Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 8 Volume 26 August 2020

Mechanical and Energy Engineering

The Effect of Staggered porous fins on the performance of Photovoltaic panel in Baghdad

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ABSTRACT

The performance of photovoltaic (PV) panel having staggered metal foam fins was examined experimentally in Baghdad, Iraq. Three staggered metal foam fin configurations attached to the backside of the PV panel were studied. The measured parameters were front and back surfaces temperature, open voltage and current circuits, maximum power, and PV efficiency. It was noted that the maximum electrical efficiency enhancement was 4.7% for staggered metal foam fins (case III) than the reference PV panel. The operating temperature of the cell was increased when the value of solar intensity was high. Thereby, the electrical efficiency was decreased. It was found that the metal foam fins decreased the PV temperature by 2-3 ºC.

Keywords: Staggered Fins, porous fins, PV panel, PV performance, experimental study.

تأثير الزعانف المسامية المتداخلة على أداء الألواح الضوئية في بغداد

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الخلاصة

تم فحص أداء الألواح الضوئية (PV) ذات الزعانف المعدنية المتداخلة .تمت دراسة ثلاثة انواع من ترتيبات زعانف الرغوة المعدنية الملتصقة مع السطح الخلفي للوح الكهروضوئي .المتغيرات المقاسة هي درجة حرارة السطح الأمامي والخلفي ، والجهد والتيار المفتوحان، والطاقة القصوى ، والكفاءة الكهروضوئية .ولوحظ أن أقصى تعزيز للكفاءة الكهربائية كان 4.7٪ بالنسبة إلى زعانف الرغوة المعدنية بالمقارنة مع اللوح الكهروضوئي المرجعي. ولوحظ أن درجة حرارة تشغيل الخلية تزداد كلما زادت قيمة الاشعاع الشمسي وبالتالي تنخفض الكفاءة الكهربائية للوح الكهروضوئي. وجد أن استخدام زعانف الرغوة المعدنية يقلل درجة حرارة اللوح بمقدار 2-3 ^{0}م.

الكلمات الرئيسية : زعانف متداخلة، زعانف مسامية، لوح كهروضوئي، اداء اللوح الكهروضوئي، دراسة تجريبية

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2020.08.01

Article received: 1/1/2020
Article accepted:24/2/2020
Article published:1/8/2020

1. INTRODUCTION

PV panel represents the primary type of the solar energy exploitation system. It attracts solar radiation at the cell to convert it into electrical power. PV panels are quickly growing; therefore, it becomes one of the essential applications in the solar energy field. An efficient PV panel with an efficiency of 10% over 1% of the area earth can generate power more than the power needed by the worldwide. A small portion is ranging between 15 – 20% of the solar irradiance falling on the PV cell, which converted into electricity. While the largest part was converted into heat that increasing the operating temperature of the PV cell **(Teo et al., 2012)**. The degradation in the PV cell due to temperature rise above 25 ^{o}C may be varied between 0.25 - 0.5 %/°C depends on the PV cell industrial quality **(Nižetić *et al.*, 2016)**. Besides that, the electrical performance of the PV cell influenced by the increment of the ambient temperature. In other words, there is an inverse relationship between the electrical performance and the ambient temperature **(Vokas et al., 2006) and (Hashim and Abbood, 2015).** Thereby, it is vital to use a cooling system to reduce the operating temperature, which leads to an enhancement in the performance of the PV cell. As a result, the PV cell age will be prolonged **(Royo et al., 2016)**.

There are two cooling methods used to improve PV electrical efficiency: active and passive cooling. Unlike passive cooling, active cooling consumes power, more efficient, and complicated **(Grubišić et al., 2016).** Anderson et al. **(Anderson *et al.*, 2008)** studied the effect of heat pipe equipped underneath the PV panel as a passive cooling technique. A phase change material (PCM) was used in direct contact with the backside of the PV module **(Atkin and Farid, 2015)**. Evaporative cooling and fins attached to the backside of two PV panels was investigated by Chandrasekar and Senthilkumar **(Chandrasekar and Senthilkumar, 2015).** It was found that the PV temperature reduced by 12%, and electrical efficiency improved by 14%.

Metal foam fins with closed-cell were equipped with the back surface of the PV panel has been examined by Slimefendigil et al**. (Selimefendigil et al., 2018)**. They concluded that the output power of the PV panel with fins was higher than the output power of the PV panel without fins. Aluminum fins underneath the PV panel were studied by Filip Grubisic-Cabo et al. **(Filip Grubišić- Čabo *et al.*, 2018).** Longitudinal and random perforated fin arrangements were used in this experimental work. Clearly, random arrangement enhances the electrical efficiency more than the longitudinal arrangement. Abdel-Raheimamr et al. presented an experimental work for the PV module, having fins on the back surface **(Abdel-raheimamr et al., 2019).** Also, a theoretical model had been exhibited to validate the results. They found that the use of fins decreased the PV temperature by 4-5 ^{o}C. The effect of the different rib angles on the output power generated by the PV panel was studied numerically by Popovici et al. **(Popovici *et al.*, 2016).** It was found that the maximum output power improved by 7.55% for rib angle 45^{o} against 6.97% for 90^{o} as compared with a reference PV panel. Under indoor surroundings, an experimental study was conducted by Cuce et al. to perform the impact of aluminum heat sink on the output power of PV cell **(Cuce et al., 2018).** An increase in the output power of the PV cell was achieved by 20% at the radiation condition of 800 W/m^{2}. Chen et al. **(H. Chen et al., 2014)** examined the influence of weather conditions like solar irradiance, wind speed, and ambient temperature besides the finned cooling on the electrical efficiency of the PV panel. Under different situations in their study, the average power output of PV panel with fins was higher than without fins by 1.8~11.8%, and the average electrical efficiency for the PV panel with ridges was 0.3~1.8% higher than the PV panel without fins. An experimental study under natural convection was carried out for PV panels with and without fins **(Gotmare et al., 2015)**. Nine aluminum perforated fins were used for the passive cooling. The results showed that the cooling by fins reducing the temperature by 4.2% and increasing the output power by 5.5%. A finned plate of aluminum was used as a cooling method on the rear surface of the PV panel to enhance efficiency **(El Mays et al., 2017)**. The results

showed an increase in the output power by 1.87 W and improving electrical efficiency by 1.77%. An experimental and theoretical study was implemented to enhance the performance of the PV panel through the cooling by fins **(Ahmed, 2018).** The results showed that there was a reduction in temperature by about 9.4% for the panel with a finned surface.

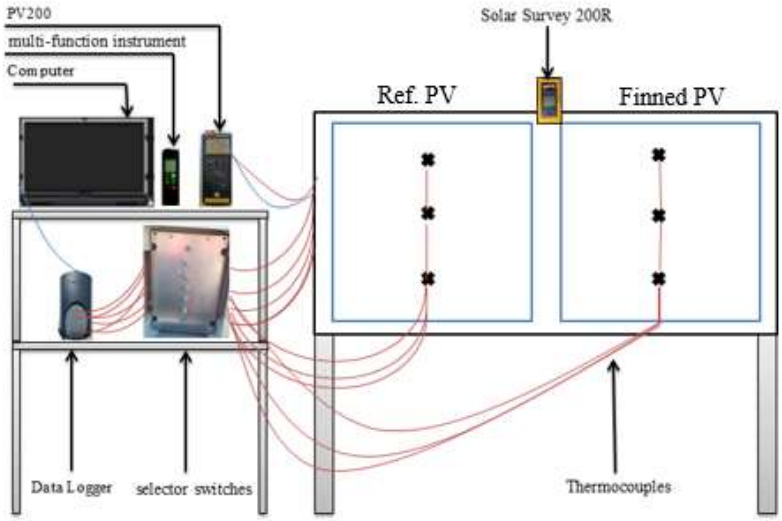
Metal foam is a cellular structure that consists of a solid metal (frequently copper, aluminum, and nickel). This structure is containing a large volume fraction of pores. The pores either consisting of ligaments that form an interconnected network, so it is called open-cell metal foam. Alternatively, the pores can be sealed with metal; then, it is called closed-cell metal foam **(J. Chen et al., 2014)**. In comparison to the solid material, metal foams have various attractive characteristics. Metal foams have a great combination of physical and mechanical properties such as high fluid permeability, high thermal conductivity, and high stiffness in conjuring with its very lightweight. So they are used in different applications that range from mechanical to thermal **(Ashby et al., 2000)**. Metal foam enhances the heat transfer rate by increasing the contact of the surface area between the working fluid and the absorber plate and provide a better mixing between them **(Hussien and Farhan, 2019) (Ammar and Hana, 2017).** The Augmentation in the generated power from the PV panel due to the longitudinal metal foam fins was studied by Jasim and Farhan **(Hasan and Farhan, 2019)**. The results indicate that the addition of ten longitudinal fins can reduce the average PV panel temperature by about 8.4% and improve the power output by an average of 4.9%.

The present work aims to examine the influence of staggered metal foam fins with different configurations on the electrical efficiency and operating temperature of the PV panel. The tests are implemented under natural convection, and the fins are equipped on the back surface of the PV panel.

2. EXPERIMENTAL WORK

Two PV panels were used in this work, as shown in **Fig. 1**. The first one having staggered metal foam fins (5 mm thickness) attached at the back surface of the PV panel. In contrast, the second PV panel worked as the reference panel (without cooling) for comparative analysis. The dimensions of the PV panel were 67 cm × 54 cm and peak power of 50W. **Table 1** listed the PV panel specifications at standard test conditions. The experimental tests were conducted in the Technical Engineering College in Baghdad (latitude 33.22˚ North and longitude 44.23˚ East) under outdoor weather conditions during May and June 2019. The PV panels were positioned for south-facing, and the PV panel slope angle was varied to the optimum value of each month. Each experiment is from 9:00 a.m. to 2:00 p.m.

(a) Photograph of the PV panels.



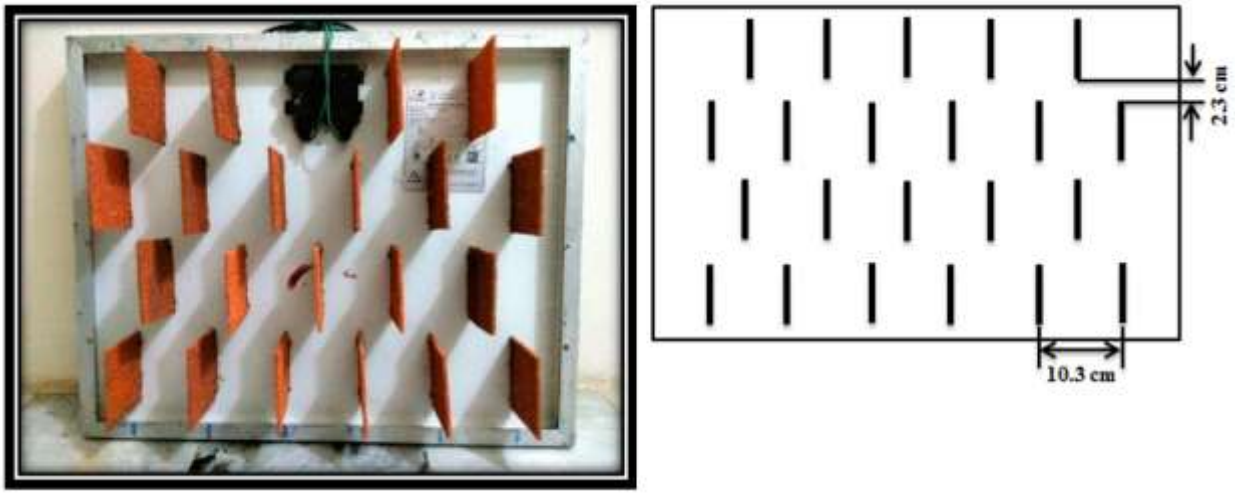
(b) Schematic diagram of the test rig

Figure. 1 PV panels test rig.

Table 1. Modules specifications at standard test conditions.

Peak voltage	18 V	Peak power	50 W
Peak current	2.8 A	Module efficiency	14.54 %
Short circuit current	3.17 A	Fill factor	75.39
Open circuit voltage	22 V	Module area	3589.74 cm^2

In this work, staggered metal foam fins consist of four rows of fins with 2.3 cm spacing between each row, and the length of fins was 10 cm. Three different cases of fins arrangements are used (the number of fins in each row was changed for each arrangement). In the first configuration, the first and third rows from the bottom contain six fins while the second and the fourth row contains five fins. The spacing between the fins inside each row is 10.3 cm. In the second configuration, the first and third rows having eight fins against seven fins for the other rows. The spacing between the fins inside each row is 7.7 cm. In the last configuration, the second and fourth rows consist of nine fins, whereas ten fins for the rest rows. The spacing between the fins inside each row is 6.2 cm. The above arrangements were shown in **Fig. 2**. K-type thermocouples measured the temperatures. Nineteen (19) of thermocouples were used in this work; six of them were placed evenly on the rear surface of each PV panel and three on the front surface. Another one thermocouple was left free in approximately 15 cm under the PV panel to measure the ambient temperature in the shade. The distribution of the thermocouples was shown in **Fig. 3.** The data logger (Whilst Pico data logger Tc-08) with eight channels was used to record the output of the thermocouple. Solar module analyzer PV200 manufactured by SEAWARD electronic limited company was used to test the open-circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum



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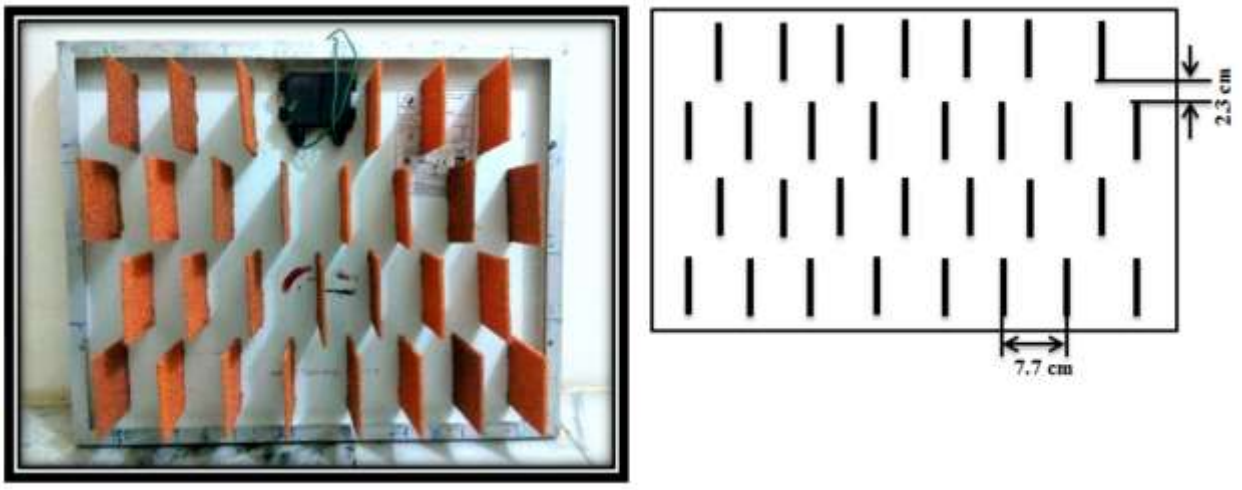

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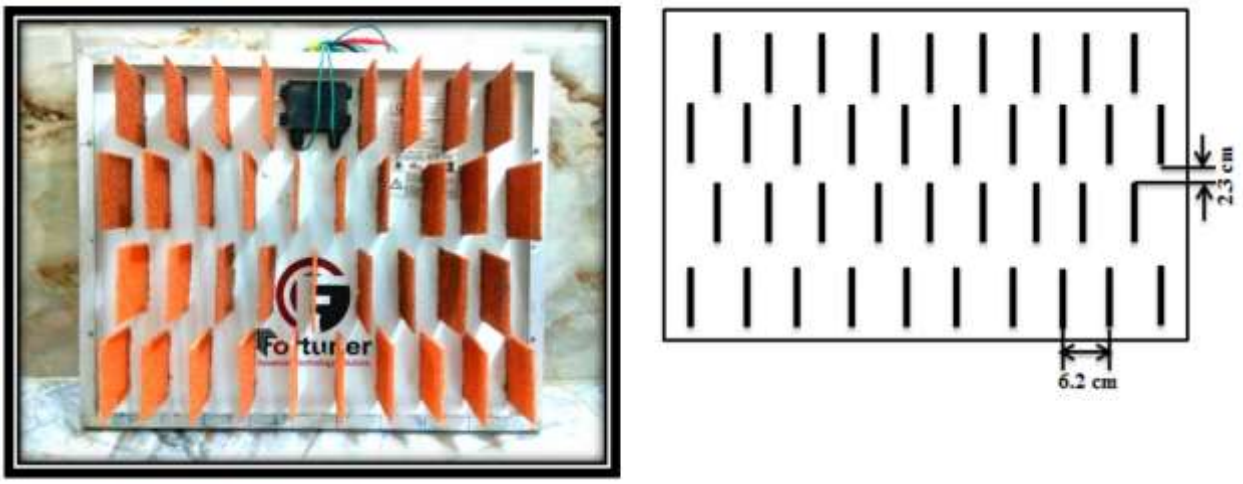

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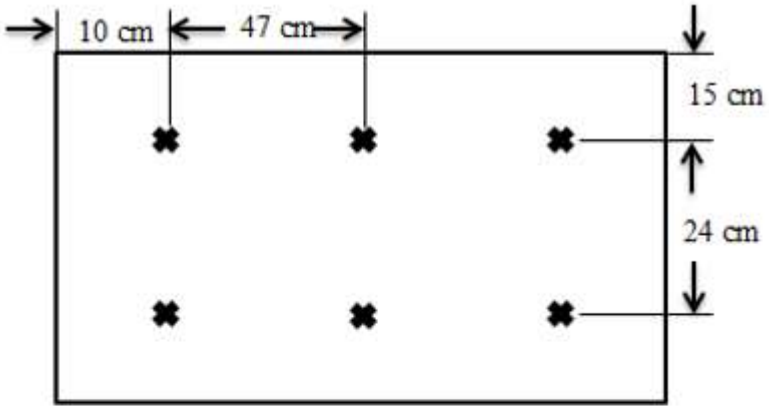
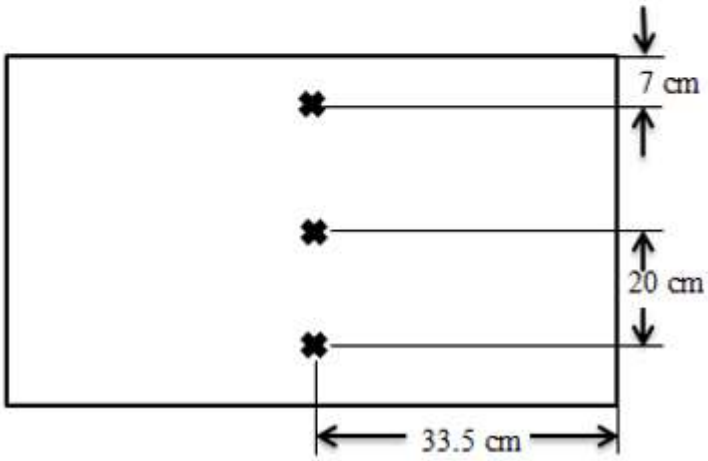
Figure. 2 Staggered metal foam fin configurations. (a) First configurations. (b) Second configuration. (c) Third configuration.



(a) Distribution of thermocouples on the back surface



(b) Distribution of thermocouples on the front surface

Figure. 3 Temperature points measurement.

Voltage (V_m), maximum current (I_m), maximum power (P_m), and fill factor (FF). Solar Survey 200R Series manufactured by SEAWARD electronic limited company is used to measure solar radiation.

The solar module electrical efficiency (η) is calculated from the ratio of (P_m) divided by the solar module surface area (A_m) and the input solar radiation (G)

$$\eta = \frac{P_m}{G\, A_m} \quad (1)$$

3. UNCERTAINTY ANALYSIS

In this study, the procedure proposed by Kline and McClintock **(Kline and McClintock, 1953)** was used, where the root mean the following formula calculates square error in a measured quantity:

$$\delta R = \sqrt{(\sum_{m=1}^{n} \frac{\partial R}{\partial X_m} \delta X_m)^2} \quad (2)$$

Where: R is the calculated quantity, and X is the measured variable.

δR is the calculated quantity error.

δX is the measured variable error.

In this study, the uncertainty values of various dependent and independent parameters were listed in **Table 2.**

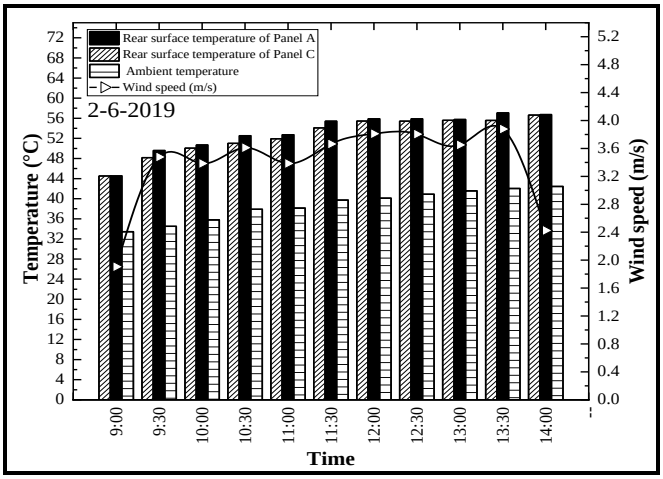
Table 2. Values of uncertainty analysis connected with measured values.

Parameters	**Range**	**Resolution**	**Accuracy**
Thermocouple K-type	-200-1370 °C	1 °C	± 0.19
Solar meter	100-1500 W/m^2	1 W/m^2	± 5 W/m^2
Thermal anemometer	0.2 m/s	0.01 m/s	± 0.03m/s
Uncertainty in measurement		**Uncertainty (%)**	
Temperature, T (°C)		± 0.19	
Solar intensity, G (W/m^2)		± 5	
Wind velocity, V (m/s)		± 0.03	
Current, I (A)		± 0.342	
Power, P (W)		± 2.11	

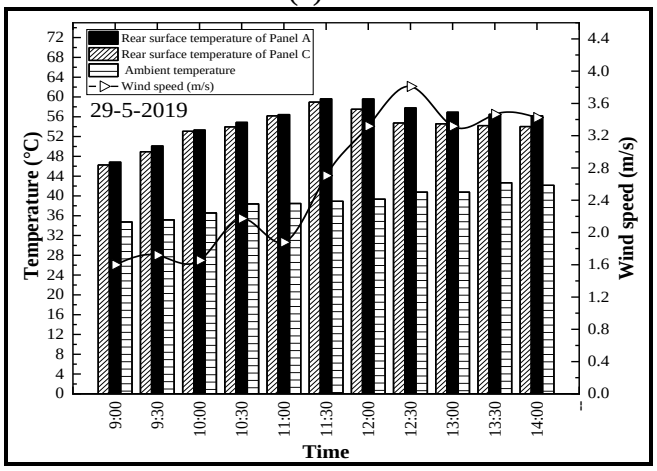
4. RESULTS AND DISCUSSION

In this experimental work, staggered metal foam fins with three different configurations were examined to study the improvement in the output power and the electrical efficiency of the PV

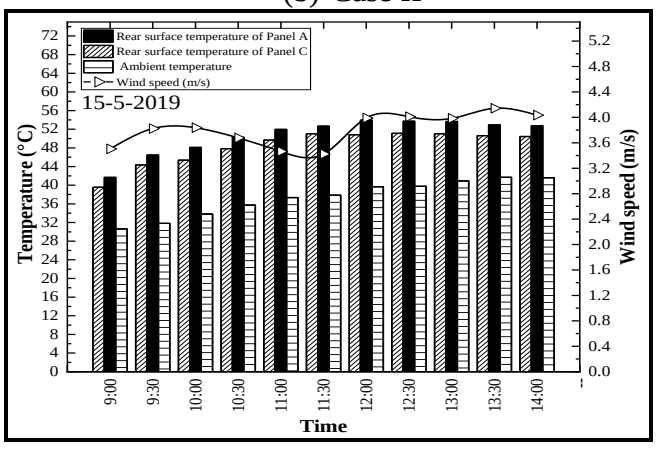
panel. PV panel having staggered fins was called panel C, while the reference PV panel without fins was called panel A. The effect of the wind speed on the PV panel rear surface temperature for the three cases of staggering fins configuration is presented in **Fig. 4**. It was concluded that the increment in fins number would help in the temperature reduction of the PV panel. Besides, it can be noted that wind speed has a direct impact on the temperature of the PV panel. For Case III, the average temperature difference between panels A and C was 2-3°C.



(a) Case I



(b) Case II



(c) Case III

Figure. 4 Hourly variations of the PV panel rear surface temperature and wind speed for Staggered Configuration.

Fig. 5 depicts the open-circuit voltage variation over the day hours for case three of the staggered configuration. The highest values of the open-circuit voltage are 21V and 20.8V for panels C and A respectively at 9:00. These values decrease with increasing temperature. For panel A when the temperature raised from 46.4C at 9:30 to 53.9C at 12:00, the open-circuit voltage dropped from 20.7V to 20.5V. For panel C when the temperature increased from 44.3C to 50.8C, the open-circuit voltage decreased from 20.75V to 20.65V. The open-circuit voltage depends on the solar irradiation and the ambient temperature (**Masters, 2004**). The measured open-circuit voltage values of the panel C were slightly higher than the panel A. The decrease of the open-circuit voltage with the increase of ambient temperature is more pronounced when comparing its improvement with the rise of solar radiation.

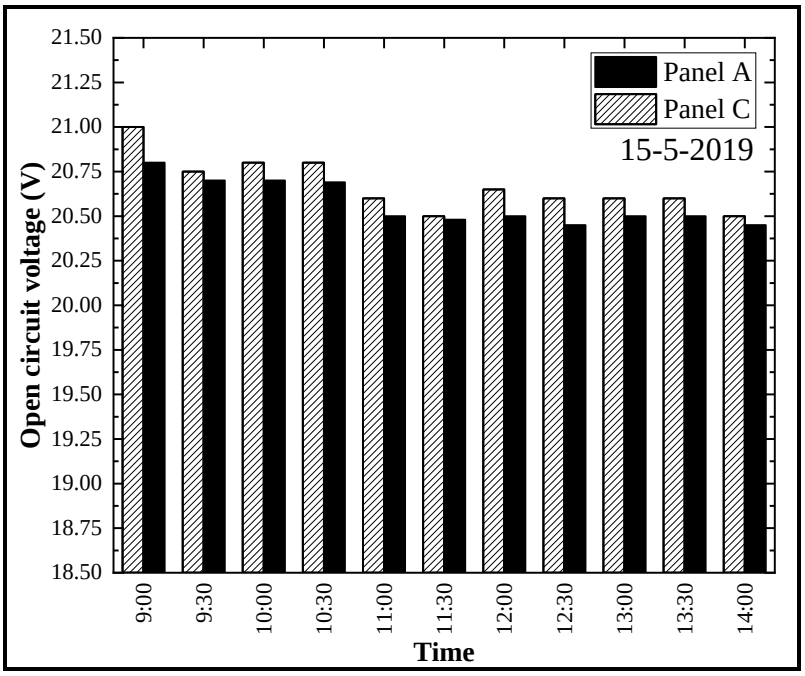


Figure. 5. Variation of the open-circuit voltage for the PV panels with and without fins.

The variation of solar intensity and the maximum power of the PV panel with and without fins for all cases of the staggered fins configuration are shown in **Fig. 6**. The improvement in the average power output of panel C was 2.8% more than panel A. Higher values of solar radiation result in higher power output for both cases. The average power output developed by the panel C was 42.8W, whereas it was 41.6W for the reference panel. The variation of electrical efficiency for the PV panel with and without fins with the solar intensity for the three cases of staggered configuration is shown in **Fig.7**. The average electrical efficiency difference between panels A and C was 4.7%. It can be concluded that the operating temperature of the cell was increased when the value of solar intensity was high. Thereby, the electrical efficiency was decreased. But, for panel

B, part of the electrical efficiency was regained by fins cooling. The behavior of the electrical efficiency curves was similar to the result found by Hashim and Abood **(Hashim and Abbood, 2015)**.

The experimental result of the present work is different from the previous works due to many factors, such as the PV panel specifications, solar intensity, ambient temperature, wind speed, and fin arrangements. Thus, the direct comparison was complicated to be held between the present and previous studies. Thereby, the comparison will be concentered on the general behaviors of the measured parameters. **Fig. 8** shows the temperature difference (Reference panel – finned panel) results done by **Gotmare et al. 2015,** which used nine perforated aluminum fins with the present work. Clearly, the porous fins have more reduction in the PV temperature than the perforated fins. This figure demonstrated that the use of porous fins has a significant influence in reducing the operating temperature, as well as it improves the output power generated by the PV panel.

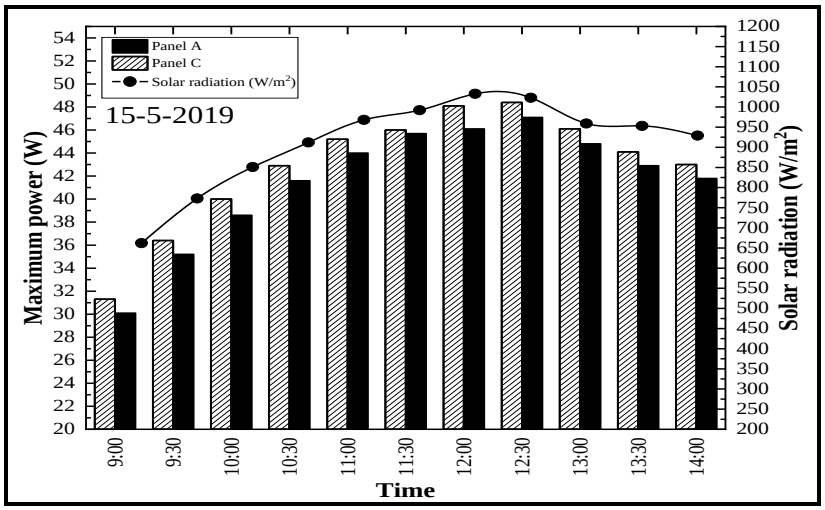


Figure. 6 Variation of the solar intensity and the maximum power for the PV panel with and without fins for Staggered Configuration.

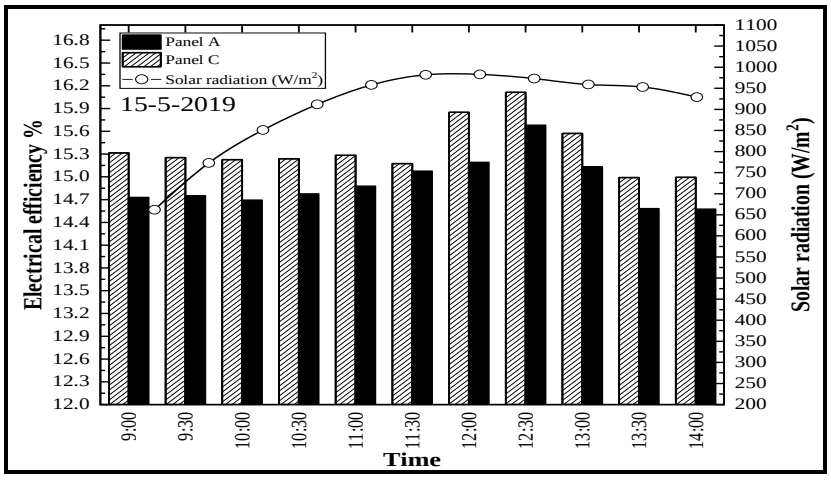


Figure. 7 Variation of the solar intensity and the electrical efficiency for the PV panel with and without fins for Staggered Configuration, Case III.

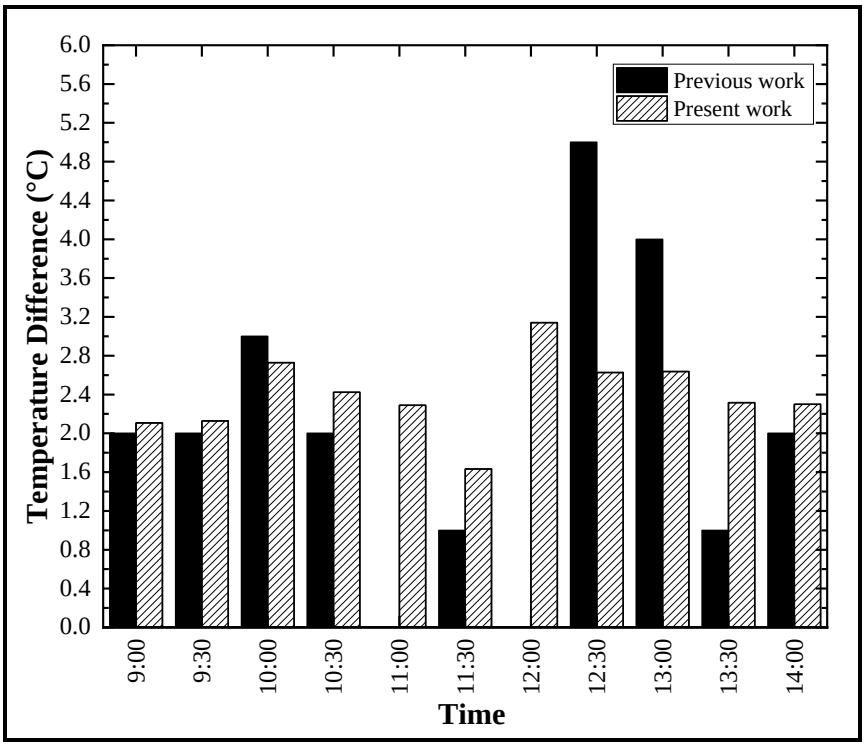


Figure. 8. Hourly variation of the temperature difference between the reference panel and the finned panel.

5. CONCLUSIONS

This study provided systematic experimental findings that affect the electrical performance of the PV panel. Staggered metal foam fins with different configurations were employed to improve the electrical efficiency and output power of the PV panel. In other words, this enhancement was achieved by reducing the operating temperature of the PV panel. Many findings can be concluded from this work.

1. The increment in fins number will help in the temperature reduction of the PV panel, thereby an improvement in the output power was achieved.
2. The wind speed has a direct impact on the temperature of the PV panel. There was an inverse relationship between wind speed and the operating temperature.
3. The operating temperature of the cell was increased when the value of solar intensity was high. Thereby, the electrical efficiency was decreased.
4. The maximum electrical efficiency enhancement was 4.7% for staggered metal foam fins (case III) than the reference PV panel.

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