Professional Solar Measurement

Contents

1. The importance of measuring solar irradiation

Accurate measurement of the solar irradiation is important for solar power plant project design and implementation. Developers require solar irradiation data for site resource analysis, system design and operation. The sun irradiation differs from site to site. Thus it is essential to measure the local irradiation to design profitable solar power plants as they require considerable investment. Before a solar project starts, project developers require reliable data about the solar resources available at the selected location. The data is processed in a detailed feasibility study, which is the basis for the financial decision to build the solar power plant. The variability of the supply of solar radiation represents the greatest uncertainty in the performance forecast of a solar power plant.

The sun radiation on the earth surface combines Direct Normal Irradiation (DNI) and Diffuse Horizontal Irradiation (DHI). Both are linked in the formula for Global Horizontal Irradiation (GHI):

$$\mathbf{GHI = DHI + DNI \cdot \cos(\theta)}$$

(where θ is the solar zenith angle)

Normally, on a sunny day the insolation is 100% GHI with 20% DHI and 80% DNI $\cdot \cos(\theta)$.

There are certain methods and technologies to measure the irradiation. Depending on the planned solar power plant, e.g., PV (Photovoltaic) or CSP (Concentrated Solar Power), different measurements are necessary:

- GHI → PV and CSP
- DHI → PV
- DNI → CSP and large PV power plants

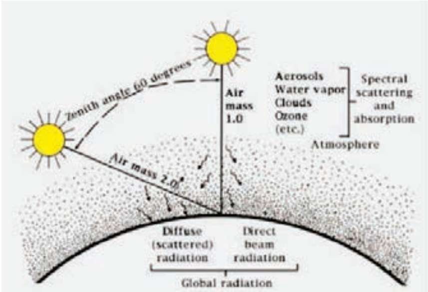
Some regions can be identified very easily for excellent solar resources, such as the Middle East or Africa. For selecting a specific site, local impacts have to be considered, e.g., morning fog or air contamination by close factories. Satellite data indicates solar irradiation for large regions, but specific sites should be evaluated by using ground-measuring stations. Accurate solar energy forecasts can increase the power plants profits by optimizing the design of the solar power plant.

After a solar power plant is built and in operation, solar resource data is still required to monitor its performance. If the performance drops, it implies that one or more components of the solar power plant require maintenance. Accurate resource data remain crucial to keep the profitability of the power plant as high as possible.

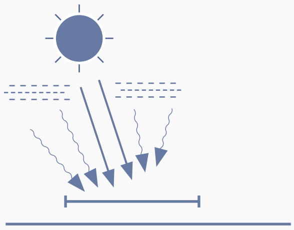
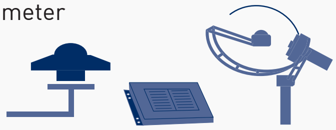
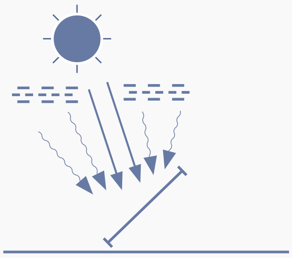
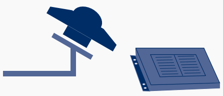
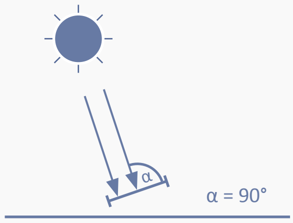
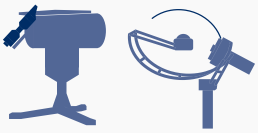
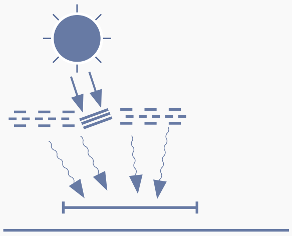
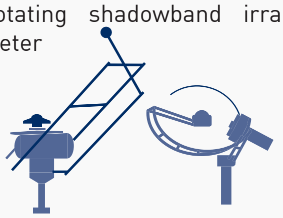
2. Type of irradiation

The total radiant power of the sun is rather constant; its output is also known as TSI (Total Solar Irradiance).

The total solar radiation is partly absorbed by ozone, oxygen, water vapor, carbon dioxide and aerosols such as dust or smoke. Based on absorption and reflection in the atmosphere and on the earth's surface, the terrestrial solar radiation is divided into two components: direct beam radiation, which reaches the earth's surface without being scattered or absorbed and diffuse radiation, which reaches the earth's surface after having one or more interactions with the atmosphere. See table below for further details:



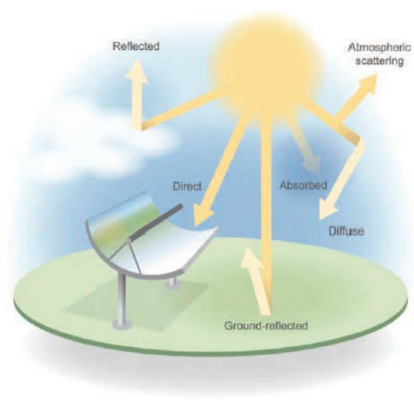
Source: NREL

Irradiation	Description	Irradiation Measurement Device
GHI Global Horizontal Irradiation 	The total amount of radiation received from above by a horizontal surface. This value includes both Direct Normal Irradiation (DNI) and Diffuse Horizontal Irradiation (DHI).	• Pyranometer (installed horizontal) to measure Global Horizontal Irradiation (GHI) • Solar reference cell • Rotating Shadowband Irradiometer 
GTI Global Tilted Irradiation 	The total amount of direct and diffuse irradiation received from above by a tilted surface. GTI is an approximate value for the energy yield calculation of fixed installed tilted PV panels.	• Pyranometer (installed tilted as solar module) for irradiation on the solar module surface • Solar reference cell (installed tilted) 
DNI Direct Normal Irradiation 	Direct Normal Irradiation is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.	• Pyrheliometer installed on sun tracker • Rotating shadowband irradiometer (calculated values) 
DHI Diffuse Horizontal Irradiation 	Diffuse Horizontal Irradiation is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.	• Pyranometer with shadow ball or shadow ring installed on sun tracker • Rotating shadowband irradiometer 

3. Parameters that influence the solar energy production

As mentioned before absorption and reflection affect the solar radiation in the atmosphere. On the earth's surface further factors influence the solar energy production, e.g.:

Insolation
The higher the solar radiation at the location of the planned solar power plant, the higher can be the energy yield. Depending on the type of the solar power plant, different radiation parameters should be measured, e.g., DNI is important for a planned CSP power plant.



Source: NREL

Wind speed and wind direction
To design and build robust module carriers, the local wind conditions have to be measured. The cooling effect of the wind can also be estimated.

Air temperature and humidity
The performance of solar modules is temperature-dependent. Higher cell temperature leads to lower performance and hence to a lower coefficient of efficiency. The coefficient of efficiency indicates how much of the sun light can be converted into usable electrical energy. Humidity affects the thermodynamic performance of CSP power plants.

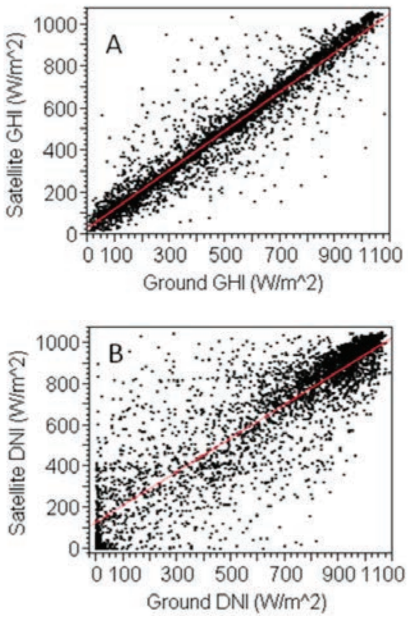
Air pressure
Barometric pressure affects the thermodynamic performance of CSP power plants. Thus measuring air pressure is important for all CSP projects.

Precipitation and soiling (sand storms)
Data about amount, frequency and type of precipitation as well as soiling can help to explain low energy yields at high sun radiation.

4. Comparison: Satellite- & weather station model based vs. ground-measured data*

Most of the available radiation data is calculated based on satellite measurement and measurements of a network of weather stations with temperature, wind speed and radiation measurement in the field (such as the BSRN network). However, there is a lot of uncertainty in these calculations. Thus there are significant deviations between satellite-based data and ground-measured data, particularly when the sky is cloudy. Another influencing fact is the area, which is considered for the data; satellite-based data refers to large areas of approx. 1km², ground-measured data are gathered at a specific point in the selected area.

However, the deviation is smaller when GHI is considered instead of DNI. If data for GHI and temperature from both satellite-based data and ground-measured data is correlated, good regression values can be reached: R^2=0.92 and R^2=0.97. If DNI and wind speed is considered, regression values show huge deviation between both measurements: R^2=0.78 and R^2=0.5.



Source: Clean Power Research

We recommend measuring the sun radiation with ground stations at the location of the planned solar power plant. Only with measurement stations on the ground you collect accurate measurement data, which can be used to calculate the annual energy yield at the site.

Additionally, the quality of the installed measurement instruments has to be carefully considered to gather accurate measurement results, e.g., classification of pyranometers. Benefit from our experience and know-how from many projects worldwide to get the best measurement system.

* Refer to Stein, J.S.; Perez, R.; Parkins, A. (2010). "Validation of PV Performance Models using Satellite-based Irradiance Measurements" a Case Study. Proc. ASES Annual Conference, Phoenix, AZ, USA.

5. Standards and guidelines for solar energy assessments

Solar measurement is becoming more and more important. In order to compare the results of measurement campaigns for solar resource assessment and also for monitoring solar power plants, international standards are required. So far there is no common standard for solar measurement applications. For your solar measurement campaign, we recommend following the standards and guidelines listed below.

NREL "Best Practice Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications" (Feb 2015 / 63112)
The NREL handbook is a comprehensive report, which summarizes important information for all steps of a solar energy project - reaching from required measurements and the design of measurement stations to forecasting the potential solar radiation. Additionally, NREL informs about measurement instruments and its application as well as sources for solar measurement data. The handbook can be downloaded from the Ammonit website: www.ammonit.com

ISO 9060 Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation
In the ISO 9060 standard pyranometers are classified in three classes: Secondary Standard for scientific measurement quality, First Class for good measurement quality and Second Class for medium measurement quality. The ISO 9060 is accepted by the WMO (World Meteorological Organisation).

IEC 61724:1998 Photovoltaic system performance monitoring – Guideline for measurement, data exchange and analysis
This standard focuses on monitoring and analysing the electrical power of PV systems. It describes parameters and processes.

BSRN (Baseline Radiation Network) Operations Manual
BSRN is a standard guide to measurement techniques for all stations within the global network. The manual provides information about accuracy requirements, installation of radiation instruments, sun trackers, as well as calibration and quality assurance procedures.

6. Data quality and security for valuable solar measurement data

Measurement data is very valuable. It is the basis for investment decisions to set up a new solar power plants. It indicates whether a solar power plant operates profitable or not. Thus measurement data can be the subject of manipulation and theft. For these reasons international standards and guidelines for wind measurement focus on data quality and data security. We recommend focussing on data quality and data security also for solar measurement projects.

By installing high quality measurement systems, authenticity and integrity of the measurement data can be protected. Our Meteo-40 data logger and our monitoring platform AmmonitOR fulfil the high quality standards requested for wind measurement campaigns. Based on the internationally accepted OpenPGP standard, we implemented Public Key cryptography to secure data authenticity and integrity with digital signatures and encryption.

7. Components of solar measurement systems

Currently there is no international standard for solar resource assessment, although there are various publications and studies from well-known research institutes discussing solar measurement and monitoring applications. Depending on the planned solar power plant, we recommend the measurements as listed below. We also recommend installing redundant sensors to increase the data quality.

	Required measurements	System components
Small PV power plant	GHI and GTI	• Data Logger • Steel cabinet with solar power supply and communication system • Pyranometer for global horizontal irradiation (GHI) • Anemometer for wind speed measurement • Temperature sensor • Precipitation sensor Optional • Pyranometer tilted as solar panel for global tilted irradiation (GTI) • 2 solar cells: one horizontal, one tilted
Medium PV power plant	GHI, DHI and calculated DNI (DNI not measured; calculated by using DHI and GHI → GHI = DHI + DNI • cos(θ)	• Data Logger • Steel cabinet with solar power supply and communication • Pyranometer for global horizontal irradiation (GHI) • Rotating shadowband irradiometer for GHI, DHI and DNI (calculated) • Anemometer for wind speed measurement • Temperature sensor • Precipitation sensor Optional • SPN1 Pyranometer (solid-state) for GHI, DHI and DNI (calculated) • 2 solar cells: one horizontal, one tilted • Pyranometer tilted as solar panel (optional)
Large PV and CPV power plant	GHI and DNI	• Data Logger • Steel cabinet with solar power supply and communication system • Sun Tracker • Pyranometer for global horizontal irradiation (GHI) • Pyrheliometer installed on tracker for direct normal irradiance (DNI) • Anemometer for wind speed measurement • Temperature sensor • Precipitation sensor Optional • 2 solar cells: one horizontal, one tilted • Pyranometer tilted as solar panel for global tilted irradiation (GTI) • Rotating shadowband irradiometer for GHI, DHI and DNI (calculated) • SPN1 Pyranometer for GHI and DNI
CSP	GHI and DNI	• Data Logger • Steel cabinet with solar power supply and communication • Sun Tracker • Pyranometer for global irradiation (GHI) • Pyrheliometer installed on tracker for direct normal irradiance (DNI) • Anemometer for wind speed measurement • Temperature and humidity sensor • Barometric pressure sensor • Precipitation sensor Optional: • Pyranometer (including shadow ball) for diffuse horizontal irradiation (DHI) • Rotating shadowband irradiometer for GHI, DHI and DNI (calculated)

8. Instruments and equipment for successful solar irradiation measurement campaigns

- **The better the installed equipment, the higher the accuracy of the gathered solar irradiation data.**

In order to collect high quality measurement data, we recommend installing high quality and classified instruments and perform redundant measurements. With our long-term experience in solar measurement, we design individual measurement systems for your selected site.

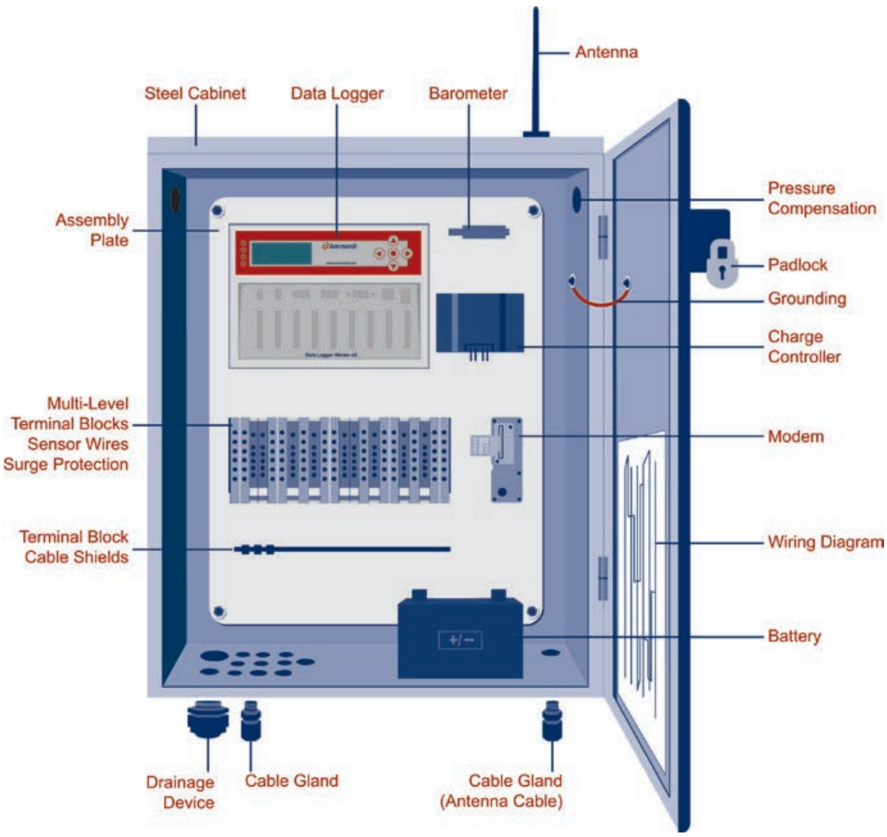
See below to learn more about measurement instruments and important equipment for smooth measurement campaigns.

8.1 Data loggers

Data logger are the core of each measurement system converting electrical values gathered by meteorological sensor into readable data, e.g., irradiation into W/m². Referring to customer requirements, international standards and our long-term experience, we developed our own data logger: Meteo-40. It is available in three configurations - for every application the best suitable data logger. Meteo-40 is designed for high performance and accuracy while working at a minimum of power - even in remote sites under extreme weather conditions, e.g., in deserts.

Meteo-40 meets the highest requirements for data security and data quality.

Meteo-40 is the first data logger in the field of wind and solar resources assessment, which includes security features like digital signature and encryption to protect integrity and authenticity of your irreplaceable measurement data!



We design each measurement system according to your requirements including all meteorological sensors, communication and power supply system. Storage in a CE-certified steel cabinet protects the data logger against weather and condensation damage, as well as theft and vandalism.

8.2. Data logger accessories

In order to supply the data logger and to transfer measurement data to the met mast operator, certain accessories are required:

8.2.1 Steel cabinet / switch board

We offer robust, weather-proof steel cabinets in various sizes. The cabinet protects your data logger against weather and condensation damage, theft and vandalism. Our CE-certified steel cabinets are easy to install and maintain.

Components, such as a communication system, barometric pressure sensor, battery, overvoltage protection and solar charger, can be accommodated within the cabinet. The size of cabinet depends on the battery size and the number of installed components. Cabinets are typically padlocked for protection from vandalism and theft.

8.2.2 Communication system: UMTS/GSM or satellite

You can communicate with your data loggers from your computer in different ways:

- UMTS/GSM system
- Satellite via BGAN (Broadband Global Area Network)
- USB interface
- LAN (Local Area Network) via Ethernet
- WiFi

You can easily configure in the Meteo-40 web interface, when and how often the data logger should be available online or send or upload data. With the modem helper, you conveniently configure the modem connection in the Meteo-40 web interface.

8.2.3 Power supply

Our measuring systems are fully self-contained; a connection to the local power network is not required. The measuring system can be reliably powered with a solar module.

8.2.4 Overvoltage protection

Overvoltage protection prevents lightning and overvoltage from disrupting DC and AC low voltage supply to the measuring system equipment. The device is a special cable clamp, which protects data and signal lines and power cables. The overvoltage protection is installed in the steel cabinet instead of a regular unprotected cable clamp.

We offer several types of overvoltage protection devices, differing in their number of pins and their voltage levels. Although the installation of overvoltage protection is not mandatory, it is highly recommended. Unprotected lightning can lead to a total breakdown of the measuring system.

8.3 Sensors for solar measurement

Before deciding about the sensors, which should be installed on the measurement station, data accuracy and uncertainty levels have to be considered. It is important to look at the specifications and manufacturer recommendations to ensure consistent measurement quality. If the necessary maintenance for the sensor cannot be provided, alternative instruments with lower maintenance requirements should be installed, e.g., rotating shadowband irradiometers instead of pyranometers.

We recommend using most accurate "secondary standard" sensors as described in the ISO 9060 standard published by the World Meteorological Organisation (WMO). The standards specifies three classes:

- **Secondary Standard**: Scientific quality and highest accuracy
  Applications: Meteorology (BSRN Network); Testing in PV , CPV and CSP
- **First Class**: Good quality
  Applications: Measurements for hydrology networks and greenhouse climate control
- **Second Class**: Medium quality
  Application: Economic solution for routine measurements in weather stations and field testing

We recommend installing redundant sensors to ensure confidence in data quality. Using multiple radiometers within the project and measuring all three solar irradiation components (GHI, DHI and DNI), regardless of the measurements required for the planned solar power plant, can enhance the data quality for later assessments.

8.3.1 Pyranometers

Pyranometers are radiometers used to measure global radiation (GHI) and diffuse radiation (DHI). The sensor is crucial for all measurements related to solar energy applications. We recommend installing only classified and calibrated pyranometers to ensure accurate results (see ISO 9060).

Installed on a horizontal platform, the pyranometer measures GHI. In order to measure global tilted irradiation, the pyranometer can be mounted in the same inclination angle as the solar modules of the solar power plant. To measure diffuse horizontal irradiation, the pyranometer has to be shaded against the direct sun beam by installing a shadow band or shadow ring. To do so, a sun tracker should be used.

For measuring global radiation, pyranometers have to be installed free from any obstructions that may shade the instrument at all times and seasons of the year. Additionally, the instrument should not be close to a light-coloured wall or other objects likely to reflect solar energy onto the pyranometer. To reduce uncertainties and to keep the quality of measurement data as high as possible, the pyranometer has to be well-maintained and its optics have to be clean. Pyranometers can be fitted with ventilators. Hence, contamination of the pyranometer optics with dust, dew, frost, snow, ice, insects etc, can be reduced. When ventilated sensors are used, power consumption significantly increases.

Abstract from ISO 9060: Specification for pyranometers used to measure GHI and DHI

	Secondary Standard	First Class	Second Class
Response time: time to reach 95% response	< 15s	< 30s	< 60s
Zero-offset: **Offset-A**: response to 200 W/m² net thermal radiation, ventilated **Offset-B**: response to 5 K/h change in ambient temperature	+ 7 W/m² ± 2 W/m²	+ 7 W/m² ± 2 W/m²	+ 7 W/m² ± 2 W/m²
Non-stability: % change in responsivity per year	± 0.8%	± 1.5%	± 3%
Non-linearity: % deviation from responsivity at 500 W/m² due to change in irradiance from 100 ... 1000 W/m²	± 0.5%	± 1%	± 3%
Directional response (for beam irradiance): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction, a beam radiation whose normal incidence irradiance is 1000 W/m²	± 10 W/m²	± 20 W/m²	± 20 W/m²
Spectral selectivity: % deviation of the product of spectral absorbance and transmittance from the corresponding mean, from 0.35 ... 1.5 µm	± 3%	± 5%	± 10%
Temperature response: % deviation due to change in ambient within an interval of 50K, (e.g. -10 ... +40°C typical)	2%	4%	8%
Tilt response: % deviation in responsivity relative to 0 ... 90° tilt at 1000 W/m² beam irradiance	± 0.5%	± 2%	± 5%
Achievable uncertainty (95% confidence level): Hourly totals Daily totals	3% 2%	8% 5%	20% 10%

8.3.2 Pyrheliometers

Direct solar radiation (DNI) is measured by means of pyrheliometers. For continuous measurement, the sensor has to be installed on an accurate sun tracker to align the sensor to the centre of the sun at any time between sunrise and sunset. According to WMO, for DNI measurement with pyrheliometers, sun tracking to within 0.2° is required and the instruments have to be inspected at least once a day. The pyrheliometer has to be installed free from any obstructions to the solar beam at all times and seasons of the year. It is recommended protecting the instrument against rain, snow and so forth.

To ensure confidence in data quality, DNI should always be measured, although it is not required for the planned solar power plant. When DNI should be calculated from GHI and DHI, uncertainties have to be considered. Measuring DNI with classified instruments is much more accurate.

We recommend installing only classified and calibrated pyrheliometers to ensure accurate measurement results (see ISO 9060). In order to reduce uncertainties and to keep the quality of measurement data as high as possible, the pyrheliometer has to be well-maintained, correctly aligned and clean.

Abstract from ISO 9060: Specification for pyrheliometers used to measure DNI

	Secondary Standard	First Class	Second Class
Response time: time to reach 95% response	< 15s	< 20s	< 30s
Zero-offset: response to 5 K/h-1 change in ambient temperature	± 1 W/m^{-2}	± 3 W/m^{-2}	± 6 W/m^{-2}
Resolution: smallest detectable change in W/m^2	± 0.5 W/m^{-2}	± 1 W/m^{-2}	± 5 W/m^{-2}
Stability: % of full scale, change/year	± 0.5%	± 1%	± 2%
Non-linearity: % deviation from responsivity at 500 W/m^2 due to change in irradiance from 100 ... 1000 W/m^2	± 0.2%	± 0.5%	± 2%
Spectral selectivity: % deviation of the product of spectral absorbance and transmittance from the corresponding mean, from 0.35 ... 1.5 µm	± 0.5%	± 1%	± 5%
Temperature response: % deviation due to change in ambient within an interval of 50K, (e.g. -10 ... +40°C typical)	± 1%	± 2%	± 10%
Tilt response: % deviation in responsivity relative to 0 ... 90° tilt at 1000 W/m^2 beam irradiance	± 2%	± 0.5%	± 2%

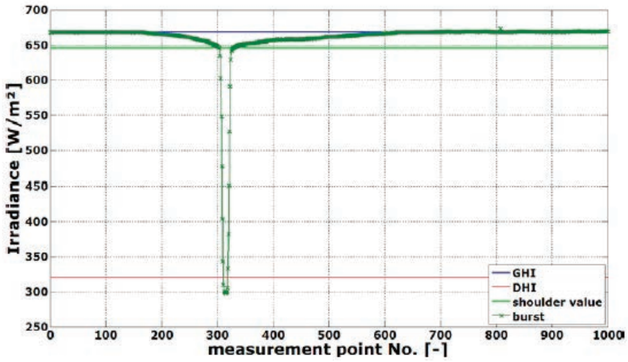
8.3.3 Rotating shadowband irradiometers (RSI)

Rotating shadowband irradiometers (RSI) use a pyranometer, which is periodically shaded against the direct sun beam by an automatic shadowband moving across the detector. The RSI measures GHI, when the pyranometer is unshaded; DHI, when the pyranometer is shaded. DNI is calculated from the measured values by the following formula:

$$DNI = (GHI - DHI) \cdot \cos(\theta)$$

(θ refers to the zenith angle of the sun)

While rotating of the shadowband, the irradiation is measured with a high sampling rate. DHI is measured in the moment, when the shadowband obstructs the direct sun beam on the pyranometer.

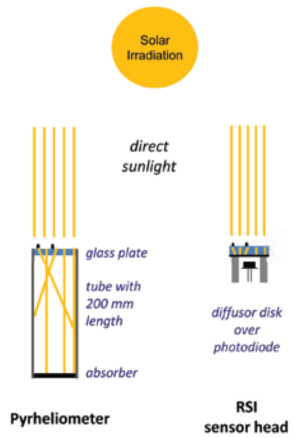


Source: NREL

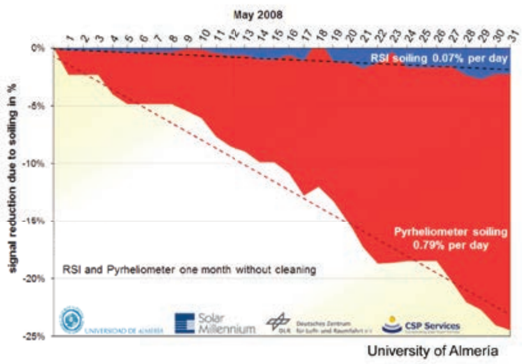
RSIs with continuous rotation of the shadowband require pyranometers with a fast response time (< 1s). Thus sensors described in ISO 9060 cannot be used. Instead, semiconductor sensors are installed, although they do not reach the measurement accuracy of secondary standard pyranometers. By correcting systematic deviations and using enhanced calibration methods, the accuracy of RSIs can be notably increased.

However, RSIs compensate the lower accuracy of the pyranometers with low soiling susceptibility, low power demand and comparatively low costs. The advantage becomes important when measuring in remote sites with reduced maintenance. See the graphic below, which compares the soiling characteristic of RSIs and pyrheliometers.

Accuracy of RSIs
As mentioned before the accuracy of RSIs strongly depends on the used correction functions and the calibration methods. During a one-year comparative evaluation* of 39 RSIs the accuracy for the annual sum of GHI, DNI and DHI has been analysed. It was shown that the average of the absolute annual deviation for the evaluated RSIs for DNI was less than 1% for the RSI, offered by Ammonit. Some other measurement campaigns presented a comparable accuracy of RSI measurements for annual scale as reached with high quality pyrheliometers.



Source: CSP Services GmbH



* Refer to Geuder, N.; Hanussek, M.; Haller, J.; Affolter, R.; Wilbert, S. (2011). "Comparison of Corrections and Calibration Procedures for Rotating Shadowband Irradiance Sensors." SolarPACES Conference Proceedings; September 20–23, 2011, Granada, Spain.

8.3.4 Pyranometer SPN1

The pyranometer SPN1 can be an option to measure GHI and DHI with one instrument. By using both measurements and the solar evaluation angle, DNI can be calculated.

With the operation principle of the SPN1, GHI, DHI and DNI can be determined without any moving parts compared to DHI and DNI measurements with sun trackers.

8.3.5 Sun trackers

Sun trackers are systems, which follow the sun on the horizon from sunrise to sunset. By using sun trackers you can accurately measure DHI and DNI with instruments installed on the sun tracker, i.e., pyrheliometers and pyranometers with shadowband or shadow-ball.

In general, sun trackers are equipped with a built-in GPS receiver to guarantee accurate sun tracking and pointing of the installed sensors. If the sun is covered on the sky, the sun tracker will follow the sun by calculating its position. Thus the installed radiometers are always in proper position to capture sun irradiation.

8.3.6 Reference cells

Reference cells or SI sensors provide a simple and cost-effective method to monitor the performance of a solar system. The design of the solar element corresponds to the design of a PV module.

8.3.7 Sunshine duration sensors

Sunshine duration sensors measure the number of sunshine hours per day. Sunshine duration is defined by the WMO as the time during which the direct radiation exceeds the level of 120 Wm².

Sunshine duration sensors have a minor importance for solar measurement projects, whereas they are often used in weather networks. Since very accurate solutions with sun tracker and pyrheliometer are very expensive, a sunshine duration sensor could be an option to get rough estimates of the sun radiation at the location.

8.4 Sensors to measure influencing meteorological parameters

Solar power performance is influenced by several meteorological factors. It is recommended to measure ambient temperature, wind speed and direction as well as precipitation. For CSP power plants also humidity and air pressure should be measured to get a complete view of the selected location for the power plant.

8.4.1 Temperature and humidity sensor

Temperature sensors measure the air temperature, while humidity sensors measure the air humidity. They are often applied in combination to reduce costs. Temperature significantly influences the module efficiency - both for PV and CSP. Thus measuring temperature is essential for every solar energy project. Humidity affects the thermodynamic performance of CSP power plants.

In order to measure the solar module temperature, surface temperature sensors are used.

8.4.2 Wind speed sensor / anemometer

Anemometers measure the wind speed, which is important to get data about the wind force at the site to design robust module carrier. Additionally, the cooling effect of the wind can be estimated.

8.4.3 Wind direction sensor / wind vane

Wind vanes indicate the wind direction. Detecting wind direction and wind speed helps to learn about the wind force at the site to build robust module carriers. The wind direction does not have an effect on the module performance.

8.4.4 Precipitation sensors

Measuring amount, frequency and type of precipitation provides important information about losses due to soiling of modules, while high irradiation.

8.4.5 Barometric pressure sensors

Barometric pressure has an effect on the thermodynamic performance of CSP power plants, thus measuring the air pressure is significant for all CSP projects.

9. Measurement station design

The proper set up of a solar resource measurement station is crucial to determine accurate solar irradiation and relevant meteorological data. The choice of measurement instruments is fundamental, because measurements with greater accuracy will better indicate the actual resource. In order to get the best possible measurement result, the measurement station should be **located away from any obstructions or objects, which could shade the instruments at any time throughout the year**. Additionally, radiation reflected from the ground or any light-coloured object should not be allowed to irradiate the instruments. Care must also be taken, that the instruments do not interfere with each other. Distances from growing vegetation should be increased to account for any future growth.

Pyranometers, which are installed to measure **global irradiation**, have to be **mounted on a horizontal platform**. Pyranometers for measuring diffuse radiation have to be shaded against direct sun beam by installing a shadow band or a shadow ball. Those pyranometers should be mounted on automatic sun trackers. The exact position of pyranometers should be described in the station report including altitude of the instrument above sea level, as well as geographical longitude and latitude. Consider also the recommendations from WMO and BSRN for irradiation measurement.

It is always recommended measuring **further meteorological parameters**. Precipitation sensors should be located no closer to the nearest obstruction than four times the height of the obstruction. Wind measurement sensors should be mounted at least 10 times the height of an object distant from the object. Example: A 20-meter tall tree should be at least 200m away from the measurement station.

Maintenance of radiation sensors is particularly important for proper measurement results. Pyranometers and pyrheliometers should be inspected at least once a day to ensure continuous high quality operation. During inspections, the optics of radiation sensors have to be cleaned and their correct alignment has to be checked. Rotating shadowband irradiometers require less maintenance. Refer to the manufacturers specifications.

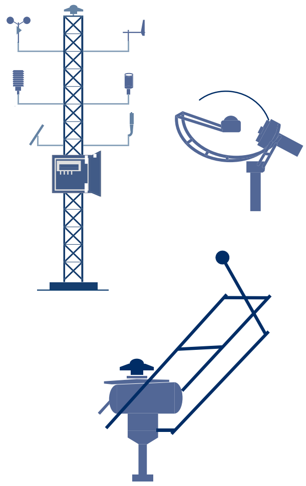
For the station design also power supply, communication options and maintenance (e.g., local sources of pollution or dust) have to be considered. In order to protect the expensive measurement equipment from theft and vandalism, **security arrangements** should be taken, e.g., the site should be well-fenced against thieves, additionally an alarm and/or video camera system can be implemented.

9.1 Measurement station design for PV power plants

For proper planning of PV power plants, GHI and DHI have to be measured. GHI is the most important parameter for PV installations. GHI is measured with pyranometers. We recommend installing two pyranometers to get redundant measurement values. In order to get GTI values, install at least one pyranometer tilted in the same angle the PV modules should be mounted.

By installing an RSI, GHI and DHI are measured with only one instrument. DNI can be calculated additionally. Note that RSIs are less susceptible to soiling that optical pyranometers. This can be important when it comes to maintenance issues.

In addition to radiation parameters, ambient temperature, wind speed and direction, as well as amount, frequency and type of precipitation should be measured. Consider a powerful data logger, reliable power supply and communication to operate the measurement system without failures and gaps in the measurement series. Continuous data quality checks are crucial for successful measurement campaigns.

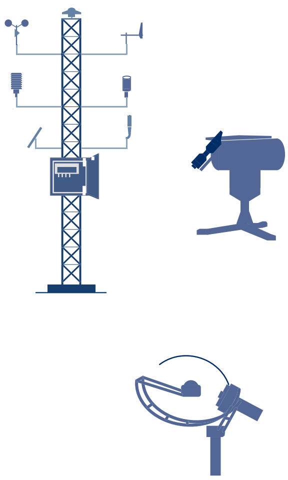


9.2 Measurement station design for CSP power plants

For proper planning of CSP power plants, accurate DNI measurement is essential. DNI is measured with pyrheliometers installed on sun trackers. We recommend installing two pyrheliometers to get redundant measurement values and at least one pyranometer for GHI measurement. In addition to DNI and GHI, DHI should be measured.

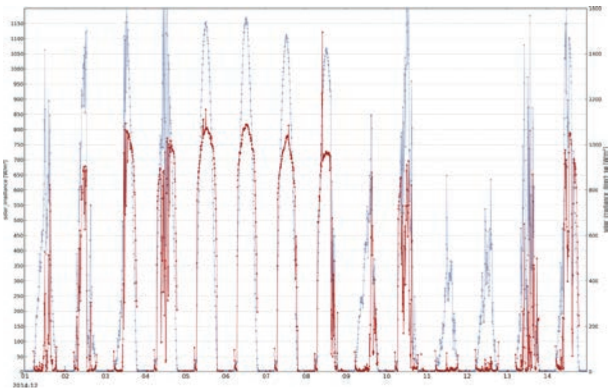
By installing an RSI, GHI and DHI are measured with only one instrument. DNI can be calculated additionally. Note that RSIs are less susceptible to soiling that optical pyrheliometers and pyranometers. This can be important when it comes to maintenance issues.

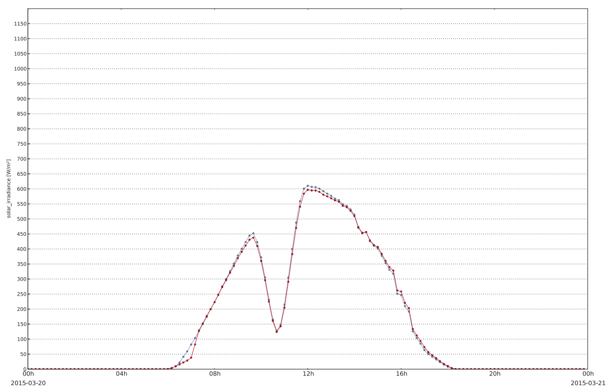
In addition to radiation parameters, ambient temperature and humidity, wind speed and direction, barometric pressure, as well as amount, frequency and type of precipitation should be measured as these meteorological parameters affect the efficiency of CSP modules. Consider a powerful data logger, reliable power supply and communication to operate the measurement system without failures and gaps in the measurement series. Continuous data quality checks are crucial for successful measurement campaigns.



10. Data quality and maintenance

Data quality depends on several factors: installed measurement instruments and its maintenance, power supply and communication of the measurement station, as well as continuous data quality checks. We recommend using our online monitoring platform AmmonitOR to check data plausibility and integrity. Measurement data can be displayed in various plots to correlate sensors or to monitor the trend of certain measurements. AmmonitOR includes a warning system. Hence, filters can be configured to send alarm messages, e.g., in case of low battery voltage or deviations in measurement values of redundant sensors.





Source: AmmonitOR (right picture displays the sun eclipse in Berlin on 20 March 2015)

In order to keep the data quality as high as possible, regular maintenance of the measurement station is required. Maintenance should include:

- Check of the alignment of the sensor.
  Pyrheliometers must be accurately aligned with the solar disk for precise DNI measurement.
  Pyranometers must be accurately installed horizontal for proper GHI and DHI measurement, or tilted as defined in the measurement documentation for GTI measurement.
- Check and clean the optics of the sensors.
  For proper solar intensity measurement, the optics of the sensors must be free from any contamination blocking or reducing the amount of sunshine falling onto the sensor. Consider the subject of soiling, which affects radiometers with clean optics much more than radiometers with optical diffusers.
- Condition check of the sensors.
  Sensors do not have to show any damages of the housing or cables.
- Check the environment for any changes.
  There do not have to be obstacles (e.g., newly grown bushes) close to the measurement station affecting the measurement data by shading the instruments.

Even if all actions have been performed for proper measurement, there is no way to significantly reduce the uncertainty of solar measurements. Although systematic effects of soiling can be reduced to some extent by regular maintenance.

We recommend introducing a quality-control procedure, which includes daily inspections, weekly quality reports and monthly summaries of the measurement campaign.

11. Notes

Dear Reader,

The information as shown in our solar measurement brochure summarizes a number of important aspects relating to solar measurement for solar power generation. The information is based upon years of practical work and it has been discussed in advance with experts in this field. Nevertheless, this study can deviate in some respects from current national and international guidelines and other publications, in particular where these are contradictory or seem to be inadequate.

It is therefore essential to take in advice of professional consultants.

We hope that our information was helpful to you. We will greatly appreciate your feedback and suggestions.

Your Ammonit Team

Thanks to our partners Climatik, Desamd, EKO, ENISOLAR and IEM for providing the photos for this brochure. For further Ammonit partners, refer to our website www.ammonit.com

Disclaimer
Ammonit disclaims any and all promises, presentations and warranties with respect to the information furnished to the customer. Ammonit assumes no liability for errors or omissions in this text, or for damages arising from the use of results or conclusions generated by it.

Ammonit

Know how for successful solar resource assessment

Ammonit
Measurement GmbH

Wrangelstrasse 100, D-10997 Berlin, Germany
T: +49 30 6003188-0, E: info@ammonit.com

measuring wind and solar power
www.ammonit.com