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Development and Calibration of a Solar Powered Automatic Weather Station for the Monitoring and Evaluation of Climate Parameters.

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ABSTRACT: In this research, a weather station was design and assembled at the site of the Center for Renewable Energy Technology {CRET}, Federal University of Technology, Akure, Ondo State, Nigeria. The materials for the instrument includes a data logger with solar radiation sensor and an anemometer, wind vane, relative humidity sensor and air particulate matter sensors built within the instrument to track and record daily radiation and PV cell temperature. The equipment is powered by a 12 V, 45 AH Lithium battery.Inside the weather station is the integrated sensor suite {ISS} which is made up of solar panel temperature, relative humidity, wind speed and direction and solar radiation sensors installed to detect physical changes in the environment and output them as digital signals into the signal conditioning circuits. This signal conditioning circuit manipulates the signals and prepares them for the next stage of processing. From the signal conditioning circuits, the data are sent to the central processing unit that interpret the data received from the sensors, stores them in the data memory, access them and uses instructions stored in its programme memory to decipher and apply the incoming data. The instrument was calibrated in comparison with standard equipment's and the results obtained were okay.

Keywords: Solar panel, data logger, sensors, arduino, signals card reader.

I. INTRODUCTION.

Weather monitoring is essential for agriculture, disaster management, environmental research and public safety. Historically, weather data collection relied on manual methods using analog instruments like mercury thermometers, barometers and rain gauges. The shift to automated weather station began in the late 20th century, primarily in research institutions and government meteorological agencies. Modern automatic weather station systems are typically based on embedded microcontrollers, digital sensors, wireless data transmission and cloud-based platforms for storage and visualization. Recent studies indicate growing interest in deploying distributed networks of low cost automatic weather stations to improve micro-climate data resolution. Several researchers have proposed and implemented systems using Arduino, Raspberry P$_i$ and ESP32 boards due to their affordability, flexibility and ease of programming. Research by Kumar et al., {2019} compared low cost sensors with professional grade equipment and found an acceptable margin of error for non-critical applications. The study identified issues such as calibration difficulties, environmental influences on sensor accuracy and the need for proper maintenance and data validation. It emphasized the importance of standardization, calibration protocols and capacity building to enhance the reliability and effectiveness of low-cost sensor networks. It also offers an affordable means to monitor air quality, enabling widespread deployment and community engagement. KhandelwaI et al., {2019} developed a low cost weather monitoring system aimed at data sparse regions, which could be analogous to rural areas in Nigeria. The system was aimed at collecting meteorological data from remote areas of the Indian Himalayas. It utilized open-source hardware and software to ensure affordability and accessibility. The system was designed to be cost

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effective making it suitable for deployment in resource constrained regions. It successfully gathered essential meteorological parameters, contributing valuable data to areas previously lacking comprehensive weather monitoring. The approach has implications for improving weather data availability in remote and underserved regions. A study by Jimohet al., {2024} developed an IoT-based weather station for real-time monitoring of environmental conditions. The system integrated various sensors to measure temperature, humidity, atmospheric pressure, wind speed and precipitation. It highlighted the scalability of the system, enabling the establishment of a network of weather stations for comprehensive environmental monitoring. Nsengiyumva and Mwebaze {2025} proposed a framework for IoT-enabled smart agriculture, utilizing raspberry Pi-based technology for real-time monitoring of weather and environmental conditions. The framework incorporated sensors for temperature, rainfall, soil moisture and pressure, connected via an MCP 3208 analog top digital converter. The approach aimed to optimize irrigation schedules and improve crop productivity through actionable insights derived from real-time and forecasted data. Ghaniet al., {2024} developed an IoT-based automatic weather station to monitor coastal weather conditions, aiding fishermen in making informed decisions regarding fishing activities. The system integrated sensors such as an anemometer for wind speed, DHT 22 for temperature and humidity and a rain sensor, all controlled through an IoT platform. The tool demonstrated an average error difference of 1.79% compared to manual readings, indicating its reliability in real time weather monitoring. Girijaet al., {2018} developed a cost effective and reliable IoT-based system for monitoring environmental conditions such as temperature, humidity and CO levels. It utilized Arduino software and ESP 8266 for data collection and transmission to a web page, enabling global access and graphical representation of sensor data. It proposed future enhancements including alarm systems and sms notifications for exceeding parameter thresholds.

The market for weather services is becoming increasingly active {Howard, 2020; Freedainet al., 2002a} and various types of weather services and weather service companies are being established {Pettifer, 2015; Freedainet al., 2002b}. And they opined that with the availability of weather and climate information, the risks for cooperation can be minimized and the scale of profit generation can be accelerated. Indeed, in the global market, weather and climate information are being used as essential business decision making tools in the industry with the application of weather risk management concepts. Countries and companies are generating profits or reducing losses by developing various solutions that analyze both weather and industrial big data {Georgesonet al., 2017 and Triocolli, 2008}. Moreover, the fields of application are comprehensive, the forms are highly diverse and the weather service sector is expected to continue to grow. Therefore if weather and climate information is used properly, our society will be able to maintain socio-economic value beyond mere disaster prevention. Furthermore, if this information is used more actively, high added value may be generated.

II. MATERIALS AND METHODS

2.1 Experimental Set Up.

The pilot study was carried out at the Centre for Renewable Energy Technology {CRET} Federal University of Technology Akure, the capital city of Ondo State, and South-West Nigeria. Akure is located within the humid region of Nigeria. The city lies within latitudes $7^0$14’N and 7^0 17’N and within longitudes $5^0$08’E and $5^0$13’E. The climate of the study site is humid sub-tropical, with an annual rainfall of 1300-1600 mm and a mean temperature of 27^0C (Fasinmirinet al., 2018). The relative humidity varied from 85% to 100% in the wet season but less than 60% in the dry season {Fasinmirin and Adesigbin, 2012}.

A weather station was design and assembled at the site of the Centre for Renewable Energy Technology {CRET}, Federal University of Technology, Akure, Ondo State, Nigeria. The materials for the instrument includes a data logger with solar radiation sensor, an anemometer wind vane placed on an iron stand which was firmly positioned on the ground in a fixed position and at an orientation to receive sunlight from all directions. It is powered by a 12V, 45 AH Lithium battery. Air irradiation sensors, relative humidity sensor and air particulate matter sensors of various sizes ranging from 1.0, 2.0 and 10.0 were built within the instrument to track and record daily radiation and PV cell temperature. Under the prevailing meteorological conditions, the temperature {above} and temperature {below} the PV panel, air pressure, relative humidity and particulate matter of various sizes, wind speed, wind direction, solar radiation and current produced by the PV panel were measured.

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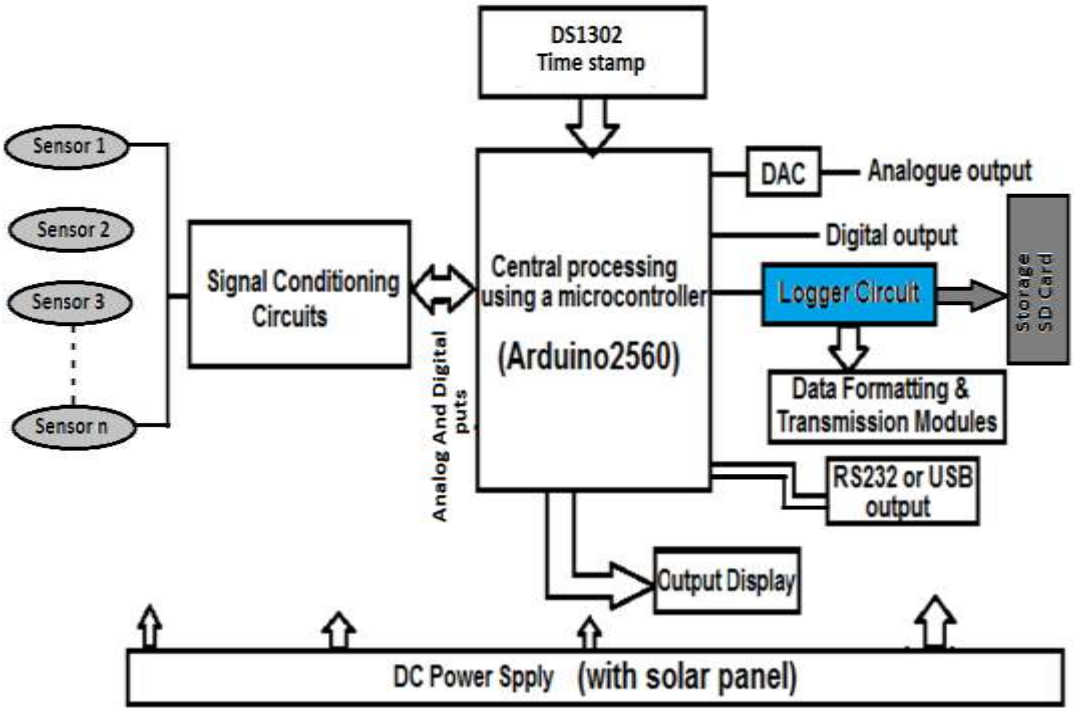

Figure 2.1: The Basic Block Diagram of Automatic Weather Station

2.1.1Description of the Basic Block Diagram of Automatic Weather Station.

The Integrated sensor suite {ISS} is made up of solar panel temperature, relative humidity, wind speed and direction and solar radiation sensors installed to detect physical changes in the environment and output them as digital signals into the signal conditioning circuits. This signal conditioning circuit manipulates the signals and prepares them for the next stage of processing. From the signal conditioning circuits, the data are sent to the central processing unit that interpret the data received from the sensors, stores them in the data memory, access them and uses instructions stored in its programme memory to decipher and apply the incoming data.

The Arduino 2560 Mega which is an open source electronics platform reads the inputs-light on the sensors and turns them into outputs. The resultant outputs are sent to the logger circuit. The logger circuit keeps and records these logged information on current operations in the operating system. The information is then sent to the Data Formatting and Transmission modules. This module organizes, encodes and formats the data for efficient and reliable transmission through cables. The information is eventually sent to the storage SD Card which is a removable storage device to store and transfer digital information. It uses flash memory to record the information. The Output Display is an output screen used to display output being received from the station weather into a human perceptible form.

The DS1302 Time Stamp is a sequence of character or encoded information, identifying when a certain event occurred, usually given date and time of day sometimes accurate to a small fraction of a second. It is not based on absolute.The Analogue output is a continuous output from the Programmable logic controller to the field devices which is the sensor’s output. It converts the digital data to analog signal before outputting that signal to the external. The RS232 or USB output is the power output form of a computer USB port. Most computer USB ports supply 5v of electricity with a maximum current of 0.5 A. This amount of current is standard across majority of computer and means the overall power output will be 2.5 watts at best.

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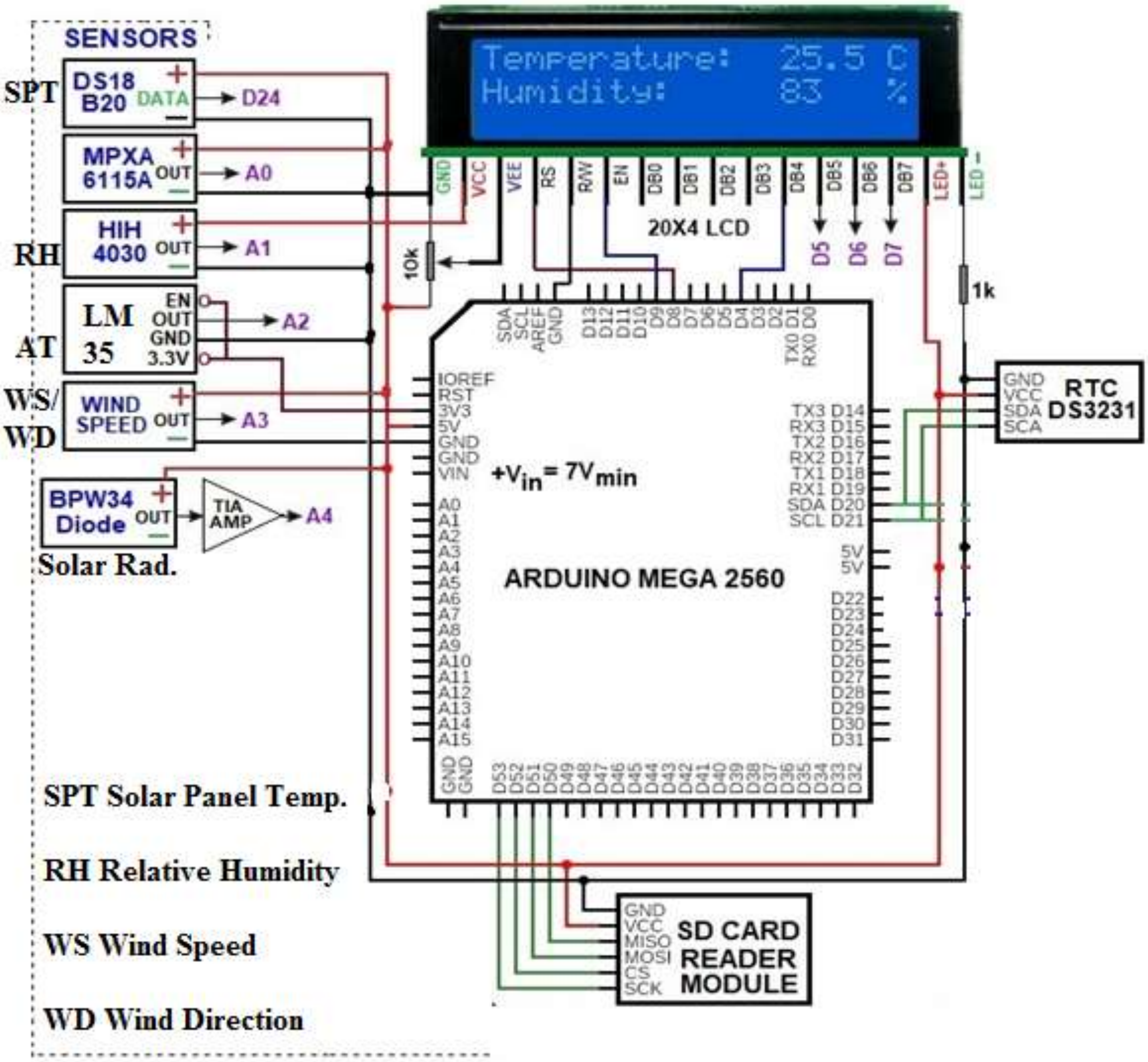

Figure 2.2: The Complete Schematic Diagram of the Developed Automatic Weather Station System.

2.1.2Description of the Complete Schematic Diagram of the Developed Automatic Weather Station.

The Schematic diagram of the developed Automatic Weather Station is made of the different sensors that detects and responds to the inputs from the physical environment such as solar panel temperature sensor, relative humidity sensor, atmospheric temperature sensor, wind speed and wind direction sensors and solar radiation sensor. The BPW34 diode solar radiation sensor is a Pin photodiode with high speed and high radiant sensitivity in miniature, flat, top view, clear plastic.

The Arduino mega 2560 is a micro controller board. It has 54 digital input/output pins of which 15 can be used as Pulse Width Modulation {PWM} outputs. PWM is a technic for getting analog results with digital means. The SD Card Reader module is memory card reader that works by connecting it to the computer or another device via a USB port. The memory card is inserted into the card reader and the device automatically detects it. The data stored on the memory card is then downloaded from the data logger to computer-laptop.

The RTC DS3231 is a high precision, low power real-time clock module from maxim integrated. It provides accurate time keeping. The time stamp encodes information identifying when a certain event occurs, like in this case displays the

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temperature reading in ^{0}C and the relative humidity in percentage.

III. CALIBRATION AND TESTING OF THE INSTRUMENT

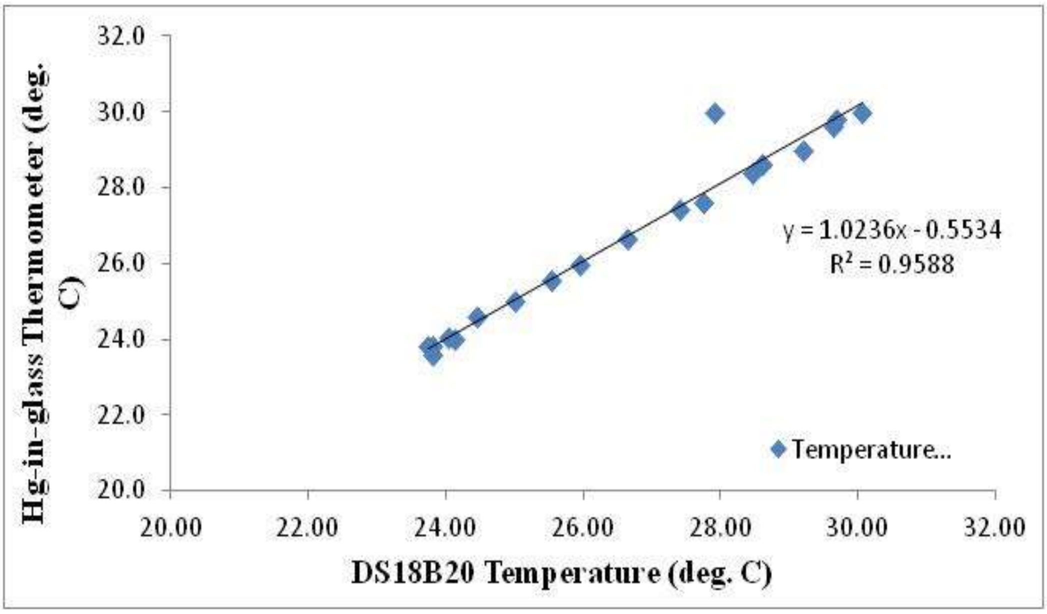

Figure 3.1: Comparison of Performance of the Temperature Sensor DS18B20 with H_g- in-glass thermometer.

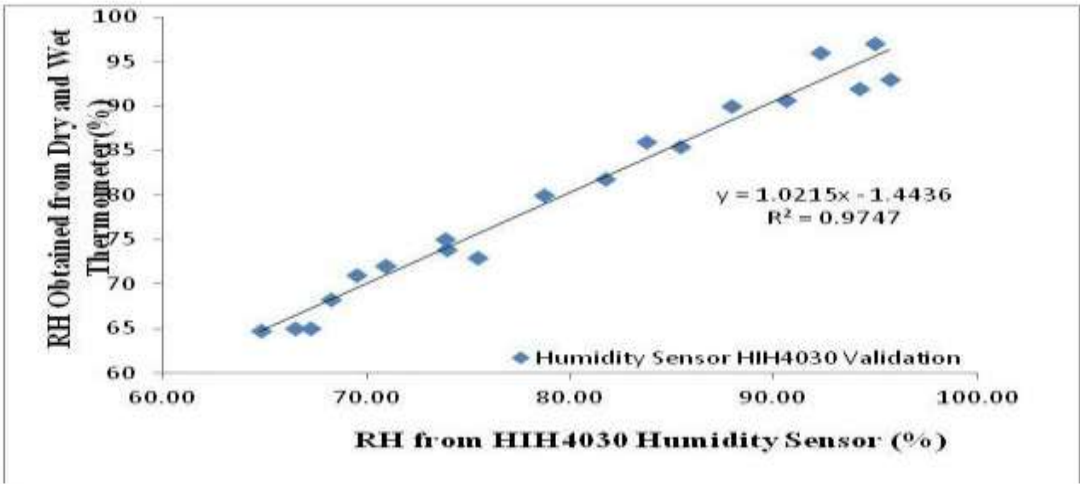

Figure 3.2: Comparison of Performance of HIH4030 with RH obtained from Dry and Wet Thermometer

Solar Irradiance Calibration

The developed solar irradiance sensor was set up and place in an un-obstructed area, alongside SRS 100 pyranometer.

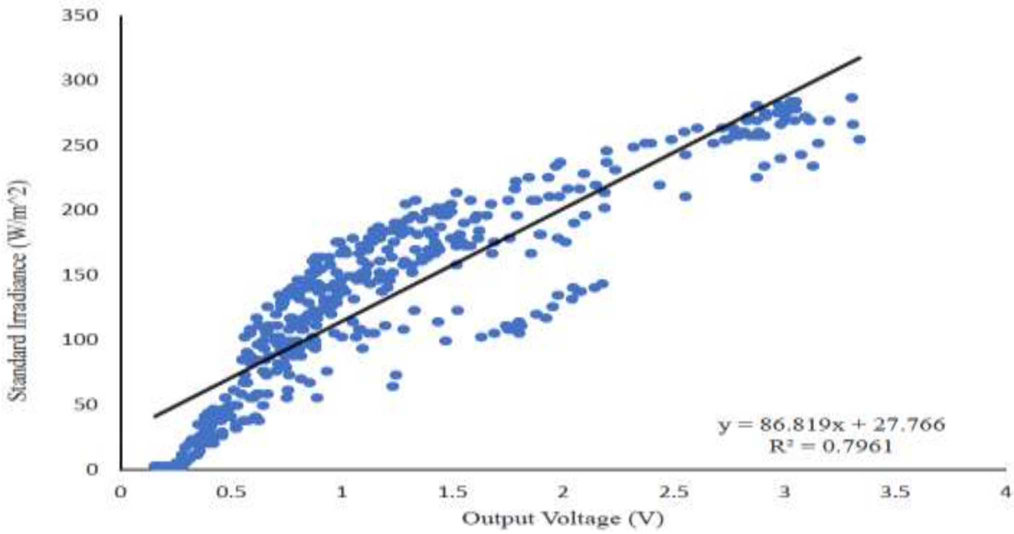

Figure 3.3: Comparison of the Output Voltage and the Standard Irradiance.

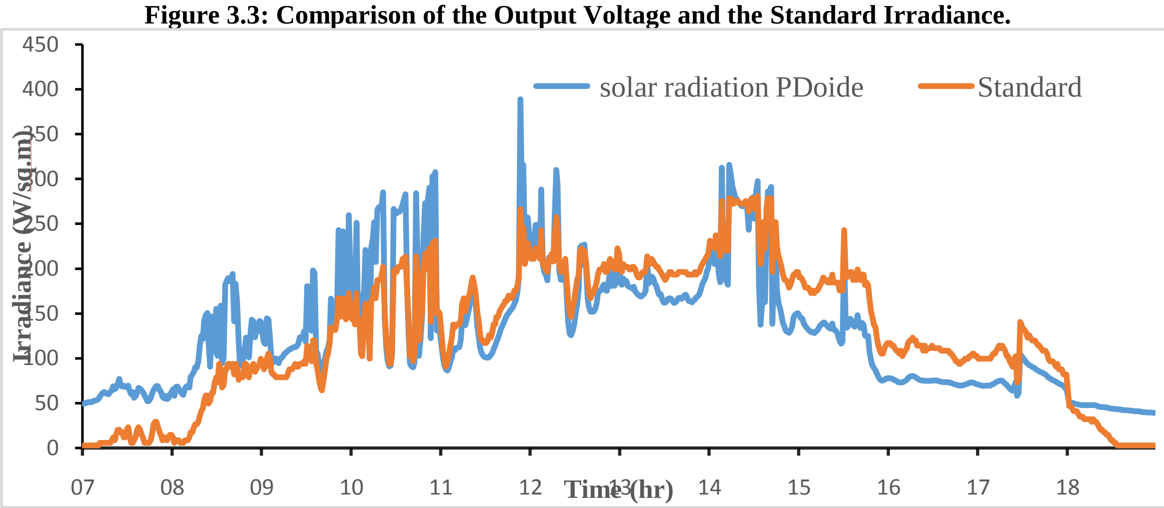

Figure 3.4: Developed Solar Irradiance Device Comparewith SRS 100 Sensor.

Table 1: Summary of Sensors Specification.

Parameter	**Sensor**	**Unit of Measurement**	**Sensitivity**	**Measurement Range**
Panel Temperature	DS 18B20	^{0}C	0.0625^{0}C	0^0C to 150^0C
Atmospheric Pressure	Barometer {MPXA6115AC7U}	millibar	0.000892kPa/V	15mbar to 115mbar
Relative Humidity	Hygrometer {HIH4030}	%	18.9%V	0% to 100%
Wind Speed	Anenometer	Ms^{-1}	6.32ms^{-1}/V	0 to 32ms^{-1}
Solar Radiation	Based on BPW34	W/m^2	868.19$Wm^{-2}V^{-1}$	Up to 1000Wm^2
Air temp	LM 35	^{0}C	10Mv/^{0}C	0^0C to 150^0C
Dust	ZH06{PM1, PM2.5, PM10}	ppm	0	1000

. Solar Radiation Sensor was with BP W34 photodiode
. Has wavelength response within 400nm to 1000nm
. The sensitivity of solar radiation is 868.19$Wm^{-2}V^{-1}$
. It has measurement range from 0 to 1000Wm^{-2}

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IV. RESULTS AND DISCUSSIONS.

The instrument constructed was used in field experimentation. It was primarily built as a digital processor in a small portable case with a battery of 12 V 45 AH Lithium battery to supply the current. It was made up of electrical cables, internal memory storage, sensors and a programmable module which takes data as a stand-alone device. The instrument was stationed at a strategic position at the Centre for Renewable Energy and. was configured to capture weather data automatically for five months duration from September, 2023 to January, 2024. Data acquired include: temperature of the top and bottom of the solar panel displayed in degree centigrade{^{0}C}, the air temperature in degree centigrade {^{0}C}, the pressure in {mbar}, the relative humidity {RH}in percent, particulate matter {PM} in parts per million {ppm} particulate matter PM 2.5 in parts per million and PM 10 in parts per million {ppm}; the solar radiation {Wm$^-$2} and the wind speed in meters per seconds {m/s}. The instrument also recorded the solar voltage, solar current and power generated in watts. The readings were taken with a memory card. The data obtained from the instrument were directly down loaded from data logger to computers laptop.

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