

Broadband Outdoor Radiometer Calibration Shortwave Shade/Unshade

BORCAL-SW 2023-07

Generated by



Radiometer Calibration and Characterization

Customer

Afshin Andreas

Organization: NREL

Address: Metrology Lab, 2054 Quaker St, Golden, CO 80401 USA

Phone: 303-384-6383

Calibration Facility

Solar Radiation Research Laboratory

Latitude: 39.742°N

Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Calibration date

08/30/2023 to 08/31/2023

Report Date

September 1, 2023



NOTICE

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Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction.....	3
Results summary.....	4
Appendix 1 Instrument Details.....	A1-1
Appendix 2 BORCAL Notes.....	A2-1

Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the International System (SI) Units of Measurement.

This report includes these sections:

- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ ($\mu\text{V}/\text{W}/\text{m}^2$)	CF@45 ¹ ($\text{W}/\text{m}^2/\text{mV}$)	U ² (%)	Rnet ³ ($\mu\text{V}/\text{W}/\text{m}^2$)	Page
17801F3 Eppley PSP	7.7430	129.15	± 3.9	N/A	A1-2
20715F3 Eppley PSP	10.041	99.596	± 1.9	N/A	A1-4

¹ CF = 1000 / R

² See certificate for valid zenith angle range

³ Instrument's Effective Net IR Response

Note: Environmental Conditions for BORCAL starts on page A1-6.

Appendix 1

Instrument Details

Calibration Certificates: 2 pages for each radiometer (3 including Environmental Conditions)

Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer **Manufacturer:** Eppley
Model: PSP **Serial Number:** 17801F3
Calibration Date: 8/31/2023 **Due Date:** 8/31/2024
Customer: Afshin Andreas **Environmental Conditions:** see page 3
Test Dates: 8/30-31

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

This certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 3

Calibration Procedure: NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

Calibrated by: Afshin Andreas, RCC, and Shawn L. Jaker

Afshin M. Andreas, Deputy Technical Manager

Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

17801F3 Eppley PSP

The responsivity (R , $\mu\text{V}/\text{W}/\text{m}^2$) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (Vu - Vs) / N * \text{COS}(Z) \tag{1}$$

where,

Vu = radiometer unshaded output voltage (microvolts),
 Vs = radiometer shaded output voltage (microvolts),

N = reference direct irradiance (W/m^2),
 Z = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

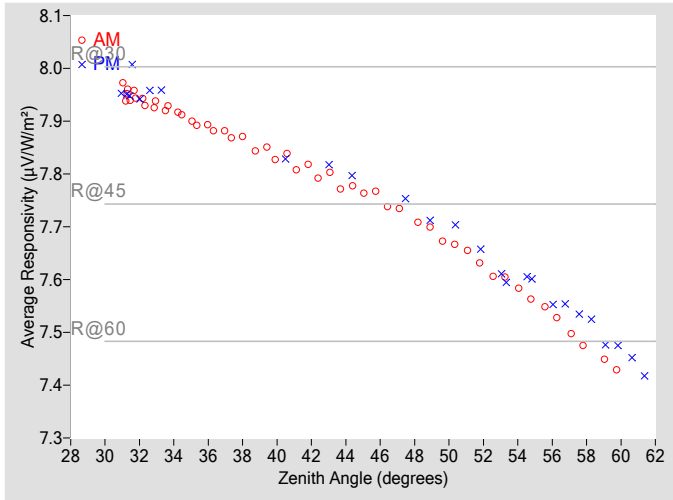


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

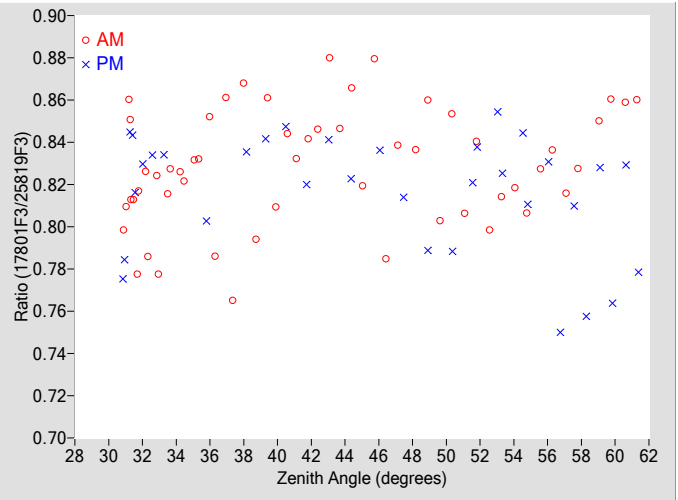
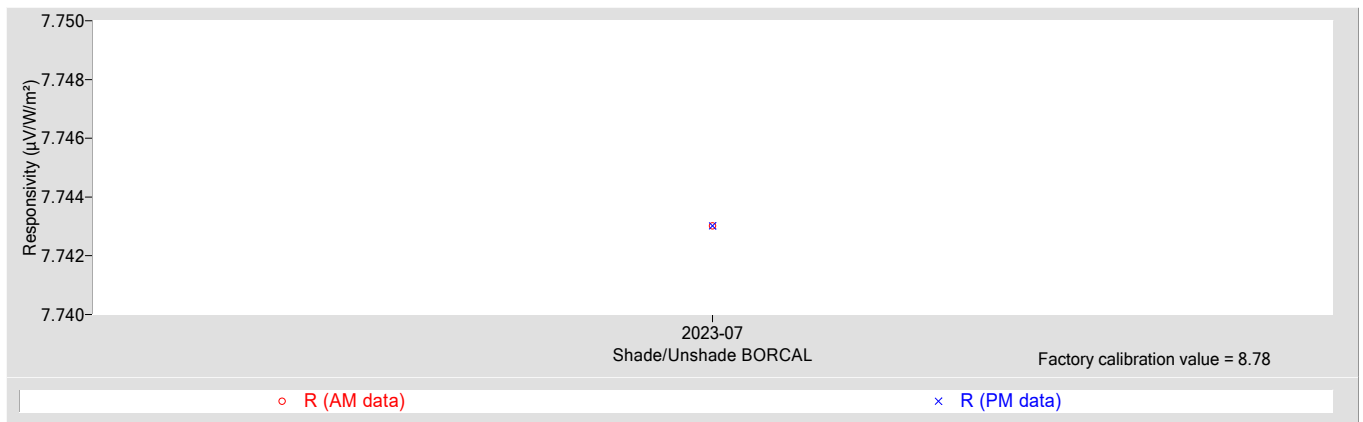


Table 2. Calibration Result and Uncertainty

R @ 45° ($\mu\text{V}/\text{W}/\text{m}^2$)	7.7430
Type-B Standard Uncertainty, $u(B)$ (%)	± 0.31
Type-A Standard Uncertainty, $u(A)$ (%)	± 0.34
Standard Uncertainty of range, $u(R)$ (%)	± 1.9
Std. Uncertainty of sensor non-linearity, $u(NL)$ (%)	± 0.12
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 3.9
Thermal Offset (W/m^2)	-20.0
Valid zenith angle range	30.9° to 62.0°

Figure 3. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoc Radiometer Calibration; NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>
- [2] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-4



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer **Manufacturer:** Eppley
Model: PSP **Serial Number:** 20715F3
Calibration Date: 8/31/2023 **Due Date:** 8/31/2024
Customer: Afshin Andreas **Environmental Conditions:** see page 3
Test Dates: 8/30-31

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Afshin M. Andreas, Deputy Technical Manager

Date

For questions or comments, please contact the technical manager at:

ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

20715F3 Eppley PSP

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where,

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N = reference direct irradiance (W/m^2),
 Z = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

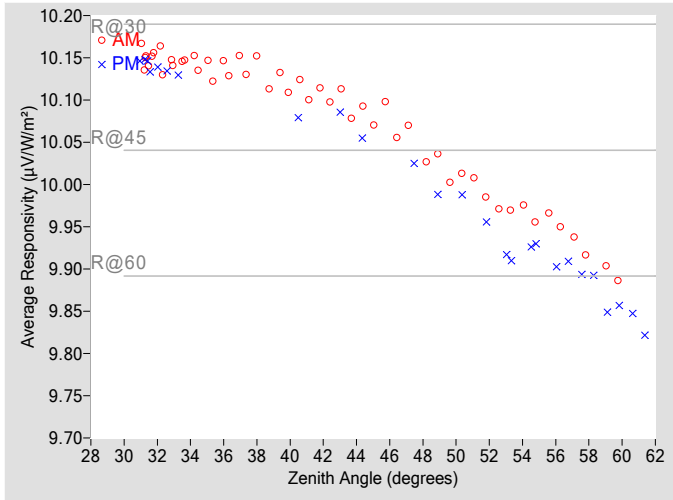


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

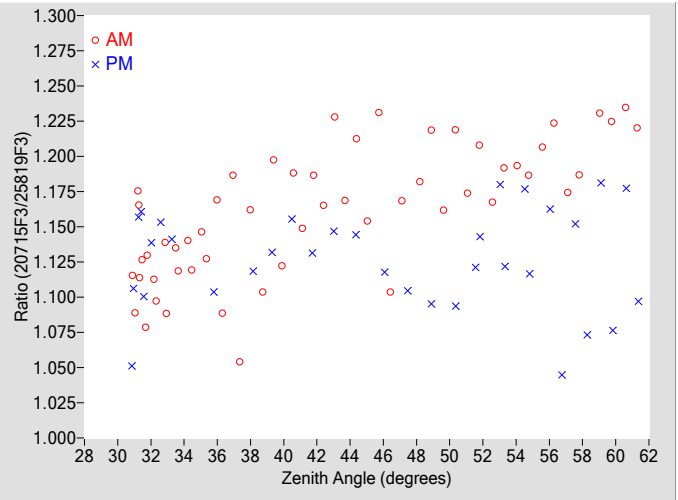
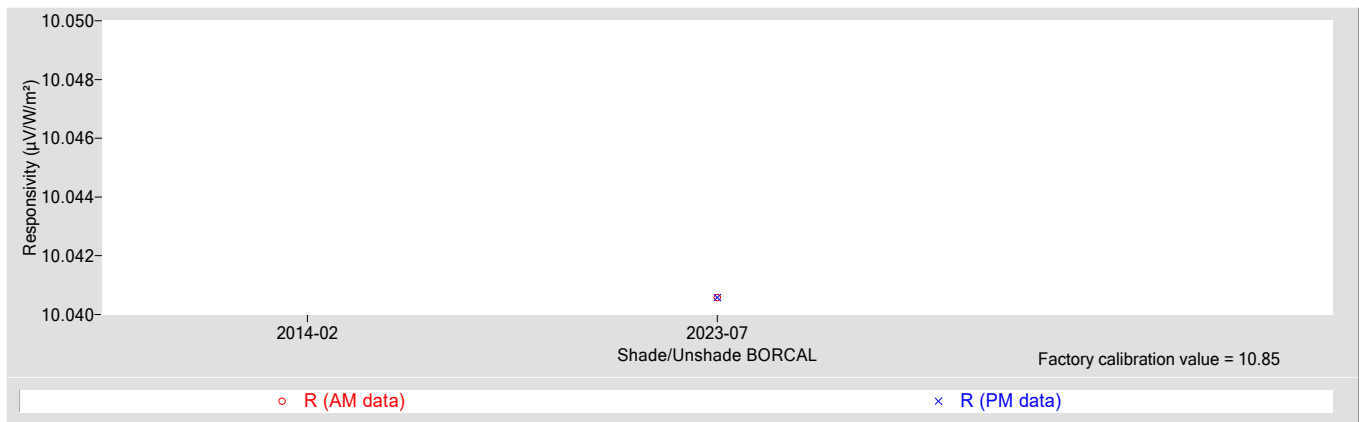


Table 2. Calibration Result and Uncertainty

R @ 45° ($\mu\text{V}/\text{W}/\text{m}^2$)	10.041
Type-B Standard Uncertainty, $u(B)$ (%)	± 0.30
Type-A Standard Uncertainty, $u(A)$ (%)	± 0.34
Standard Uncertainty of range, $u(R)$ (%)	± 0.86
Std. Uncertainty of sensor non-linearity, $u(NL)$ (%)	± 0.12
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (%)	± 1.9
Thermal Offset (W/m^2)	-20.0
Valid zenith angle range	30.9° to 62.0°

Figure 3. History of instrument at Zenith Angle = 45°



References:

- [1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoor Radiometer Calibration; NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>
- [2] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-4

Environmental and Sky Conditions for BORCAL-SW 2023-07

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.742°N

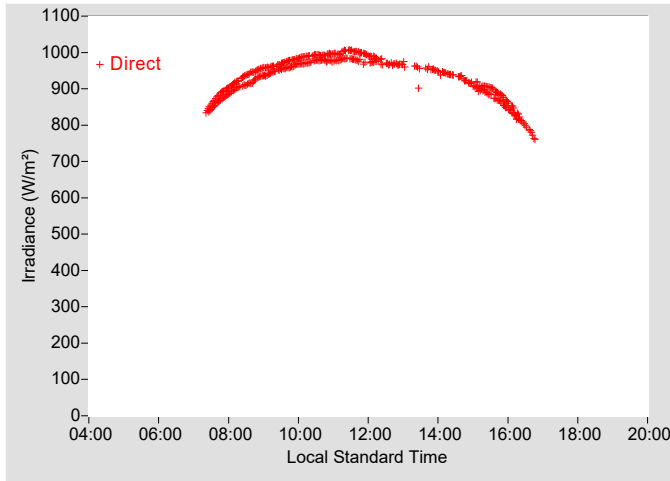
Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Reference Irradiance:

Figure 4. Reference Irradiance



Meteorological Observations:

Figure 5. Temperature

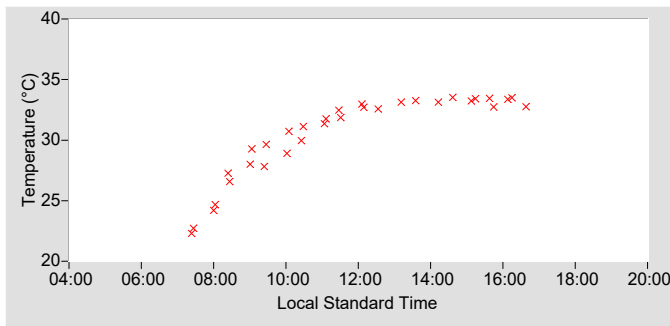


Figure 6. Humidity

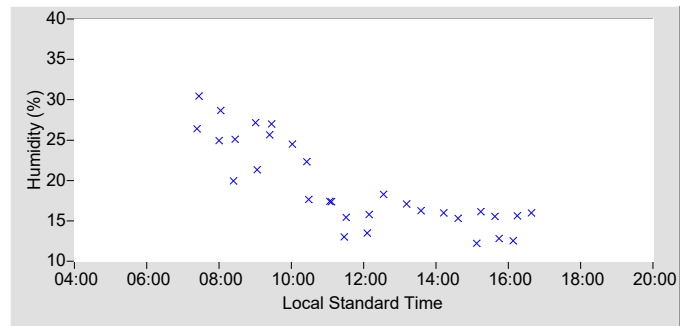


Figure 7. Pressure

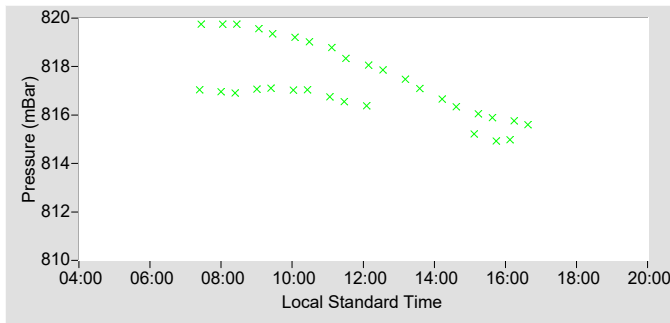


Figure 8. Estimated Broadband Aerosol Optical Depth

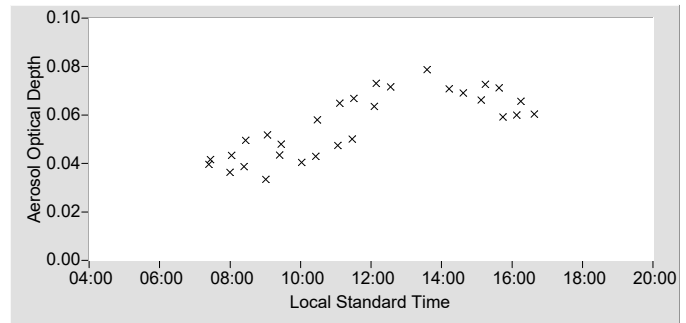


Table 3. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	30.45	22.29	33.52
Humidity (%)	19.27	12.22	30.44
Pressure (mBar)	817.3	814.9	819.8
Est. Aerosol Optical Depth (BB)	0.056	0.033	0.079

For other information about the calibration facility visit: <https://www.nrel.gov/grid/solar-radiation-research-laboratory.html>

Appendix 2

BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Solar Radiation Research Laboratory

Comments:

Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).