

Article

Global Solar Irradiance Measurement System Based on a Pyranometer, Data Acquisition Board, and LabVIEW Interface

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Abstract

This paper presents a global solar irradiance measurement system developed at Politehnica University Timisoara (UPT), comprising a Kipp & Zonen CMP11 thermopile pyranometer (Kipp & Zonen, OTT HydroMet B.V., Delft, The Netherlands), a National Instruments myDAQ board (National Instruments Corporation, Austin, TX, USA), and a LabVIEW 2018 interface (National Instruments Corporation, Austin, TX, USA). The platform provides configurable acquisition, voltage-to-irradiance conversion, temporal averaging, data storage, and MATLAB R2024b-based analysis (The MathWorks, Inc., Natick, MA, USA). A preliminary operational validation was performed against ten-minute global-irradiance data supplied by the National Meteorological Administration of Romania (ANM) at the same site. The dataset comprised five non-consecutive days between December 2025 and May 2026, with 215 paired values. The global metrics were $MBE = -0.33 \text{ W/m}^2$, $MAE = 4.55 \text{ W/m}^2$, $RMSE = 6.05 \text{ W/m}^2$, $nRMSE = 1.29\%$, and $MARE = 0.96\%$. Incident solar energy was 60.357 MJ/m^2 for UPT and 60.399 MJ/m^2 for ANM, a relative difference of -0.07% . Day-specific Bland–Altman analyses showed $0.00\text{--}4.65\%$ of differences outside the corresponding limits of agreement. Regression of the differences against the pairwise mean irradiance identified an irradiance-dependent bias component in the combined dataset. The results demonstrate promising operational agreement under the tested conditions. Longer campaigns and traceable low-level characterization of the acquisition chain remain necessary for extended metrological assessment.

Keywords: global solar irradiance; radiometric measurement; photovoltaic monitoring; measurement validation; uncertainty framework; Bland–Altman agreement analysis; virtual instrumentation



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1. Introduction

The electricity generation of photovoltaic systems is influenced by their technical condition, installation site, and atmospheric parameters. Among these atmospheric parameters, solar irradiance has the strongest influence. Because atmospheric parameters are stochastic rather than deterministic quantities, they can only be assessed probabilistically. Accurate estimation of photovoltaic electricity generation is important both for investors and for ensuring the stability of power systems that integrate such sources.

Mancilla-David et al. [1] highlighted the importance of accurately determining solar irradiance for maximizing photovoltaic electricity generation. Consequently, solar irradiance measurement is a critical task. The authors proposed a low-cost sensing solution based

on a photovoltaic cell used as an irradiance sensor, a temperature sensor, and a microcontroller, combined with neural-network-based processing. Habte et al. [2] showed that the accuracy of solar radiation measurements performed with radiometers depends on instrument performance, installation method, calibration procedure, measurement conditions, maintenance, location, and environmental conditions. Their study examined the effects of different radiometric calibration methods on the resulting calibration accuracy. Zapién-Castillo et al. [3] showed that partial shading of photovoltaic panels significantly affects electricity generation; therefore, real-time irradiance measurement is required, and a low-cost data acquisition system can be used for this purpose. In that study, data transmission was performed wirelessly.

Solar irradiance measurement is also important for improving the accuracy of irradiance forecasting, which is essential for predicting photovoltaic electricity generation. Abdel-Nasser et al. [4] proposed a solar irradiance forecasting method based on long short-term memory (LSTM) models and an aggregation function using the Choquet integral, with input data obtained from solar irradiance measurements.

Solar irradiance can also be estimated indirectly from the DC voltage and current supplied by the photovoltaic system, together with temperature. Such a method is described in [5]. Hishikawa et al. [6] showed that the effect of temporal irradiance variation on the I–V characteristics of a photovoltaic system remains within $\pm 0.4\%$ when the time interval between measurements is 0.2 s. They also reported that spatial non-uniformity of irradiance within the photovoltaic module and the irradiance difference between the module and the irradiance sensor are residual factors affecting performance measurements. The corresponding effects on $P_{\max}$ uncertainty were estimated at approximately $\pm 1\%$ and $\pm 2\%$ for irradiance levels of 1.0 kW/m^2 and 0.4 kW/m^2 , respectively.

Gericke and Luwes [7] presented differences between solar irradiance values measured with a pyranometer installed at the photovoltaic system site and values obtained from fixed meteorological stations located near the photovoltaic system. The differences between the two measurement systems were substantial; therefore, real-time irradiance measurement at the photovoltaic system installation site is recommended.

The maximum power delivered by a photovoltaic panel equipped with a solar tracking system can also be used to estimate solar irradiance. Ding et al. [8] presented such a system. The system can track the sun in real time, and its low cost makes it a less accurate but practical alternative to more sophisticated and expensive sensors.

In smart grids, photovoltaic generation sources play an important role; therefore, forecasting their energy output is necessary. Kapoor et al. [9] showed that the latitude and longitude of a site are important parameters for solar irradiance values, which confirms the need for local irradiance measurements. Hinkov et al. [10] presented smartphone-based software applications for solar irradiance measurement. Although the measurement accuracy is limited, the high degree of mobility makes this type of application useful.

In photovoltaic systems, irradiance is frequently used as an input quantity for numerical models. In a previous article [11], the authors presented a MATLAB numerical model for simulating the operation of a real photovoltaic string consisting of 19 series-connected modules, corresponding to an installed power of 8.645 kWp. In that study, solar irradiance and module temperature were used as experimental input data, and the model was validated by comparing the simulated voltage, current, and power with the values measured at the input of the inverter maximum power point tracking (MPPT) system. Therefore, the accuracy of the measured irradiance directly affects the quality of photovoltaic model validation.

This paper presents a global solar irradiance measurement system and its preliminary operational validation under field conditions. The system designed and implemented at

Politehnica University Timisoara (UPT) includes a thermopile pyranometer, a National Instruments myDAQ board, and a LabVIEW-programmed interface. The UPT measurements were compared with global-irradiance values supplied by the National Meteorological Administration of Romania (ANM). The UPT and ANM sensors were co-located at the ANM Lugoj station and therefore operated under nominally comparable exposure conditions. Co-location reduces differences associated with site, local horizon, and microclimate, but it does not eliminate sensor-specific effects related to leveling, dome condition, directional response, thermal offset, or averaging-window alignment.

Pyranometers are established instruments for measuring global solar radiation. ISO 9060:2018 establishes classification criteria for instruments intended to measure hemispherical and direct solar radiation [12]. For photovoltaic applications, IEC 61724-1:2021 defines requirements for monitoring photovoltaic system performance and includes recommendations on the use of irradiance sensors [13]. The World Meteorological Organization (WMO) Guide treats solar radiation measurement as part of meteorological observations [14]. ASTM G213-17 (2023) is relevant for evaluating measurement uncertainty when using pyranometers and pyrheliometers [15], while review papers and best-practice guides provide a framework for interpreting solar resource data and data quality [16,17]. Reference radiometric networks, such as the Baseline Surface Radiation Network (BSRN), emphasize the importance of uniform operating and quality-control procedures [18,19].

Photovoltaic monitoring platforms based on data acquisition and virtual instrumentation have been proposed in the literature. Madeti and Singh synthesized the requirements and architectures of monitoring systems for photovoltaic plants [20]. Chouder et al. used LabVIEW for the monitoring, modeling, and simulation of photovoltaic systems [21], while Rohit et al. developed a real-time data acquisition platform for photovoltaic modules [22]. Other studies have focused on low-cost autonomous systems, including Arduino-based data loggers, Internet of Things (IoT) systems for solar radiation measurement, and open-source modular platforms for photovoltaic and meteorological monitoring [23–25].

Existing LabVIEW-based platforms generally emphasize photovoltaic-module monitoring and visualization, whereas IoT-based irradiance systems primarily emphasize low cost, autonomy, and remote data transmission [20–25]. The present paper's technical contribution lies in the transparent integration of a Class A thermopile pyranometer with a configurable differential data-acquisition chain and a combined LabVIEW-MATLAB workflow, together with an agreement-oriented validation procedure that evaluates pointwise errors, incident solar energy, and day-specific Bland–Altman limits.

The validation workflow was designed to retain direct access to the primary voltage data, conversion parameters, averaging procedure, statistical indicators, and graphical analyses. Unlike simplified optical sensors, the UPT system uses a thermopile pyranometer with a broad spectral response. Unlike closed commercial platforms, the acquisition and processing parameters remain accessible to the user. This combination is intended for research and teaching activities in which measurement transparency and reproducibility are more important than autonomous cloud operation.

The specific contributions of this study are: (i) implementation of a configurable pyranometer-myDAQ-LabVIEW measurement chain; (ii) extension of the experimental comparison to five non-consecutive days representing different irradiance levels and temporal profiles; (iii) joint assessment through conventional error metrics, incident-energy integration, and separate Bland–Altman analyses; and (iv) quantification of the expected order of magnitude by which irradiance disagreement may affect photovoltaic power and energy estimates. The study is presented as a preliminary operational validation rather than as a complete metrological calibration of the measurement chain.

The paper is structured as follows: Section 1 presents the introduction, the scientific context of solar irradiance measurement, and the motivation for developing the UPT system. Section 2 describes the materials and methods, the experimental configuration of the measurement system, the voltage-to-irradiance conversion, and the analyzed dataset. Section 3 presents the experimental validation of the solar irradiance measurement system, including the temporal evolution of irradiance, statistical error metrics, calculated incident solar energy per unit area, and Bland–Altman analysis. Section 4 discusses system performance, the interpretation of differences between the two datasets, and the relevance of the results for photovoltaic applications. Section 5 presents the conclusions and future development directions.

2. Materials and Methods

2.1. Structure of the Measurement System

The solar irradiance measurement system designed and implemented at Politehnica University Timisoara (UPT) includes the following elements: a Kipp & Zonen CMP11 thermopile pyranometer (Kipp & Zonen, OTT HydroMet B.V., Delft, The Netherlands), a National Instruments myDAQ data acquisition board (National Instruments Corporation, Austin, TX, USA), a differential analog input, and a LabVIEW 2018 interface. Figure 1 shows a photograph of the measurement system and its main components.

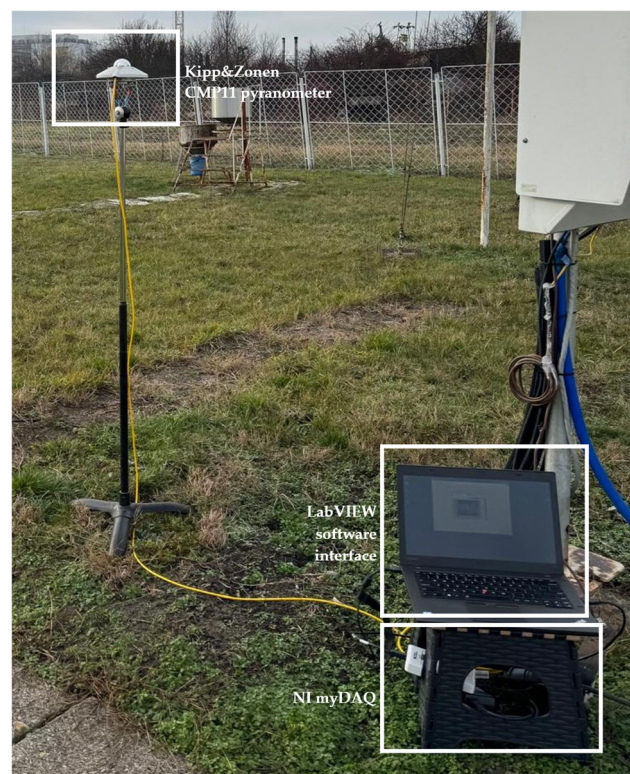


Figure 1. Overview of the UPT measurement system.

The acquired data are digitized and transferred to a computer. The mathematical functions implemented in MATLAB R2024b are used for data processing and error analysis. The selected structure combines a dedicated radiometric sensor with a laboratory data acquisition board that provides a differential analog input, 16-bit resolution, and a configurable input range [26,27]. The information flow of the measurement system, including its experimental verification by comparison with standard measurements, is presented in Figure 2.

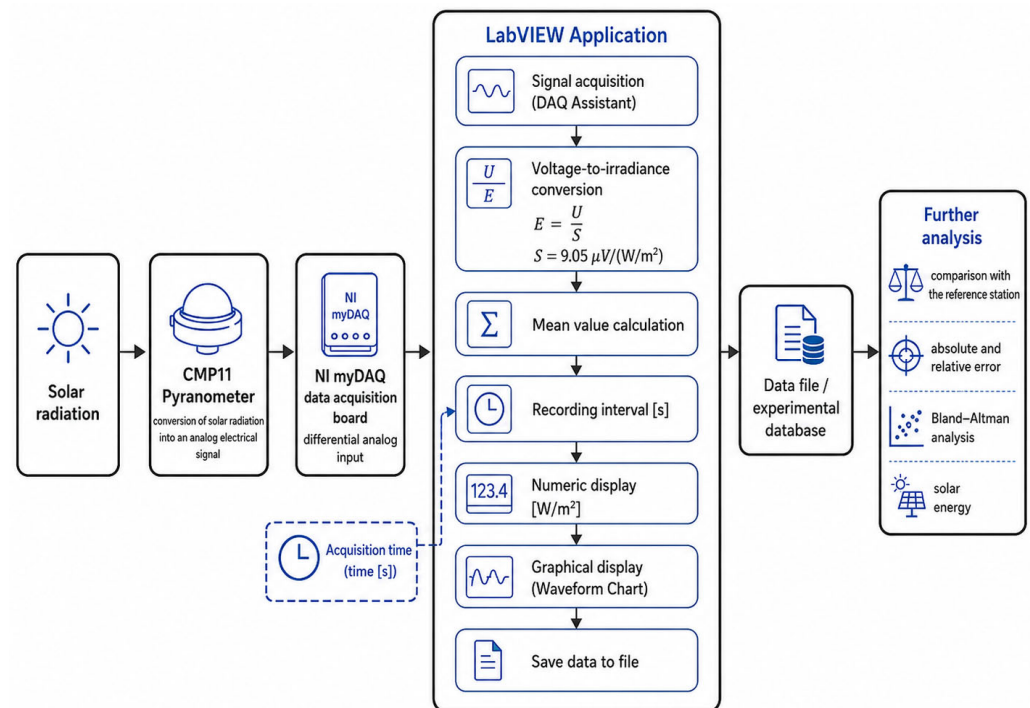


Figure 2. Information-flow diagram of the measurement and validation system.

The pyranometer signal was sampled at 1 kHz, and one averaged irradiance value was generated at 1 min intervals. The final comparison values were obtained by averaging over 10 min intervals. The ± 2 V range, which is the smallest analog-input range available on the NI myDAQ, was selected for the implemented configuration. At an irradiance of 1000 W/m^2 , the CMP11 sensitivity of $9.05 \mu V/(W/m^2)$ corresponds to an output of approximately 9.05 mV; therefore, the pyranometer signal occupies only a small fraction of the selected input range. The configuration is functional for the present operational comparison, but it is not metrologically optimized for low-level thermopile signals. Traceable low-level characterization of the complete acquisition chain and/or a low-noise instrumentation-amplifier stage would improve signal utilization and support a numerical uncertainty budget. The LabVIEW interface used for irradiance acquisition and display is presented in Figure 3.

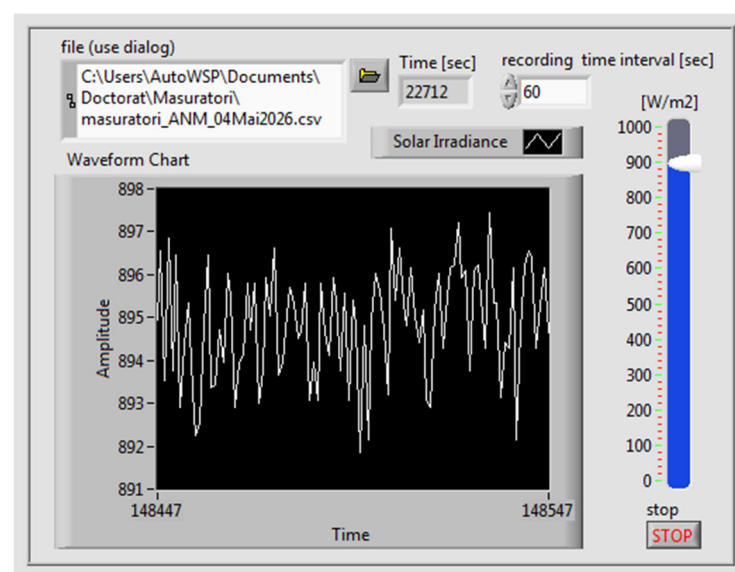


Figure 3. LabVIEW interface for solar irradiance acquisition and display.

The LabVIEW program developed for the solar irradiance measurement system acquires, processes, displays, and saves the solar irradiance values measured with the CMP11 pyranometer. When the application is initialized, the user selects the output file in which the experimental data are recorded. The analog signal provided by the pyranometer is acquired through the NI myDAQ board using the DAQ Assistant Express VI in the LabVIEW environment. The block diagram of the LabVIEW program is shown in Figure 4.

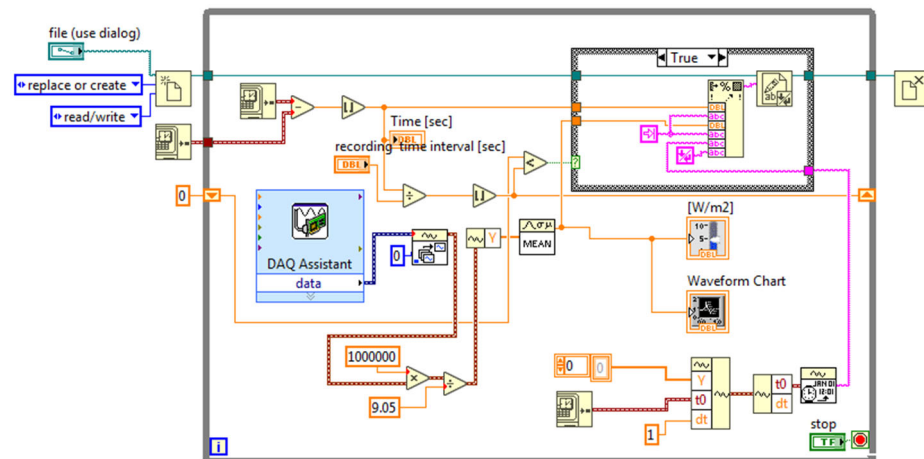


Figure 4. LabVIEW block diagram used for data acquisition, conversion, and saving.

The conversion is performed by relating the measured voltage to the pyranometer sensitivity. Since sensitivity is expressed in $\mu\text{V}/(\text{W}/\text{m}^2)$, the software applies the required conversion factor to obtain irradiance in W/m^2 . The resulting value is numerically averaged, displayed in real time in both numerical and graphical form, and saved together with the acquisition time. The characteristics of the implemented system and the role of its component elements are summarized in Table 1.

Table 1. Parameters of the UPT system.

Element	Configuration	Role
Pyranometer	Kipp & Zonen CMP11, thermopile type	Conversion of irradiance into voltage
Sensitivity	$9.05 \times 10^{-6} \text{ V}/(\text{W}/\text{m}^2)$	Voltage-to-irradiance conversion
Data acquisition board	National Instruments myDAQ	Analog signal acquisition
Analog input	Differential	Reduction in common-mode noise
Input range	$\pm 2 \text{ V}$	Adapted to the low-level signal
ADC resolution	16 bits	Analog-to-digital conversion
Sampling rate	1 kHz	Raw signal acquisition
Averaging/comparison interval	10 min	Temporal averaging and comparison with ANM
Acquisition software	LabVIEW	Display, recording, and primary processing
Operational reference	ANM Lugo	Experimental comparison

The CMP11 is a thermopile pyranometer classified as ISO 9060 Class A (secondary standard). Manufacturer specifications include a response time below 5 s, non-linearity below 0.2% over $0\text{--}1000 \text{ W}/\text{m}^2$, temperature dependence below 1% from -10°C to $+40^\circ\text{C}$, non-stability below 0.5% per year, directional error below $10 \text{ W}/\text{m}^2$, and tilt error below

0.2% [26]. These specification limits characterize the sensor type but do not replace the uncertainty stated in the calibration certificate of the individual instrument.

2.2. Voltage-to-Irradiance Conversion

For a calibrated pyranometer, the output voltage is proportional to the incident solar irradiance. The voltage-to-irradiance conversion used in this paper is based on instrument sensitivity, in accordance with the principles of pyranometer use and calibration [12,26,28].

$$G_{\text{UPT}} = \frac{\bar{U}}{S} \quad (1)$$

where G_{UPT} is the solar irradiance determined with the UPT system, $\bar{U}$ is the mean voltage at the pyranometer output, and S is the pyranometer sensitivity.

For the pyranometer used in the experimental system, the calibration sensitivity is given in Table 1.

The nominal quantization step of the analog-to-digital converter is determined using the following equation [27]:

$$q_U = \frac{\Delta U}{2^N} \quad (2)$$

where N is the converter resolution, expressed in bits.

For $N = 16$ bits, the following value is obtained:

$$q_U = \frac{4}{2^{16}} = 61.0 \mu\text{V} \quad (3)$$

The ratio between the voltage step and the pyranometer sensitivity represents the nominal step expressed in irradiance units:

$$q_G = \frac{q_U}{S} = q_G = \frac{61.0 \times 10^{-6}}{9.05 \times 10^{-6}} = 6.74 \text{ W/m}^2 \quad (4)$$

The value q_G represents the nominal irradiance increment corresponding to one ADC code for the selected input range and pyranometer sensitivity. It characterizes the single-conversion quantization step and does not represent the total measurement uncertainty or the smallest resolvable change after temporal processing. Averaging can reduce random electrical noise and improve repeatability, but it does not remove deterministic quantization limitations unless sufficient noise or dithering is present. The overall measurement behavior also depends on pyranometer calibration, temperature dependence, directional response, sensor leveling, dome cleanliness, analog-input offset, electrical noise, wiring quality, time alignment, and the averaging procedure [15,17].

2.3. Reference Data, Time Alignment, and Uncertainty Framework

The ANM Lugoj station is part of Romania's national meteorological observing network. ANM is Romania's national meteorological service and performs its observing activities within the World Meteorological Organization (WMO) framework. The WMO Guide to Instruments and Methods of Observation includes guidance on quality management, testing, calibration, and instrument intercomparison, while the ANM Annual Report 2024 documents the participation of national meteorological services in international observing systems based on common standards of accuracy and reliability and discusses measurement uncertainty and instrument intercomparison [14,29]. However, the station-specific instrument model, calibration certificate and date, maintenance records, exact averaging-window convention, and numerical uncertainty were not included in the dataset supplied to the authors. Therefore, the processed ten-minute global-irradiance

series supplied by ANM is used in this study as an operational reference rather than as a traceable primary reference. Consequently, the comparison assesses operational agreement at the available temporal resolution and does not claim primary-standard traceability or absolute metrological calibration of the UPT measurement chain.

Each UPT timestamp represents a trailing ten-minute average ending at the indicated time. The UPT and ANM datasets were paired by identical nominal timestamps and a common ten-minute cadence. Because the ANM series was supplied as processed operational data, the comparison was performed at the available time resolution; any residual difference in the exact averaging-window implementation is retained as a timing contribution, particularly under rapidly varying irradiance.

The uncertainty discussion is presented as a component-wise uncertainty-source framework based on ASTM G213 and radiometric best-practice guidance [15,17]. Table 2 identifies the available manufacturer specifications, installation and maintenance factors, acquisition-chain limitations, timing contribution, and the institutional reference framework. Because station-specific ANM uncertainty data and a traceable low-level calibration of the complete UPT acquisition chain were not available, the table is not presented as a complete numerical uncertainty budget and no combined expanded uncertainty is assigned. This distinction preserves the scope of the study as an operational agreement assessment rather than a laboratory calibration of both measurement chains.

Table 2. Principal uncertainty sources, operational evidence, and treatment in the present study.

Source	Operational Evidence	Treatment in This Study
CMP11 sensitivity calibration	Sensitivity = $9.05 \mu\text{V}/(\text{W}/\text{m}^2)$	Applied in the voltage-to-irradiance conversion; instrument-specific calibration uncertainty retained as a reference contribution
CMP11 non-linearity	$<0.2\%$ over $0\text{--}1000 \text{ W}/\text{m}^2$ [26]	Retained as a Type B bounding contribution
CMP11 temperature dependence	$<1\%$ from -10°C to $+40^\circ\text{C}$ [26]	Manufacturer limit retained; no separate temperature correction applied
CMP11 directional response	$<10 \text{ W}/\text{m}^2$ up to 80° at $1000 \text{ W}/\text{m}^2$ beam irradiance [26]	Retained as a solar-angle-dependent contribution
CMP11 zero offset	$<7 \text{ W}/\text{m}^2$ under the stated thermal-radiation condition [26]	Manufacturer limit retained; no separate field offset correction applied
CMP11 non-stability	$<0.5\%$ change per year [26]	Relevant to extended deployment and periodic calibration
Leveling, dome cleanliness, and wiring	Controlled through installation and operational checks	Treated as bounded installation and maintenance contributions
myDAQ quantization	16 bit, $\pm 2 \text{ V}$; nominal $61 \mu\text{V}$ per code, equivalent to $6.74 \text{ W}/\text{m}^2$	Reported as the nominal single-conversion resolution
myDAQ absolute accuracy	4.9 mV typical and 8.6 mV maximum for the $\pm 2 \text{ V}$ range under specified conditions [27]	Used as conservative instrument limits; not interpreted as pointwise measurement errors
Electrical noise and repeatability	Reduced through temporal averaging	Retained as a residual acquisition-chain contribution

Table 2. *Cont.*

Source	Operational Evidence	Treatment in This Study
Time synchronization	Matching nominal timestamps and common ten-minute cadence	Residual averaging-window alignment contribution retained for variable irradiance
ANM operational reference	Ten-minute irradiance values generated within ANM's national observing network; WMO guidance covers quality management, testing, calibration, and instrument intercomparison, and ANM reports participation in international observing systems based on common standards of accuracy and reliability [14,29]. Station-specific instrument and calibration records were not available to the authors.	Used as an operational reference rather than as a traceable primary reference; no separate numerical ANM uncertainty is propagated.

The NI accuracy values in Table 2 are used as conservative device-specification limits rather than as pointwise measurement errors. Since the CMP11 output occupies only a small fraction of the ± 2 V range, the present results are interpreted as an operational comparison. A defensible numerical uncertainty budget would require traceable characterization of the complete acquisition chain in the millivolt range and, preferably, a low-noise instrumentation-amplifier stage with a documented gain and uncertainty. The agreement observed against the ANM series is therefore reported as empirical evidence for the tested configuration and conditions, rather than as a substitute for calibration of the analog input.

2.4. Experimental Measurements and Dataset

To verify the operation of the designed and implemented irradiance measurement system (UPT), the system was installed at the meteorological station of the National Meteorological Administration located in Lugoj, Romania, at latitude 45.686110, longitude 21.900560, and altitude 123 m. The UPT sensor and the ANM operational system were installed at the same station (Figure 5) and were therefore exposed to nominally comparable global solar irradiance. Co-location reduces differences associated with site, local horizon, shading environment, and microclimate; however, it does not guarantee identical sensor responses. Residual differences may remain because of sensor leveling, dome condition, directional response, thermal offset, instrument-specific calibration, and exact averaging-window alignment.

The experimental measurements considered in the extended validation were conducted on five non-consecutive days: 16 December 2025, 13 March 2026, 25 March 2026, 4 May 2026, and 7 May 2026. To ensure an identical comparison interval for all datasets, 43 irradiance values were selected for each day, uniformly distributed from 09:04 to 16:04 at 10 min intervals. The resulting dataset contained 215 paired UPT-ANM values. The measured quantity was global solar irradiance, expressed in W/m^2 . Each reported UPT value represents the arithmetic mean associated with the corresponding ten-minute interval. All statistical calculations used the full numerical precision contained in the source file, whereas the values in Tables 3 and 4 are displayed to one decimal place.

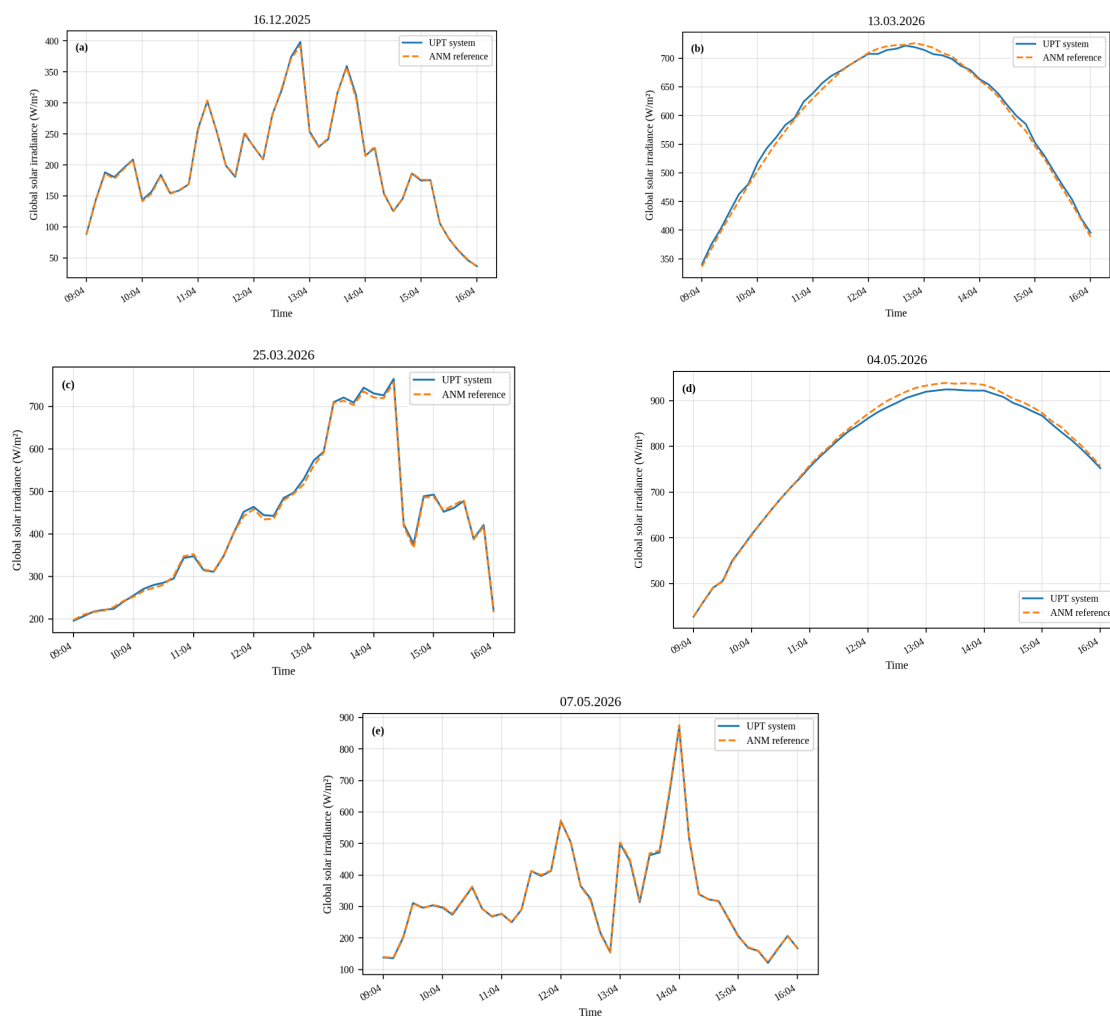


Figure 5. Temporal evolution of global solar irradiance measured by the UPT system and the ANM system: (a) 16 December 2025; (b) 13 March 2026; (c) 25 March 2026; (d) 4 May 2026; (e) 7 May 2026.

Table 3. Solar irradiance values measured with the UPT system.

Time	16 December 2025 (W/m²)	13 March 2026 (W/m²)	25 March 2026 (W/m²)	4 May 2026 (W/m²)	7 May 2026 (W/m²)
09:04	88.7	340.4	196.0	427.6	138.1
09:14	143.7	374.8	206.7	459.7	135.9
09:24	188.1	401.6	217.4	490.3	201.3
09:34	180.5	432.6	221.5	505.6	311.0
09:44	195.0	462.9	223.9	550.3	296.1
09:54	208.7	480.2	240.9	578.3	303.6
10:04	143.5	517.2	255.6	607.5	296.5
10:14	156.9	542.9	270.9	634.1	274.0
10:24	184.0	561.7	279.9	660.6	317.6
10:34	154.6	583.4	285.4	685.7	360.9
10:44	158.9	595.5	295.3	709.4	293.8
10:54	169.0	624.4	343.4	731.1	268.1
11:04	258.5	639.3	347.5	755.1	276.6
11:14	302.6	656.7	314.5	776.5	249.9

Table 3. *Cont.*

Time	16 December 2025 (W/m ²)	13 March 2026 (W/m ²)	25 March 2026 (W/m ²)	4 May 2026 (W/m ²)	7 May 2026 (W/m ²)
11:24	254.3	669.5	310.9	795.9	289.8
11:34	198.8	678.2	348.1	815.2	412.4
11:44	180.7	688.6	401.9	832.9	397.0
11:54	250.4	698.4	451.9	846.2	413.1
12:04	229.2	707.8	463.6	861.1	570.6
12:14	208.9	707.5	444.1	874.6	504.3
12:24	281.4	714.4	442.3	885.5	365.7
12:34	320.5	716.6	484.5	895.4	325.1
12:44	373.8	722.1	496.8	906.1	217.2
12:54	398.2	719.3	528.6	912.8	155.4
13:04	254.1	714.6	572.3	919.4	500.2
13:14	229.4	707.2	593.1	921.8	444.3
13:24	241.4	705.0	709.8	924.4	314.1
13:34	316.3	699.0	720.4	924.0	462.8
13:44	359.4	686.6	708.6	922.3	471.6
13:54	312.2	679.7	743.7	921.8	656.4
14:04	215.0	663.6	730.2	921.9	869.6
14:14	227.3	654.1	725.6	914.7	517.7
14:24	153.6	638.6	764.2	907.9	338.9
14:34	125.4	618.2	422.8	894.9	322.5
14:44	145.2	599.2	376.3	886.7	317.2
14:54	186.3	585.2	488.4	876.4	261.8
15:04	174.7	552.4	492.3	866.8	206.3
15:14	175.5	530.2	452.0	848.2	168.8
15:24	106.4	503.5	460.7	830.6	159.3
15:34	80.8	477.8	477.2	814.1	121.1
15:44	62.0	453.5	388.4	795.0	164.7
15:54	46.8	420.0	420.9	774.3	206.8
16:04	36.9	395.6	218.6	752.3	167.6

Table 4. Solar irradiance values measured by the ANM station.

Time	16 December 2025 (W/m ²)	13 March 2026 (W/m ²)	25 March 2026 (W/m ²)	4 May 2026 (W/m ²)	7 May 2026 (W/m ²)
09:04	87.8	336.4	198.0	428.1	139.5
09:14	142.6	366.9	210.4	460.0	137.5
09:24	185.9	396.9	216.5	491.4	204.0
09:34	177.6	424.4	219.8	504.0	309.6
09:44	193.3	451.3	228.2	548.1	294.7
09:54	207.9	478.0	242.8	577.3	304.8
10:04	141.3	503.3	252.4	605.5	299.0
10:14	153.9	528.0	266.0	634.2	277.3

Table 4. *Cont.*

Time	16 December 2025 (W/m ²)	13 March 2026 (W/m ²)	25 March 2026 (W/m ²)	4 May 2026 (W/m ²)	7 May 2026 (W/m ²)
10:24	182.7	551.7	273.2	660.2	319.2
10:34	153.2	573.3	280.7	686.2	363.4
10:44	159.8	593.4	300.9	708.9	292.8
10:54	169.2	613.5	347.4	733.8	269.7
11:04	255.8	630.0	352.3	759.0	277.4
11:14	304.1	646.5	316.2	780.4	249.7
11:24	253.5	661.6	312.3	799.3	290.9
11:34	199.0	676.7	349.2	821.3	412.9
11:44	183.0	688.7	403.1	838.0	400.4
11:54	253.0	698.5	441.5	855.0	414.7
12:04	228.4	709.6	458.2	870.8	573.7
12:14	209.5	716.6	434.0	885.9	502.7
12:24	280.3	721.0	435.7	899.6	364.6
12:34	323.5	723.0	479.6	910.1	320.1
12:44	370.6	723.5	494.4	920.2	213.7
12:54	392.4	726.4	516.7	928.2	154.0
13:04	252.1	723.0	560.3	932.6	503.8
13:14	228.5	718.3	591.0	936.2	449.5
13:24	243.9	709.1	707.8	938.6	319.0
13:34	316.5	703.6	712.8	936.9	469.0
13:44	356.9	690.2	702.9	937.8	477.5
13:54	306.6	676.1	735.0	936.8	664.8
14:04	214.3	661.8	720.5	934.2	875.6
14:14	229.9	649.0	718.9	926.7	520.3
14:24	154.7	633.5	755.9	915.7	340.0
14:34	125.7	612.0	418.4	904.4	322.9
14:44	146.2	590.1	366.9	896.7	315.8
14:54	187.0	573.3	485.7	885.6	259.7
15:04	176.3	546.4	487.1	872.8	204.0
15:14	175.8	525.5	455.1	854.9	171.1
15:24	106.4	497.1	467.9	841.5	159.9
15:34	80.5	471.5	480.2	821.1	123.4
15:44	62.8	445.2	386.8	802.3	167.0
15:54	47.8	418.0	417.3	780.3	205.6
16:04	36.2	388.6	216.4	757.0	168.2

3. Validation of the Irradiance Measurement System

For each of the five days, 43 ANM values generated within the standardized national observing framework described in Section 2.3 and corresponding to the common comparison interval were used. The analysis therefore comprised 215 UPT-ANM pairs. The ANM series, used as the operational reference, is presented in Table 4.

3.1. Temporal Evolution of Solar Irradiance

The five measurement days covered distinct irradiance levels and temporal profiles. On 16 December 2025, the UPT values ranged from 36.9 to 398.2 W/m², while the ANM values ranged from 36.2 to 392.4 W/m². On 13 March 2026, the corresponding ranges were 340.4–722.1 W/m² for UPT and 336.4–726.4 W/m² for ANM. On 25 March 2026, the UPT and ANM ranges were 196.0–764.2 W/m² and 198.0–755.9 W/m², respectively.

For 4 May 2026, the irradiance profile was comparatively regular, with UPT values between 427.6 and 924.4 W/m² and ANM values between 428.1 and 938.6 W/m². For 7 May 2026, the profile was more variable, with ranges of 121.1–869.6 W/m² for UPT and 123.4–875.6 W/m² for ANM. The temporal evolution for all five days is presented in Figure 5.

Although the pyranometer signal was sampled at 1 kHz and the CMP11 has a nominal response time below 5 s [26], the present comparison uses ten-minute averages. This averaging attenuates short transients produced by passing clouds or brief shading. Accordingly, the current results validate agreement at the ten-minute averaging scale and do not constitute a direct characterization of the sub-minute dynamic response of the acquisition chain.

3.2. Error Metrics

For each pair of values corresponding to the same time point, the pointwise difference was calculated between the irradiance values measured with the UPT system and the ANM data used as the reference (d_i):

$$d_i = G_{\text{UPT},i} - G_{\text{ANM},i} \quad (5)$$

The relative error at each considered point was calculated using the following equation:

$$\varepsilon_i = \frac{d_i}{G_{\text{ANM},i}} \times 100 \quad (6)$$

where $G_{\text{UPT},i}$ is the irradiance value measured with the UPT system, $G_{\text{ANM},i}$ is the value provided by ANM, and $i = 1, 2, \dots, n$, where n is the total number of analyzed pairs.

For the overall evaluation of differences between the two datasets, the following statistical indicators, frequently used in photovoltaic system performance monitoring and in solar radiation data-quality assessment [13,16,17], were used: MBE—mean bias error, MAE—mean absolute error, RMSE—root mean square error, nRMSE—normalized root mean square error, MRE—mean relative error, and MARE—mean absolute relative error.

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^n d_i \quad (7)$$

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^n |d_i| \quad (8)$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n d_i^2} \quad (9)$$

$$\text{nRMSE} = \frac{\text{RMSE}}{G_{\text{ANM}}} \times 100 \quad (10)$$

$$\text{MRE} = \frac{1}{n} \sum_{i=1}^n \varepsilon_i \quad (11)$$

$$\text{MARE} = \frac{1}{n} \sum_{i=1}^n |\varepsilon_i| \quad (12)$$

Although the nominal single-conversion irradiance step is 6.74 W/m^2 , the reported error metrics are calculated from temporally averaged values obtained from many raw samples. Averaging reduces random noise, but it does not eliminate deterministic quantization effects unless sufficient noise or dithering is present. Consequently, the nominal quantization step is discussed as one component of the acquisition-chain resolution and not as the total measurement uncertainty.

The mean of the ANM reference values is:

$$\overline{G}_{\text{ANM}} = \frac{1}{n} \sum_{i=1}^n G_{\text{ANM},i} \quad (13)$$

The incident solar energy per unit area over the analyzed interval was determined by summing the product of the mean irradiance corresponding to each interval and the duration of that interval [17,28,30].

$$E = \sum_{i=1}^n G_i \cdot \Delta t \quad (14)$$

$$\Delta t = 10 \text{ min} = 600 \text{ s} \quad (15)$$

$$1 \text{ J/m}^2 = 1 \text{ W} \cdot \text{s/m}^2 \quad (16)$$

$$E [\text{MJ/m}^2] = \frac{E [\text{J/m}^2]}{10^6} \quad (17)$$

Bland–Altman analysis was applied to the differences expressed in W/m^2 to identify the systematic deviation and the limits of agreement in the physical unit of the measured quantity [31,32]. For each pair of values, the pair mean was calculated as follows:

$$m_i = \frac{G_{\text{UPT},i} + G_{\text{ANM},i}}{2} \quad (18)$$

The method bias was calculated as the mean of the differences:

$$\text{bias} = \bar{d} = \frac{1}{n} \sum_{i=1}^n d_i \quad (19)$$

The standard deviation of the differences was calculated as follows:

$$s_d = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (d_i - \bar{d})^2} \quad (20)$$

The Bland–Altman limits of agreement (LoA) were calculated using the following equation:

$$\text{LoA} = \text{bias} \pm 1.96 \cdot s_d \quad (21)$$

These limits theoretically indicate the interval within which approximately 95% of the differences between the UPT and ANM values are expected to fall, assuming an approximately normal distribution of the differences.

To examine possible irradiance-dependent bias, the UPT–ANM differences were regressed against the corresponding pairwise mean irradiance values. The following linear regression model was used [32]:

$$d_i = \beta_0 + \beta_1 m_i + \varepsilon_i, \quad (22)$$

where d_i is the difference between the UPT and ANM measurements, m_i is their pairwise mean, β_0 is the intercept, β_1 is the regression slope, and ε_i is the residual error. A statistically significant slope different from zero indicates a proportional component of bias, meaning that the difference between the two measurement systems varies with the irradiance level. The regression analysis was performed for the combined dataset and separately for each measurement day.

3.2.1. Temporal Variation in Relative Error

The temporal variation in the relative error is presented in Figure 6. The ranges obtained for the five days were as follows: 16 December 2025: -2.13% to 1.98% (maximum absolute value 2.13%); 13 March 2026: -1.55% to 2.82% (maximum absolute value 2.82%); 25 March 2026: -1.88% to 2.56% (maximum absolute value 2.56%); 4 May 2026: -1.66% to 0.40% (maximum absolute value 1.66%); 7 May 2026: -1.86% to 1.64% (maximum absolute value 1.86%).

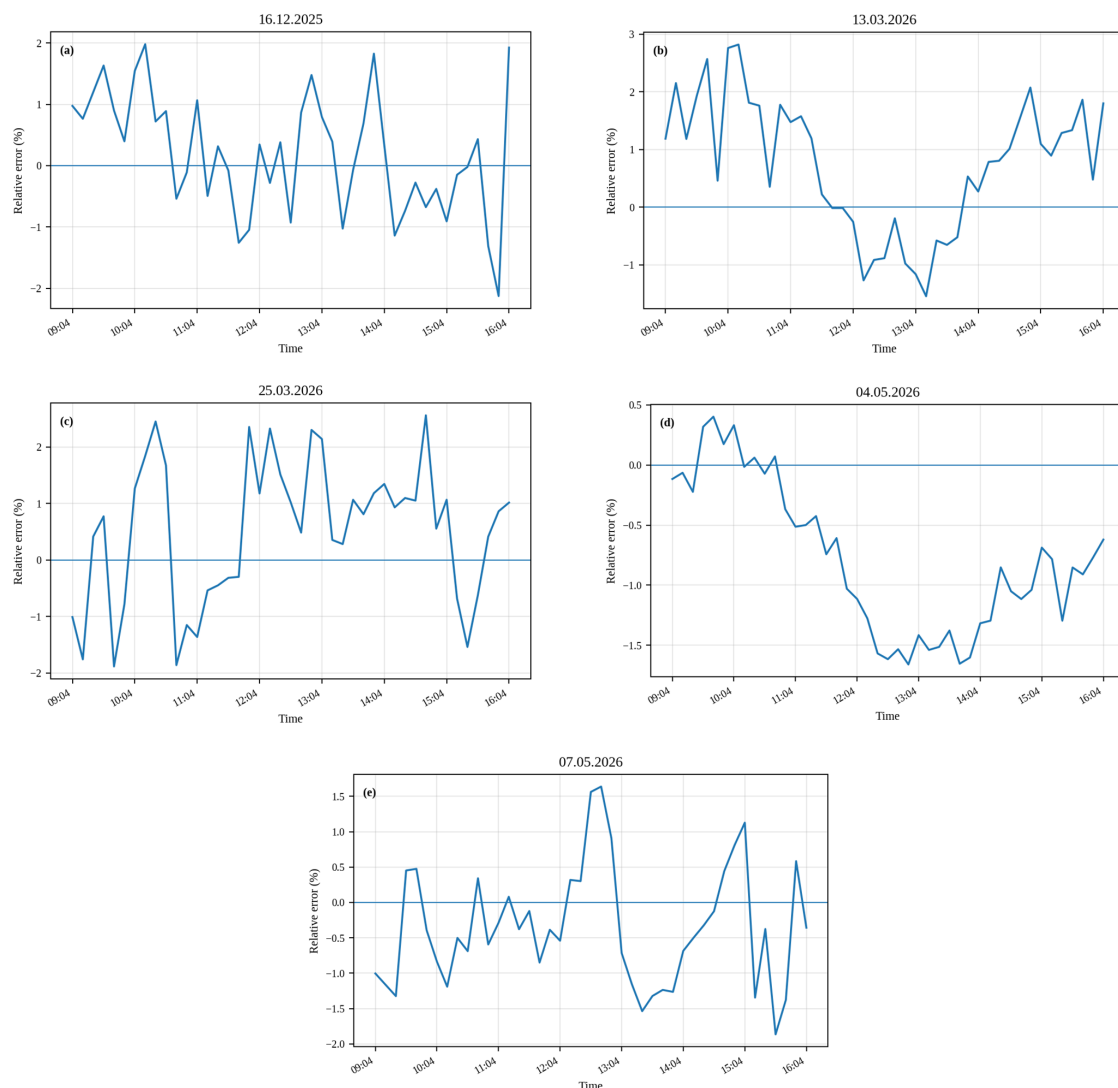


Figure 6. Relative error of the UPT system with respect to the ANM values: (a) 16 December 2025; (b) 13 March 2026; (c) 25 March 2026; (d) 4 May 2026; (e) 7 May 2026.

3.2.2. Absolute Relative Error and Mean Absolute Relative Error

The temporal variation in the absolute relative error is presented in Figure 7. For 16 December 2025, MARE was 0.82% . For 13 March 2026, MARE was 1.16% . For 25 March 2026, MARE was 1.18% . For 4 May 2026, MARE was 0.85% . For 7 May 2026, MARE was

0.78%. For the global dataset, MARE was 0.96%, indicating a mean absolute percentage deviation below 1%.

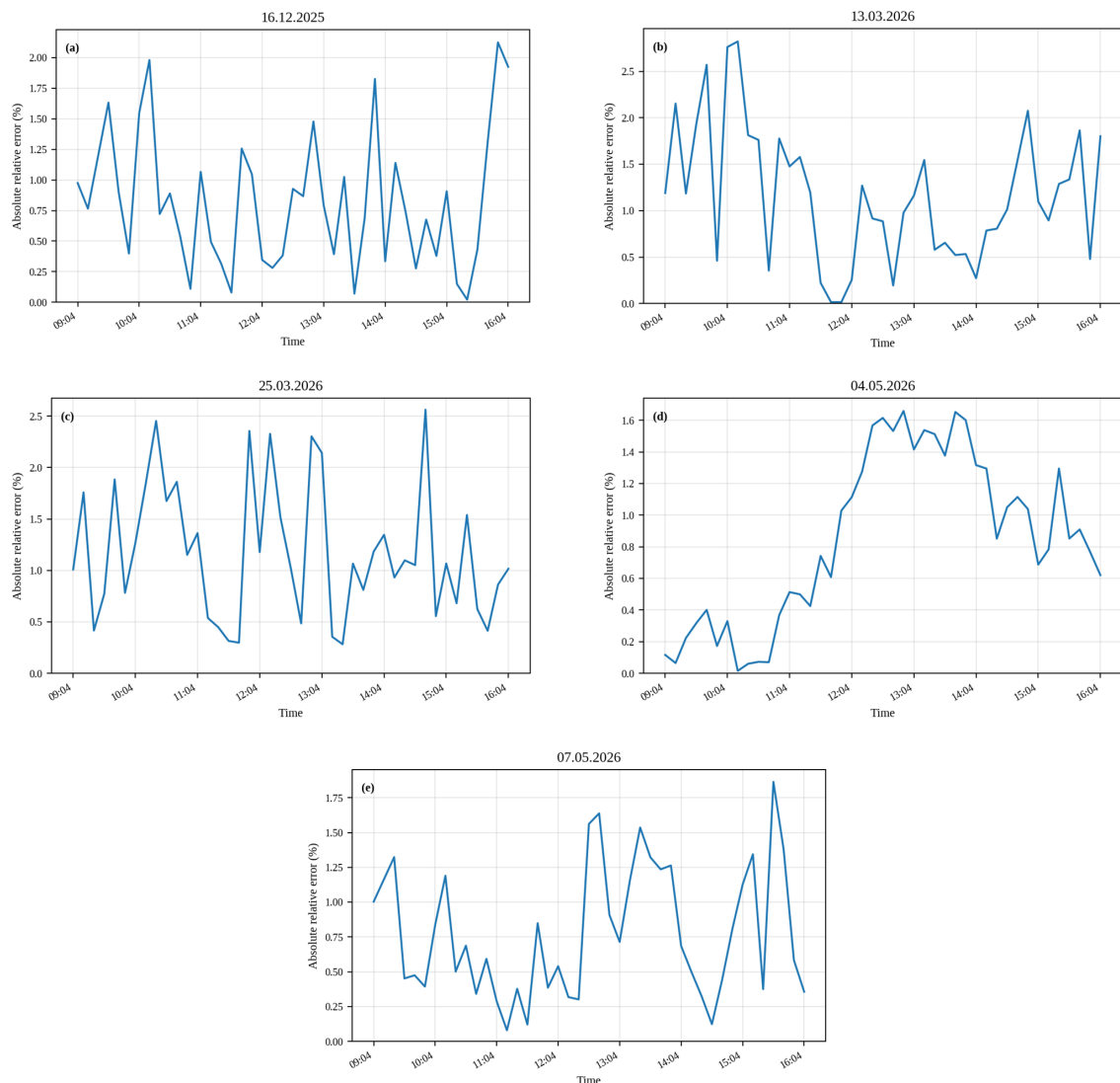


Figure 7. Absolute relative error between the UPT and ANM values: (a) 16 December 2025; (b) 13 March 2026; (c) 25 March 2026; (d) 4 May 2026; (e) 7 May 2026.

3.2.3. Error Metric Values

The values obtained for the error metrics, calculated using Equations (7)–(12) and implemented in MATLAB, are presented in Table 5.

Table 5. Statistical indicators for the UPT-ANM comparison.

Dataset	N	MBE (W/m ²)	MAE (W/m ²)	RMSE (W/m ²)	nRMSE (%)	MRE (%)	MARE (%)	Maximum Absolute Relative Error (%)
16 December 2025	43	0.49	1.59	2.04	1.01	0.19	0.82	2.13
13 March 2026	43	3.45	6.45	7.41	1.26	0.75	1.16	2.82
25 March 2026	43	2.81	4.90	5.78	1.35	0.51	1.18	2.56
4 May 2026	43	−7.04	7.40	9.00	1.13	−0.79	0.85	1.66
7 May 2026	43	−1.34	2.44	3.04	0.93	−0.36	0.78	1.86
Global	215	−0.33	4.55	6.05	1.29	0.06	0.96	2.82

The statistical indicators for the five individual datasets and for the combined dataset are summarized in Table 5.

For the global dataset, $MBE = -0.33 \text{ W/m}^2$ indicates an almost negligible mean signed deviation. The global MAE was 4.55 W/m^2 , while RMSE was 6.05 W/m^2 . The normalized error $nRMSE = 1.29\%$ and $MARE = 0.96\%$ confirm that the deviations remained small relative to the measured irradiance levels under the tested conditions.

3.3. Incident Solar Energy per Unit Area

The incident solar energy per unit area over the measurement interval was calculated using Equation (14), implemented in MATLAB. The results are presented in Table 6.

Table 6. Incident solar energy per unit area calculated from the UPT and ANM values.

Dataset	E_UPT (MJ/m ²)	E_ANM (MJ/m ²)	Absolute Difference (MJ/m ²)	Relative Difference (%)
16 December 2025	5.207	5.194	0.013	0.24
13 March 2026	15.312	15.223	0.089	0.59
25 March 2026	11.122	11.050	0.072	0.66
4 May 2026	20.289	20.471	−0.182	−0.89
7 May 2026	8.427	8.462	−0.035	−0.41
Global	60.357	60.399	−0.042	−0.07

For the entire dataset, the energy calculated from the UPT values was 60.357 MJ/m^2 , while the energy calculated from the ANM values was 60.399 MJ/m^2 . The difference was -0.042 MJ/m^2 , corresponding to a relative difference of -0.07% . The graphical comparison of the calculated incident solar energy per unit area is presented in Figure 8.

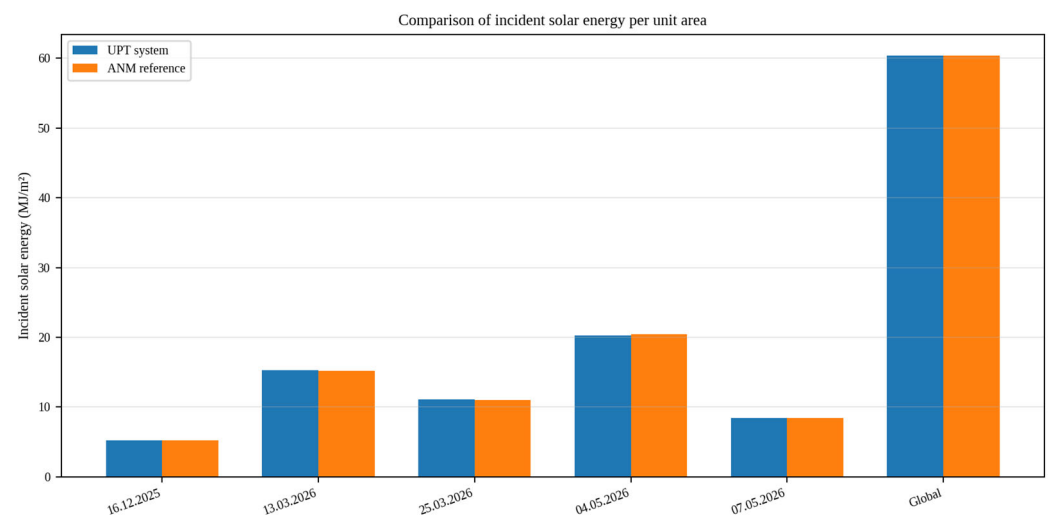


Figure 8. Comparison of incident solar energy per unit area calculated from the UPT and ANM values for each measurement day and for the global dataset.

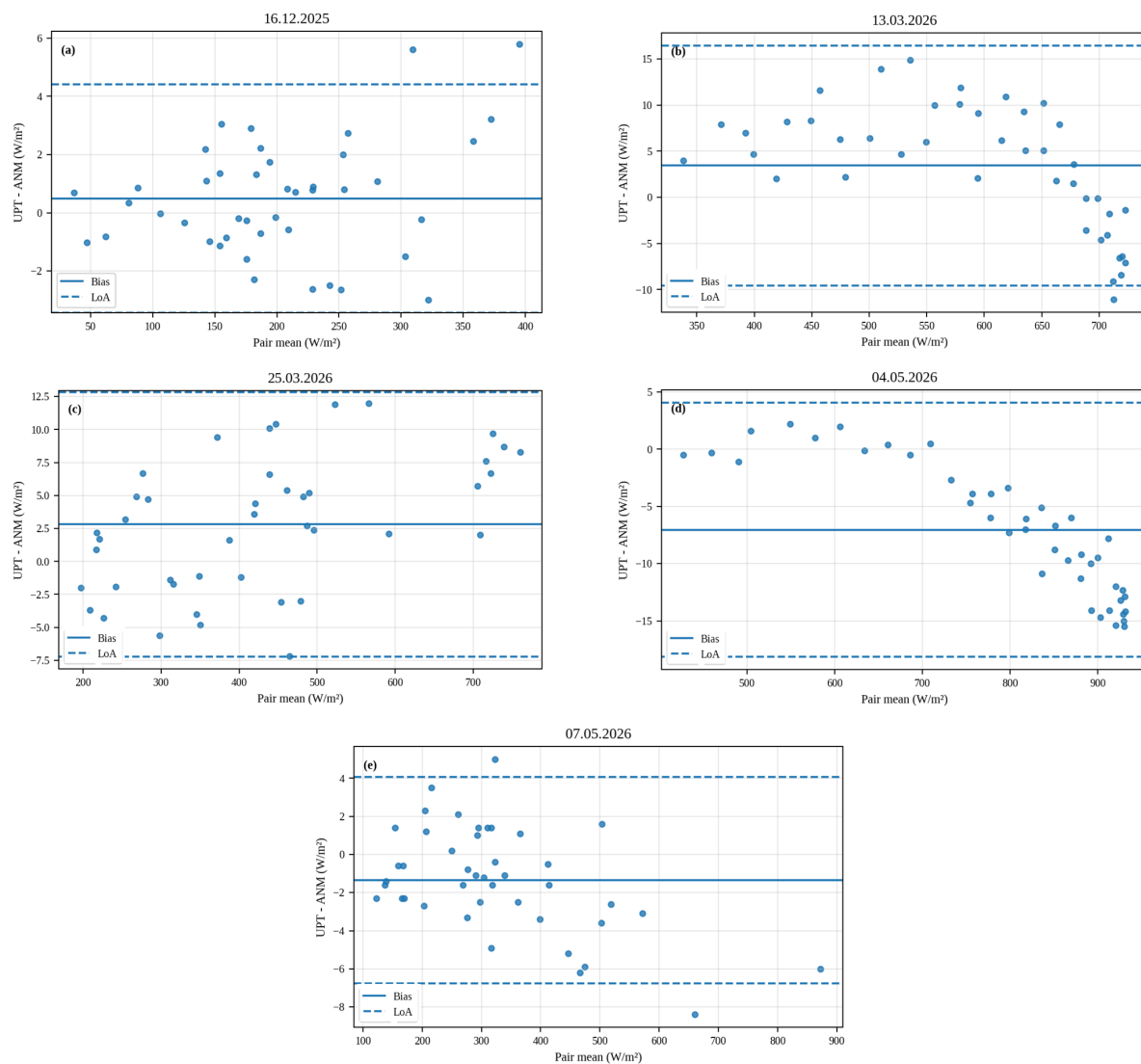
3.4. Bland–Altman Analysis

Bland–Altman analysis was performed separately for each measurement day. A single pooled set of limits of agreement was not used because the five datasets exhibited different irradiance profiles and day-specific biases; pooling them would impose one common bias and one common dispersion on heterogeneous measurement conditions. Table 7 presents the day-specific Bland–Altman parameters.

Table 7. Day-specific results of the Bland–Altman analysis for the UPT-ANM comparison.

Dataset	Bias (W/m ²)	SD (W/m ²)	Lower LoA Limit (W/m ²)	Upper LoA Limit (W/m ²)	Points Outside the Limits (%)
16 December 2025	0.49	2.00	−3.43	4.42	4.65
13 March 2026	3.45	6.64	−9.55	16.46	2.33
25 March 2026	2.81	5.11	−7.21	12.82	0.00
4 May 2026	−7.04	5.68	−18.16	4.09	0.00
7 May 2026	−1.34	2.76	−6.75	4.07	4.65

The daily biases ranged from -7.04 W/m^2 to 3.45 W/m^2 , confirming that the direction and magnitude of the systematic deviation varied among the measurement days. Consequently, the separate daily limits provide a more representative assessment of agreement under each tested radiative condition. The corresponding Bland–Altman plots are presented in Figure 9.

**Figure 9.** Bland–Altman analysis for the UPT-ANM comparison: (a) 16 December 2025; (b) 13 March 2026; (c) 25 March 2026; (d) 4 May 2026; (e) 7 May 2026.

The percentages of differences outside the day-specific limits of agreement were 4.65%, 2.33%, 0.00%, 0.00%, and 4.65% for 16 December 2025, 13 March 2026, 25 March 2026, 4 May 2026, and 7 May 2026, respectively.

4 May 2026, and 7 May 2026, respectively. Thus, for every individual dataset, at least approximately 95% of the differences were contained within the corresponding day-specific limits of agreement.

Regression of the UPT-ANM differences against pairwise mean irradiance indicated an irradiance-dependent component of bias. For the combined dataset, the slope was $\beta_1 = -0.0092 \text{ W/m}^2 \text{ per W/m}^2$ ($R^2 = 0.140$, $p < 0.001$), corresponding to an average change of approximately -0.92 W/m^2 in the UPT-ANM difference for each 100 W/m^2 increase in mean irradiance. Significant day-specific slopes were obtained for 13 March 2026, 25 March 2026, 4 May 2026, and 7 May 2026, whereas the slope for 16 December 2025 was not statistically significant ($p = 0.063$). The strongest irradiance dependence occurred on 4 May 2026 ($\beta_1 = -0.0341$, $R^2 = 0.772$, $p < 0.001$), when the UPT-ANM difference became progressively more negative at high irradiance.

4. Discussion

The extended five-day comparison showed promising agreement between the UPT measurement system and the ANM operational reference under the tested conditions. For the combined dataset, MAE = 4.55 W/m^2 , RMSE = 6.05 W/m^2 , nRMSE = 1.29%, and MARE = 0.96%. The global MBE was -0.33 W/m^2 ; however, this near-zero aggregate value partly results from compensation between positive deviations in December and March and negative deviations in May.

The measurement days represented different irradiance levels and temporal profiles. The December dataset contained lower irradiance and several short-term variations; the March datasets included both comparatively regular and strongly variable profiles; and the May datasets included a high-irradiance regular profile and a highly variable profile. The use of a common 09:04–16:04 interval makes the daily statistical and energy indicators directly comparable, but five non-consecutive days still do not represent complete seasonal or long-term behavior.

The cumulative incident energy calculated from the UPT values was 60.357 MJ/m^2 , compared with 60.399 MJ/m^2 for ANM, corresponding to a global difference of -0.07% . At the daily level, the relative energy difference ranged from -0.89% to 0.66% . These results indicate that the cumulative disagreement was small for the analyzed intervals, while individual instantaneous deviations remained dependent on the irradiance regime.

The Bland–Altman assessment was interpreted on a day-specific basis. The daily biases ranged from -7.04 W/m^2 to 3.45 W/m^2 , and the percentages of differences outside the corresponding limits of agreement ranged from 0.00% to 4.65%. The change in both sign and magnitude of the daily bias shows that the comparison cannot be represented adequately by one pooled constant offset. Day-specific limits are therefore more informative for the tested radiative regimes than a single set of global limits.

The regression analysis further indicated irradiance-dependent bias. For the combined dataset, the negative slope $\beta_1 = -0.0092$ ($R^2 = 0.140$, $p < 0.001$) shows that the UPT-ANM difference tended to become more negative as irradiance increased. This effect was most pronounced on 4 May 2026, for which $\beta_1 = -0.0341$ ($R^2 = 0.772$, $p < 0.001$), consistent with the larger negative deviations observed at high irradiance. The positive slope obtained on 25 March 2026 and the negative slopes obtained on 13 March 2026 and the two days in May also show that the proportional component was not invariant between days. Consequently, the present data do not support the use of one constant correction factor over the full irradiance range. Possible contributors include directional response, temperature dependence, zero offset, instrument-specific calibration, leveling and dome condition, analog-input offset and noise, and residual differences in time-window alignment.

The error indicators were also compared with representative irradiance-monitoring studies, as summarized in Table 8. The present nRMSE of 1.29% is of the same order as the 1.22% outdoor nRMSE reported for a neural-network-based irradiance estimator [33], while the MARE of 0.96% is lower than the reported MAPE magnitudes of 2.19–3.82% for two IoT photodiode prototypes [24]. These numerical comparisons should not be interpreted as a ranking because the sensor principles, reference instruments, averaging intervals, calibration procedures, meteorological conditions, and validation durations differ substantially.

Table 8. Comparison with representative irradiance-monitoring and acquisition studies.

Study	Measurement Architecture	Validation Scope	Reported Performance/Emphasis
Rohit et al. [22]	PV-module monitoring platform with LabVIEW-based acquisition	Laboratory monitoring of PV modules	Real-time visualization and PV performance parameters; no dedicated irradiance-agreement metric reported
Rocha et al. [24]	Silicon photodiodes, conditioning circuit, ESP8266, cloud/IoT interface	200 days; comparison with official meteorological data	$R^2 = 0.958\text{--}0.962$; reported MAPE magnitude = 2.19–3.82%; remote operation
Chouay and Ouassaid [33]	PV-cell/module signals, neural-network estimator, embedded controller	Indoor and outdoor tests, including rapid changes	Outdoor nRMSE = 1.22%; indoor irradiance MAPE = 1.45%
Present study	CMP11 thermopile, NI myDAQ, LabVIEW acquisition, MATLAB analysis	Five non-consecutive days; 215 ten-minute pairs	nRMSE = 1.29%; MARE = 0.96%; energy difference = -0.07% ; day-specific Bland–Altman analysis

The technical contribution of the UPT system therefore lies in the combination of a broad-spectrum thermopile sensor, a configurable laboratory acquisition board, an accessible LabVIEW implementation, and a validation workflow that retains the physical units of the measured quantity. The system does not provide the autonomous wireless and cloud functions of dedicated IoT platforms, but it offers direct control of the acquisition settings, conversion algorithm, averaging interval, primary data, energy integration, and agreement analysis.

The link to the authors' previous photovoltaic modeling study is methodologically relevant because irradiance is an input to the simulated PV electrical quantities [11]. For a first-order estimate at fixed module temperature and operating conditions, the relative change in predicted PV power is approximately proportional to the relative change in irradiance, $\Delta P/P \approx \Delta G/G$. Accordingly, the daily incident-energy differences observed here, from -0.89% to 0.66% , imply an irradiance-driven PV energy difference in the same order of magnitude, while the cumulative five-day estimate is approximately -0.07% . This is an input-sensitivity estimate rather than a complete PV case study; the exact electrical effect also depends on module temperature, model nonlinearity, inverter operation, and MPPT behavior.

The five-day campaign characterizes short-term operational agreement across several irradiance regimes. Long-term stability, seasonal drift, and calibration evolution remain outside the temporal scope of this dataset. Manufacturer limits for non-stability and temperature dependence [26] define relevant bounds for extended deployment. Periodic calibration, leveling verification, dome maintenance, connector inspection, and offset checks are therefore included as operational requirements for future long-duration campaigns.

5. Conclusions

This paper presented a global solar irradiance measurement system designed and implemented at Politehnica University Timisoara. The system combines a Kipp & Zonen CMP11 thermopile pyranometer, a National Instruments myDAQ acquisition board, and a LabVIEW 2018 interface for acquisition, conversion, averaging, display, and storage of irradiance data.

The preliminary operational validation comprised five non-consecutive measurement days: 16 December 2025, 13 March 2026, 25 March 2026, 4 May 2026, and 7 May 2026. A common interval from 09:04 to 16:04 provided 43 ten-minute averaged pairs per day and 215 UPT-ANM pairs in total. The global values were $MBE = -0.33 \text{ W/m}^2$, $MAE = 4.55 \text{ W/m}^2$, $RMSE = 6.05 \text{ W/m}^2$, $nRMSE = 1.29\%$, $MRE = 0.06\%$, and $MARE = 0.96\%$.

The incident solar energy per unit area was 60.357 MJ/m^2 for the UPT dataset and 60.399 MJ/m^2 for the ANM dataset. The difference was -0.042 MJ/m^2 , or -0.07% , while the daily differences ranged from -0.89% to 0.66% . Under a first-order fixed-temperature assumption, the irradiance-driven effect on predicted PV energy is expected to be of the same order of magnitude.

Separate Bland–Altman analyses showed that the direction and magnitude of the bias varied with the measurement day and irradiance profile. The percentages of points outside the day-specific limits of agreement were 4.65%, 2.33%, 0.00%, 0.00%, and 4.65%, respectively. Regression of the differences against pairwise mean irradiance also identified an irradiance-dependent component of bias for the combined dataset ($\beta_1 = -0.0092$, $R^2 = 0.140$, $p < 0.001$), with the strongest dependence occurring on 4 May 2026. These findings support day-specific interpretation and indicate that one constant correction factor is not representative of all tested irradiance regimes.

The results demonstrate promising agreement with the ANM operational reference for the five tested days. The ANM data originate from Romania's national meteorological observing network, which operates within the WMO framework. WMO guidance addresses quality management, testing, calibration, and instrument intercomparison, while the ANM Annual Report 2024 documents participation in international observing systems based on common standards of accuracy and reliability [14,29]. However, because the station-specific reference instrument, calibration certificate, exact averaging convention, and numerical uncertainty were not supplied with the dataset, the conclusions are limited to operational agreement at the available ten-minute resolution and do not constitute traceable calibration of the UPT chain.

Future work will extend the assessment through longer-duration monitoring, traceable millivolt-level characterization of the UPT acquisition chain, synchronized high-resolution reference measurements, and, where available, incorporation of station-specific reference uncertainty into a combined uncertainty budget. The platform will also be developed toward wireless data transmission, cloud-based monitoring, and integration into Internet of Things architectures for real-time photovoltaic performance evaluation. After sufficiently extensive and quality-controlled datasets have been collected, the measured irradiance series may also support machine-learning-based irradiance and photovoltaic-power forecasting [4,24,25,33].

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ADC	Analog-to-digital converter
ANM	National Meteorological Administration of Romania
ASTM	ASTM International; standards organization
BSRN	Baseline Surface Radiation Network
DAQ	Data acquisition
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISO	International Organization for Standardization
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
LoA	Limits of agreement
MAE	Mean absolute error
MARE	Mean absolute relative error
MATLAB	Matrix Laboratory
MBE	Mean bias error
MPPT	Maximum power point tracking
MRE	Mean relative error
myDAQ	National Instruments data acquisition board
NI	National Instruments
nRMSE	Normalized root mean square error
Pmax	Maximum power of the photovoltaic module
RMSE	Root mean square error
SD	Standard deviation
UPT	Measurement system developed at Politehnica University Timisoara
WMO	World Meteorological Organization

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