PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 27 (8) 1825-1837 August 2023

Monocrystalline Photovoltaic Panel Response Pattern to Relative Humidity and Temperature under Distinct Wavelengths in Mangrove Swamp Environment in Calabar, Cross River States, Nigeria

NJOK, AO; KAMGBA, FA

Department of Physics, Faculty of Physical Sciences, University of Cross River State, Calabar, Nigeria
**Corresponding Author Email: njokarmstrong@unicross.edu.ng; Tel: +2348132283875*
**Other Authors Email: fkamgba@gmail.com; njokarmstrong@unicross.edu.ng*

ABSTRACT: A meticulous experimental investigation was conducted to study the response pattern of monocrystalline photovoltaic technology to relative humidity and temperature under distinct wavelengths under the mangrove swamp atmosphere in Calabar, Cross River State, Nigeria, by in-situ measurement approach using a precision digital hygrometer, precision digital infrared gun thermometer and an intelligent photovoltaic panel maximum power point tracker (MPPT) to track and determine the maximum power, voltage and current produced by the photovoltaic (PV) technology at a particular panel temperature and humidity level. The result reveals that 100% efficiency from the PV technology may not be possible with the various wavelengths aside from the natural spectrum because the humidity level will have to drop below 10% for 100% efficiency to be achieved. However, under the natural spectrum the results revealed that the PV technology could attain 100% efficiency at a humidity level of 35%. The results also reveal that an increase in efficiency as temperature rises is not indefinite as there is a threshold temperature above which the efficiency will begin to drop for all wavelengths. Results of the study reveal that under the natural and red wavelengths, the maximum efficiency that could be attained is 62% and 41% respectively at a threshold of 44^{0}C. With the orange wavelength, 46% efficiency is possible at a threshold of 44.7^{0}C. With the lemon, green and violet wavelengths, the maximum efficiency that could be attained is 50%, 40% and 44% respectively at a threshold of approximately 43^{0}C. While 43% and 48% efficiency is possible with the blue and peach filter at a threshold of 40.5^{0}C and 42.3^{0}C respectively.

DOI: https://dx.doi.org/10.4314/jasem.v27i8.29

Cite this paper as: NJOK, A. O; KAMGBA, F. A (2023). Monocrystalline Photovoltaic Panel Response Pattern to Relative Humidity and Temperature under Distinct Wavelengths in Mangrove Swamp Environment in Calabar, Cross River States, Nigeria. *J. Appl. Sci. Environ. Manage.* 27 (8) 1825-1837

Dates: Received: 12 July 2023; Revised: 21 July 2023; Accepted: 14 August 2023; Published: 30 August 2023

Keywords: monocrystalline photovoltaic technology; response pattern; threshold temperature; mangrove swamp

Globally there is an energy crisis due to the ongoing war between Ukraine and Russia, which has led to significant unavailability of fossil fuel products, which triggered an upsurge in the cost of these products (Nerlinger and Utz, 2022). Generation of electricity via fossil fuel products by residents in rural areas with limited or no access to electricity via grid electrification finds it very difficult to generate electricity due to the surging prices of these fossil fuel products (Steffen and Patt, 2022). Production of electrical power through fossil fuel has an undesirable effect due to its role in depleting the ozone layer and triggering climate change globally (Akonjom and Njok, 2022). Traditional forms of electrical power generation via coal, oil or gas may be relatively cheap but comes at a colossal cost to our environment. Fluctuations in fossil fuel products create huge uncertainties, and the safety of our energy availability and supplies is constantly threatened, which is the reason for more war around the world than most politicians care to admit to (Boxwell, 2017). In Nigeria, oil and gas prices constantly fluctuate and remain highly volatile. The fluctuating price of oil and gas makes and breaks the economy, inevitably pushing the bills to Nigerians. Developed countries identify the problem of price fluctuation and are moved to

**Corresponding Author Email: njokarmstrong@unicross.edu.ng; Tel: +2348132283875*

implement renewable energy schemes to reduce their reliance on fossil fuels. Yet there is still a price to pay because investment into new power stations and new technologies for energy production is expensive. Many countries, including Nigeria, have ageing power plants and stations which have suffered for decades of under-investment in new technologies. Whilst this is now changing, the costs for these changes are huge and are reflected in the price we are paying for our energy. In Nigeria, the prices of cooking gas, premium motor spirit and electricity in 2023 are more than three times they were ten years ago. With the removal of the fuel subsidy in May 2023 by the new president without proper measures to cushion the effect, the cost of electricity could easily skyrocket again. It is due to this constant increase in energy prices that photovoltaic systems can become cost-effective for many homes and business premises. This is particularly true when the government can provide incentives to help fund photovoltaics, but even if funds are not available, photovoltaic systems can often be cost-justified by comparing the cost of mounting a photovoltaic system to the likely combined cost of electricity bills and money spent on fuel for generators over ten to fifteen years, once energy inflation is taken into account. At present in Nigeria, solar photovoltaic technology is applied to limited areas which include telecommunications masts, highway streetlights, garden lightning, rural electrification, and parks (Njok *et al*., 2020a). Regardless of the unfavorable policies toward solar energy in Nigeria, the efficiency of solar photovoltaic systems may be among the reasons why it is limited to the aforementioned areas in Nigeria; hence a need for a thorough study to be conducted on the response patterns of photovoltaic systems under the Nigerian climate. Nigeria is endowed with an abundance of sunshine yearly, which is supposed to be an ideal location for harvesting solar energy via photovoltaic technology. But the mean daytime temperature of Nigeria is a huge percentage above the standard test temperature recommended for photovoltaic technology. Speaking of temperature regarding solar photovoltaic technology, the efficiency of solar photovoltaics declines by about 0.40%-0.50% for each degree rise in temperature (Natarajan *et al*., 2011), then it is of utmost importance that different studies should be conducted to reveal their response pattern in different locations under distinct wavelengths. Photovoltaic technologies are designed and tested in a constant ideal standard test environmental condition, but when they are deployed for domestic use in different areas or atmospheres, environmental issues like relative humidity, temperature and also the nature of radiation play key roles in influencing its behavior and efficiency. Since environmental conditions are hardly constant and the nature of radiation is changing, then it follows that its response to environmental parameters will also be changing. Meteorological parameters including relative humidity, solar power, solar flux and temperature influence the production of electricity via photovoltaic technologies and are accepted as dependable renewable energy sources (Abdelkader *et al*., 2010). Among all the major meteorological parameters, only relative humidity, temperature and nature of radiation have been considered for this study. The smooth functioning of the photovoltaic system relies on some amazing features including charge controller topology, battery technology, solar panel technology and inverter design. Irrespective of these amazing features, photovoltaic (PV) systems are still affected by atmospheric factors including temperature variations, wind, relative humidity, ageing, shading and dust (Adıgüzel *et al*., 2019; Anjos *et al*., 2017; Darwish *et al*., 2018). Shifting our attention to shading, it is one factor which causes a plummet in the performance of photovoltaic systems because it reduces the available solar radiation at the surface of photovoltaic systems (Njok *et al*., 2022), so it is pertinent to fully understand its effect on photovoltaic systems because such knowledge can be instrumental in the upgrading of its design, fabrication and efficiency (Koutroulis and Blaabjerg, 2012). Even if only a very small part of your PV module or array is shaded, its impact on the entire system can be huge. Unlike solar photovoltaic/thermal (PV/T) systems in which if only 1% of the module is under a shade, you lose just around 1% of the power generated. With photovoltaic systems, depending on the peculiarity of the situation, even if only 1% of the PV module is shaded, you can lose up to 50% of the power produced (Boxwell, 2017). For this reason, it is a must that your photovoltaic module is shade free throughout the daytime. Shade exists in two distinct categories: hard shade and soft shade. Hard shade has to do with obstructions such as fallen leaves, bird droppings or a tree branch sitting on top of the glass that can completely obstruct light from getting to the solar cells. While a soft shade is a distant obstruction such as the diffused or dispersed shadow of a tree, adjacent building, towers, telephone poles or clouds which significantly reduces the amount of radiation reaching the solar cells (Boxwell, 2017). When soft shade is affecting photovoltaic panels, there is always a significant loss in energy generated. When it is affected by hard shade and partially covered, the energy generated will drop to the same level as the affected cells: if the cells are hard-shaded and completely covered, a total power shutdown may be experienced. A huge percentage of intellectuals may be tempted to view solar filters as shade, but that is not the case. To buttress this, the solar filters employed for wavelength selection for this study can neither be viewed as a hard nor soft shade. When compared to hard shade, it does not completely stop radiation from reaching the cells. When compared to soft shade, though it lowers the radiation incident upon the solar panel, the decrease is intentional as it is a result of filtering or selecting a particular wavelength. Unlike soft shades that decreases the intensity of the incident wavelengths in equal proportion, the solar filter grant access to the selected wavelength while offering great resistance (blocking or absorbing) to other wavelengths. Kazem *et al*., (2017); Krishna and Moger, (2019); Andrea *et al*., (2019); Njok *et al*., (2022) investigated the impact of shade on the performance of photovoltaics. After a thorough analysis, they reported that there was a significant amount of power loss when cells combined in parallel were covered by shade, while a relatively lower amount of power was lost due to the shade hovering only around the cells connected in series. Their studies also disclosed that the power generated by photovoltaic modules decreases considerably due to non-uniform irradiance. They further disclosed that the loss in output power is not directly proportional to the shaded area but is related to the shading pattern and array configuration.

Joshi *et al*., (2011); Ogherohwo *et al*., (2015); Ali *et al*., (2013) investigated how the visible color spectrum influences the behavior and performance of photovoltaic technology. They revealed that the red color of light profoundly influences photovoltaic technology, while the energy of a PV system lies between the yellow and green wavelength of light. Also, Njok et al., (2022a); Kazem and Chaichan, (2016) conducted a study to show how PV technology responds to distinct wavelengths. They disclosed that PV technology is highly efficient with the yellow wavelength and least efficient with the blue wavelength, but attained its highest efficiency when exposed to the wavelength of the natural spectrum. Njok and Ogbulezie, (2018); Syafiqah *et al*., (2017); Amelia *et al*., (2016); Ogbulezie *et al*., (2020) examined the temperature response pattern of photovoltaics and concluded that PV modules will remain efficient with a high performance ratio given that the temperature of the cells did not exceed its maximum operating cell temperature. They also demonstrated that the high operating temperature of photovoltaic cells triggers a plummet in module efficiency. They further made it glaring that the percentage of solar energy that is converted to electrical energy via photovoltaics hinges on the temperature of the cells; the higher the cell temperature, the higher the loss in power output. Njok and Ogbulezie, (2018); Akonjom *et al*., (2021); Ettah *et al*., (2021); Njok et al., (2022b) examined how relative humidity affects PV module output electrical parameters. They observed that as the level of relative humidity drops the temperature of the PV module rises. They also revealed that low relative humidity levels which corresponds to high module temperature deteriorated the electrical performance and efficiency. However, it was revealed that the photovoltaic output voltage will remain fairly stable between 65% to 75% relative humidity. A plethora of studies are accessible regarding how relative humidity and temperature affect PV modules, but a vast percentage of the accessible studies are only valid for a specific PV technology in a particular location and do not cover the response pattern to relative humidity and temperature of photovoltaics under distinct wavelengths. Generally, there is very little information on the response pattern of photovoltaics to relative humidity and temperature under distinct wavelengths for specific locations in the mangrove swamp regions of Nigeria that can be effectively utilized for the design and sizing of photovoltaic modules. Solar filters detect which wavelength gets to the solar cells, which causes the PV module to respond to a particular wavelength and also enables researchers in unravelling the response pattern of a particular PV technology to a particular wavelength. This study therefore investigates the response pattern of monocrystalline photovoltaic technologies enhanced with solar filter to relative humidity and temperature in the mangrove swamp of Calabar, Cross River State, Nigeria. The importance of this study can never be overestimated since the manufacturer's specification sheet does not contain information regarding which level of relative humidity that maximum power could be abstracted from a PV module at various locations, especially the mangrove swamp. Also, the manufacturer specification sheet does not contain the maximum cell temperature that maximum power could be abstracted from a PV module when exposed to different wavelengths at a particular location (especially the mangrove swamp). To alleviate the fear concerning utilizing monocrystalline PV technology for the generation of electricity in mangrove swamps, it is worth noting that 62% efficiency (as revealed by this study) can be achieved under the natural spectrum in the core months of the wet season in this atmosphere and location. Therefore, the objective of this study is to evaluate the response patterns of monocrystalline photovoltaic panel to relative humidity and temperature in the mangrove swamp environment of Calabar, Cross River States, Nigeria under distinct wavelengths of light.

MATERIALS AND METHOD

Materials Used in This Study: a monocrystalline photovoltaic technology (model AF-100 W) produced by Africell Solar with a maximum power rating of 100 W was deployed for the study (d) as shown in figure 1: output electrical characteristics of the PV technology is disclosed in table 1. Figure 1 also displays other materials employed in the study which include; a precision digital hygrometer (model KT-908) (b) and a precision digital infrared gun thermometer (model GM320) (a). Different colored filters were employed for wavelength selection (e) to (k), while an intelligent photovoltaic panel maximum power point (MPP) tracker of the model WS400A (c) was used to track and determine the maximum power, voltage and current produced by the PV technology.

Fig 1: materials used for the experimental setup

Table 1: PV module technical parameters

Electrical Specification	Value
Maximum Power	100 W
Current at Maximum Power	5.49 A
Voltage at Maximum Power	18.2 V
Short Circuit Current	6.59 A
Open-circuit Voltage	21.8 V
Number of cells	33
Nominal Operating Cell Temperature	47±2
Module dimension	1340 mm*540 mm*25 mm

Experimental Setup: the experiment was carried out in an outdoor environment at the University of Cross River State (UNICROSS), Calabar (latitude 4055'43.6379" N and Longitude 8019'52.2361"). The PV technology was installed horizontally flat facing the sun on a platform 6m above sea level. The intelligent photovoltaic panel MPP tracker was connected directly to the output of the PV technology for precise tracking and determination of the maximum power points as can be seen in figure 2.

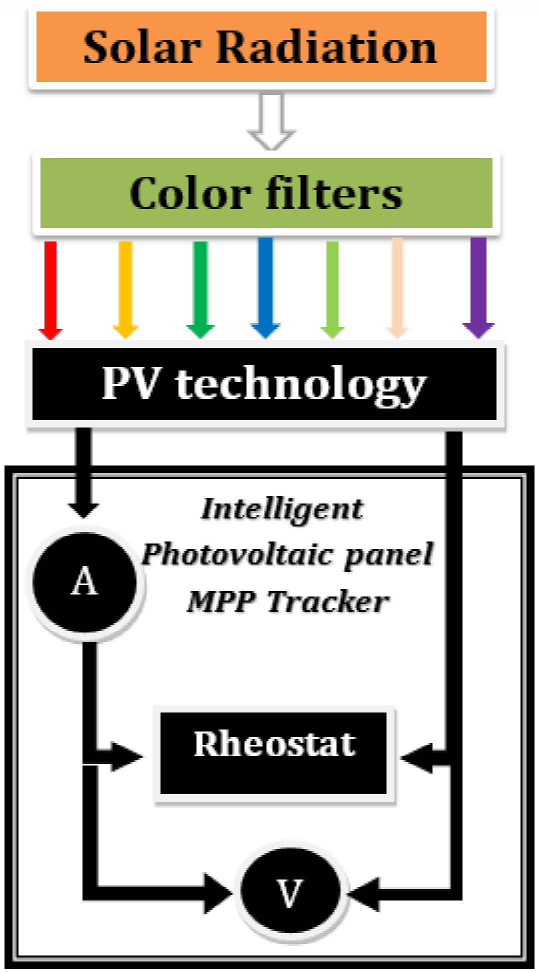

Fig 2: PV module experimental setup

Measurement procedure: data was acquired from the photovoltaic technology at an interval of 30 minutes from 8:00 to 17:00 for a period of 4 months (from June to September which are the core months of the wet season). During data acquisition, measurements were first taken without the filters, before the variation of the colored filters. For each colored filter applied to the photovoltaic technology, the relative humidity, temperature, and the maximum voltage, current and power that the PV technology can deliver at that level of relative humidity and temperature were measured.

Data processing and measurements: the experiment was conducted in real outdoor conditions under varying levels of relative humidity and temperature at a particular time every day. The level of relative humidity at the surface of the PV technology and the panel temperature were measured and recorded for each colored filter applied. The instantaneous voltage V_{mp} and Current I_{mp} at maximum power under a particular real-time condition were measured and recorded. The open circuit voltage V_{oc}, V_{mp}, I_{mp} and maximum power P_{max} were measured directly with the aid of the intelligent photovoltaic panel MPP tracker. The efficiency of the PV technology is greatly influenced by the voltage and current it can generate which in turn is influenced by several climatic factors as well as design and maintenance. The I_{mp}, the V_{mp} and the V_{oc} of the PV technology are largely influenced by relative humidity and temperature (T) and can be easily determined by employing (1) and (2) respectively as shown by (Njok *et al*., 2023).

Load current

$$I = I_{ph} - I_0\left(\frac{qV}{e^{K_BT}} - 1\right) \quad (1)$$

Open circuit voltage

$$V_{OC} = \frac{K_BT}{q}\ln\left(\frac{I_{ph}}{I_0} + 1\right) \quad (2)$$

I_{ph} is the photogenerated current, I_0 is the diode reverse saturated current, q is the electron charge, K_B is the Boltzmann constant, T is the absolute temperature, and V is the voltage at the terminals of the PV module. According to Dincer and Meral (2010) (2) can be approximated and reduced to (3)

Approximated open circuit voltage

$$V_{OC} = \frac{K_BT}{q}\ln\left(\frac{I_{ph}}{I_0}\right) \quad (3)$$

According to Ike (2013), the photogenerated current I_{ph} is equal to the short circuit current I_{sc} and is closely related to the photon flux incident on the PV modules and given as (4)

Short circuit current

$$I_{sc} = bH \quad (4)$$

Where H is the incident solar flux and b is a constant that depends on the junction properties of the semiconductor used in manufacturing the photovoltaic technology. From the data acquired, the normalized power output efficiency was computed using (5) as shown by (Njok *et al*., 2020b), while the efficiency of the PV technology was confirmed using (6) as shown by (Hoseinia and Mehdipourb, 2018).

Normalized power output efficiency

$$\eta_p = \frac{P_{mea}}{P_{max}} \times 100\% \quad (5)$$

Module efficiency

$$\eta_{Mod} = \frac{Power\ of\ photovoltaic\ technology \times 100\%}{Area\ of\ photovoltaic\ technology \times 1000\ {}^{W}/_{m^2}} \quad (6)$$

Where P_{mea} is the measured power at maximum power points, while P_{max} is the maximum power of the PV technology (as specified by the manufacturer) at STC (standard test condition).

Study location: Calabar which is our chosen location for the mangrove swamp lies on Latitude 4°57'06"N and longitude 8°19'19"E. It has an elevation of 32m above sea level and is the capital of Cross River State located in southern Nigeria. The dominant climate is a rare type of climate known as the tropical monsoon climate. It experiences precipitations almost throughout the entire year excluding the core months of the dry season which occurs in two short periods of January to March and October to December during a calendar year (Kamgba *et al.,* 2017). Rainfall is substantial in most months with the short dry season having little effect. In Calabar, it is hot and oppressive throughout the year. The rainy season (wet season) is overcast, while the dry season is mostly cloudy. Throughout the year, the temperature ranges between 64^0F (17.78^0C) to 92^0F (33.33^0C) and rarely goes above 96^0F (35.56^0C) or below 58^0F (14.44^0C) (Weatherspark, 2022). The average percentage of the sky covered by clouds varies throughout the year. The part of the year with clear skies starts around November 25 and ends around February 15 with December being the clearest. While the part of the year with cloudier (unclear) skies starts around February 15 to November 25 with April being the cloudiest; in which 89% of the time the sky is cloudiest (Weatherspark, 2022). The length of daytime in Calabar varies very little throughout the year, staying within 24 minutes of 12 hours throughout. The longest day is June 21, with 12 hours, and 25 minutes of daylight; the shortest day is December 21 with 11 hours, and 50 minutes of daylight (Weatherspark, 2022). Calabar experiences significant seasonal variation in its average hourly wind speed; From May 23 to October 15 (4.7 months) is the windier part of the year with an average wind speed of more than 5.8 miles per hour, with August as the windiest month with an average hourly speed of 7.5 miles per hour. The calmer part of the year begins from October 15 to May 23 (7.3 months) with an average wind speed of less than 5.8 miles per hour, with December as the calmest month with an average hourly wind speed of 4.2 miles per hour [39]. The hottest month in Calabar is January, with a mean high temperature of 95.4^0F (35.2^0C) and a mean low temperature of 74.8^0F (23.8^0C), while the coldest month is August, with a mean high temperature of 82.9^0F (28.3^0C). However, the highest and lowest recorded temperature so far is 102^0F (38.9^0C) and 66^0F (18.9^0C) which were recorded in the months of January and April respectively (Weatherbase, 2022). The least humid month is January with a mean relative humidity of 69%, while July through September are the most humid months with a mean relative humidity of 87%. Regarding rainfall, December and July are the months having the least (13.5 days) and most rainfall (29.9 days) respectively (Weather-atlas, 2022). Regarding sunshine hours, December (9.5 hours) is the month with the most sunshine, while August (4 hours) is the month with the least sunshine (Weather-atlas, 2022).

RESULTS AND DISCUSSION

This section is all about the results gotten from the experimental measurement and analysis, and it is divided into four parts. The first part is about the varying state of the atmospheric parameters considered for this study during data acquisition in the location of the study. The second part reveals the response pattern of the PV technology to relative humidity under distinct wavelengths. While the third part presents the response pattern of the PV technology to panel temperature under distinct wavelengths. The last part displays the level of efficiency attained by the PV technology for different levels of cell temperature for the different wavelengths. It is pertinent to note that the voltage, current, power and efficiency used in the analysis of the results are the maximum voltage, current, power and efficiency respectively that the PV technology produces instantly under distinct wavelengths for a particular level of relative humidity and cell temperature. Furthermore, it is also pertinent to note that the data used for this work was acquired from June to September which are the core months of the wet season in the location of study.

Diurnal and descriptive analysis of the atmospheric condition at the location of study: Fig. 3 reveals the fluctuation in the atmospheric parameters at the location of study, i.e., relative humidity, temperature and wind speed. Fig. 3a reveals a high level of relative humidity above 90% at 8:00, followed by a constant decrease to about 59% at 9:30. Between 9:30 and 14:30, constant fluctuations in the humidity level were observed. After 14:30, the humidity level begins to rise again in an almost linear manner. However, fig. 3b helps us to understand that the minimum and maximum level of relative humidity was 52.25% and 92.67% respectively, with an average of 66.86%. Also, fig. 3a reveals that despite the intense fluctuations in the relative humidity, the variations in the ambient temperature are not large as the figure reveals an almost fairly stable temperature. However, fig, 3c disclose that the minimum and maximum temperatures of the study location are 27.63^{0}C and 36.65^{0}C, occurring at 8:00 and 14:30 respectively. Furthermore, fig. 3c shows that the average daytime temperature is 33.18^{0}C. Fig. 3a also shows the wind speed of the location of the study. It helps us to understand that our location of study is not characterized by high wind. However, fig 3d shows that the average wind speed of the location is 1.71 m/s, while the mean maximum wind speed of the location is 4.3 m/s which occurs at about 14:30.

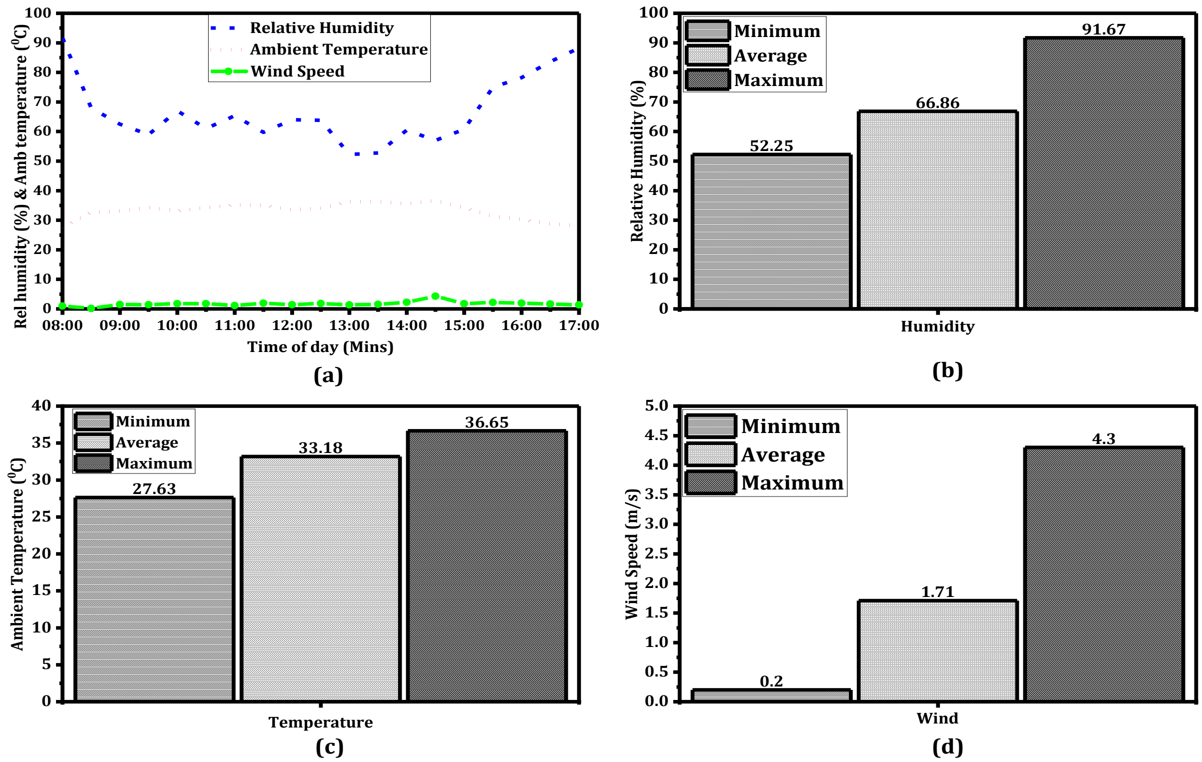

Fig. 3. Variations in atmospheric parameters at location of study

PV output electrical response pattern to relative humidity under distinct wavelengths: Fig. 4 shows how the PV technology responds in terms of voltage, current, power generated and its efficiency to varying levels of relative humidity under distinct wavelengths. Fig. 4a shows the voltage response pattern to relative humidity under distinct wavelengths. The figure reveals that high levels of relative humidity do not favor voltage production with PV technology with and without solar filters which correspond with earlier studies by Njok and Ogbulezie, (2018); Akonjom *et al*., (2021) which reported that high levels of relative humidity adversely affect the performance of photovoltaics. Still in Fig. 4a, an almost linear increase in voltage was observed with and without solar filters as the level of relative humidity decreases, but this increase in voltage as humidity decreases is only down to a particular level of humidity, below which the voltage begins to plummet. To further expatiate on the voltage response pattern, the figure portrays an increase in voltage under the natural spectrum down to about 62.5%, below 62.5% the voltage begins to plummet. With the PV technology under the red wavelength, an increase in voltage was observed down to about 55.5%, below which a fall in voltage was observed. Under the orange wavelength, the increase in voltage continued down to 61.5% before starting to decrease. While with the lemon filter, the decrease in voltage occurred below 59.5% of relative humidity. When the PV technology was exposed to the green wavelength, a similar response pattern as that of the natural spectrum was observed with an increase in voltage occurring down to 62.5% before a fall was experienced. However, under the blue wavelength, the voltage increase peaked at 61.7%. but with the peach filter, the voltage increase progressed down to 60.5% before undergoing a gradual fall. When the PV technology was exposed to the violet wavelength, an increase in voltage was observed down to as low as 55.3% of relative humidity, below 55.3% of humidity a steep fall in voltage was observed. From the response patterns observed under the different wavelengths, it can be said that monocrystalline PV technology should be operated between 63% and 58% of relative humidity for optimum performance which agrees with work by (Njok and Ogbulezie, 2018). However, Fig. 4a, reveals the PV technology producing the highest voltage under the natural spectrum and the least voltage produced with the red wavelength. Fig. 4b shows the current response pattern to relative humidity under distinct wavelengths. The figure reveals a pattern of linear increase in the current generated by the PV technology with and without the solar filters as relative humidity decreases. The figure strongly suggests that a linear relationship exists between current and relative humidity is also in agreement with earlier research by Njok and Ogbulezie, (2018) which reported that high relative humidity does not enhance current production from the PV modules but rather aids in limiting the available solar radiation that would have gotten to the module to enhance current production. Fig. 4b further helps us to understand that the natural spectrum is less affected by humidity when compared to the other wavelengths. Aside from the natural spectrum, it could be seen that the red wavelength followed by orange is most affected by humidity, while peach, green and blue wavelengths are least affected by humidity. The PV technology technical parameters as displayed in Table 1 which reveal that the current at maximum power from the PV technology is approximately 5.5 A helps to unravel some interesting information from Fig. 4b. Buttressing on the interesting information, Fig. 4b reveals that maximum current can be harvested from the PV technology under the natural spectrum when the PV technology is exposed to humidity level of 36% and below. When the PV technology is exposed to wavelengths of lemon, blue or peach, the maximum current can be gotten at a humidity level below 6%. While with the green and violet wavelengths, the level of relative humidity has to drop to about 1.5% for the maximum current to be harvested. Fascinatingly, maximum current may never be harvested with the red and orange wavelengths as the figure reveal that the PV technology will have to be subjected to a relative humidity level below 0% for maximum current to be harvested. Fig. 4c portrays the power response pattern to relative humidity under distinct wavelengths. The figure also reveals a pattern of linear increase in power produced by the PV technology under the distinct wavelength as relative humidity varies. The figure strongly suggests that a negative linear relationship exists between current and relative humidity is also in agreement with earlier research by Njok and Ogbulezie, (2018) which reported that high levels of relative humidity hinder the generation of electrical power via photovoltaics. Fig. 4c further assists us in understanding that maximum power may never be abstracted via the PV technology under some wavelengths. From fig. 4c it is obvious that maximum power may never be abstracted under the red, orange and green wavelengths as long as the humidity level never drops below 0%, as the figure reveals an approximate power output of 90 W (which is 10 W less than the maximum power the PV technology could generate) being generated at 0% of humidity. Furthermore, the level of relative humidity has to drop to about 1.5% for maximum power to be abstracted under the lemon wavelength. Under the blue, peach and violet wavelengths, maximum power could be abstracted when the humidity level drops below 10%. Interestingly, under the natural spectrum maximum power could be abstracted from the PV technology at a humidity level of approximately 35%. The efficiency response pattern to relative humidity under distinct wavelengths is depicted in Fig. 4d. A linear response pattern in efficiency to relative humidity is observed for the various wavelengths. However, it could be seen from the figure that 100% efficiency from the PV technology may not be possible with the red, orange and green wavelengths because the humidity level will have to drop below 0% for 100% efficiency to be achieved. Under the lemon and blue wavelength, 100% efficiency is to be expected at 0%. While for peach and violet wavelengths, 100% efficiency is to be expected at 7% and 10% respectively. When the PV technology exposed to the natural spectrum, 100% efficiency can be expected at a humidity level of 35%.

PV output electrical response pattern to panel temperature under distinct wavelengths: Fig. 5 depicts how the PV technology responds in terms of voltage, current, power generated and efficiency to varying levels of its temperature under distinct wavelengths. Fig. 5a depicts the voltage response pattern to temperature under distinct wavelengths. The figure reveals that high-temperature levels above a certain temperature hinder the production of voltage with PV technology with and without solar filters which corresponds with earlier studies by Ogbulezie *et al.*, (2020); Syafiqah *et al.*, (2017) in which their reports concluded that PV modules will remain efficient with a high-performance ratio given that the temperature of the cells did not exceed its maximum operating cell temperature.

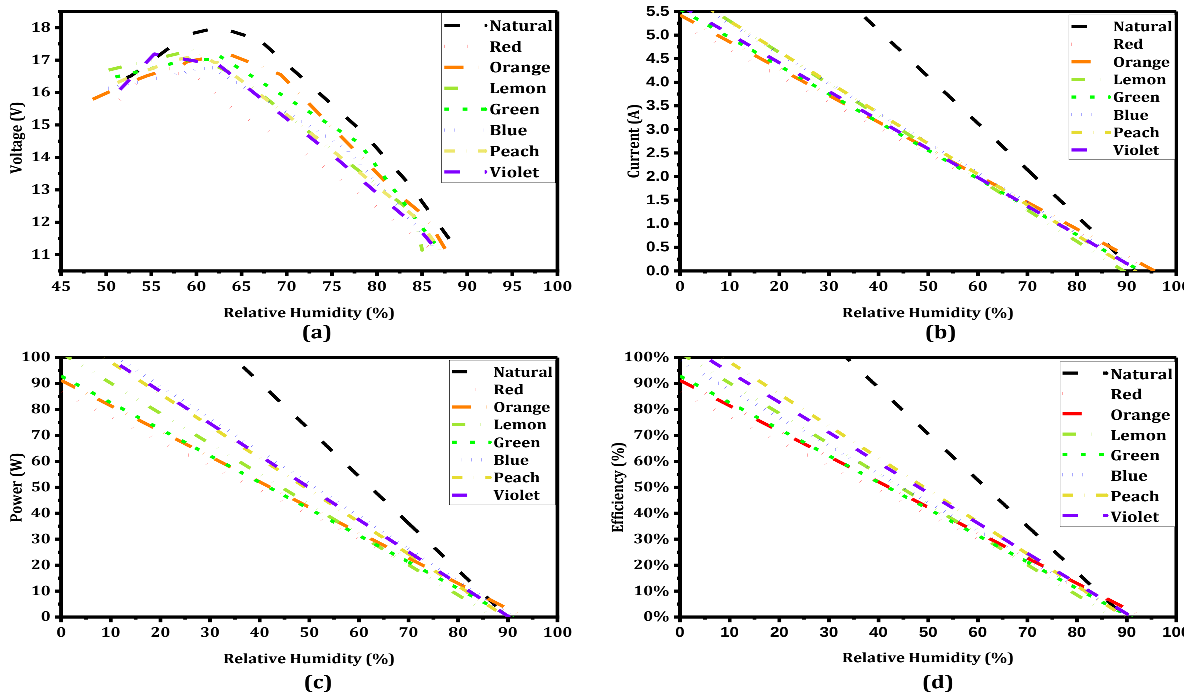

Fig. 4. Response pattern of PV technology to relative humidity under distinct wavelength

Still in Fig. 5a, an almost linear increase in voltage was observed with and without solar filters as temperature increases, but this increase in voltage as temperature increases is only up to a particular temperature level, above which a gradual decrease in voltage begins, which still in agreement with work by (Njok and Ogbulezie, 2018). To further dichotomize the voltage response pattern in Fig. 5a, the figure portrays an increase in voltage under the natural and red spectrum up to 40.5^{0}C (with a peak voltage of 18.01 V and 17.05 V respectively), above 40.5^{0}C, the voltage begins to drop, giving an insight of what the maximum operating cell temperature should be. Under the orange and blue wavelength, the increase in voltage continued above 40.5^{0}C up to 41^{0}C (with a peak voltage of 17.19 V and 17.41 V respectively) before starting to decrease. Interestingly, the peak in voltage occurred as low as 36^{0}C with the lemon filter (with a peak voltage of 16.48 V). When the PV technology was exposed to the green and violet wavelength, the increase in voltage continued above the peak temperature of the orange wavelength up to 42^{0}C (with a peak voltage of 17.13 V and 17.15 V respectively) before starting to decrease. However, with PV the technology under the peach filter, the voltage increase peaked at 41.5^{0}C (with a peak voltage of 17.37 V) before commencing a gradual fall. From the response patterns observed under the different wavelengths, it can be said that the temperature of monocrystalline PV technology should be regulated such that the temperature does not exceed 42^{0}C. However, Fig. 5a, reveals the PV technology is more temperature tolerant under the natural spectrum and least tolerant with the lemon filter. Fig. 5b shows the current response pattern to temperature under distinct wavelengths. The figure reveals a pattern of linear increase in the current generated by the PV technology with and without the solar filters as it temperature rises. The figure strongly suggests that a positive linear relationship exists between current and temperature which still agrees with previous studies by (Njok and Ogbulezie, 2018). Fig. 5b further helps us to understand that current production under the natural spectrum is enhanced by temperature when compared to the other wavelengths. Aside from the natural spectrum, it could be seen that generation of current under the peach filter and blue wavelength is most and least enhanced by temperature respectively. Concerning the PV technology technical parameters as displayed in Table 1, Fig. 5b help us to clearly understand that for maximum current to be harvested from the PV technology the module temperature will have to be more than 42^{0}C which is not healthy for the overall efficiency of the PV technology as reported by (Njok and Ogbulezie, 2018). Fig. 5c shows the power response pattern of the PV technology to varying temperatures under distinct wavelengths. The figure also reveals patterns of an almost linear increase in power produced by the PV technology up to a particular temperature (before starting to decrease) under the distinct wavelengths as temperature increases, which shows that high temperature hinders the performance of photovoltaics as reported by (Ogbulezie *et al*., 2020). Fig.5c further assists us in confirming that maximum power may never be abstracted via the PV technology under some wavelengths in this atmosphere. From fig. 5c it could be seen that 61.5 W and 41.4 W are the highest power that could be abstracted from the PV technology at a threshold of 44^{0}C for the natural and red wavelengths respectively. For the orange wavelength, the highest power that could be abstracted is 46 W at 44.6^{0}C. When the PV technology is under the lemon filter and green wavelength, about 50 W and 40 W respectively at approximately 43^{0}C is possible. While with the blue wavelength, 43.5 W could be abstracted from the PV technology at a threshold of 40.5^{0}C. with the PV technology under the peach filter about 48 W could be harvested at about 42^{0}C, while with the violet wavelength, only 38 W can be generated at a threshold of about 44.2^{0}C. The efficiency response pattern to temperature under the various wavelengths is depicted in Fig. 5d. An almost linear response pattern in efficiency to temperature is observed for the various wavelengths. From the figure, it could be seen that this increase in efficiency as the temperature rises is not indefinite as there is a threshold temperature above which the efficiency begins to plummet, which also conforms to prior research by (Ogbulezie *et al*., 2020). To further buttress Fig. 5d, the efficiency response pattern is simplified in Fig. 6. From Fig. 6 it could be seen that under the natural and red wavelengths, the maximum efficiency that could be attained is 62% and 41% respectively at the threshold of 44^{0}C as revealed in Fig. 6a and Fig. 6b respectively. With the orange wavelength, 46% efficiency is possible at a threshold of 44.7^{0}C as displayed in Fig. 6c. When the PV technology is under the influence of the lemon, green and violet wavelengths, the maximum efficiency that could be attained is 50%, 40% and 44% respectively at a threshold of approximately 43^{0}C as shown in Fig. 6d, Fig. 6e and Fig. 6h respectively. Also, 43% and 48% efficiency are possible with the blue and peach filter at a threshold of 40.5^{0}C and 42.3^{0}C as displayed in Fig. 6f and Fig. 6g respectively. It is quite comforting to know that an efficiency of 50% and above is possible in the core months of the wet season in this location.

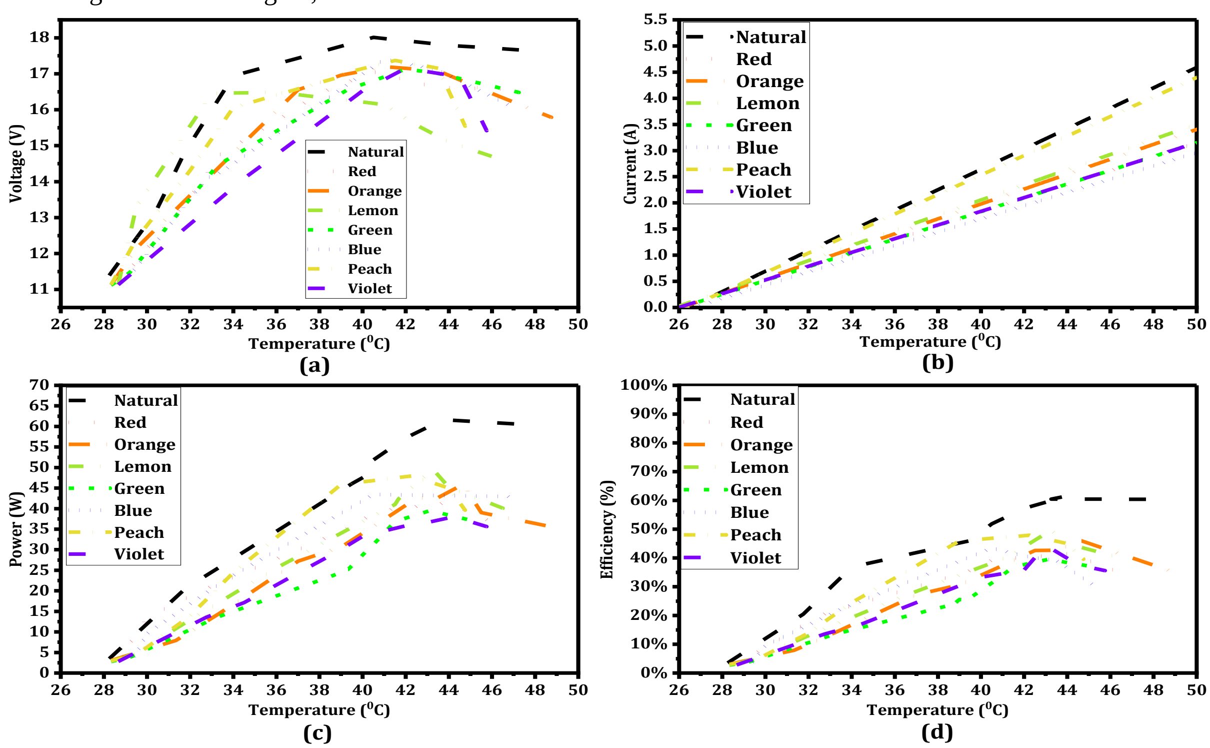

Fig. 5. Response pattern of PV technology to panel temperature under distinct wavelength

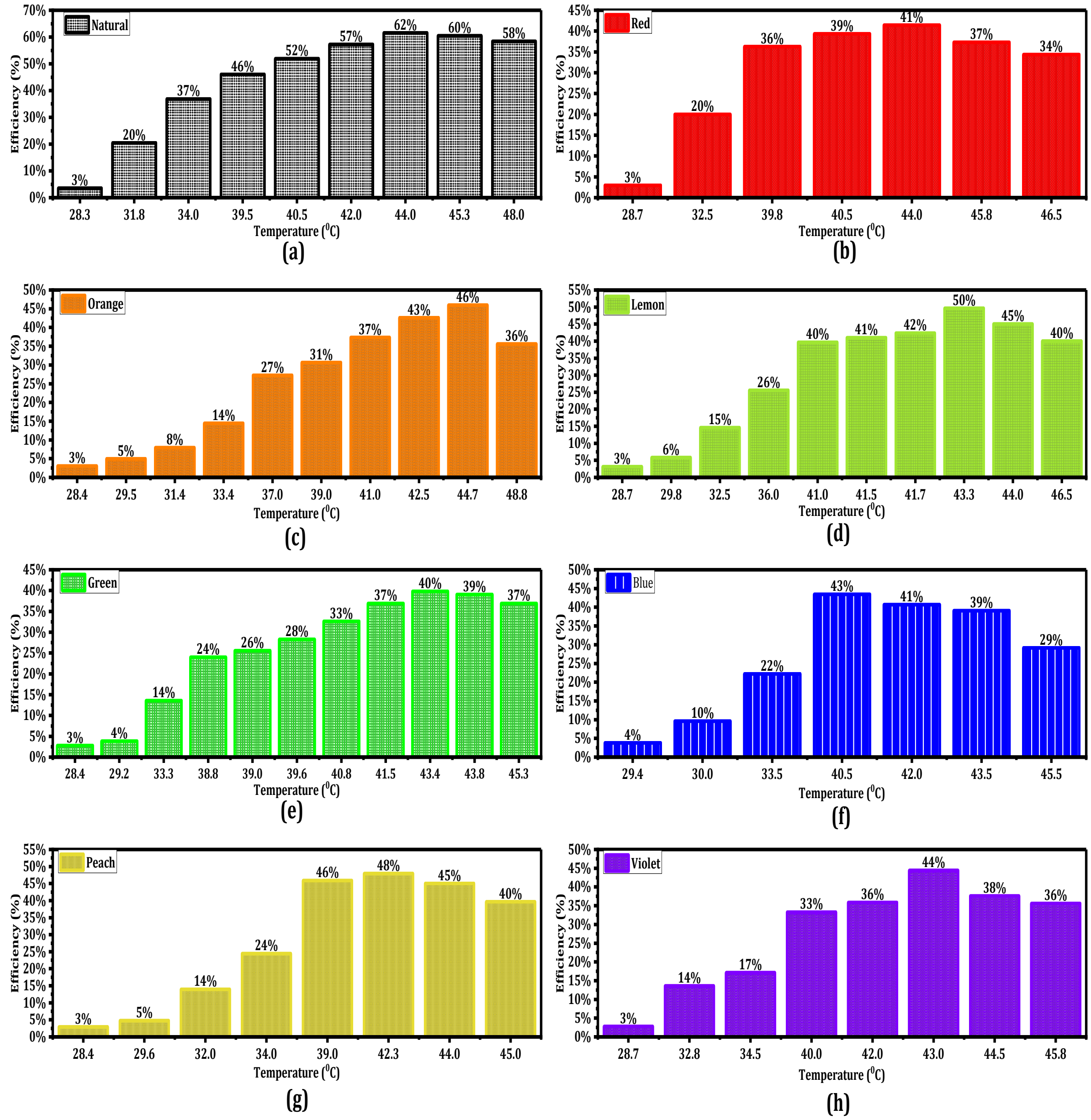

Fig. 6. Efficiency response pattern of PV technology to panel temperature under distinct wavelength

Conclusion: This study reveals that maximum efficiency from monocrystalline photovoltaic technologies may not be possible with the various wavelengths aside from the natural spectrum because the humidity level will have to drop below 10% for 100% efficiency to be achieved. However, this study revealed that the PV technology could attain 100% efficiency when exposed to the natural spectrum at a humidity level of 35%. Furthermore, an almost linear response pattern in efficiency to temperature was observed for the various wavelengths, but this increase in efficiency with temperature is not indefinite as there is a threshold temperature above which the efficiency begins to plummet.

ACKNOWLEDGEMENTS
The authors of this article give special thanks to Tertiary Education Trust fund (TETFund) for funding this institution-based research (IBR).

REFERENCES

Abdelkader, MR; Al-Salaymeh, A; Al-Hamamre, Z; Firas, S (2010). A comparative analysis of the performance of Monocrystalline and multicrystalline PV cells in semi-arid climate conditions: the case of Jordan. *Jordan J. of Mech and Industrial Engineer*, 4: 543–552.

Adıgüzel, E; Özer, E; Akgündoğdu, A; Ersoy, YA (2019). Prediction of dust particle size effect on efficiency of photovoltaic modules with ANFIS: An experimental study in Aegean region, Turkey. *Solar Energy*. 177: 690–702.

Akonjom, NA; Njok, AO (2022). Effect of meteorological parameters on the performance of photovoltaics installed under the guinea savannah atmosphere in Ogoja, Cross River State, Nigeria. *J. App. Sci. Environ. Manage*. 26(7): 1299-1306.

Akonjom, NA; Umuji, JI; Ekah, UJ (2021). Performance evaluation of polycrystalline modules in Guinea Savanna and Mangrove swamp. *World J. of Advance Engineer. Tech. and Sci*. 4(1): 11-21.

Ali, SM; Arjyadhara, P; Prabeer, KD; Batala, KR (2013). Analysis of color spectrum on the performance of photovoltaic cell. *Inter. J. of Renew. Energy*. 8(1): 25-30.

Amelia, AR; Irwan, YM Leow, WZ; Irwanto, M; Safwati, I; Zhafarina, M (2016). Investigation of the Effect of Temperature on Photovoltaic (PV) Panel Output Performance. *Inter. J. on Advanced Sci. Engineer. Info. Tech*. 6(5): 682-688.

Andrea, Y; Pogrebnaya, T; Kichonge, B (2019). Effect of industrial dust deposition on photovoltaic module performance: Experimental measurement in the tropical region. *Inter. J. of Photoenergy*. 2019: 10. Article ID 189 2148.

Anjos, RS; Melício, R; Mendes, VM; Pousinho, HM (2017). Crystalline silicon PV module under effect of shading simulation of the hot-spot condition," in doctoral conference on computing, electrical and industrial systems, Camarinha- Matos L, Parreira-Rocha M, Ramezani J. Eds. *Springer, Cham*. 479–487.

Boxwell, M (2017). Solar electricity handbook. A simple, practical guide to solar energy-designing and installing solar PV systems (11th ed). Greenstream publishing Limited, United Kingdom. Pp 206.

Darwish, ZA; Kazem, HA; Sopian, K; Alghoul, MA; Alawadhi, H (2018). Experimental investigation of dust pollutants and the impact of environmental parameters on PV performance: An experimental study. *Environment, Dev and Sustainability*. 20(1): 155–174.

Dincer, F; Meral, ME (2010). Critical factors that

affecting efficiency of solar cells. *Smart Grid and Renew Energy*. 1:47-50.

Ettah, EB; Ekah, UJ; Oyom, E; Akonjom, NA (2021). Performance analysis of monocrystalline and polycrystalline solar panels in a Semi-Arid region. *Inter. J. of Engineer. Sci. Invention*. 1(7):10-14.

Hoseinia, H; Mehdipourb, R (2018). Evaluation of solar-chimney power plants with multiple-angle collectors. *J. of Computational and Appl Res in Mech. Engineer*. 8(1):85-96.

Ike, CU (2013). The effect of temperature on the performance of a photovoltaic solar system in eastern Nigeria. *Inter. J. of Engineer. and Sci*. 3(12):10-14.

Joshi, SA; Dincer, B; Reddy, BV (2011). Effect of color of light on the PV/T system performance. *Inter. J. of Energy Res*. 36(5): 572-578.

Kamgba, FA; Edet, CO; Njok, AO (2017). Effects of some Meteorological Parameters on Wind Energy Potential in Calabar, Nigeria. *Asian J. of Phys. and Chem. Sci*. 4(1): 1-7.

Kazem, HA; Chaichan, MT (2016). The impact of using solar coloured filters to cover the PV panel in its outcomes. *Scholars Bulletin*. 2: 464-469.

Kazem, HA; Chaichan, MT; Alwaeli, AH; Mani, K (2017). Effect of Shadows on the Performance of Solar Photovoltaic, In: Sayigh, A. (eds) Mediterranean Green Buildings & Renewable Energy. *Springer, Cham*. 379-385. https://doi.org/10.1007/978-3-319-30746-6_27.

Koutroulis, E; Blaabjerg, F (2012). A new technique for tracking the global maximum power point of PV arrays operating under partial-shading conditions. *IEEE Photovoltaic*. 2(2): 84–190.

Natarajan, S; Mallick, T; Katz, M; Weingaertner, S (2011). Numerical investigations of solar cell temperature for photovoltaic concentrator system and without passive cooling arrangements. *Inter. J. Thermal Sc*. 50(12): 2514-2521.

Nerlinger, M; Utz, S (2022). The impact of the Russia-Ukraine conflict on the green energy transition–A capital market perspective. *Swiss Finance Institute Res Paper Series*. 22-49.

Njok, AO; Akonjom, NA; Ogbulezie, JC (2022). Design and performance evaluation of photovoltaic systems with automatic dust wiper in a natural dusty environment. *Asian j. of Phys and Chem sci*. 10(4): 1-15.

Njok, AO; Archibong, EA; Fischer, GA (2023). Diurnal analysis of the performance of photovoltaic systems under the Guinea Savannah atmosphere in Ogoja, Cross River State, Nigeria. *Phys. Sci. Inter. J*. 27(1): 1-15.

Njok, AO; Ewona, IO; Akonjom, NA (2022b). The effect of relative humidity on photovoltaics enhanced with automatic cooling mechanism. *Unicross J. of Sci. Tech*. 1(1): 172-183.

Njok, AO; Iloke, JI; Panjwani, MK; Mangi, FH (2020a). The impact of colored filters on the performance of polycrystalline photovoltaic panel in an uncontrolled environment. *Inter. J. of Elect. Comp. Engineer*. 10(4): 3927–3935.

Njok, AO; Ogbulezie, JC (2018). The Effect of Relative Humidity and Temperature on Polycrystalline Solar Panels Installed close to a River. *Phys. sci. Inter. J*. 20(4): 1-11.

Njok, AO; Ogbulezie, JC; Akonjom, NA (2022a). Evaluation of the performance of photovoltaic system under different wavelengths from artificial light in a controlled environment. *J. of App. Sci. and Environ. Manage*. 26(6):1015-1020.

Njok, AO; Ogbulezie, JC; Panjwani, MK; Larik, RM (2020b). Investigation of monthly variations in the efficiencies of photovoltaics due to sunrise and sunset times. *Indonesian J. of Elect. Engineer. Comp. Sci*. 18(1): 310-317.

Ogbulezie, JC; Njok, AO; Panjwani, MK; Panjwani, SK (2020). The impact of high temperature and irradiance source on the efficiency of polycrystalline photovoltaic (PV) panels in a controlled environment. *Inter. J. of Elect. Comp. Engineer*. 10(4): 3942–3947.

Ogherohwo, EP; Barnabas, B; Alafiatayo, AO (2015). Investigating the Wavelength of Light and Its Effects on the Performance of a Solar Photovoltaic Module. *Inter. J. of Innovative Res. in Comp. Sci. Tech*. 3: 61-65.

Sai Krishna, G; Moger, T (2019). Reconfiguration strategies for reducing partial shading effects in photovoltaic arrays: State of the art. *Solar Energy*. 182: 429-452.

Steffen, B; Patt, A (2022). A historical turning point? Early evidence on how the Russia-Ukraine war changes public support for clean energy policies. *Energy Res. Social Sci*. 91:1-10.

Syafiqah, Z; Irwan, YM; Amin, NAM; Irwanto, M; Leow, WZ; Amelia, AR (2017). Thermal and Electrical Study for PV Panel with Cooling System. *Indonesian J. of Elect. Engineer. Comp. Sci*. 7(2): 492-499.

Weather-atlas. “Calabar, Nigeria”. https://www.weather-atlas.com/en/nigeria/calabar-climate. Retrieved October 15, 2022.

Weatherbase. “Calabar, Nigeria”. https://www.weatherbase.com/weather/weather-summary.php3?s =46256&cityname=Calabar,+Nigeria. Retrieved October 15, 2022.

Weatherspark. “Calabar, Nigeria”. https://weatherspark.com/y/58500/Average-Weather-in Calabar-Nigeria-Year-Round. Retrieved October 15, 2022.