Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v33i2.2024.233
Volume 33(2), June 2024

Evaluation of the Impact of Temperature on the Performance of Photovoltaic Solar Panels Installed on Various Roofing Sheets

[*1]Taddy, E. N., [2]Victor, C. D. and [1]Makama, E. K.

[1]Department of Physics, University of Jos, Plateau State, Nigeria.
[2]General Studies Department, Federal College of Animal Health and Production Technology, Vom, Plateau State, Nigeria.

[*]Corresponding author's email: emmanueltaddy@yahoo.com

ABSTRACT

The performance and efficiency of Photovoltaic (PV) Modules are usually rated under standard test conditions (STC). However, PV modules operate over a wide range of environmental conditions at the field, which are further affected by the method of installation, especially when it comes to roof-mount systems, as different roofing materials are used for roofing houses and solar modules are mounted on them directly. In this study the effect of temperature on the output performance of photovoltaic modules mounted on four different roofing materials (stone coated, long span aluminum, corrugated zinc and short span aluminum) is investigated. Solar panels are separately installed directly on, and then elevated over, different types of roofing sheets. Results show that module installed directly on stone coated roofing material had an overall output performance of 89.52% followed by short span, long span aluminum, and corrugated zinc roofing materials with performances of 89.40%, 89.32%, and 85.54%, respectively. For the elevated set up, the same modules showed improved output performances of 96.16%, 90.30%, 89.30% and 87.84% for stone coated, long span, short span aluminum and corrugated zinc, respectively. The best output performance by the elevated stone coated roof type may be attributed to the fact that the roofing material absorbs nearly all the solar radiation thereby reflecting very little radiation back on the module. The converse is also true for the corrugated zinc material, which had the least output performance. Modules mounted directly on the roof show a strong correlation between the roof and module temperatures with the corrugated zinc roofing sheet showing the strongest correlation with a coefficient of 0.980 while for modules elevated above the rooftop the stone coated roofing sheet showed the strongest correlation with a coefficient of 0.888. For optimum performance, it is recommended that panels mounted on rooftops be elevated above the roof.

Keywords:
Solar panels,
Roofing sheets,
Module temperature,
Performance,
Efficiency.

INTRODUCTION

The use of fossil fuels has increased green-house gas levels in the atmosphere. This is largely due to the combustion of the fossil fuels as a source of energy. This has caused global warming which has led to serious climate change resulting in floods, forest fires, rising sea levels and melting of glaciers. These are just but a few of the consequences of the over-reliance on fossil fuels to meet energy demands. Moreover, the prices of petroleum products and other fossil fuels in Nigeria have been increasing exponentially in the last few years.

Therefore, it is very common in recent times that people are now seeking for renewable energy in order to replace the current fossil fuels. One of the most potential and accessible renewable energy sources is solar energy. Solar energy is the radiant heat and light from the sun that has been harnessed and used by humans since ancient times using a wide range of technologies. Amongst the wide applications of solar energy is photovoltaic systems (PVS) (Ike, 2013).

The outdoor performance of a PV module is influenced by many factors. Some of these issues are related to the module itself and others are related to the location and environment. Few of these factors are: material degradation, solar irradiance, module temperature, parasitic resistances, fill-factor, shading, soiling, tilt-angle etc.

Furthermore, the installation of these panels is carried out in such a way that they can capture the solar radiation from sunrise to sunset. This can be done via solar tracking systems or permanent mount systems. Nigeria is located just around the equator giving it the advantage of not having to use the solar tracking system instead, the permanent mount system is used. There are 3 major permanent mount systems used for solar panel installations namely; Roof mount, pole mount and ground (table) mount (Casimir, 2019).

According to Dash and Gupta (2015), PV module performance/Efficiency is usually rated under standard test conditions (STC) i.e. irradiance of 1000 W/m², solar spectrum of Air Mass 1.5 and module temperature at 25°C. Manufacturers of photovoltaic modules typically provide the ratings at only one operating condition (STC). However, PV modules operate over a wide range of environmental conditions at the field.

And in Nigeria today, these environmental conditions are also further affected by the method of installation especially when it comes to roof mount systems as people use different roofing materials (such as corrugated, long span aluminum, stone-coated, asbestos, etc) for roofing their houses and panels are mounted on them directly.

These roofing materials conduct and reflect the sun's heat radiation differently and when solar panels are mounted on them, they contribute to the increase of the ambient temperature surrounding the panels thereby affecting the overall performance and efficiency of the panels in comparison to the STC as the electrical efficiency of the photovoltaic panel depends on ambient temperature and it reduces when the temperature increases (Vokas *et al*., 2006). This is because increase in temperature reduces the band gap of a semiconductor, thereby affecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. (Nelson, 2003). The aim of this study is to evaluate the impact of temperature on the performance of photovoltaic modules installed on various roofing sheets.

MATERIALS AND METHODS

Materials

Four pieces of 50 W solar panel (monocrystalline) with the following specifications shown in Table 1 were used for the study. The roofing sheets each of 1m^2 in dimension, were stone-coated (Black), long span aluminum (Black), corrugated zinc (silver) and short-span aluminum (Ghana zinc) (Black) were used.

Methods

Wooden mini roofs, each inclined at one end with a height of 6 inches were constructed and the different roofing sheets mounted accordingly, using nails. The solar modules were installed on the roofing sheets facing the south at an elevated angle of 15^0. Each of the roofing sheets had enough room to house the solar panels and also allow for reflection and absorbance as shown on plate 1. The solar panel installation on the roof was carried out in two parts. The panels were, at one setting, installed directly on the roof without any clearance between them and the different types of roofs, while at another set up, they were installed a few inches above the respective roofs as shown in plate 1 (a & b).

The second set up was such that the panels were elevated above the roof (6 inches at the upper side) and (3 inches at the lower side) given an inclination of 15^0 as shown on plate 1b. The two installations were exposed to sun light between 9 am and 3 pm each day from which hourly readings of ambient temperature, module temperature, roof temperature, solar irradiance, voltage, and current were recorded.

Table 1: Solar module parameters

Rating	Values
Rated max. Power:	50 W (±3%)
Rated Voltage:	17.2 V
Open Circuit Voltage:	21.5 V
Rated Current	2.91 A
Short Circuit Current	3.17 A

Standard test condition: Irradiance is 1000 W/m^2, temperature is 25^{0}C, AM 1.5

(*a*) (*b*)

Plate 1 Solar panels mounted: (a) directly on and (b) elevated above different roofing sheets

Ambient temperature was measured using a thermocouple thermometer which expands as temperature increases and contracts as temperature reduces. The panel and roof temperatures were measured simultaneously using an infrared digital thermometer. The thermometer was focused on the surface of the panel or roof and via infrared, which measures surface temperature. Solar radiation was determined using a TENMAS (TM-20) solar power meter. This device, once exposed to sunlight, measures both the beam and diffused radiation from the sun in W/m^2.

A total load of 50 W (2 pieces of 25 W 12 V Tungsten lamp) each was connected to the solar panels using 3m of cables. A digital multimeter was connected in series with the panel to measure the current and another multimeter was connected in parallel with the lamp to measure the corresponding voltage across the lamp. This was done simultaneously for all the four (4) panels and values were taken hourly between 9 am and 3pm daily for 3 days. This procedure was repeated except that the panels were elevated (3 inches at the bottom and 6 inches on top) above the roofing sheets.

RESULTS AND DISCUSSION

Results

The results of the experiments carried out on solar panels installed on different roofing sheets for the two orientations are respectively given in Tables 2 and 3. The results, in each of the two cases, present the values of hourly variations in power, roof and module temperatures at different solar irradiance for the period of the study. Graphical representations of temporal variations of solar power in watts, roof sheets and module temperatures are depicted in Figures 1 and 2, while the linear relationships between module and roof temperatures for the two set ups are presented in Figures 3 & 4. Correlation coefficients between module and roof temperatures were also obtained and are shown in Table 3.

Table 2: Panels mounted directly on the roof

Time	Ambient temperature (°C)	Solar irradiance (W/m^2)	Roofing Sheet types	Roof temperature (°C)	Module temperature (°C)	Current (A)	Voltage (Volts)	Power (W)
9 am	21	765	A	46.20	39.40	1.85	4.88	9.03
			B	40.80	41.10	1.89	4.90	9.26
			C	25.00	44.40	1.86	4.74	8.82
			D	40.00	41.40	1.88	4.80	9.03
10 am	21	874	A	52.80	48.00	2.58	8.75	22.56
			B	49.80	50.30	2.58	8.76	22.60
			C	28.00	54.60	2.58	8.89	22.94
			D	49.70	50.90	2.58	8.75	22.56

11 am	23	950	A	64.40	59.50	3.09	12.90	39.86
			B	59.90	62.80	3.10	12.94	40.11
			C	32.80	67.30	3.07	12.52	38.44
			D	59.40	63.00	3.09	12.92	39.92
12 Noon	28	1009	A	70.00	63.30	3.11	12.70	39.50
			B	65.10	62.70	3.12	12.65	39.47
			C	33.00	66.70	3.11	12.56	39.06
			D	63.00	61.60	3.11	12.70	39.50
1 pm	29	980	A	69.00	61.30	3.26	13.73	44.76
			B	64.20	62.50	3.26	13.70	44.66
			C	31.00	65.80	3.25	13.16	42.77
			D	62.20	60.20	3.26	13.71	44.70
2 pm	31	950	A	61.80	57.80	3.01	13.15	39.58
			B	54.30	57.40	3.05	13.20	40.26
			C	30.00	61.20	2.98	12.15	36.21
			D	52.10	56.20	3.01	13.10	40.61
3 pm	28	810	A	56.20	47.00	3.00	12.35	37.05
			B	49.00	49.80	3.05	12.57	38.34
			C	27.00	53.00	2.80	12.89	36.09
			D	47.00	48.60	3.00	12.50	37.50

Key: A = Stone coated, B = Long span aluminum, C = Corrugated zinc, D = Short span (Ghana zinc)

Table 3: Panels mounted at an elevation above the roof

Time	**Ambient temp. (℃)**	**Solar irradiance W/m²**	**Roofing sheets**	**Roof temperature (℃)**	**Module temperature (℃)**	**Current (A)**	**Voltage (Volts)**	**Power (W)**
9 am	28	902	A	45.60	39.80	2.16	6.48	14.00
			B	40.10	39.90	2.12	6.00	12.72
			C	30.00	39.60	2.13	5.96	12.70
			D	38.20	39.00	2.12	5.99	12.70
10 am	30	1020	A	53.60	46.30	2.92	10.90	31.83
			B	44.40	44.50	2.92	10.91	31.86
			C	33.00	47.80	2.89	10.68	30.87
			D	44.00	47.00	2.91	10.88	31.66
11 am	32	1075	A	56.40	50.80	3.25	13.08	42.51
			B	46.30	50.6	3.25	13.07	42.48
			C	34.00	51.40	3.21	12.85	41.25
			D	51.00	51.40	3.20	12.86	41.15
12 Noon	33	1055	A	60.20	52.80	3.40	14.14	48.08
			B	56.70	53.30	3.31	13.64	45.15
			C	38.00	52.40	3.29	13.35	43.92
			D	52.40	53.10	3.30	13.53	44.65
1 pm	34	1062	A	60.10	53.40	3.34	13.63	45.52
			B	52.80	53.10	3.26	13.13	42.80
			C	40.20	52.00	3.24	13.00	42.12
			D	48.80	54.20	3.24	13.07	42.35

			A	54.20	50.50	3.06	11.68	35.74
2 pm	35	1034	B	48.50	48.40	3.00	11.41	33.42
			C	33.80	47.40	2.90	11.78	34.16
			D	48.70	51.50	3.02	11.42	34.49
			A	44.00	45.40	2.55	8.36	21.32
3 pm	33	960	B	51.40	47.40	2.52	8.26	20.82
			C	33.40	44.00	2.49	7.56	18.82
			D	48.50	57.50	2.50	8.04	20.10

Key: A = Stone coated, B = Long span aluminum, C = Corrugated zinc, D = Short span (Ghana zinc)

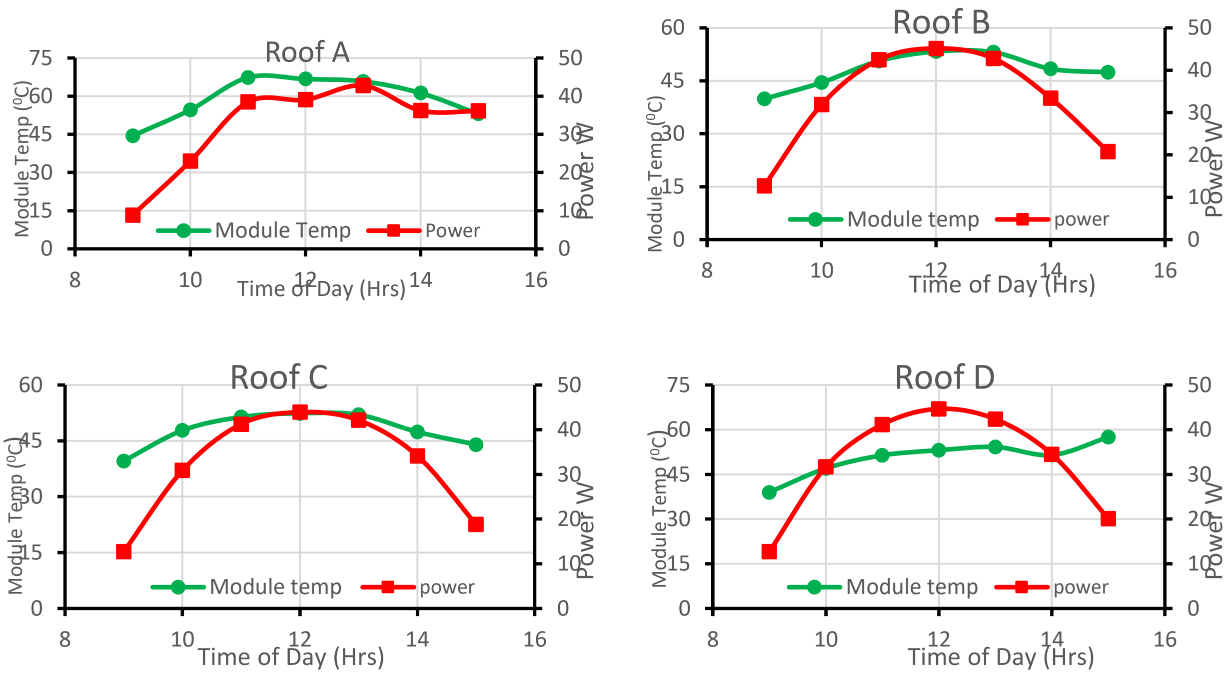
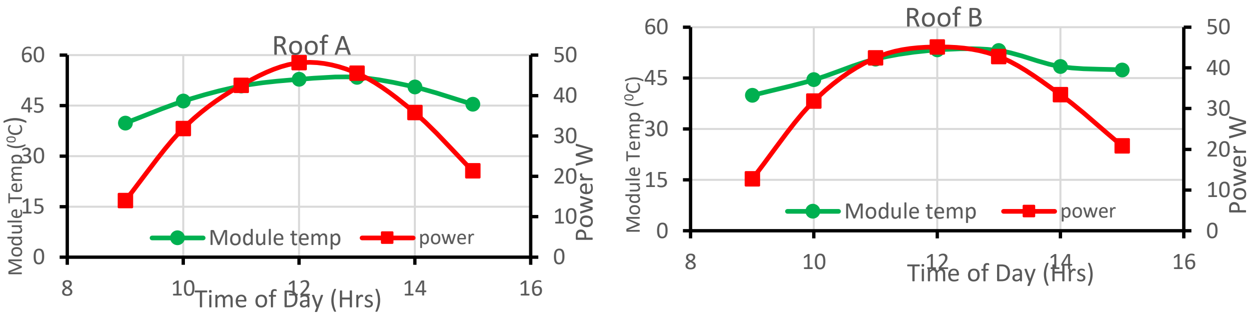


Figure 1: Variation of module temperature and power with time of the day for the different roofing types installed directly on the roof top



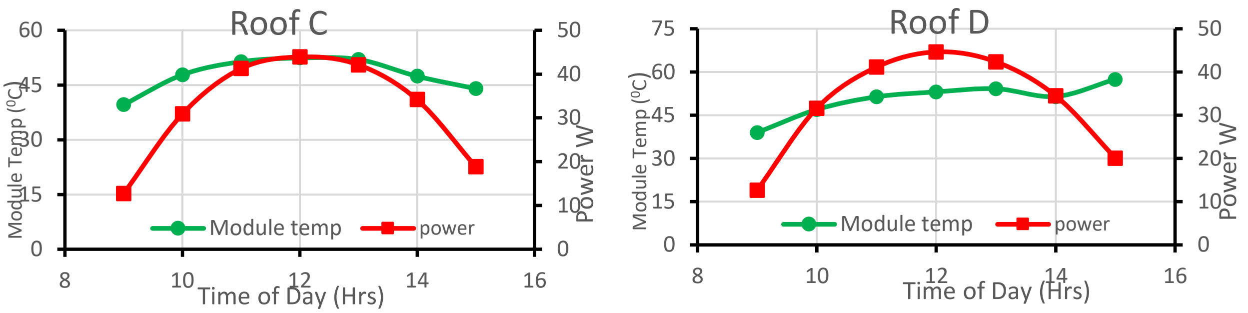


Figure 2: Variation of module temperature and power with time of the day for the different roofing types installed at an elevation above the roof.

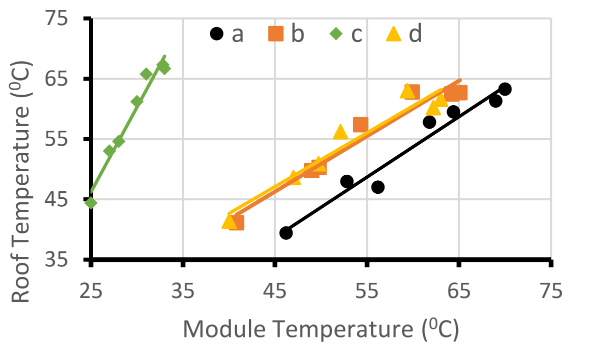


Figure 3: Correlation between roof and module temperatures when modules are placed directly on roof

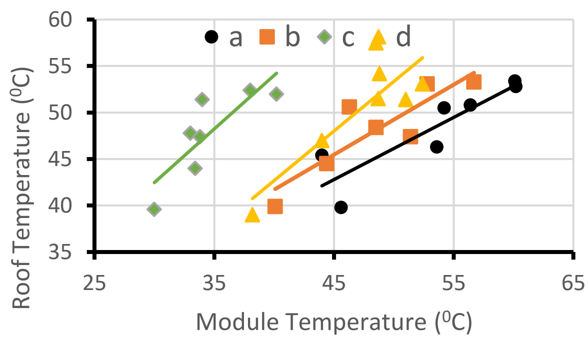


Figure 4: Correlation between roof and module temperatures when modules are elevated above roof

Table 4: Correlation coefficient values obtained when roof temperature was regressed against module temperature for the different roofing sheets

Roof type	**Correlation coefficient between roof and module temperatures**	
	Solar panels placed directly on roof	**Solar panels elevated above roof**
A	0.979	0.888
B	0.973	0.871
C	0.980	0.829
D	0.965	0.855

Discussion

Set up A (modules installed on roof directly)

The overall results show that as the module temperature increases, modules installed on roof type A (i.e. stone coated) produced the highest current, voltage and power and also had the highest overall performance of 89.52 % followed by roof type B (i.e. long span Aluminum) with performance of 89.40 % and the performance of roof type D (i.e. short span Ghana zinc) was 89.32 %. Module installed on roof type C (i.e. corrugated zinc) had the least output performance of 85.54% which is attributed to the fact that it had the highest recorded temperature as shown on Table 1 and Fig. 1, where performance here is the output power as a percentage of the module rating. These agrees with the results of Qais (2015), Satish and Usha (2018), Dhass, *et al*., (2014) and Ike (2013), ascertaining that the power output of a PV module is not only dependent on the ambient temperature but also on the type of roof material and manner of installation.

Set up B (modules installed at an elevation above roof)

The elevation of the modules above the roofing sheets allows for the cooling of the modules by natural air flow. The roof absorbs heat just as the modules do but the elevation does not allow conduction (transfer of heat from one material to the other). Modules installed at an elevation above the same roofing sheets showed improved output performance of 96.16%, 90.30%, 89.30% and 87.84% for stone coated, long span, short span aluminum and corrugated zinc respectively as seen on Table 2 and Fig. 2. The results indicate that PV module installed at an elevation above the stone coated roofing material had the best output performance owing to the fact that the roofing material absorbs about 95% of the solar radiation and reflecting very little radiation back on the module, while corrugated zinc material had the least output performance of 86%. This is because the material reflects most of the radiation back to the PV module thereby increasing the temperature of the module and reducing the energy generation.

The correlation between the roof and module temperatures for the modules placed directly and elevated above the different roof types is shown in figures 3 & 4. The correlation coefficients are presented in Table 4. As can be seen from the Table, there is a strong correlation between the roof and module temperatures when the modules are placed directly on the roof with the corrugated zinc sheet showing the strongest correlation with a coefficient of 0.980. When the modules are elevated above the roof, the correlation decreases. In this case the stone coated roofing sheet shows the strongest correlation with a coefficient of 0.888 since it absorbs most of the radiation falling on it which raises its temperature as compared to the corrugated zinc roofing sheet which reflects most of the radiation falling on it.

CONCLUSION

The effect of temperature on the output performance of photovoltaic modules mounted on four different roofing materials (stone coated, long span aluminum, corrugated zinc and short span aluminum) installed directly on the roof and at an elevation above the roof was investigated. The results showed that modules installed both directly and at an elevation on stone coated roofing material had the highest output performance followed by long span aluminum roofing material then short span aluminum material and corrugated zinc material performed the least. The results further indicate that PV modules installed at an elevation above the roofing material had an overall best output performance compared with modules installed directly on the roof owing to the fact that modules installed at an elevation above the roof allows for aeration and cooling of the modules.

Also, PV module installed at an elevation above the stone coated roofing material had the best output performance because the roofing material absorbs about 95% of the solar radiation thereby reflecting very little radiation back on the module. The corrugated zinc material, on the other hand, had the least output performance because the material reflects most of the radiation back to the PV module thereby increasing the ambient and module temperatures and reducing the power generation.

Finally, it can be stated that for every Solar Module installed directly on the roof, there is a 5% to 10% loss of power depending on the roofing material. It can also be inferred that an increase in ambient temperature reduces the output performance of the solar module. It is, therefore, recommended that panels mounted on rooftops be elevated above the roof to provide for aeration of the modules. For new house owners who are yet to roof their houses and plan to install photovoltaic modules on their roofs, it is recommended that they use stone coated roofing sheets for maximum power output.

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