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Numerical Analysis of Photovoltaic Solar Panels Integrated with Various Pin-Fin Structures

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ABSTRACT

Energy production from sustainable renewable sources is one of the demanding aspects of modern times. The sun's irradiation plays a great role in this aspect. Photovoltaic cells (PVCs) can convert solar energy into electricity with around 20% efficiency. The rest of the solar energy dissipates as heat, overheating, and reducing performance. This study introduces a PV solar panel model that incorporates wavy, square, and circular-shaped pin-finned structures. The steady-state thermal analyses reveal that the surface and body temperature of solar panel is reduced when fins are incorporated into its structure. Compared to the base solar panel model, square and circular pin-fins reduce the PVC temperature by about 23.1% and 22.88% respectively, while wavy pin-fins achieve a reduction of 28.46% where the lowest PVC temperature is 40.513□C in wavy pin-fin. These findings indicate that the wavy-shaped fin design improves PVC performance by reducing operating temperatures. Thus, it can absorb more photons, which results in more electricity generation.

Keywords: Heat flux, Photovoltaic solar cell, Pin-fins, ANSYS Mechanical, Steady State Thermal analysis

1. Introduction

Clean, renewable energy is the pre-condition to reduce global warming. Fossil fuels' carbon emissions harm the environment and quickly their supply is running out, so we must look for alternative energy source. Solar energy is considered the best replacement of fossil fuel due to its accessibility as Earth's surface receives solar radiation from sun around 1.8×10^{11} MW [1].

Photovoltaic Cell (PVC) system provides an efficient means to generate electrical energy from solar radiation by utilizing excitation across the semiconductor bandgap for electrons. Meanwhile, standard PV technology dissipates heat. Material's bandgap and spectral mismatches between photon energy hampered the PV solar panel's electricity generation [2]. Excess thermal energy elevates temperature of solar panel which facilitates recombination activities and narrows the bandgap resulting in a substantial reduction in electricity conversion efficiency [3].

Various research projects have been undertaken to enhance solar panels' heat transfer and electricity generation performance. First-generation solar panels are reported to reach energy conversion efficiency up to 24.7% [4]. Sabry et al. developed a concentrator system to lower temperatures of PV cell, thereby increasing solar energy absorption [5].

Reduction of the temperature of PVC cells would result in more amount of consumption of solar heat radiation. This would significantly increase the power production of a solar panel [6], [7], [8]. Despite these improvements, passive cooling approaches such as fins still have been relatively ignored. Although if this efficiently improves thermal transfer in PV modules, it is a low-cost and energy-free method.

This study will assess thermal performance of PV solar panels of square shaped, circular shaped and wavy shaped pin-fins. Fins increase surface area to allow for heat escaping and airflow occurring around them passively. Kazemian et al. [9] investigated that integrating wavy shaped fin with PV systems enhances the thermo-physical properties due to better heat dissipation. Therefore, this research proposes the attachment of wavy-pin, square-pin, and circular-pin fin designs on solar photovoltaic panels to analyze their thermal characteristics.

2. Methodology

In this research, a structured approach is applied to study temperature distribution and heat transfer of solar panels through steady-state thermal simulations. The overall methodology employed in the investigation is depicted in Fig. 1.

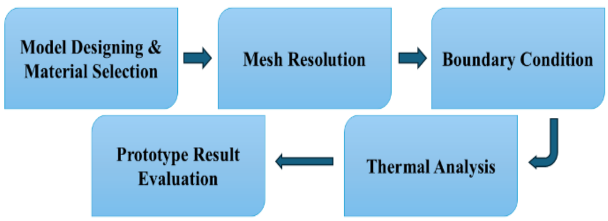


Fig.1: Methodological Flowchart of the Study.

2.1 Modeling & Material Selection

This system of this study includes a PV solar panel with a top glass cover with thickness of 0.0015 m, an upper and lower layer of Ethylene Vinyl Acetate (EVA) thickness of

0.0005 m, photovoltaic cell layer thickness of 0.0013 m, a Tedlar (Polyvinyl fluoride) backsheet thickness of 0.0015 m and a supportive aluminum alloy frame with a thickness of 0.0012 m. Dimensions of the whole system having length of 35.5 cm , width 30 cm and 1.8 cm thickness .Material used in photovoltaic (PV) cells is monocrystalline silicon. SolidWorks 2023 is used to construct the geometric model of this PV solar panel.

Table 1: Thermal properties of PV Solar panel parts material

Parts Name	Thermal conductivity (W/m·K)	Density (kg/m^3)	Specific heat capacity (J/kg·°C)
Upper and lower glass layer’s	1.8	3000	500
EVA layers	0.35	960	2090
Tedlar layer (Polyvinyl fluoride)	0.2	1250	1200

We followed Leow et al. [10], for deriving the thermophysical properties of the materials in Table 1. The interfacial contact between layers is represented using thermal contact resistance (R_tc). For the laminated glass–EVA–cell–Tedlar assembly, R_{tc} is considered negligible (≈0 m²·K/W) due to complete bonding [11]. In contrast, the interface between metallic fins and the polymeric Tedlar back sheet necessitates a non-zero $R_{tc,fin\text{-}Tedlar}$ to accurately capture the heat transfer characteristics dictated by the chosen bonding method [12].

Under free convection conditions, the pin-fins exhibit less thermal resistance corresponding to that of plate-fins [13]. In this study, fin structures are attached to the back side of the solar panel, which is directly interfacing with the Tedlar layer.

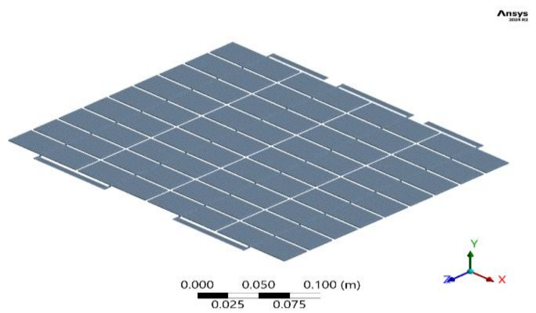


Fig.2: PV cell.

Fig. 2 is the PV cell with fin. There are 36 blocks, each length of 0.0775 m and width of 0.026 m.

This study investigates three distinct-shaped pin-fin configurations. The design parameters corresponding to each configuration are summarized in Table 2, while the geometric representations of the models are illustrated in Fig. 3.

Table 2: Proposed Fin dimensions

Fin Shape	Dimension (m)	Width (m)	Thickness (m)	Total Fin
Square	0.035	0.035	0.0191	30
Circular	Radius= 0.02	-	0.0191	30
Wavy	Length=0.79 ×3,Radius 0.09x3	0.002	0.0191	40

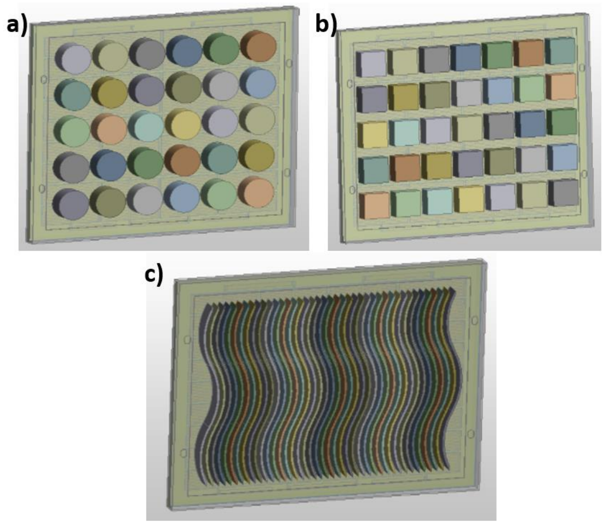


Fig. 3: Pin-fin model design of a solar panel with (a) circular, (b) square, (c) wavy shape.

The total weights of the base model (no fin) were found 1.1619 kg, 2.1502 kg for wavy-fin design, 3.0522 kg for square-fin model and 3.1024 kg for circular-fin. The circular, square, and wavy fins are arranged in a linear configuration. These proposed designs can be manufactured through additive manufacturing (AM), a technique that is increasingly utilized to transform Computer-Aided Design (CAD) models into physical components. American Society for Testing and Materials (ASTM) defines additive manufacturing as a process of creating objects from 3D model data by joining materials layer by layer, in contrast to traditional subtractive methods [14]. In the metal-based AM process, a laser is used to fuse the material together to create the item layer by layer, with flexibility and high resolution. Traditional manufacturing processes cause material waste, high tooling costs, and may be limited in the manufacture of advanced geometries. Complex geometrical structures can be created using aluminum alloy powder and laser with the help of advanced manufacturing.

In this study aluminum is used as fin material due to its mechanical flexibility, affordability, softness and thermal conductivity [15]. Metallic fins can be structurally attached to the polymeric Tedlar backsheet using high-thermal-conductivity structural epoxies or silicone adhesives [12]. This approach minimizes the thermal contact resistance ($R_{tc,fin\text{-}Tedlar}$) while ensuring mechanical stability and long-term durability under thermal cycling, moisture exposure, and mechanical loads typical of outdoor photovoltaic operation [16].

2.2 Mesh Resolution

After completing the CAD model, material properties were assigned to the different parts using Ansys 2024 software. Then meshing of the CAD geometry applied using ANSYS 2024. In ANSYS Mechanical software we used finite element method (FEM) to assess the thermal profile across the fin surface [17].

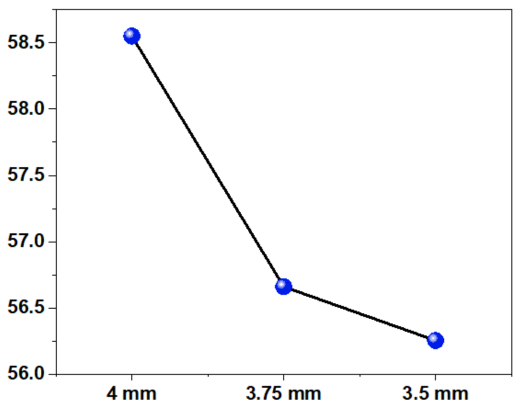


Fig. 4: Mesh Impedance test.

From Fig.4, the temperature difference for no fin PVC solar panel between the 3.75 mm and 3.5 mm meshes is only about 0.72% which indicates mesh independence. So, 3.75 mm was selected as the optimal mesh size for accuracy and computational efficiency. A gradual mesh transition was applied, and an appropriate span angle center was selected to enhance element quality. Additionally, mesh smoothing was set to a high level to facilitate convergence and ensure the reliability of the anticipated accuracy. The detailed counts of elements and nodes for the meshed model are provided in Table 3. Meshing was performed for square, circular, and wavy fin shown in Fig.5.

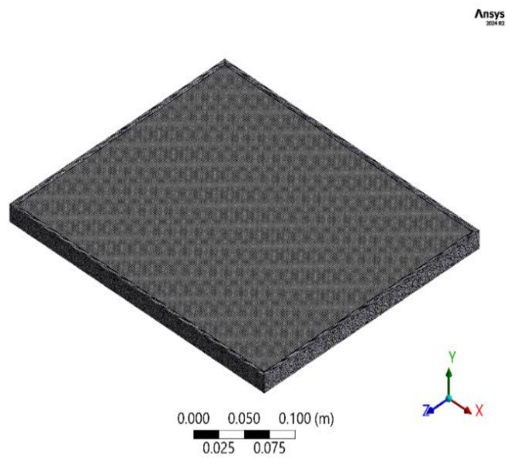


Fig. 5: Layout of solar panel model's mesh.

Table 3: Number of elements and node in solar panel's mesh.

Model	Number of Nodes	Number of Elements
No fin	376932	105900
Square shape	470296	123893
Circular shape	580906	149273
Wavy shape	624506	137333

2.3 Boundary Conditions

Numerical simulation was conducted by ANSYS steady-state thermal tool to analyze the cooling performance of whole model and PVC module with and without fins on its backside using three-dimensional Steady-State Heat Conduction Equation [18]:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}_g=0 \qquad (i)$$

Where:
T is the temperature (K).
k is the thermal conductivity (W/m.K).
$\dot{q}_g$ is the volumetric heat generation rate ($W\ /\ m^3$) in the PV cell layer.

The main goals were to decrease the solar panel's body temperature. Before obtaining a solution, suitable boundary conditions were applied to perform simulation for running. For the simulation, a vertically positioned solar panel receives irradiation of 617 W/m², while the ambient temperature is progressively increased to 25 °C [11]. Absorbed solar heat flux on the PVC module surface was determined using the following relation [11],

$$q_{abs}=G.\alpha.(1-\eta) \qquad (ii)$$

Where:
G is the incident irradiance (W/m²).
α is the effective absorptance of the top surface.
η is the electrical conversion efficiency of the PV.

In ANSYS, an absorptivity (α) of 0.94 and a module efficiency (η) of 0.20 were used which resulting applied heat flux of approximately 467 W/m² on the top surface of the tempered glass. Natural convection condition applied on the panels' outside area in still air with a heat transfer coefficient of 8 $W/m^2{\cdot}K$ and natural radiation applied with the emissivity of 0.9 and ambient temperature of 25 °C. The heat transfer coefficient of 9 $W/m^2{\cdot}K$ was applied to the finned surfaces for consistency in the model. The temperature distribution of a fin is the change of temperature from its hot base to the cool tip due to heat conduction and convection.

3. Results

Steady-state heat transfer analysis demonstrates that heat conduction within or across system is considered steady when temperature remains constant over time [18]. ANSYS steady-state thermal simulation tool evaluates the internal temperature distribution of a system in thermal equilibrium. Applying heat flux through the ANSYS Mechanical's steady-state thermal module models better flows in the pin-fins.

Temperature distribution plots from simulation reveal that high-temperature regions are bright red and low-temperature regions are deep blue. Besides, top glass layer exhibiting the highest temperature within the photovoltaic module and aluminum frame, pin-fins are cooler than the components within the panel. Heat dissipates from the panel into the neighboring air through conduction and convection.

In Fig. 6 (No Fin), the panel temperature becomes high up to 56.661°C at the center, and minimum values remain above 35.882 °C at the border side. PVC layer also records a high temperature 56.632 °C because of its low conductivity.

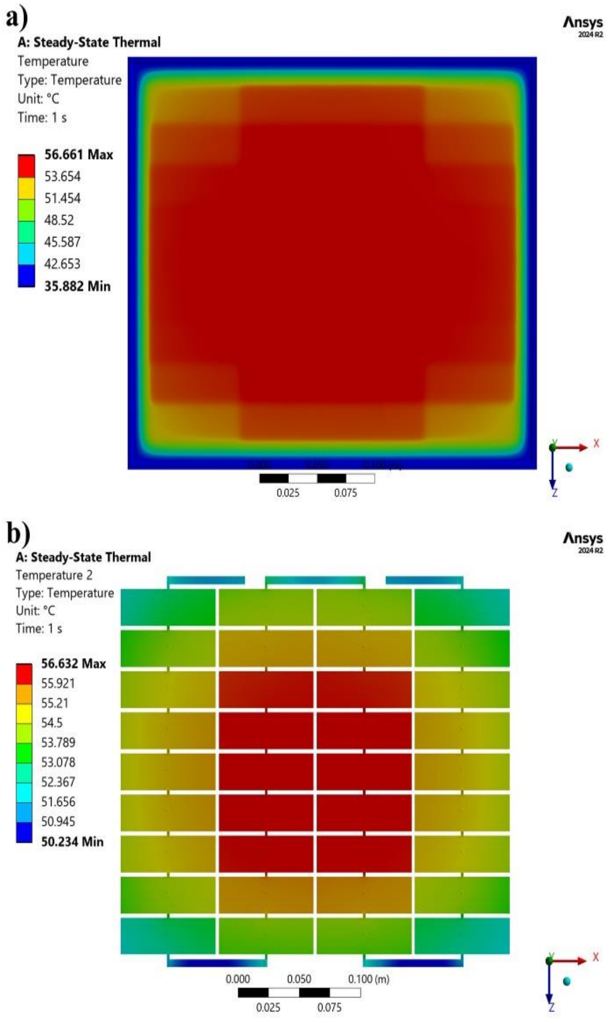
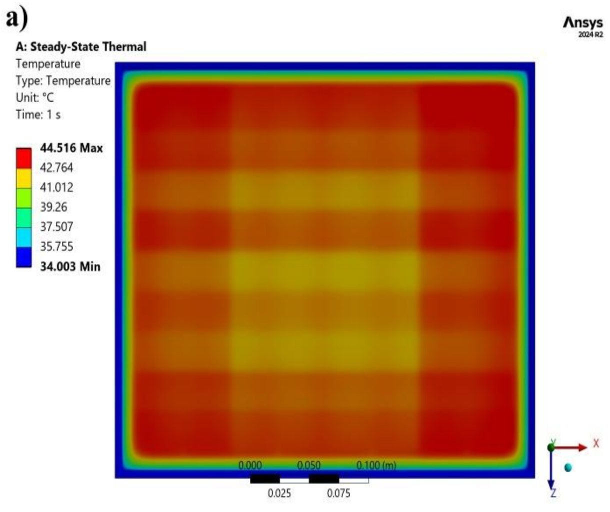


Fig. 6: Temperature distribution of No fin PVC Solar panel (a) Whole model temperature distribution, (b) PVC temperature distribution

In Fig. 7 (Circular fin) performs better in cooling compared to No fin. The highest panel temperature drops from 56.661°C to 44.516°C, and the PVC layer temperature decreases from 56.632 °C to 43.545°C. This shows that adding circular fins improves heat dissipation, prevents heat accumulation, and ensures better thermal performance of the solar panel.



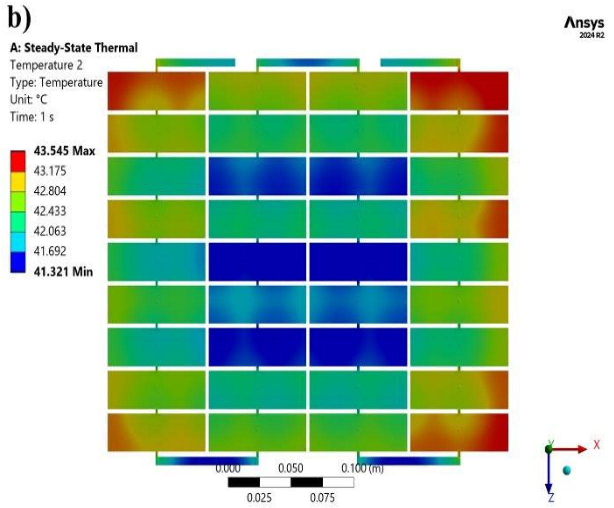


Fig. 7: Temperature distribution of Circular fin PVC Solar panel (a) Whole model temperature distribution, (b) PVC temperature distribution.

In Fig. 8 (Square fin), the panel temperature further decreases to 44.103°C, while the PVC temperature drops to only 43.673°C, showing better cooling than both No-fin (56.632°C) and Circular-fin (43.545°C), proving that square fins offer better heat dissipation, minimize hotspots, and ensure good thermal performance of the solar panel.

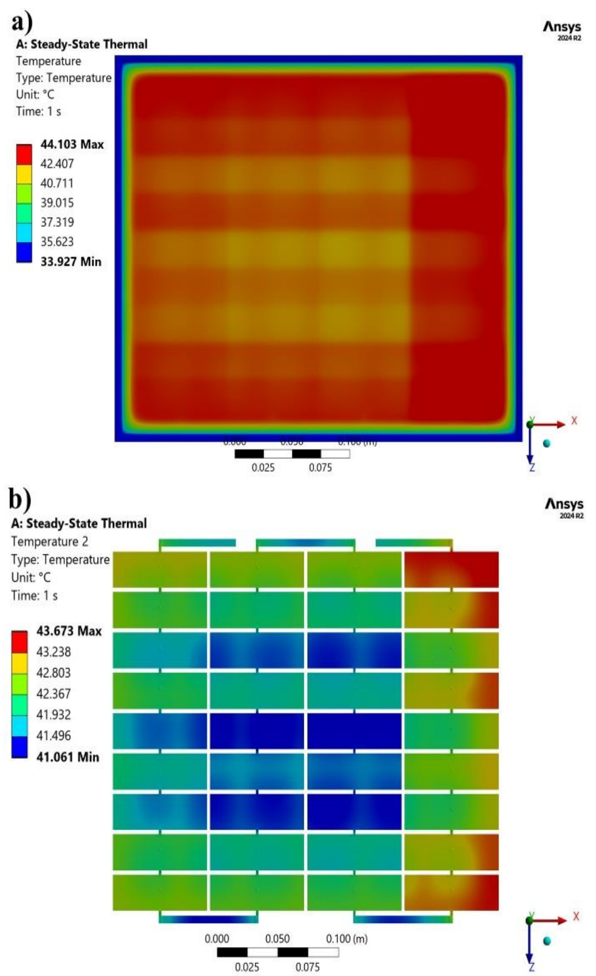


Fig.8: Temperature distribution of square fin PVC Solar panel (a) Whole model temperature distribution, (b) PVC temperature distribution.

In Fig. 9 (Wavy fin), the panel temperature reduces further to 42.256°C, while the PVC layer reaches a minimum of 40.513°C, which is lower than No-fin (56.632°C), Circular-fin (43.545°C), and Square-fin (43.673°C). This shows that wavy fins provide the best thermal management, offering maximum cooling, the lowest PVC temperature, and the most effective heat dissipation, ensuring the highest efficiency and reliability of the solar panel.

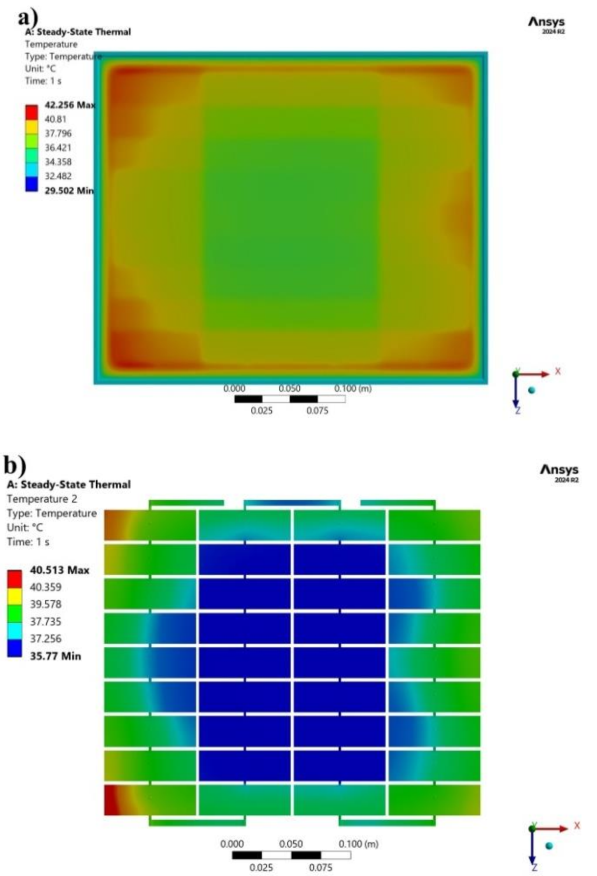


Fig.9: Temperature distribution of Wavy fin PVC Solar panel. (a) Whole model temperature distribution, (b) PVC temperature distribution.

Table 4 and Fig. 10 show the temperature and heat flux variation of three types of fins. An air-cooling system is the best option among all solar cooling systems since it is inexpensive and can employ both forced and free convection to lower the temperature of the solar panel [19].

Table 4: The result obtained after the analysis.

Solar panel	T_{max} (whole model) °C	T_{min} (whole model) °C	T_{max} (PVC) °C	T_{min} (PVC) °C
No fin	56.661	35.882	56.632	50.234
Circular fin	44.516	34.003	43.545	41.321
Square fin	44.103	33.927	43.673	41.061
wavy fin	42.256	29.502	40.513	35.77

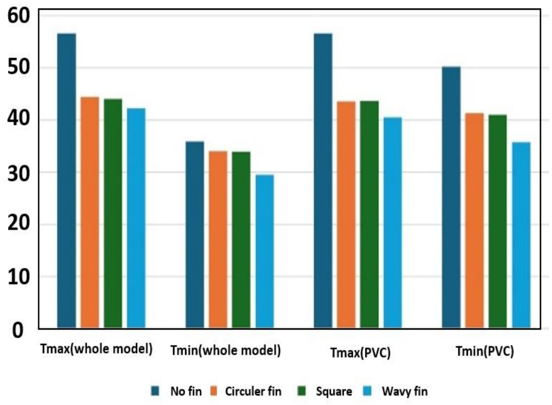


Fig. 10: Comparison Between properties

By eliminating any hot spots of overheating and through the application of pin fins, this solar panel research is available for free circulation of air cooling to be able to maintain that the system will function within its thermal limits.

4. Prototype Evaluation

After conducting the analyses, compared to the no-fin case (131.82°C), circular, square and wavy fin configurations reduced the PVC temperature by 61.7% (50.5°C), 63.5% (48°C), and 67.8% (42.4°C), respectively, where the wavy fins provided the highest reduction. From simulation results, wavy fins offer the most balanced performance in both reducing temperature and enhancing heat dissipation. Popovici et al. [20] numerically investigated a PV solar panel integrated with an air-cooled heat sink and found a minimum temperature reduction was 10℃ while maximum power production enhanced by 4%. In a comparative analysis, Wongwuttanasatian et al. [21] showed that a PV module in a finned container heat sink faced an efficiency improvement of 5.3% with an average performance enhancement ratio of 4.8%. In one study by Mrinmoy et al. [16] circular-shaped pin fin reduced PVC temperature by 55%. The temperature-dependent efficiency of a photovoltaic module was estimated using the standard correlation [18]:

$$\eta_T = \eta_{ref}[1 - \beta(T_{cell} - T_{amb})] \quad \text{(iii)}$$

Here,

η_{ref} is reference efficiency at standard test conditions.
β is the temperature coefficient of efficiency.
T_{cell} is the PV cell temperature.
T_{amb} is the ambient temperature.

Based on the simulated PV temperatures, the no-fin case produced a cell efficiency of 17.15%. The square fin configuration yielded an efficiency of 18.33% while the circular fin configuration with 18.32% efficiency. The wavy-fin design demonstrated the best thermal and electrical performance resulting in an efficiency of 18.60%.

The corresponding electrical power output for each configuration was calculated using the relation [19],

$$P_{0ut} = \eta_T . G . A \quad \text{(iv)}$$

Here,
G is the incident solar irradiance (W/m²).
A is the effective PV surface area (m²).
Electrical output of no fin PVC module is found 11.27 W, for square fin power output is 12.05 W, for circular fin 12.04 W output and for wavy fin electrical output is found 12.22 W.

5. Conclusion

Considering the need for electricity in the rural side of Bangladesh, this research was conducted. The key results suggest efficient solar panels that can be manufactured at minimal cost and installed in rural areas that aren't connected to the national grid. Utilizing solar radiation as effectively as possible to overcome energy deficiency with this environmental interface. Solar technologies available face stability issues, one of the key reasons is overheating, considering that the solar panel's temperature rises with time. This analysis resulted in a temperature reduction of about 28.46% for the wavy pin-finned solar panel PVC module, 22.88% temperature reduction for the square pin-finned PVC module and circular pin-finned solar panel PVC module temperature reduction of approximately 23.1%. This indicates an increased rate of solar photon conversion of electricity. So, the solar panel will be able to produce more electricity compared to no-fin models.

6. Acknowledgment

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7. References

[1] B. Parida, S. Iniyan, and R. Goic, "A review of solar photovoltaic technologies," Renewable and Sustainable Energy Reviews, vol. 15, no. 3, pp. 1625–1636, Apr. 2011.
[2] C. Pelosi, "Light concentration increases solar-cell efficiency and reduces cost," SPIE Newsroom, 2007.
[3] I. P. E. S. U. T. M. I. M. S. Institute of Electrical and Electronics Engineers, "2015 IEEE Conference on Energy Conversion (CENCON)," Johor Bahru, Malaysia.
[4] "A Review: Comparative studies on different generation solar cells technology." Accessed: Aug. 07, 2025. [Online]. Available: https://www.researchgate.net/publication/274195294_A_Review_Comparative_studies_on_different_generation_solar_cells_technology
[5] M. Sabry et al., "Optical filtering of solar radiation to increase performance of concentrator systems," Conference Record of the IEEE Photovoltaic Specialists Conference, pp. 1588–1591, 2002.
[6] A. K. Pandey et al., "Solar Energy Utilization Techniques, Policies, Potentials, Progresses, Challenges and Recommendations in ASEAN Countries," Sustainability (Switzerland), vol. 14, no. 18, Sep. 2022.
[7] J. U. Ahamed, M. A. Wazed, S. Ahmed, Y. Nukman, T. M. Y. S. T. Ya, and M. A. R. Sarkar, "Enhancement and prediction of heat transfer rate in turbulent flow through tube with perforated twisted tape inserts: A new correlation," J Heat Transfer, vol. 133, no. 4, 2011.
[8] J. U. Ahamed, N. A. Madlool, R. Saidur, M. I. Shahinuddin, A. Kamyar, and H. H. Masjuki, "Assessment of energy and exergy efficiencies of a grate clinker cooling system through the optimization of its operational parameters," Energy, vol. 46, no. 1, pp. 664–674, 2012.
[9] A. Kazemian, K. Khosravi, S. Sen, P. Talebizadehsardari, A. Cairns, and T. Ma, "Optimizing photovoltaic thermal systems with wavy collector Tube: A response Surface-Based design study with desirability analysis," Appl Therm Eng, vol. 258, Jan. 2025.
[10] W. Z. Leow et al., "Investigation of solar panel performance based on different wind velocity using ANSYS," Indonesian Journal of Electrical Engineering and Computer Science, vol. 1, no. 3, pp. 456–463, Mar. 2016.
[11] J. A. Duffie and W. A. Beckman, "Solar Engineering of Thermal Processes: Fourth Edition," Solar Engineering of Thermal Processes: Fourth Edition, Apr. 2013.
[12] Theodore L. Bergman, Adrienne S. Lavine, Frank P. Incropera, and David P. DeWitt, Introduction to Heat Transfer, 6th ed. Wiley, 2011.
[13] D. K. Kim, S. J. Kim, and J. K. Bae, "Comparison of thermal performances of plate-fin and pin-fin heat sinks subject to an impinging flow," Int J Heat Mass Transf, vol. 52, no. 15–16, pp. 3510–3517, Jul. 2009.
[14] W. E. Frazier, "Metal additive manufacturing: A review," J Mater Eng Perform, vol. 23, no. 6, pp. 1917–1928, 2014.
[15] "Mechanical Properties of Alurninium Alloy." Accessed: Jul. 28, 2025.
[16] M. R. Rony, M. M. Parves, P. C. Dash, A. D. Turjo, J. U. Ahamed, and B. Esakki, "Investigation of steady state and transient state thermal analysis of solar panels integrated with different finned structures," AIP Conf Proc, vol. 3178, no. 1, Aug. 2024.
[17] J. Taler and P. Duda, "Solving direct and inverse heat conduction problems," Solving Direct and Inverse Heat Conduction Problems, pp. 1–889, 2006.
[18] C. Y. A. and G. A. j., "Heat and Mass Transfer," McGraw Hill Education (India) Private Limited, New Delhi.
[19] W. Z. Leow, Y. M. Irwan, M. Irwanto, M. Isa, A. R. Amelia, and I. Safwati, "Temperature distribution of three-dimensional photovoltaic panel by using finite element simulation," Int J Adv Sci Eng Inf Technol, vol. 6, no. 5, pp. 607–612, 2016.
[20] C. G. Popovici, S. V. Hudişteanu, T. D. Mateescu, and N. C. Chereches, "Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks," Energy Procedia, vol. 85, pp. 425–432, Jan. 2016.
[21] T. Wongwuttanasatian, T. Sarikarin, and A. Suksri, "Performance enhancement of a photovoltaic module by passive cooling using phase change material in a finned container heat sink," Solar Energy, vol. 195, pp. 47–53, Jan. 2020.