An Employee Owned Company

# Application Notes
# Light

## Pyranometers for Solar Farms

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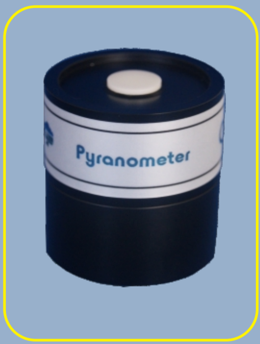
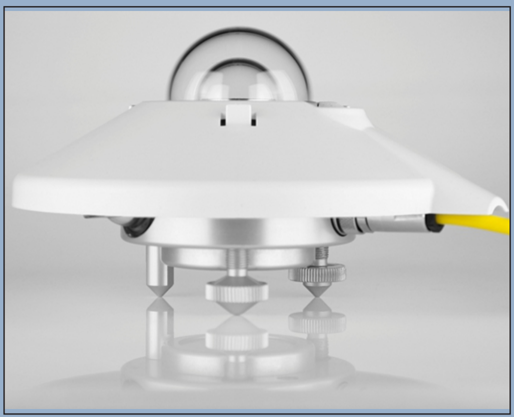



The importance of renewable energy is constantly growing worldwide, and solar energy is a clean and popular option. To install and operate a solar energy farm it is necessary to measure the solar irradiance or solar energy received by the panel arrays.

This is important for the assessment of potential installation sites, and of course during the entire lifetime of the farm, to monitor and control the system's efficiency.

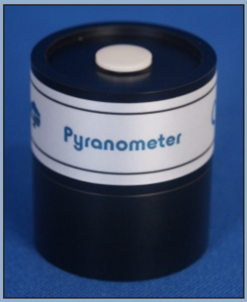
Solar irradiance is measured using pyranometer sensors. The World Meteorological Office (WMO) use thermopile type pyranometers for general



meteorological use, and have classified these pyranometers according to their specifications.

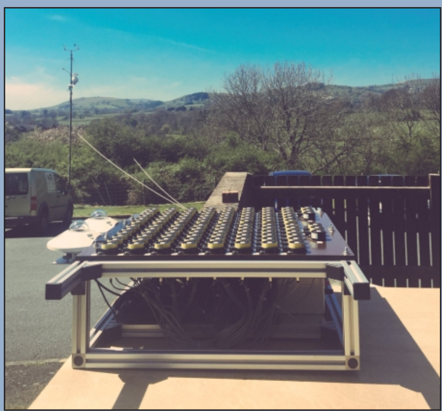
Thermopile pyranometers are generally slow to respond to changes in solar irradiance, between 5-18 seconds depending on the classification.

The silicon crystals in solar panels respond very quickly (in nanoseconds) to changes in irradiance, and so thermopile pyranometers with their dissimilar response time are not necessarily the best option for measuring solar irradiance in this application.




Skye Instruments manufacture silicon cell type pyranometers, which, due to the similar silicon crystal technology also respond in nanoseconds, possibly making them a better option in solar farm monitoring. The same technology of sensor and solar panel also means that they have similar responses to the solar energy wavelengths.

Each Skye Pyranometer sensor is individually calibrated at the time of manufacture under clear sky conditions, directly against a calibrated reference World Meteorological Office Secondary Standard thermopile pyranometer and following WMO guidelines. The calibration is traceable to the World Radiometric Reference. Please see a fuller description in the datasheet "Calibration of Pyranometers".



In traditional meteorology, Pyranometers are installed horizontally to measure irradiance from the hemisphere of the whole sky. On solar farms, additional pyranometers are also installed in the same plane as the solar panels, to measure the exact irradiance falling on the panel surface.

Skye silicon cell Pyranometers are a much lower cost option than the thermopile type, enabling larger networks of sensors to be deployed in multiple monitoring sites across the solar farm area.


Skye pyranometers are fully weatherproof and waterproof to IP68, robust and durable. They are cosine corrected enabling accurate measurements even at low sun angles. There is a range of output options to suit most dataloggers and control systems, from mV to 0-10V and 4-20 mA.

These sensors have been used in photovoltaics (PV) research for many years and are quoted in several scientific research journals. Please request a list for those references specific to PV applications.

A typical Skye MiniMet meteorological station for solar farm efficiency monitoring can include the pyranometer plus sensors for panel surface temperature, wind speed and direction, relative humidity and air temperature, air pressure and rainfall.

Please request further details

# Calibration of Pyranometers

Skye Instruments have been designing Light and Radiation sensors for outdoor use since 1983.

The Silicon Cell Pyranometer is one of the most popular in the range, and is designed and calibrated to measure Global and Diffuse Sky Solar Radiation. Silicon cell pyranometers are responsive to wavelengths between 350-1100nm, and are cosine corrected to measure incoming light and radiation from a 180° hemisphere according to Lambert's Cosine Law, which is the standard method for measuring irradiance. These sensors are completely waterproof, sealed to IP68, and can be left indefinitely in exposed conditions.

Each Pyranometer sensor is individually calibrated at the time of manufacture under clear sky conditions, directly against a calibrated reference World Meteorological Office Secondary Standard thermopile pyranometer. This takes place over several days as described in the WMO publication "Guide to Meteorological Instruments and Methods of Observation" and is traceable to the World Radiometric Reference.

This calibration method allows the silicon cell pyranometers (with response wavelengths 350-1100nm) to measure Global Radiation as per a thermopile pyranometer (which has response wavelengths 300nm-3000nm), in natural daylight conditions.

Different conditions of sun, cloud, etc., will slightly affect calibration, but absolute errors will always be within 5% and typically much better than 3%. Linearity is excellent, with a maximum of 1% deviation up to levels of 3000 W.m-2 (more than twice maximum solar irradiances).

Skye Pyranometer sensors (SKS 1110) are recommended to be recalibrated at a minimum of 2 yearly intervals, even though these sensors are very stable and rarely change by more than a few percent under normal usage.

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**email: skyemail@skyeinstruments.com**
**website: www.skyeinstruments.com**

CALIBRATION CERTIFICATE

NO: PYR 8009 0814

**UNIT TYPE** PYRANOMETER SENSOR

**SERIAL NO:** SKS 1110/I 42856

**OUTPUTS:** 0.04538 µA / W m-2

10.00 µV / W m-2

**DATE OF CALIBRATION:** 05/09/2012

**A/D UNIT** E7090

Calibrated outdoors under natural daylight conditions by the ratiometric method, against a WMO Secondary Standard Pyranometer, which is traceable to the World Ratiometric Reference via the Met Office standard cavity radiometer.
Uncertainty 5% (typically < + 3%) based on an estimated confidence of not less than 95%

THIS UNIT IS DUE FOR RECALIBRATION WITHIN 2 YEARS OF THE ABOVE CALIBRATION DATE.

Calibrated By: G. Sims

Checked By:

Issue Date: 20/08/2014

# Pyranometers in Solar Energy Research

| AUTHOR | PAPER TITLE | JOURNAL | YEAR |
|---|---|---|---|
| | | | |
| Casaluci, Simone | Graphene-based large area dye-sensitized solar cell modules | Nanoscale | 2016 |
| Divitini, G. et al | In situ observation of heat-induced degradation of perovskite solar cells | Nature Energy | 2016 |
| Driesse, Anton. et al | Indoor and Outdoor Evaluation of Global Irradiance Sensors | 31st European Photovoltaic Conference | 2014 |
| De Rossi, Francesca Tadeo, Pontecorvo, and Thomas M. Brown | Characterization of photovoltaic devices for indoor light harvesting and customization of flexible dye solar cells to deliver superior efficiency under artificial lighting | Applied Energy | 2014 |
| Di Giacomo, Francesco, et al | High efficiency CH 3 NH 3 PbI (3- x) Cl x perovskite solar cells with poly (3-hexylthiophene) hole transport layer | Journal of Power Sources | 2014 |
| Matteocci, Fabio, et al | Solid state dye solar cell modules | Journal of Power Sources | 2014 |
| Matteocci, F., et al | High efficiency photovoltaic module based on mesoscopic organometal halide perovskite | Progress in Photovoltaics: Research and Applications | 2014 |
| Fragaki, Aikaterini, and Tom Markvar | System memory effects in the sizing of stand alone PV systems | Progress in Photovoltaics: Research and Applications | 2013 |
| Matteocci, F., et al | Blocking layer optimisation of poly (3- hexylthiopene) based solid state dye sensitized solar cells | Organic Electronics | 2013 |
| Zardetto, Valerio, et al | Fully plastic dye solar cell devices by low temperature UV irradiation of both the Mesoporous TiO2 Photo and Platinized Counter Electrodes | Advanced Energy Materials | 2013 |
| Vesce, Luigi, et al | Fabrication of spacer and catalytic layers in monolithic dye-sensitized solar cells | IEEE Journal of Photovoltaics | 2013 |
| Mastroianni, Simone, et al | Reverse bias degradation in dye solar cells | Applied Physics Letters | 2012 |
| Vesce, Luigi and Riccardo Riccitelli | Processing and characterization of a TiO2 paste based on small particle size powders for dye sensitized solar cell semi transparent photo electrodes | Progress in Photovoltaics: Research and Applications | 2012 |
| Giordano, Fabrizio, et al | Series-connection designs for dye solar cell modules | IEEE Transactions on Electron Devices | 2011 |
| Mincuzzi, Girolamo, et al | Laser-Sintered films for dye solar cell fabrication: an electrical, morphological, and Electron Lifetime Investigation | IEEE Transactions on Electron Devices | 2011 |

## ORDERING INFORMATION

| | |
|---|---|
| **PV1** | **Pyranometer with mount for a solar panel & 3m cable* (current/mV output)** |
| **PV2** | **Pyranometer with mount for a solar panel & 3m cable* (voltage output)** |
| **PV3** | **Pyranometer with mount for a solar panel & 3m cable* (4-20mA output** |
| **PV4** | **Pyranometer with mount for a solar panel, 3m cable* and 1-channel DataHog datalogger** |
| **PV5** | **Pyranometer with mount for a solar panel, 3m cable* and display meter** |
| **PV6** | **7-channel MiniMet Weather Station** |

*** extra cable is available**

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