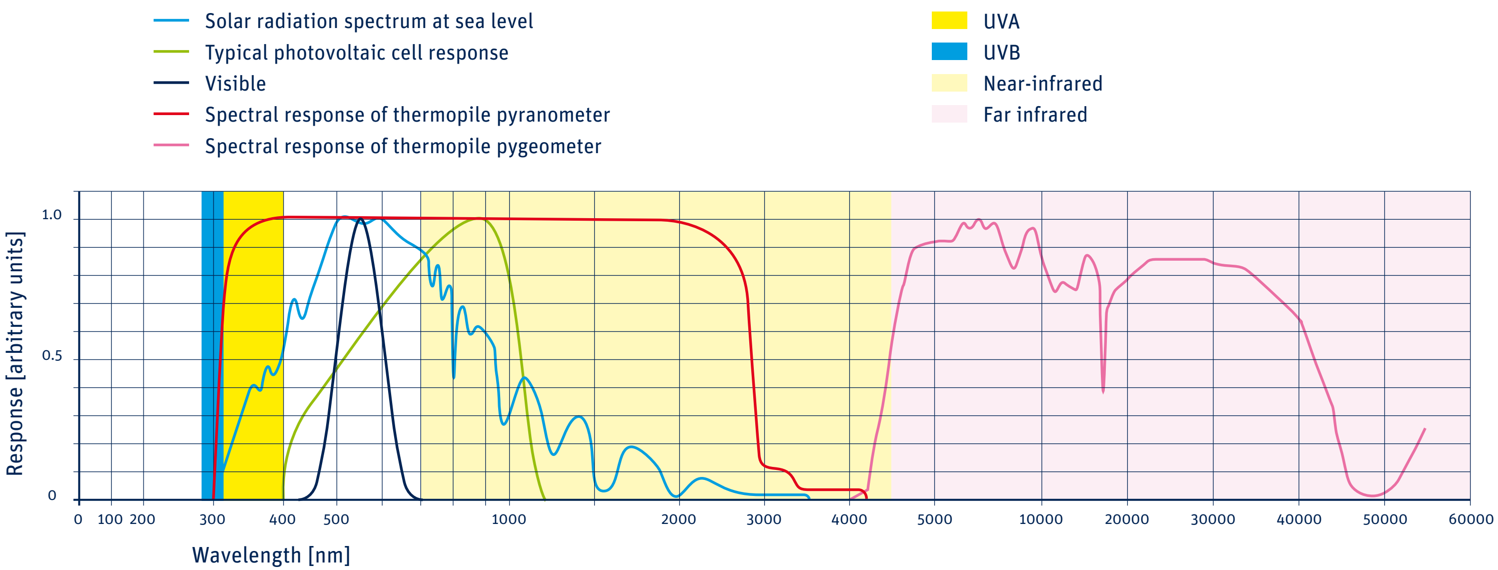
Make the most of the sun

KIPP & ZONEN
SINCE 1830

A Guide to maximising the Performance of
Photovoltaic and Thermal Solar Energy Systems
with Precision Monitoring of Solar Radiation

improve technology • find optimal locations • help investment decisions • select the appropriate system type • maximise operating efficiency • schedule maintenance • monitor performance



The solar spectrum, and the responses of PV cells and the instruments for measuring solar radiation

What is solar radiation?

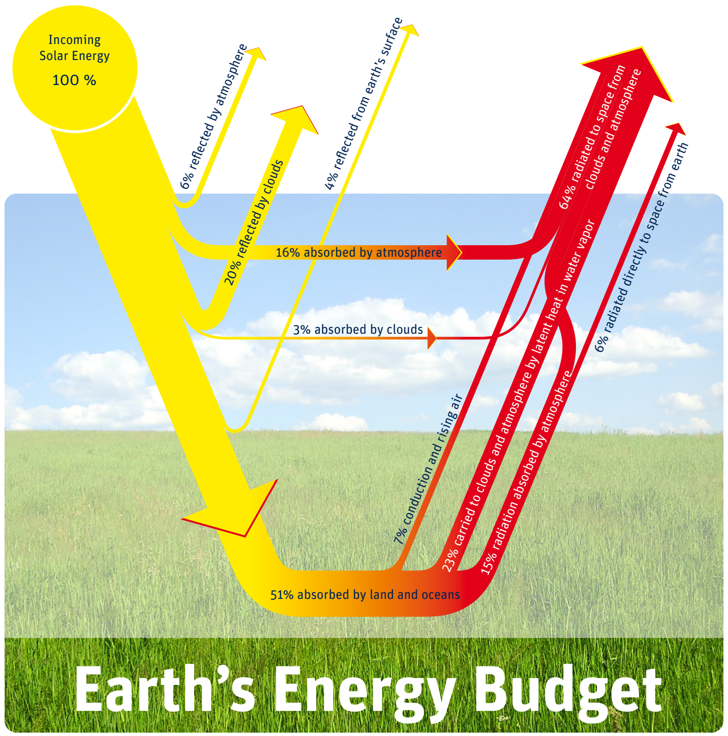
The sun is the energy supply for our planet that allows, directly or indirectly, the existence of life on Earth. The sun consists of 71 % Hydrogen, 27 % Helium and 2 % solid matter. Near its centre the temperature is around 16 million degrees and the nuclear reaction area in its core takes up almost one quarter of its whole diameter. The energy emitted by the sun is 3.72 x 1020 MW.

At the mean distance between Earth and sun this radiation reaches the outside of our atmosphere with an intensity of 1,367 Watts per square metre (W/m^2). This is called the Solar Constant. The total energy emitted by the sun does not change by more than 0.1 %, no matter at which point the sun is in its active or inactive cycles, which last 11 years each.

The solar radiation is partially reflected, scattered and absorbed in the atmosphere by its constituent gases, water vapour and clouds. Radiation reaching the ground is partly reflected but mostly it is absorbed, heating up the land and the oceans. Some of the energy absorbed by the surface and the atmosphere is re-radiated in the far infrared. The Earth's energy budget (or 'energy balance') is shown in the diagram.

Radiation reaching the Earth's surface from the sun and sky is split into short-wave radiation, at a number of bands in the wavelength range from 300 to 4,000 nm (4 µm), and long-wave radiation from 4.5 to more than 40 µm (far infra-red). The short-wave radiation includes the ultraviolet, visible and near-infrared bands.

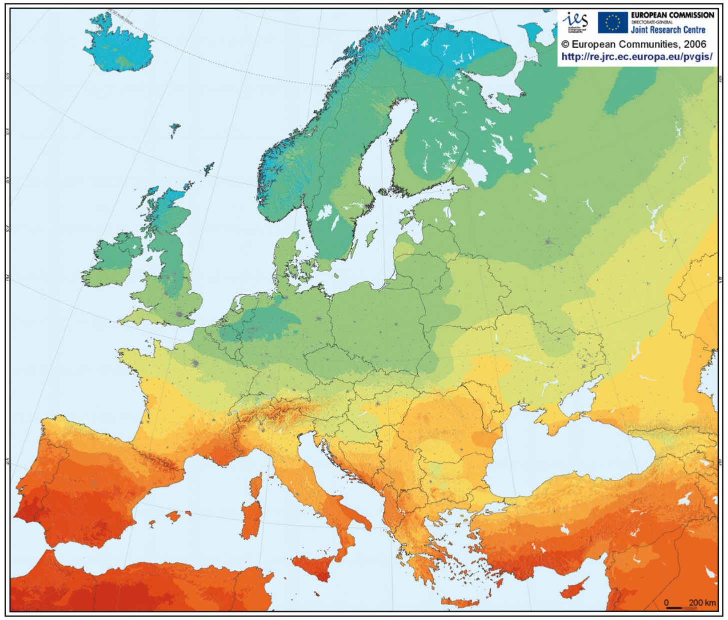
The amount of short-wave radiation reaching the ground is mainly influenced by clouds, particles, pollutants and aircraft contrails in the atmosphere. On a clear sunny day it is typically in the range of 1,000-1,300 W/m^2 at midday, depending on the latitude, altitude and time of year.



Why should I measure it?

Good quality, reliable solar radiation data is becoming increasingly important in the field of renewable energy with regard to both photovoltaic (PV) and thermal systems. It helps well-founded decision making on activities such as research and development, production quality control, determination of optimum locations, monitoring the efficiency of installed systems and predicting the system output under various sky conditions.

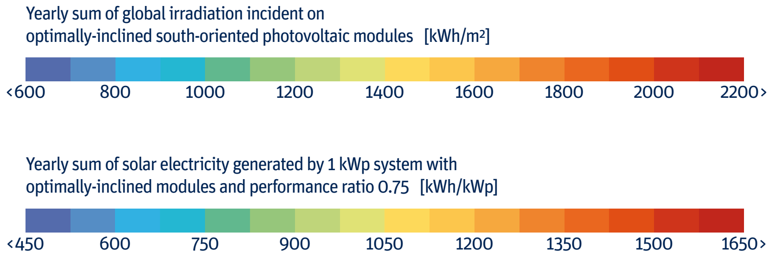
Maps are available showing the potential for solar electricity generation, as below for European countries.



However, such energy maps and satellite data are not localized enough, or accurate enough, to provide a reliable basis on which to make technology and investment decisions. Due to micro-climate differences, changes of a few hundred kilometers can give a yearly change of several hundred sun shine hours.

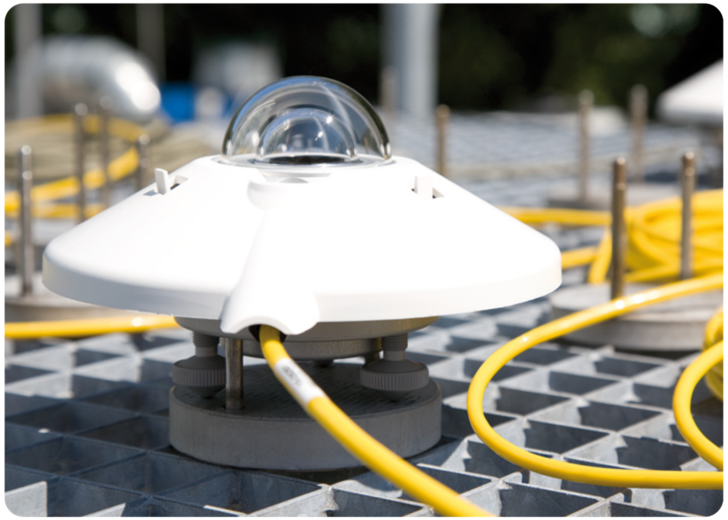
The real available energy at a given location needs to be measured on-site over a full year. The differences in efficiency between PV technologies are often very small, so accurate measurements are essential to make meaningful price/performance comparisons. Errors in the solar radiation measurement can significantly impact upon the return on investment.

High quality solar radiation data enables the choice of optimum locations and the most effective solar energy system type.



Šúri M., Huld T.A., Dunlop E.D. Ossenbrink H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81, 1295–1305, http://re.jrc.ec.europa.eu/pvgis

What do I measure it with?



Measurements of solar radiation are usually made using thermopile type radiometers with a flat spectral response. The types of instruments, performance specifications, and calibration methods are defined by the World Meteorological Organisation (WMO) and International Standards Organisation (ISO). They provide accurate measurements of the total solar energy available under all sky conditions. The data can be compared with measurements from meteorological networks and satellites, across various locations and for different types of solar energy systems.

Photovoltaic materials have most of their sensitivity in the visible and near-infrared parts of the spectrum, from approximately 400 to 1100 nm with a peak just beyond the visible range. There is little response to ultraviolet, and none to long-wave radiation.

Commercial-scale thermal energy systems typically use reflective solar collectors that focus the full spectrum of short-wave and long-wave energy onto the medium that is to be heated for the energy transfer process.

The 'global' short-wave radiation in the ultraviolet, visible and near-infrared bands is measured by a horizontally mounted Kipp & Zonen CMP series pyranometer (as shown at left).

The long-wave far infrared radiation is measured by a horizontally mounted Kipp & Zonen CGR series pyrgeometer (as shown above). Typical spectral responses of the instruments are shown in the graph on page 2.

What instruments do I need for my installed system?

PV panels have a wide field of view and are positioned to receive the maximum amount of solar radiation. Depending on location and cost/benefit decisions these panels may be at a fixed angle or move to follow the sun using one-axis or two-axis tracking systems. PV modules characterized by commercial solar simulators can seriously overestimate module performance. PV modules are specified under Standard Test Conditions, in reality the conditions are often less optimal resulting in a lower performance. A pyranometer will always give a correct measurement of the available solar radiation whatever the environmental conditions.

Therefore, in addition to the horizontally mounted CMP series pyranometer that is used for reference purposes, it is recommended to have another mounted on the panel or array to measure the energy available from the hemisphere that the panel can see. This is sometimes called the ‘tilted global radiation’ and the pyranometer is usually connected to the inverter control system and allows the system efficiency to be monitored and maintenance, such as cleaning, to be scheduled.

Where relative measurements of trends are sufficient, a lower specification and lower cost sensor can be used. Our SP Lite2 silicon pyranometer uses a photo-diode detector with a spectral response similar to most types of solar cells. It is widely used for field testing and monitoring applications, particularly in conjunction with our METEON hand-held display and datalogger unit.

Some PV systems use solar concentrators with lenses to focus the sun’s radiation onto the cells in order to increase the output. Many thermal solar energy systems have some form of reflector to focus the sun’s energy onto a target. In both cases they have a relatively small angle of view and must be continuously moved to point at the sun.

For these systems it is important to know the amount of radiation available directly from the sun. This ‘direct’ short-wave radiation is measured by the Kipp & Zonen CHP 1 pyrheliometer that has a 5 ° view and is mounted on our SOLYS 2 automatic sun tracker. The pyranometer for horizontal global radiation can be conveniently mounted on top of the tracker.

What do I need for research or solar prospecting?

As previously described, measurements using WMO / ISO type pyranometers and pyrgeometers can be compared directly across sites anywhere in the world, with data from meteorological networks, with satellite information, and with solar radiation prediction algorithms. They are technology independent and can be used for any type of solar thermal energy or PV system and are therefore the ideal solution for solar energy research and site prospecting.

The next step is the extension to a complete Solar Monitoring Station. It comprises a SOLYS 2 or 2AP sun tracker fitted with a CMP pyranometer for global radiation, a CHP 1 pyrheliometer for direct radiation, and a CMP pyranometer shaded from the direct sun to measure the 'diffuse' sky radiation. There may also be a tilted CMP pyranometer measuring the total radiation available to a PV system that has 2-axis tracking arrays. For thermal energy systems a CGR pyrgeometer is added. All of these instruments are mounted on the sun tracker (as shown in the picture at right) using the accessory shading ball assembly.

The outputs from all the radiometers are connected to a dedicated data logger and stored for retrieval by remote access. Kipp & Zonen can supply solutions for most data logging and data transfer requirements.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Why Kipp & Zonen?

Kipp & Zonen has been designing and manufacturing solar radiation measurement equipment for over 75 years and supplies leading meteorology and climatology organisations, research institutes and energy companies around the globe. Our radiometers can help you to optimize the performance of your system. We have a world-wide reputation for quality, reliability, expertise and support.

In addition to our radiometers and sun trackers, we have a wide range of accessories, data loggers and interfacing solutions. All our products have a 2-year warranty.

Please visit our website **www.kippzonen.com** for more information.

Ing. Giuseppe Terzaghi of Albarubens

“The difference in performance of PV panels is quite small, so an objective power measurement has to be made with very high precision and low uncertainty to certify the performance. Therefore we choose the Kipp & Zonen CMP 11 pyranometer as the absolute irradiance meter. A reference cell has an uncertain spectral response; however we do use a reference PV module for comparison. The best way to quantify PV module performance for certification purposes is in their real working condition: natural sun light!”

Albarubens S.r.l. is a test laboratory, located near Milan in Italy that specialises in Solar Energy systems.

The laboratory is accredited under IEC 17025 for all the performance and endurance tests on photovoltaic (PV) solar panels, as described in the standards IEC EN 61215 (crystalline silicon), IEC EN 61646 (thin film) and IEC EN 61730-2 (safety aspects). Albarubens is also testing to IEC 62108 (concentrators) and EN 12975 (thermal solar panels).

Dr. Lourdes Ramirez Santigosa of CENER

"As part of the BSRN (Baseline Service Radiation Network) group, we monitor the background shortwave and long wave radiative components and their changes with the best methods currently available. We use a CMP 22 pyranometer for global and diffuse radiation measurements and a CH 1 pyrheliometer measures the direct radiation. All Kipp & Zonen instruments are mounted on a 2AP sun tracker. The data is important for characterisation and monitoring of Solar Thermal Power Plants and Concentrated Solar Power systems. Furthermore the meteorological variables are also inputs for energy performance models and energy forecasting."

The National Renewable Energy Centre (CENER) in Spain is a worldwide recognised technology centre specialised in applied research, development and promotion of renewable energies. The CENER Photovoltaic Solar Energy Department collaborates in projects sponsored by AECI and in initiatives of the International Energy Agency (IEA). The Solar Thermal Energy Department of the CENER offers technological services and carries out applied research activities.

Ing. Simon Boddaert of CSTB

"As part of our research, development and innovation programme to develop new photovoltaic components and hybrid systems integrated into buildings, we - Renewable Energy Department of CSTB - use numerical simulation tools and experimental platforms to characterize electrical performance and thermal behaviour. For the numerical models it is necessary to determine the real-world performance of the components used, and it is also necessary to know the weather conditions, such as wind, temperature and solar radiation. For more than five years, we have used Kipp & Zonen pyranometers for most of our photovoltaic activities, in order to meet customers' requirements and expectations."

CSTB stands for Centre Scientifique et Technique du Bâtiment, the French Scientific and Technical Building Centre (contact: simon.boddaert@cstb.fr)

System configurations

Basic Solar Monitoring
For fixed (tilted) panels
1 horizontal pyranometer for global radiation
1 tilted pyranometer for tilted global radiation

Recommended instruments:
SP Lite2 / CMP 3 / CMP 6 / CMP 11

Advanced Solar Monitoring
For concentrating and / or tracking systems
1 horizontal pyranometer for global radiation
1 pyrheliometer with sun tracker for direct radiation
1 tilted pyranometer fitted to sun tracker
1 horizontal pyrgeometer for infrared radiation (thermal systems)

Recommended instruments:
CMP 11, CHP 1, SOLYS 2, CGR 4

Complete Solar Monitoring System
Includes global, direct, diffuse and global tilted measurement
1 horizontal pyranometer for global radiation
1 pyrheliometer with sun tracker for direct radiation
1 tilted pyranometer fitted to sun tracker
1 shaded pyranometer for diffuse radiation (shading assembly on sun tracker)
1 horizontal pyrgeometer for infrared radiation (thermal systems)

Recommended instruments:
CMP 11 / CMP 21, CHP 1, SOLYS 2, CGR 4

Relevant IEC standards for PV panel testing

IEC 60904 (part1/10) Photovoltaic devices, measurements and requirements

IEC 61215 Design qualification and type approval, crystalline silicon

IEC 61646 Design qualification and type approval, thin film

IEC 61853 Module performance testing

IEC 62108 Design qualification and type approval, concentrator photovoltaic (CPV) modules and assemblies

Relevant EN standard for thermal solar panels

EN 12975 Thermal solar system testing

Relevant ISO standards for pyranometers

ISO 9060 Specifications and classifications of instruments

ISO 9847 Calibration of field pyranometers

Traceability

All Kipp & Zonen solar radiation instruments are fully traceable to the World Radiometric Reference (WRR) in Davos, Switzerland, where Kipp & Zonen instruments form part of the World Standard Groups.

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