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IoT Application of Simple Solar Intensity Monitoring System Using Photovoltaic Panel

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Abstract
Solar radiation data is useful for solar power plant (PLTS) development, the agricultural sector, renewable energy, transportation and communication, and other disciplines. This data is generally obtained from government agencies. The device used to measure solar radiation is a pyranometer. However, this equipment has limited availability and the data information is only owned by certain regions. Therefore, it is necessary to develop a simpler measuring instrument for the intensity of solar radiation. So that data information is obtained easily and the operation of tools is easy. In this study, photovoltaic panels were used to read the intensity of solar radiation. When this panel is exposed to the sun it will generate electricity and its output is proportional to its radiation. Data monitoring utilizes IoT. The measured results of measuring the intensity of solar radiation have a maximum value of 450.21 W/m2. The measured magnitude of the solar radiation value shows that the influence factors in the form of sunlight intensity, ambient temperature, and panel output power are proportional to the radiation value while environmental humidity is inversely proportional to the radiation value.
Keywords: Humidity; IoT Application; Photovoltaic; Pyranometer; Solar radiation, and Temperature.

1. Introduction

The sun is a source of energy that greatly affects life on Earth. One of the physical phenomena of the sun is the intensity of solar radiation which affects weather and climate [1]. Solar radiation is an electromagnetic wave generated from the nuclear fusion process in the solar core. Solar radiation that reaches the earth's surface is called horizontal global radiation which consists of two types of components, namely direct radiation and diffuse radiation [2].

Indonesia is a country located at the equator, where the sun shines for 10 to 12 hours a day with the potential for solar radiation intensity to reach 4.8 kWh/m2 or equivalent to 112,000 GWP. This gives Indonesia great potential to develop solar power plants [3], [4]. To develop this potential, solar radiation intensity data is needed to provide preliminary information on the planning of solar power generation systems [5]. In addition, solar radiation intensity data is also useful in various sectors such as agriculture, renewable energy, transportation and communication, and many other disciplines [6]. However, the solar radiation intensity data is only available in certain regions. Direct measurement of solar radiation needs to be carried out to support the completeness of data that is not yet available [7].

The intensity of solar radiation in each region has different values, this is influenced by astronomical location, geographical conditions, the earth's rotation cycle (morning, afternoon, evening, and night), the quality and quantity of clouds (sunny/cloudy), and so on [8]. The intensity of solar radiation is measured and monitored by government agencies such as the Meteorological Climatology and Geophysics Agency (BMKG). In general, the device used to measure solar radiation is a pyranometer [9]. A pyranometer is a semi-spherical glass dome-shaped solar radiation measuring device in which there is a sensor that produces readings of solar radiation values from a spectrum of 300 nm – 3000 nm [10]. However, the equipment used is limited to nearby agencies [11], [12]. Therefore, it is necessary to develop a simpler solar radiation intensity measuring instrument. So that information or data is obtained easily and the operation of the tool is easy [13]. In this study, photovoltaic (PV) panels were used to read the intensity of the sun, namely direct normal irradiance (DNI). The photovoltaic (PV) panel of the device converts energy from sunlight into electrical energy directly. In simple terms, photovoltaic panels consist of the connection of semiconductor materials of type P and N P-N junction semiconductors which if exposed to sunlight will occur electron flow, this flow of electrons is what is referred to as electric current flow [14]. The photovoltaic panel used is a monocrystalline photovoltaic panel that has a spectral response sensitivity of 80% from 500 nm to 1000 nm, so the response to radiation is higher than that of a light-dependent resistor (LDR) which has a spectral response of 550 nm or an apparent spectrum so it is not suitable for radiometers [15].

Research on solar radiation intensity monitoring systems has been widely carried out [16], [17], [18], [19] one of which is A. D. Habibullah (2018) who measures DNI in real-time through wireless communication using NRF 244 sensors or under other names radio sensors and has not measured the parameters of factors that affect the value of solar irradiation. Therefore, this study aims to develop an instrumentation tool to measure the intensity of solar radiation in the form of a simpler solar DNI by measuring factors that affect the magnitude of the DNI value, namely the intensity of sunlight, temperature, and humidity of the environment, as well as the estimated average power obtained. In addition, to facilitate the monitoring system, it is carried out with an IoT system using the IoT platform, namely Thinger.Io.

2. Method

This research consists of several stages, namely the first manufacture of an electronic circuit consisting of two parts of electronic circuit design and sensor calibration that will be used to see the accuracy of sensor measurements. Secondly, conduct tool testing aimed at seeing the performance of the tool. The results of these tests are analyzed at a further stage. The research block diagram can be seen in Figure 1.

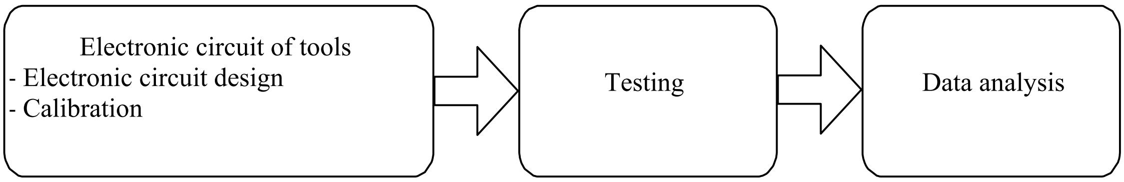

Figure 1. Research block diagramc.

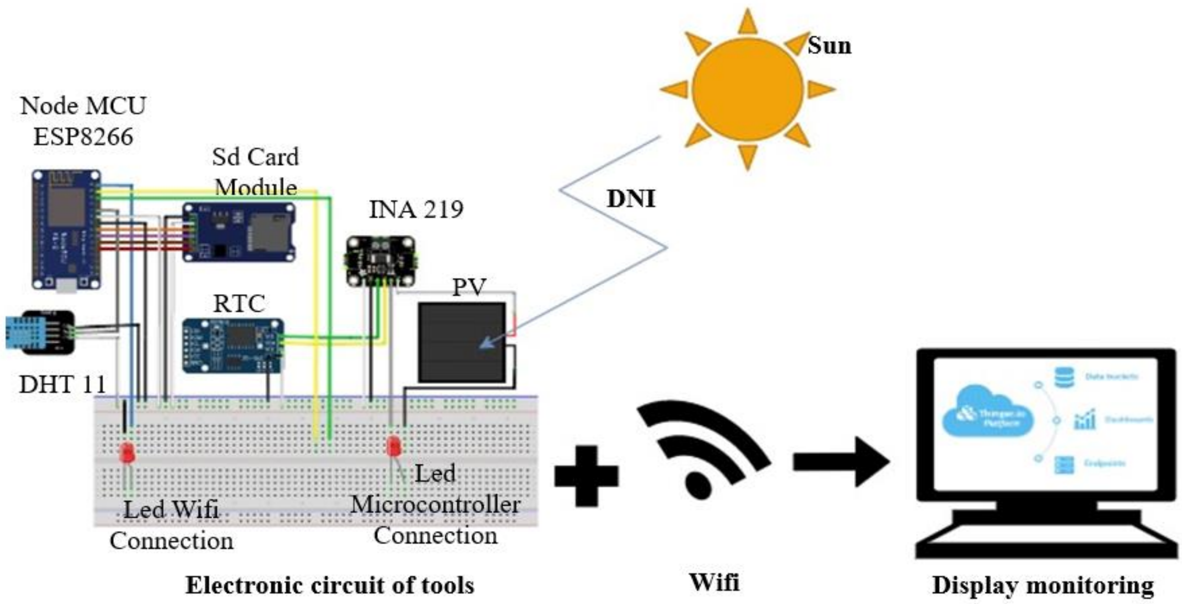

Figure 2. Electronic circuit system.

The electronic system consists of an ESP8266 MCU node, photovoltaic panel, DHT11 sensor, INA 219 sensor, RTC module, SD card module, and two leads. The connectivity of each electronic component can be seen in Figure 2. Each sensor on the circuit is also calibrated. Monocrystalline photovoltaic panels as sensors measure DNI. When this panel is illuminated by the sun directly it will generate electricity. Then, the ESP8266 MCU node as a microcontroller will read the DNI value of the sun using a formula that has been developed by previous research that is more effective for estimating solar radiant energy. The algorithm contains only two unknown parameters I and V that can be easily measured under different conditions. It is essentially a comparison of changes in the current and voltage of the module due to variations in climatic conditions concerning the Standard Test Condition (STC) values provided on the datasheet [18]. Equation (1) is a formula that will be used in the script coding program for the DNI value of the sun.

$$G = G^* \left(\frac{I^*_{SC} + \Delta I}{I^*_{SC} + (K_I / K_V)(R_S \Delta I + \Delta V)} \right) \quad (1)$$

$$\Delta I = I - I^*_{mp} \quad (2)$$

$$\Delta V = V - V^*_{mp} \quad (3)$$

G is the irradiance (W/m2) dan G* is the irradiance at STC (1000 W/m2). ΔI is the change in module current due to variation of climatic conditions concerning its STC values (A). ΔV is the change in module voltage due to variation of climatic conditions with to its STC values (V). KI is a short-circuit current temperature coefficient (A/°C) dan KV is an open-circuit voltage temperature coeffisient (V/°C). I*sc is the short-circuit current at STC and KV < 0 is the open-circuit voltage temperature coefficient. These constant values can be found in datasheet information, which is provided by manufacturers for each PV module. Changes in module current and voltage due to variations of climatic conditions concerning their STC. Rs is a series resistance of load (Ω). I*mp is a current at the maximum power at STC (A) and V*mp is a voltage at the maximum power at STC (V). Based on the datasheet on the solar panel used, namely the 3W/6V type monocrystalline. The specifications of this panel are Isc = 0.55A, Vmp = 6, Imp = 0.5 A. It has a standard test condition (STC 1000 W/m2 250C) and a Rs of 12Ω.

In addition to processing DNI data, the microcontroller also receives temperature and humidity data measured by the DHT11 sensor, and voltage and current data read by INA219. The readings by the microcontroller are measured in real-time using the RTC module and will be stored on the SD card module. When the microcontroller is connected to the internet, the sun's DNI value will be sent to the web thinger.io. Thinger.io is an Internet of Things (IoT) platform that provides cloud features to connect various Internet-connected devices that can visualize sensor readings in the form of values or graphs [20].

After the design of the electronic circuit is completed, the calibration of the sensor to be used is carried out. Calibration of this sensor is carried out by comparing the sensor values with standard measuring instruments. Two types of sensors are calibrated, namely the INA 219 sensor as a voltage and current meter. The calibration of this sensor is done by comparing the magnitude of the voltage and current read on the sensor with a multimeter. The second sensor is the DHT11 sensor as a measure of ambient humidity and temperature. This calibration is done by comparing the legible sensor values with standard tools in the form of hygrometers and thermometers. For measuring light intensity, a standard instrument in the form of a digital lux meter is used.

The next stage is the testing of tools that are carried out to find out whether the data sent to thinger.io is received and processed by the MCU Node. Figure 3 shows the website has not been activated marked by the non-appearance of measured data. Figure 4 shows the website when the tool is enabled. The last stage is data analysis to see the magnitude of the sun's DNI which is measured with factors that affect the magnitude of the solar DNI in the form of sunlight intensity, temperature, and environmental humidity.

3. Result and Discussion

After the design process, testing and analyzing the results obtained and comparing them with supporting theories. The measured magnitude of the DNI can be said that the tool works well because of a good solar radiation value approaching 1000 W/m2. The highest solar radiation value was during the day with an average value of 450.21 W/m2 with a solar light intensity of 42708.95 lux, 34.96oC, producing 152.06 mW of power and humidity of 61.29%. It is influenced by the angle of incidence of sunlight perpendicular to the earth's surface. So it can be concluded that the higher the measured radiation value, the intensity of sunlight, temperature, and power produced will be higher while the humidity is smaller or inversely proportional.

a. INA219 voltage calibration

Sensor calibration testing is carried out by removing the voltage value from the power supply as the next voltage source compared to the outflow voltage generated by the INA219 sensor with a standard measuring instrument, namely a multimeter. Based on the calibration results, it was found that the output of the INA219 sensor is comparable to that of a multimeter. The voltage calibration graph between the INA219 sensor and the multimeter can be seen in Figure 5.

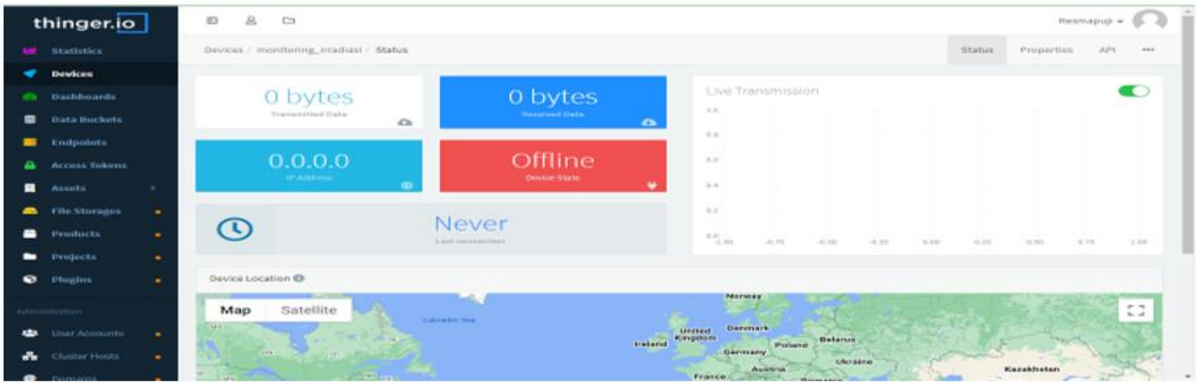

Figure 3. Display thinger.io when the tool is not yet active.

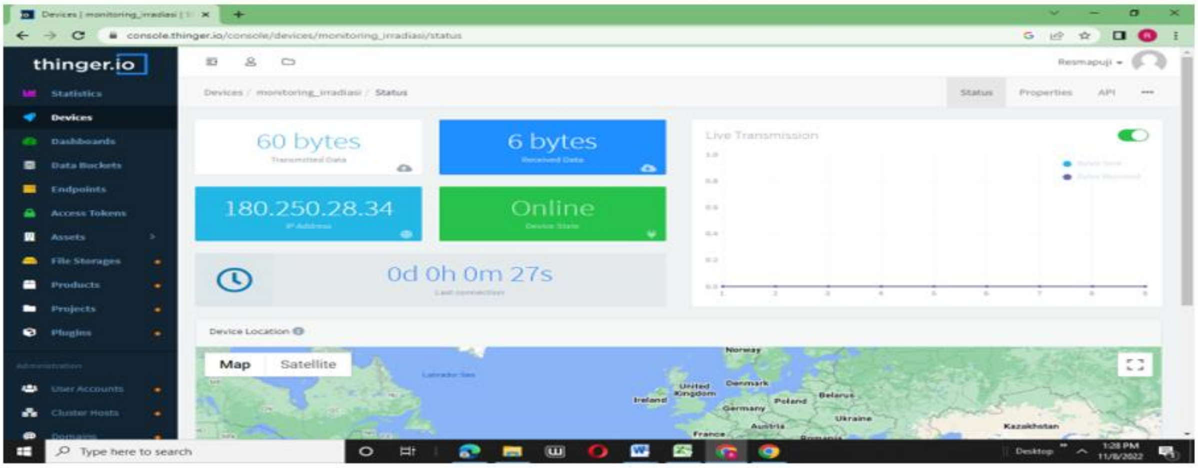

Figure 4. Display thinger.io when the tool is activated.

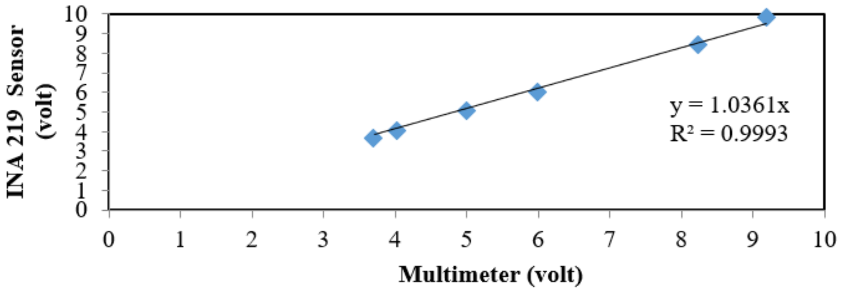

Figure 5. Voltage calibration graph.

In Figure 5, the multimeter is on the x-axis and the INA219 sensor is on the y-axis. Based on the linear graph, the equation is y = 1.0361x with a regression of 0.9938. Based on the calibration results, voltage measurement by the INA219 sensor has a strong correlation, so it can be said that the INA219 sensor in measuring voltage has a high accuracy or is almost the same as the multimeter reading results.

b. INA219 curent calibration

Sensor calibration testing is carried out by removing the current value from the power supply as the next current source compared to the output produced by the INA219 sensor with a standard measuring instrument, namely a multimeter. Based on the calibration results, it was found that the output of the INA219 sensor is comparable to that of a multimeter. A current calibration graph between the INA219 sensor and the multimeter can be seen in Figure 6.

In Figure 6, the multimeter is on the x-axis and the INA219 sensor is on the y-axis. Based on the linear graph, the equation is y = 1.0307x with a regression of 0.9997. Based on the calibration results, voltage measurement by the INA219 sensor has a strong correlation, so it can be said that the INA219 sensor in measuring voltage has a high accuracy or is almost the same as the multimeter reading results.

c. Temperature calibration

Sensor calibration testing is carried out by comparing the temperature value of the DHT11 sensor with a standard measuring instrument, namely a thermometer. Based on the calibration results, it was found that the output of the DHT11 sensor is comparable to that of a thermometer. A graph of temperature calibration with a thermometer can be seen in Figure 7. In Figure 7, the thermometer is on the x-axis and the DHT11 sensor is on the y-axis. Based on the linear graph, the equation is y = 0.9415x + 1.047 and the regression is 0.9994. Based on the calibration results, the temperature measurement by the DHT11 sensor has a strong correlation, so it can be said that the DHT11 sensor in measuring temperature has a high accuracy or is almost the same as the thermometer reading.

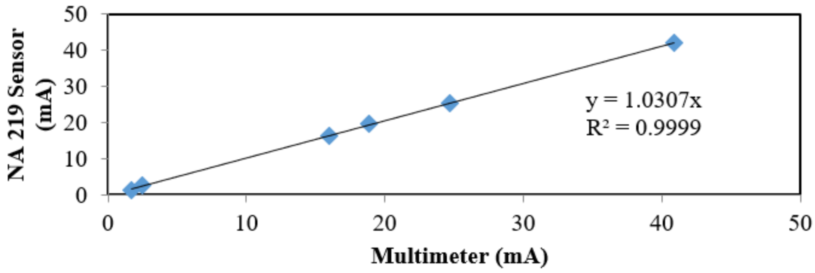

Figure 6. Current calibration graph.

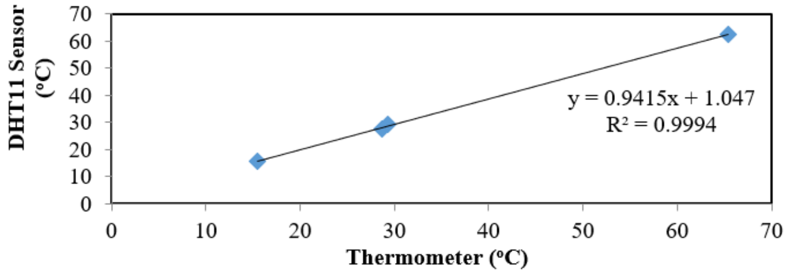

Figure 7. Temperature calibration graph.

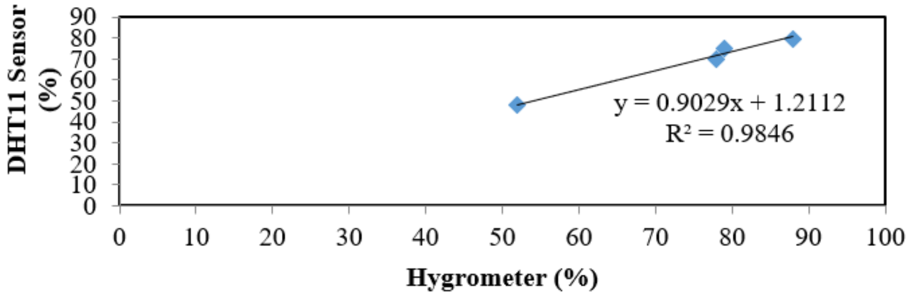

Figure 8. Humidity calibration graph.

d. Humidity calibration

Sensor calibration testing is carried out by comparing the humidity value read by the DHT11 sensor with a standard measuring instrument, namely a hygrometer. Based on the calibration results, it was found that the output of the DHT11 sensor is comparable to that of a hygrometer. The temperature graph with the hygrometer can be seen in Figure 8. In Figure 8, the hygrometer is on the x-axis and the DHT11 sensor is on the y-axis. Based on a linear graph, the equation is $y = 0.6891x + 19.54$ with a regression of 0.9479. Based on the calibration results, the measurement of humidity by the DHT11 sensor has a strong correlation, so it can be said that the DHT11 sensor in measuring humidity has a high accuracy or is almost the same as the hygrometer reading.

Based on the sensor calibration that has been carried out, the two sensors used have good measurement accuracy. Furthermore, testing of solar radiation monitoring equipment is carried out. Solar radiation testing that is pursued is DNI carried out with three conditions, namely in the morning starting from 08.00 AM, at noon, and at 04.00 PM. Each measurement is carried out with a time interval of one second for 30 minutes with monitoring visualizations in the form of graphs can be seen in Figures 9, 10, and 11.

Figure 9. Monitoring direct normal irradiance (DNI) at 08.00 AM.

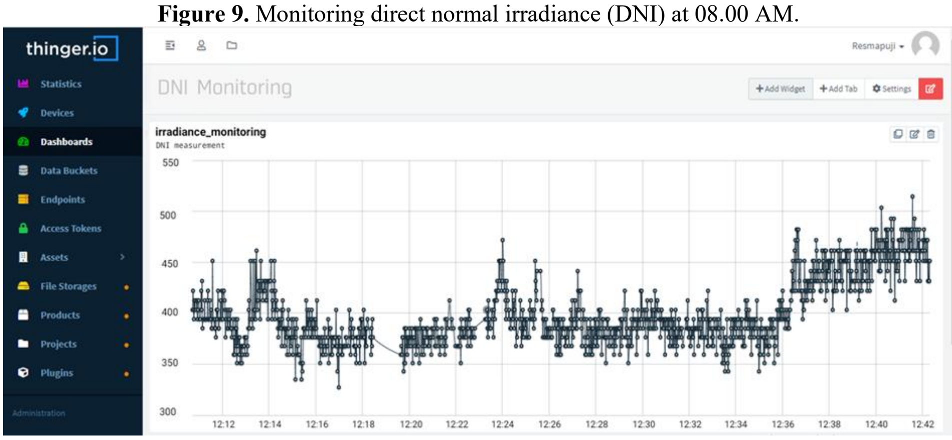

Figure 10. Monitoring direct normal irradiance (DNI) at noon.

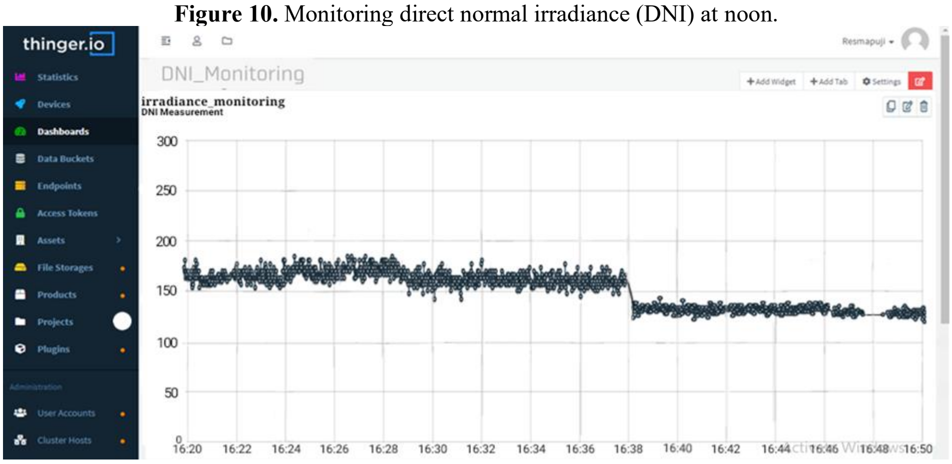

Figure 11. Monitoring direct normal irradiance (DNI) at 16.00 AM.

Of the three images of solar irradiation values presented at thinger.io, the solar irradiation value is on the left y-axis, while the lower side shows the length of time the solar irradiation is over. In these three conditions, the highest average irradiation was located in Figure 10 which was a test during the day with an average irradiation of 450.21W/m2, while in the afternoon the average irradiation produced was 212.99 W/m2 and the smallest average irradiation was located in the morning, which was 196.18 W/m2. The magnitude of this solar irradiation is influenced by the intensity of light as seen in Figure 12. Meanwhile, solar irradiation that affects the amount of power generated by photovoltaic panels can be seen in Figure 13. The magnitude of the temperature and humidity values of the environment can be seen in Figure 14.

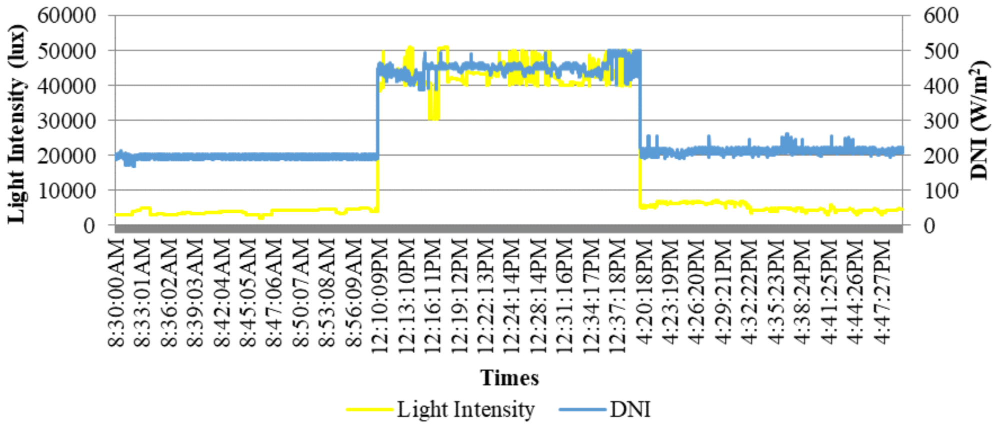

Figure 12. Graph of light intensity against solar irradiation.

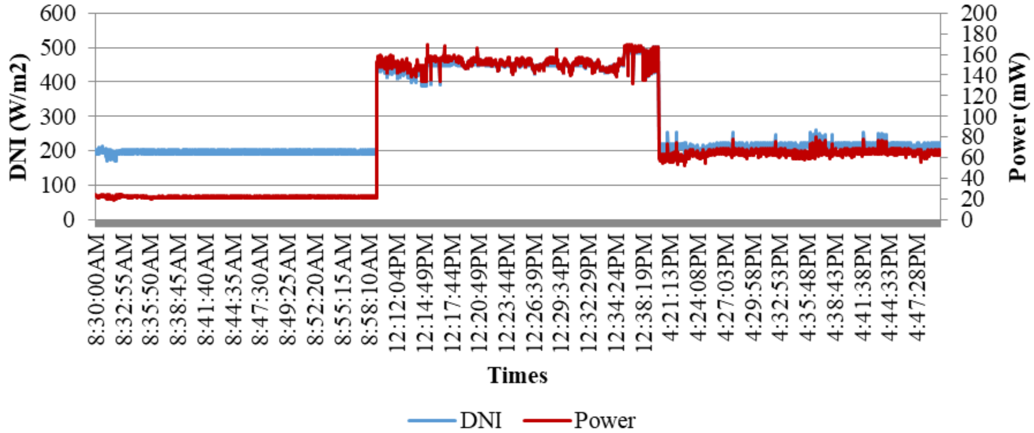

Figure 13. Graph of panel power against DNI values.

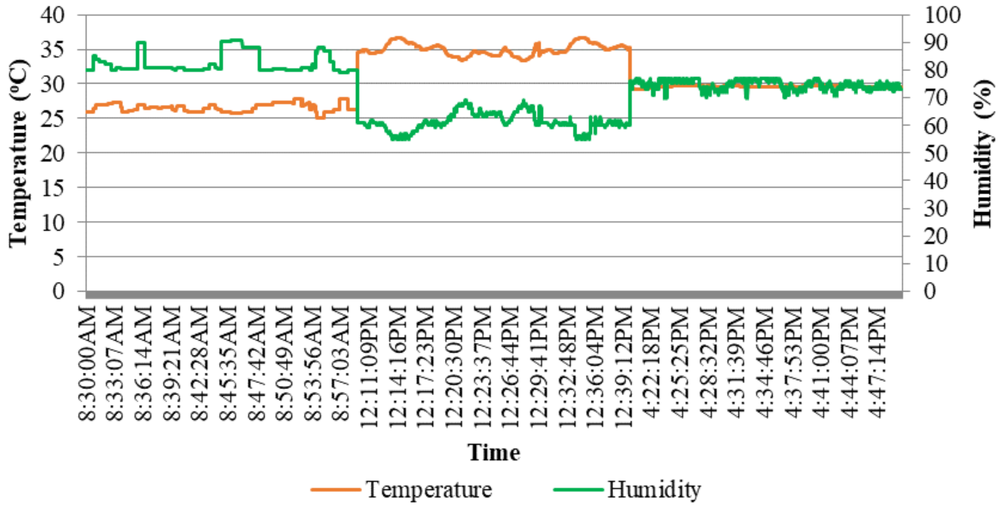

Figure 14. Graph of temperature agianst humidity.

Figure 12 the intensity of sunlight affects the solar irradiation read by the sensor, where the greater the light intensity, the greater the solar irradiation read with a maximum solar irradiation value of 450 W/m2 [21]. Figure 13 is a graph of the relationship between solar irradiation and the power generated by photovoltaic panels. The blue trendline is irradiation and the red trendline is the power generated by the panel, the higher the solar irradiation value, the greater the panel power produced. This is because solar energy depends on the irradiance of sunlight [22]. In Figure 14 the trendline graph of temperature is orange and environmental humidity is green. The higher the solar irradiation value, the higher the ambient temperature value and the lower the humidity value [23]. Factors of influence of solar irradiation can also be seen in Table 1.

From the table, it is found that the highest solar radiation value is at noon while the smallest irradiation is at 04.00 PM. This is influenced by the angle of incidence of sunlight, where when the sun forms an angle of 900, the irradiation of the sun occurs optimally while at an angle of less than 900, the solar irradiation obtained by the earth's surface will be minimal [24]. Therefore, sunlight perpendicular to the earth's surface will make the temperature hotter than the angle of incidence of sunlight at an oblique angle.

Air temperature has a strong association with relative humidity, as the temperature increases, the air will have a greater water vapor saturation pressure so that the amount of water vapor it can hold becomes more and more. If the concentration of moisture does not increase, then the relative humidity will decrease. High relative humidity will make an area tend to always be shrouded in clouds. The presence of clouds in the atmosphere will reduce the transmitivity of the atmosphere, that is, the percentage of direct irradiation that reaches the earth's surface without undergoing scattering in the atmosphere. Low atmospheric transmissivity will reduce the direct irradiation component and add to the diffuse irradiation component [7].

In Table 1, it can be seen that the daytime temperature has the highest value of 34.96 oC and the humidity value is very low, which is 61.24% with sunny weather conditions having a high intensity of sunlight of 42708.95 lux. This value affects the magnitude of the solar irradiation value measured by photovoltaic panels which reaches 450.21 W/m2 and the power generated is 152.06 mW. In the morning, the magnitude of the DNI value reached 196.18 W/m2 of sunlight intensity of 3819.05 lux with clear weather conditions having a temperature of 26.56oC, air humidity of 86.52% of the power generated by the panel of 21.76 mW. The afternoon has a DNI value of 212.99 W/m2 with cloudy weather conditions having a solar light intensity value of only 6139.30 lux and an air temperature of 29.61oC, air humidity of 74.97% and the power generated is 64.33 mW

Tabel 1. The average value of factors of influence of solar irradiation.

Time	Average				
	DNI (W/m^2)	Light Intensity (lux)	Temperature (ºC)	Humidity (%)	Power (mW)
08.00 AM	196.18	3819.05	26.56	86.52	21.76
12.00 AM	450.21	42708.95	34.96	61.24	152.06
04.00 PM	212.99	6139.30	29.61	74.97	64.33

4. Conclusion

After the design process, testing and analyzing the results obtained and comparing them with supporting theories. The measured magnitude of the DNI can be said that the tool works well because of a good solar radiation value approaching 1000 W/m2. The highest solar radiation value was during the day with an average value of 450.21 W/m2 with a solar light intensity of 42708.95 lux, 34.96oC, producing 152.06 mW of power and humidity of 61.29%. It is influenced by the angle of incidence of sunlight perpendicular to the earth's surface. So it can be concluded that the higher the measured radiation value, the intensity of sunlight, temperature, and power produced will be higher while the humidity is smaller or inversely proportional.

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