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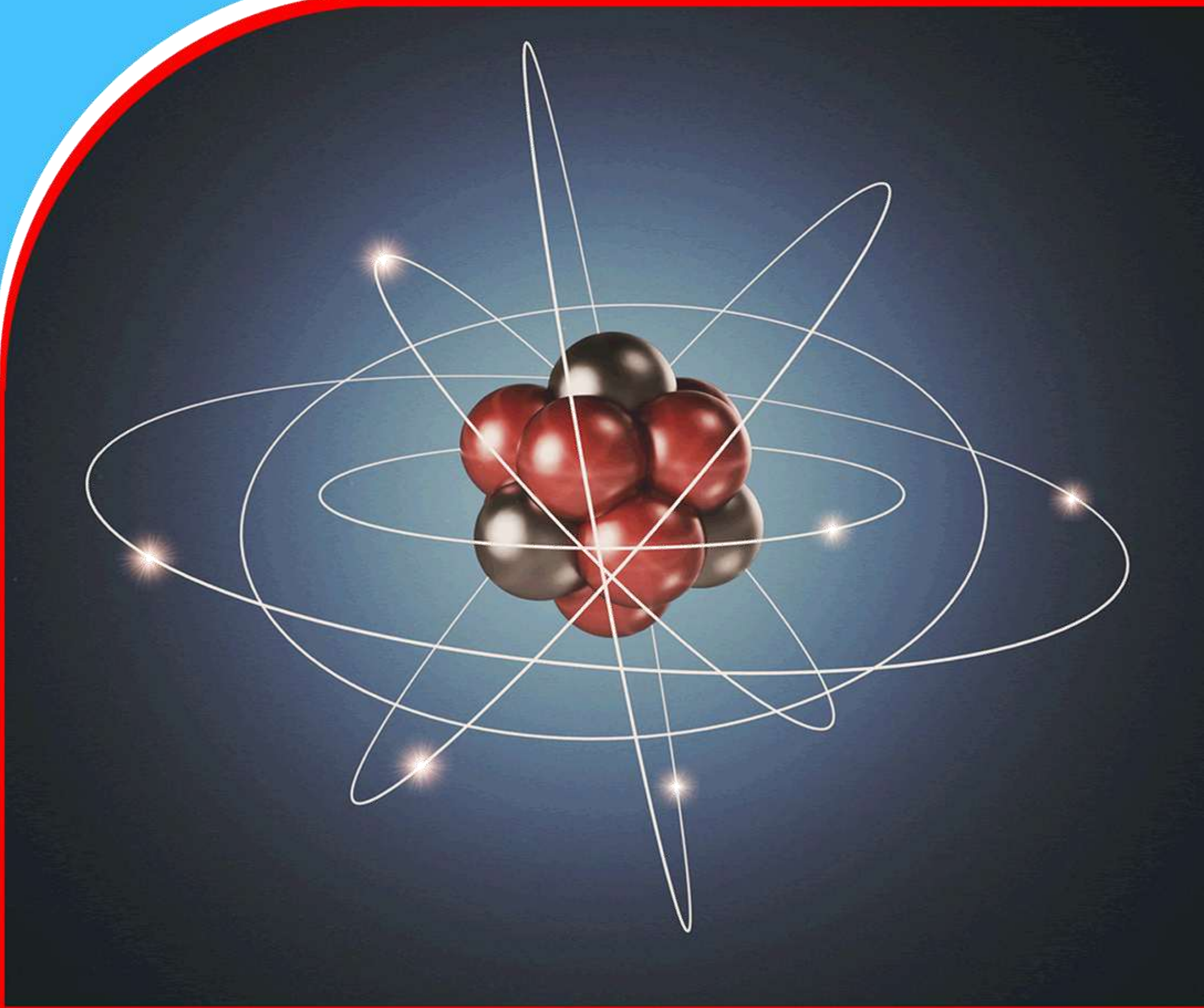

EFFECT OF ALUMINIUM HEAT SINKS ON THE TEMPERATURE REDUCTION AND ELECTRICAL EFFICIENCY OF MONOCRYSTALLINE SOLAR PANELS

Mfon R.E., Al Amri Z., Esaduwha S.O., and Echo M. E.

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[1*]Mfon R.E., [2]Al Amri Z., [3]Esaduwha S.O., [1]Echo M.E.

[1]Department of Physics, Federal University of Lafia, P.M.B. 146, Lafia, Nasarawa State, Nigeria.

[2]Engineering Department, University of Technology and Applied Sciences, Salalah Dhofar Region, Thumrait Rd, 211 Salalah, Sultanate of Oman.

[3]Department of Physics, Federal College of Education, P.M.B. 2042 Yola, Adamawa State, Nigeria.

*Corresponding Author's Email: mfonbecca2000@yahoo.com

ABSTRACT

High temperatures could hinder the effective working of solar panels and negatively impact on their performance. This research employed the passive cooling method using aluminium heat sinks with diagonal and vertical fins with holes attached to the back of two monocrystalline solar panels to reduce their surface temperatures. While the vertical-fins heat sink produced a temperature reduction of 2.48 ℃ (5.9 %), the diagonal- fins heat sink only provided a temperature reduction of 1.25 ℃ (2.9 %). The short circuit current (I_{sc}) of the solar panels reduced at high temperatures and so did their fill factors (FF) and efficiencies. The highest efficiency of 6.8 % was for the module with the vertical-fins and holes while the lowest efficiency of 4.7 % was for the module with no heat sink. The module with the diagonal-fin heat sink had an efficiency of 6.5 %. This study confirms that heat sinks can provide some level of cooling for solar panels in order to improve on their electrical efficiencies.

Keywords: *heat sink, passive cooling method, solar cell temperature, fill factor, efficiency*

1. Introduction

The epileptic nature of power supply in most parts of Africa coupled with the high cost of running fuel-powered generators as well as the environmental pollution caused by this practice has necessitated the switch from fossil fuels and fuel-driven generators to renewable energy sources and the more environmentally friendly solar energy. Photovoltaic cells like Solar panels though used for power generation (Popovici, Hudisteanu, Mateescu, & Chereches, 2016) are said to provide cheap, reliable and environmentally friendly power, but it turns out that they have some down turns to their performance. One of the most important characteristics of photovoltaic cells is its power conversion efficiency and available literature has identified high surface temperatures of the solar panels as a possible reason for their reduced power conversion efficiency (PCE). Solar panels on receiving solar radiations from the sun get heated up to very high temperatures which impacts negatively on their performance. (Buni, Al-Walie, & Al-Asadi, 2018).

Heat sinks have been reported to be useful (Rajput & Yang, 2018), (Soliman, Hassan, Ahmed, & Ookawara, 2018) in curbing this menace as they are said to provide a cooling system for the solar panels and can dissipate the heat due to the overheating of the solar panels by the solar radiations they receive, thereby returning it to reasonably low temperatures. Heat sinks are made with metals and when they are attached to the back of solar panels have been reported to reduce the surface temperature of solar panels with attendant increased power conversion efficiency.

Heat sinks can be made from copper or aluminium because of their good heat conductivities (Cengel, 2002) and when fins with holes are added on heat sinks and attached to the back of solar panels, they bring about temperature reduction in the solar panels and enhance their performance. Two types of cooling system methods namely the Active cooling system and the Passive cooling system methods have been used to achieve this feat but the method adopted for this present research, is the passive cooling method. This is because this method will not draw energy from the solar panels to which the heat sinks are attached. Three Monocrystalline solar panels were used for the research and while one monocrystalline solar panel had no heat sink fixed to it and considered to be the reference panel, the other two had heat sinks fixed on their backs. Two heat sink configurations were adopted. One heat sink had diagonal fins with holes fixed on it while the other had vertical fins with holes fixed on them. The heat sinks used for this study were made of Aluminium because it is affordable, does not rust and has a high thermal conductivity. For each of these solar panels with different fin configurations, the percentage temperature reductions achieved their maximum power output as well as electrical efficiencies was studied. The experiments were carried out under the effect of natural air and between the hours of 10.00 and 16.00 for three consecutive days and the average values of measured parameters were used for the analysis.

It is hoped that the result of this study will point end users of solar panels and solar panel installers to better practices which can deliver higher power output. Furthermore, the end users will be educated on which heat sink fin configuration to adopt for minimal temperature raises and improved solar panel performance. Cooling a solar panel can bring about an improvement in its electrical efficiency, enhance its power output and invariably extend its life span (Sharma, Gupta, Gopal, Dwivedi, & Kumar, 2018).

2. Literature Review

Aluminium heat sinks with fins inclined at 45°, 90° and 135° have been used to extract heat from solar panels with a 10 % heat reduction (Popovici, Hudisteanu, Mateescu, & Chereches,

2016) and though the power of the solar panel increased by 4 %, a lower electrical efficiency was produced. A passive fin cooling method using water and air has also been employed in cooling PV panels to enhance their efficiency (Chen, Chen, Li, & Ding, 2019). That research studied the performance of PV panels with and without fins and investigated how the PV panels inclination, solar radiation, ambient temperature and wind velocity impacted on the maximum power output and hence electrical efficiency of the PV panels. The work showed that the PV panels' efficiencies decreased with increasing ambient temperature and that a high wind velocity produced better cooling effect and improved the PV panels' performance. Average PV panel efficiency ranged from 0.3 approximately 1.8 % more than the PV panel without fins and the average power output was 1.8 W, approximately 11.8 % higher than that of the PV panel with no fins. Aluminium heat sinks combined with water have also been used for cooling solar panels (Rakin, Suherman, Hasan , Rambe, & Gunawan, 2019). The straight fins heat sink configuration used resulted in the surface temperature of the solar panel under investigation dropping by 12.66 % while the output voltage was raised by 21.5 %. When compared to the reference panel, the power output was 40 %.

The effect of heat sink properties on solar cell cooling systems have also been reported (Arifin Z. , et al., 2020). Cooling fins were made using two different materials namely Copper and Aluminium with 5, 10 and 15 fins. The speeds of wind gliding through the solar panels as well as the distribution temperature were obtained through simulation. The work showed that the best cooling was obtained using the Copper base with 15 fins. The temperature reduction was 10.2 ℃ and the electrical efficiency rose by 2.74 %. From this brief review, it is obvious that information on the effect of heat sink with diagonal fins and holes on monocrystalline Solar Panels is scarce and that is what this present research is set to explore. In this present research, monocrystalline solar panels were used. This choice is borne out of the knowledge that they are reliable, their maintenance cost is low and they have been reported to be ecofriendly (Cuce, Cuce, & Bali, 2013).

3. Method

Materials

Three identical Monocrystalline solar panels of same specifications (table 1) were used for the study. Two heat sinks each of area $680.6\ cm^2$ with 6 fins spaced $3.3\ cm$ were used for the study. The fins had a total of 16 holes drilled on them and each hole had a diameter $0.08\ cm$. Two orientations of the fins namely: diagonal-fins heat sink and vertical-fins heat sink were adopted (figure 1). While the diagonal fins heat sink had a mass $0.9\ kg$, the vertical fins heat sink had a mass $1.1\ kg$. For this work, the passive cooling system was employed because it will not need additional energy. Other instruments used include an ammeter, voltmeter, multi-meter, thermometer and a Sunshine recorder which was used for measuring incident solar radiation flux irradiance on the solar panel planar surface.

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Table 1: Monocrystalline solar panel's specification

Parameters	Specifications
Open circuit voltage(V_{oc})	22.05 volt
Short circuit current(I_{sc})	0.63A
Maximum power(P_{max})	10 watt
Voltage at $P_{max}(V_{mp})$	17.5 volt
Current at $P_{max}(I_{mp})$	0.57A
Maximum system voltage suitable for the panel	12 volt
Maximum series fuse rating	DC 1000 volt
Dimensions of Solar panel (in cm)	35.022× 29.94 × 2.48

The diagonal – fins heat sink (figure 1b) was attached to the back of one solar panel while the vertical-fin heat sink (figure 1a) was attached to the second solar panel and the third solar panel without a heat sink was the reference as shown in figure 2. The experimental set up was as shown in figure 3a.

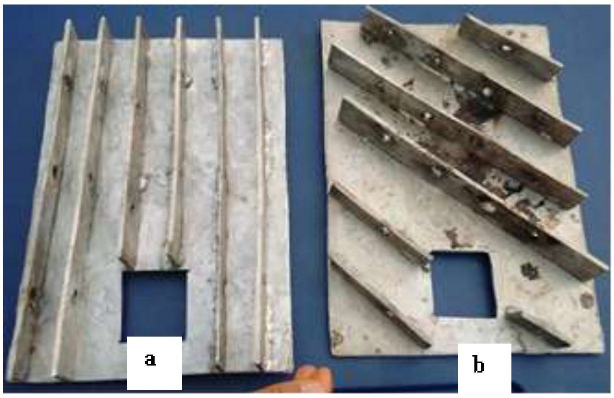


Figure 1: Heat sinks with (a) vertical and (b) diagonal fins with holes.

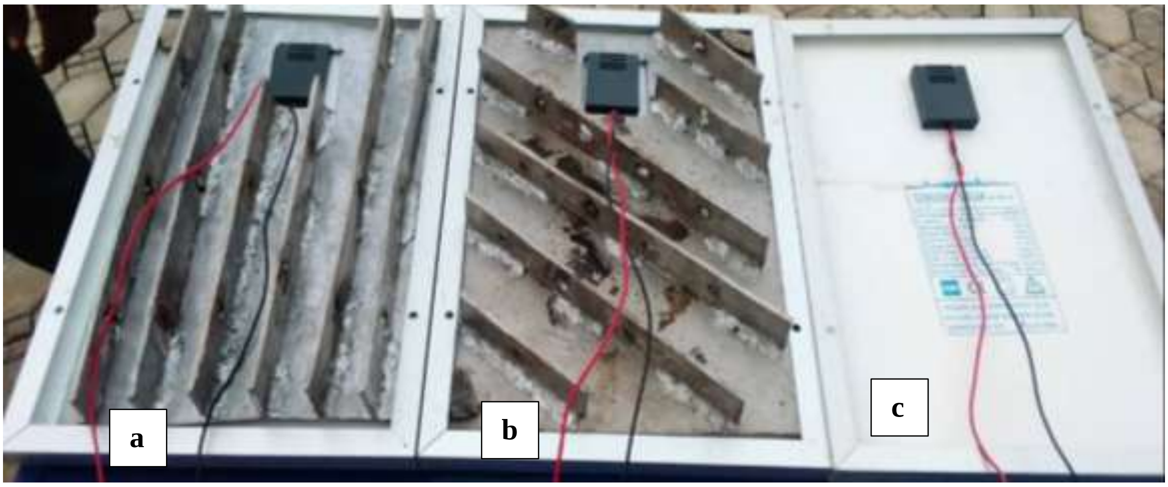


Figure 2: Solar panels with heat sinks fixed to their backs (a) Panel with vertical -fins heat sink (b) Panel with diagonal -fins heat sink (c) Reference panel- no heat sink attached

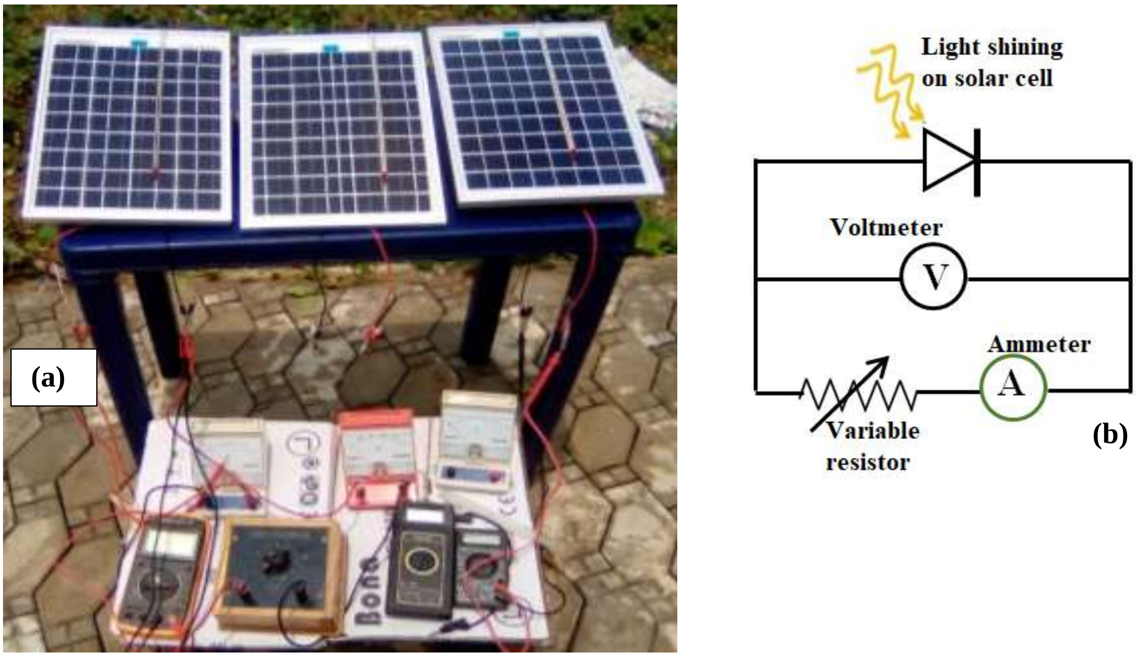


Figure 3: (a) Experimental setup (b) circuit diagram for taking I and V readings.

The solar panels receive solar energy directly from the sun and convert it into electricity. The heat sink attached to the back of the panels act as a cooling system which is supposed to reduce the surface temperature of the solar panels and improve on their performance and efficiency. A digital thermometer was used to measure the ambient temperature while three liquid-in-glass thermometers were each attached to the front surface of a solar panel using ceramic thermal pad. These thermometers were used to record the temperatures of the solar panels to which they were attached.

Theoretical framework

The maximum power of a solar panel is:

$$P_{max} = I_{mp} \times V_{mp} \quad (1)$$

(Where P_{max} is the maximum power output from the solar panel in Watts, and V_{mp} and I_{mp} are the maximum voltage and current respectively from the solar panel)

The fill factor FF of a solar panel determines the power conversion efficiency of a solar cell and is:

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \quad (2)$$

(Where V_{oc} is the open circuit voltage and I_{sc} is the short circuit current.)

The electrical efficiency of a solar panel $\Phi_{\mathbf{pv}}$ refers to the ability of the solar panel to convert sunlight into useful electrical power and is:

$$\Phi_{\mathbf{pv}} = \frac{Power\ output}{Power\ input} \times 100 \quad (3)$$

In terms of solar irradiance and the surface area of the solar panel $\Phi_{\mathbf{pv}}$ is expressed as:

$$\Phi_{pv} = \frac{P_{max}}{\mathrm{G} \times A_{pv}} \quad (4)$$

Where G the solar irradiance and is measured in watt per meter square (W/m^2), A_{pv} is the surface area of the solar panel and P_{max} is the maximum power from the solar cell. For this work, $A_{pv} = 1048.5 \times 10^{-4} m^2$ and the mean value of the solar irradiance $G = 272.33\ Wm^{-2}$(table 2)

Experiment

The experimental set up for this study was as shown in figure 3a. The three solar panels were mounted in an appropriate direction to achieve maximum irradiance. A variable resistor (100 Ω) was connected in the circuit (figure 3b) and varied from 0-100 ohms in steps of 10 ohms to obtain the voltage and current readings with which the IV characteristics of each module was plotted. From this plot, the Open circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum current (I_{mp}) and maximum voltage (V_{mp}) and hence maximum power (P_{mp}) for each module was obtained. The fill factor (FF) and the efficiency ϕ_{pv} for each module was also calculated from these data. The cooling process was made possible by natural air flow over and under the solar panels. This experiment was carried out in the month of July (Rainy season period) and so the weather was dull and hazy. The sunshine was also hazy and it looked as if there was some dust in the atmosphere consequently the solar panels seemed to be poorly illuminated. This experiment was done between the hours 10.00 to 16.00. Readings of the ambient temperature, solar panel surface temperature as well as the solar radiation were all taken after every hour and obtained results are as displayed in table 2.

4. Results and Discussion

The results obtained from this study (Figures 4 & 6) show that the surface temperature of the solar panels increased with the solar irradiance and with the ambient temperature of the surroundings (table 2). The heat sinks actually provide some level of cooling for the solar panels and the heat sink with the diagonal fins provided the highest temperature drop (figure 6). For an average solar irradiance of 272 Wm^{-2}, the module with vertical-fins and holes had the lowest surface temperature (39.82 °C) while that with the diagonal-fins and holes had a surface temperature of 41°C.

Table 2: Showing the variation of the surface temperature of three modules with solar irradiance and ambient temperature from 10.00 hrs to 16.00 hrs

Time	Solar irradiance (W/m^2)	Surface Temperature of the reference panel (^{o}C)	Surface temperature of the solar panel with diagonal fins heat sink (^{o}C)	Surface Temperature of the solar panel with vertical fins heat sink (^{o}C)	Ambient Temperature (^{o}C)
10-11	98.70	36.90	36.40	36.20	27.90
11-12	123.70	40.00	39.10	39.10	25.00
12-13	273.50	45.20	43.30	40.80	36.50
13-14	410.10	46.30	44.00	43.00	37.30
14-15	353.90	41.50	40.10	39.80	33.80
15-16	374.10	44.00	43.10	40.00	35.30
Average	**272.33**	**42.32**	**41.00**	**39.82**	**32.63**

When compared with the reference panel (with no heat sink), the module with the vertical-fins and holes heat sink had a temperature reduction of 2.48 ℃ (5.9 %) while that with diagonal-fins and holes showed a temperature reduction of 1.25 ℃ (2.9 %) (figure 5)(table 3). Changes in V_{oc} and I_{sc} values were found to impact on the maximum power delivered by the solar panels and hence their efficiencies (table 4). As the module temperature increased, the maximum power output P_{max} and V_{oc} values were low and it was also observed that the I_{sc} values reduced as temperature increased (Cander, et al., 2015). The highest fill factor of 0.622 was obtained for the module with the diagonal-fins while the least fill factor of 0.488 was calculated for the reference panel. Furthermore, the module with the vertical-fins had the highest efficiency of 6.8 % and the module with diagonal-fins was found to be 6.5 % efficient (table 4).

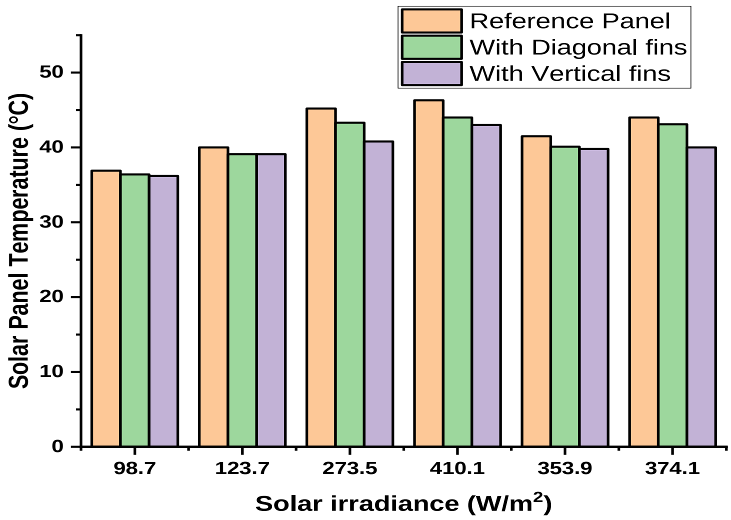


Figure 4: Solar panel surface temperature changes with solar irradiance

Table 3: Temperature reduction of the solar panels when compared with that of the reference panel

Reference panel temperature (℃)	Temp. reduction of panel with diagonal fins and holes	Temp. reduction of panel with vertical fins and holes
36.90	0.05	0.70
40.00	0.50	0.90
45.20	1.90	4.40
46.30	2.30	3.30
41.50	1.40	1.70
44.00	0.90	3.90
Average: 42.31	1.25	2.48

For all configurations of the modules studied however, the power output was found to be very low as shown in table 4. This could be either due to the quality of silicon used for making the solar panel or due to environmental conditions such as earlier on mentioned : hazy weather, humidity, dust accumulation on the surface of the module, wind direction or its mounting angle (Adinoyi & Said, 2013) which may not have allowed the solar panel to be adequately illuminated for best results (Chegaar, et al., 2013) (Khan, Singh, & Husain, 2010) (Reich , et al., 2009). Furthermore, the solar panels may have been on the shelf for over six months prior to its purchase in which case its power output capacity may have dropped by more than 50 % (Adinoyi & Said, 2013) (Rahman, Islam, Karim, & Ronee, 2012).

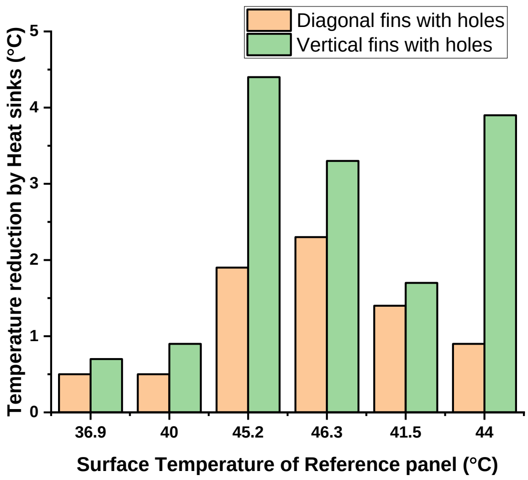


Figure 5: Temperature reduction in solar panels due to Heat sinks

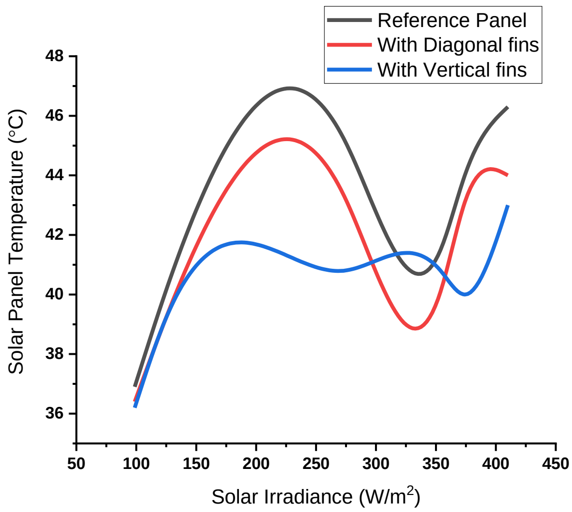
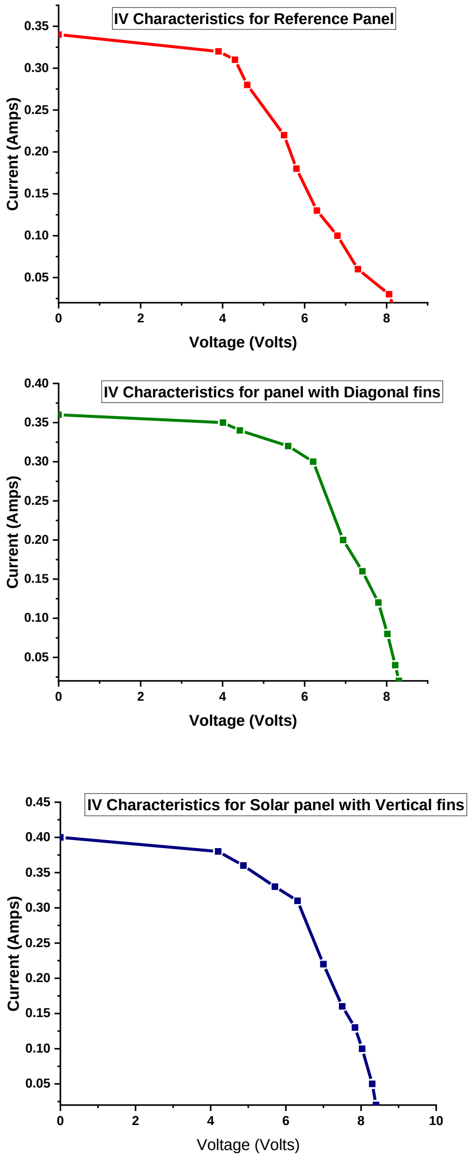


Figure 6: Variation of solar panels temperatures with solar irradiance

Table 4: Showing the different module configurations, their average temperatures and their obtained parameters.

Solar Panel(module configuration)	Average Temperature (°C)	V_{oc} (Volts)	I_{sc}(Amps)	P_{max} (W)	Fill factor (FF)	Efficiency (%)
Reference Panel(no fins)	42.32	8.14	0.34	1.35	0.488	4.7
Module with Diagonal fins	41.00	8.30	0.36	1.86	0.622	6.5
Module with Vertical fins	39.82	8.41	0.40	1.95	0.579	6.8



$V_{oc} = 8.14\ V$

$I_{sc} = 0.34\ A$

$V_{mp} = 4.36\ V$

$I_{mp} = 0.31 A$

$FF = 0.488$

$P_{max} = 1.35\ W$

$V_{oc} = 8.30\ V$

$I_{sc} = 0.36\ \ A$

$V_{mp} = 6.209\ V$

$I_{mp} = 0.30\ A$

$FF = 0.622$

$P_{max} = 1.86\ W$

$V_{oc} = 8.41 V$

$I_{sc} = 0.4 A$

$V_{mp} = 6.3\ V$

$I_{mp} = 0.31 A$

$FF = 0.579$

$P_{max} = 1.95\ W$

Figure 7: IV characteristics of the three modules and their obtained circuit parameters.

Conclusion

This work studied how effective diagonal-fins and vertical-fins heat sinks with holes were in bringing about a reduction of the surface temperature and hence efficiency of monocrystalline solar panels to which they were attached. While the module with the vertical-fins heat sink had a 5.9 % temperature reduction, the diagonal-fins heatsink produced a 2.9 % temperature reduction for the module to which it was attached. The highest efficiency of 6.8 % was for the module with the vertical fins and holes and the least efficiency of 4.7 % was for the reference module with no heat sinks. The maximum power output of all three solar panels studied was very low and this was attributed to either environmental condition, poor illumination of the solar panels or dust particles that may have settled on the surfaces of the solar panels.

Recommendations

Cooling solar panels with the help of heat sinks was the main focus in this work therefore any step taken to achieve this is worth it. In this regard, the cooling ability of the heat sinks can be improved by increasing the contact area of the heat sink on the solar panels or by using anti reflecting materials to reflect heat away from the solar panels in order to improve on its efficiency and therefore power output. Furthermore, to improve on the illumination of the solar panels, it might be a good idea to carry out this study on bright sunny days. The authors hope that the result of this study will be helpful and a guide to solar panel installers and the end users of these solar panels.

References

Adinoyi, M. J., & Said, S. A. (2013). Effect of dust accumulation on tha power output of Solar Photovoltaic Modules. *Renewable energy, 60*, 633-636. Retrieved from https://doi.org/10.1016/jrenene.2013.06.014

Arifin, Z., Suyitno, S., Tjahjana, D. D., Juwana, W. e., Putra, M. R., & Prabowo, A. R. (2020). The effect of Heat Sink Properties on Solar Cell Cooling Systems. *Applied Sciences*(10,7919;), 1-15. doi:doi:10.3390/app10217919

Buni, M. J., Al-Walie, A. A., & Al-Asadi, K. A. (2018). Effect of Solar Radiation on Photovoltaic Cell. *International Research Journal of Advanced engineering and Science*, 47-51.

Cander, S., Purohit, A., Nehra, A., Arvind, Nehra, S. P., & Dhaka, M. (2015). A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperatue. *energy eports, 1*(1), 104-109.

Cengel, Y. A. (2002). *HEAT TRANSFER A practical approach* (2nd Edition ed.). New York, USA: Scientific Reasearch Publishing.

Chegaar, M., Hamzaoui, A., Namoda, A., Petit, P., Aillerie, M., & Herguth, A. (2013). Effect of illumination intensity on solar cells parameters. *energy Procedia, 36*, 722-729.

Chen, H., Chen, X., Li, S., & Ding, H. (2019). Comparative Study on the performance improvement of photovoltaic panel with passive cooling under natural ventilation. *International journal of smart Grid and clean energy, 3*(4), 374-379. doi:doi:10.12720/sgce.3.4.374-379

Cuce, E., Cuce, P. M., & Bali, T. (2013). An experiment analysis of illumination intensity and temperature dependvncy of photovoltaic cell parameter. *App. energy 111*, 374-382.

Khan, F., Singh, S., & Husain, M. O. (2010). Effect of illumination intensity on cell parameters of a silsicon solar cell. *Solar energy Materials and Solar cells*, 1473-1476. doi:10.1016/j.solmat.2010.03.018

Popovici, C. G., Hudisteanu, S. V., Mateescu, T. D., & Chereches, N.-C. (2016). Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks. *energy Procedia, 85*, 425-432.

Purohit, A., Sharma, A., Arvind, A. S., Nehra, S., & Dhaka, M. (2015). A study on photovoltaic parameters of monocrystalline silicon solar cell with cell temperature. *energy reports, 1*, 104-109.

Rahman, M., Islam, M., Karim, A. Z., & Ronee, A. H. (2012). Effects of Natural dust on the performance of PV Panels in Bangladesh. *I.J. Modern education and Computer Science, 10*, 26-32. doi:10.5815/ijmecs.2012.10.04

Rajput, U. J., & Yang, J. (2018). Comparison of heat sink and water type PV/T collector for polycrystalline photovoltaic panel cooling. *Renewable energy*, 479-491.

Rakin, S. A., Suherman, S., Hasan , S., Rambe, A. H., & Gunawan. (2019). A Passive ooling System for Increasing efficiency of Solar Panel OutputJournal. *Journal of Physics, 1373(2019)012017*, 1-6. doi:doi:10.1088/1742-6596/1373/1/012017

Reich , N., Sark, W., Alsema, e., Lof, R., Schropp, R., Sinke, W., & Turkenburg, W. (2009). Crystalline Silicon Cell performance at low light intensity. *Sol. energy Mater. Sol Cells, 93*, 1471-1481.

Sharma, K., Gupta, A., Gopal, N., Dwivedi, G., & Kumar, S. (2018). Life Span and overall performance enhancement of Solar Photovoltaic cell using water as coolant: A recent review. *Materials Today: Proceedings*, 18202-18210. doi:https://doi.org/10.1016/j.matpr.2018.06.156

Soliman, A. M., Hassan, H., Ahmed, M., & Ookawara, S. (2018). A 3d model of the effect of using heat spreader on the performance of photovoltaic panel (PV). *MATHEMATICS AND COMPUTErS IN SIMULATION (ELSEVIER)*, 1-14.