Mathematical Simulation of Plat-Pin Fin Heat Sink Installed under the Solar Panels

P. Nachaisit[1], P. Satuwong[2], P. Vengsungnle[3], P. Khantikomol[2], B. Krittacom[2,*]

[1] Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus, Khon Kaen, 40000 Thailand.

[2] Development in Technology of Porous Materials Research Laboratory (DiTo-Lab), Department of Mechanical Engineering, Faculty of Engineering and Technology, Rajamangala University of Technology Isan, Nakhonratchasima, 30000 Thailand.

[3] Department of Agricultural Machinery Engineering, Faculty of Engineering and Technology, Rajamangala University of Technology Isan, Nakhonratchasima, 30000 Thailand.

* Corresponding author. Email: bundit.kr@rmuti.ac.th (B.K.)

Manuscript submitted December 26, 2023; revised January 2, 2024; accepted April 9, 2024; published June 25, 2024.

doi: 10.12720/sgce.13.2.54-64

Abstract: Mathematical simulation of plat–pin fin heat sink installed under solar panels was conducted. Based on the problem of heat accumulation inside the solar panel, the electricity generation efficiency become reduced with a higher heat. Thus, the objective was to design and simulate plate and pin cooling. Two shapes of pin consisting of plate and cylindrical pin were studied. The investigated process was divided into two stages. The design and calculation of the heat sink fin was the first stage. The process of simulating solar panels with fins attached and without fins using the SOLIDWORKS program was the second stage. Three factors were considered: the direction of the panel installation (S, SE, and SW), the inclination angle (θ) of the solar panel, and the style of installation (Transvers and longitude fins). The appropriated condition for reducing the temperature of solar panels was discussed. The results showed that the minimal temperature of the solar panel was obtained at the southeast (SE) direction with an inclination angle (θ) of 18°. Heat dissipation was achieved by the transvers fins in which a maximum temperature reduction gave 6.39 °C.

Keywords: Heat sink, solar panel, temperature reduction

1. Introduction

Cooling is very important in engineering and industrial areas such as the electrical industry, petroleum industry, metal industry, electronics industry, etc. There are two methods of cooling which are active cooling and passive cooling. Active cooling methods can reduce the temperature more than passive cooling. Active cooling methods can effectively lower temperatures to a greater extent than passive cooling. However, they exhibit diminished effectiveness due to the additional power requirement from external sources, leading to an overall decrease in system performance [1].

Heat sinks are heat exchangers that reduce temperature by increasing the exposed surface area to air which aids in transferring heat from the device to the ambient air [2]. There are numerous types of heat sinks, including a flat plate and a pin. The manufacturing process for triangular, oval, and especially cylindrical shapes is straightforward and uncomplicated. Consequently, it is commonly used to install small electronic devices. In the past, it has begun by installing heat sinks beneath the solar panel to reduce the temperature that has accumulated within the solar panel. Reducing the solar panel's operating temperature improved the panel's electricity production efficiency [3] by installing heat sinks for solar cells. The advantages were easy installation and flexibility in positioning solar cells. As many studies have been studied before such as Egab *et al.* [4], Namwong *et al.* [5], Bayrak *et al.* [6], Arshada *et al.* [7], and Alzahrani [8]. All works were placed on flat surface heatsink fins. This demonstrated the great potential of a heat sink approach in maintaining the temperature of the solar panel [9, 10].

Due to the problems described above, the solar cell's accumulated heat will reduce its ability to generate electricity. The authors, therefore, interested in studying the mathematical simulation of plate and cylindrical fin heat transfer. The study approach was divided into two stages: the fin design & calculation stage, and the stage of the simulating the heat-sink fin installed under the solar panels using the SOLIDWORKS program. Three factors were investigated: the direction of installation of the panel (S, SE, and SW, the inclined angle of the solar panel (θ), and the style of installation (Transvers and longitude fins). An appropriated condition was found following by increasing the efficiency of electricity generation and reducing the temperature of the solar panel.

2. Principles and Theories

2.1. Principles of Electricity Generation of Solar Cells

Devices converting the solar energy into electrical energy were created for the first time with only 6% efficiency. Later, many researches and developments can be increased the efficiency being more than 15% [11]. The principles used to achieve this outcome were as follows: as illustrated in Fig. 1, when the sun's rays reach a semiconductor solar cell, electric current flows through it and, at completion of a full cycle, the semiconductor generates an electromotive force [5].

2.2. Heat Transfer Inside the Solar Panel

The ambient air temperature (T_{air}), the intensity of the solar radiation (I_T), and the wind speed of the surrounding air all have an impact on the amount of energy that solar panels produce. Solar panels will produce electricity when there is enough solar radiation to fall on them. The solar cell's temperature will rise as a result of these factors. In a cooler environment, the heated fluid will naturally ascend due to the surface heat. However, as illustrated in Fig. 2, if the hot surface is oriented downward, the plate will obstruct the heated fluid's tendency to rise, preventing heat transmission [12, 13] that is lost to the surroundings by air convection.

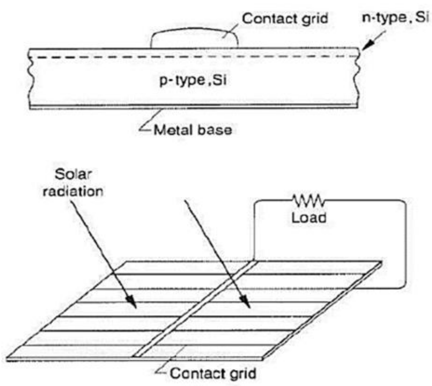


Fig. 1. Solar panel operating principle [5].

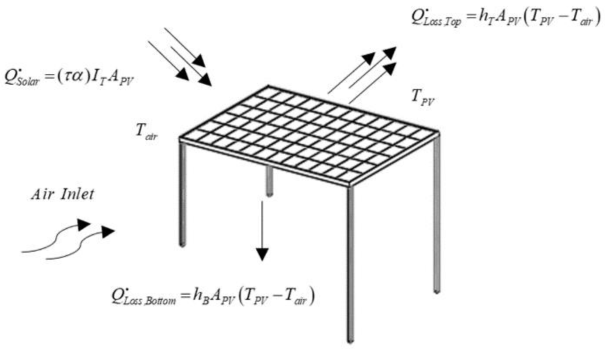


Fig. 2. Characteristics of heat transfer of solar panels.

Fig. 2. depicts the rate of heat energy falling on the panel. It can be calculated from Eq. (1).

$$Q^{*}_{Solar} = I_T (A_{PV})(\tau\alpha) \tag{1}$$

When I_T is solar radiation intensity (W/m^2), A_{PV} is the area receiving light at the top of the solar panel (m^2), and $\tau\alpha$ is the transmittance and absorption of solar radiation.

The front panel is illuminated by the light. A significant amount of solar radiation is absorbed by the solar panel. Furthermore, convection will cause some of the solar radiation to be lost as heat to the surrounding air at the peak of the panel. As a result, there is a temperature differential between the air outside and the panel [5]. The rate of heat loss that can be computed using Eq. (2) at the top of the panel.

$$Q^{*}_{Loss,Top} = h_T (A_{PV})(\triangle T) \tag{2}$$

where h_T is the convection coefficient of heat at the top of the panel (W/m^2 K), and $\triangle T$ is the difference between the temperature of the panel and the ambient air temperature (°C)

It is possible to get the convection coefficient of the solar panel's top [13] using Eq. (3).

$$h_T = Nu_T \left(\frac{k}{L}\right) = 0.13\left[(Gr\ \mathrm{Pr})^{1/3} - (Gr\ \mathrm{Pr})^{1/3}\right] + 0.56\ (Gr\ \mathrm{Pr}\cos\theta)^{1/4} \times \left(\frac{k}{L}\right) \tag{3}$$

where Gr is the Grasov number, Pr is the Prandtl number, k is the thermal conductivity coefficient (w/m K), and L_{PV} is the length of the solar panel (m).

Furthermore, using the method in Eq. (4), the convection coefficient of the fins can be computed (h_{fin}) [13].

$$Nu_L = \frac{h_{fin}S}{k} = \left[\frac{576}{(\cos\theta \cdot Ra_L \cdot \frac{S}{L})^2} + \frac{2.873}{(\cos\theta \cdot Ra_L \cdot \frac{S}{L})}\right]^{-0.5} \tag{4}$$

where Nu_L is the Nutselt number, h_{fin} is the convection coefficient of the fins (w/m^{2}K), is the distance between the fin plates (m), Ra_L is the Reynolds number of the plate fin, and L is the length of the fin (m).

The Reynolds number (Ra_L) [13] can be calculated from Eq. (5).

$$Ra_L = \frac{g\beta(\triangle T)(L^3)}{\nu^2} Pr = Ra_S \left(\frac{L^3}{S^3}\right) \tag{5}$$

where g is the gravity of the Earth (m/s^2), β is the coefficient of thermal expansion (K), ν is the kinematic viscosity (m^2/s), and Ra_S is the Reynolds number of the distance between the fins.

The distance between the fins [13] can be calculated from Eq. (6).

$$S = 2.714\left(\frac{L}{(Ra_L \cos\theta)^{0.25}}\right) \tag{6}$$

where $S = S_{opt}$ Nutselt number value (Nu) is equal to 1.307 and the Nutselt number of pin fins can be calculated from Eq. (7)

$$Nu_p = \frac{h_p L}{k} \tag{7}$$

or can be estimated from Eq. (8)

$$Nu_P = 0.6 - 0.488 \sin\theta^{1.03}\, Gr_L \mathrm{Pr}^{\frac{1}{4}+\frac{1}{2}(\sin\theta)^{1.75}} \tag{8}$$

whereas $GrPr = Ra_L$ and can estimated the heat transfer rate absorbed by the panel from Eq. (9)

$$Q^{*}_{absorb} = h_{avg}(A_{fin})(\triangle T) \tag{9}$$

where h_{avg} is an average convection coefficient (W) retrieved from $\left(h_{fin} + h_{pin}\right)/2$ and A_{fin} is the surface area of the fin (m^2).

The fin surface area can be calculated from Eq. (10).

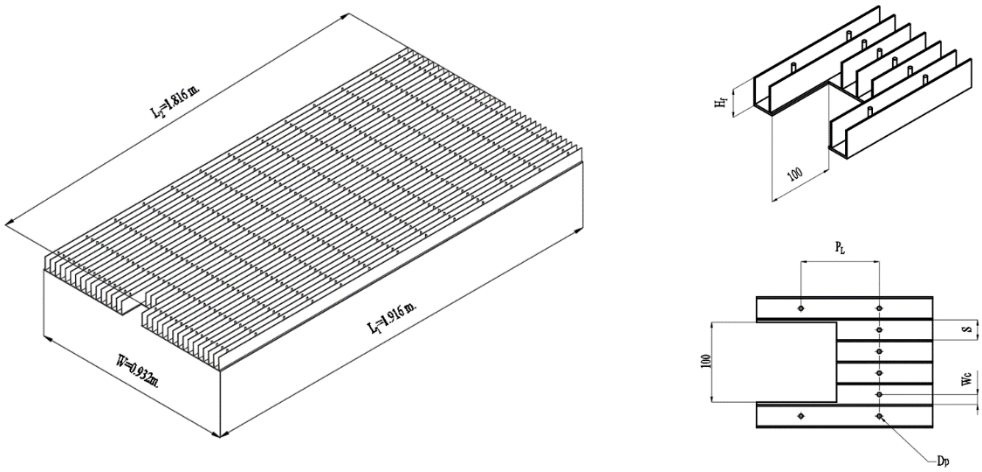
$$A_{fin} = (2LHn_1 + 2LHn_2) + \pi D n_{pin} + \left[A_{base} - (tLn_1 + tLn_2) - \pi r^2 n_{pin}\right] \tag{10}$$

where H is the fin height (m), n is the number of fins, A_{base} is the area of the base of the fin (m^2), t is the thickness of the fin (m), and r is the cylindrical radius of the fin (m).

3. Operational Procedures

3.1. Design Process of Heat Sinks

Characteristics of pin fins heat sink was presented in Fig. 3. To reduce the interior temperature of the solar panel to less than 55 °C, the following assumptions were used: (a) Both the air and the fins were maintained at a constant temperature, (b) The thermal conductivity along the length of the fin was unidimensional, (c) There was no source of heat within the fins, and (d) Radiation to the surrounding environment gave not considered.



(a) (b)

Fig. 3. Details of plate-pin fins heat sinks: (a) Characteristics of heat sinks and (b) Sizing details.

Step 1: The rate of heat absorbed by the solar panel was calculated by determining the intensity of solar radiation (I_T) which was equal to 1,000 W/m^2, the temperature of the panel (T_{PV}) was 62 °C. The transmittance and absorption of solar radiation value ($\tau\alpha$) was 0.64 according to the experimental results of Ref. [12]. Air temperature (T_{air}) gave 30 °C with the solar panel tilted at an angle of 15° from horizontal plane [14–17]. The physical properties of the average fluid temperature were used by k = 0.02753 W/m K, ν = 1.754×10^{-5} m^2/s, Pr = 0.708, and β = 0.003125 K. The rate of heat absorbed by the solar panel, which was equivalent to 807 W utilized in the design of heat sinks, was then obtained by substituting the values into Eqs. (1)–(3).

Step 2: Design heat sinks are described as follows:

1) The convection coefficient of the plate fins was acquired by determining the air temperature (T_{air}) = 30 °C, panel temperature (T_{PV}) = 55 °C, fin length (L) = 1.196 m, fin width (W) = 0.932 m, fin height (H_f) = 0.03 m, fin plate thickness (T_f) = 0.002 m, and the thickness of the fin base (T_b) = 0.003 m. The physical properties of the average fluid temperature were applied by k = 0.02725 W/m k, ν = 1.716×10^{-5} m^2/s, Pr = 0.708, and β = 0.003165 K. All properties were replaced into Eqs. (4)–(6), thus the distance between the fins (S) became 0.025 m and the convection coefficient gave 1.85 W/m^2 K.

2) The convection coefficient of pin fins was predicted by determining the height of pin fins (H_f) = 0.03 m and size (D_P) = 0.005 m which could be calculated from Eqs. (7) to (9). It revealed that the convection coefficient of pin fin became 11.10 W/m^2 K resulting in the average convection coefficient (h_{AVG})was (1.85 + 11.10)/2 = 6.47 W/m^{2}K.

3) The cooling surface area of the fins (A_{fin}) could be estimated by the Eq. (10). It was found that the total fin surface area required was 5.00 m^2.

4) The quantity of pin fins was determined due to the need to leave room for insertion of the junction box device, the fin length was specified in two sizes; L_1 = 1.916 m and L_2 = 1.816 m calculated from Eq. (10). It was found that at the height of the fin was 0.03 m would get the number of pin fins in a total of (n) = 1242 pieces. Therefore, the height was reduced to (H_f) = 0.024 m and the calculation was redone again. Panel temperature was reduced not more than 55 °C with 391 pin fins. However, at a height of 0.024 m, when attached to the area under the panel, it would be obscured by the structure of the solar panel, resulting in poor air circulation. Additionally, a better air circulation was obtained, if the fins' height (H_f) rose by 0.06 m leading to the number of pin fins (n) gave 438 at the fins' distance (P_L) of 0.15 m.

3.2. Simulation Process

In the present study, the schematic of the generic structure of the thermophysical properties of the layers in the PV cell module is show in Table 1 and the simulation solar cell assembly is shown in Fig. 4.

In this simulations, the pin fins heat sink (PCPFHS) of solar panels was made of an aluminum alloy 6063 T5 with a thermal conductivity of 209 W/m K.

Table 1. Thermophysical properties of layers of the PV cell module [14]

Name	Thickness (mm)	Density (kg/m^3)	Thermal Conductivity (W/m K)	Heat Capacity (J/kg K)
Glass	3.2	2515	0.98	820
EVE	0.45	960	0.31	2090
PV cell	0.2	2330	150	712
EVE	0.45	960	0.31	2090
Tedlar	0.35	1162	0.23	1465

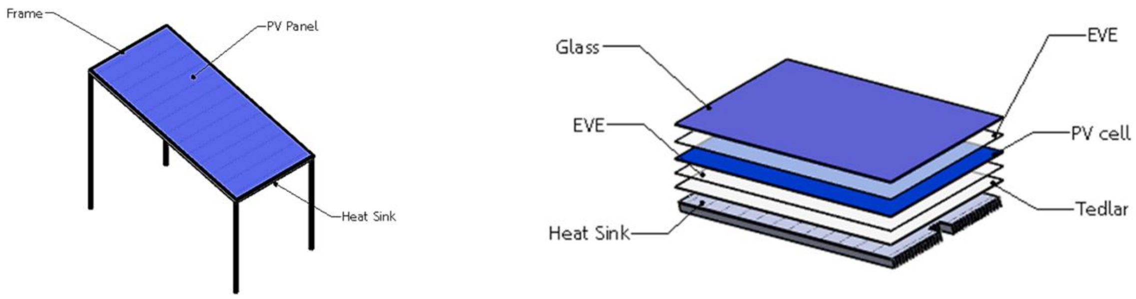


Fig. 4. The schematic of the generic structure of the solar cell: (a) the solar cell assembly and (b) The layers in the solar cell.

A 340-watt polycrystalline solar panel, which has a size of 1.96×0.99×1.50 m, was simulated to determine the size of the domains used in the calculations in each axis, i.e., axis X = 2L, Y = 2L and Z = 4L as shown in Fig. 5.

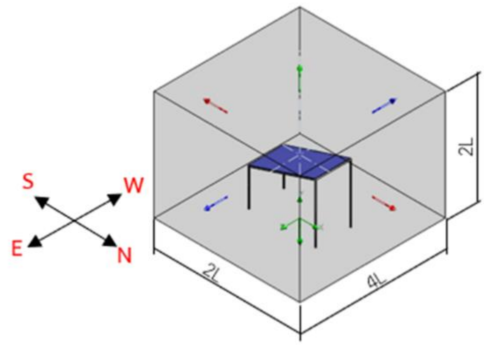


Fig. 5. Domain sizing scheme of solar panels.

In the present study, the solar panel and Heat sink was realized using SOLIDWORKS Flow Simulation Modeler for analyzing fluid heat transfer problems. We validated the model by comparison with previous studies for the same solar cell size with adjusted the PV model to the same conditions in [15] shown that the present numerical results match the experimental results of previous studies well as depicted in Fig. 6.

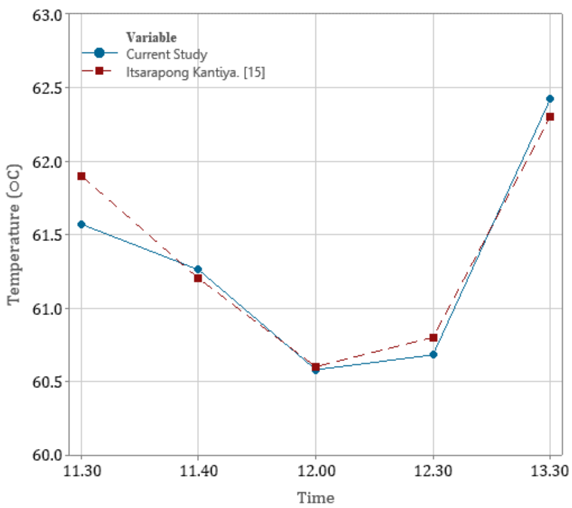


Fig. 6. Comparison of experimental data for solar panel temperature from the correlation presented [15].

In addition, six different mesh sizes, namely 60, 70, 90, 110, 120, and 140, were determined. It was discovered that the mesh size suitable for both accurate results and efficient calculation time was 110. This mesh size yielded an average temperature of 51.92 °C for the solar panel, as depicted in Fig. 7.

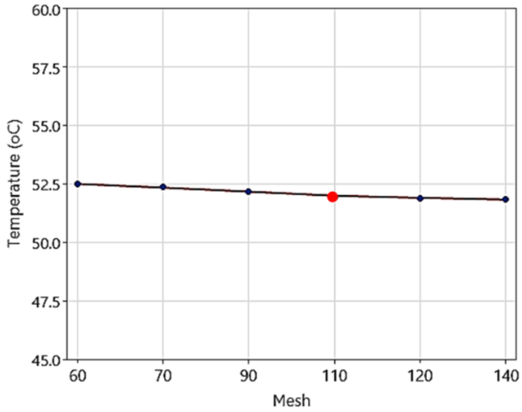


Fig. 7. Selection of the suitable mesh size.

The solar panel model was appointed to include heat from solar radiation with the average maximum equal to 785 W/m^2 (The highest average solar radiation intensity of Nakhon Ratchasima Province). The normal solar panel temperature was 44 °C and the ambient air temperature was 30 °C. The wind speed in the southeast was equal to 1.1 m/s where temperature and average wind speed was based on Nakhon Ratchasima Province. Altitude angle and azimuth angle were 71.71° and 128.88°, respectively. A SOLIDWORKS program was used for analyzing the temperature of the solar panel model.

For recording the temperature, the results of the solar panel obtained from the simulation can be divided into 3 factors as follows: (a) The installation direction was divided into 3 directions: South (S), Southeast (SE) and Southwest (SW), (b) Tilt angles for installing solar panels could be divided into six inclination angles: 10, 13, 15, 18, 20, and 25 degrees, and (c) Characteristics of heat sink installation were considered for the installation of fins in each form, two styles, which were installed along the length (Longitudinal Fins) and along the transverse (Transverse Fins) of the solar panel as in Fig. 8.

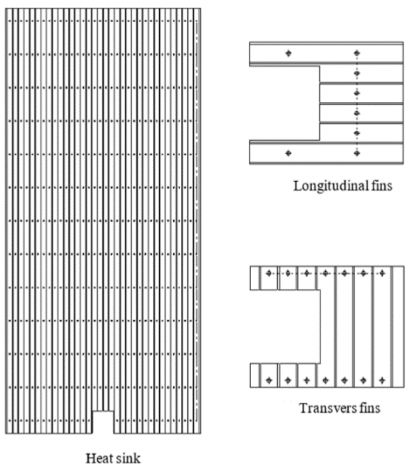


Fig. 8. Installation characteristics of heat sink fins.

4. Results and Discussion

Fig. 9 to 11 depict the simulation results of the present study using the SOLIDWORKS software. The temperature of the solar panel without heat sink fins is shown in Fig. 9. It was discovered that when a solar panel was oriented toward the Southwest (SW), its temperature tended to decrease continuously as the tilt angle of the panel increased. In contrast to South and Southeast (S and SE), solar panel temperatures tended to be rather steady as the tilt angle increased, reaching a maximum temperature of 53.07 °C as a result of the sun's position. As a result, when facing the panels to the South (S) and Southeast (SE), the temperature of the panels was higher than the Southwest (SW), which is consistent with the research of Ref. [11] and Ref. [16].

Based on Fig. 10 in terms of the solar panel temperature, it was discovered that when heat sinks were attached along the longitudinal fin (s), the Southwestern (SW) temperature of the solar panel decreased steadily. When the panel's inclination angle was increased, the minimum temperature gave 45.20 °C. In contrast to the South (S) and Southeast (SE) sides, the panel temperature tended to decrease and increase at an inclination angle (θ) of 25°. As the angle of inclination (θ) increases, airflow velocity decreased in front of the panel. Additionally, the air swirling characteristics under the panel are drastically reduced, consequently reducing cooling efficiency.

From Fig. 11, it can be observed that when heat sinks were installed along the transverse fins of the solar panel, the temperature of the solar cells exhibited a continuous decrease in both the Southwest (SW) and Southeast (SE) directions. With an increase in the tilt angle of the panel, the temperature dropped to as low as 45.19 °C. In contrast, in the Southern (S) direction, the panel's temperature showed a slight tendency to rise. However, it decreased at an inclination angle (θ) of 25° due to the orientation of the panels and the installation characteristics of the fins. This reduction in temperature was attributed to a decrease in airflow between the fins.

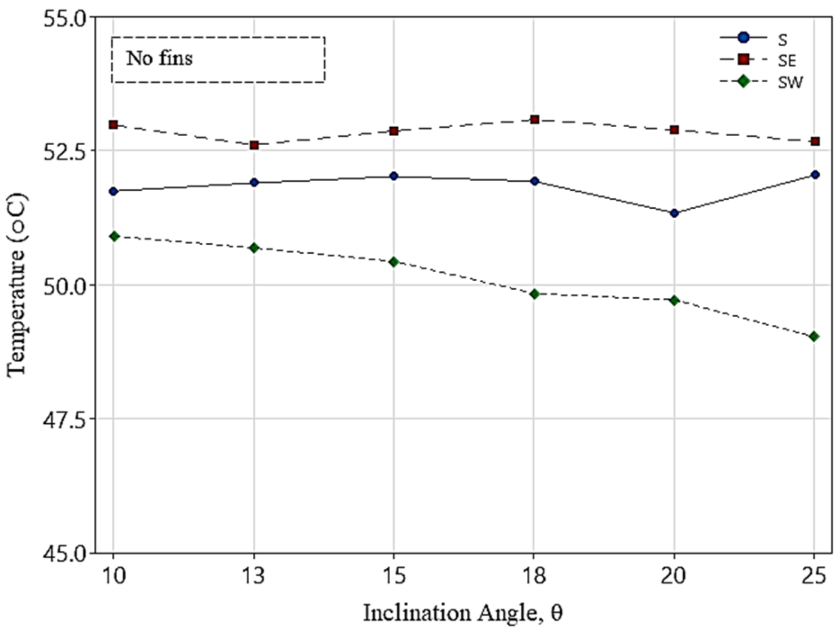


Fig. 9. Average temperature of solar panels in case of non-installation of plate pin fins heat sink.

Regarding to Fig. 9 to Fig. 11, several literature reviews indicated that the efficiency of solar cell electricity generation was directly proportional to temperature and solar radiation intensity. Therefore, lower temperatures will increase the efficiency of solar panels. This was consistent with the research presented in [17–22], and the sun's position must also be considered in order for the surface in front of the solar panel to receive the most solar radiation [23–30].

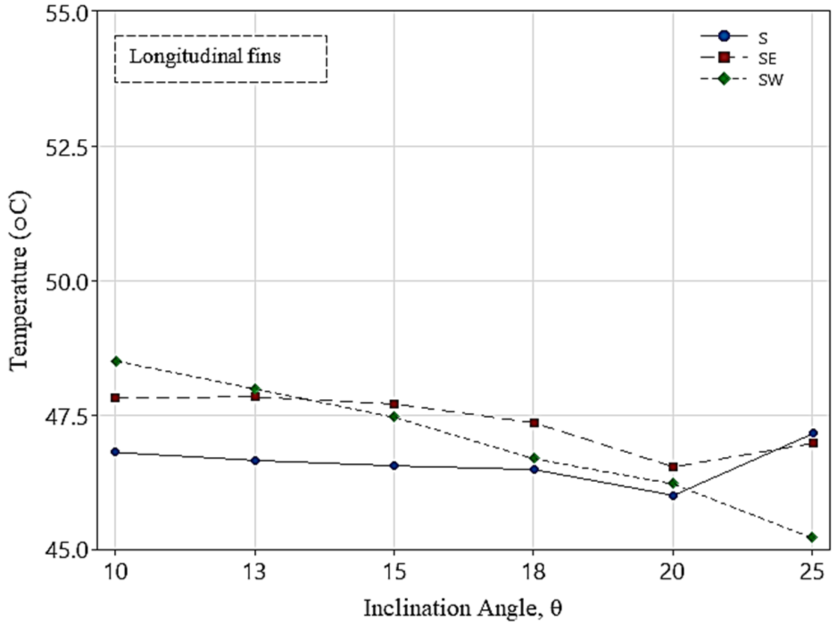


Fig. 10. Average temperature of solar panels in case of longitudinal fins.

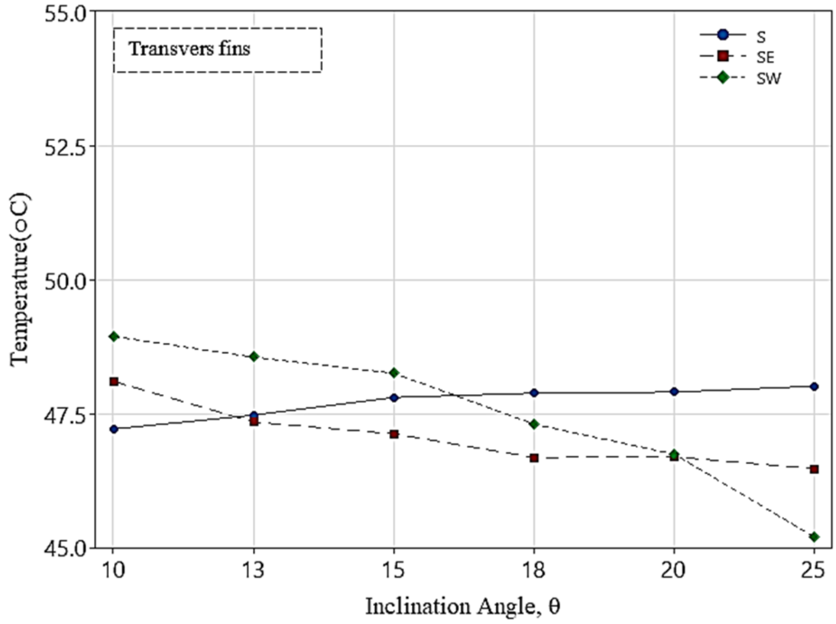


Fig. 11. Average temperature of solar panels in case of transvers fins.

5. Conclusion

The cooling simulation of plat-pin fin heat sink installed under solar panels was investigated by the SOLIDWORKS program to describe the electricity generation efficiency which was varied directly to the cooling of solar pane. Three factors including of panel installation direction (S, SE, and SW), inclination angle (θ), and the style of installation (Transvers and longitude fins), were executed. From the study, it was discovered that the most reduction of the panel temperature were Southeast (SE) with a tilt angle of 18°. A transvers arrangement of heat sink fins increased the cooling temperature in the solar panel by up to 6.39 °C.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

P. Nachaisit, P. Satuwong, P. Vengsungnle, and P. Khantikomol analyzed the simulation with the SOLIDWORKS program. P. Nachaisit, P. Satuwong and B. Krittacom wrote the paper. The results were discussed and gave the reasons or the related theories in the paper by all authors. Also, the final version had proven by all authors.

Acknowledgment

Many thanks to Faculty of Engineering and Technology, Rajamangala University of Technology Isan, Thailand, for supporting the research fund.

References

[1] Arifin, Z., Suyitno, S., Tjahjana, D. D. D. P., Juwana, W. E., Putra, M. R. A., & Prabowo, A. R. (2020). The effect of heat sink properties on solar cell cooling systems. *Applied. Science*, *10*, *7919*, 1–15.

[2] Liu, S., & Sakr, M. (2013). A comprehensive review on passive heat transfer enhancements in pipe exchangers. *Renewable and Sustainable Energy Reviews, 19*, 64–81.

[3] Popovici, C. G., Hudisteanu, S. V., Mateescu, T. D., & Chereches, N.-C. (2016). Efficiency improvement of photovoltaic panels by using air cooled heat sinks. *Energy Procedia*, *85*, 425–432.

[4] Egab, K., Okab, A., Dywan, H. S., & Oudah, S. K. (2020). Enhancing a solar panel cooling system using an air heat sink with different fin configurations. *Proceedings of International Conference on Engineering Sciences 2020, IOP Conference Series: Materials Science Engineering*, 671012133.

[5] Namwong, K., Phannarapong, P., & Yontsathitkul, T. (2019). Evaluating the heat transfer performance of solar cell panels by using an automatic cooling fan. *Proceedings of The 33rd Conference of the Mechanical Engineering Network of Thailand*, July 2nd–5th, 2019. (in Thai)

[6] Bayrak, F., Oztop, H. F., & Selimefendigil, F. (2019). Effects of different fin parameters on temperature and efficiency for cooling of photovoltaic panels under natural convection. *Solar Energy, 18,* 484–494.

[7] Arifin, Z., Suyitno, S., Tjahjana, D. D. D. P., Juwana, W. E., Putra, M. R. A., & Prabowo, A. R. (2020). The effect of heat sink properties on solar cell cooling systems. *Applied Science, 10*, 7919.

[8] Alzahrani, M., Baig, H., Shanks, K., & Mallick, T. (2020). Estimation of the performance limits of a concentrator solar cell coupled with a micro heat sink based on a finite element simulation. *Applied Thermal Engineering*, *176*, 1359–4311.

[9] Do, K. H., Kim, T. H., Han, Y. S., Choi B.-I., & Kim M.-B. (2012). General correlation of a natural convective heat sink with plate-fins for high concentrating photovoltaic module cooling. *Solar Energy, 86*, 2725–2734.

[10] Nilpueng, K., Mesgarpour, M., Asirvatham, L. G., Dalkç, A. S., Ahn, H. S., Mahian, O., & Wongwises, S. (2021). Effect of pin fin configuration on thermal performance of plate pin fin heat sinks. *Case Studies in Thermal Engineering, 27*, 101269.

[11] Department of Alternative Energy Development and Efficiency. (2023). *Power Generation from Solar Energy by Transmission and Dissemination of the Use of Solar Energy*. Ministry of Energy. Bangkok. 10330.

[12] Langkadi, T., & Arsanakam A. (2016). Performance assessment of rooftop solar cell module with and without air cooling. *Engineering Journal. Chiang Mai University, 23*(*3*), 130–141.

[13] Çengel, Y. A. (2002). *Heat transfer*. Nevada: Mcgraw-Hill.

[14] Chamkha, A. J., & Selimefendigil, F. (2018). Numerical analysis for thermal performance of a photovoltaic

thermal solar collector with SiO_2-water nanofluid. *Applied Science*, *8,* 2223.

[15] Kantiya, I. (2015). *Efficiency enhancement and temperature reduction of solar cell module by air cooling with augmented fin*. Master thesis of Engineering (Energy Engineering), Chiang Mai University.

[16] Phonnak, C., Waewsak, C., Cheamongkolkan, S., & Nuthongkaew, P. (2017). Evaluation of the efficiency of a 3 kW rooftop-connected PV power generation system using PVsyst program simulation. *Thaksin University Journal*, *20,* 261–268.

[17] Pichitkunchorn, W., & Chayakulkheeree, K. (2018). Design and economic analysis of solar rooftop electric system on the building of post engineer department. *Engineering Journal of Research and Development, 29*(*1*).

[18] Ronnaronglit, N., & Maneerat, N. (2019). A cleaning robot for solar panels. *Proceedings of International Conference on Engineering, Applied Sciences and Technology*.

[19] Saad, H. (2019). Simulating the performance of solar panels in Iraq. *Journal of Applied and Advanced Research, 4*(*1*), 6–10.

[20] Edward, A., Dewi, T., & Rusdianasari. (2019). The effectiveness of solar tracker use on solar panels to the output of the generated electricity power. *Proceedings of International Conference on Sustainable Agriculture, Food and Energy*, *Earth and Environmental Science*, *347*, 012130.

[21] Boonraksa, P. (2022). Evaluation of technical potential and analysis of investment cost-effectiveness of rooftop photovoltaic system case study: Faculty of engineering, Bangkok Thonburi University. *The Journal of Industrial Technology: Suan Sunandha Rajabhat University, 10,* 94–105.

[22] Narenrit, K., Sulaksana, M., and Sarawut, P. (2023). Performance and economics evaluation of bifacial solar panel installation on the roof of Kanchanaphisek King Rama 9th Sports Center Building, Maejo University. *RMUTI JOURNAL Science and Technology, 16(1)*, 51–66.

[23] Bakirci, K., (2012). General models for optimum tilt angles of solar panels: Turkey case study. *Renewable and Sustainable Energy Reviews, 16*, 6149–6159.

[24] Sassine, E. (2016). Optimal solar panels positioning for Beirut. *Proceedings of International Renewable Energy Congress (IREC)*.

[25] Xu, B., Wang, S., & Zhao, L. (2019). Solar panel recognition of non-cooperative spacecraft based on deep learning. *Proceedings of International Conference on Robotics and Automation Sciences (ICRAS)*.

[26] Hasan, A., & Dincer, I. (2020). A new performance assessment methodology of bifacial photovoltaic solar panels for offshore applications. *Energy Conversion and Management*, *220*, 11297.

[27] Ismail, M. A., Ramanathan, K. A/L, Idris, M. H., Ananda-Rao, K., Mazlan, M., & Fairuz, N. (2020). Improving the performance of solar panels by the used of dual axis solar tracking system with mirror reflection. *Proceedings of First International Conference on Emerging Electrical Energy, Electronics and Computing Technologies, 1432*, 012060*.*

[28] Imthiyas, A., Prakash, S., Vijay, N., Abraham, A. A., Kumar, B. G. (2020). Increasing the efficiency of solar panel by solar tracking system. *Proceedings of International Conference on Mechanical, Electronics and Computer Engineering*, *993*, 012124.

[29] Tillmann, P., Jager, K., & Becker, C. (2020). Minimising the levelised cost of electricity for bifacial solar panel arrays using Bayesian optimization. *Sustainable Energy Fuels*, *4*, 254–264.

[30] Said, M. N. A. M., Jumaat, S. A., & Jawa, C. R. A. (2020). Dual axis solar tracker with IoT monitoring system using Arduino. *International Journal of Power Electronics and Drive System (IJPEDS)*, *11*(1), 451–458.