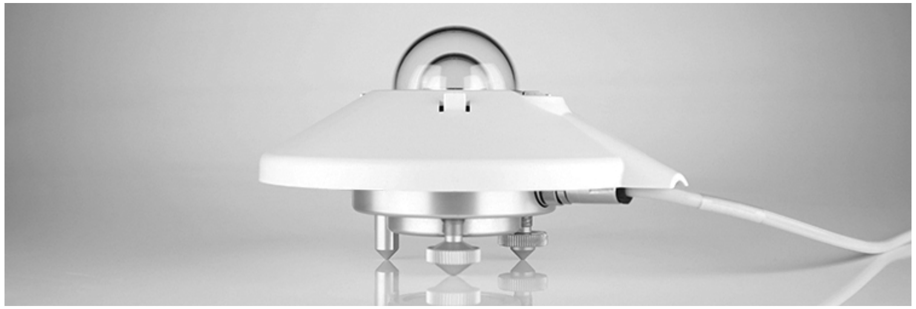
Local pyranometer GHI measurements allow comparison of the available solar energy between sites and between data sets and the validation of satellite and model estimates for the specific location.

**Plane of Array (POA) Irradiance**

When a pyranometer is mounted at an angle it measures the tilted global irradiance. If the azimuth and zenith tilt angles are the same as the adjacent PV panels it is in the same plane and measures all the solar radiation available to that array. It also includes reflections from the ground and from the structure of PV panels and frames in front of the pyranometer. This varies with the panel tilt angle, the row spacing and the surface albedo.

Accurate measurement of POA irradiance is critical to calculating plant efficiencies, performance ratios and return on investment.

# 3. How to measure solar irradiance, introducing the pyranometer and pyrheliometer



High quality ground-based measurements of solar radiation are made using radiometers that respond to radiation in the wavelength range from 300 nm or less to 3,000 nm or more, covering up to 99% of the energy arriving at the Earth's surface from the sun and sky.

**ISO 9060**

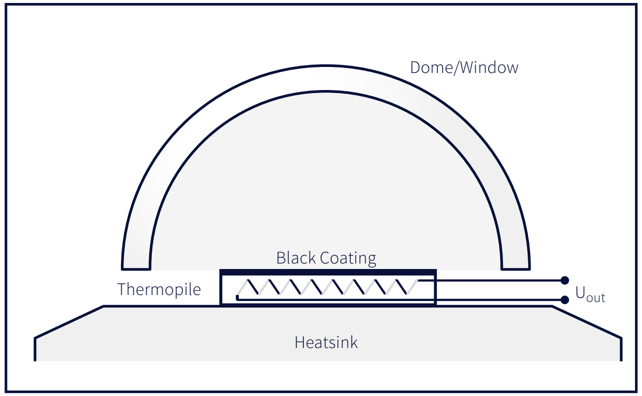
This standard is titled "Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation". It defines what a pyranometer is for measuring global horizontal or tilted irradiance (GHI and POA) and, when shaded, DHI. The standard also defines what is a pyrheliometer for measuring DNI.

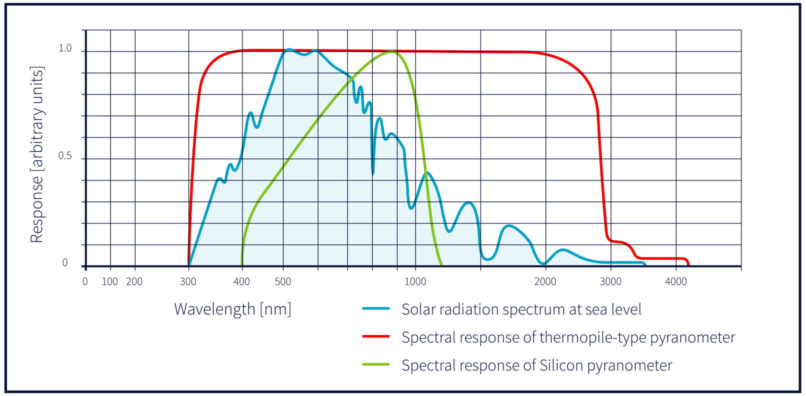
The original standard dates from 1990 and has been updated to ISO 9060:2018.

The radiometer should have a flat spectral response over a wide spectral bandwidth, to measure all the available incoming solar energy independent of types of PV cells or solar collectors used. This measurement is usually achieved using a 'thermoelectric' type of detector with a black coating that absorbs the incoming radiation, heats up a thermopile, and converts the temperature rise into a small voltage.

Nearly all pyranometers use an optical quality glass for their hemispherical single or double domes to protect the black detector surface from dirt and environmental effects. 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.

Another type of sensor is photoelectric, typically with a silicon photodiode mounted below a diffuser. The graphs below show a typical solar radiation spectrum and the response of an entry- level glass dome thermopile pyranometer, such as the Kipp & Zonen CMP3 and SMP3 models. The limited and very uneven spectral response of a typical silicon photodiode sensor shows why these do not meet the specifications for a 'spectrally flat radiometer' as defined by ISO 9060 and are often described as a 'Silicon Pyranometer' or similar (for example the Kipp & Zonen SP Lite2).




ISO 9060 specifies the minimum performance requirements for pyranometers and pyrheliometers. Classifications in the 1990 version are Second Class, First Class and Secondary Standard, in order of improving measurement performance. In 2018 the approximate equivalents became Class C, B and A, respectively and with the addition of a higher Class AA for pyrheliometers. Many pyranometers exceed the requirements of Secondary Standard / Class A, but there is no higher classification. For the lowest uncertainty, GHI is calculated from very accurate diffuse and direct irradiance measurements and the solar zenith angle ( θ ), using the formula GHI = DHI + DNI*cos( θ ).

| Pyranometer Classifications | | | |
|---|---|---|---|
| **ISO 9060:2018** | **Spectrally Flat C** | **Spectrally Flat B** | **Spectrally Flat A** |
| **ISO 9060:1990** | **Second Class** | **First Class** | **Secondary Standard** |
| Kipp & Zonen Model | Lower | → | Higher |
| Passive pyranometers | CMP3 | CMP6 | CMP10<br>CMP11<br>CMP21<br>CMP22 |
| Smart pyranometers | SMP3 | SMP6 | SMP10<br>SMP11<br>SMP21<br>SMP22 |

In essence, a pyrheliometer is a pyranometer with a collimation tube that restricts the view to 5° and it has a quartz disk as the entrance window for the radiation. The majority of pyrheliometers on the market are First Class / Class B such as the Kipp & Zonen CHP1 and SHP1. A Class AA pyrheliometer is usually an 'absolute cavity radiometer' that is very expensive and can only make measurements in fine weather conditions. The only model currently in production is the PMO6-cc from the World Radiation Center (WRC) in Davos, Switzerland.

**Pyranometer measurement uncertainty**

The International Standards Organisation (ISO) and the World Meteorological Organisation (WMO) now only refer to the 'uncertainty' in the measurement of a parameter under specific conditions, not 'accuracy'. In general, uncertainties (and Kipp & Zonen specifications) are expressed at the 95 % confidence level (k=2).

Each pyranometer (and pyrheliometer) has a unique sensitivity to radiation that is determined during a calibration procedure. The sensitivity and its uncertainty, traceability to the World Radiometric Reference (WRR) at the WRC, and other information must be given on the calibration certificate.

The 'absolute' calibration uncertainty is always present in the solar irradiance measurements, but there is an additional 'relative' uncertainty caused when the field measurement conditions are different from the calibration conditions, which are typically in a laboratory at about +20°C and with the 'sun' directly overhead. ISO 9060 defines parameters that affect pyranometer measurement performance and 6 of them are relevant to short-term measurements of GHI.

The effects on measuring the daily total of irradiance are shown in the table below, using the actual performance of Kipp & Zonen pyranometers. 'Overall' uncertainties are calculated by taking the Root Sum Square (RSS) of the contributing uncertainties. The typical GHI daily measurement uncertainties given are for temperatures in the range from -10°C to +40°C and are, in effect, 'worst case' values; achievable in non-extreme climate conditions in most parts of the world.

The uncertainty of hourly totals of irradiance varies throughout the day. They may be higher or lower than the daily total uncertainty and tend to partially cancel out over the day. As a guide, the worst hourly total uncertainty for a spectrally flat radiometer is likely to be about 1.5 times the daily total uncertainty.

Of course, these uncertainty values depend upon the pyranometer being correctly installed and maintained (a clean dome) and that the data logger or acquisition system performance does not degrade the measurements.

| **ISO 9060**<br>**Sources of Pyranometer Uncertainty** | CMP3 | SMP3 | CMP6 | C/SMP10<br>C/SMP11<br>C/SMP21 | C/SMP22 |
|---|---|---|---|---|---|
| Zero offset a) (thermal) | 1.5 % | 1.5 % | 1.2 % | 0.7 % | 0.3 % |
| Zero offset b) (ambient 5°C/hr change) | 0.3 % | 0.3 % | 0.3 % | 0.1 % | 0.1 % |
| Non-linearity (ref. 500 W/m$^2$) | 1.0 % | 1.0 % | 1.0 % | 0.2 % | 0.2 % |
| Directional response (sun beam angle) | 2.0 % | 2.0 % | 2.0 % | 1.0 % | 0.5 % |
| Spectral error and spectral selectivity | 0.1 % | 0.1 % | 0.1 % | 0.1 % | 0.1 % |
| Temperature response (-10 to +40°C) | 5.0 % | 2.5 % | 4.0 % | 1.0 % | 0.5 % |
| **Relative daily field uncertainty** | 5.7 % | 3.7 % | 4.7 % | 1.6 % | 0.8 % |
| **Absolute calibration uncertainty** | 4 % | 4 % | 3 % | 1.5 % | 1 % |
| GHI daily measurement uncertainty | 7.0 % | 5.4 % | 5.6 % | 2.2 % | 1.3 % |

The CMP22 and SMP 22 models have expensive synthetic quartz domes instead of the optical glass used by all the other models. These domes have significantly improved optical and thermal properties, providing probably the best overall GHI measurement uncertainty on the market.

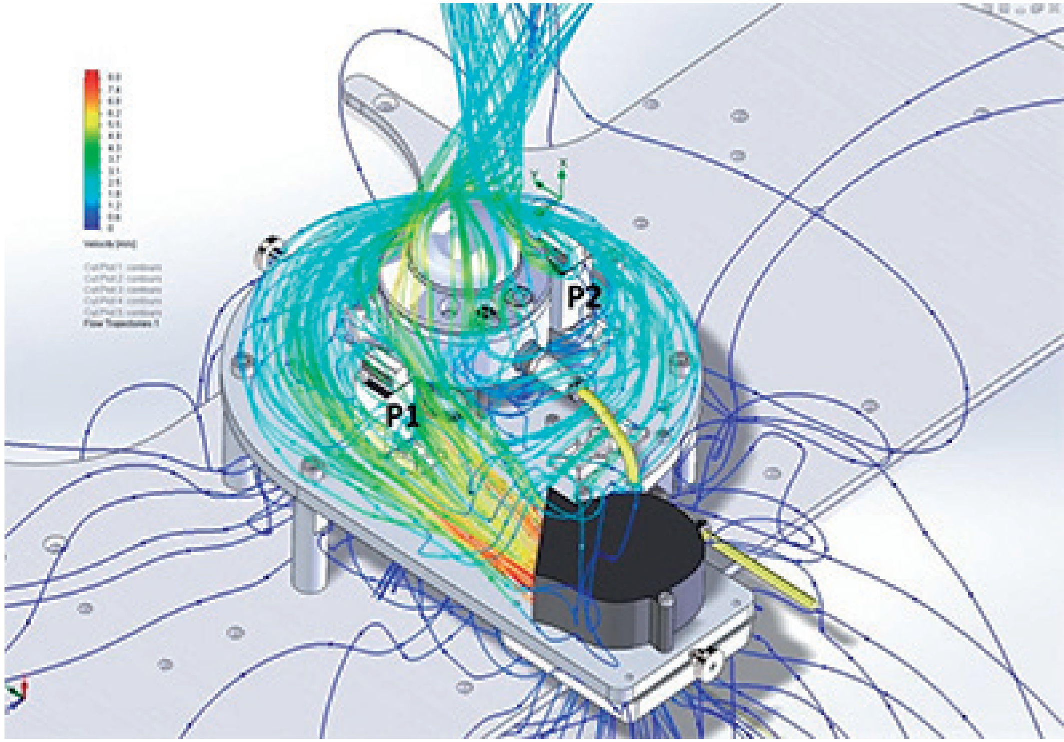
The table above shows the reasoning behind the statement often made that a good quality and well calibrated Secondary Standard or Spectrally Flat Class A pyranometer should be capable of measuring the daily total of irradiance within 2%; and why these are recommended or required for most solar energy applications. Around 50,000 Kipp & Zonen CM11 and CMP11 Secondary Standard pyranometers have been installed around the world in meteorology, climatology and solar energy applications.

**Keeping it clean**

If you have a pyranometer capable of an uncertainty in daily measurements of 2%, or less, it will be readily appreciated that it does not take much in the way of deposits on the dome to completely disrupt the readings:

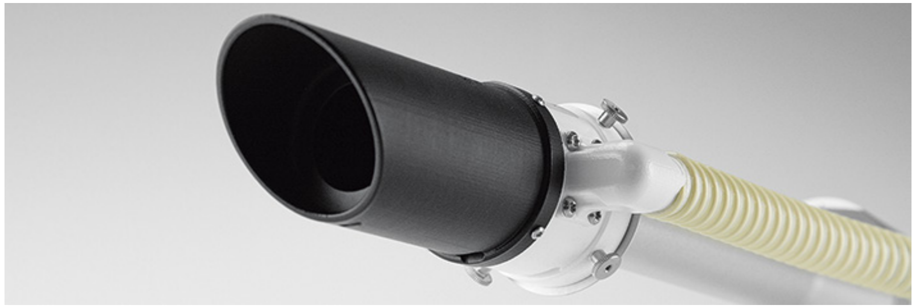
- Dew and raindrops absorb and scatter radiation
- Frost, and snow are highly reflective
- Dust, dirt and sand block radiation from reaching the detector and may stick to a damp dome and form a hard layer
- Atmospheric pollutants on the dome attenuate radiation and also alter the spectrum of the radiation reaching the detector
- Most sites do not have permanent staff who can regularly clean the domes

The answer is to fit a ventilation unit, such as the Kipp & Zonen CVF4. CVF4 has high-flow fan that produces a swirling, spiral, flow of filtered clean air close to the dome. This provides a barrier layer of air against deposition and evaporates dew and raindrops. The fan runs from 12 VDC at 5 W and the speed can be monitored.




5.5 W of heating (P1 and P2) can be switched on externally to melt frost and snow with minimal temperature rise of the pyranometer. There is a small improvement in the pyranometer performance due to stabilizing temperatures within the ventilation unit. However, the main benefit is a much greater up-time of high quality, reliable measurement data and reduced frequency of cleaning.

For pyrheliometers Kipp & Zonen has a system to keep the window clean, the AirShield DNI.



**How to connect a pyranometer or pyrheliometer**

Since 1913 Kipp & Zonen had been manufacturing a fast and sensitive thermopile (made up of many thermocouples) for the measurement of thermal radiation and light designed by Dr. Moll of Utrecht University. In 1923 Professor Gorczynski of the Polish Meteorological Institute decided to construct a pyrheliometer and a pyranometer using modified thermopiles to measure solar radiation.

The thermopile enabled the instruments to be small, light, low cost, have a continuous voltage output signal, and not require any external electrical power or control systems. Kipp & Zonen began manufacture of these instruments in 1924 and the basic measurement principle remains today.

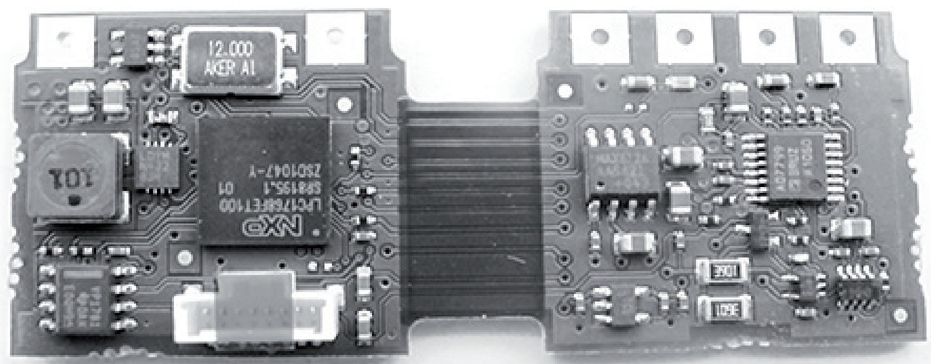
Thermopile pyranometers and pyrheliometers do not require a power supply because the detector generates a small voltage in proportion to the temperature difference between the black absorbing surface and the instrument housing. This is of the order of 10 µV (microvolts) per $W/m^2$ of irradiance, so on a sunny day of 1,000 $W/m^2$ the output will be around 10 mV (millivolts). Each radiometer has a unique sensitivity defined during the calibration process, which is used to convert the output signal in microvolts into irradiance in $W/m^2$.

The advantage of the CMP series pyranometers and CHP1 pyrheliometer is that they do not require any power. However, the very small voltage generated is easily degraded. High quality cables, proper shielding and a very good, low offset, low noise and high resolution amplifier or data logger is needed. To see changes in irradiance of 1 $W/m^2$ requires accurate measurement down to 10 µV.

High quality amplifiers, such as the Kipp & Zonen AMPBOX, and scientific data loggers (including the Kipp & Zonen LOGBOX SE) are designed for this type of input, but most 'industrial' signal amplifiers or data loggers significantly degrade the accuracy of the measurement data. The use of inferior or unshielded cables will affect the small radiometer signals.

The CMP Class A pyranometers and the CHP1 pyrheliometer have a temperature compensation circuit, but this is not perfect as it is a linear correction for a polynomial response function. However, the lack of active components means that these 'passive' radiometers are not prone to damage from lightning and other ESD sources and have a very long operating life.

Kipp & Zonen was the first to develop a Smart generation of pyranometers, the SMP series, and the partner SHP1 Smart pyrheliometer. They look the same as the passive series on the outside, but have built-in high performance analogue to digital (ADC) conversion for the thermopile signal, internal temperature and supply voltage readings.



Digital signal processing by a microcontroller includes accelerating the response time and polynomial temperature correction. The last 10 calibration dates and sensitivities are stored in memory and the digital irradiance output is directly in $W/m^2$.
Smart radiometers have a RS-485 Modbus® interface and are addressable so that many instruments can be connected on a single cable to a solar power plant supervisory control and data acquisition (SCADA) system, along with other Modbus equipment such as inverters.

There is also a digital to analogue converter (DAC) that provides 0–1 Volt or 4–20 mA amplified outputs, according to the model selected. In both cases the critical (microvolt) signal handling is done inside the instrument.  In general, the 4-20 mA version is preferable as it maximizes the data logger input resolution and works with long and relatively low cost cables.

Kipp & Zonen Smart radiometers operate from 5-30 VDC with very low power, down to 35 mW when using only the Modbus® communication. Due to the digital electronic, Smart instruments require more careful shielding, grounding and protection from power and data surges and spikes than the passive models.

**Solar monitoring stations**
For monitoring all the components of solar radiation, DNI, DHI and GHI a solar monitoring station is required and these are often used for solar energy research and as a reference system for larger operating solar power plants.

Typically, this comprises a SOLYS2 or SOLYS Gear Drive automatic sun tracker with a sun sensor for active tracking and a pyrheliometer for DNI measurement. The shading ball assembly mounts two Class A pyranometers on the tracker, one shaded for DHI and one unshaded for GHI. A high quality data logger or digital data acquisition system completes the equipment, and usually there is an automatic weather station to monitor meteorological parameters, including wind speed and direction, ambient temperature and humidity and precipitation.

Where soiling is an issue, the pyranometers can be fitted with CVF4 ventilation units and the pyrheliometer with an AirShield DNI.

A lower cost, but slightly lower performance, alternative is the unique Kipp & Zonen RaZON+ all-in-one solar monitoring system. This measures DNI and DHI with dedicated designs of soiling-resistant pyrheliometer and shaded pyranometer. Using GPS information the solar zenith angle is derived and GHI is calculated.

A built-in data logger samples every second and stores the average values every minute, along with the running total of the energy received. It has an auxiliary serial input so that data can be logged from compatible Modbus instruments, such as SMP pyranometers for POA, a panel temperature sensor and a Lufft UMB series all-in-one weather station.

# 4. Benefits of monitoring irradiance for the phases of utility-scale solar energy projects

High quality, reliable radiation data is extremely important for all activities in the solar energy sector. Photovoltaic (PV), concentrating photovoltaic (CPV) and concentrating solar power (CSP) thermal systems may have slightly differing requirements, but they need accurate solar radiation information for similar reasons.

**Technology research**

Improvements in mass-produced PV technologies, such as crystalline silicon cells, are often incremental; each step is small, but the total gain can be large. For example, two different solutions may show efficiencies of 20% and 22% (10% improvement) under controlled laboratory test conditions. However, the irradiance needs to be measured with an uncertainty of better than 2% to be sure that the efficiency improvement is genuine.

Laboratory testing under 'ideal' indoor conditions is not enough. The performance of cells, modules and thermal systems needs to be verified in the real world under varying weather and sky conditions compared to 'reference' quality solar radiation measurements. Therefore, research institutes are equipped with scientific level pyranometers, and in many cases, a complete solar monitoring station.

**Quality control**
If a manufacturer or a supplier wishes to ensure that the performance of their PV cells or panels does not vary by more than (for example) 5%, they need to test samples from production batches and measure the solar radiation with a significantly lower uncertainty.

To verify published specifications of equipment the manufacturer, or an independent test laboratory, needs reference quality measurements.

**Performance ratios**
There are many stages in the development of a utility-scale solar power plant and throughout its operational life and in all of them the Performance ratio (PR) is of key importance. In the early stages this is an estimation or prediction but, in the later stages, it uses real plant monitoring data.

PR is the ratio between the final (actual) yield of a solar power generating system and its reference (design) yield over a defined period of time. Typically this is calculated over a year, since this filters out daily and seasonal influences, and it is an important quality indicator of a solar power system; the quality of components, design, installation and maintenance.

**Performance Ratio = (final yield / reference yield) x 100 %**

Although the formula for PR looks simple, the definition of final yield and reference yield is a subject open for discussion. Most software tools for solar plant monitoring allow the user to choose several definitions and constraints for the calculation.

For PV systems, the final yield of AC power generated is easily measured with high accuracy at the grid connection. The reference yield is the theoretical power produced by irradiance on the PV panels; the solar energy received by the panels multiplied by the efficiency of the conversion to electrical energy and which should include the inverter efficiency and cabling / connection losses.

The conversion efficiency of silicon PV cells is temperature-related, higher temperatures reduce the power produced for the same irradiance. Therefore, the cell temperature should be taken into account, resulting in a temperature corrected performance ratio. For the reference yield, accurate local measurements of irradiance and cell temperature are of key importance.

Performance ratios (if defined and monitored in the same way) can be used to compare solar plants at any locations: a well-designed, -installed and –maintained solar park in the Arctic could have a better PR than an averagely designed and installed solar park near the Equator (although the latter receives far more energy from the sun).



**Site prospecting**

A solar energy project starts with site prospecting - finding the optimal location for the plant. Solar energy resource maps are widely available and are often used to derive the potential for solar electricity generation in a particular region. These are usually generated from models using up to 10 years of satellite data and ground-based meteorological observations (often widely spaced and not very accurate) and interpolation.

However, the map data is not good enough quality, and the spatial scale too large, to provide a reliable basis on which to make technology and investment decisions for a power plant. Due to local climate and topographical differences relatively small changes in location can result in a gain, or loss, of hundreds of annual sunshine hours per year. This is particularly true in mountainous and coastal areas and for islands.

Other meteorological factors also have to be taken into account. Cloud, fog and rain greatly reduce the amount of energy produced; low temperatures may induce dew, frost or snow, high wind speeds will require more substantial mounting structures and might preclude the use of two-axis tracking systems.

Many of the locations receiving high irradiance throughout the year tend to be hot and dry (semi-arid) and soiling of the panels is a major issue in loss of power generated and higher cleaning costs. For such sites it is highly desirable to monitor soiling as part of the prospecting phase, so that these losses and costs can be factored in. The Kipp & Zonen DustIQ Soiling Monitoring System is the ideal simple and cost-effective solution for this.

Local infrastructure issues also play an important part, site access for construction and maintenance and proximity to a grid to feed in the power generated. In the case of a CSP plant a major consideration is often co-location with an existing fossil-fuel power plant with steam turbine electricity generators.

The above information and factors allow a number of potential sites to be short-listed. However, in order to decide on which are the most economically attractive, and to select the optimum power generation technology for a site, high quality ground-based irradiance measurements over at least a year are required. Meteorological measurements by an automatic weather station are also needed and allow comparison with historical data to ascertain if it is a typical year.


The parameters are usually wind speed and direction, precipitation, air temperature and relative humidity, GHI measurements by pyranometers can be used to validate and ‘train’ for that specific location the GHI estimates derived from satellite data models. POA irradiance cannot be derived from models with a suitable level of uncertainty to make investment decisions, this always needs local tilted pyranometers; DNI, if required, must be measured locally by a pyrheliometer on a sun tracker.

Experienced investors want the lowest uncertainty of the on-site solar resource data, generating equipment performance and proven reliability, before making decisions on the locations for solar energy plants and on the most effective solar energy system types to use. Errors in the solar radiation measurements can significantly impact upon the difference between predicted and achieved return on investment.

The estimated performance ratio is an indicator for the potential profitability of a solar plant and high quality, reliable local solar radiation data is critical to the bankability of projects.

**Plant design**

Good solar plant design optimises yield and reduces losses, resulting in a high PR. The design and the equipment selected is heavily influenced by the environment surrounding a solar energy plant as each location has its own micro-climate in terms of irradiation, sun elevation paths, shading (by mountains, woods, buildings, clouds), temperature ranges, precipitation, wind, pollutants and soiling.

These environmental factors are important information obtained during the site prospecting phase; most are naturally occurring and cannot be changed and they not only influence the mechanical and electrical design but the likely maintenance required during plant operation. For example, in a location with a lot of soiling, mounting panels at a steeper tilt angle than usual could offset the 'clean' power loss by reducing cleaning costs.

Often, key stakeholders have a list of preferred 'bankable' suppliers; a short list of companies and products with proven quality, performance, reliability and lifetime costs. Better quality and higher performance products will, in general, provide a more reliable long-term performance ratio, with lower uncertainty.

By using accurately measured irradiance and the temperature corrected performance ratio, two of the critical environmental factors for PV systems are taken into account, both for the reference and final yields. A mean annual temperature 2°C higher than the value used in the reference calculations can drop the PR by 1%. Accurate local measurements also enable PR to be used over shorter time periods, typically monthly.

**Installation and commissioning**

Following the design scheme as closely as possible during construction and installation is key to reaching the projected reference PR. An initial operational period, from several weeks to months, is used to calculate the commissioning PR. From this a contractually agreed target PR is derived.

The contractually agreed target performance ratio (sometimes called the Guaranteed Performance Ratio) is often slightly lower than the final PR, to allow O&M parties to correct faults and restore interrupted operation. A checklist for this is provided by the 2015 International Finance Corporation Project Developer's Guide, Utility-Scale Solar Photovoltaic Power Plants.

By showing high performance ratios after the initial building, commissioning and operating period, EPCs can demonstrate their ability to design and construct well-performing solar energy plants. Such plants will generate higher selling prices on the secondary market, and reduce future risk for the buyers. But, to do this requires suitably high quality irradiance data.

**Plant operation**

The monitoring of a solar power plant is a complex process with many stages, from solar energy input to grid electrical power output. For all these stages separate sensors and associated software are available to monitor the whole process. During the first few years the final performance ratio of the plant is determined, operating efficiency is maximised and the true O&M costs can be assessed; leading to an overview of the financial return on the investment. Of course, this includes the quality and reliability of the solar irradiance data.

By maintaining yield and availability at high levels at modest costs, O&M parties can show their added value in optimised operating and maintenance policies. A high performance ratio is a reflection of the quality of their work.

Gradual changes in efficiency compared to the local irradiance measurements may indicate dirty panels or reflectors, so cleaning actions can be scheduled. More sudden changes may indicate a defective section, a cable and connection problem or an inverter issue, so further service actions are required to investigate the problem.

During this phase of the plant life the most cost-effective times to clean the panels or reflectors can be determined using real-time soiling measurements across the plant – it does not get dirty at the same rate everywhere. When the cost of lost energy production exceeds the cost of cleaning it is time to remove the panel soiling, but only where necessary. Areas of the plant will become soiled at different rates and this can be determined with a network of Kipp & Zonen DustIQ units.

**Output forecasting**

Using high quality solar radiation, meteorological and other monitoring at the plant, a database of performance can be built up; allowing more accurate forecasting of the future energy yield and financial returns.

Real-time measurements and a historical database can be used in conjunction with satellite data and weather forecasts as inputs to now-casting models for the output of the plant in the coming 2-3 hours. This is of particular interest to grid operators, as other power generation sources cannot be switched in instantly when clouds pass over the solar energy plant (or when the wind speed drops at turbine farms).

**Re-investment**

Over time the plant PR will decrease and a business case for refurbishment can be made involving investment in new equipment; replacement panels or reflectors, inverters, transformers, cabling, etc. Studies such as the Compendium of Photovoltaic Degradation Rates (NREL 2015) show that the performance of PV panels commonly reduces by 0.5-1% per annum.

A refurbishment might take place after 20 years of operation, or when a power plant is sold-on, and the replacement will normally have better specifications and performance than the original equipment. It would typically include the replacement of the monitoring systems for irradiance and other plant parameters.

**Monitoring differences for PV, CPV and CSP**

The first requirement is a high quality pyranometer to measure global horizontal irradiance (GHI), and ISO 9060 Class A or Secondary Standard models are recommended, or required, by most standards, to monitor with a daily uncertainty of about 2%. GHI allows comparisons of the available solar radiation to be made between sites, irrespective of the power generation technology used; and with the data derived from models using satellites and meteorological weather stations, which is for GHI.

PV panels have a wide field of view and must be positioned in such a way as to receive the maximum amount of solar radiation at the desired time of year. Depending on the location and cost/benefit decisions these panels are usually installed at a fixed angle. In this case, another pyranometer is required, tilted in the plane of array of the fixed panels to measure the solar radiation available to the modules.

As this pyranometer forms part of the plant performance monitoring system, a second POA unit is often fitted for redundancy and back-up when one unit is off-site for recalibration. If the panels vary significantly in their azimuth and/or zenith angles, for example where the plant is across a valley or an undulating hillside, additional pyranometers are needed. As the plant size increases it takes time for clouds to move across and some parts will be in shadow and others will be in sunshine, requiring more irradiation measurement points.

To maximise use of the available solar energy PV panels are often installed on mountings that move to follow the sun during the day, either by rocking about a single axis or on a two-axis sun tracker. POA pyranometers can be mounted to the module frames to move with them. For PV installations the cell/module temperatures must be monitored.

Concentrating photovoltaic (CPV) and concentrating solar power (CSP) systems require the lenses or reflectors to be pointed at the sun with a high accuracy and only see the DNI. For these technologies it is necessary to measure the direct normal irradiance (DNI) with a pyrheliometer and an automatic sun tracker.

The pyrheliometer should be ISO 9060 Class B / First Class, such as the Kipp & Zonen CHP1 or Smart SHP1 models, which can measure daily totals of solar irradiance with an uncertainty of about 1.5 %.

To minimise the measurement uncertainty, the sun tracker should have a pointing accuracy of 0.1°, as with the Kipp & Zonen SOLYS models.

At many larger solar power plants of all types there are one or more complete solar monitoring stations as reference systems monitoring DNI, DHI and GHI. An all-in-one solution is the Kipp & Zonen RaZON+.

It is important to have measurements of the other meteorological parameters affecting plant performance and operation. A typical system is the Lufft WS600-UMB all-in-one weather station.

It is also important that high quality data loggers and data acquisition systems are used that do not degrade the measurements made by the solar radiometers and other sensors.


# 5. International Standard: IEC61274-1

There are a number of international standards with regard to the monitoring of solar energy plant performance that have become adopted by major stakeholders around the world.

The newest and most comprehensive international standard is IEC 61274-1, March 2017 Photovoltaic system performance – Part 1: Monitoring. It also serves as a basis for two other standards which rely upon the data collected for performance analysis; IEC TS 61724-2 and IEC TS 61724-3.

IEC 61274-1 outlines equipment, methods, and terminology for performance monitoring and analysis of solar energy plant systems, from irradiance input to AC power output. It is applicable to fixed angle and tracking PV and CPV technologies. Three classes of monitoring systems are defined (A, B and C) corresponding to different levels of uncertainty and different intended applications.

| Typical applications | Class A<br>High accuracy | Class B<br>Medium accuracy | Class C<br>Basic accuracy |
|---|---|---|---|
| Basic system performance assessment | x | x | x |
| Documentation of a performance guarantee | x | x | |
| System losses analysis | x | x | |
| Electricity network interaction assessment | x | | |
| Fault localization | x | | |
| PV technology assessment | x | | |
| Precise PV system degradation measurement | x | | |

The standard addresses sensors for all the parameters affecting the plant operation, including the installation and uncertainties of monitoring equipment. In addition it covers data acquisition and quality checks, calculated parameters, and performance metrics.

**IEC 61274-1 refers to the following important standards:**

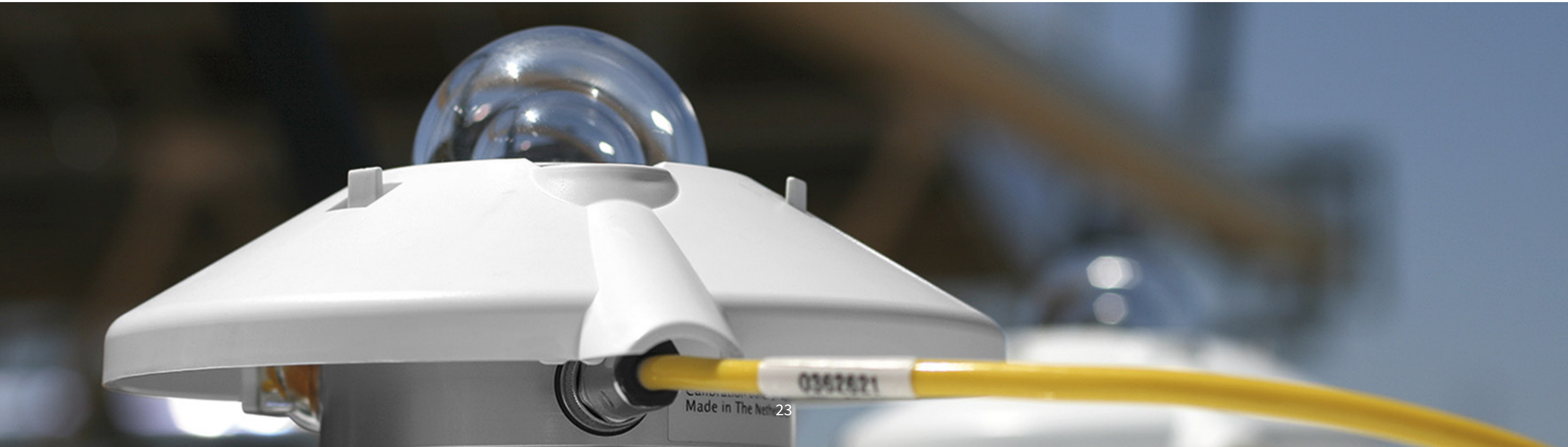
- ISO 9060:1990 Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation. This is the standard that defines and classifies pyranometers and pyrheliometers and has been updated to ISO 9060:2018.
- ISO 9847:1992 Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer. Part of this standard defines the procedures and requirements used for the calibration and recalibration of pyranometers indoors in controlled conditions. Annex A.3.1 is 'The Kipp & Zonen device and procedure'.
- ISO 9846:1993 Solar energy – Calibration of a pyranometer using a pyrheliometer. This defines how a reference pyranometer should be calibrated outdoors.

Pyrheliometers are calibrated according to ISO 9059:1990 – Calibration of field pyrheliometers by comparison to a reference pyrheliometer.

For Class A monitoring the irradiance input, temperature, wind, and the electrical outputs (DC and AC) should be sampled at least every 3 seconds and the 1 minute averages recorded. Kipp & Zonen systems normally sample every second. It is also desirable to store the maximum, minimum and standard deviation over the 1 minute period to aid with data QA/QC so that erroneous readings are not included in the subsequent analysis. Other parameters; such as the soiling ratio, humidity and precipitation should be sampled and recorded every minute.

IEC 61274-1 states that for Class A monitoring a Secondary Standard (now Spectrally Flat Class A) pyranometer should measure hourly totals of irradiance within an uncertainty of 3%. If correctly installed, maintained, clean and with suitable data logging or data acquisition this is generally true. For POA measurements it is important that the pyranometer detector surface is in the same plane as the PV cell surface. The standard provides angular limits for this.

There are requirements for the maintenance, cleaning and recalibration of pyranometers. The possible drift in sensitivity during operation of high quality Secondary Standard / Class A pyranometers is up to 0.5% per year. Therefore, in 2 years it could change by 1%, which is significant compared to the achievable measurement uncertainty. This is why recalibration is recommended every 2 years by Kipp & Zonen and is specified for IEC 61274-1 Class B monitoring; it is required every year for Class A.



# 6. Projects large and small rely on Kipp & Zonen

Kipp & Zonen has been designing and manufacturing solar radiation measurement equipment since 1924 and has supplied its instruments for many decades to most of the leading meteorological, climatological and atmospheric science organisations, research institutes and energy companies around the world. There are ranges of radiometers to measure sun, sky, atmospheric and terrestrial radiation; from the ultraviolet to the far infrared parts of the spectrum.

Kipp & Zonen also provides automatic sun trackers and complete scientific-level solar monitoring stations. A wide range of accessories includes mountings, ventilation units, data loggers and interfacing solutions. Our instrument calibrations are fully traceable to the World Radiometric Reference at the World Radiation Centre in Davos, Switzerland, and to relevant international standards.

In addition to solar irradiance, an important input to PV plant operation and monitoring is the soiling of panels. This directly affects the yield and the Performance Ratio. Our revolutionary DustIQ is a cost-effective digital product that provides the Soiling Ratio every minute, day and night and with no regular maintenance required. DustIQ can be easily mounted to fixed, single-axis and dual-axis PV panels and to CPV installations; informing decisions on when and where it is cost-effective to clean panels across the plant.

**Warrranty, MTBF and lifetime**

Kipp & Zonen has a global reputation for quality, reliability, expertise and support and all Kipp & Zonen products have a minimum of 2 years worldwide warranty. For most radiometers, including the CMP and SMP pyranometers and the CHP1 and SHP1 pyrheliometers the warranty is 5 years.

The mean time between failures (MTBF) of these radiometers is in excess of 10 years and there is no designed life-time; many pyranometers return for service and calibration that are 20, 30 and even 40 years old.

**The leading supplier of solar irradiance monitoring solutions worldwide**

Kipp & Zonen, together with its sales channel partners and customers, has thousands of installations around the world. Here are some examples of typical solar irradiance monitoring solutions.

# 1. Leading PV in Datong, Shanxi, China

| | |
|---|---|
| Plant size | 1 GW (1,000 MW) fixed PV |
| Kipp & Zonen equipment used: | 14 x solar monitoring stations, each including:<br>- SOLYS2 sun tracker with sun sensor and shading assembly<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 2 x CMP10 pyranometers (DHI, GHI)<br>- 1 x CMP11 pyranometer (POA) |

The 'PV Leader Program' was launched in 2015 by the NEA to promote manufacture and use of the latest technologies in solar energy PV modules. In 2016 the first demonstration projects were constructed in Datong and they all have Kipp & Zonen solar monitoring stations.

The technology demonstration for the PV Leader Program has been developed around Datong City in Shanxi province, Northern China, on a former coal-mining site. This resulted in 13 PV plants, each with a capacity between 50MW and 100MW.

**Importance of solar monitoring**

The evaluation of the performance ratio (PR) of each plant is one of the most important efficiency indicators and solar irradiance data at the sites plays an extremely important role. Power China and Beijing Solarsky Technology Co. Ltd. carefully selected suppliers and equipment to provide all 13 of the generating PV plants in Datong, and a central reference site, with an objective and very reliable solar monitoring system.

The basis of each station is a Kipp & Zonen SOLYS2 sun tracker fitted with a sun sensor for active tracking and a shading assembly. It is equipped with a CHP1 pyrheliometer for DNI and two CMP10 pyranometers for DHI and GHI, and an additional CMP11 pyranometer for POA irradiance. At the same time other parameters, such as ambient temperature and humidity, tilted global (plane of array, POA) irradiance, air pressure and precipitation, are also measured by individual sensors. All the measurements are collected by a high quality data logger and then checked and analysed using dedicated, user-friendly graphics based software.

**Installed by Power China and Beijing Solarsky**

It took one and half months for the commissioning work including processes of micro-site prospecting and installing the 14 systems (one reference station and one on each of the 13 PV plants). Now the project can rely on the quality of Kipp & Zonen solar monitoring products to maximize the efficiency of the energy yield. The Datong sites will grow to 3 GW in the coming phases of development.

## 2. Ruicheng PV Pioneer Project, Shanxi, China

| | |
|---|---|
| Plant size | 500 MW fixed PV |
| Kipp & Zonen equipment used: | 7 x solar monitoring stations, each including:<br>- SOLYS 2 sun tracker with sun sensor and shading assembly<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 2 x CMP10 pyranometers (DHI, GHI)<br>- 1 x CMP11 pyranometer (POA) |
| | 14 x CMP11 pyranometers at different orientations |

China's solar energy capacity continues to grow. In 2017 almost 53 GW of PV modules were installed, and a further 24 GW in the first half of 2018. Following the Datong program a second PV Pioneer Project was deployed, this time in Ruicheng in 2017 and again monitored with Kipp & Zonen quality instruments installed by Beijing Solarsky.

**About Ruicheng**

Ruicheng is a small city located in the south-west of Shanxi province with a population of 410,000. The PV pioneer project has two stages, the first is 500 MW and the second could be 520 MW. The investment in this project reaches 4.2 billion Chinese Yuan and the site covers an area of 14 square kilometres. There are six PV plant companies participating in the first stage.

**7 solar monitoring stations installed by Beijing Solarsky**

Thanks to the success of the Datong project, Solarsky has installed 7 high performance solar monitoring stations at Ruicheng with the same configuration, one for each PV site and one reference set for comparison. A SOLYS2 sun tracker with sun sensor and shading assembly, CHP1 pyrheliometer for DNI, CMP10 pyranometers for DHI and GHI, and a CMP11 pyranometer for POA irradiance; plus all the meteorological sensors.

However, some parts of the Ruicheng project area have a hilly and undulating landscape with many different orientations of the PV panels. In these areas Solarsky has installed an additional 14 CMP11 pyranometers at a range of tilt angles to allow for the POA differences.

# 3. NOOR II and III, Quarzazate, Morocco

| | |
|---|---|
| Plant size NOOR II | 200 MW CSP rocking parabolic troughs |
| Kipp & Zonen equipment used: | 3 x solar monitoring stations, each including:<br>- SOLYS Gear Drive sun tracker with sun sensor and shading assembly<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 2 x CMP11 pyranometers (DHI, GHI) with CVF4 ventilation units |

| | |
|---|---|
| Plant size NOOR III | 160 MW CSP power tower with reflectors |
| Kipp & Zonen equipment used: | 4 x solar monitoring stations, each including:<br>- SOLYS Gear Drive sun tracker with sun sensor<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 1 x CMP11 pyranometer (GHI) with CVF4 ventilation unit |


Morocco's 2009 Solar Plan called for the development of 2000 MW of solar energy, starting with the Ouarzazate Solar Power Station (OSPS). Ouarzazate is a town in Morocco at a height of 1160m on a plateau south of the High Atlas Mountains, the name means 'door of the desert' in the Berber language. The power plant is located 10 km north-east of the town and is also known as the Noor Power Station, noor is Arabic for 'light'.

**About NOOR**

This is the first in a series of planned developments in the area by the Moroccan Agency for Sustainable Energy (MASEN) and the Noor project is planned to produce an actual 580 MW at peak and is being built in four phases and is expected to cost $9 billion. If you visit the site you will find a sea of parabolic reflectors and a large solar power tower. It is the biggest thermal solar energy generating complex with 'molten salt' energy storage in the world.

Noor I was officially commissioned in February 2016 and involved the construction of a 160 MW concentrated solar power (CSP) plant. It has half a million ‘rocking’ parabolic trough reflectors covering 450 hectares. The focused sunlight heats up a transfer fluid which is then used as the energy source for conventional steam turbine electricity generators, instead of oil or gas. Excess energy is used to heat molten salt, which is stored in heavily insulated tanks at about 560°C and can be used to produce steam at night for up to 3 hours.

Noor II is similar in construction to Noor I but covers 680 hectares and has 200 MW of installed capacity with up to 7 hours of molten salt storage. Commissioning was completed by the end of March 2018.

Noor III is rather different and even larger in area, 750 hectares. It has a 160 MW solar power tower and became fully operational in the third quarter of 2018. Flat mirrors on 2-axis trackers (heliostats) are used to reflect the sunlight onto a receiver on top of a tower that heats up the molten salt directly to generate steam, and also provides up to 7 hours of heat storage.

SENER, a Spanish engineering and technology group, designed and built Noor I and II and is also the technology provider for Noor III. EPC duties are shared with SEPCOIII of China.

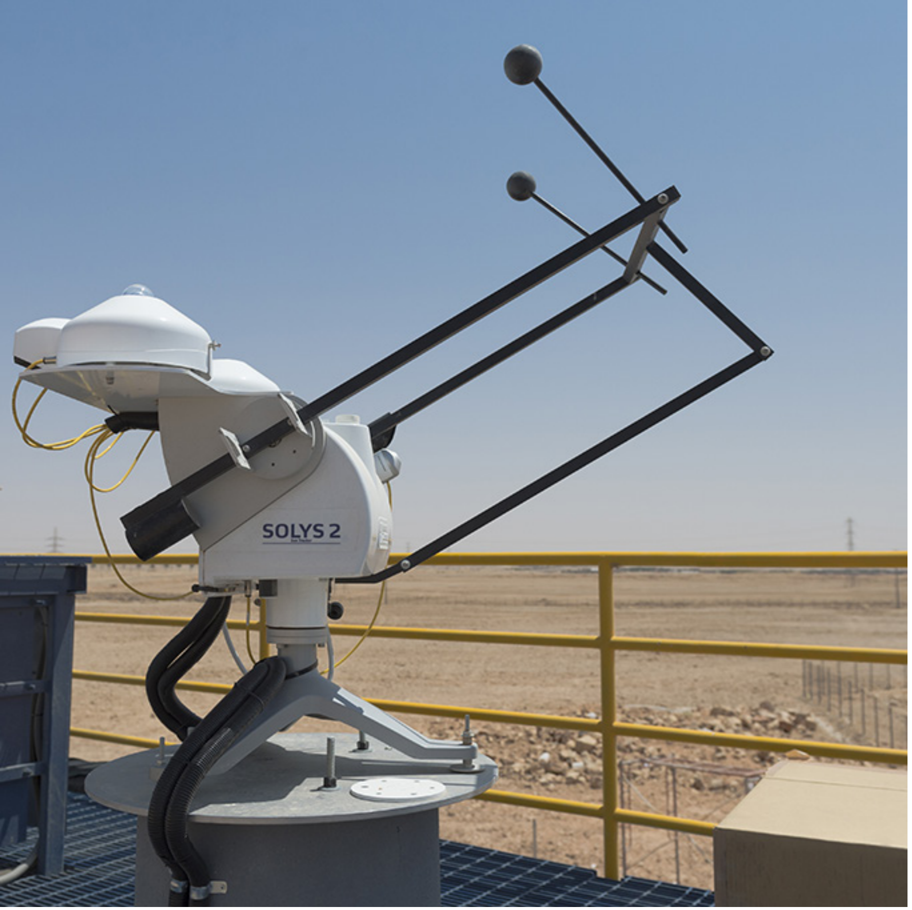
**NOOR II and NOOR III solar monitoring stations**

SENER awarded in 2016 a contract to DILUS Instrumentation y Sistemas of Madrid to design, supply, install and commission the meteorological and radiometric instrumentation systems for Noor II and Noor III. Each of the three solar monitoring stations for NOOR II measures DNI, DHI and GHI, based on a SOLYS Gear Drive sun tracker with a CHP1 pyrheliometer and two ventilated CMP11 pyranometers. NOOR III does not require DHI and the four stations have only one ventilated CMP11 (for GHI).


**These measurements are used as inputs to the plant solar energy production management systems.** Alongside the solar irradiance it is also important to measure wind speed and direction because both plants use reflector technologies that can be affected by strong winds. Six 2D and seven 3D ultrasonic wind sensors have been mounted by the reflector fields on 20 m high masts that fold down for servicing.

**Installed by DILUS Instrumentacion y Systemas**

DILUS, the Kipp & Zonen distributor for Spain, supplied and installed the meteorological and radiometric instrumentation systems for the innovative Noor Concentrated Solar Power (CSP) complex in Morocco in 2016 and 2017.




# 4. K A.CARE Solar Atlas for the Kingdom of Saudi Arabia

| Solar Atlas for Saudi Arabia | Tier 1 solar resource monitoring stations |
|---|---|
| Kipp & Zonen equipment used: | 18 x solar monitoring stations, each including:<br>- SOLYS2 sun tracker with sun sensor and shading assembly<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 2 x CMP21 or CMP22 pyranometers (DHI, GHI)<br>- 1 x CGR4 pyrgeometer (down-welling FIR)<br>- 1 x CMP21 or CMP22 pyranometer tilted (POA)<br>- 1 x CMP21 or CMP22 inverted (reflected radiation)<br>- 1 x CGR4 inverted (up-welling FIR)<br>- 4 x CVF4 ventilation units (for upward facing pyranometers and pyrgeometer)<br>- 1 x UVS-AB-T (UVA and UBV radiation)<br>- 1 x PQS1 (photosynthetically active radiation) |

King Abdullah City for Atomic and Renewable Energy (K.A.CARE) in Riyadh was established by Royal Decree A/35 of H. M. King Abdullah bin Abdulaziz Al Saud on 17th April 2010 with the fundamental aim of building a sustainable future for Saudi Arabia by developing a substantial alternative energy capacity fully supported by world-class local industries.

In the light of the enormous solar energy potential of Saudi Arabia, with an average of 3,000 hours of sunshine per year, one of the first technical projects undertaken by K.A.CARE is the Renewable Resource Monitoring and Mapping (RRMM) Program to develop a highly accurate Solar Atlas for the Kingdom of Saudi Arabia.

**About the RRMM Program**

Around 50 solar resource monitoring stations have been deployed, to capture the spatial and temporal variability across the Kingdom. Depending upon the parameters measured and the uncertainty of the measurement equipment, stations are categorised as Tier 1, Tier 2 or Tier 3. The majority of these stations are equipped with Kipp & Zonen instruments.

**Tier 1 solar resource monitoring stations**

Tier 1 stations are the top level in the network and there are 3 configurations; A is the Research and Development Laboratory at Al-Uyaynah, 3 x B Solar Broadband and Spectral Monitoring Stations and 14 x Broadband Baseline Monitoring Stations. At the Al-Uyaynah site near Riyadh there is the reference 'Tier 1A Research Station' that fully complies with the measurement practices described in the World Meteorological Organization (WMO) Baseline Surface Radiation Network (BSRN) Operations Manual. This station also has a complete duplicate set of back-up equipment.

Tier 1 stations all include a SOLYS2 sun tracker equipped with a CHP1 pyrheliometer for the measurement of DNI and two CMP21 or CMP22 pyranometers for DHI and GHI and also have a CGR4 pyrgeometer to measure the down-welling far infrared (FIR, thermal) radiation emitted by the atmosphere and clouds. Stations also have additional pyranometers and pyrgeometers to measure reflected radiation from the surface and tilted global irradiance and up-welling far infrared radiation emitted by the ground. All the upward-facing pyranometers and pyrgeometers have CVF4 ventilation units.

Tier 1 stations also monitor UVA and UVB radiation with the UVS-AB-T, photosynthetically active radiation (PAR) with the PQS1, and have high quality automatic weather stations for environmental monitoring. Tier 3 stations include ventilated horizontal and tilted CMP21 pyranometers. There are 12 POM-02 sky radiometers supplied by Kipp & Zonen for sites that monitor aerosol optical depth and properties of particles in the atmosphere that affect the solar radiation reaching the ground.

K.A.CARE specified the best available instrumentation to provide the lowest uncertainty in solar resource monitoring data that is also suitable for the highest level of weather and climate research.

**Installed by K.A.CARE and Battelle**

The technical adviser to the Program was the National Renewable Energy Laboratory of Colorado, USA. Installation was carried out by K.A.CARE and managed by the Battelle Memorial Institute of the USA.

# 5. Solar energy research in the Gobi Desert, Dunhuang, China

| Gobi Desert research site | |
|---|---|
| Kipp & Zonen equipment used: | 1 x SOLYS2 sun tracker with sun sensor and<br>1 x PGS-100 sun photometer (spectral DNI)<br>7 x CMP11 pyranometers at 7 tilt angles (POA)<br>1 x solar monitoring station including:<br>- SOLYS2 sun tracker with sun sensor and shading assembly<br>- 1 x CHP1 pyrheliometer (DNI)<br>- 2 x CMP11 pyranometers (DHI, GHI) with CVF3 ventilation units<br>- 1 x CMP11 (2-axis tracking POA) |

The Gobi is a large desert region in Northern China and Southern Mongolia. It is cold, with frost, and occasionally snow, occurring on its dunes. The climate is one of great extremes, from -40°C in winter to +50°C in summer, and with rapid changes of temperature of as much as 35°C within 24 hours.

**About the test site**

A solar energy field observation and test station is installed in Dunhuang, Gansu Province on a field of 40 by 30 meters that is divided into 6 zones for; spectral measurement, tilted global radiation measurement, wind speed and direction, dual-axis tracking solar radiation, rainfall observation and comprehensive meteorological measurements.

With this scientific observation site, Beijing Hua Sheng Ji Zhi New Energy Technology is researching the possibilities of the Gobi region for solar energy power plants. The data obtained will help to choose the best technology, the best angle for fixed PV panel installation, and the expected solar energy budget.

**Zone 1, spectral measurement**

The spectral measurement of direct solar radiation in zone 1 is performed by a PGS-100 sun photometer mounted on a SOLYS2 sun tracker with sun sensor correction. The PGS-100 is directly connected to a computer to download spectral data in the wavelength range from 350 to 1050 nm.

The data can be processed to obtain optical thickness, scattering coefficient, aerosol distribution, energy distribution, absorption rate through the atmosphere and the spectral irradiance.

**Zone 2, tilted global radiation measurement**

Seven CMP 11 pyranometers are installed, each tilted at a different angle (10°, 20°, 30°, 40°, 50°, 60° and 70°) to determine the optimum angle for fixed solar panels in this region.

**Zone 4, dual axis tracking solar radiation measurement**

There is one more zone with Kipp & Zonen instruments, zone 4, with a complete solar monitoring station based on a SOLYS2 sun tracker with sun sensor and shading assembly. A CHP 1 pyrheliometer measures DNI and there are two ventilated CMP 21 pyranometers to provide measurement of DHI and GHI. A third CMP21 is mounted on the tracker to measure tilted global irradiance when pointing at the sun throughout the day, as for 2-axis tracking PV panels.

**Zones 3, 5 and 6**

The remaining zones are installed with a wind observation system that includes a 10 m high tower, a rainfall observation system, with a horizontally mounted precipitation sensor, and a general observation platform with temperature, humidity and pressure sensors.

**Installed by Beijing Zenith Technologies**

In 2014 Beijing Zenith Technologies Co. Ltd. installed this unique meteorological observation system in the Gobi Desert for its customer Beijing Hua Sheng Ji Zhi New Energy Technology.

# 6. High precision irradiation measurement in PV power plants

| Fixed angle PV monitoring | |
|---|---|
| Kipp & Zonen equipment used: | 1 x CMP11 pyranometer horizontal (GHI)<br>1 x CMP11 pyranometer tilted ( POA)<br>Both connected to skyCONNi<br>Number of sets depends upon plant size |

Investors of utility-scale photovoltaic installations base their decision for or against such an investment project on detailed yield and performance ratio forecasts for the plant to be built. Once up and running, the plant's performance and yield are continuously monitored, analysed, and compared with the expected values.

High precision irradiation measurements form an essential information base for yield and performance ratio assessment. However, not all solar energy plants require a complete solar monitoring station. For fixed angle PV panels it is sufficient to monitor GHI and POA irradiance, although this could be at multiple points across the site depending upon the area covered and the topography (panels at different orientations).

**About skytron® energy**
skytron® energy GmbH of Berlin develops and manufactures high-precision measurement, monitoring and control systems for the photovoltaic sector and offers solutions for the entire energy conversion chain in PV solar power plants.

No matter how sustainable and attractive investments in renewable energy may appear, power plants are affected by external factors and local conditions. Thanks to on site high quality irradiance measurement, impairments and damage can be localized rapidly with the aid of real-time data. The quicker problems are detected, the more efficiently a power plant will operate.

Solar irradiance measurements are integrated into the monitoring solutions of skytron® energy. The higher the precision and reliability of irradiation measurement in the field, the more accurate is the performance ratio and yield information provided to the plant operator and the investor.

**Kipp & Zonen pyranometers**

skytron® energy have developed skyCONNi; a universal system for the measurement of environmental conditions at a PV plant. skyCONNi is capable of integrating a number of weather sensor measurements into the plant communication network, including irradiance.

skytron® energy always strongly recommends its clients to opt for Kipp & Zonen Secondary Standard / Spectrally Flat Class A pyranometers for their irradiation measurement. Compared to reference cells they have high precision over a larger spectral range, reduced temperature response and negligible directional error at large angles of radiation incidence. skyCONNi has additional facilities to power and control two Kipp & Zonen CVF 4 ventilation units to further improve the availability and quality of the measurements.

Only such high-precision measurement data collected in the field leads, in the end, to meaningful and realistic conclusions about the performance of a photovoltaic power plant.

**Installed by skytron® energy**

As one of the leading suppliers in the photovoltaics industry specializing in commercial and utility-scale PV power plants, skytron® energy has installed monitoring solutions in more than 1000 plants around the globe.


Insights for Experts