Report prepared for Hukseflux Thermal Sensors B.V.

Brief Analysis of Class A Pyranometers at the NREL Solar Radiation Research Laboratory

Version 1.0

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Table of contents

1.0 Introduction

The Solar Radiation Research Laboratory (SRRL) at the National Renewable Energy Laboratory (NREL) located in Golden, Colorado operates and maintains a large number of radiometers. The measurements are made publicly available and constitute a very reliable, independent source of comparative data [1]. For this report, we use a small subset of the data to analyse the performance of eight modern commercial ISO 9060 Class A [2] pyranometers from three leading manufacturers: Kipp & Zonen, EKO Instruments and Hukseflux. They are listed in Table 1.

The analysis examines only two causes of pyranometer measurement error: directional error and zero offsets. The results should not be regarded as definitive because neither effect was completely isolated from other potential causes of measurement error. Also, a comprehensive comparison should take into account a full year of operation, which is not available yet for some of the newer instruments.

One of the strengths of NREL SRRL is the ability to correct thermal offsets in order to reduce measurement error. Three of the instruments shown in this report have benefited from these corrections, which biases the results of the analysis to some degree. To obtain an unbiased comparison the raw data would have to be reprocessed *without* applying the offset corrections. In this report, instruments benefitting from the correction are identified with “(cor)” after the model number. One of the instruments also has a separate external ventilator and this is flagged with “(vent)” after the model number.

Table 1 ISO 9060 Class A pyranometers included in the analysis

Manufacturer	Model	Input	Output	External temperature correction	NREL thermal offset correction	Separate external ventilator	NREL instrument name
Kipp & Zonen	CMP11	Black disk	Analog		Yes		Global CMP11 (cor)
	CMP22	Black disk	Analog		Yes		Global CMP22-2 (cor)
	SMP11	Black disk	Digital				Global SMP11
	SMP12	Diffuser	Digital				Global SMP12
EKO Instruments	MS-80	Diffuser	Analog				Global MS-80
	MS-80S	Diffuser	Digital				Global MS-80S
Hukseflux	SR20	Black disk	Analog	Yes	Yes	Yes	Global SR20 (vent/cor)
	SR30	Black disk	Digital				Global SR30

2.0 Directional response

All the pyranometers of interest are mounted horizontally to measure global horizontal irradiance (GHI) and a reference GHI measurement is needed in order to evaluate their measurement errors. For this analysis the reference (GHI) is calculated from the primary direct normal irradiance (DNI) and primary diffuse horizontal irradiance (DHI) measurements that are made using redundant Kipp & Zonen CHP1 and CM22 instruments respectively.

Directional error is assessed using direct radiation only; therefore, the reference diffuse measurement is subtracted from each GHI. The percentage error in the remainder is found by comparison to the reference direct irradiance projected on a horizontal surface. Finally, this percentage error is multiplied by 1000 W/m^2 to obtain an absolute directional error. Note that this is not a pure directional response since the calculated measurement errors may be partly attributed to other effects like non-linearity, temperature response, spectral error or offsets; however, it is a good estimate from field data.

Four of the clearest days in summer 2025 are selected for the analysis. On each day, each instrument's GHI measurements are normalized (scaled) to the reference GHI based on readings between zenith angle 25° and 35°. This compensates for potential small drifts in calibration factor. Ideally this normalization would have been done at zenith angle 0°, but there is no data available for this.

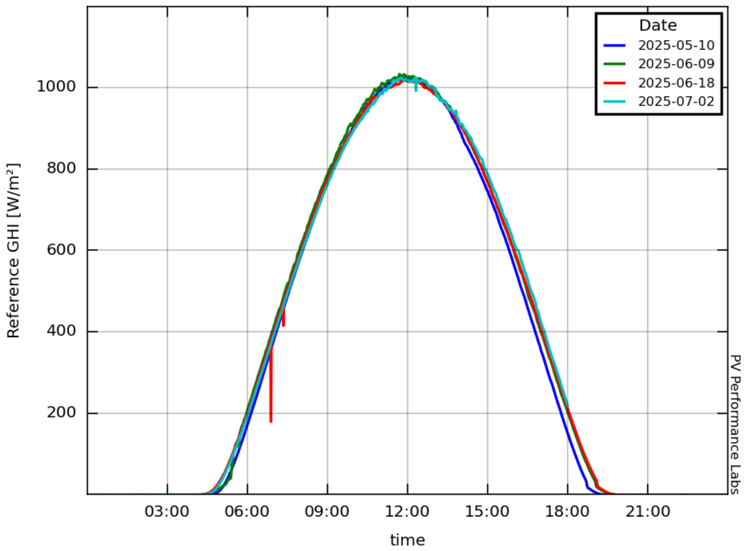

Figure 1 Reference irradiance during the four chosen clear days.

Observations on the directional* error graphs in figure 2:

- The errors of the SMP12 and MS-80S have typical "cat-ear" profiles often seen with diffusers. Despite having the same diffuser design, the MS-80 profile doesn't have this signature shape. The MS-80S is the newer digital version of the MS-80.
- The SMP12 errors fluctuate much more than the other instruments, but this is unrelated to direction.
- The SMP11 result is probably influenced by its large zero offset (see next section).
- The responses of the SR30 and CMP22 are very similar to each other and substantially flatter (i.e. closer to the ideal response) than the other 6 instruments.
- Several instruments show some errors beyond the class A specification of (±10 W/m^2) however a proper assessment of compliance would need observations at zero degrees angle of incidence and elimination of other simultaneous sources of error.

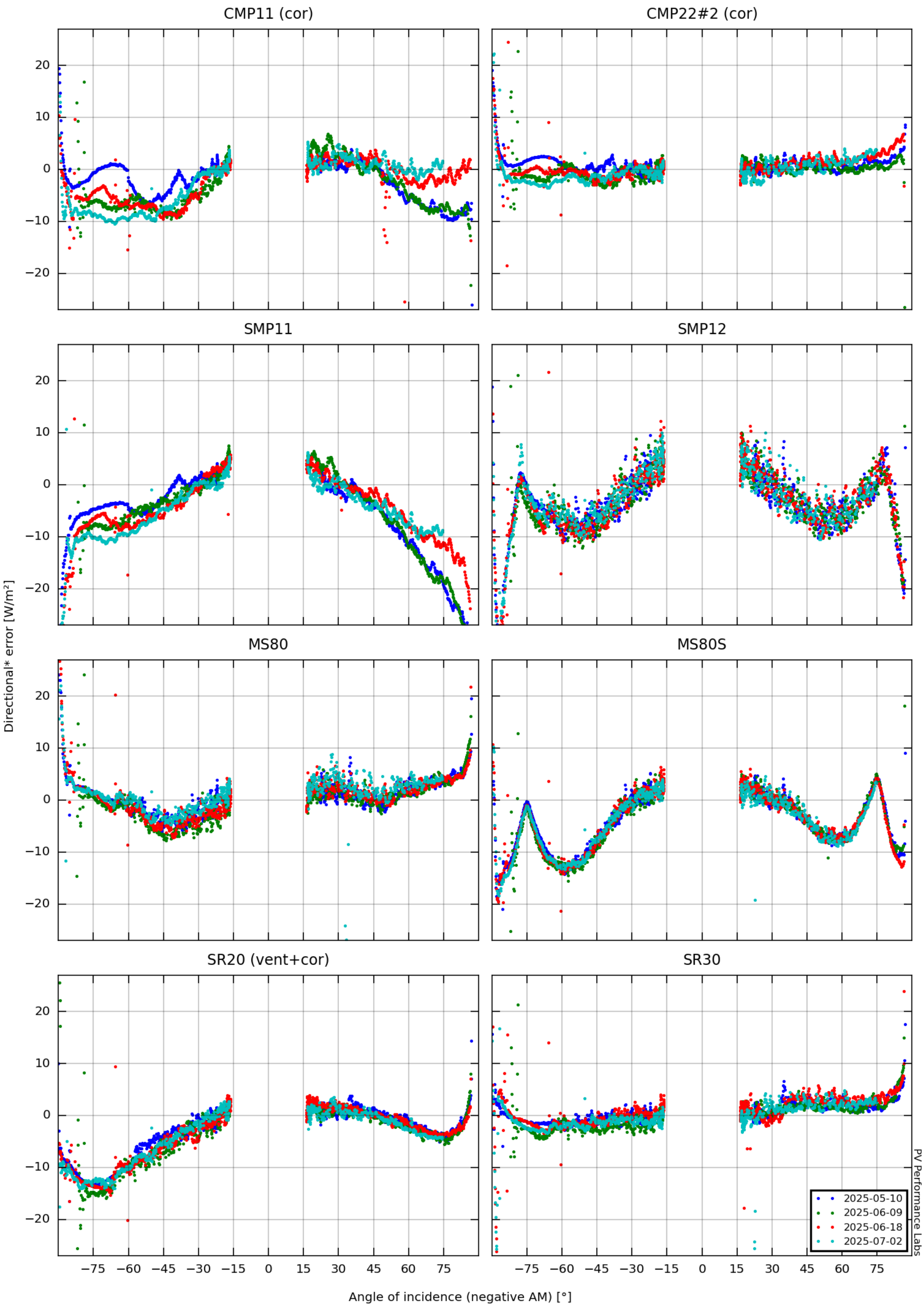

Figure 2 Directional* errors. The * indicates that these errors may be partly attributed to other effects like non-linearity, temperature response, spectral error or offsets.

3.0 Zero offsets

Non-zero values recorded at night can be an indication that daytime measurements are also skewed by zero offsets. Since offset A is greatest during clear days, we use the same data as for the directional response analysis. Conveniently, there is a sudden drop in temperature near 2 am on June 9, and another around 3 am on July 2, therefore offset B effects are also visible.

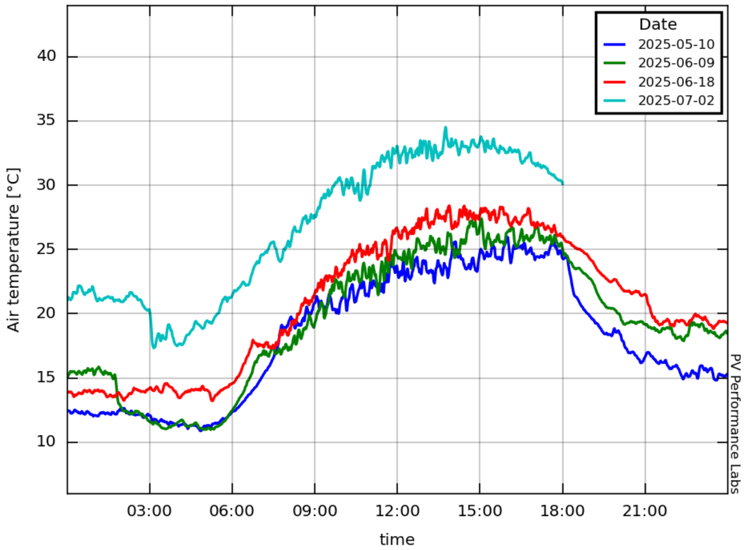

Figure 3 Ambient temperature during the four chosen clear days.

Observations on the night-time graphs in figure 4:

- Thermal offset correction hides the true instrument type A offset errors, but does not always work perfectly. It also does not correct for type B errors.
- Among the uncorrected instruments, the three diffuser-based models (MS-80, MS-80S and SMP12) have average night-time signals very near to zero. The SR30 with black absorber also achieves near zero offsets, whereas the SMP11, which also has a black absorber, has offsets in the range −2 to −5 W/m^2.
- Rapid, random-looking fluctuations are more likely to be type B offset errors, and indeed the magnitudes of the two spikes caused by the drops in ambient temperature are in proportion to those random fluctuations. The CMP22 is by far the most stable, but runner-up SR30 also has noticeably smaller spikes and fluctuations than the other 6 instruments.
- Offset B for the CMP11 and SMP11 is in the opposite polarity of most of the other instruments, suggesting internal design differences.
- The distinct steps in the night-time output of the SMP11 are due to the 1 W/m^2 resolution of the Modbus register that stores the irradiance values.

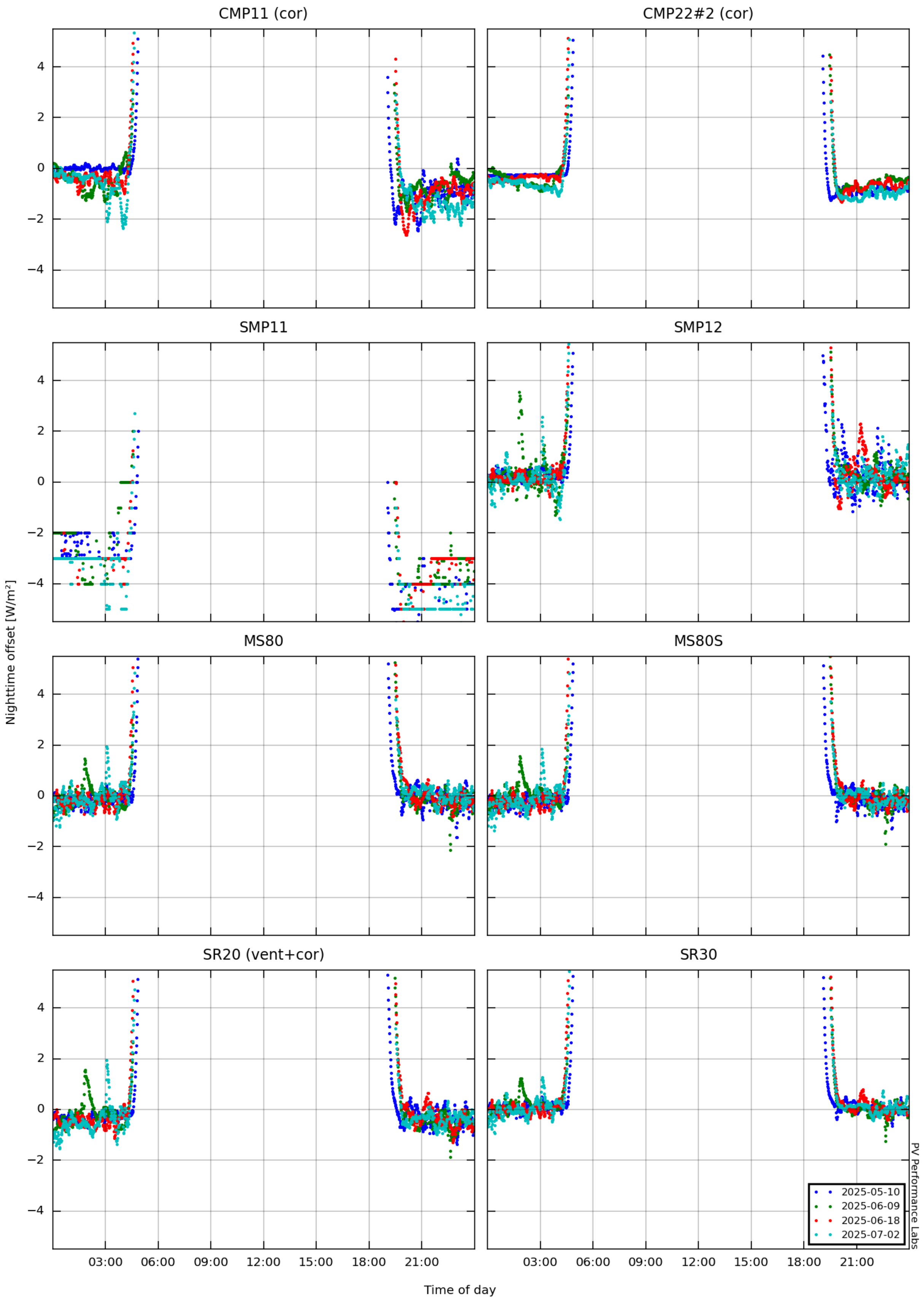

Figure 4 Night-time readings during the four chosen clear days.

4.0 Limitations and future work

The foregoing analysis has several limitations. First, we analyse only a single unit of each model, and that unit may or may not be representative of other units of the same model. It is possible that one or more of the suppliers selected a particularly good unit, or that NREL selected a particularly good unit. This would be consistent with NREL's usual goal to obtain the best achievable accuracy for on-site measurements. A random selection using several units of each model would be more suitable for comparing manufacturers and models.

Second, as already mentioned, the outdoor measurements are affected by multiple factors simultaneously; therefore, it is difficult to evaluate the pure directional response. It would be advantageous to study a longer time series—preferably a year—and to assess multiple characteristics simultaneously. This should be possible for effects that are not correlated.

A further limitation is that the normal incidence angle response is never observed for GHI measurements at this location. The normal incidence angle could be obtained by tilting the pyranometers toward the equator in a future experiment, preferably with ground reflections blocked. The tilted position also has the advantage that incidence angles greater than 90° can be observed and evaluated during summer. Going one step further, the tilted instruments could be subjected to alternating sun and shade, which would conveniently remove both diffuse irradiance and offset errors from the evaluation. This approach is used in the alternating sun and shade pyranometer calibration method described in ISO 9846 [3].

5.0 References

[1] T. Stoffel and A. Andreas, “NREL Solar Radiation Research Laboratory (SRRL): Baseline Measurement System (BMS); Golden, Colorado (Data).” https://midcdmz.nrel.gov/, 1981. doi: 10.5439/1052221.

[2] ISO, “ISO 9060:2018 Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.,” ISO, Geneva, International Standard, Nov. 2018.

[3] ISO, “ISO 9846:2025 Solar energy — Calibration of a pyranometer using a pyrheliometer,” ISO, Geneva, International Standard, Aug. 2025.