

**Broadband Outdoor Radiometer Calibration
Longwave**

**BORCAL-LW
2022-01**

Generated by



Radiometer Calibration and Characterization

Customer

Bryan Fabbri

Organization: SSAI

Address: One Enterprise Parkway, Suite 200, Hampton, VA 23666 USA

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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

02/25/2022 to 03/31/2022

Report Date

March 31, 2022



NOTICE

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Broadband Outdoor Radiometer Calibration Report

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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 World Infrared Standard Group (WISG).

This report includes these sections:

- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- 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.

Control Instrument History

Figure 1. Eppley PIR Control Instrument (Residual means of current data using historical coefficients)

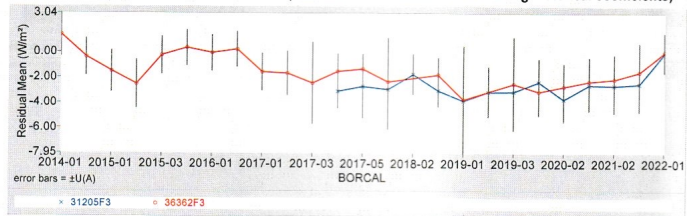


Figure 2. Eppley PIR Control Instrument History (K1 Coefficient)

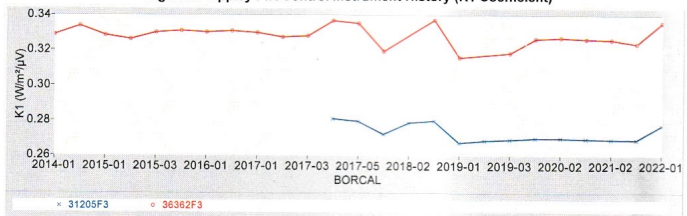


Figure 3. Eppley PIR Control Instrument History (K2 Coefficient)

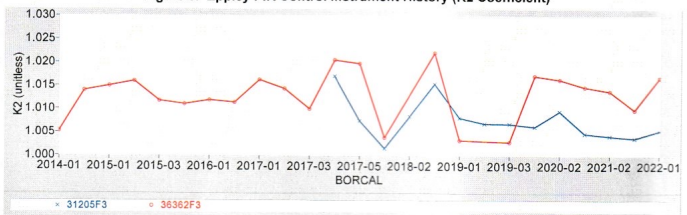
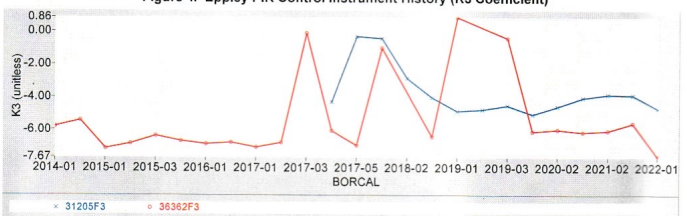


Figure 4. Eppley PIR Control Instrument History (K3 Coefficient)



Results Summary

Table 1. Results Summary

Instrument	K1 (W/m ² /μV)	K2	K3	Kr * (KμV)	U95 (W/m ²)	Page
170256 Kipp & Zonen CGR4	0.10850	0.9970	0.00	7.044e-4	±1.8	A1-2
25169F3 Eppley PIR	0.22968	1.0021	-3.23	7.044e-4	±2.8	A1-5

Note: Environmental Conditions for BORCAL starts on page A1-8.

* Kr used to derive coefficients

Appendix 1 Instrument Details

Calibration Certificates: 3 pages for each radiometer (4 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: Pyreometer
Model: CGR4
Calibration Date: 3/31/2022
Customer: Bryan Fabbri
Test Dates: 2/25-28, 3/1-5, 3/7-31

Manufacturer: Kipp & Zonen
Serial Number: 170256
Due Date: 3/31/2024
Environmental Conditions: see page 4

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 World Infrared Standard Group (WISG).

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
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/08/2021	02/08/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/08/2021	02/08/2023
Infrared Irradiance †	Kipp & Zonen Pyreometer Model CG4, S/N 060881	10/16/2021	10/16/2026
Infrared Irradiance †	Eppley Downwelling Pyreometer Model PIR, S/N 31197F3	09/25/2021	09/25/2026

† Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-LW-P00-Calibration and QA Procedure; available upon request.

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

Calibrated by: Afshin Andreas, Peter Gotseff, and Mark Kutchenreiter


Ibrahim Reda, Technical Manager

4/1/2022
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

170256 Kipp & Zonen CGR4

The incoming irradiance (W_m , W/m^2) of the test instrument during calibration is calculated using this Measurement Equation:

$$W_m = K1 \cdot V + K2 \cdot W_r + K3 \cdot (W_d - W_r) \quad [1]$$

where,

$K1, K2, K3$ = calibration coefficients,
 V = thermopile output voltage (μV),
 $W_d = \sigma \cdot T_d^4$ = dome irradiance (W/m^2),
 where, T_d = dome temperature (K),

$W_r = \sigma \cdot T_r^4$ = receiver irradiance (W/m^2),
 where, $\sigma = 5.6704e-8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 $T_r = T_c + Kr \cdot V$ = receiver temperature (K),
 T_c = case temperature (K),
 Kr = efficiency coefficient (K/ μV).

Figure 1. Residuals for calculated using coefficients vs reference irradiance

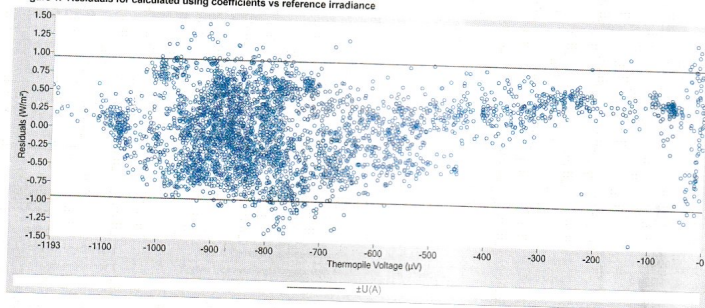
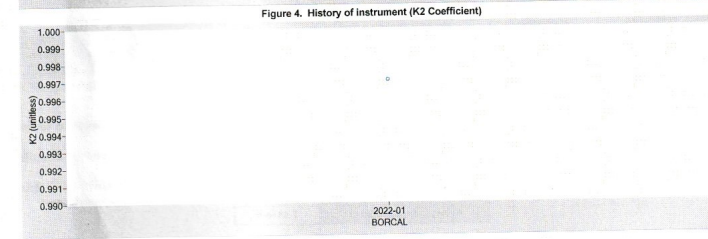
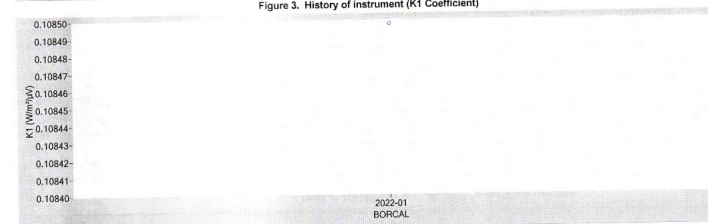
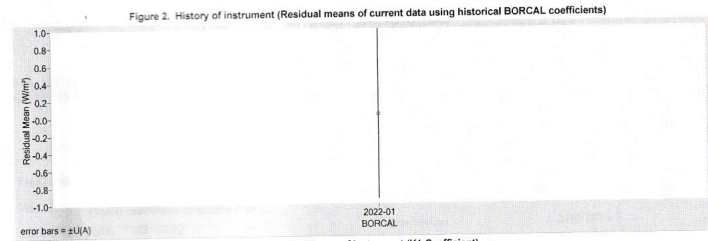


Table 1. Calibration Coefficients

K1	0.10850
K2	0.9970
K3	0.00
Kr used to derive coefficients	7.044e-4

Table 2. Uncertainty using coefficients

Type-B Standard Uncertainty, $u(B)$ (W/m^2)	± 0.78
Type-A Standard Uncertainty, $u(A)$ (W/m^2)	± 0.48
Combined Standard Uncertainty, $u(C)$ (W/m^2)	± 0.92
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (W/m^2)	± 1.8



References:

- [1] Reda, I.; Stoffel, T. (2010). Pyrogeometer Calibration for DOE-Atmospheric System Research Program using NREL Method (Presentation), 9 pp.; NREL Report No. PR-380-47756, <http://www.nrel.gov/docs/ty10/os/47756.pdf>.



National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Downwelling Pyreometer **Manufacturer:** Eppley
Model: PIR **Serial Number:** 26169F3
Calibration Date: 3/31/2022 **Due Date:** 3/31/2024
Customer: Bryan Fabbri **Environmental Conditions:** see page 4
Test Dates: 2/25-28, 3/1-5, 3/7-31

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 World Infrared Standard Group (WISG).

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.

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Infrared Irradiance ‡	Eppley Downwelling Pyreometer Model PIR, S/N 31197F3	09/25/2021	09/25/2026

† Through the World Infrared Standard Group (WISG)


Number of pages of certificate: 4

Calibration Procedure: BORCAL-LW-P00-Calibration and QA Procedure; available upon request.

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

Calibrated by: Afshin Andreas, Peter Gotseff, and Mark Kutchenreiter


Ibrahim Reda, 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 26169F3 Eppley PIR

The incoming irradiance (W_{in} , W/m^2) of the test instrument during calibration is calculated using this Measurement Equation:

$$W_{in} = K1 \cdot V + K2 \cdot W_r + K3 \cdot (W_d - W_r) \quad [1]$$

where,

$K1, K2, K3$ = calibration coefficients.
 V = thermopile output voltage (μV),
 $W_d = \sigma \cdot T_d^4$ = dome irradiance (W/m^2),
 where, T_d = dome temperature (K).

$W_r = \sigma \cdot T_r^4$ = receiver irradiance (W/m^2),
 where, $\sigma = 5.6704e-8 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}$,
 $T_r = T_c + Kr \cdot V$ = receiver temperature (K),
 T_c = case temperature (K),
 Kr = efficiency coefficient ($K/\mu V$).

Figure 1. Residuals for calculated using coefficients vs reference irradiance

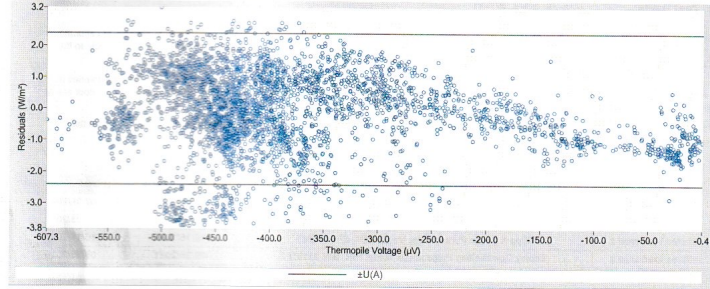
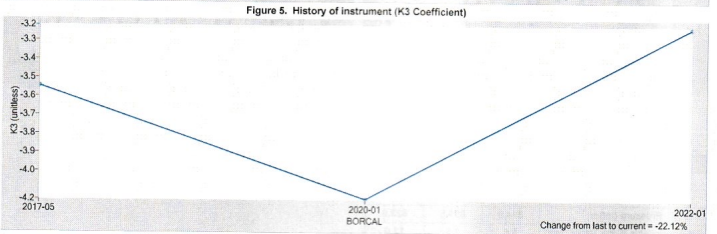
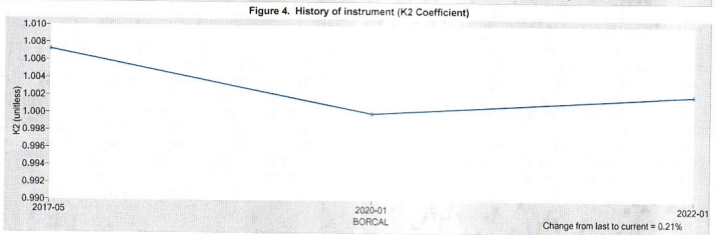
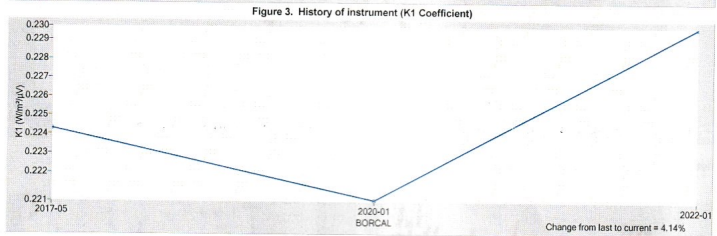
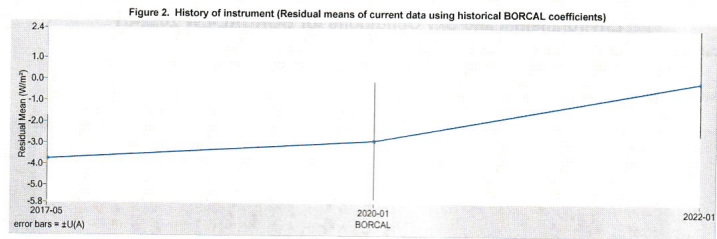


Table 1. Calibration Coefficients

K1	0.22968
K2	1.0021
K3	-3.23
Kr used to derive coefficients	7.044e-4

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Type-B Standard Uncertainty, $u(B)$ (W/m^2)	± 0.78
Type-A Standard Uncertainty, $u(A)$ (W/m^2)	± 1.2
Combined Standard Uncertainty, $u(c)$ (W/m^2)	± 1.5
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, k	1.96
Expanded Uncertainty, $U95$ (W/m^2)	± 2.8



References:

- [1] Reda, I.; Stoffel, T. (2010). Pyrogeometer Calibration for DOE-Atmospheric System Research Program using NREL Method (Presentation), 9 pp.; NREL Report No. PR-3B0-47756; <http://www.nrel.gov/docs/ty10osti/47756.pdf>.

Environmental and Sky Conditions for BORCAL-LW 2022-01

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.742°N

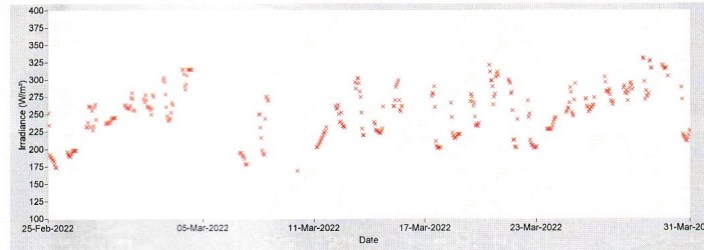
Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Reference Irradiance (hourly averages):

Figure 6. Reference Irradiance



Meteorological Observations (hourly averages):

Figure 7. Temperature

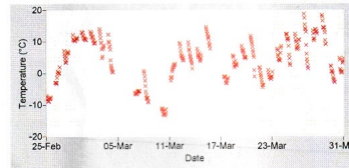


Figure 8. Humidity

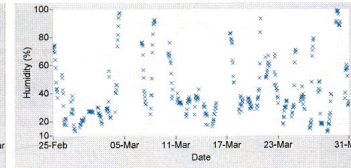


Figure 9. Pressure

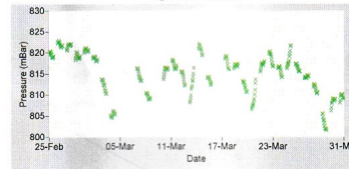


Figure 10. Estimated Precipitable Water Vapor (PWV)

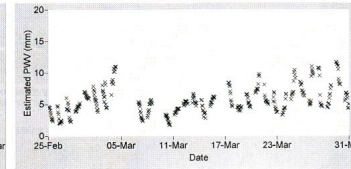


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	3.99	-14.20	18.90
Humidity (%)	41.33	11.98	99.83
Pressure (mBar)	814.9	801.5	823.0
Est. Precipitable Water Vapor (mm)	5.6	1.5	12.0

For other information about the calibration facility visit: <http://www.nrel.gov/esifsolar-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).