International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 11 | Nov 2026 www.irjet.net p-ISSN: 2395-0072

# Development of an ESP32-based Global-and-Direct-Solar-Radiation Measuring Device

**Nikola Kolev[1], Elena Tolstosheeva[2], Rumen Popov[3], Hristina Petrova[4]**

[1]*Undergraduate Student, Department of Physics, University of Plovdiv "Paisii Hilendarski," Bulgaria*
[2]*Assistant, Department of Physics, University of Plovdiv "Paisii Hilendarski," Bulgaria*
[3]*Professor, EKIT Department, University of Plovdiv, "Paisii Hilendarski," Bulgaria*
[4]*Associate Professor, Department of Physics Education, University of Plovdiv "Paisii Hilendarski," Bulgaria*

---

**Abstract -** *In light of the latest unprecedented fluctuations in global weather dynamics, the significance of climate forecasting has grown exponentially. Minor fluctuations can trigger large-scale non-linear outcomes within dynamic atmospheric systems. This work is based on professional Kipp & Zonen solar radiation sensors. A stand-alone ESP32-based system gathers measurement data in real time. It enables second-wise monitoring of global and direct radiation, with a relative error of less than 1%, indicating high accuracy. This cost-effective, open-source, and highly precise system can be used to study solar radiation dynamics in educational and research settings, paving the way for an enhanced understanding of weather dynamics, particularly in institutions with limited financial support.*

**Keywords: Weather monitoring, ESP microcontroller, direct solar radiation, global solar radiation, Kipp & Zonen.**

## 1. INTRODUCTION

Temperature anomalies, as a prominent parameter in weather data, have reached unprecedented levels in 2026 [1]. Minor fluctuations can trigger large-scale, non-linear outcomes within chaotic atmospheric systems, revealing that large-scale atmospheric processes to originate from the averaging of microscopic fluctuations, for example, within clouds themselves [2]. In [3] the authors present a pyranometric system, capable of measuring solar radiation, based on BH1750 [4, 5, 6] and VEML7700 light sensors. BH1750 measures illuminance up to 65,000 lx, and VEML7700 is a high-sensitivity photodiode with a range of 0.003 - 120,000 lx. The latter is reported to measure correctly up to 1000 lx, and beyond this level, a polynomial correction should be applied. Another critical requirement for utilizing photometric sensors is the necessity to convert illuminance units (lux) to solar irradiance ($W/m^2$) [7].

As far as pyranometric sensor-based systems are concerned, state-of-the-art automated systems rely on low-cost pyranometers, originally calibrated against a Kipp & Zonen reference [8, 9]. A recent advancement in automating the Kipp & Zonen SP Lite2 silicon photodiode within the Arduino framework utilizes an AD620 instrumentation amplifier circuit. This circuit scales the sensor's millivolt-level output voltage to ensure full compatibility with the microcontroller's analog-to-digital converter (ADC) interface [10]. Testing confirmed the system's performance under indoor artificial lighting.

This work utilizes the high-quality global solar radiation thermocouple Kipp & Zonen CMP6 with a far broader spectral domain (285–2800 nm), providing more comprehensive global solar radiation data by accounting for ultraviolet and infrared wavelengths, together with a Kipp & Zonen Pyrheliometer CH1. The Kipp & Zonen sensor data are matched to the input of an ESP32 microcontroller via two AD620 instrumentation amplifiers, while an LCD and a keypad allow the measurement date, time, and resolution to be set. The system can function autonomously in the long term using a solar-powered battery.

Solar radiation measurements were performed in predominantly clear-sky conditions in the presence of a barely visible thin cloud. A direct-to-global solar radiation ratio could be estimated. The results revealed, under stable conditions, a relative error of the measured solar radiation in the range of 0.45%, a sign of high accuracy.

## 2. MATERIALS AND METHODS

The hardware block diagram of the overall ESP32-based system with its primary peripheral modules is shown in Fig. 1: two AD620 instrumentation amplifiers for voltage scaling (one for the direct radiation sensor and another for the global solar radiation data), the SD card module for data logging, the LCD for visualization, and the keypad for menu navigation.

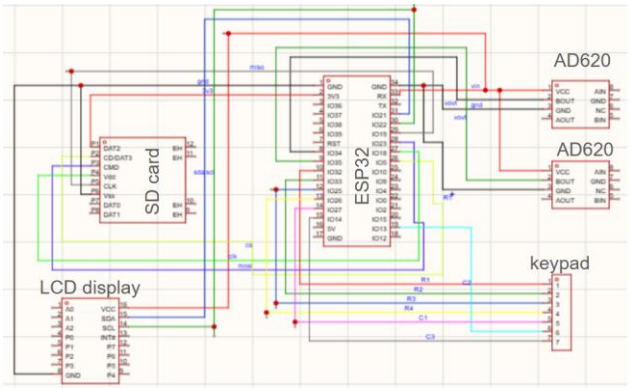



**Fig -1**: Schematic Diagram of the Hardware Implementation: Interfacing the ESP32 with the AD620, SD Card Module, LCD, and Keypad.

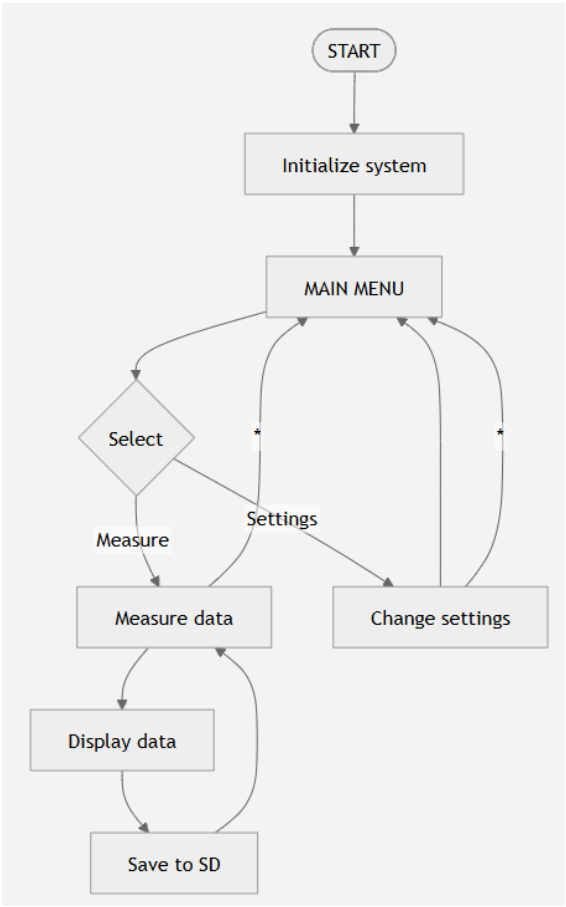



**Fig - 2**: Simplified flowchart of the proposed software algorithm.

As shown in Figure 2, the software algorithm executes through three primary phases (full code provided in [11]):

- **Initialization:** Upon power-up, the system configures the ESP32 analog inputs for the dual AD620 amplifiers at a 12-bit ADC resolution. Simultaneously, it initializes the 1602 LCD via I2C, mounts the local SD card via SPI, and verifies data-write readiness.
- **Data Acquisition and Processing:** Upon pressing "select," one can configure the date, time, and temporal resolution for the upcoming measurement. Every 1 second, the software samples the analog channels. Then the ADC values are converted to corresponding voltage values.
- **Display and Data Logging:** At each 1-minute interval, the averaged global and direct radiation data are displayed on the first and second lines of the 1602 LCD, respectively. Concurrently, upon a keypad button press, the microcontroller saves the data to the SD card.

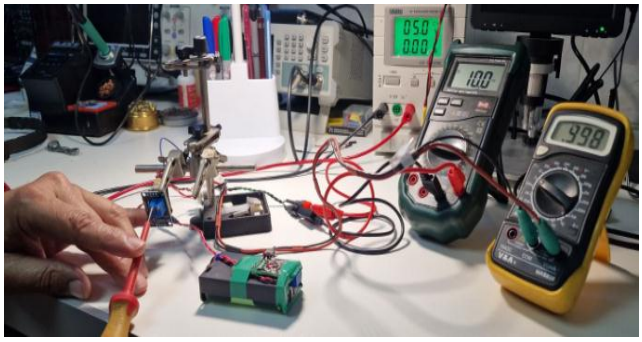


**Fig - 3**: Adjustment of a 100 potentiometer gain.

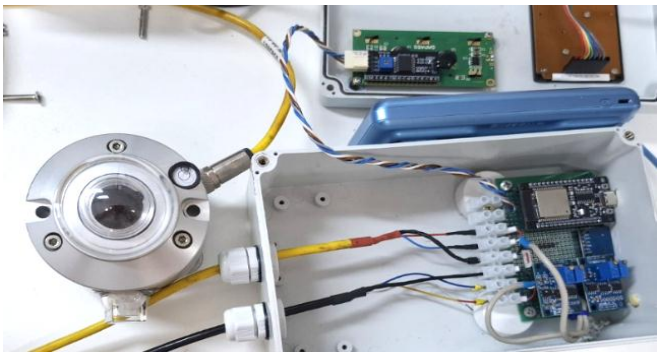


**Fig - 4**: Inside view of the proposed ESP32 system.



**Fig - 5**: Outdoor test setup for recording solar radiation.

## 3. RESULTS

The exemplary data obtained from a representative measurement campaign under stable conditions are summarized in Table 1. The final measured voltages for global ($U_G$) and direct ($U_E$) solar radiation, along with their respective relative errors (δ), are calculated as follows:

1). $U_G$=0,985±0,0018 V with $\delta_G$≈0,19%
2). $U_E$=0,637±0,0031 V with $\delta_E$≈0,49%

Since both error margins remain well within this boundary, the experimental data demonstrate high statistical precision, confirming the accuracy and robustness of the developed measurement system. At the same time, it should be noted that at the onset of the trial, the solar radiation values rapidly decreased to 0.300 V and 0.04 V, respectively, indicating the high dynamics of the direct-to-global ratio within thin clouds.

**Table -1**: Measurement data of global and direct radiation voltages.

| № | $U_G$ (V) | $\Delta U_G$ (V) | $\Delta U_G^2$ ($V^2$) | $U_E$ (V) | $\Delta U_E$ (V) | $\Delta U_E^2$ ($V^2$) |
|---|---|---|---|---|---|---|
| 1 | 0.984 | -6.67e-4 | 4.44e-7 | 0.637 | 3.33e-4 | 1.11e-7 |
| 2 | 0.984 | -6.67e-4 | 4.44e-7 | 0.637 | 3.33e-4 | 1.11e-7 |
| 3 | 0.99 | 5.33e-3 | 2.84e-5 | 0.645 | 8.33e-3 | 6.94e-5 |
| 4 | 0.99 | 5.33e-3 | 2.84e-5 | 0.645 | 8.33e-3 | 6.94e-5 |
| 5 | 0.98 | -4.67e-3 | 2.18e-5 | 0.628 | -8.7e-3 | 7.51e-5 |
| 6 | 0.98 | -4.67e-3 | 2.18e-5 | 0.628 | -8.7e-3 | 7.51e-5 |
| Σ | 5.908 | — | 1.01e-4 | 3.82 | — | 2.89e-4 |
| Avg | 0.985 | — | — | 0.637 | — | — |

## 4. DISCUSSION

As stated previously, a Kipp & Zonen CH1 pyrheliometer was used in this work, with sensitivity 10.35 × $10^{-6}$ V /$W^{-1}m^2$; and a CMP 6 pyranometer, with sensitivity 12.55 × $10^{-6}$ V /$W^{-1}m^2$. Taking these constants into consideration and applying them to the measured data, presented in Table 1, to the mean values of global and direct solar radiation voltages. A 985 W/$m^2$ global solar radiation value was estimated around noon in Plovdiv, Bulgaria, with a 100 amplification factor, in good agreement with theoretical predictions. A mean ratio of direct-to-global radiation of 64.67% is calculated, corresponding to predominantly clear-sky conditions with only slight cloudiness. This result demonstrates the device's capability to measure minimal changes in cloud dynamics.

## 5. CONCLUSION

With unprecedented dynamics in recent weather trends, monitoring solar radiation can turn into a key parameter for near-future weather predictions. The proposed ESP32-based dual solar radiation device is capable of measuring direct and global solar radiation with a relative error of 0.45%. As an open-source platform, it can serve as an educational and scientific platform for institutions of limited resources in exploring cloud density dynamics and other direct-to-global solar radiation ratio weather parameters.

## REFERENCES

1) Copernicus Climate Change Service (C3S). (2026). July 2026 Climate Bulletin: Exceptional summer heatwaves and record-breaking sea surface temperatures. European Centre for Medium-Range Weather Forecasts (ECMWF). Available: https://climate.copernicus.eu [Accessed: August 17, 2026].

2) Selvam, A. M. (2025). Fractal Fluctuations and Climate Cycles in Atmospheric Flows: Order in Chaos. Cambridge Scholars Publishing.

3) Nava-Pintor, J. A., Alcalá-Rodríguez, U. E., Guerrero-Osuna, H. A., Mata-Romero, M. E., Lopez-Neri, E., García-Vázquez, F., Solís-Sánchez, L. O., Carrasco-Navarro, R., & Luque-Vega, L. F. (2025). Development and Evaluation of Solar Radiation Sensor Using Cost-Effective Light Sensors and Machine Learning Techniques. Technologies, 13(5), 182. https://doi.org/10.3390/technologies13050182

4) Sandryadi, A.; Tarigan, H. Development of Solar Radiation Intensity Measurement Tool Using BH1750 Sensor Based on The Internet of Things with Smartphone Display. Pillar Phys. 2022, 15, 149–157.

5) Wahyu, S.; Syafaat, M.; Yuliana, A.; Meliyani, R. Aplikasi Sensor BH1750 Untuk Sistem Monitoring Pertumbuhan Tanaman Cabai Menggunakan Arduino Bertenaga Surya Terintegrasi Internet of Things (IoT). J. XYZ 2021, 9, 71–78.

6) Martinez, L., & Chen, Y. (2026). Development of an Irradiance Meter using Arduino Technology and

Distributed IoT Meteorological Sensors. ResearchGate/MDPI Weather, Vol. 14, Issue 2.

7) Michael, Peter & Johnston, Danvers & Moreno, Wilfrido. (2020). A conversion guide: solar irradiance and lux illuminance. Journal of Measurements in Engineering. 8. 10.21595/jme.2020.21667.

8) Ramos Ancajima, César & Aldana Yarleque, Cristhian & Huayanay, J & Moncada, Wilmer. (2025). Prototype based on a low-cost solar transducer for monitoring solar irradiance. Journal of Physics: Conference Series. 3088. 012002. 10.1088/1742-6596/3088/1/012002.

9) Coffin, A., Bonnefoy-Claudet, C., Chassaigne, M., Jansen, A., & Gée, C. (2024). PARADe: A low-cost open-source device for photosynthetically active radiation (PAR) measurements. HardwareX, 15.

10) Megantoro, Prisma & Syahbani, Muhammad Akbar & Dani, Sigit & Muzadi, Ahmad & Afif, Yusrizal & Mukhlisin, Agus & Pandi, Vigneshwaran. (2022). Analysis of instrumentation system for photovoltaic pyranometer used to measure solar irradiation level. Bulletin of Electrical Engineering and Informatics. 11. 3239-3248. 10.11591/eei.v11i6.4390. https://bit.ly/4zsS5Ao

11) Yang, D., & Boland, J. (2016). Solar irradiance decomposition models: A review. Renewable and Sustainable Energy Reviews, 63, 1–12.