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Experimental and Numerical Studies on Passive Cooling Techniques with Perforated Fins for Photovoltaic Modules

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Abstract: High temperatures in tropical regions during summer affect the electrical efficiency of photovoltaic (PV) panels, as the efficiency of PV panels decreases with increasing cell surface temperature. An experimental and numerical study was conducted to enhance the efficiency of PV panels by passively cooling them with 110 mm high perforated fins. The test was conducted in the hot Iraqi summer weather for three consecutive days in May 2025. The results showed an improvement in the temperature of the fin-cooled panel compared to the reference panel by up to 15.6%, impacted by both air speed and air temperature, and an improvement in electrical current by up to 7.4%.

Keywords: Photovoltaics, PV cooling, Passive cooling, Renewable energy, Electrical efficiency, Experimental and numerical investigation.

Introduction

Over the past ten years, the phenomena of global warming has been significantly influenced by the energy produced by burning fossil fuels (Al Khabyah et al., 2024). Because of this, conventional approaches that depend on burning fossil fuels are causing the global energy system to become unstable (Beigzadeh et al., 2020). The ongoing population explosion has made it difficult for traditional fossil fuels to meet energy needs, leading to an increase in carbon dioxide emissions (Das et al., 2018). There are many countries now that rely primarily on renewable energy sources in all their forms (Mishra et al., 2020; Sikdar et al., 2016). To solve the environmental problems caused by burning fossil fuels for energy production, scientists are increasingly focusing on sustainable energy options (Habchi et al., 2024a) . Photovoltaic PV panels are one of the most important methods for producing clean energy (Kumar Behura et al., 2021). In the future, solar energy will be the primary choice for electricity generation (Sahoo, 2016). The process of integrating solar energy into buildings is one of the methods that helped the European Union to benefit from renewable energy (Patil et al., 2021). Exploiting some areas in buildings, such as the roof and facades, to build a photovoltaic thermal complex makes it less expensive to build the roof, while still providing great benefits from the photovoltaic energy system (Athienitis et al., 2018). This is due to its widespread availability and high capacity and stability (Gong et al., 2019). Hot and arid climates with high levels of solar radiation can benefit greatly from solar energy systems that use PV panels to generate electricity (Grosu et al., 2020; Mussard & Amara, 2018). Variable environmental conditions (such as solar radiation, ambient temperature, wind speed, humidity, rainfall, and dust) are the primary determinants of photovoltaic systems' lifetime and efficiency. The way in which the photovoltaic modules are installed (tilt angle, location, and orientation), and the operating point, which has a significant impact on the intensity of photovoltaic power (Mustafa et al., 2020). Although photovoltaic (PV) technology has its advantages, the operating temperature can greatly affect its efficiency (Shah & Ali, 2019). As the operational temperature rises, PV panel efficiency falls (Habchi et al., 2024b). To achieve high efficiency and stability in solar PV panels, the implementation of effective passive thermal management systems is essential (Madurai Elavarasan et al., 2022; Sheik et al., 2022). To address the problems associated with overheating caused by PV panels, Researchers employ a range of cooling techniques, such as phase change material cooling, heat pipe cooling, air and water cooling, and nanofluid (Dixit et al., 2020). Passive cooling is considered the best method because it does not consume additional energy and does not require maintenance (Özbaş, 2022).

Passive Cooling

Passive cooling removes heat from photovoltaic modules without using energy or mechanical parts. It works by transferring heat to the surrounding environment .To improve heat transfer, tubes or fins made from materials that conduct heat well are added. Passive cooling systems usually involve natural circulation using air, water, or phase change materials. This method is simple, popular, and enhances energy efficiency while being cost-effective with minimal investment (Maleki et al., 2020; Nižetić et al., 2021).

Passive Air Cooling

Researchers concentrated on passive natural air cooling technologies, which employ natural convection and conduction to remove heat generated by PV panels. Unlike active cooling methods that require external energy to operate moving parts (such as fans), passive air cooling uses natural processes to remove heat from PV panels without the need for power or moving parts. It is cost-effective and environmentally friendly (Mahdavi et al., 2022). When the panels absorb solar radiation, some of it is converted into energy and some into heat, warming the surrounding air, which then rises. Cooler air then replaces it, generating a convection current that helps cool the panels. The efficiency of this cooling depends on the ambient temperature, wind speed, and how the panels are installed. In addition, heat can travel through the mounting structure, so using thermally conductive materials improves heat dissipation.This is what caught the attention of a large number of researchers, (Razali et al., 2023) To find out how the cell temperature is impacted, the researchers theoretically examined heat transmission through solar modules with and without fins. Fins lower the cell temperature by roughly 4–5 °C; the proportion varies depending on the fins' size and height as well as the air velocity. The results demonstrated the effectiveness of using aluminum alloy multidirectional conical fins (MTFHS). Under some circumstances, two PV panels were utilized for comparison in order to increase the efficiency of photovoltaic modules. The recorded temperature ranged from 26 °C to 38 °C, while the intensity of solar radiation varied between 200 and 1000 W/m^2. The findings demonstrated that the MTFHS system can lower the photovoltaic module's temperature by 12 °C. As a result, the solar module's efficiency increased by 1.53%.

Experimental analysis of the efficacy of 75W polycrystalline photovoltaic panels in the climatic conditions of Elazığ, Türkiye (Bayrak et al., 2019). Ten distinct configurations of aluminum fins were applied. Based on the experimental study measurements, energy efficiency, cell temperatures, output powers and power loss ratios were computed. Along the PV panel, it was noted that the temperature distribution was not uniform. The fins were arranged in a staggered row and measured (7 cm) by (20 cm) in order to maximize efficiency. With a staggered fin perpendicular to the PV panels, the panels' optimal energy efficiency and thermal stress performances were determined to be 11.55% and 10.91%, respectively.

Abidi (2021) conducted a numerical study on cooling a 5W PV panel using airflow at the bottom of the panel are several hexagonal pin fins arranged in two different configurations. Under a turbulent flow regime, the air cools the panel as it enters the channel at a speed of 1 to 3 m/s. The peak temperature of the panel, as well as the electrical, thermal and overall efficiency of the panel are evaluated at different air velocities for the pin and fin arrangement. Increasing the air velocity enhances the electrical and thermal efficiency of the panel. The electrical, thermal and overall efficiency improves at a speed of 3 m/s, which are 13.1%, 60.8% and 74%, respectively.

To improve the energy conversion efficiency of photovoltaic (PV) panels, the researchers looked into a passive cooling method (Grubišić-Čabo et al., 2018). Aluminum fins adhered to the PV panel's back surface using conductive epoxy glue make up the suggested passive cooling method (the experiment was conducted on a Si-poly panel, 50 W). Parallel aluminum fins (L-profile) were used to test the first two combinations, and perforated L-profiles positioned at random were used to create the second variant. Since the first strategy was shown to be less effective than the second, it was not examined further.because of its reduced effectiveness when sun radiation levels are low. With an average efficiency gain of almost 2% in relation to the total power output for the measured period, the second, modified method performed better over the whole solar exposure spectrum.

Two distinct passive fin heat sink designs were used to examine the concentrator photovoltaic module's passive cooling performance. real-world environmental conditions and optimal passive fin heat sink design characteristics were used for the experimental study (Elbreki et al., 2021). The results indicate that passive cooling with coil fins performs best when the ambient temperature is 33 °C and the solar radiation intensity is 1000 W/m2. The average temperature of the PV module is 24.6 °C lower than that of the reference PV module, resulting in an electrical efficiency of 10.68% and a power output of 37.1 W, respectively.

The impact of cell temperature by heat transmission between solar modules with and without fins was examined theoretically (Amr et al., 2019). According to the data, fin cooling reduced panel temperature and increased electrical efficiency. The module's electrical efficiency rises sharply as the number and height of fins increase. Cell temperature increases consistently with increasing ambient temperature for both finned and finless modules, regardless of still air or wind cooling. Fins reduce cell temperature by approximately 4−5°C, and this ratio varies depending on the fin height and size and the air velocity.

Kim et al. (2019) focused on cooling photovoltaic modules, particularly through passive methods such as installing heat sinks. the effectiveness of iron and aluminum meshes in cooling photovoltaic modules. According to tests, the solar module's temperature was lowered by roughly 4.35°C for iron meshes and 6.56°C for aluminum meshes. Simulations showed that cooling fins outperform metal meshes. However, meshes are easier to produce and more stable in the face of high winds, making them a practical choice for photovoltaic systems.

Al-Rabghi (2020) investigated how a finned heat sink positioned on the back of a photovoltaic PV panel can lower cell temperature and improve electrical efficiency by studying thermal and electrical modeling of the panel. A typical PV panel's performance was programmed using MATLAB, which was also used to track changes in voltage and current. Thermal modeling included all heat transfer modes, both with and without a heat sink, to evaluate their impact on cell temperature and photovoltaic efficiency. According to the results, at an ambient temperature of 25 to 50°C and a solar radiation of roughly 1000 W/m2, the ideal fin spacing of 12 mm and a height of 150 mm led to a cell temperature decrease of about 25% and an efficiency increase of 10.8%.

Idan et al. (2024) the primary impediment to enhancing the efficiency of solar panels was their increased temperature as the surrounding working environment rose. This issue was addressed using a PVT system that included a cooling system. This study focuses on an economical and simple construction approach, aiming to provide clear insights into how cooling affects the performance of PV panels under different conditions in Kut, Iraq. The experimental section included two parts, one basic (with unribbed fins) and the other (with ribbed fins), and the addition of thermoelectric modules to utilize the excess heat. The results showed that the ribbed fin model improved performance compared to the basic model by approximately 0.77% and 1.26% at different temperature levels. Egab et al. (2020) for temperature of PV panels has a considerable impact on their performance and efficiency; hence, cooling solutions are crucial for increasing energy generation. looked into the usage of air-cooled heat sinks to lower PV panel temperatures. These heat sinks have rectangular and perforated fins made of a substance that conducts heat well. Using ANSYS software, the researchers evaluated how alternative designs, such as the number of fins and hole spacing, affected cooling effectiveness at temperatures ranging from 25 to 35 degrees Celsius. Panel temperatures reduced as the number of fins and holes increased; panels with fins showed a 50% temperature reduction over panels without fins.

Kim and Nam (2019) looked into how high temperatures can reduce the efficiency of photovoltaic (PV) panels. Fins installed on the rear of the PV panels were used in a passive cooling technique that was studied using a computational fluid dynamics (CFD) simulation model. The process of generating slits in the frame was also investigated to promote ventilation. It assessed how various fin and slit shapes affected cooling efficiency. According to the findings, the module's temperature reached 62.78°C without cooling, and its electrical efficiency was 13.24%. By lowering the temperature by about 15.13°C, fins increased efficiency to 14.39%. Additionally, by boosting airflow velocity and lowering the temperature even more, the slits improved cooling.

The Scope of the Study

Previous research has primarily focused on solar panel cooling, whether via active or passive cooling, computational simulations, or laboratory experimentation. Although passive fin cooling has been successful in lowering photovoltaic panel temperatures, more research is needed that focuses on passive cooling, combining numerical modeling with actual experimental validation in hot climate conditions, such as those encountered in Iraqi summers or hot tropical regions during summer. The fundamental issue with this research is the low electrical efficiency and voltage of solar panels, which are influenced by high temperatures. This study recommends using passive cooling technology, specifically installing passive cooling fins under the panel, to enhance natural convection cooling.

This paper proposes ideas for passive cooling fins put below photovoltaic panels It has holes, and is L-shaped.to improve natural convection. To validate the design's efficacy and ability to survive climatic conditions, numerical simulations with COMSOL Multiphysics are utilized, as well as a practical experiment. The primary goal is to lower the temperature of solar panels while enhancing their electrical efficiency, without the use of external power sources or mechanical cooling equipment.

The proposed approach aims to directly address the issue of high temperatures in solar panels. One of the primary benefits of this strategy is that it is both inexpensive and simple to use. It has no operating costs, no periodic maintenance, and is simple to apply, particularly in hot areas. This method could be improved in the future by changing the fin design, employing fins made of various metals with high thermal conductivity, and covering the fins with nanomaterials to increase thermal conductivity.

Experimental Setup

A prototype of perforated fins mounted on an aluminum plate was designed to be mounted on a 100W PV panel, measuring 830mm long and 670mm wide at the back, to enhance heat transfer with the air. The fins are L-shaped, approximately 110mm high, 0.7mm thick, and approximately 30mm wide at the base. These fins were mounted on a plate of the same metal, aluminum, and also 0.7mm thick. The fins are installed by welding the L-shaped fin base to the aluminum sheet. The aluminum sheet is linked to back of PV panel and secured with wooden pieces fixed to the panel sheathing in eight evenly distributed areas to ensure no gaps between the panel and the sheet, and to ensure resistance to harsh weather conditions. The plate measures 800mm long and 650mm wide. The fins and plate were cut into small squares for the junction box. The images below from Soldworks show the dimensions of the PV panel, the plate, and the cooling fins. as shown in (Figure 1,2)

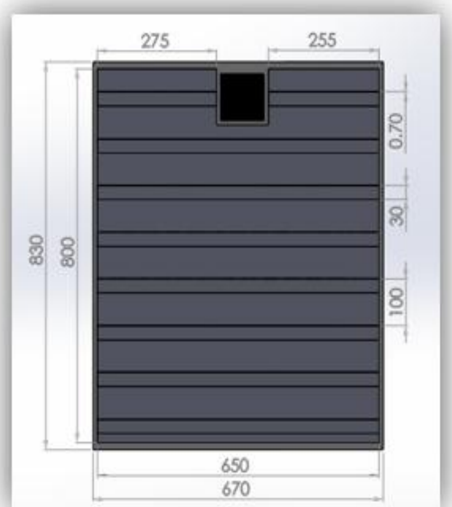

Figure 1. 2D Back view of PV with fins

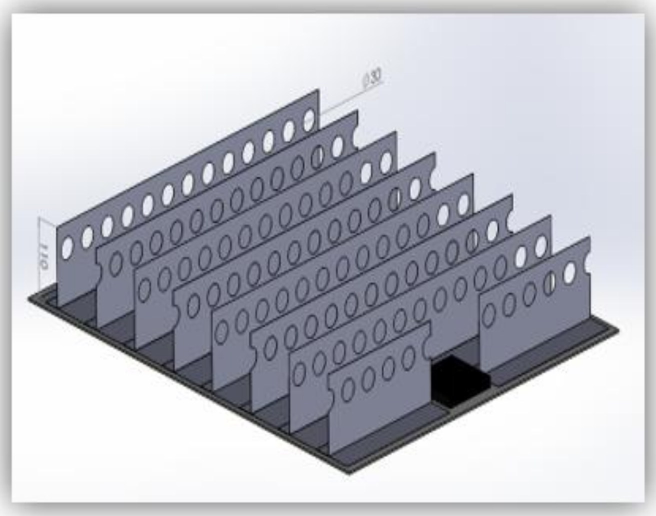

Figure 2.3D PV shape with fins

The experiment was conducted under the climatic conditions of Iraq, Babil Governorate, at coordinates (latitude 32.76516°N, and longitude 44.28516°E). Several measuring devices were used to monitor the changes that occur in all variables, such as a Solarimeter to measure solar radiation intensity, an Anemometer to measure wind speed, and temperature changes were measured by two Thermometers, each with four temperature sensors, and a Multimeter to measure both current and voltage. All this data was recorded hourly throughout the day from 7:00-AM to 5:00-PM. Thermal sensors were mounted on the reference solar modules: one on the front front glass and two on the back of the modules—one in the middle and one at each end of the reference solar module. For the fin-cooled solar module, the thermal sensors were placed on the front front glass and the back on the aluminum plate.

The fins were positioned approximately 20 mm from the base of the fin and approximately 10 mm from the end of the fin to monitor the effect of fin length and heat dissipation at the fin tips.

The PV panels were installed on the exterior roof of the first floor of my city home, facing south at an angle of approximately 18 degrees. The fin-cooled panel faced west and the reference panel faced east. The figure below illustrates the practical experiment. The mounting structure on which the panels were attached was positioned near the beginning of the roof to achieve high wind flow. The test was conducted over three consecutive days in the summer of 2025 in Iraq, on May 29, 30, and 31.

Figure 3. Experimental work on cooled PV panel and reference panel

Modern PV panels with a thickness of approximately 7 mm are used. Modern PV panels are thinner, which enhances solar absorption and improves heat dissipation when fin-cooled technology is used on these types of PV panels. The specifications of photovoltaic panels used in this study are listed in Table 1.

Table 1. PV panel specifications

Category	Value
Rated power (-0;+5w)	100w
Open circuit voltage	21.6v
Short circuit current	5.83a
Voltage at pmpp	18v
Rated current (ımp/a)	5.55a
Max. System voltage	1500v
Module efficiency	21.01%
Values at standard test condition	(am1.5;1000w/m²;25°c) ±5%

Numerical Solution

Comsel software, version 6.0, was utilized in the numerical process to examine and track temperature variations on the PV panel's surface as well as the impact of wind speed, air temperature, and solar radiation intensity on the temperature distribution. The PV panel was drawn and analyzed using Comsel software, taking into account the layers it consists of: glass, the front EVA layer, the silicone layer, the back EVA layer, and the tread layer. Each layer has specific thicknesses and properties, as density, heat capacity , thermal conductivity at constant pressure, and others, as shown in Table 2. The Ambient Properties feature was activated and the properties and atmospheric conditions were entered according to the recorded data to be checked.

Table 2. The properties of PV layer (Jones & Underwood, 2001; Lu & Yao, 2007)

Layer	Thickness (mm)	Thermal conductivity k (W/m·K)	Density ρ (kg/m^3)	Specific heat capacity c (J/kg·°C)
Glass	3	1.8	3000	500
EVA	0.5	0.35	960	2090
PV Cells	0.225	148	2330	677
Tedlar	0.1	0.2	1200	1250

Geometry and Physics

In geometry, the PV panel was drawn as rectangular layers, each with a specific thickness. The aluminum pallet was drawn with fins behind the PV panels, and the fins were positioned and perforated. In material selectio), all materials were specified (glass, silicon panel, Ethylene Vinyl Acetate (EVA) layer, Tedlar layer, aluminum pallet, and fins).

In physics interface, the heat transfer in solids option was selected. The heat transfer condition between the fins and the air was entered. The COMSOL program provides the External Forced Convection option. This option compensates for creating a closed system through which air flows. In this option, the heat transfer surfaces are specified, such as the fins through which the forced air flows, and whether the airflow is lengthwise or widthwise, the position of the fins or the pallet is selected, and the airflow velocity is entered in m/s. From the Physics Interface, the Boundary Heat Source was chosen, specifying that the glass is the surface where the heat is generated according to Equation 1.

$Q_{heat} = G \times A \times (1 - \eta)$ ....(Duffie, 2013)
G: Solar radiation intensity (W/m^2)
A: PV panel area surface (m^2) , $[A = 0.83m \times 0.67m = 0.5561m^2]$
η: PV panel efficiency (where 0.2101 = 21.01%)
Q_{heat}: Thermal energy generated on the surface (W)

In the numerical analysis, various data were entered for the weather conditions that were recorded during the test days.

Mesh Generation

In numerical simulation, the geometric domain of PV panel and passive fins was modeled using a finite element mesh. A physically controlled mesh was used in COMSOL Multiphysics, optimized in areas where high thermal gradients are expected, particularly near the fin base and at the junction of the panel and fins. The mesh consists primarily of trihedral elements (Table 3 shows the Complete mesh consists). The stability of the mesh was verified by comparing it with results obtained using other, coarser, and finer meshes to ensure the accuracy and stability of the results.

Table 3. Complete mesh consists

Mesh Component	Number of Elements	Description
Domain Elements	2588781	3D volume elements (Tetrahedral).
Boundary Elements	1110335	Elements representing surfaces between domains or boundaries (Triangles).
Edge Elements	28610	Line elements at the intersection of boundaries or edges.

The digital mesh used in the numerical simulation. A physically controlled tetrahedral mesh was used, and the mesh accuracy was improved in critical thermal regions, such as the fin base and the contact between the PV panel and the fins. Figure 4 below shows the Skewness distribution where the mesh quality was evaluated using the Skewness parameter, and more than 90% of the elements were within a range of less than 0.3, indicating that the accuracy of the numerical solution is of high quality.

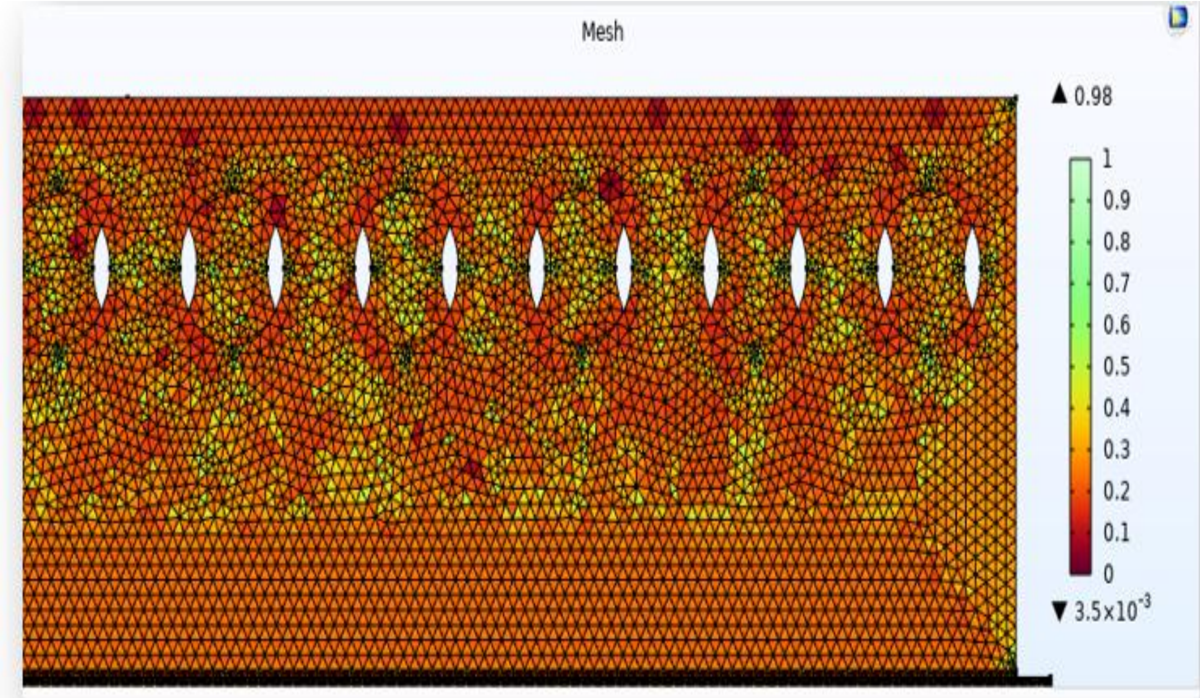

Figure 4. Skewness gradient

Reducing calculation time while preserving high accuracy in the anticipated outcome by performing a grid independence test. this was done using a different grid, and the grid that achieved consistent results was used over the more accurate grid, in order to reduce the user's time in numerical calculations.

Results and Discussion

By conducting the numerical analysis on several cases of different geometric shapes, the best fin shape was proven, which did not require high material costs and solved most of the problems related to poor thermal conductivity between the fins and the aluminum plate, problems related to aluminum welding, and air flow. The shape specified in the experiment provided us with a practical solution to all these difficulties, so it was manufactured, tested practically, and verified analytically and numerically under the same climatic conditions as the test time.

Experimental Results

Experimental data recorded throughout the day on May 29th shows an improvement in the front glass temperature of the fin-cooled PV (TGC) compared to reference PV (TGR) panel, as shown in Figure 5. In the first hours of the test, there is a high temperature difference between two panels. This is because the sun is two feet away from the cooler panel, which is towards the south, and the air is colder and faster. The wind speed in the first two hours of the test reached about 2.4-2 m/s. During the day, the average improvement was about 9.58 %. The highest improvement was recorded at 12:00 PM, reaching about 13.75 %. The wind speed around 12:00 PM, which was around 2.1 m/s, is to blame for this. The fins' temperature rises in response to the photovoltaic panel's increased temperature during the midday hours of strong solar radiation, which accelerates the rate of heat dissipation into the surrounding environment.

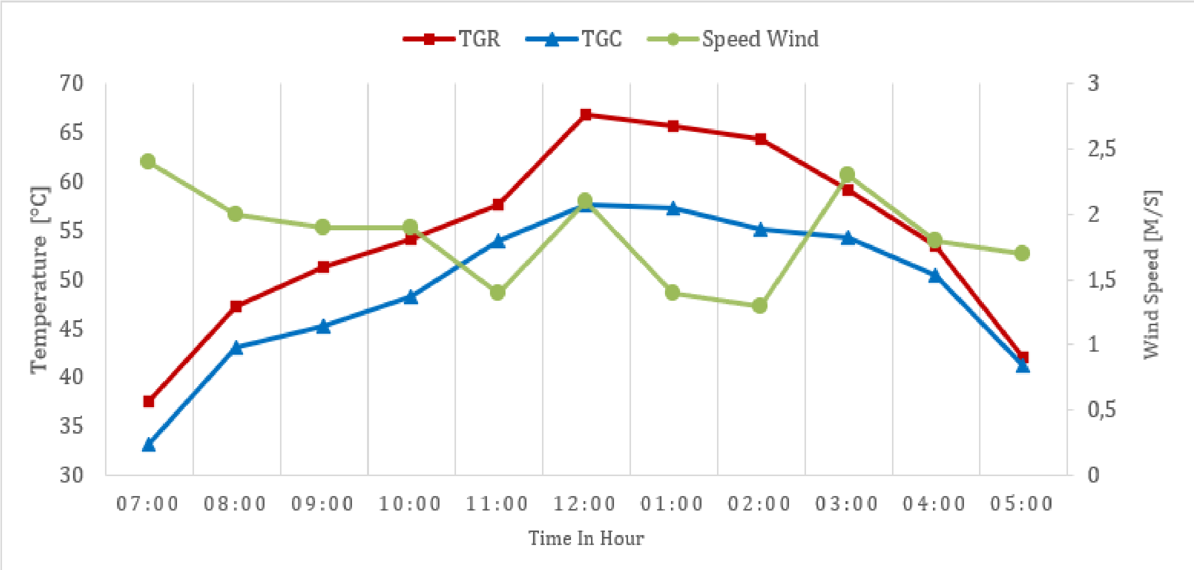

Figure 5. Reference and fin-cooled PV temperatures

The passive fin cooling improved the current and voltage recorded throughout the day, when a 70-watt load was applied. showed results and an average improvement in current of approximately 2.94% for that day, May 29. (Figure 6) shows the current changes for both the fin-cooled PV panel (current C) and the reference PV panel (current R) measured in *amperes* during the period from 7 am to 5 pm.

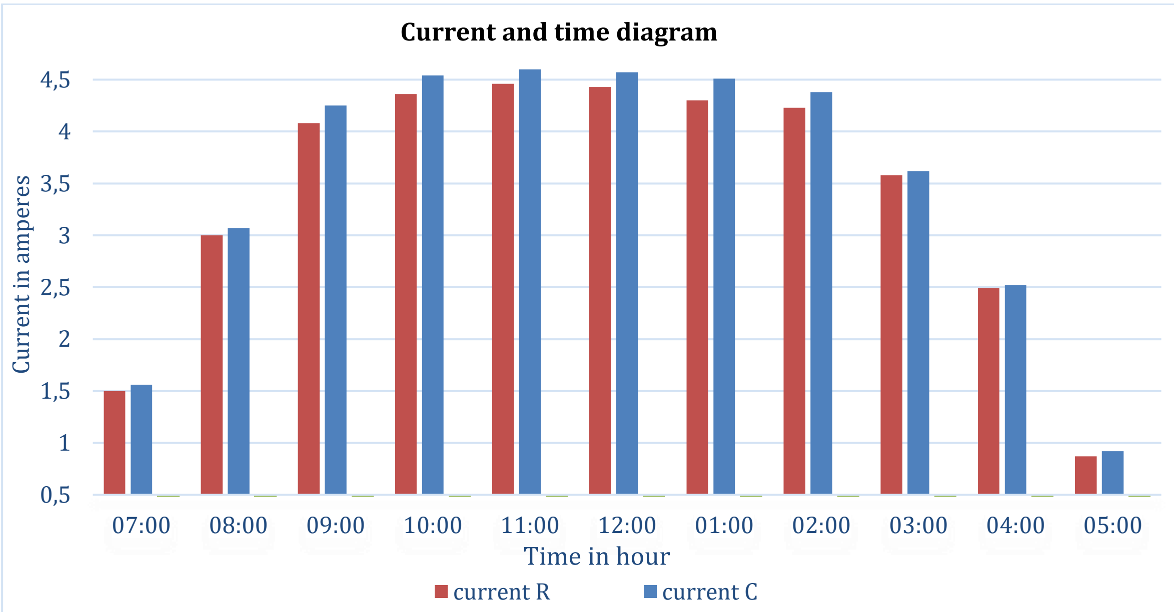

Figure 6. Improved electrical current with cooling fins

The average improvement in voltage of a fin-cooled PV panel is about 1.67% throughout the day. In the results recorded for May 30, the average daytime front glass temperature improvement between the reference PV modules and the passive fin-cooled PV module was 9.91%. In the Figure 7 below, we can see the temperature gradient in a fin-cooled PV module from the front glass to the fin tip The passive fin-cooled PV module and the reference PV module exhibit a midday thermal improvement at an average wind speed of roughly 1.87 m/s. The terms in the figure7 below refer to TGR (Temperature at front glass of reference solar module), TBR (Temperature behind the reference solar module), TGC (Temperature at front glass of fin-cooled solar module), TBC (Temperature behind the fin-cooled solar module, i.e., on the aluminum plate), TBFC (Temperature at the base of the fin in a fin-cooled PV module), and TEFC (Tip-of-fin Cooled Photovoltaic Module).

The highest improvement in the PV panels with cooling-fin temperature at the fins was recorded at 12:00 PM, with an improvement rate of approximately 15.61% at a wind speed of 2.1 m/s and an air temperature of 40.2°C.

This is because as the panel and fin temperatures rise, the temperature differential between the fins and the surrounding air also rises. and the uniform air flow between the fins at a speed of about 2.1 m/s enhances the high heat dissipation in the photovoltaic panel with the cooling fins.

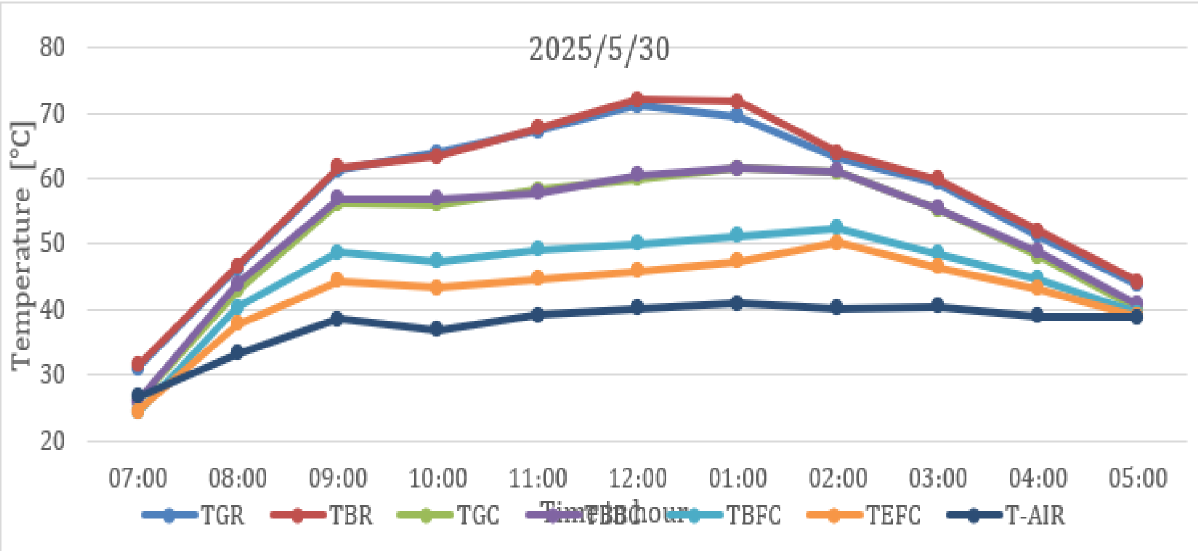

Figure 7. Temperature gradient chart over time

Figure 8 shows the times of improvement in the measured electric current of the fin-cooled PV panel (Current C) during the middle of the day, i.e. from 9:00 a.m. to 3:00 p.m. This improvement in the electric current increases at 12:00 p.m., to record the highest value improvement, which is about 7%. The reason is that with the increase in solar radiation levels and the rise in temperatures at midday, the temperature of the uncooled PV panels increases. Therefore, the efficiency of the PV panel decreases whenever the temperature of the PV panel exceeds 25 °C. Therefore, the passive fins work to get rid of the excess temperatures of the PV panel, which improves electrical production and extends the life of the photovoltaic cell.

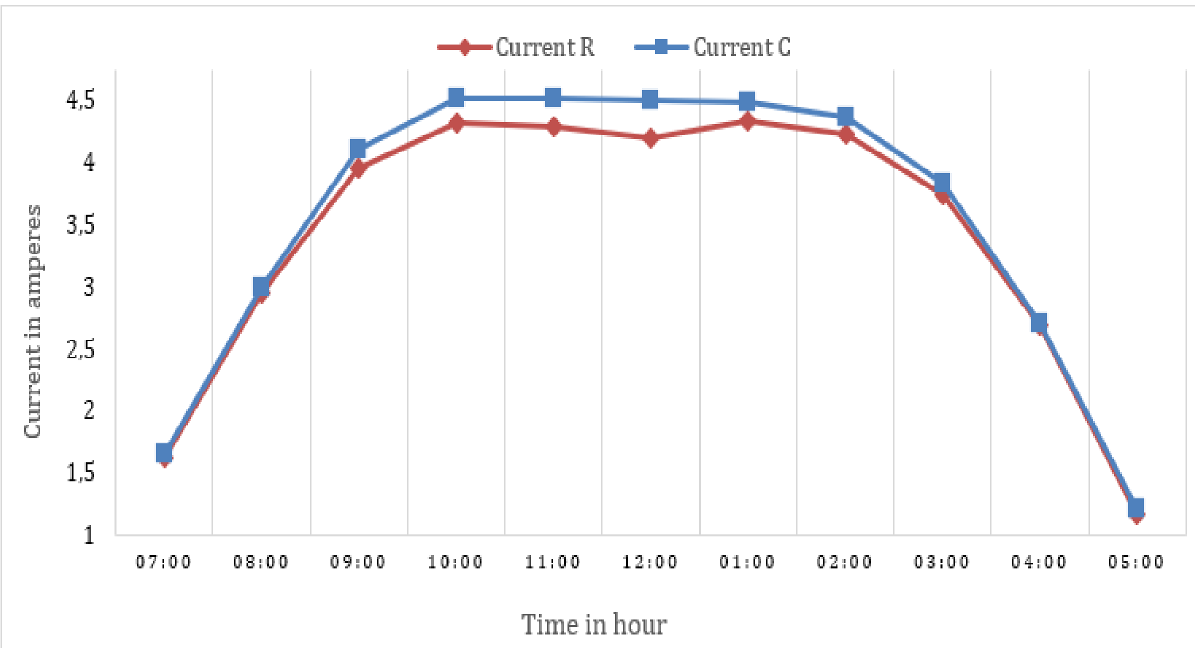

Figure 8. Current [amps] and time in hours diagram

The average improvement in electrical voltage reached about 2% throughout the day. The best improvement rate was recorded at 12:00 PM, reaching about 3.52%. According to the data for that day, the northerly wind levels increased on May 31st. The wind at the test site is typically westerly, which means it originates in the west. The PV panel is exposed to westerly gusts from the side because it is oriented southward. Due to its tilt, the PV panel is exposed to northerly breezes from the rear at an angle of roughly 18 degrees. The effectiveness of the westerly winds is better in dispersing heat due to their flow between the fins, while the northern winds are slightly less effective due to their weak flow between the fins. Despite the high wind speed, it did not achieve a significant thermal improvement. Figure 9 shows the changes in temperature over time throughout the day, and in different areas of the fin surface.

The average wind speed was 2.5 m/s. The highest temperature was recorded behind the reference PV panel at approximately 68.1°C, and at its front glass at 67.4°C at 1:00 p.m. This temperature increase was attributed to the wind speed decreasing to 1.9 m/s. The greatest temperature improvement between the reference PV panel and the passive fin-cooled PV panel was approximately 11.54% at 9:00 a.m. The improvement was approximately 9.06% at 12:00 p.m. The highest temperature increase was recorded at 1:00 p.m., with an improvement of approximately 9.64%. The Table 4 below shows the recorded temperature and thermal improvement percentage data for both the reference and fin-cooled panels on May 31.

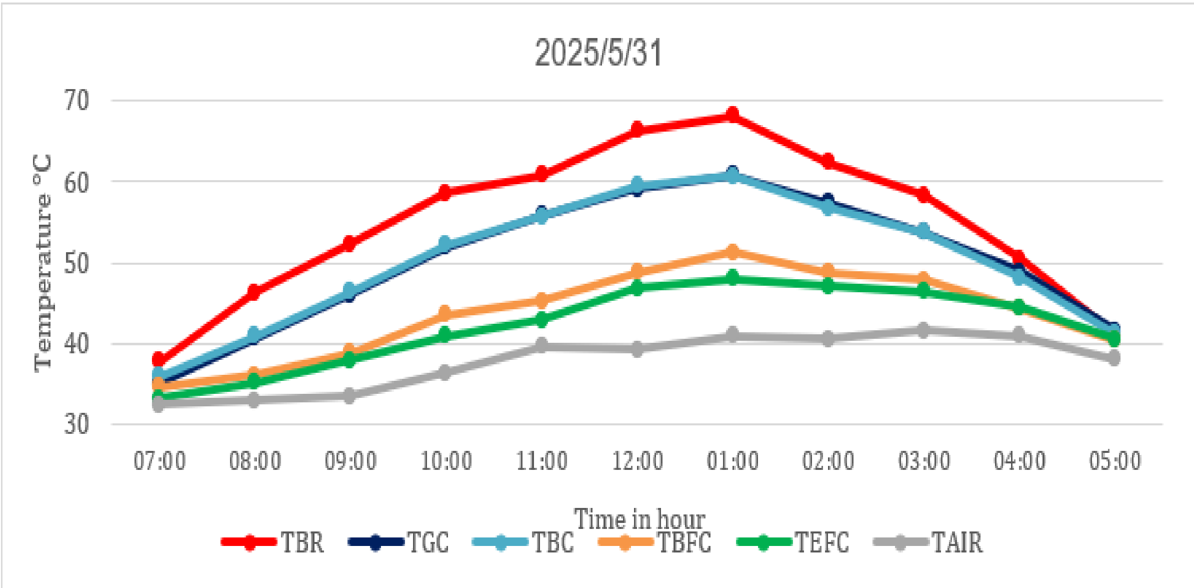

Figure 9. Experimental results recorded for May 31

Table 4. PV panel temperatures with and without passive fin

Reference Panel Temperature (°C)	Finned Panel Temperature (°C)	Temperature Difference (ΔT)	Time (hour)
45.6	40.7	4.9	8:00 - AM
57.5	52	5.5	10:00 - AM
65.1	59.2	5.9	12:00 - PM
62	57.4	4.6	2:00 - PM
50.6	48.9	1.7	4:00 - PM

Table 5 shows the recorded current and voltage data for both the reference and fin-cooled PV panels, as well as the percentage improvement in current and voltage between the two cases.

Table 5. Current and voltage characteristics of PV panels with and without passive fin

Reference Current (A)	Finned Panel Current (A)	Current Improvement (%)	Reference Voltage (V)	Finned Panel Voltage (V)	Voltage Improvement (%)	Time (hour)
3	3.07	2.33	21.4	21.6	0.93	8:00 - AM
4.36	4.54	4.13	20.2	20.8	2.97	10:00 - AM
4.43	4.57	3.16	20.5	20.9	1.95	12:00 - PM
4.23	4.38	3.55	20.5	20.9	1.95	2:00 - PM
2.49	2.52	1.20	20.8	20.9	0.48	4:00 - PM

Based on the experimental study, I came to the conclusion that the temperature differential between the panels is increased and the rate of improvement is accelerated when westerly winds strike the panel from the side. When air flows parallel to the fins, the airflow over all fin surfaces promotes better heat dissipation. Northerly winds, on the other hand, blow perpendicular to the fin plane, and the fin surface blocks most of the incoming air. The perforations allow some airflow to the remaining fins. This explains why westerly winds increase the rate of thermal improvement between the panels.

Numerical Results

The purpose of this numerical simulation is to assess how PV panels with and without passive cooling fins behave thermally in the presence of solar radiation , wind, and air temperature. Initially, numerical analysis results recorded by COMSEL software showed that the temperature curves on the front glass surface of the photovoltaic panel increased in the junction box area above the panel surface. This is because the plastic junction box is well insulated, typically with an IP65 rating or higher, protecting the connections and electronic components from environmental factors such as water and dust. This prevents airflow in this area, which could cause the temperature to rise. The COMSOL numerical analysis used to confirm the experimental test results obtained on May 29, 2025, is displayed in Figure 10. The temperature on the surface of the PV panel, both with and without fins, at 3:00 p.m., when the air temperature was 40.7°C, the wind speed was 2.3 m/s, and the solar radiation intensity was 616.5 W/m2.

Figure 10 shows the temperature gradient for the PV panel with and without fins. The maximum temperature surface of front glass was 59.6°C. The red color in the reference panel indicates the higher surface temperature in the junction box area, which lacks airflow due to insulation. At the center of the front glass of the finless PV panel, the same location where the thermal sensor was installed in the experimental study, the temperature was 58.7°C, and the minimum was 57°C. For the passively cooled PV panel with fins, the maximum temperature was 57.8 °C. The highest temperature was concentrated in the junction box area without fins. At the center of the front glass of the passively cooled PV panel with fins, temperature was 53.9 °C. The minimum was 43.6 °C, located at the end of the fin. The Figure 10 shows the difference in temperatures between the fin-cooled panel and the panel without fins. This difference results in a thermal improvement of approximately 8.18%, and the thermal improvement is supposed to improve the electrical efficiency of the PV panel.

High temperatures significantly affect the lifetime and electrical efficiency of photovoltaic (PV) solar panels. The (figure 11) analyzed using COMSOL shows the effect of ambient air temperature on the surface temperature increase of a PV panel with and without cooling fins. This was done under a constant wind speed of 2 m/s and a constant solar irradiance of approximately 900 W/m². A difference of up to 7.58°C is observed between the PV panel with and without cooling fins.

PV with fins

PV without fins

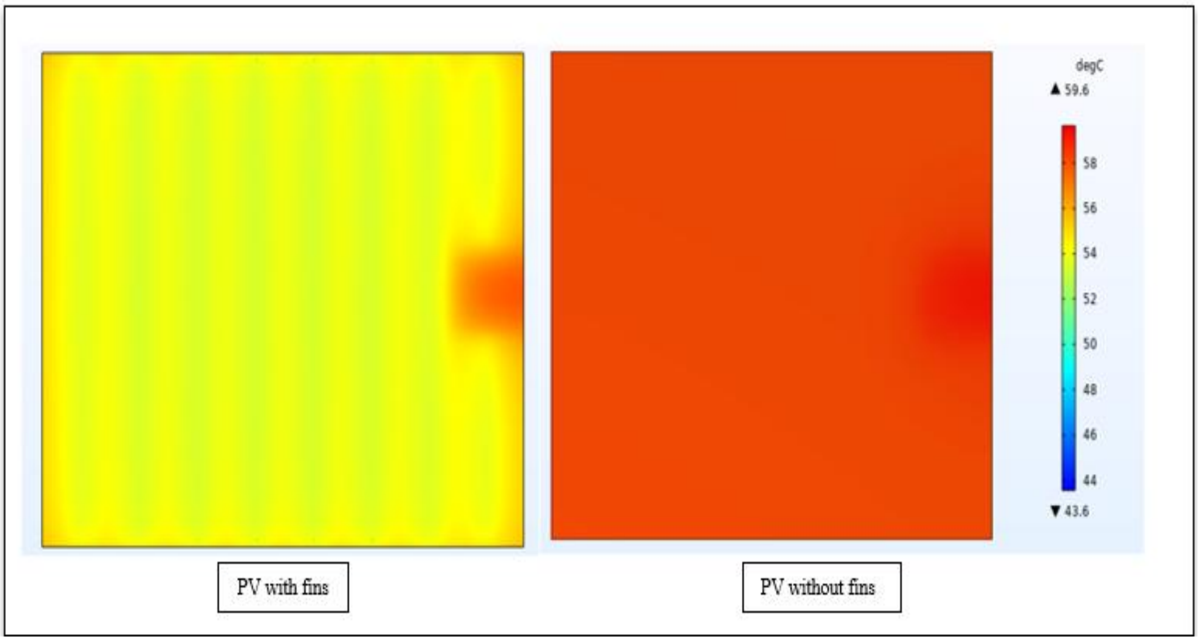

Figure 10. Thermal gradient of the front glass surface of PV with and without fins

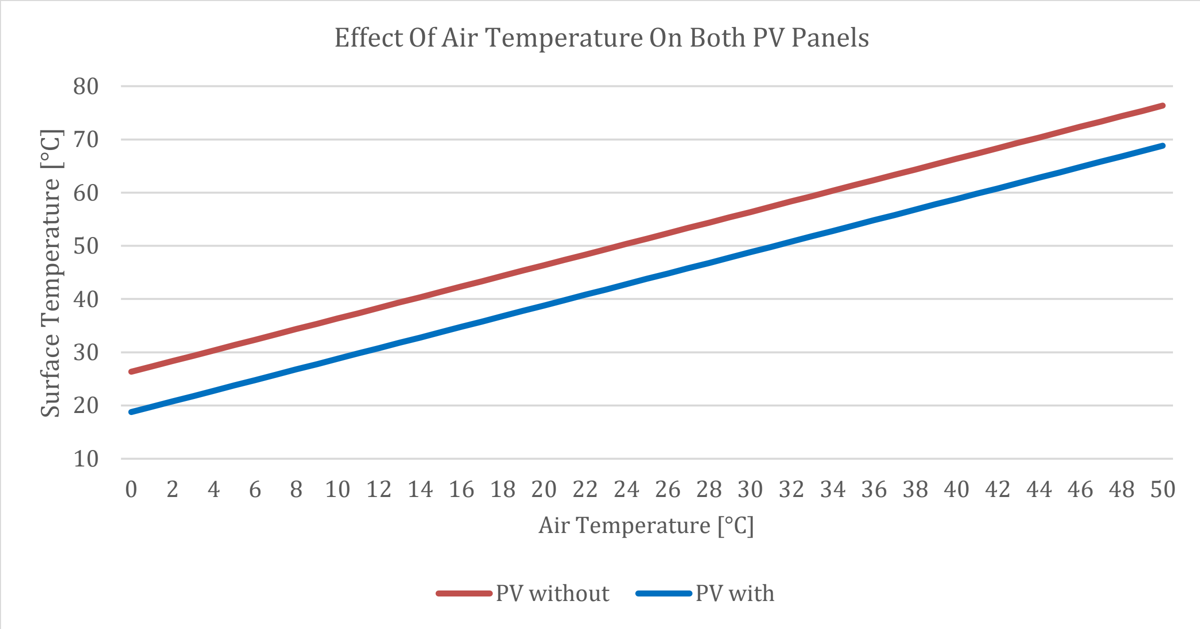

Figure 1. Effect of air temperature on PV with and without fin

All experimental results recorded from 7:00 to 17:00 on May were analyzed and verified using COMSEL software, taking into account the time-varying inputs of solar radiation intensity, wind speed, and air temperature, The Figure 12 shows the difference between the surface temperature of the photovoltaic panel with cooling fins in both the experimental study and the numerical analysis study.

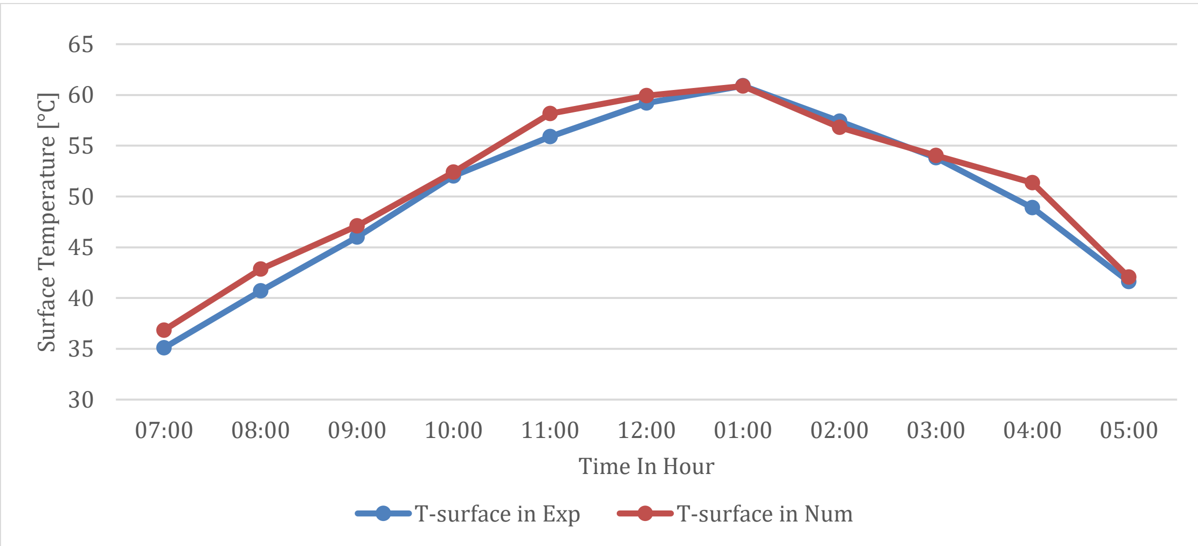

Figure 2. Verify the experimental results for May 31

Conclusion

The goal of this experimental and numerical study is to increase the electrical efficiency and thermal performance of a PV panel with passive aluminum fins. COMSOL Multiphysics was used to run numerical simulations. When compared to the panel without passive fins, the results demonstrated a considerable decrease in surface temperature of up to 7.5°C. The PV panel with passive fins dropped by 11°C in comparison to the PV panel without fins, according to the experimental data. This temperature reduction indicates a potential improvement in electrical efficiency, voltage, and module lifetime in high-temperature regions. The application of passive cooling techniques with fins has proven effective, especially at high wind speeds, and is also cost-effective. Future studies may focus on optimizing the fin geometry and fin base and using nanomaterials to improve thermal performance.

Narrower nozzles could also be used to collect maximum air and direct it toward the fins to enhance heat dissipation.

Recommendations

The following proposals are made in light of the study's findings:

- Improving the fin geometry: Future studies should investigate different shapes, different fin arrangements, and different fin thicknesses to improve heat dissipation.
- A number of experimental experiments ought to be carried out in various climates (such as those with fluctuating wind speeds, sun radiation, and air temperatures).
- The use of alternative materials, as copper, nanomaterials, or even aluminum with higher thermal conductivity, improves thermal performance.
- For experimental validation, it is recommended to verify all experimental results to ensure the validity of numerical results from COMSOL simulations or other simulation software.
- It's best to install PV panels on elevated roofs to ensure trees don't block sunlight and improve airflow. It's also best to install PV panels with passive fins on the windward edge of the roof to ensure better airflow.
- Furthermore, it's also recommended to raise the base of the PV panels above the ground to avoid the thermal radiation they emit, which increases temperature. It's preferable to use or cover the roof with materials that don't store heat, such as cardboard or fabric.
- Hybrid systems are recommended to combine passive fin cooling with water cooling or even phase change material cooling to enhance heat dissipation.

Scientific Ethics Declaration

* The author or authors affirm that they are scientifically, ethically, and legally responsible for this article that was published in the EPSTEM Journal.

Conflict of Interest

* The authors affirm that none of the research and findings in this paper could be influenced by any conflicts of interest, whether they be financial, personal, or otherwise.

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