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The effect of installing different arrangements of aluminum fins on the photovoltaic performance

Talib K. Murtadha[1*], Ahmed A. H. Alalwany[1,2], Ali Adil Hussein[1,3]

[1] *Mechanical Engineering Department, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jordan*
[2] *Eastern Anbar Electricity, Middle General Electricity Distribution Company, Ministry of Electricity, Iraq*
[3] *Al-Mansurya Gas Power Station, General Company of Electricity Production/ Middle Region, Ministry of Electricity, Iraq*

ABSTRACT

One of the significant obstacles for improving the photovoltaic (PV) performance and lowering their surface temperature are the cost, durability and simplicity of cooling systems. Regular aluminum fins have been added in various configurations to the back surface of a PV panel in order to reduce the PV surface temperature and improve the output power. The experimental set-up consists of four photovoltaic panels. PV-1 was used as a baseline, and PV-2 was utilized with longitudinal fins and exposed to natural air cooling. PV-3 was employed to offer forced air cooled at different air velocities with similar longitudinal fins. PV-4 was used with forced air cooling at various air velocities and fins installed in an S shape arrangement. The largest percentage of temperature drops on the PV surface was achieved by the PV-3 with longitudinal fins and forced air cooling. Panels PV-2, PV-3 and PV-4, respectively, have surface temperature drops of 5.48%, 11.86% and 9.57% in comparison with the baseline panel PV-1. The output power of PV-3 panel having longitudinal fins and forced air cooling increased by 5.42% compared to the baseline PV-1. Additionally, it will be possible to use the heat that absorb by the cooling medium, air, for other purposes.

Keywords: Cooling photovoltaic, Aluminium fins, PV surface temperature, PV efficiency.

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Corresponding Author:
Talib K. Murtadha
talib_km@mutah.edu.jo

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1. INTRODUCTION

Solar energy, particularly photovoltaic technology, is the highly significant source of the renewable energy accessible to people and is too appropriate for meeting the rising energy needs of humans without resulting any harmful influences upon the nature. Also, the solar energy can be converted into electric energy or thermal energy, with benefits, like an unlimited and reliable energy supply, no ecological influence, and the highly important potential energy source. The PV systems transform the solar energy into electric power. Solar energy can continuously meet all of the world's energy needs, both now and in the future, and is environmentally beneficial clean energy that emits zero carbon dioxide, and its use decreases the need for fossil fuels.

Due to a lack of domestic energy supplies, Jordan imports gas and oil from other nations (Abu Qadourah et al., 2022). Solar energy is seen as one of the solutions to the problem of climate change as it is environmentally friendly where Jordan’s traditional sources of energy are the largest problem and the main cause of disability in many vital sectors of Jordan (Alrwashdeh, 2018). Jordan receives a high amount of solar radiation, which ranges from 4 to 8 kWh/m^2. As a result, the best investment has made in the energy sector is in solar energy (Alrwashdeh, 2018). Waste heat is the term used to denote heat that is produced in a system as a byproduct or that exits the system without contributing useful work. Additionally, this extra heat becomes unreachable and challenging to retrieve as it mixes with the ambient air (Gomaa et al., 2022).

Many researches have done on cooling options for solar PV systems in order to increase the heat dissipation rate from solar PV panels and, consequently, the efficiency of the PV module.

When the rays of sun fall, only a small part of it is converted into electricity by photovoltaic panels, and the rest is converted into heat, which reduces the efficiency and performance of the photovoltaic panels, resulting in lower energy production. Solar energy is a very large source of energy and never runs out, as well as the exploitation of this capacity would lead to the preservation of the environment from the effects of the fossil fuels uses, which is basically starting to decrease dramatically. The sun provides energy to the earth, estimated at about 1.8×10^{11} MW, which is several thousand times more than the current consumption rate on the earth for all traditional energy sources (Parida et al., 2011).

The PV output power will decrease if the surface temperature rises over the Standard Testing Condition of 25°C (Dash and Gupta, 2015). Due to the changes in solar radiation and temperature, the parameters of photovoltaic solar modules will change. The solar cell performance, especially the open-circuit voltage, is mainly dependent on temperature (Green, 2003; El-Shaer, 2014; Senthil et al., 2019). The efficiency decrease is caused by the high temperature of the solar PV panels that formed from the silicon wafer (Ye et al., 2013). Temperature and solar radiation affect the characteristics and efficiency of the current and voltage (Malik and Damit, 2003).

Siecker et al. (2017) this study presents a review of most of the different methods that can be used to reduce the negative effects of increasing the temperature of solar panels with an attempt to increase the efficiency. Several cooling technologies were reviewed such as the Floating Tracking Concentrated Cooling System; Hybrid Solar PV/Water-cooled Thermal System; Hybrid solar PV/thermal PV/TE system cooled by heat sink; Solar photovoltaic/thermal (PV/T) cooled by forced water circulation; Improving the performance of solar panels through the use of phase change materials; Solar panels with water immersion cooling technology; Cooling of the photovoltaic solar panels with a transparent coating (photonic crystal cooling); Solar PV/thermal hybrid system cooled by forced air, and solar panel with thermoelectric cooling.

Murtadha and Hussein (2022) in this experimental study, monocrystalline solar panels are cooled using water or aluminum-oxide nanofluid at various concentrations 1, 2 and 3 wt.%. The experiments were done at different flow rates ranging from 0.6–1.6 L/min. In these experiments, an increase in efficiency and power output was achieved. When compared to laminar flow, the best photovoltaic performance was found at a turbulent flow rate of 1.6 L/min. For the same nanofluid concentration of 3 wt.%, the panel efficiency was 15% in laminar flow and was improved to 20.2% in turbulent flow. nanofluid with a 3 wt.% concentration resulted in the greatest improvement in output power. In comparison to an uncooled panel, the output power increased by 13% at cooling by nanofluid with a 3 wt.% concentration. Murtadha et al. (2022) also used titanium dioxide nanofluid with the concentrations 1, 2 and 3 wt.% in order to cooled the PV panels but in two passes circulation. The most significant finding was achieved by using a nanofluid at a concentration of 3 wt.%. In comparison to an uncooled panel, the surface temperature at this concentration decreased by 19.0%.

Kumar et al. (2007) presented the advantages that the photovoltaic technology exhibits, and the conversion system possesses certain general problems, like dust, cold, and surface working temperature that can adversely influence the conversion system efficiency. External climatic factors, like the solar radiation, speed of wind, relative humidity, ambient temperature, and accrued dust are the highly common natural factors affecting the PV module's surface. Each increase in the PV module surface temperature by 1°C will decrease the efficiency by 0.5%.

Shukla et al. (2017) stated that the solar PV cells can possibly absorb till 80% of the incident solar radiation got from the solar band; nevertheless, a small quantity of such absorbed energy is converted into electricity relying upon the conversion efficiency of the PV cells. The high solar radiation as well as the ambient temperature increases the temperature, at which the photovoltaic cells operate, negatively affecting their lifespan and energy production.

Bar-Cohen et al. (2003) mentioned that the rectangular fins are the simplest cost-reliable solution that is widely used in the convection cooling systems. Therefore, the material used in manufacturing the heat sink is aluminum because it provides a good trade-off between weight and thermal performance.

Gardas and Tendolkar (2013) worked on designing a cooling system for a solar cell for increasing its electrical efficiency and extracting thermal energy. A hybrid solar system that generates both electricity and thermal energy at the same time was investigated. Such hybrid system comprises PV cells connected to an absorbent plate having fins attached to the opposite side of the absorber surface.

Du et al. (2016) studied the effects of solar radiation, ambient temperature, wind speed on the photovoltaic panel temperature. Results of the parametric study showed a significant effect of solar radiation and wind speed on the temperature of photovoltaic panel. As the ambient temperature increases, the temperature rise of the solar cells reduces.

Bayrak et al. (2019) experimentally investigated the performance of a 75 W photovoltaic panel with a polycrystalline cell structure using different fins under normal load to reduce the amount of heat on the surface of the photovoltaic panels. System performance, like efficiencies, temperature, and power were analyzed via implementing various fin parameters (length and sequence) to the photovoltaic panels. Also, aluminum fins were implemented in ten various configurations, as described via A1-A10. PV parameters were computed depending upon the pilot study measurements. And, it was noticed that the temperature wasn't homogeneously distributed upon the photovoltaic panel. The highest energy and energy efficiency values calculated for the A5 finned panels were 11.55% and 10.91%, respectively. Where, the specification panels A5 were overlapping-vertical, height 20 cm girth 7 cm, and number of fins 26.

Murtadha (2023) installed a clear acrylic sheet in a variety of slopes according to the PV panel in order to control the amount of solar radiation that was not utilized by the PV panels. The radiation with a wavelength of less than 1.1 μm will be reflected and absorbed by this sheet to a degree of 10%. While a significantly higher percentage of radiation with a wavelength between 1.1 μm and 2.2 μm will be reflected. The findings of the experiments revealed that the PV surface temperature decreased by 14.5%. This will lengthen the life of the cell and improve PV performance and electrical energy generation.

Tiwari et al. (2020) referred to the design, fabrication and testing of an effective PV-T system for cooling the photovoltaic module, in which a parallel set of ducts having inlet and outlet was built for a homogenous distribution of air flow and linked to the cell back. The experiments were conducted with and without effective cooling. And, the forced convection fan cooling was supplied with 2 kinds of cooling arrangements. In a single arrangement, down one air channel, a panel was supplied, which is made of a conductive material, and an additional panel was used as a reference panel without a cooling arrangement.

Ömeroğlu (2018) ranked three methods of mounting the fins in terms of increasing number and airflow velocity under a constant irradiance of 1100 W/m^2 and 3 different air velocities 3.3, 3.9 and 4.5 m/s. It was found that the highest efficiency was achieved at the highest number of fins in the experiment. The highest performed efficiency was 12.02%. Besides the velocity of air and the heat transfer surface area, it was observed that the arrangement of fin is a significant factor in the rate of heat transfer.

Gotmare et al. (2015) examined the optimization of the PV panels performance by utilizing passive cooling of the fins under natural convection. The researchers conducted a comparative experimental investigation upon photovoltaic panels with and without cooling fin to verify the working temperature influence upon the power output, voltage, and current of the evolved panel. And, the results evinced that the PV panel temperature reduced very considerably, and the output power enhanced via 5.5% at the natural convection owing to the fin cooling.

Mojumder et al. (2016) experimented with analyzing the performance and operation of an integrated pneumatic-type thermoelectric collector system having cooling fins. The final outcomes manifested that the ultimate thermal efficiency and PV efficiency were 56.19% and 13.75%, correspondingly, employing 4 fins with a rate of mass flow 0.14 kg/s and a solar radiation of 700 W/m^2.

El Mays et al. (2017) evaluated the performance and efficiency of photovoltaic panels utilizing aluminum fins. The comparison of the 2 photovoltaic panels indicates that the efficiency of photovoltaic panels as well as standard photovoltaic improved via 17.7% and 15.9%, correspondingly. From the other side, it was found that the surface temperature of the photovoltaic panel reduced by about 6 degrees Celsius.

Verma et al. (2021) reviewed a number of techniques that have recently been studied in many researches and used aluminum fins to cool photovoltaic panels. One of these involved using L-shape aluminum fins with holes that were adhered to the PV panel's backside using thermal conductive paste, as illustrated in Fig. 1. During analysis, it was discovered that randomly placed fins with holes at the backside give the best cooling of the PV panel as air could penetrate the inner part of the structure with natural blowing air of 1 m/s. This review summarized the electrical and thermal performance of PV panels using different kinds of aluminum fins. The increase in electrical performance ranged from 2% to 18.6%, depending on the fin type. While the reduction in PV temperature range from 7.4ºC to 12.5ºC.

The major goal of this study is to cool the photovoltaic panel in order to lower the working surface temperature of the photovoltaic system, improve the thermal efficiency, and to use passive energy produced by the heat absorbed by air flow in other applications. Three distinct techniques for adding aluminum fins to the cooling system were used. These techniques included the arrangement of the fins and the natural or forced flow of the air cooling. A variable speed fan was used to deliver the air over the fins at various velocities in order to achieve the forced flow method. The choice of the aluminum fin was made due to its low cost, wide availability, and high thermal conductivity, which improves the heat extraction that accelerates the heat removal from the PV panel. The performance and photovoltaic efficiency increased in each of these experimental applications of aluminum fins. This enhancement increased the output power and life span. The optimum solution was achieved using PV-3, which has longitudinal fins and forced air flow.

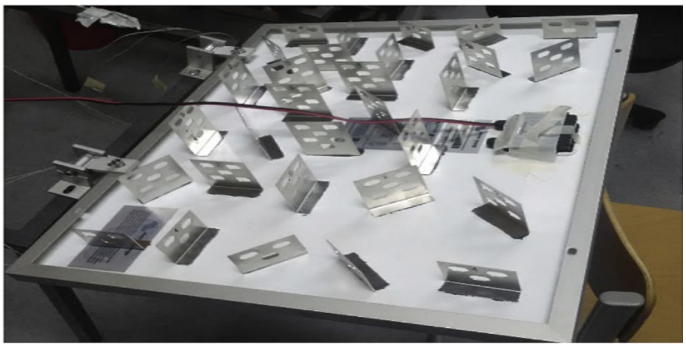

Fig. 1. Use aluminum fins in backside of PV panel (Verma et al., 2021)

2. DESCRIPTION OF THE EXPERIMENTAL WORK'S METHODOLOGY

2.1 Location of the Study

The experiment and evaluation of solar panels PV was placed at Mutah University in the Hashemite Kingdom of Jordan. The all photovoltaic modules in this experiment were tilted at a 30° angle and pointed south. A uniaxial manual tracking device was used (Al-Sayyab et al., 2019).

2.2 Experimental Work Setup

The technical support needed for the experiment (photovoltaic stand, electric current, carpentry, tin, welding, etc.) was provided in the workshops of Faculty of Engineering at Mutah University. Fig. 2 depicts this experimental setup. Four PV panels have been utilized, as shown in this Figure, and they are all working under the same operating conditions (i.e., intensity of solar radiation, atmospheric temperature, speed of wind, and the content of atmospheric dust). And, the specifications of the PV modules utilized in this work are listed in the Table 1.

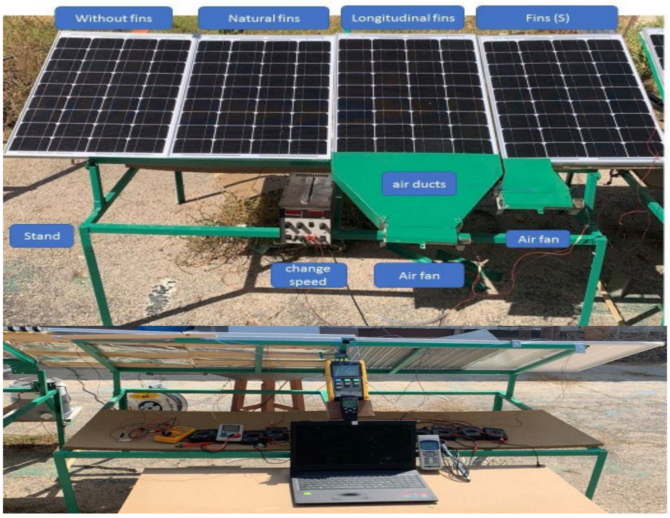

Fig. 2. The experimental rig's front and back views

Table 1. Summary of the specifications of the experiment's PV modules

Solar Module Type	SFPVM-50
Cell Type	Monocrystalline
Short-Circuit Current, I_{sc}	3.1 A
Open-Circuit Voltage, V_{oc}	21.6 V
Maximum Power Voltage	18 V
Maximum Power Current	2.78 A
Maximum Power, P_{max}	50 WP
Operating Temperature Range	-40~85°C
Cell Number	36
Standard Test Conditions	1000 W/m^2, AM1.5, 25ºC
Weight	3.3 kg
Size	630 × 540 × 18 mm

In this experiment, the surface temperature influence of the photovoltaic unit upon the electrical and thermal efficiency and performance of this system was studied. That was done by cooling three photovoltaic panels by installing fins on the back of panel with different designs, sizes and paths.

The first photovoltaic panel PV-1 was utilized without cooling in order to be compared with the other cooled panels under standard conditions. Aluminum (Al) fins were added to the second photovoltaic panel PV-2, in a longitudinal pattern that runs from the panel's beginning to its end. The size of the fin was 60 × 1.7 × 1.7 cm, and there were 28 fins arranged symmetrically, 1.5 cm apart from one another. The cooling system for these PV panels used natural air.

The fins were joined with excellent fixing and adhesion using thermal adhesive. The placement of the aluminum fins on the panel's back surface is shown schematically in Fig. 3.

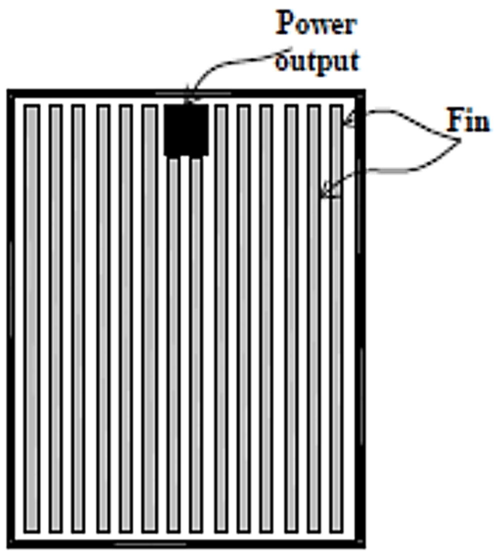

Fig. 3. Schematic diagram of the PV-2 system with natural cooling

The third photovoltaic panel, PV-3, was utilized with forced air cooling with similar longitudinal fins and varying air velocities. To ensure that the supplied air does not escape from the enclosing box, an Al lid with a 0.8 mm thickness was placed and insulated with a layer of rock wool. The fan is positioned in the center of the supply duct to guarantee the uniform air distribution. As depicted in Fig. 4, a schematic diagram was used to illustrate this panel.

The fourth photovoltaic panel, PV-4, has an entirely unique design from the others. Within the confines of the solar panel's back surface, the aluminum fins were arranged in the shape of the letter S with dimensions of 2.06 × 0.17 × 0.17 m. This solar panel's design combines a fan to push the air into the duct from one side and out the other, as seen in Fig. 5. A layer of rock wool was used as insulation, and an aluminum cover with a thickness of 0.8 mm was added.

2.3 Measuring Instruments and Experiment Data

Several measuring tools and pieces of equipment that gave the necessary readings for this experiment were utilized. Thermocouple sensors of type K were used to measure the temperatures. The top and back surfaces of the solar panels, as well as the supply and exiting air temperatures were to be measured.

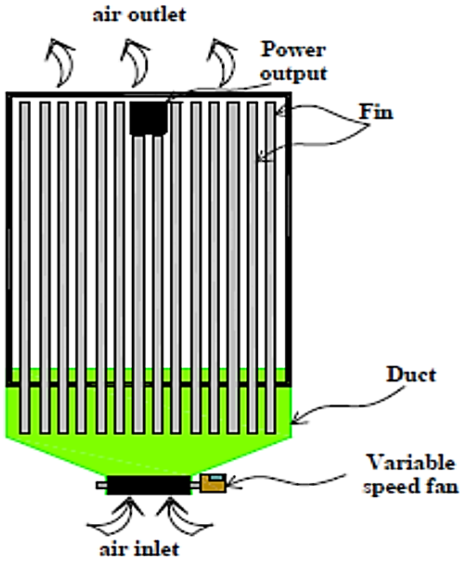

Fig. 4. Schematic diagram of the PV-3 panel with forced air cooling

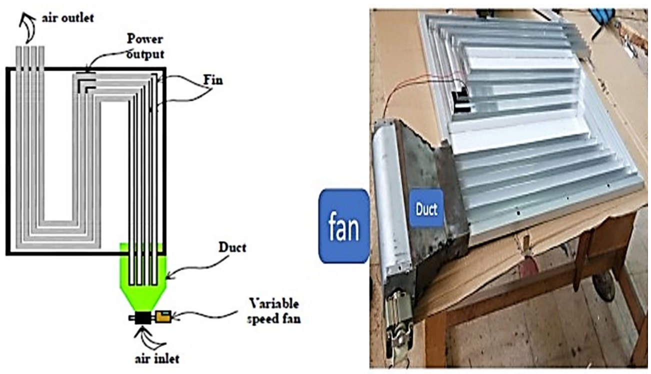

Fig. 5. Schematic diagram of the PV-4 with forced air cooling

The thermocouples are connected to a digital data locker device, a storage device for information, which is connected to a computer in order to save and preserve the data at the time the readings are taken. Some data were acquired from the Prince Faisal Center for Environmental and Energy Research in the Dead Sea at Mutah University, including the speed of wind, radiation of sun, humidity, and temperature. At the experiment location, a device measured the wind speed (ANEMOMETER: AM-4217SD). The output voltage and current were measured using a resistance device (SMART MULTIMETER: DM-9982B).

2.4 Steps for Experiments Readings

All photovoltaic panels were prepared to take readings and tilted at a 30° angle towards the south, where they will all work under the same conditions. In order to supply air at a 1 m/s velocity at the test start, the fans' speed was controlled by a regulator. After the system's stabilization, the readings were taken every hour over the course of many days.

The solar panels' top and back surfaces, as well as the air being supplied to the system and leaving it, were all tested for temperature. The four photovoltaic panels' output voltage and current were measured simultaneously as the ambient temperature, the velocity of air, and the intensity of solar radiation.

Each test included six different kinds of reading. At a supply air velocity of 1 m/s, the first and second readings were collected one h apart. The third and fourth readings were taken at the supplied air velocity of 1.5 m/s, whereas the fifth and sixth readings were taken at 2 m/s. The electric output power of a photovoltaic panel can therefore be determined using Equation 1 (Dubey et al., 2009; Wang and Ge, 2016; Fan, 2018).

$$P_{PV} = I_m V_m = FF I_{sc} V_{oc} \quad (1)$$

Where, P_{PV} is the photovoltaic output power (W), V_m and I_m are voltage and current at the maximum power point, FF is the Fill factor, I_{sc} is the short-circuit current, and V_{oc} is the open-circuit voltage.

In other words, the output power from the photovoltaic system can be calculated using the famous Equation as follows:

$$P_{PV} = V_{PV} \times I_{PV} \times FF \quad (2)$$

The performance of the PV panel can be estimated by away the FF (Fill Factor) which is defined as the ratio between the maximum power extracted from the system and the product between the open-circuit voltage and the short-circuit current (Sharma and Jain, 2014).

In general, for the good PV cell, the value of fill factor much be more than 0.7. The other performance method is η (conversion efficiency) which is defined as the ratio of the output power generated by the photovoltaic cell to the power input to the cell. The fill factor and conversion efficiency of the PV cell could be found by Equations 2 and 3, respectively (El Chaar and El Zein, 2011).

$$FF = P_{PV} / I_{SC} \times V_{OC} \quad (3)$$

The fill factor adopted in this experiment in accordance with the standard information of the photovoltaic panel used according to Equation 3 is 0.7595.

$$\eta_{el} = P_{PV} / P_{in} \quad (4)$$

The Reynolds number (Re) can be defined as the ratio of the inertial force to the viscous force within an airflow. The main Re function is to describe the flow nature (i.e., laminar, transitional or turbulent). The Re is universally used to correlate experimental data about pressure drop, friction, heat transfer, and mass in heat flow (Alami, 2014).

$$R_e = (\rho \times v \times L)\ /\mu\ = (v\ \times L)/\upsilon \qquad (5)$$

Where, v represents the air velocity (m/s), υ represents the kinematic viscosity (m^2/s), μ is the dynamic viscosity (kg/m s), ρ is the air density (kg/m^3), and L length of the fin (m).

The Re value changes for a flat plate lengthways the flow. As for the flow above a flat plate, the transition from laminar to turbulent initiates at around $R_e \cong 1 \times 10^5$, but it doesn't get completely turbulent prior the Reynolds no. attains much higher values, usually about 3×10^6 . In the engineering analysis, the largely accepted value of the crucial Reynolds no. is in Equation 6 (Çengel et al., 2017).

$$R_{e_{cr}} = \frac{\rho \times v \times x_{cr}}{\mu} = 5\ \times 10^5 \qquad (6)$$

The actual value of the critical geometric Reynolds number for a flat plate may vary somewhat from 10^5 to $3 \times\ 10^6$, depending on the surface roughness, the level of turbulence, and the stress change along the surface (Çengel et al., 2017).

3. RESULTS AND DISCUSSION

According to Fig. 6, the experimental rig consists of four photovoltaic panels and operates under the same conditions. Each photovoltaic panel has the following characteristics:

- PV-1 used without adding fins as a baseline,
- PV-2 Install longitudinal fins on the panel's backside and exposed to natural air,
- PV-3 Install longitudinal fins on the panel's backside and exposed to forced air cooling
- PV4 Install fins in S shape arrangement and exposed to forced air cooling.

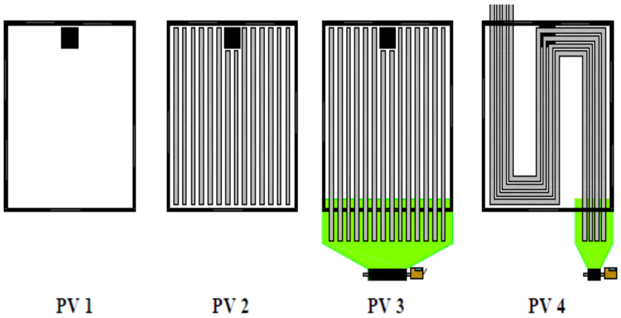

Fig. 6. Schematic showing the arrangement of the PV panels in the test rig

The surface temperature reading of the PV panels was taken with the ambient temperature measurement, solar radiation intensity, voltage and current. Three air velocities 1, 1.5 and 2 m/s have been used, where the air flow rate progressively corresponded to two h for each velocity over time, in order to determine the temperature of the entrance and exit air in PV-3 and PV-4.

3.1 The Impact of the Cooling Technique on the Output Current and Voltage (I-V)

Depending upon the cooling system employed, there is a difference in the output current's value. As the solar radiation intensity rises through the day, one can see that the voltage rises steadily as well, reaching its peak during the solar noon. The value of the output voltage then starts to gradually drop as the amount of solar energy decreases during the day. With the increased incident solar radiation and a low PV surface temperature, the output current values likewise rise. If the surface temperature rises throughout the day, the value of the output electrical current will then drop, as shown in Table 2.

Additionally, while comparing the solar panels with various cooling techniques, a difference was seen in the output voltage value depending on the kind of cooling system used. The PV-3 panel with longitudinal fins and forced air cooling recorded the highest output voltage 21V, while the PV-4 panel, which has a finned photovoltaic with "S" shape, became next. Then, the natural air fin cooling system came, and final was the uncooled photovoltaic panel. So, the output voltages for PV-3 during the hours of the test were 20.1, 20.9, 21, 21, 20.52 and 20.31 V, respectively.

3.2 Effect of Cooling Method on the Output Power and Surface Temperature

The main and significant factor in the PV panels is to know the output power generated by the output (current - voltage) of the photovoltaic panels, which primarily relies upon the solar radiation intensity and the temperature of photovoltaic panel's surface in addition to the ambient temperature and other climatic conditions in the work site. It can be seen from that the output electrical power reaches its peak at the midday solar time, with values for PV-3, PV-4, PV-2 and PV-1 of 44.52, 43.376, 42.64 and 42.23 W, respectively. The output power of the solar panels in the experiments is given in Table 3 together with the % drop in PV surface temperatures. The panel with longitudinal fins and forced air cooling, PV-3, demonstrated the highest percentage drop 11.86% in the temperature of PV surface in comparison with the baseline panel, PV-1.

Fig. 7 portrays that the electrical output power is at its peak during the midday sun time, with values of 44.52, 43.376, 42.64 and 42.23 W for PV-3, PV-4, PV-2 and PV-1, respectively. This is because the solar radiation is at its highest value during this time. These are congruent with the research's findings, which are displayed in the this study (Mojumder et al., 2016).

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Table 2. The experimental voltage and current (I-V) characteristics

Time (h)	G W/m^2	Photovoltaic panel							
		PV-1		PV-2		PV-3		PV-4	
		I (Am)	V (volt)	I (Am)	V (volt)	I (Am)	V (volt)	I (Am)	V (volt)
10	750	1.92	20.1	1.92	20.2	1.96	20.5	1.94	20.3
11	840	1.98	20.2	1.97	20.5	2.02	20.9	2.00	20.7
12	867	2.05	20.6	2.05	20.8	2.12	21.0	2.05	21.1
13	833	2.05	20.3	2.05	20.5	2.05	21.0	2.03	20.9
14	731	2.02	20.1	2.01	20.3	2.02	20.5	2.02	20.4
15	568	2.01	20.0	2.0	20.2	2.01	20.3	2.01	20.2

Table 3. Output power with the percentage drop in PV surface temperatures

Time (h)	G W/m^2	T_a (°C)	Photovoltaic panel						
			PV-1	PV-2		PV-3		PV-4	
			Power (W)	Power (W)	% T_S drop (%)	Power (W)	% T_S drop (%)	Power (W)	% T_S drop (%)
10	750	31.0	38.63	38.76	2.86	39.39	7.48	38.99	5.64
11	840	33.2	39.99	40.38	4.27	42.21	9.18	41.40	7.844
12	867	36.7	42.23	42.64	5.48	44.52	11.86	43.37	9.57
13	833	34.5	41.61	42.02	3.78	43.05	10.68	42.42	9.36
14	731	30.3	40.62	40.80	3.76	41.47	8.54	41.10	6.33
15	568	30.1	40.20	40.40	3.56	40.82	7.06	40.60	5.66

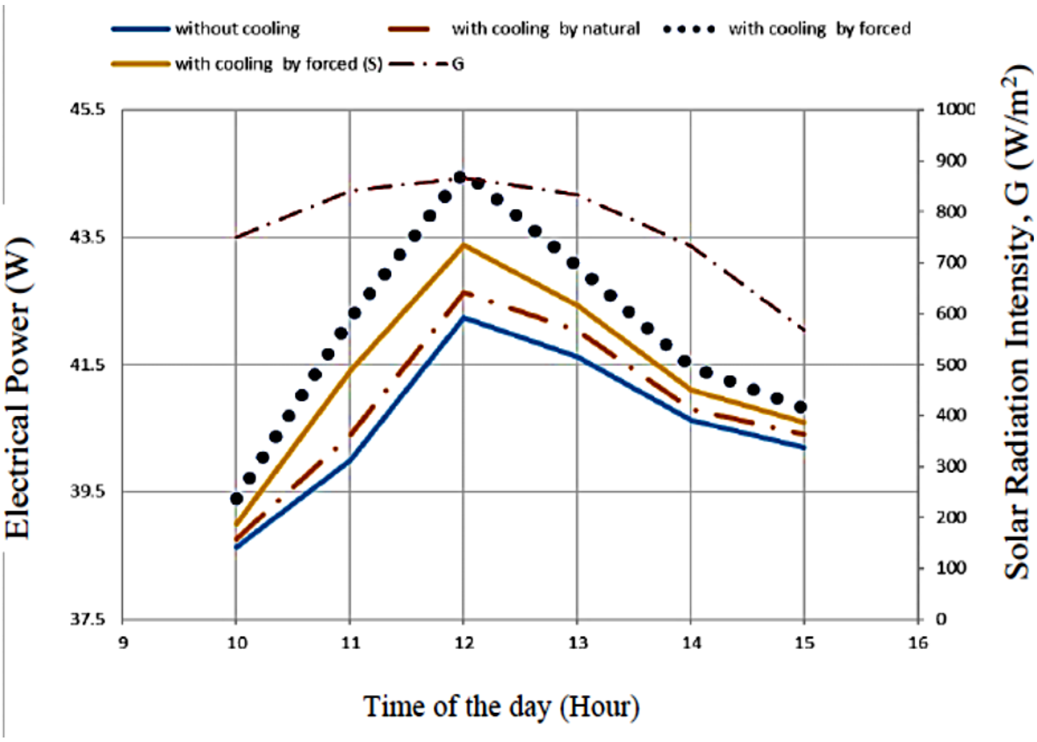

Fig. 7. PV output power with solar radiation intensity during the time of the day

3.3 Photovoltaic Efficiency

Efficiency, which indicates the functionality of the panel itself, is one of the crucial and essential criteria for solar panels. It is directly influenced by the solar radiation intensity and the temperature of solar panel's surface. The variance in electrical efficiency with the various types of PV cooling systems used in this investigation is illustrated in Fig. 8. The cooling system with longitudinal fins and forced air cooling PV-3 provides the maximum efficiency when compared to other cooling systems, as shown in the figure. This is caused by the cooling air's greater temperature rise and higher thermal conductivity. The PV-3 solar panel system, which has fins arranged in a S form with forced air cooling, comes next. The following is the cooling system for PV-2 that makes use of fins and natural air cooling. The last photovoltaic panel is PV-1, which has the lowest efficiency without utilizing cooling. The electrical efficiency values at the maximum radiation for PV-3, PV-4, PV-2 and PV-1 were 21.11%, 20.9%, 20.8% and 20.7%, respectively. These results are consistent with other published research on the same topic (Tiwari et al., 2020).

3.4 Effect of Cooling Air Velocity on the PV Surface Temperature and Output Power

The cooling air velocity, or Reynolds Number, significantly affects the PV surface temperature and the output power. The cooling air for the PV-3 and PV-4 panels was blown through them by a variable speed fan. Two sets of data were gathered for each of the three air speeds 1, 1.5 and 2 m/s, at various solar intensities. They were separated by one h of time.

Table 4 shows the effect of varying the velocity of cooling air on the PV surface temperature. The major influences on the PV surface temperature are the solar radiation intensity and the ambient temperature. As a result, it was discovered that the maximum surface temperature of the PV panels occurred in the middle of the day if the solar radiation being at the peak. And, the results allowed drawing the following conclusions. At the constant air cooling velocity, the PV-3 photovoltaic that utilized longitudinal fins with forced air cooling had the greatest percentage drop in the surface temperature, followed by the PV-4. This is the same thing that was stated in previous Section 3.2.

The cooling effect increases with the rise in PV surface temperature, which is carried out by the rise in solar radiation, at the same air cooling velocity. According to the findings, there is a relatively little impact of increasing air cooling velocity on the percentage decrease in the PV surface temperature. The similar outcome was obtained while determining the PV output power, as elucidated in Table 5. These findings align with those of the subsequent study (Mojumder et al., 2016).

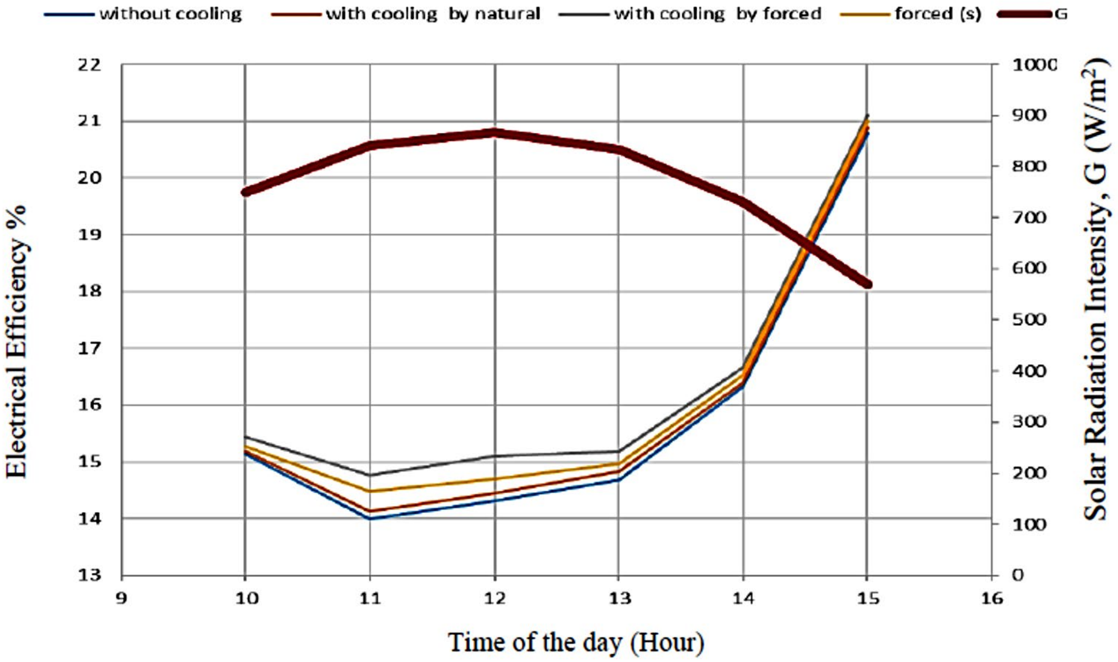

Fig. 8. The electrical efficiency and the solar radiation intensity with the time of the day

Table 4. Influence of cooling air velocity on the PV surface temperature

Time (h)	G W/m^2	PV-1 baseline PV natural air	PV-2 longitudinal fins natural air		Air velocity (m/s)	PV-3 longitudinal fins forced air cooling		PV-4 S-shape fins forced air cooling	
		T_S (ºC)	T_S (ºC)	% T_S drop (%)		T_S (ºC)	% T_S drop (%)	T_S (ºC)	% T_S drop (%)
10	770	45.0	42.7	5.39	1.0	42.0	7.14	42.5	5.88
11	859	52.0	47.9	8.56	1.0	46.9	10.87	47.5	9.47
12	879	59.8	54.6	9.52	1.5	53.1	12.62	53.9	10.95
13	841	58.5	54.4	7.53	1.5	52.0	12.5	53.0	10.38
14	748	53.2	50.9	4.52	2.0	50.1	6.19	50.4	5.56
15	598	46.3	45.0	2.89	2.0	44.0	5.27	44.6	3.81

Table 5. Influence of cooling air velocity on the PV output power

Time (*h*)	*G* W/m^2	PV-1 baseline PV natural air Power (W)	PV-2 longitudinal fins natural air Power (W)	PV-2 % Increase power (%)	Air velocity (m/s)	PV-3 longitudinal fins forced air cooling Power (W)	PV-3 % Increase power (%)	PV-4 S-shape fins forced air cooling Power (W)	PV-4 % Increase power (%)
10	770	37.64	37.86	0.58	1.0	38.72	2.87	38.52	2.34
11	859	40.03	40.50	1.18	1.0	41.76	4.32	40.85	2.05
12	879	41.70	42.14	1.06	1.5	43.68	4.75	43.03	3.19
13	841	41.02	41.49	1.15	1.5	42.74	4.19	42.31	3.15
14	748	38.88	39.12	0.62	2.0	40.57	4.35	39.80	2.37
15	598	36.21	36.60	1.08	2.0	37.47	3.48	36.80	1.63

4. CONCLUSIONS

For the experimental examination, a tilt of 30 degrees toward the south was adopted. The test rig consisted of four solar panels, each with a distinctive cooling system. PV-1 is used as a base panel without fins or other forms of cooling. The PV-2 has longitudinally placed fins for natural air cooling. With similar longitudinal fins and different air velocities, the PV-3 panel was utilized to offer the forced air cooling. While using a PV-4 panel with the forced air cooling, different air velocities were used, and the fins were fitted in an S form. The following are the most notable conclusions:

1. The largest percentage of temperature drops on the PV surface was achieved by the PV-3 with longitudinal fins and forced air cooling. Panels PV-2, PV-3 and PV-4, respectively, have surface temperature drops of 5.48%, 11.86% and 9.57% in comparison with the baseline panel PV-1.
2. The output power of the PV-3 panel with longitudinal fins and forced air cooling increased by 5.42% to the baseline PV-1 panel that was used without any additional cooling system.
3. The PV-3 panel with longitudinal fins and forced air cooling was prepared to have the best electrical efficiency. Where, the relative efficiencies for the PV3, PV4, PV2 and PV1 panels were 21.11%, 20.9%, 20.8% and 20.7%, respectively.
4. It is advised to use aluminum fins since they have a high thermal conductivity, are readily available and inexpensive, have a high tolerance for design changes, and are simple to install. In addition, it will be possible to use the heat that will be absorbed by the cooling medium air for other purposes.
5. There is a relatively small impact of increasing air cooling velocity on the percentage decrease in the PV surface temperature and the percentage increase of output power.

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