Verifying DustVue™10 accuracy with controlled artificial soiling

1. Introduction

Soiling is the buildup of dust, dirt, pollen, and other particles on a solar module's surface, and it is one of the most common causes of energy loss in photovoltaic (PV) systems. Soiling blocks light from reaching the PV cells, which lowers electrical output. Accurate measurement of soiling loss matters for yield modeling, performance checks, maintenance planning, and financial decisions.

This paper describes the design and operating principle of the DustVue 10 soiling sensor and presents an improved approach to soiling measurement that reduces dependence on routine maintenance of a clean reference while remaining compatible with the two-panel comparison method and the measurement definitions and reporting requirements described in IEC 61724-1. Results from a controlled artificial-soiling experiment validate its accuracy against two independent reference instruments.

2. Soiling and the soiling ratio

Why the clean reference is the weak point:

Dust, dirt, pollen, and other airborne particulates that accumulate on a module surface block a portion of the incoming sunlight before it reaches the PV cells. The resulting energy loss varies with climate, module tilt, surface properties, and cleaning schedule, so accurate, continuous soiling measurements are essential for yield modeling, performance assurance, cleaning schedule optimization, and bankability assessments.

The standard field measurement method, formalized in IEC 61724-1, uses a two-device comparison: one reference device is kept clean while a second is allowed to soil naturally. The soiling ratio (SR) is calculated as the ratio of soiled device output to clean reference output:

$$SR = G_{soiled} / G_{clean}$$

www.campbellsci.com | ph: (435) 227-9000 fax: (435) 227-9001 | 815 W 1800 N, Logan, UT 84321
Australia | Brazil | Canada | China | Costa Rica | France | Germany | India | Japan | South Africa | Spain | Thailand | UK | USA

- **SR = 1.00** indicates no soiling loss.
- **SR = 0.90** indicates the soiled surface transmits 90% of the light received by the clean reference, corresponding to a 10% soiling loss.

Because SR is calculated as a ratio of two measured irradiance values, its accuracy depends directly on the clean reference remaining representative of an unsoiled surface. In practice, four sources of systematic error arise in maintaining the clean reference under field conditions:

Table 2-1: Sources of error in the clean-reference method

Challenge	Cause of error
Manual cleaning	Site visits are labor-intensive, and cleaning technique is not standardized; partial re-soiling between cleaning cycles introduces a negative bias into the clean-reference baseline.
Automated water-based cleaning	Automated washing brings water spotting, micro-staining, and its own maintenance burden.
Device-to-device mismatch	Differences in electrical characteristics, aging, temperature response, or mounting geometry between the clean and soiled devices produce a systematic offset that is indistinguishable from soiling in the SR calculation.
Calibration drift	Without frequent recalibration and inspection, systematic bias accumulates over time, increasing measurement uncertainty and the risk of data gaps.

The DustVue 10 mitigation approach:

The DustVue 10 uses the IEC-recognized two-device principle but protects the clean reference instead of relying on frequent cleaning. The clean reference cell is housed beneath a dust-free, watertight cover and is exposed to the sky only for a few brief measurements around solar noon. Because its exposure is minimal, little soiling accumulates, allowing the reference to remain a reliable baseline without manual or water-based cleaning.

3. DustVue 10 components

1. Front clean cell
2. Rear clean cell
3. Front soiled cell
4. Rear soiled cell
5. Clean cell cover
6. Clean cell housing
7. USB-C port
8. M12 5-pin port
9. Ground lug
10. Guard rail
11. Vent
12. Power LED
13. Tx/Rx LED

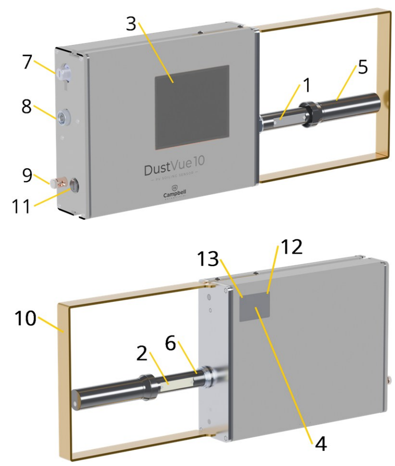

Figure 3-1. DustVue 10 components, front and rear views

Figure 3-2. The cover slides along the shaft to expose the clean cell for measurement, then closes to protect it from soiling

4. Methods

4.1 Artificial soiling with optical filters

Sensor performance was evaluated indoors under a stable, high-intensity LED light source. The LED lamp was selected because it provides high irradiance with minimal heat generation, allowing light intensity to remain stable throughout the test.

Soiling was simulated using wavelength-selective optical filters, which provided a repeatable method for producing controlled reductions in light transmission. A Class A pyranometer and a PV reference cell served as independent reference instruments for comparison.

To verify light source stability, measurements were alternated between filtered and unfiltered conditions. The filter conditions were then ordered by increasing transmission loss to represent progressively greater levels of artificial soiling. The experimental arrangement is shown in Figure 4-1 (p. 4).

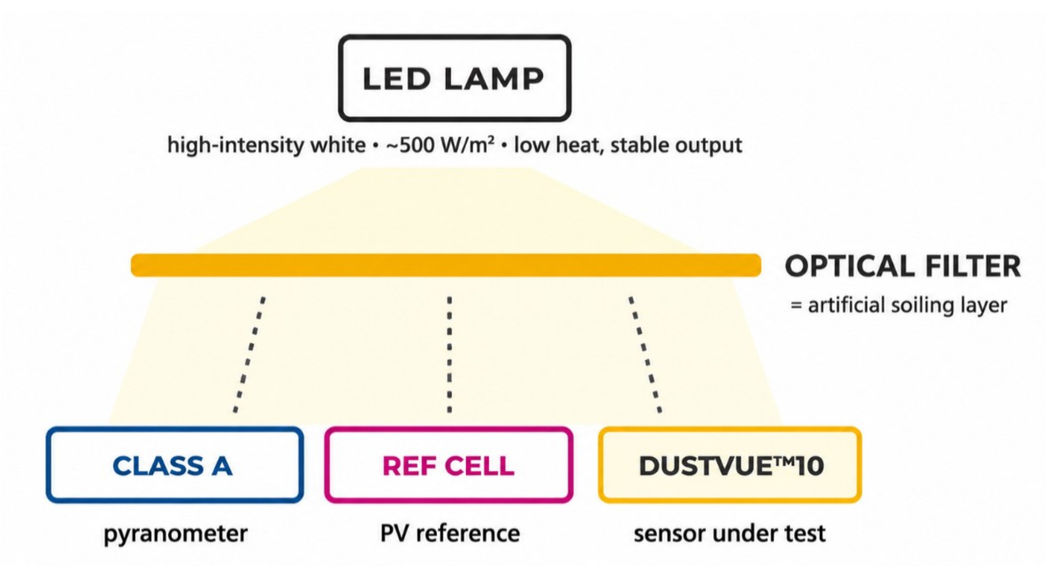

Figure 4-1. Bench setup: each filter attenuates the LED illumination reaching all three instruments equally

4.2 Procedure

Stable light source: An LED lamp was selected for its high irradiance, minimal heat generation, and stable output over extended periods.

Interleaved baseline measurements: Measurements were alternated with and without optical filters so that each filtered measurement could be normalized to the nearest-in-time unfiltered baseline, minimizing the effects of any residual source drift.

Artificial soiling conditions: Ten wavelength-selective optical filters were applied individually to produce transmission losses ranging from negligible to severe. The filter conditions were then ranked by increasing attenuation to simulate progressively greater soiling.

Common transmission calculation: Transmission was calculated identically for all three instruments, allowing direct comparison of their responses:

$$T_i = \frac{I_i}{I_0}$$

where I_i is the measured irradiance with filter i in place and I_0 is the nearest-in-time unfiltered baseline measurement.

The **Class A pyranometer** served as the irradiance reference standard, verifying that the DustVue 10 accurately measured transmission losses. The **PV reference cell**, with a spectral response similar to that of photovoltaic modules, verified that the measured transmission losses corresponded to the response expected from an actual PV module.

5. Results

All three instruments exhibited a monotonic decrease in soiling ratio, from 1.0 to below 0.3, as attenuation increased. This span corresponds to conditions ranging from light to severe soiling. Across all attenuation levels, the DustVue 10 matched the PV reference cell within 0.01 soiling-ratio units at any measurement point. It also maintained close, monotonic agreement with the Class A pyranometer, demonstrating accurate measurement of transmission loss over the entire test range.

www.campbellsci.com | ph: (435) 227-9000 fax: (435) 227-9001 | 815 W 1800 N, Logan, UT 84321
Australia | Brazil | Canada | China | Costa Rica | France | Germany | India | Japan | South Africa | Spain | Thailand | UK | USA

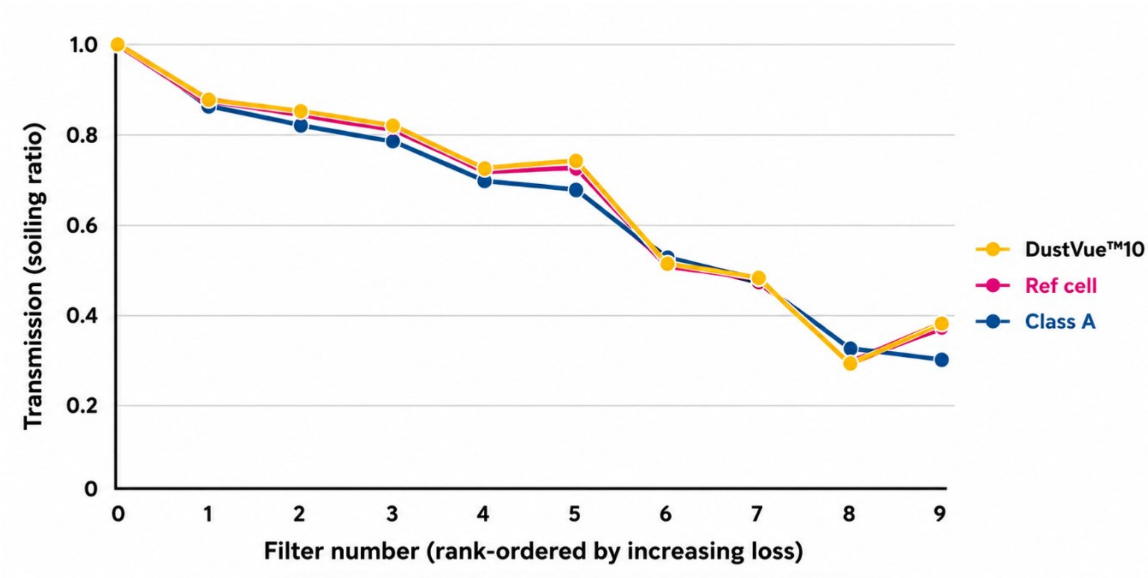

Figure 5-1. Soiling ratio at each rank-ordered attenuation level, all three instruments

Summary of results

- The DustVue 10 deviated by ≤ 0.01 from the PV reference cell at every attenuation level.
- All 10 test conditions showed monotonic agreement with both references, from clean through severe attenuation.
- Measured soiling-ratio range: 1.0 to < 0.3.

6. Conclusion

Under controlled, repeatable artificial soiling, the DustVue 10 reproduced the transmission loss measured by a Class A pyranometer and matched a spectrally representative PV reference cell to within 0.01 soiling-ratio points. This agreement indicates that the soiling ratio reported by the DustVue 10 corresponds to the soiling loss experienced by production modules, supporting its use for soiling monitoring on PV plants with low data uncertainty.

References

1. C. P. Ryan, F. Vignola, and D. K. McDaniels, “Solar Cell Arrays: Degradation Due to Dirt,” Proc. American Section of the Int. Solar Energy Society, Denver, CO, 1989, pp. 234–237.

2. A. Kimber et al., “The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States,” 2006 IEEE 4th World Conf. on Photovoltaic Energy Conversion, Waikoloa, HI, 2006.

3. S. Canada, “Quality Assurance: Impacts of Soiling on Utility-Scale PV System Performance,” SolarPro Magazine, no. 6.3, pp. 14–20, May 2013.

4. IEC 61724-1, Photovoltaic System Performance — Part 1: Monitoring, Edition 2.0 (2021).

5. IEC 60904-2, Photovoltaic Devices — Part 2: Requirements for Reference Solar Devices, 2nd Edition, 2007.