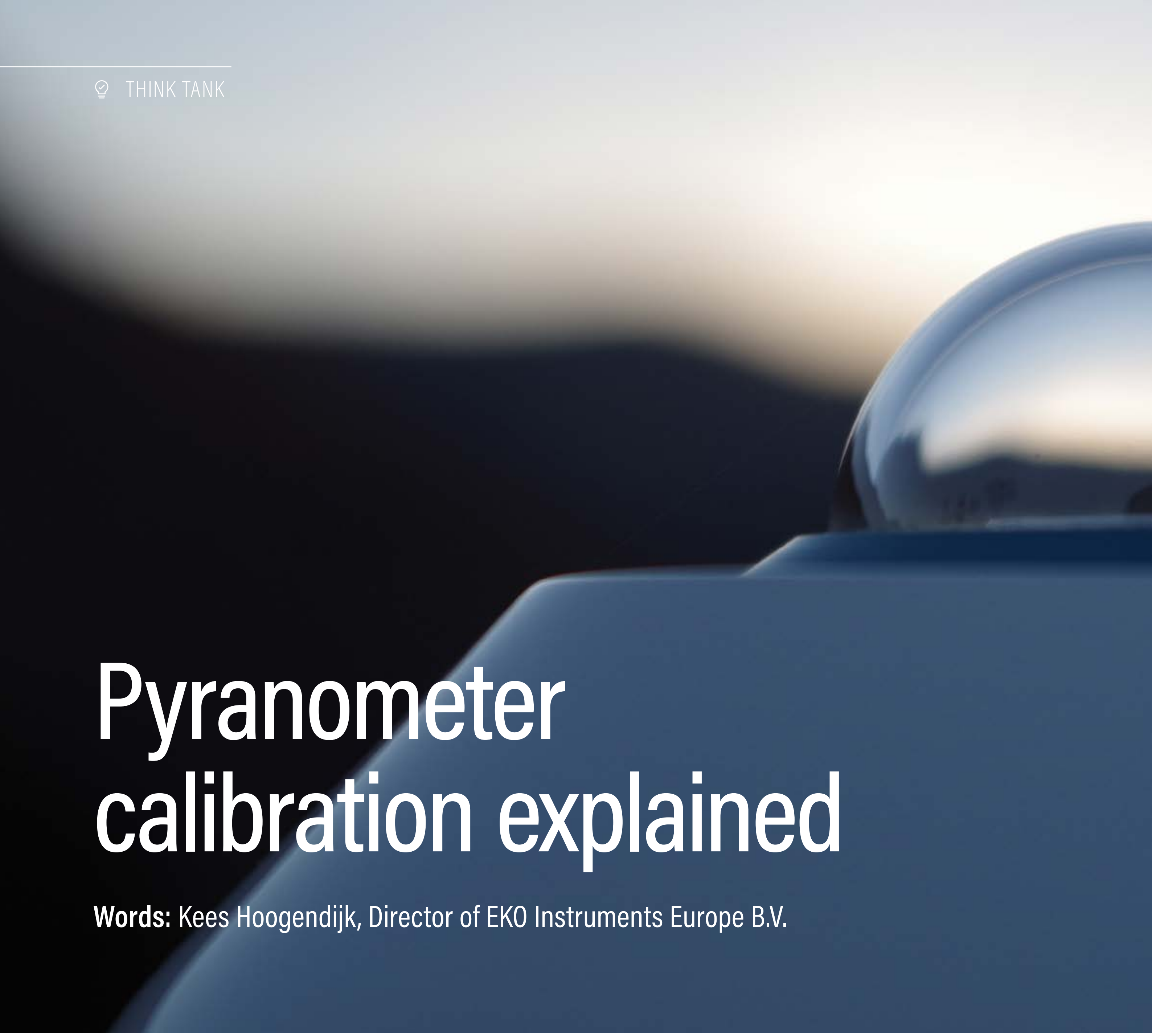


Pyranometer calibration explained

Words: Kees Hoogendijk, Director of EKO Instruments Europe B.V.

MS-80 Class A Pyranometer deployed at AMI Solar Park in Japan

In the realm of solar energy and atmospheric research, pyranometers play a pivotal role. These instruments are essential for accurately measuring solar radiation at a specific location, a key factor in optimizing the design and efficiency of solar energy systems. Pyranometers, classified under various accuracy categories, are not only crucial in the planning stages of solar installations but also vital for the ongoing monitoring and maintenance of existing systems.

In a site assessment project, pyranometers provide accurate measurements of the solar radiation available in a specific location, allowing engineers to optimise the design of the solar system for maximum efficiency.

For existing solar power installations, pyranometers available in different accuracy categories (ISO 9060) are used to monitor the performance of the system. By comparing the actual solar irradiance with the energy output of the system, operators can determine if the system is working as expected and identify any issues, like shading, dirt accumulation on panels, or equipment malfunctions.

Pyranometers are also used in meteorological research to study atmospheric conditions, earth energy balance studies and solar radiation patterns. This data can help predict weather patterns, understand climate change, and develop better models for solar energy production.

In general, we can say that pyranometers are used to provide a standardised measure of solar power which hits the Earth's surface, measured in watts per square meter (W/m²). This ensures that the solar energy generating systems can be tested and rated consistently. Therefore, the calibration of pyranometers is critically important to ensure that pyranometers which are deployed are calibrated properly to the international irradiance scale known as the World Radiometric Reference (WRR).

Pyranometer manufacturers and pyranometer calibration laboratories follow the calibration standard ISO 9847:2023 for 'Calibration of field pyranometers by comparison to a reference pyranometer,' which is an international standard that outlines the procedures and requirements for calibrating pyranometers for ensuring the reliability and accuracy of these measurements.

Re-calibration of pyranometers will be a recurring process over time. The calibration interval is usually recommended by the pyranometer manufacturer, based on the 'long-term stability properties of a sensor model, which can be either two or five years. Besides field operating standards, such as IEC 61724, outline the methods for continuous performance monitoring of PV systems, provide the requirements for pyranometer re-calibration every two years to ensure long-term and reliable performance.

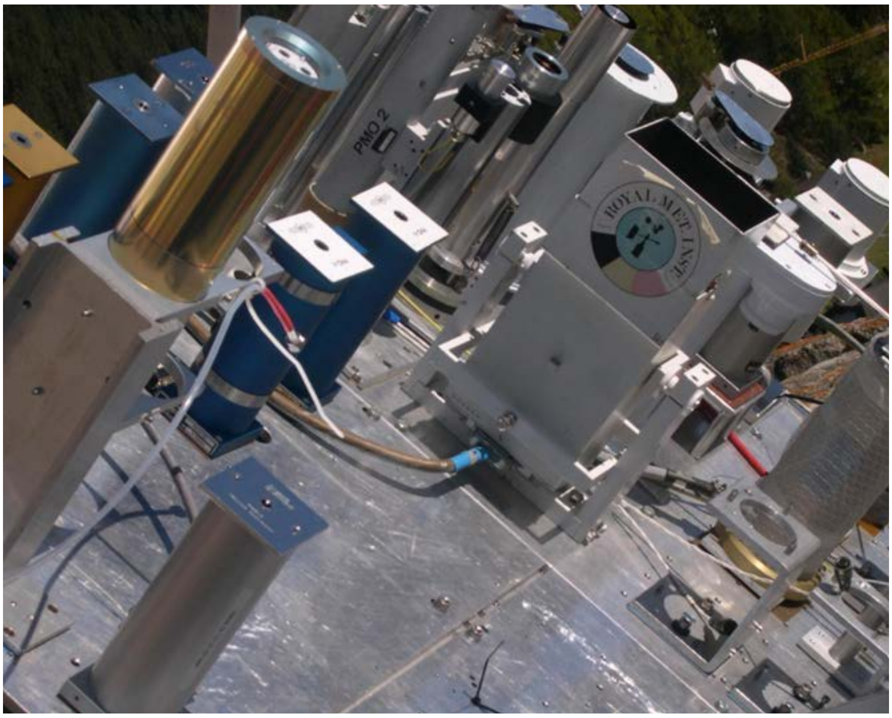
Solar irradiance scale

In order to understand about calibrations, it is important to understand what it is based on. When pyranometers are calibrated, it is done to the reference scale of solar irradiance. The solar irradiance scale is defined based on the measurement of the power per unit area of solar electromagnetic radiation. The measurement is typically expressed as SI unit in Watts per square meter (W/m²).

A key reference point in defining this scale is the Solar Constant. The Solar Constant is the average solar irradiance (DNI) received at the top of Earth's atmosphere on a surface perpendicular to the sun's rays. This value is approximately 1361 W/m², as measured from space, where atmospheric effects are absent. This constant provides a baseline for understanding the maximum potential solar irradiance that can be received by the Earth.

Although the measurement equipment used in space differs from the sensors used for ground-based applications, similar absolute measurements principles are applied by the Absolute cavity reference sensors used on Earth. They can convert the measured solar shortwave energy flux (W) to irradiance (W/m²) hence defined as the irradiance scale.

The World Radiation Center (WRC) maintains and operates the World Standard Group (WSG) of Pyrheliometers which represents the World Radiometric Reference (WRR) for



WRR at PMOD (2005 archive picture)

ground-based total solar irradiance measurements. Every five years, calibration laboratories around the world participate in a collaborative effort to measure their reference devices against the World Radiometric Reference (WRR) at the World Radiation Center (WRC) in Davos, Switzerland. This practice is essential to ensure the consistency and accuracy of the irradiance scale used globally.

By comparing their reference pyranometers against the WRR, laboratories can confirm that their measurements are consistent with international standards, maintaining the integrity and comparability of solar irradiance data worldwide.

How calibration works

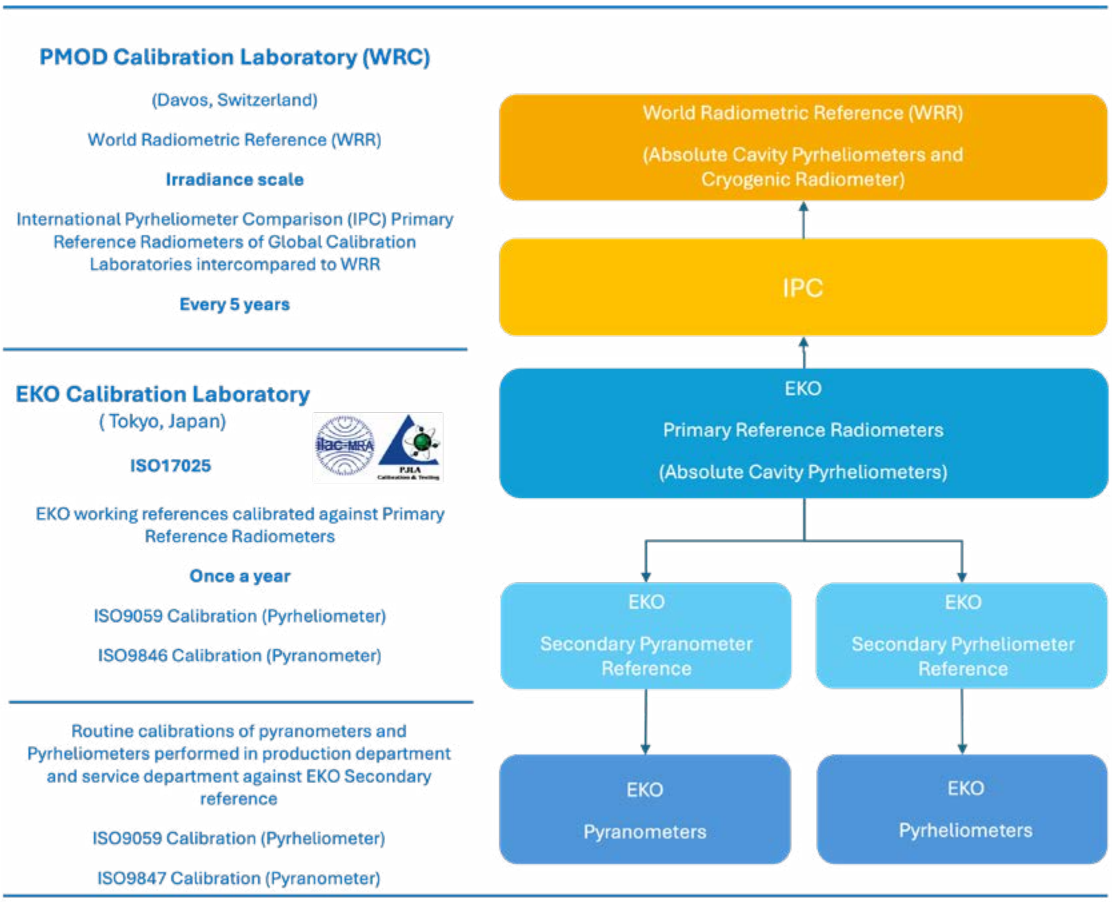
Pyranometer calibration involves comparing the readings of the test pyranometer against a reference pyranometer under controlled conditions, usually indoors under a calibration lamp or outdoors under clear skies. The ISO 9847, titled 'Calibration of field pyranometers by comparison to a reference pyranometer,' is an international standard that outlines the procedures and requirements for calibrating pyranometers.

During calibration, the pyranometers are exposed to a stable and wide range spectral lamp or sunlight, and their readings are compared to understand the calibration factor needed for the test pyranometer to match the reference. Understanding measurement uncertainties is critical in the pyranometer calibration process, whether the calibration will be done indoors or outdoors. These uncertainties include factors such as WRR Reference at highest level, the uncertainty of the irradiance scale.

Instrumental errors can also arise from the pyranometer itself, including sensor non-linearity, temperature response, and zero offset changes. Environmental factors may include variations in ambient temperature, humidity, and atmospheric conditions can affect readings.

The method used for calibration, including the stability and uniformity of the solar radiation

IPC at PMOD (2021 archive picture)



Traceability diagram to WRR

during the test, contributes to uncertainty, as does the accuracy of the reference pyranometer used in calibration.

The synchronisation of measurements and the period over which irradiance is integrated can affect results, while the angle at which sunlight strikes the pyranometer's sensor can cause deviations.

Each of these factors contributes to the overall uncertainty in pyranometer calibration, and understanding and minimising them is essential for accurate solar irradiance measurements.

Based on the estimated measurement uncertainties a combined measurement uncertainty can be calculated for the calibration transfer and indicated on the calibration certificate. The calibration combined uncertainty depending on the laboratories Calibration and Measurement Capability (CMC) is usually in the range of 0.6 to 1.2% and adds to the overall measurement uncertainty of the pyranometer deployed in the field.

It is worth noting with respect to the outcome of pyranometer re-calibration, changes within the calibration uncertainty interval do not automatically lead to an adjustment in the calibration factor. The calibration uncertainty interval reflects the range within which the true value of the measurement can be expected to lie, considering potential errors and variabilities.

If the changes in calibration measurements are within this predefined uncertainty range, it's generally considered that the pyranometer is still operating within its expected accuracy, and thus, an adjustment to the calibration factor may not be applied.

What is ISO/IEC 17025?

ISO/IEC 17025 is an international standard that specifies the general requirements for the competent, impartial, and consistent operation of laboratories, and focuses on ensuring the quality and reliability of testing, calibration, and sampling results.

For people working with pyranometers and referring to ISO/IEC 17025 it can be confusing to understand about the international standards which are often interchanged and not to be confused with recently published ISO 9847:2023 which describes about pyranometer calibration methods.

The ISO/IEC 17025 standard is relevant for all types of laboratories, regardless of their size or industry, and includes recognition of technical competence. ISO 17025:2017 is the current version, developed collaboratively by the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC). Accreditation to this standard signifies that a laboratory is effective in meeting its requirements and is competent in its field. The calibration can be about anything, not necessarily about pyranometer calibrations.

EKO instruments was the first pyranometer manufacturer that successfully implemented the procedures for the ISO/IEC 17025 accreditation with approval in 2013. It significantly impacted our organisational processes to meet the strict requirements. Accredited companies are subject to annual inspections by technical compliance experts. These inspections ensure that the company adheres to all procedures in accordance with international standards.

This rigorous oversight promotes consistent quality and reliability in their products and services, aligning with global best practices for its customers. When calibrations are performed at an ISO 17025 accredited laboratory, it typically provides an extra level of confidence in the results. This is because ISO 17025 accreditation ensures that the laboratory adheres to internationally recognised standards for accuracy, reliability, and competence in testing and calibration. The accreditation implies that the laboratory follows stringent quality control procedures and its calibrations are recognised globally for their precision and validity.

The EKO calibration facility

Future of calibration

Frequently we get the question about what will happen with pyranometer calibrations in the future, do we expect any changes? Are re-calibrations still required? We believe that in the future pyranometer calibrations remain very important as it currently is. Provided by the international operating standards, pyranometer specifications, and diligent assessment of the Solar irradiance data quality, re-calibration of pyranometers will be required to ensure that the solar energy generating systems can be tested and rated consistently.

As solar energy and climate research continue to advance, the demand for accurate solar irradiance measurements increases provided by the many pyranometers deployed around the world. This necessitates ongoing calibration to ensure the precision and reliability of pyranometers.

Technological advancements may improve sensor performance stability over time, hence the fundamental need for accurate calibration in ensuring data accuracy will persist for new pyranometers which enter the market and the ones deployed in the field and need to be examined over time.

Within our company strategy and vision, we have developed ideas to further improve the measurement performance and most important data quality. Our focus will be more on providing consistent and sustainable on-site verification methods to maintain sensor stability and monitor data quality in the field.

We believe that recalibration in the lab is just one way to check the sensor stability against the reference irradiance scale. There are already interesting ideas explored, which are ultimately more practical and desirable from a user perspective.

eko-instruments.com/eu

References:

EKO Instruments (eko-instruments.com/eu)

EKO Instruments Calibration Standards and handbook

PMOD / World Radiation Center (pmodwrc.ch)

ISO/IEC (iso.org)

ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories

ISO 9847:2023 Solar energy Calibration of pyranometers by comparison to a reference pyranometer

The EKO reference calibration set-up