Feasibility and Environment & Social Assessment Studies of the Priority Generation Investment Project in Liberia

Solar Measurement Station – Tier 2 automatic weather station installation report

Funded by

ARTELIA / September 2021 / 8211050

VERSION	DESCRIPTION	ESTABLISHED BY	CONTROLLED BY	APPROVED BY	DATE
0	Draft Report	CSPServices	APT/GDS	SSP	05/07/2021
1	Included requested information from matrix of comments	CSPServices	APT/GDS	SSP	02/09/2021

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FIGURE

Site and Installation Information	
Client:	West African Power Pool
Site:	Mount Coffee hydro power plant, Liberia
Coordinates:	6.4978°N, -10.6517°E, altitude: 20 m
Station Type:	Tier2 automatic weather station
Date of installation:	2021-05-14 to 2021-06-09
Date of commissioning:	2021-06-10
Commissioning	
Installation performed by Date: 10 June 2021	Installation on site: Timothy Chollom, Bezaleel + Turnkey Contractors, Inc. Remote commissioning: Roman Affolter, CSP Services GmbH

1 SUMMARY

In the framework of the current “Feasibility and Environment & Social Assessment Studies of The Priority Generation Investment Project in Liberia”, an automatic weather station (AWS) was installed in Liberia for the measurement of the solar irradiance and other parameters relevant for the development of solar energy power plant projects. The station was installed at the Mount Coffee hydro power plant facility.

The purpose of this installation is to collect up to two years of ground measurement data for the planned utility scale photovoltaic (PV) power plant at the described location. Measurement parameters are primarily global horizontal irradiance (GHI), direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI). Further, temperature and relative humidity, barometric pressure, rain, wind speed and direction as well as the soiling rate on PV modules and the corrosion rate on different metal samples is measured. The GHI is measured with a CMP10 pyranometer, the DNI and DHI with a Rotating Shadowband Irradiometer (RSI).

Figure 1 - Mount Coffee site in Liberia. The site is located on the Saint Paul River around 30 km north-east of Monrovia

Measurement data from the station will be transferred to CSPS in regular intervals for data quality monitoring and control. Additionally, the data will be available on a protected web server for near-real time data monitoring and download.

CSP Services will apply daily data quality tests and send quality-controlled final measurement data in monthly intervals to the client-defined recipients.

Local subcontracted staff will be in charge of the maintenance and sensor cleaning of the solar irradiance sensors and the reference PV module for the soiling measurement. The responsible person was present on the last day of the installation and was briefed on the maintenance and cleaning procedures.

2 SITE DESCRIPTION

2.1 LOCATION

Table 1 - Location information.

Site:	Mount Coffee hydro power plant, Liberia
Coordinates:	6.4978°N, -10.6517°E, altitude: 20 m
Climate:	Tropical monsoon climate (Köppen-Geiger Am, (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006))

Figure 2 - Location at the Mount Coffee site

2.2 SURROUNDINGS AND SHADING PROFILE

The immediate surroundings are mainly flat with a dam of the hydropower facility to the east and south-east. After the installation of the automatic weather station, pictures of the horizon in all directions were taken from the location of the irradiance sensors and a panoramic view was generated from these pictures.

Figure 3 shows the panoramic picture with the horizon line and the sun path throughout the year.

Figure 3 - Horizon line from the perspective of the pyranometer and sun path throughout the year

Figure 4 shows the analysis of the horizon line and the expected shading occurrences on the irradiance data measurements. The analysis shows an almost free field of view for the sensors, no relevant obstructions at sun elevations higher than a few degrees above horizon exist, especially in east and west direction where the sun is near the horizon on sunrise and sunset. Only very little shading is expected for a very short period after sunrise from the dam in the east and for a very short period before sunset from the trees in the west of the measurement site.

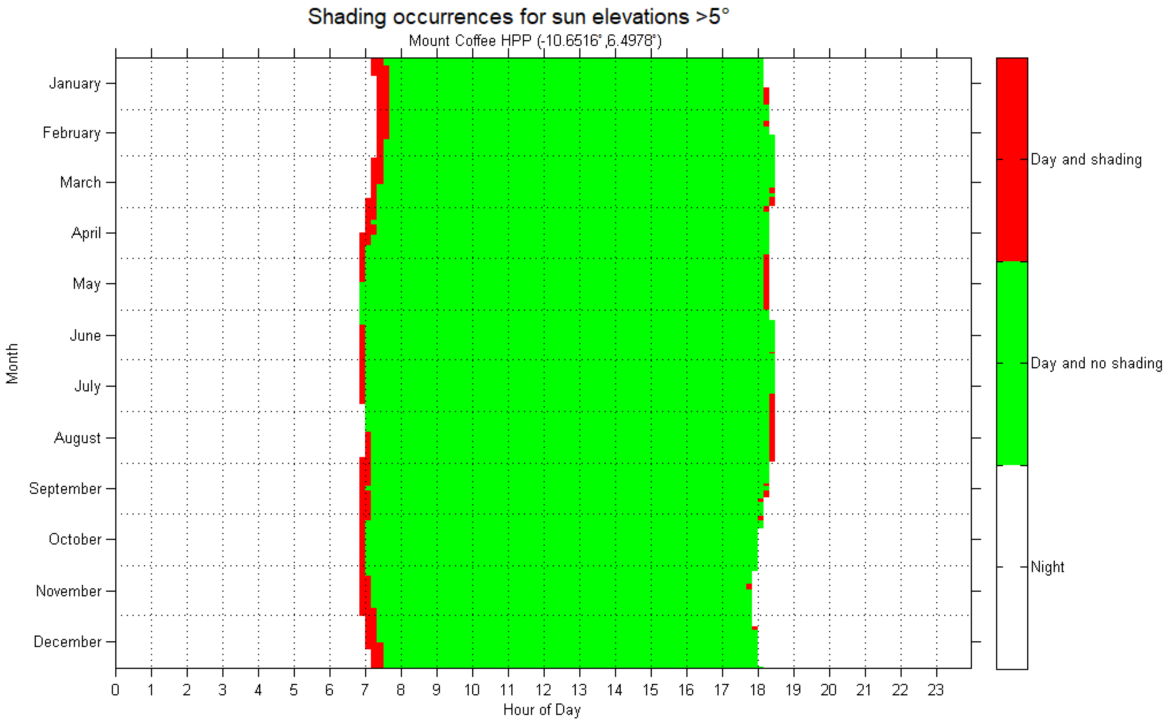


Figure 4 - Shading occurrences for sun elevations >5º

3 AUTOMATIC WEATHER STATION CONFIGURATION AND LAYOUT

This section gives an overview of the installed equipment and sensors with respective serial numbers. Further, a layout drawing of the weather station as built is shown.

3.1 MEASUREMENT EQUIPMENT

Equipment and serial numbers		
Automatic weather station	CSP Services Tier2 automatic weather station	CSPS.MT.21.229
Main control box	CSP Services	CA.21.202.0004
Datalogger	Campbell CR1000X	18088
Modem	RUT240 Teltonika Networks	1110018427
Power supply	Autonomous power supply with PV panels and battery	-
RSI drive unit	CSP Services Twin RSI	CSPS.DR.20.201.0002

Measured parameter	Unit	Sensor type	Serial Number
GHI	W/m²	Kipp&Zonen CMP10 pyranometer (installed 2m above ground)	210860
DHI, DNI	W/m²	CSP Services Rotating Shadowband Irradiometer (installed 2m above ground)	CSPS.MS.19.201.0005
Temperature (T)	°C	Hygrovue5 temperature and relative humidity sensor with RAD06 radiation shield (installed 1.5m above ground)	E2596
Humidity (RH)	%		
Barometric pressure (BP)	hPa	Vaisala PTB110 (CS106)	S4750162
Precipitation (Rain)	mm	Campbell Scientific 52203 (installed 2m above ground)	TB 16367
Wind speed (WS)	m/s	NRG #40C Class 1 anemometer (installed 10m above ground)	17950-0334055
Wind direction (WD)	°N	NRG #200M wind vane (installed 10m above ground)	10070-00009014
Soiling rate	%	CSP Services PV soiling measurement system (installed 1.5m above ground)	-
Corrosion rate	%	Fraunhofer corrosion sampler with 12 standardized metal samples of aluminum, carbon steel, zinc and copper (three samples from each metal)	-

Further information on the listed sensors and measurement systems can be found in the station specification documentation. For calibration certificates of sensors see chapter 9.

3.2 STATION LAYOUT

The layout of the Tier2 AWS is shown in the figures below. The main components are the mounting structure with the irradiance sensors and the wind mast with additional sensors. The autonomous power supply system is integrated in the station (2x 30W PV panel and 1x 60 Ah battery).

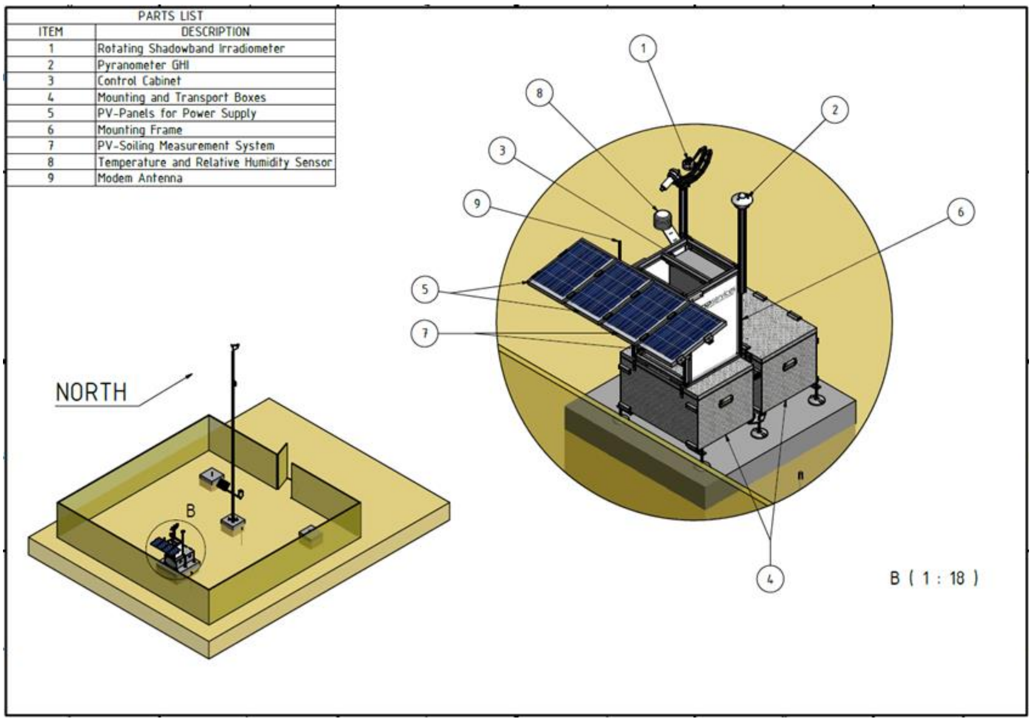


Figure 5 - Tier2 automatic weather station layout: Irradiance sensors, PV soiling rate measurement system, PV panels for power supply

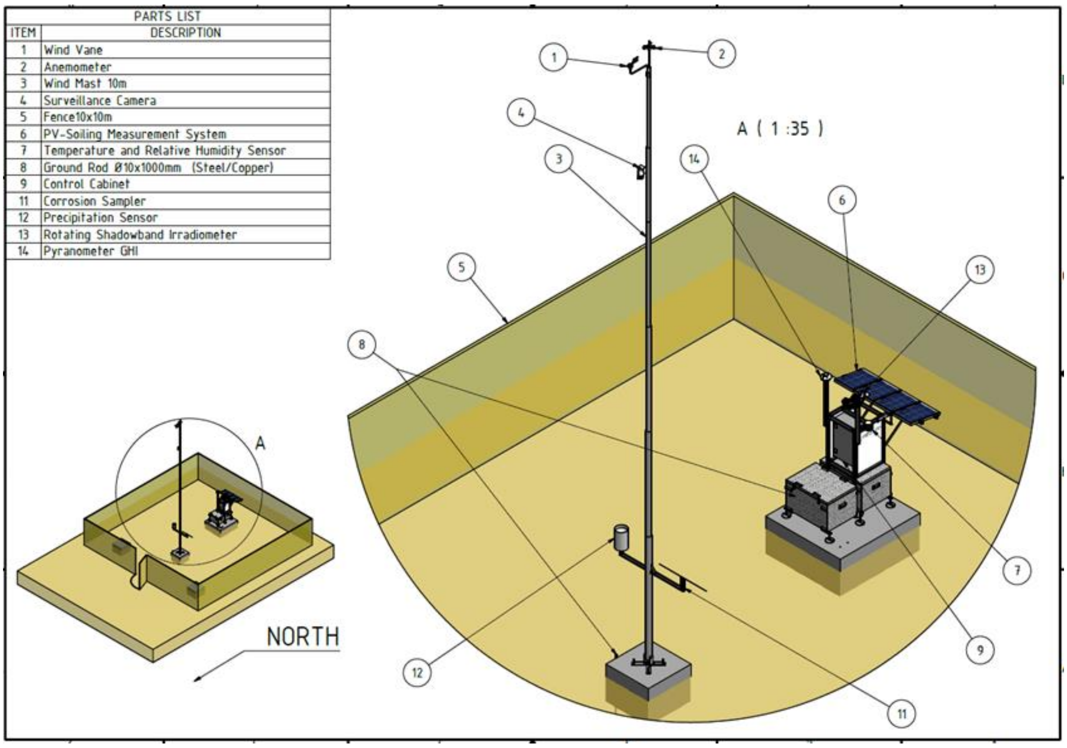


Figure 6 - Tier2 automatic weather station layout: wind mast and wind sensors details

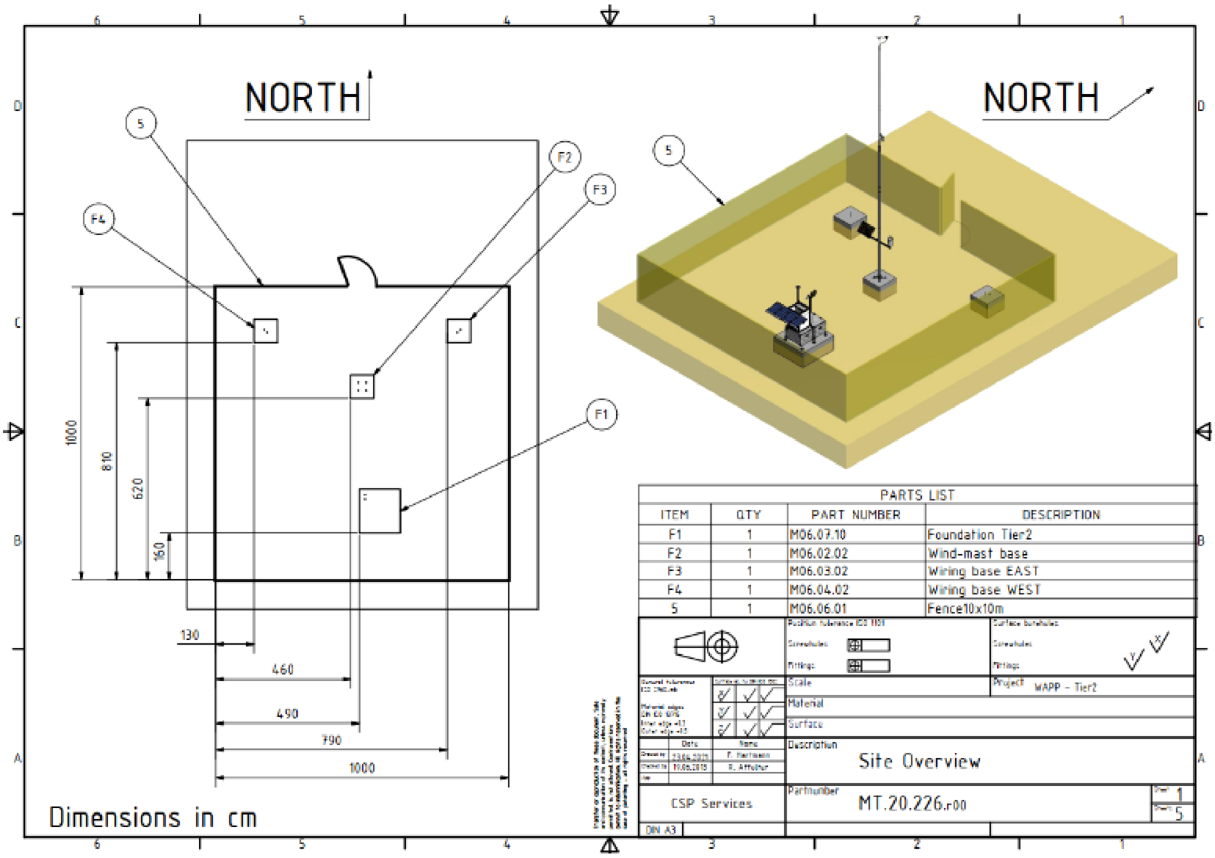


Figure 7 - Tier2 automatic weather station layout: foundation detail

The wind mast is anchored to the wind mast foundations and guying rope foundations. The station itself stands freely on its concrete foundation.

The dimensions and distances are shown in the foundation drawings in the figure above. The height of the fence is 2m plus the barbed wire on top. The distance of the PV-Soiling system to the fence is approximately 1.5m.

3.3 DATA MEASUREMENT,TRANSMISSION AND QUALITY CONTROL

The sensor signals are scanned with a frequency of 1 Hz and stored in 1-minute and 10-minute average data tables in the datalogger's internal memory. The measurements are taken in 1 second resolution (1 Hz) and stored in 1 minute average tables together with the max, min and StDev values.

The measurement data is sent to the CSPS servers in near-real time through a 4G LTE router with a SIM card from a local operator (Orange Liberia).

The measurement data is sent in parallel to the CSPS data processing server and the web server for client access for data monitoring and download (see section 7). It is stored in the internal memory of the datalogger for more than 3 months. In case of prolonged network issues, the data can be retrieved after the network issues have been resolved or manually on site via direct USB access to the datalogger if necessary.

Together with the measurement data, pictures from the surveillance camera are transmitted to the CSPS server in regular intervals (usually one picture every 10 minutes, depending on network availability, data usage and battery charging status).

The communication status of the LTE router and the settings of the mobile configuration (Auto APN) is shown in Figure 8. The data usage depends mainly on the amount of transmitted pictures and videos from the camera and is expected to be less than 1 GB/months during normal operation (Figure 8 shows the usage including the tests performed during the installation).

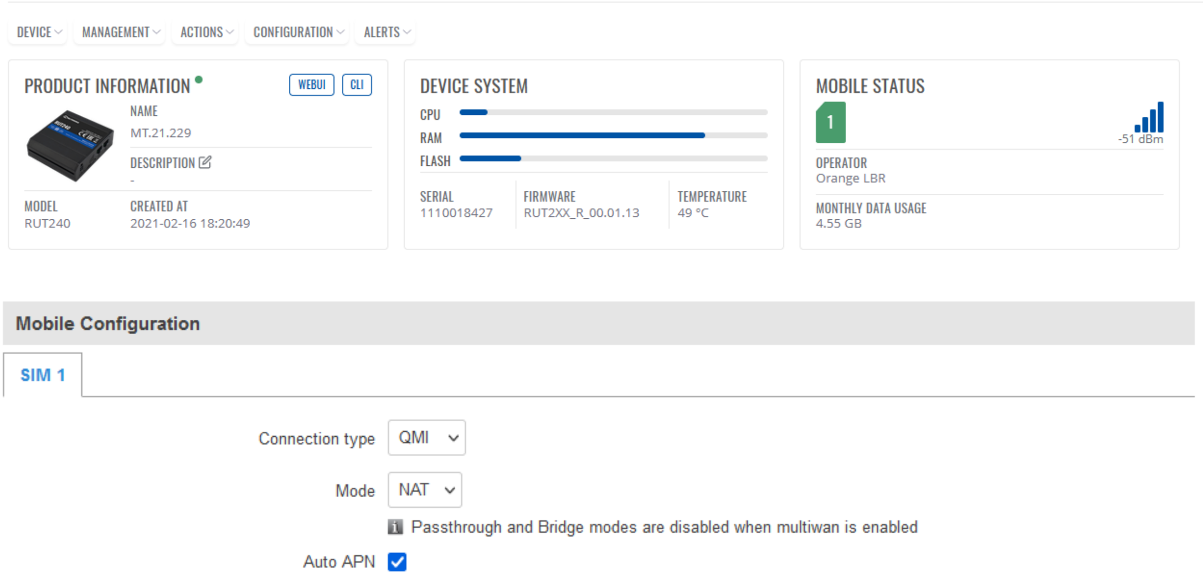


Figure 8 - Communication status of LTE router for data transmission

For the data quality control procedures, CSPS performs the following tasks for data QA/QC:

- Daily data retrieval via mobile phone network,
- Check of correct operation of the equipment, coordination of local maintenance staff,
- Data analysis including data quality screening and reporting according to international standards,
- Correction of apparently erroneous values and gap filling (where possible and reasonable),
- Supervision of maintenance frequency, correct sensor cleaning, analysis of sensor soiling.

For the surveillance of the measurement station, a surveillance camera is installed which sends pictures to a server in regular intervals. This server is operated by CSPS.

4 STATION INSTALLATION

The station installation and commissioning were completed on 10 June 2021. Before the installation, the site was prepared with a fence and foundations for the stable and secure installation of the automatic weather station for the period of the measurement campaign.

This chapter describes the installation timeline and the completed tasks until the commissioning as well as a checklist for the installation completion and functionality of the equipment.

A complete photographic documentation of the installation process is given in chapter 6.

- Completed tasks and installation timeline

The site preparations and the station installation took place in May and June 2021. The table below details each completed task and its completion time.

Completion time dd/mm	Task	Picture
2021-05-14	Determination of the station location and the north direction. Perimeter marked and correct location and orientation verified.	
2021-05-17 – 2021-05-26	Levelling of the ground and installation of the fence.	
2021-05-31 – 2021-06-04	Positioning of the cement blocks and casting of the foundations.	
2021-06-06	Installation of the mounting structure and measurement control box	
	Installation of the PV module soiling measurement system (PV-S): • PV panel mounting structure installed • PV thin-film panels mounted on structure, orientation towards south • PV panel temperature sensors installed on panel backsides	

2021-06-07	Installation and connection of the irradiance and other meteorological sensors	
2021-06-08 – 2021-06-09	Verification of the PV panel structure levelling and inclination. Connection of the PV-S soiling measurement system and the power supply panels.	
	Installation of 10m wind mast with wind speed and wind direction sensors, wind direction sensor oriented towards north	
2021-06-10	• Functionality checks (local engineers with remote support from CSPS staff) • Commissioning of the station (remotely by CSPS staff) • Operator training	

5 INSTALLATION CHECKLIST

Component	Work item	Checked/ approved		Comments
		yes	no	
Foundations, fence	Foundations correctly prepared	X		
	Threaded bolts correctly prepared	X		
	Fence correctly prepared	X		
	Door can be locked	X		
Support structure with Control box	Sensor mounts extended	X		
	PV mounting bar adjusted	X		
	Horizontally leveled	X		
	Grounding cable connected	X		
	All bolts tightened	X		
Wiring, cables	Visual examination	X		
	Fuses ok	X		
	All sensors connected	X		Data connection to CSPS server established
	All cables orderly fixed	X		
RSI	Fixed to MDI Stand	X		
	PU Unit with Licor installed	X		
	Shadow band installed	X		
	Horizontal leveling	X		
	Licor Sensors Clean	X		
	Cable connected to RSI and Box	X		
	RSI operative	X		
Pyranometer	Pyranometer installed	X		
	Horizontal leveling	X		
Barometric Pressure Sensor	Sensor installed and cabled	X		
	Pressure exchange vent	X		Inside control cabinet
	Visual examination, operability	X		
Precipitation Sensor	Sensor installed and leveled	X		
	Visual examination, operability	X		
T_{amb} / RH	Irradiation shield fixed to MDI stand	X		

	Sensor probe with filter cap inserted	X		
	Cable connected to Control Box	X		
Wind tower, wind speed and direction sensors	Tower extended	X		Extended to length of 10 m
	Guy wires safely attached and tense	X		
	Grounding cable connected	X		To metal rod driven into ground
	Wind sensors installed	X		
	North Orientation of WD sensor	X		
	Cable fixed to sensors, tower and box	X		
	Operability of sensors	X		
PV soiling measurement system	Mounting structure installed and fixed to concrete foundations guying ropes fixed	X		
	Mounting structure leveled and aligned to south	X		
	PV panels installed	X		Top of panels horizontally levelled
	Inclination angle adjusted	X		9 degrees from horizontal
	Module temp. sensors installed	X		
	Shunt box connected to AWS	X		
	Operability of system	X		
	Panels cleaned	X		
Modem	SIM card inserted	X		
	APN, username, password of SIM	X		Correctly configured (Auto APN, see section 3.3)
	Server connection	X		Connection to server confirmed
Datalogger	Operation system installed	X		Version: CR1000X Std.05.00
	Datalogger configuration saved	X		
	IP visible in logger configuration	X		IP: dynamic
	Correct sensor constants in program	X		Compared against photographs of installed sensors
	Correct coordinates in program	X		Obtained from GPS
	Datalogger program installed	X		Program name: Lr-MChpp_2021-06-10_str.CR1X Subroutines: Subroutines-Tier2_2021-02-21.CR1X
	Program set to "Run always"	X		
	Datalogger clock correct	X		Local standard time, no daylight saving time: UTC +0

6 PHOTOGRAPHIC DOCUMENTATION

Figure 9 - Fence and foundation

Figure 10 - Station and wind mast foundations

Figure 11 - Wind mast preparations

Figure 12 - Wind mast foundations, ground cable fixed to ground bolt, protective tube for wind mast cables.

Figure 13 - Water holes in foundations to prevent flooding (1).

Figure 14 - Water holes in foundations to prevent flooding (2).

Figure 15 - Wind direction sensor north mark aligned with mounting cantilever and north direction

Figure 16 - Wind sensors installed on wind mast

Figure 17 - Wind mast erected; wind direction sensor cantilever orientated to North

Figure 18 - Mounting of weather station structure

Figure 19 - CMP10 pyranometer serial number

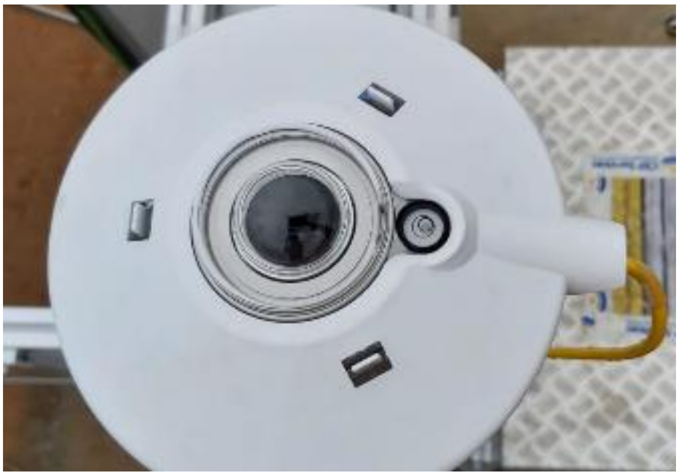


Figure 20 - CMP10 pyranometer leveling

Figure 21 - Sensor levelling of the RSI (1)

Figure 22 - Sensor levelling of the RSI (2)

Figure 23 - Serial number of RSI.

Figure 24 - Installed RSI.

Figure 25 - RSI motor serial number

Figure 26 - Rain sensor and corrosion sampler

Figure 27 - Rain sensor mounting bar leveling

Figure 28 - Rain sensor serial number

Figure 29 - T/RH sensor and modem antenna

Figure 30 - T/RH sensor serial number

Figure 31 - Control box interior; top: datalogger; bottom: fuses and 12V circuit distribution, relays, RSI motor controller

Figure 32 - Modem with SIM card

Figure 33 - Assembly of PV-S structure + modules

Figure 34 - PV-S support structure with 9° tilt angle towards South

Figure 35 - PV-S modules connections

Figure 36 - PV-S system reference panel A (clean panel)

Figure 37 - PV modules cleaning.

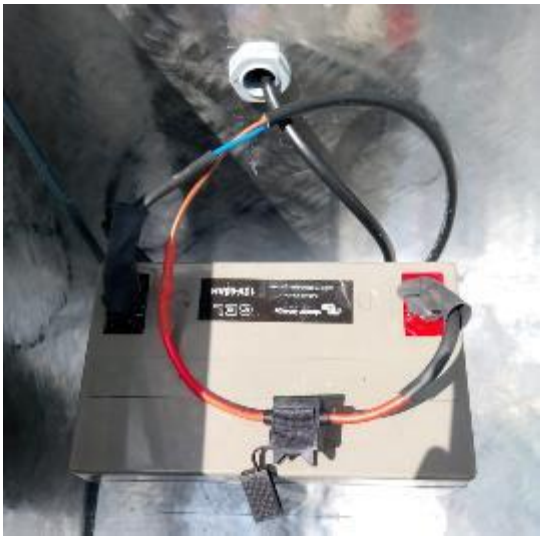


Figure 38 - 12V, 60Ah battery

Figure 39 - Wind mast with rain sensor and corrosion sampler

Figure 40 - Main mounting structure with solar sensors, T/RH sensor and PV panels for soiling measurement and power supply.

Figure 41 - Solar sensors and PV panels on mounting structure

Figure 42 - Site with completed station installation as seen from south-west. Picture taken from 6.49767°N, -10.65176°E

7 STATION MAINTENANCE PROCEDURES

Regular on-site maintenance and sensor cleaning is performed by a locally contracted on-site maintenance team (OMT). The maintenance and sensor cleaning procedures were defined prior to the installation of the station and a manual with the defined procedures was provided to the OMT. Additionally, an operator training was held during the commissioning phase of the station. The irradiance sensors and the PV panels for the PV-S soiling measurement system will be cleaned according to the table below.

(The measurement of the soiling rate with the PV-S soiling measurement system is based on the comparison of a clean reference module (Module A) to a measurement module (Module B) which is allowed to accumulate soiling on its surface. Module A is therefore cleaned upon each visit by the OMT and Module B is cleaned once per month to restart the soiling measurement cycle.)

Sensors	Cleaning		Comments
	2 x per week	1 x per month	
RSI Licor sensors	x		First and fourth day of each week
GHI pyranometer	x		First and fourth day of each week
Clean module (Module A)	x		First and fourth day of each week
Dirty module (Module B)		x	First day of each month

Scheduled maintenance visits for extended system maintenance are planned to be performed every six months for the duration of the measurement campaign.

8 MEASUREMENT DATA

The measurement data can be accessed on a protected web server for near-real time data monitoring and download. Additionally, CSPS will provide monthly data reports with the final quality-controlled measurement data. The graphs below show exemplary data shortly after the installation.

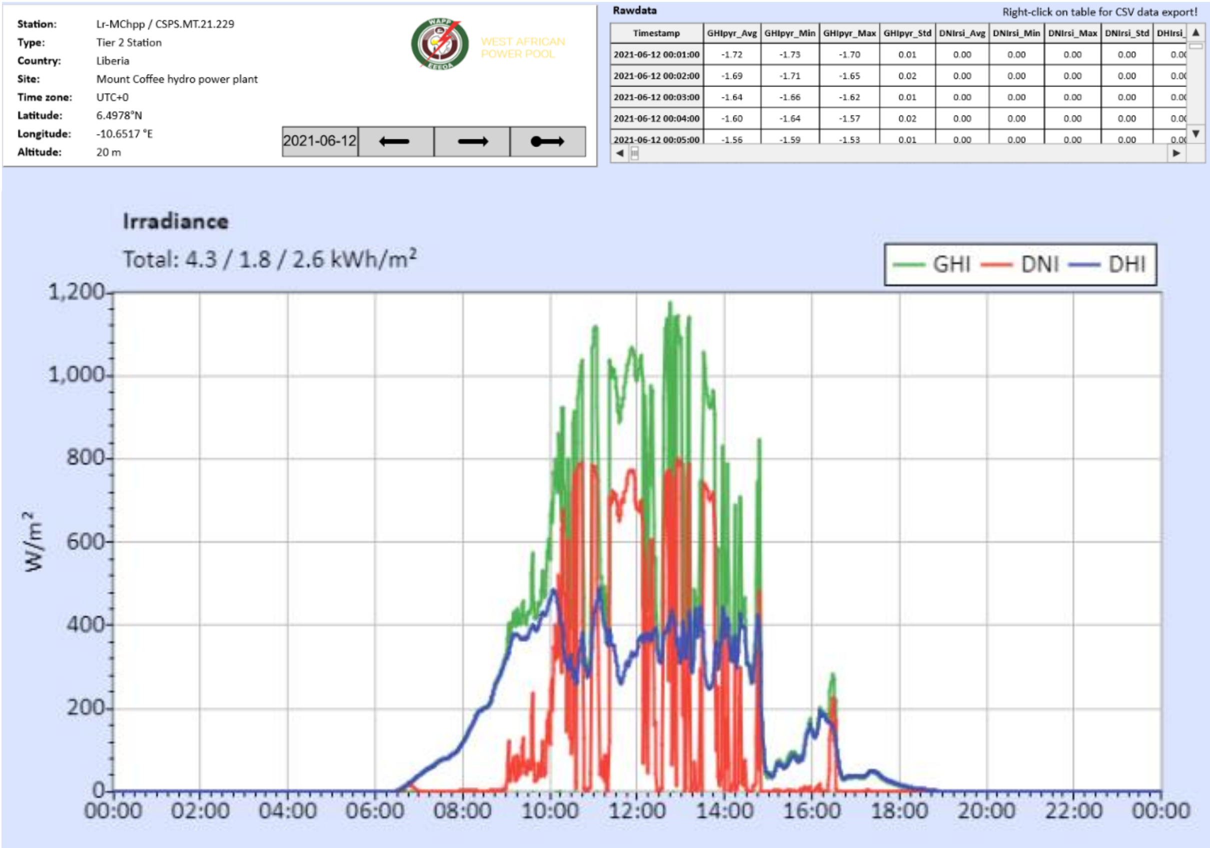


Figure 43 - Irradiance measurement. GHI, DNI and DHI

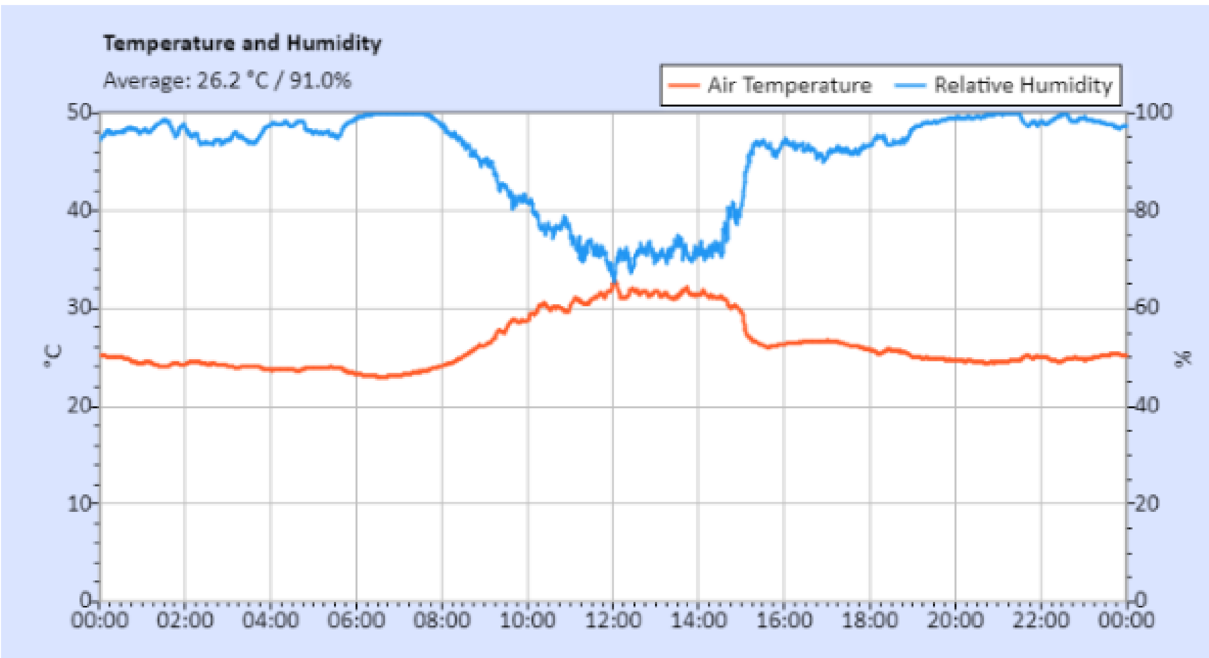


Figure 44 - Temperature and Humidity measurements

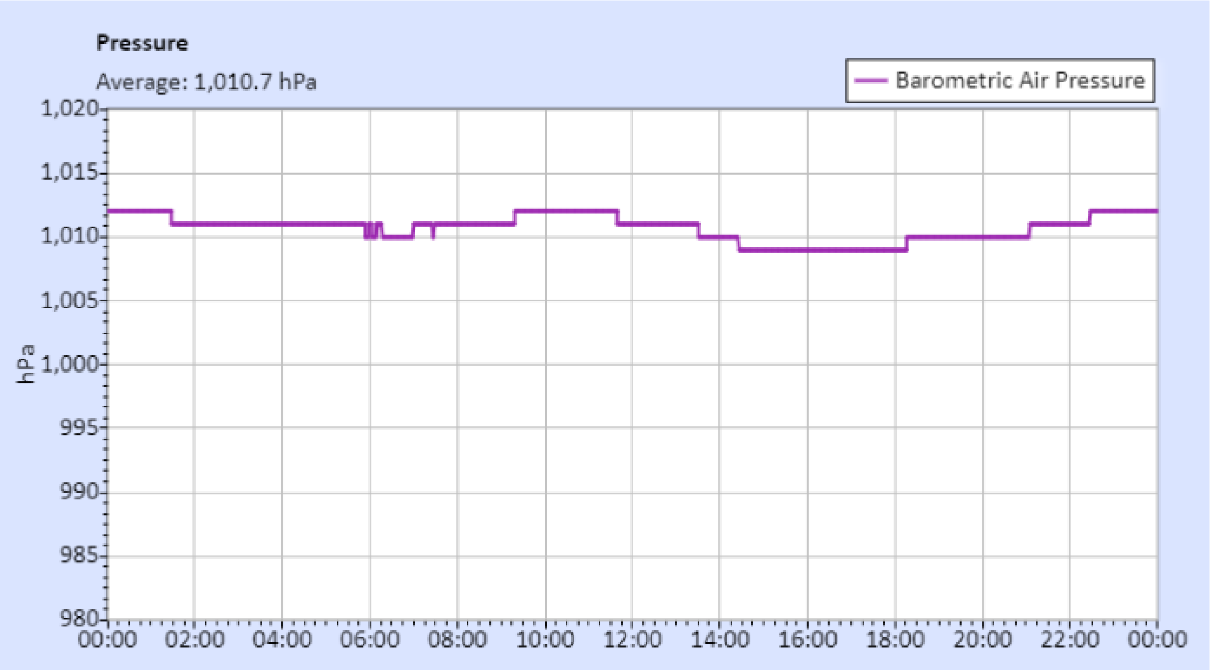


Figure 45 - Barometric air pressure measurement

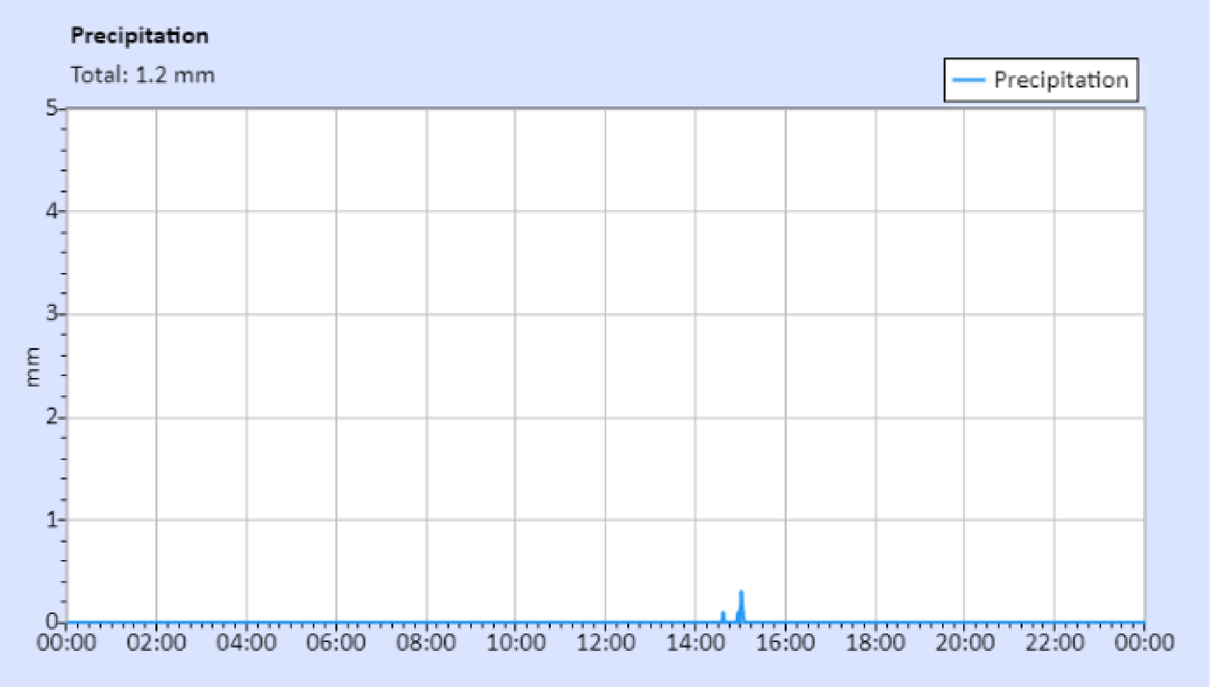


Figure 46 - Precipitation measurement

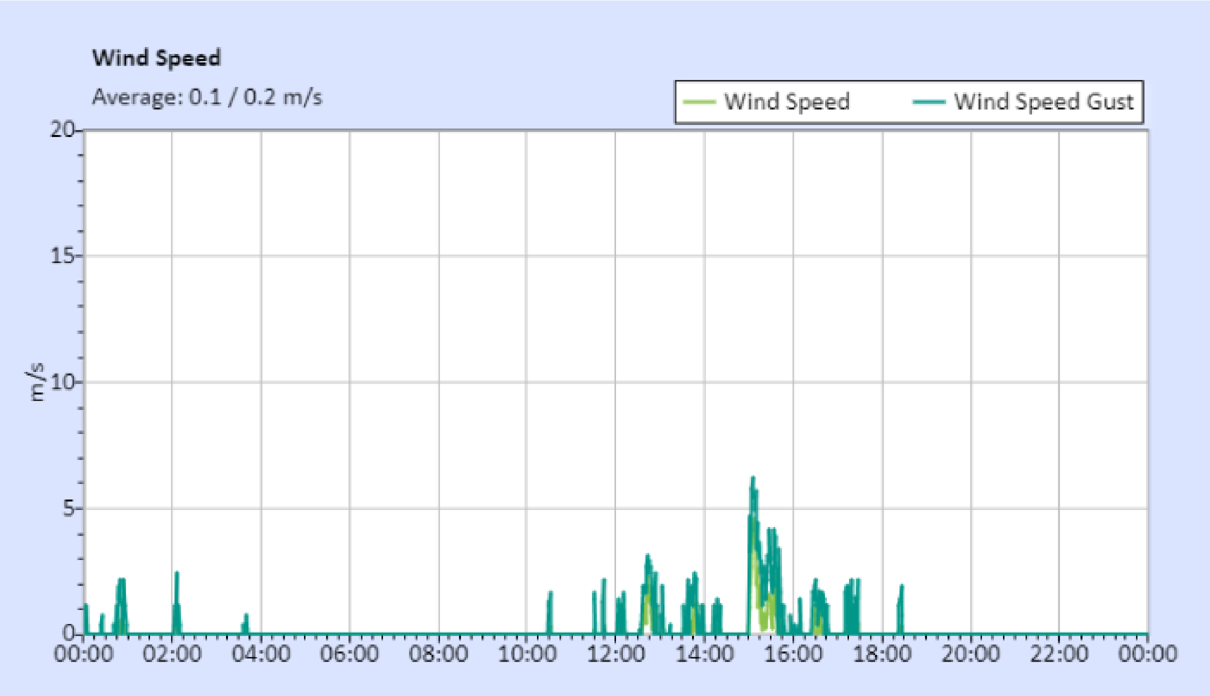


Figure 47 - Wind speed measurement

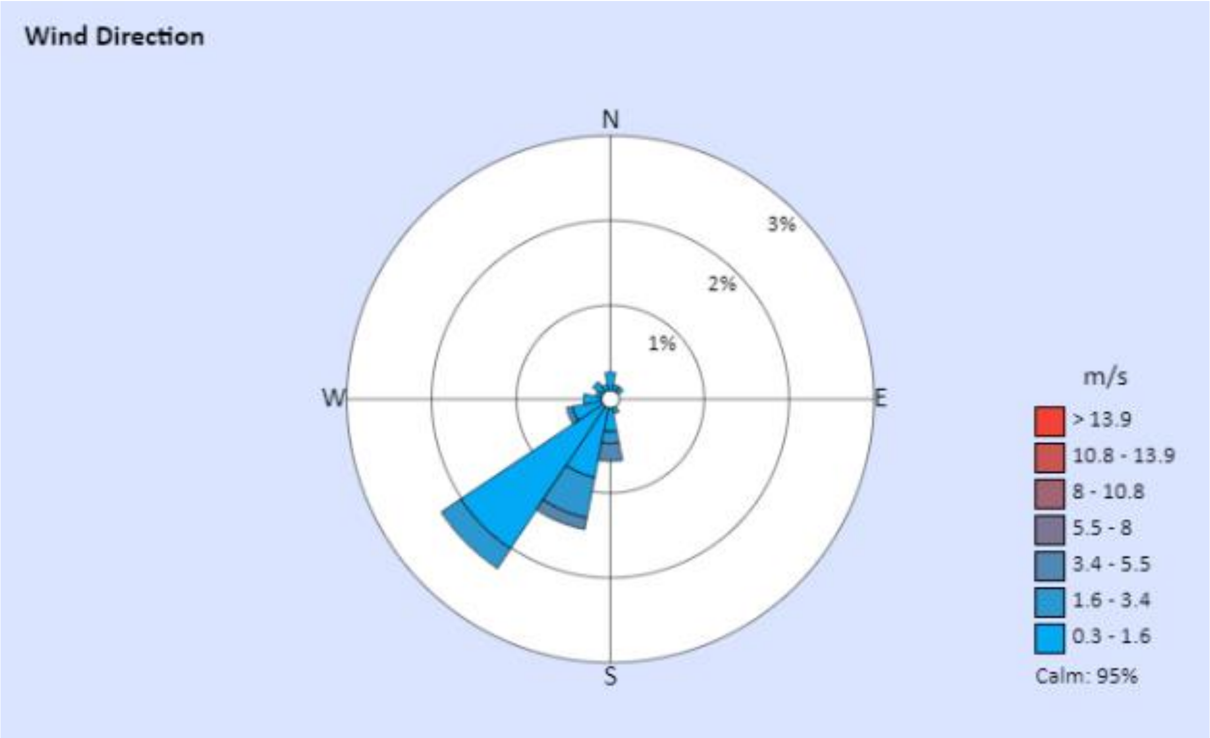


Figure 48 - Wind direction measurement

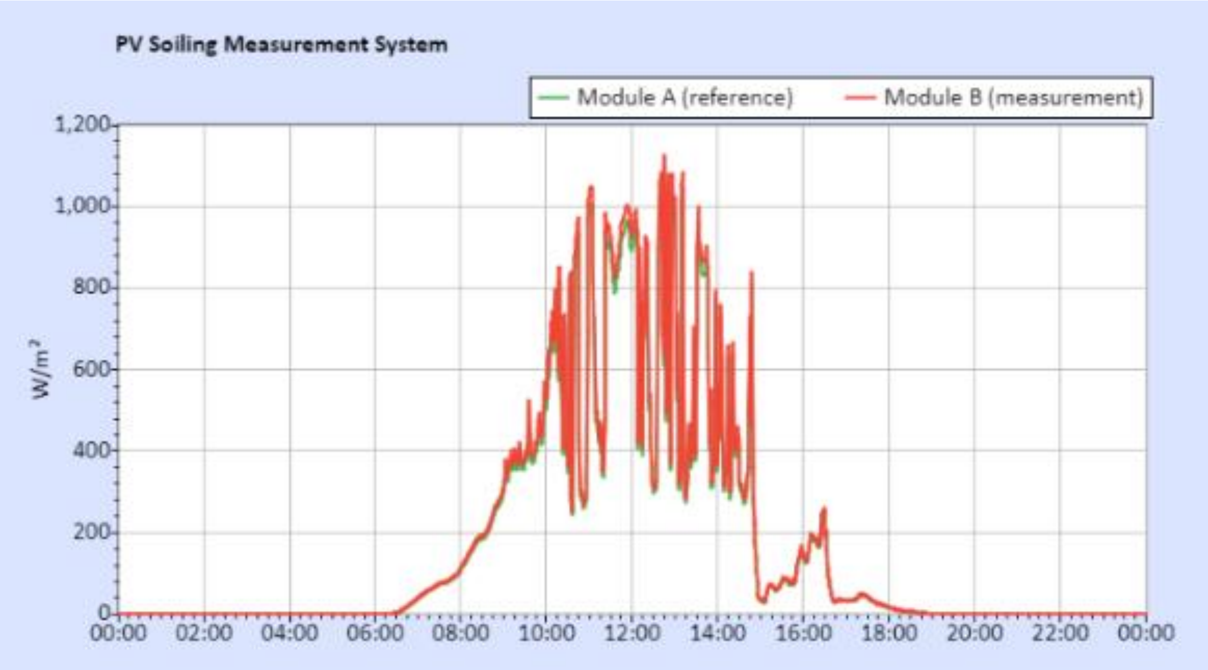


Figure 49 - PV soiling measurements

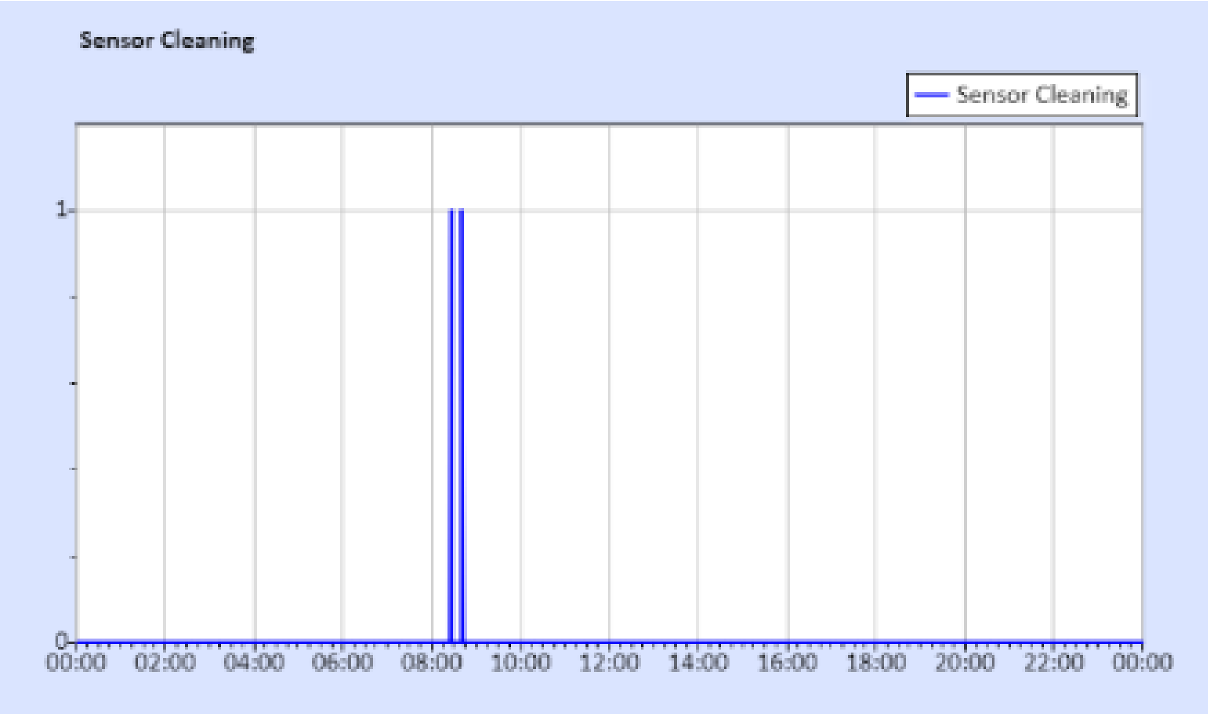


Figure 50 - Sensor cleaning recordings. 2021-06-14, first cleaning of irradiance sensors and PV-S reference module

9 CALIBRATION PROCEDURES AND CERTIFICATES

This section provides the calibration certificates for each sensor. All measurement equipment is new, unused and includes factory calibrations.

At the end of the first year of measurements, a field calibration using a reference pyranometer (referenced to the World Radiometric Reference established in Davos, Switzerland) will be conducted at the solar measurement station.

Measured parameter	Sensor type	Serial number	Calibration date	Installation date
DHI, DNI	RSI solar sensor	CSPS.MS.19.201.0005	2020-03-03	2021-06-10
GHI	CMP10 pyranometer	210860	2021-02-12	2021-06-10
Wind speed (WS)	NRG 40C anemometer	17950-0334055	2020-04-12	2021-06-10
Wind direction (WD)	NRG #200M wind vane	10070-00009014	2020-12-13	2021-06-10
Barometric pressure (BP)	PTB110 (CS106)	S4750162	2020-11-20	2021-06-10

9.1 RSI SOLAR SENSOR

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
German Aerospace Center

Calibration Protocol

For Model: **Twin Rotating Shadowband Irradiometer**

Pyranometer Unit Serial Number: CSPS.MS.19.201.0005
With pyranometer sensor: LI-COR LI200R PY108327 (primary)
and LI-COR LI200R PY108328 (secondary)
Original LI-COR Calibration Constant: 62.16 microamps per 1000 W/m²
and 65.53 microamps per 1000 W/m²

Correction factors from (DLR2008)

	PY108327	PY108328
Constant Correction Factor	0.990	1.025
Diffuse Correction Factor	1.004	1.035
Root Mean Square Deviation (DNI)	14.4 W/m²	13.5 W/m²
Bias (DNI)	-0.5 W/m²	-0.8 W/m²
Root Mean Square Deviation (GHI)	6.3 W/m²	6.7 W/m²
Bias (GHI)	-0.2 W/m²	0.9 W/m²

Calibration period: 2019-10-08 to 2020-03-03
Effective period: 653 h (GHI) 430 h (DNI) 653 h (DHI)
Temporal resolution: 10 min

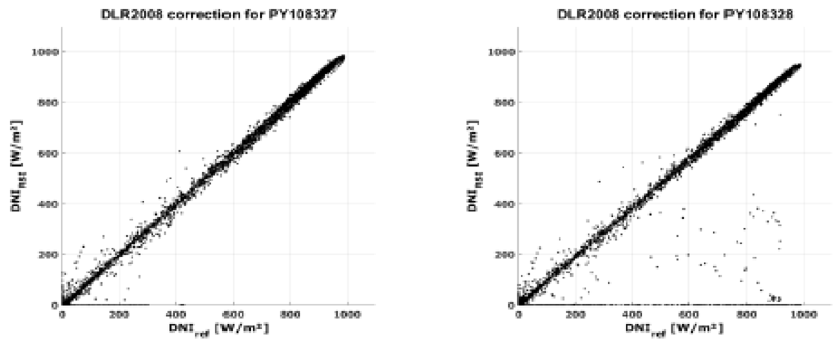
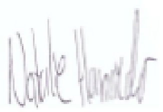


Figure 1: DNI after correction corresponding to chosen function set including calibration constant vs. reference DNI (10-min)

Please consult the detailed description for further information on the calibration process.
Almeria, 12-Jun-2020
i. A. Dr.rer.nat. Natalie Hanrieder



DLR is statutorily represented by its Executive Board. The Executive Board may empower authorized persons to act as its representatives. DLR's head of Legal Department, D-51170 Cologne, provides information on the extent of this empowerment.

Plataforma Solar de Almeria
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04200 Tabernas, Spain
Telephone +34 950 278802
Telefax +34 950 365313
Internet www.DLR.de

DETAILED DESCRIPTION OF THE RSI SENSOR CALIBRATION PROCEDURE

The RSI irradiation sensor is mounted and operated parallel to the reference DLR meteorological station during a specified period (recommended to be at least one month) at the Plataforma Solar de Almería in Spain for calibration under real sky conditions.

The Constant Calibration Factor and the Diffuse Correction are determined by comparing the reference direct normal and diffuse horizontal irradiance to corresponding RSI irradiance data as determined with the LI-COR (LI-200) Calibration Constant and including correction functions developed by DLR for RSIs with LI-COR LI200 pyranometers in 2008 (see publications: *Geuder, N., Pulvermüller, B., Vorbrugg, O., "Corrections for Rotating Shadowband Pyranometers for Solar Resource Assessment", Proc. of Solar Energy and Applications, part of SPIE Optics + Photonics, 10-14 August 2008, San Diego, USA*). The RMS deviation of the 10-minute means for DHI is minimized by variation of the thereby determined Diffuse Correction. Then the RMS deviation for the DNI is minimized using the Constant Calibration Factor.
Irradiance data from the RSI and the DLR station is logged as 60 second averages during the entire calibration process. For calibration, only the relevant operation range of solar thermal power plants was considered with DNI > 300 W/m², GHI > 10 W/m², DHI > 10 W/m² and at sun height angles > 5°. Outliers with deviations of more than 25% were not considered.

The following instruments were used during the calibration period:

Manufacturer	Model	Serial Number	Functionality/ Measurand	Calibration/Test remarks		
				constant	by	date
Kipp&Zonen	CMP21	110875	GHI	10.01 µV/(W/m²)	DLR	Oct-2015
Kipp&Zonen	CV 2	070990	ventilation unit, GHI			
Kipp&Zonen	CMP21	110869	DHI	9.35 µV/(W/m²)	DLR	Oct-2015
Kipp&Zonen	CV 2	070992	ventilation unit, DHI			
Hukseflux	DR03-05	10025	DNI	10.12 µV/(W/m²)	DLR	Jun-2016
Campbell Scientific	CS215	E1839	air temp. and rel. humidity		Sensirion	
Campbell Scientific	CS100	3696476	air pressure		setra	Aug-2008
EKO	STR-22G		sun tracking		EKO	
Campbell Scientific	CR1000	7164	data logger for precise sensors			

9.2 CMP10 PYRANOMETER

Kipp & Zonen B.V. | Delftechpark 36 | 2628 XH Delft | The Netherlands | +31 15 2755 210 | info@kippzonen.com | www.kippzonen.com

Meteorology Division of OTT HydroMet

ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER	022874210860
PYRANOMETER MODEL	CMP 10
SERIAL NUMBER	210860
CALIBRATION DATE	12 February 2021
INSTRUMENT CLASS	ISO 9060, Class A (Sec. Standard)*
CALIBRATION PROCEDURE	ISO 9847 par5.3.2, A3
REFERENCE PYRANOMETER	Kipp & Zonen CMP 21 sn 070114 active from 01 January 2021
REFERENCE PYRANOMETER CALIBRATION PROCEDURE	ISO 9846 par5
CALIBRATION LOCATION	Delft The Netherlands
CUSTOMER	
REMARKS	

Delft, The Netherlands, 12 February 2021

J. Mes
(in charge of calibration facility)

F. de Wit
(in charge of test)

Page: 1 of 2

Kipp & Zonen B.V.
Trade name: OTT HydroMet
Company registered in Delft

Trade register no.: 27239004
VAT no.: NL0055.74.857.B.01
Member of HMEI

EUR payments
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IBAN: NL70 DEUT 0265 2482 48
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Meteorology Division of OTT HydroMet

ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER 022874210860

Calibration procedure

The indoor calibration procedure is based on a side-by-side comparison with a reference pyranometer under an artificial sun fed by an AC voltage stabiliser. It embodies a 150 W Metal-Halide high-pressure gas discharge lamp and a reflector with a diameter of 16.2 cm. The lamp is positioned 1 m above the pyranometers producing a vertical beam. The reference- and test pyranometer are mounted horizontally on a table, which can rotate. The irradiance at the pyranometers is approximately 500 W/m². During the calibration procedure the reference and test pyranometer are interchanged to correct for any non-homogeneity of the beam. Temperature during calibration: 22 °C ± 2 °C.

Hierarchy of traceability

The measurements have been executed using standards for which the traceability to international standards has been demonstrated towards the RvA.

The reference pyranometer was compared with the sun and sky radiation as source under clear sky conditions using the "alternating sun-and-shade method" ISO 9846 paragraph 5. The measurements were performed in Delft, The Netherlands (latitude: 51.9969', longitude: 4.3863', altitude: 10m above sea level). Dates of measurements: 22-24 June 2020.
The receiver surface was pointed directly at the sun using a solar tracker. During the comparisons, the instrument received tilted global radiation intensities from 834 W/m² to 1124 W/m² with a mean of 992 W/m² and tilted diffuse radiation intensities from 83 W/m² to 250 W/m² with a mean of 148 W/m². The ambient temperature ranged from +19.0 °C to +29.9 °C with a mean of +23.9 °C.
The direct radiation on the reference pyranometer as obtained with the alternating-sun-shade method was compared to the DNI measured by the absolute cavity pyrheliometer PMO6 SN 103. The PMO6 is calibrated against the World Standard Group (WSG), maintained at the WRC Davos every International Pyrheliometer Comparison (IPC). WRR factor of PMO6: 0.99787 (from the last IPC-2015).

This calibration proved that the reference pyranometer has been stable and that the original sensitivity 8.37 µV/(W/m²) ± 0.11 µV/(W/m²) is valid and will be applied (see PMOD calibration details). Observed sensitivity differences between the consecutive years are well within the calibration uncertainty.

PMOD calibration details: The reference pyranometer was compared with the sun and sky radiation as source under mainly clear sky conditions using the "continuous sun-and-shade method". The pyranometer was installed horizontally. During the comparisons, the global radiation ranged from 638 W/m² to 1195 W/m² with a mean of 874 W/m². The solar zenith angle varied from 23.5° to 49.8° with a mean of 32.9°. The ambient temperature ranged from +12.6 °C to +26.2 °C with a mean of +23.7 °C. The sensitivity calculation is based on 435 individual measurements. The readings of the WSG are referred to the World Radiometric Reference (WRR). The estimated uncertainty of the WRR relative to SI is ±0.3%. The obtained sensitivity value and its expanded uncertainty (95% level of confidence) are valid for similar conditions and are:8.37 ± 0.11 µV/W/m². The measurements were performed in Davos (latitude: 46.8143', longitude: -9.8458', altitude: 1558 m above sea level). Dates of measurements: 24, 30 June 1, 2 July 2015. Global radiation data were calculated from the direct solar radiation as measured with the absolute cavity pyrheliometer PMO2 (member of the WSG, WRR- factor: 0.998623 from the last international Pyrheliometer Comparison, IPC-2015) and from the diffuse radiation as measured with a continuous disk shaded pyranometer Kipp & Zonen CM22 SN 020059 (ventilated with heated air).

SENSITIVITY	9.59 µV/(W/m²) at normal incidence on horizontal pyranometer
UNCERTAINTY	0.14 µV/(W/m²) = 1.44 %
IMPEDANCE	23 ± 1.5 Ω

Justification of total instrument calibration uncertainty

The combined uncertainty of the result of the calibration is the positive "root sum square" of the following components.
1. The expanded uncertainty due to random effects and instrumental errors during the calibration of the reference CMP 21 is ±0.11/8.37 = ±1.31% (k=2). See traceability text.
2. The expanded uncertainty of the transfer procedure (calibration by comparison) is estimated to be ±0.5% (k=2).
3. The estimated uncertainty of the WRR relative to SI: ±0.3% (k=2).
The expanded uncertainty is: $\sqrt{(1.31\%^2 + 0.5\%^2 + 0.3\%^2)} = \pm 1.44\%$ (k=2).

The resistance measurement uncertainties are due to the PXI 4065 uncertainty in the 100 Ω range: 150ppm of range (=15mΩ) the cable resistance (estimated 0.1 Ω) and due to the electrothermal effect the measurement current in the thermal detector of the pyranometer. This was found to be a resistance error of 1.5 Ω, which results in a total resistance uncertainty of $\sqrt{(0.015^2+0.1^2+1.5^2)} = 1.5$ Ω or 5%.

The PXI 4065 is calibrated by National Instruments Hungary, on 7 november 2018 at a temperature of 22.7 °C, under ISO 17025:2005 accreditation. This calibration is traceable to NIST and/or other National Measurement Institutes (NMI's).

The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor k, such that the coverage probability corresponds to approximately 95%. The standard uncertainty has been determined in accordance with EA 04/2.

Notice

The calibration certificate supplied with the instrument is valid at the date of first use. Even though the calibration certificate is dated relative to manufacture, or recalibration, the instrument does not undergo any sensitivity changes when kept in the original packing.

* from October 2018 the classification conforms to ISO 9060:2018. Instruments issued before that date conform to ISO 9060:1990.

RvA is member of the European Co-operation for Accreditation (EA) and is one of the signatories to the EA Multilateral Agreement (MLA) and to the ILAC Mutual Recognition Arrangement (MRA) for the mutual recognition of calibration certificates.

Kipp & Zonen B.V.
Trade name: OTT HydroMet
Company registered in Delft

Trade register no.: 27239004
VAT no.: NL0055.74.857.B.01
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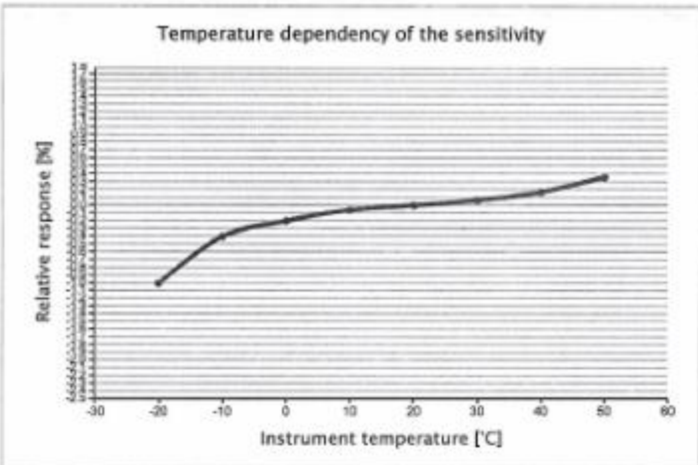
MEASUREMENT REPORT
PYRANOMETER

Routine measurement of temperature dependency during final inspection

PYRANOMETER TYPE	CMP 10
SERIAL NUMBER	210860
DATE OF MEASUREMENT	21 December 2020
PERFORMED BY	F. de Wit
PROCEDURE	The pyranometer is mounted inside the climate chamber and illuminated with a white light source under normal incidence. A CMP22 pyranometer outside the chamber is used to monitor the lamp stability.

The pyranometer is tested over a temperature range from 50 °C down to -20 °C in steps of 10 °C. The relative temperature dependency is plotted below.

The measurement uncertainty of this characterisation is ±0.1% (k=2).



Instrument temperature [°C]	Relative response [%]
-20	-1.00
-10	-0.40
0	-0.20
10	-0.06
20	0.00
30	0.07
40	0.17
50	0.36

MEASUREMENT REPORT

PYRANOMETER

Routine measurement of directional error during final inspection

Mean cosine error of each new pyranometer type CMP 10 is measured by a simple routine.

Routine:

The pyranometerbase is placed against the vertical turntable of a goniometer in the parallel (0,5°) beam of a sunsimulator.
Voltage output U(z) is measured for beam incidence (zenith) angles of 0°,40°, 60°, 70° and 80° coming in over azimuth south (cable pointing to North).
Next the pyranometer output U(-z) is measured for incidence angles of -80°, -70°, -60°, -40° and 0° consequently for azimuth south. The dark signal is measured at the beginning of the routine in the middle and at the end. For each beam incident angle the dark signal is interpolated.

During the CMP 10 measurement cycle, a check is done on the azimuth error at 40° and 70° by measuring voltages for azimuth-directions S, E, N and W . Also at -70° and -40° this azimuth error is measured and the mean of both azimuth measurements cancels out the eventual error in the 0° position.

With the extended procedure at both 40° and -40° and 70° and -70° the specific cosine error for 8 azimuth directions (40° S, W, N and E and 70° E, N, W, S) can be calculated according to formula 1 and verified whether it is within ± 10 W/m².

The applied formula for the relative cosine error is:

U(0°) Pyranometer output voltage for normal incidence
U(z) Pyranometer output voltage for angles (z)
Zero(z) Dark signal for angles

$$\frac{\frac{(U(z)+U(-z))}{2} - zero(z)}{\left(\frac{U(0°)+U(0°)}{2} - zero(z)\right)\cdot \cos(z)} 100\%$$

Formula 1.

Relative cosine error at zenith angle in %

Zenith angle	South	East	North	West
40	-0.55	-0.43	-0.28	-0.41
60	-0.28			
70	-0.10	-0.56	-0.08	0.04
80	0.15			

Absolute cosine error for 1000 W/m² beam radiation in W/m²

Zenith angle	South	East	North	West
40	-4.20	-3.33	-2.14	-3.11
60	-1.38			
70	-0.35	-1.91	-0.28	0.13
80	0.26			

PYRANOMETER MODEL: CMP 10 SERIAL NUMBER: 210860

9.3 #40C ANEMOMETER

SOH Wind Engineering LLC

141 Leroy Road · Williston, VT 05495 · USA

Tel 802.316.4368 · Fax 802.735.9106 · www.sohwind.com

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 20.US1.01215 **Date of issue:** December 04, 2020

Type: NRG 40C Anemometer **Serial number:** 179500334055

Manufacturer: NRG Systems Inc, 110 Riggs Road, Hinesburg, VT 05461, USA

Client: NRG Systems Inc, 110 Riggs Road, Hinesburg, VT 05461, USA

Anemometer received: December 02, 2020 **Anemometer calibrated:** December 03, 2020

Calibrated by: MEJ **Procedure:** MEASNET, IEC 61400-12-1:2017 Annex F

Certificate prepared by: EJF **Approved by:** Calibration engineer, EJF

Calibration equation obtained: v [m/s] = 0.75816 · f [Hz] + 0.38739

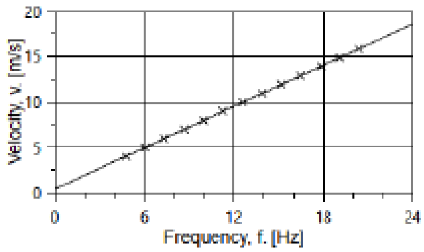
Standard uncertainty, slope: 0.00135 **Standard uncertainty, offset:** 0.03575

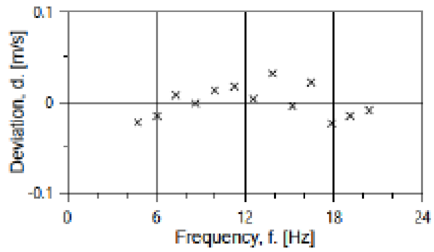
Covariance: -0.0000132 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999990

Absolute maximum deviation: 0.031 m/s at 10.933 m/s

Barometric pressure: 1003.1 hPa **Relative humidity:** 28.5%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in d.p. box [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
1-first	9.35	21.5	26.0	3.976	4.7627	-0.022	0.023
13-last	14.55	21.8	26.1	4.962	6.0543	-0.015	0.026
2	21.00	21.5	26.0	5.959	7.3381	0.008	0.030
12	28.58	21.8	26.1	6.955	8.6646	-0.002	0.034
3	37.31	21.5	26.0	7.942	9.9477	0.013	0.038
11	47.44	21.8	26.1	8.962	11.2867	0.017	0.042
4	58.37	21.5	26.0	9.935	12.5884	0.003	0.046
10	70.60	21.9	26.1	10.933	13.8686	0.031	0.051
5	83.97	21.5	26.0	11.917	15.2134	-0.005	0.055
9	98.36	21.9	26.0	12.905	16.4829	0.021	0.059
6	114.28	21.6	26.0	13.905	17.8606	-0.024	0.063
8	130.48	21.8	26.0	14.863	19.1135	-0.015	0.067
7	148.35	21.7	26.0	15.846	20.4024	-0.009	0.071





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EQUIPMENT USED

Serial Number	Description
Njord1	Wind tunnel, blockage factor = 1.0017
2254	Control cup anemometer
-	Mounting tube, D = 12.7 mm
TT003	Summit Electronics, 1XPT100, 0-10V Output, wind tunnel temp.
TT001	Summit Electronics, 1XPT100, 0-10V Output, differential pressure box temp.
DP005	Setra Model 239, 0-1inWC, differential pressure transducer
HY002	Dwyer RHP-2D20, 0-10V Output, humidity transmitter
BP001	Setra Model 278, barometer
PL8	Pitot tube
XB002	Computer Board. 16 bit A/D data acquisition board
LAB2-PC	PC dedicated to data acquisition

The accuracies of all measurements were traceable to the SI through NIST or CIPM recognized NMI's. A real-time analysis module within the data acquisition software detects pulse frequency.

Photo of the wind tunnel setup. The cross-sectional area is 2.5m x 2.5m.

UNCERTAINTIES

The documented uncertainty is the total combined uncertainty at 95% confidence level (k=2) in accordance with EA-4/02. The uncertainty at 10 m/s comply with the requirements in the IEC 61400-12-1:2005 procedure. See Document US.12.01.004 for further details.

COMMENTS

(none)

Certificate number: 20.US1.01215

The results on this certificate relate only to the serial number listed.
All calibrations are done in the "As Found" condition unless otherwise noted.

9.4 #200M WIND VANE

NRG Systems

Factory Calibration

NRG Systems 200M Wind Direction Vane

Serial No. 10070 00009014

Product Description:

Manufacturer	**Description**	**Cal. Date**
NRG Systems	200M Wind Direction Vane	12/13/2020

NRG Systems, hereby certifies that the above instrumentation has been calibrated and tested to meet or exceed the published specifications. This calibration and testing was performed using instrumentation and standards that are traceable to the National Institute for Standards and Technology (NIST).

Standard Uncertainty of Degree Measurement = ±0.31°

The output (in Deg.) for this 200M sensor is defined by: $\Theta = V * Scale\ Factor + Offset$

Criteria	**Value**	**Units**
200M Scale Factor	147.9896	Deg./Volt
200M Offset	-1.4056	Deg.

Linearity Results (R^2): 0.99999

Slope (Scale Factor) and Offset Conversion Chart for NRG Systems' Data Loggers.

To Scale to...	**SymphoniePLUS3 and Older** *[Symphonie Data Retriever (SDR) software]*		**SymphoniePRO Data Logger** *[SymphoniePRO Desktop Application]*	
	enter Scale Factor	**and enter Offset**	**enter Scale Factor**	**and enter Offset**
°	0.368	-5.3	147.9896	-1.4056

Procedure: WI-ELE-489

Calibration performed by: ms **Date:** 12/13/2020

NRG Systems' management system has been certified to ISO 9001: 2015.

110 Riggs Road • Hinesburg, Vermont 05461 | o: +1 802.482.2255 f: +1 802.482.2272 | nrgsystems.com

9.5 CS106 (PTB100) BAROMETER

VAISALA

1 (1)
Certificate report no. H47-20470021

CALIBRATION CERTIFICATE

Instrument PTB110 Barometer
Serial number S4750162
Manufacturer Vaisala Oyj, Finland
Calibration date 20th November 2020

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
510.3	510.3	0.043	0.0	± 0.15
610.0	610.0	0.458	0.0	± 0.15
700.0	700.1	0.834	-0.1	± 0.15
810.1	810.2	1.292	-0.1	± 0.15
900.0	900.0	1.667	0.0	± 0.15
1000.3	1000.3	2.085	0.0	± 0.15
1059.8	1059.8	2.333	0.0	± 0.15
1099.9	1099.9	2.500	0.0	± 0.15

*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer.
**The calibration uncertainty given at 95 % confidence level, k = 2

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HP34970A	EM 12997	2020-03-10	11-9485435-009
PTB220	PA 14018	2020-06-11	K008-D02088

Ambient conditions
Humidity: 32 ± 5 %RH   Temperature: 23 ± 2 °C   Pressure: 998 ± 20 hPa

Technician

Doc214685-B

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