Journal of Al-Azhar University Engineering Sector

Vol.17, No, 65, October 2022 ,1276 -1289

EXPERIMENTAL STUDY ON CONVECTIVE HEAT TRANSFER USING FINS FOR COOLING PV CELLS

B. M. Khaled[1], M. Taysier[1], Ahmed A. A. Attia[2], O. E. Abdellatif [2]

[1] Mechatronics department, High Institute of engineering Culture and science city, Egypt

[2] Mechanical department, Shubra faculty of engineering, Benha university, Egypt.

Corresponding: basma.mk93@gmail.com

Received: 24 July 2022   Accepted: 13 August 2022

ABSTRACT

Experimental research on the impact of fin cooling on silicon solar cell performance metrics was performed, and it was compared to two other cells, one cooled with water and the other without cooling. Photovoltaic (PV) cell waste heat is dispersed, using aluminum fins. The tests were conducted out at a variety of ambient temperatures and with varying levels of illumination. Three test panel were used, the first one used a freestanding photovoltaic system module as a model. The second has a water-cooling system as well, where the water passes through a serpentine heat exchanger, and the third has a fin cooling system, in which water passes through a rectangular helical heat exchanger and fins put on It is equipped with a water-cooling system. as well, although the water passes through a serpentine heat exchanger. Figures (1) and (2) (Serpentine and rectangular helical with fins). The suggested cooling technique significantly increases the produced power and the photovoltaic cell's electric efficiency (helical form) via fins, according to experimental data. At 6 LPM, power climbed to 76.85W and efficiency increased to 9.97%, a performance gain of 38.7% above the uncooled panel.

KEYWORDS: photovoltaic cell; passive and active cooling; fins; performance; efficiency

دراسة تجريبية لانتقال الحرارة بالحمل الحراري باستخدام زعانف لتبريد الخلايا الكهروضوئية

بسمه محسن خالد[١] , محمد تيسير[١] , أحمد عطية[٢] , أسامة عزت عبداللطيف[٢]

[١] قسم ميكاترونكس، بالمعهد العالي للهندسة مدينة الثقافة والعلوم، مصر

[٢] قسم ميكانيكا، كلية الهندسة بشبرا، جامعة بنها، مصر

البريد الالكتروني للباحث الرئيسي: basma.mk93@gmail.com

الملخص:

تم إجراء بحث تجريبي حول تأثير تبريد الزعانف على مقاييس أداء خلايا السيليكون الشمسية، وتمت مقارنته مع خليتين أخريين، إحداهما مبردة بالماء والأخرى بدون تبريد. يتم تشتيت الحرارة المهدرة للخلايا الكهروضوئية باستخدام زعانف الألمنيوم. أجريت

الاختبارات في درجات حرارة محيطة متنوعة ومستويات متفاوتة من الإضاءة. تم استخدام ثلاث لوحات اختبار، الأولى استخدمت وحدة نظام كهروضوئية قائمة بذاتها كنموذج. الثاني به نظام تبريد مائي أيضًا، حيث يمر الماء من خلال مبادل حراري سربنتين، والثالث به نظام تبريد زعنفة، حيث يمر الماء من خلال مبادل حراري حلزوني مستطيل وتوضع الزعانف عليه وهو مزود بنظام التبريد بالماء. كذلك، على الرغم من أن الماء يمر عبر مبادل حراري اعوج. الشكلان (١) و (٢) (حلزوني سربنتين ومستطيل بزعانف). تزيد تقنية التبريد المقترحة بشكل كبير من الطاقة المنتجة والكفاءة الكهربائية للخلايا الكهروضوئية (الشكل الحلزوني عبر الزعانف، وفقًا للبيانات التجريبية. عند ٦ لتر / دقيقة، ارتفعت الطاقة إلى ٧٦,٨٥ وات وزادت الكفاءة إلى ٩,٩٧٪، وهو ما يمثل ٣٨,٧٪ زيادة على أداء الخلايا الغير مبردة.

الكلمات المفتاحية: الخلية الضوئية، التبريد السلبي والنشط الزعانف، أداء، الكفاءة

1. INTRODUCTION

The usage of renewable sources of energy is becoming more popular as the number of humans grows, and ecological concerns grow. One of the most significant sorts of sources of renewables is solar energy, and it has piqued the interest of many academics throughout the world. Solar energy may be divided into two different types of energy: electrical and heat energy. photovoltaic board can be used into generate electrical energy. The incoming irradiance is immediately transformed into electrical energy by the PV cell. PV systems are the most efficient, converting a tiny amount of solar irradiation to electricity, sustainable, and environmentally beneficial solutions. The leftover sun irradiation is transformed into heat, raising cell temperatures and lowering PV module performance. so photovoltaic (PV) solar panels must be kept cool in order to maintain competitive efficiencies with other traditional and nonconventional electricity generation methods. In the previous literature, a variety of cooling techniques have been tried and published. A PV module's adequate cooling eliminates output loss and extends the PV module's lifetime [1]. A heat sink is a cooling method that includes removing heat from a solar cell using a metal with a high thermal conductivity. Popovici et al. Using various combinations of ribbed wall air heat sinks and passive cooling, on a clear summer day, the temperature decrease of PV panels was numerically examined. The panel's maximum temperature was found to be lower at 45-degree angle than it was at 135 degrees. According to the study, using a heat sink boosted the maximum power generated by a PV panel by 6.97 percent and 7.55 percent, respectively [2]. Odeh and Behnia conducted an experiment to see if cooling PV modules with water may improve their efficiency. The photovoltaic panel was cooled by installing a water trickling structure above the panel's topmost surface. At peak radiation conditions, the experimental findings revealed that a 15% increase in system output was achieved [3]. abdolzadeh and Ameri experimented with splashing water on the front of PV cells. In that investigation, a 225 W PV-powered water pump was deployed. The effectiveness of PV cells is increased by spraying water over them by 3.26 percent, subsystem efficiency by 1.40 percent, and overall efficiency by 1.35 percent, respectively [4]. Farhana et al. to achieve the electrical performance of the PV module, Researchers looked at the operational temperature variation for the PV module with and without an active cooling system. Two multi-crystal silicon solar modules were tested. One of the modules served as a standard, and the other had an aluminium heat sink and DC brushless fan installed at the bottom of the PV panel. The temperature of the PV module with the cooling system was 30% and 70% higher than the surrounding air, respectively. The PV module with the cooling system consequently had a somewhat greater open circuit voltage (Voc) than the PV module without the cooling system. [5]. Zhu et al. Researchers developed a cooling method based on liquid immersion for effective removing heat from closely packed solar cells in a densely concentrated system. At varied Concentration ratios, liquid temps, and flow velocities, the effectiveness of direct contact heat transfer was examined. The submerged module's electrical performance was also assessed. According to data from experiments, the temperature of the module may be lowered to below 45°C, and Convective heat transfer coefficients of greater than 3000 W/m2

°C are possible [6]. Irwan et al. The PV panel's performance was investigated experimentally utilizing the water-cooling method. Based on the findings of the tests, The operating temperature of a photovoltaic panel with the system for water cooling was decreased by temperature ranges from 5 to 23 degrees Celsius, and the power generation was growing by 9% to 22%. Cooling of the water is one method for increasing the PV panel's electrical efficiency [7]. Hussien et al. In an experiment, water-cooling technology was employed to boost the photovoltaic/thermal system's electricity efficiency. The cooling system consisted of a heat exchanger and seven water pipes linked to the back of the PV panel. the PV panel's electrical efficiency was enhanced more in the case of 0.3 L/s water flow rate than in the other water flow rate cases [8]. Bahaidarah. The performance of a Photovoltaic panel with a rear-mounted rectangular heat exchanger (RHX) was compared to that of a solar panel with no cooling. For rectangular heat exchanger cooling, the greatest cell efficiency was 13.07 percent, whereas the maximum cell efficiency for PV cells that have not been cooled was 7.82 percent [9]. Bahaidarah et al. Both in terms of experiment and numbers, the performance of a water-cooled hybrid power system was investigated. An exchanger of heat was built at the rear of photovoltaic cells to increase Dhahran's solar panel performance. the temperature of the water-cooled Photovoltaic panels was decreased by approximately 20%, with a 9% improvement in electricity efficiency Furthermore, the water-cooled PV system collected approximately four times the amount of energy as the PV-only system. [10]. Nehari et al. The optimum length of the fins was numerically analyzed to determine how phase change material may be used to increase the power of the PV panels when cooling is passive. In comparison to the case not having fins, the PV's temperature was dramatically lowered. Fins with lengths 25mm, 30mm, and 35mm also enable greater Cooling of PV cells. [11]. Chandrasekar et al. To maintain a steady temperature on the PV panel, aluminum fins and cotton wick were utilized as a passive cooling system. the cooling system comprised three fins made of aluminum (630-100-60 mm) Using a wick made of cotton linked to the crystalline silicon PV cells' backside. According to the experimental results, Using the cooling system, The PV panel's maximum temperature was lowered by 12 percent while There was a 14 percent increase in output power. [12]. Gotmare et al Experiments were conducted on the utilization of fins cooling under natural convection to enhance the performance of photovoltaic cells. In the test, two 37 W PV panels were employed, with 9 aluminum fins mounted to the back of one of them. When comparing the PV panel with fins cooling to the panel without fins, the cell temperature was lowered by 4.2 percent, while the output power on average was raised by 5.5 percent. [13]. El Mays et al. (2017). They measured the efficiency of solar panels with fins made of aluminum. When the standard PV and PV panels are compared, the efficiency of ordinary PV and PV panels have been increased by 15.9% and 17.7%, respectively. The surface temperature of the photovoltaic panel, on the other hand, has dropped by about 6 degrees Celsius [14]. Jobair (2017) To improve efficiency, the solar cell was tested fins that are triangular and rectangular at the rear of a photovoltaic panel. The analysis was carried out in this situation, taking into consideration variations in velocity of the fluid, length of fin, thickness of fin, and spacing of fin. The triangular fin configuration, when compared to the rectangular fin arrangement, has a stronger ability to reject heat and is more efficient [15]. Cruey et al. Cell temperature fell as the fins' thickness put towards the back of solar boards rose, whereas panel effectiveness improved at a same rate. thickness of the fin should be between 2 and 10 mm, according to research. The temperature of the cell increased when the distance between the fins was increased. A gap of 20 mm to 50 mm was discovered between the ideal fins. [16]. Mojumder et al. A fin design and forced air circulation were employed to examine the photovoltaic thermal system. The heat gain increased as the solar radiation rose with constant air velocity. It has four fins., at 700 W/m^2 solar radiation, the collector heat gain was determined to be 159.8 W. [17]. Elsafi and Gandhidasan. The performance of compound parabolic concentrated (CPC) and PV/T systems with and without fins was investigated in terms of thermal and electrical performance. According to the findings, the yearly thermal gain of PV/T with fin was 1% greater than PV/T without fin. In contrast, PV/T with fins had a 3% greater annual electrical gain than PV/T without fins. When compared to CPC-PV/T (without fin), the CPC-PV/T (fin) was projected to have a thermal and electrical gain of more than 3% and 8%, respectively [18].

2. EXPERIMENTAL SET-UP

The experimental setup is designed to measure and test three identical and separate PV modules in identical conditions. On a platform with a 30-degree inclination angle and horizontal support, each PV cell is oriented south (latitude of Cairo, Egypt).

As a reference, the first one used a freestanding photovoltaic system module as a model. The second has a water-cooling system as well, where the water passes through a serpentine heat exchanger, and the third has a fin cooling system, in which water passes through a rectangular helical heat exchanger and fins put on It is equipped with a water-cooling system. as well, although the water passes through a serpentine heat exchanger. Figures (1) and (2) (Serpentine and rectangular helical with fins).

The test setup was erected on the rooftop of Cairo's high institute of engineering in culture and science city in On October 6th City. to investigate the effect of cooling on performance of monocrystalline photovoltaic modules. This was performed in June of 2021, with data being taken every 15 min from 8:30 a.m. to 3:30 p.m.

During operation, to detect solar radiation, a digital solar power meter was mounted at the same height as the solar panels. In these tests, Temperature measurements are crucial, hence a calibrated K type Thermocouple was used to measure the temperature of the lower surfaces. As illustrated in fig. 3, each PV cell contains sixteen thermocouples connected the cell's backside, sandwiched Between of steel plate and the cell. The thermocouples' output signal was transferred to DACs, which stored the information on the laptop. PV current and voltage are both measured during the functioning of the system, to compute the overall power output of the PV modules. The experimental test setup's components have all been calibrated.

Fig. 1. A serpentine shape

Fig. 2. A rectangular helical shape of copper tube with fins.

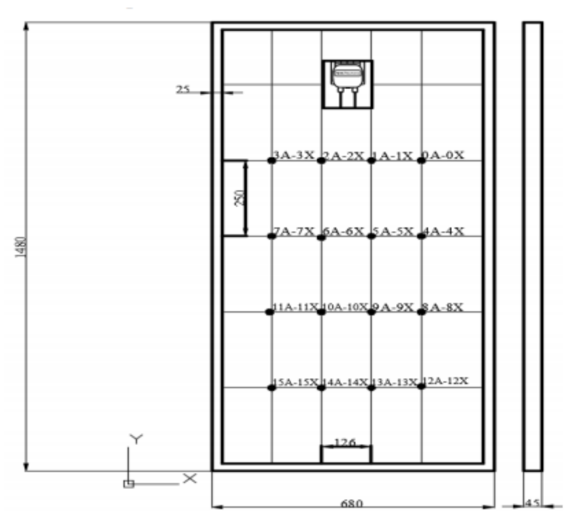


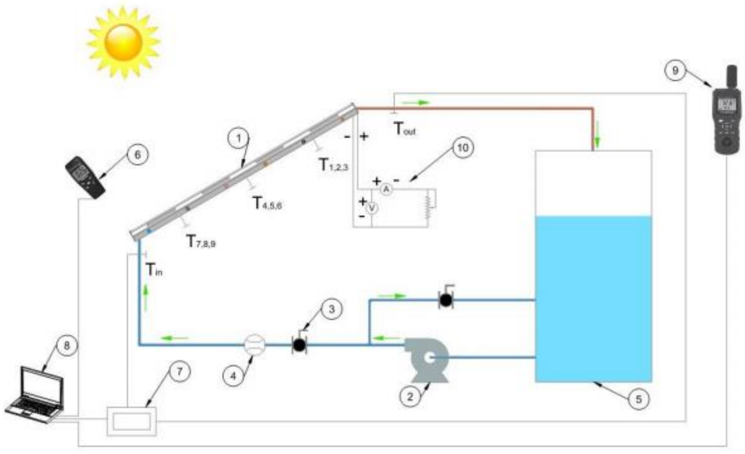
Fig. 3. The distribution of thermocouples on the PV cell's rear surface.

The experimental setup's installation settings are The experimental setup's installation settings are 29.952654 latitude , 30.921919 longitude , tilt angle 30 , orientation is south at 6 october city , Cairo, Egypt. Figure (4) depicts a general view of the entire experimental setup.

Fig. 4. The experimental system is seen in this photograph.

2.1 System description for photovoltaic cooling

This study establishes two similar systems, each having a separate heat exchanger on the solar power module's backside surface. Figure (5) depicts a schematic design of the setup for the experiment.



Component number	Component type
1	PV test module with cooling pipes
2	Ac pump
3	1/2" Throttling valve
4	Digital millimeters
5	170 liters tank
6	Digital solar power meter
7	16 Bit data acquisition
8	Lap top
9	Environmental meter

Fig.5. The PV cooling system in the experimental setup is depicted schematically.

2.2 Calculation techniques

After drawing the characteristic curve at each time and determining the optimal voltage and current levels, the properties and performance of the three solar panels are analyzed using the equations below:

- $P_{in} = I_t * A$ (1)
- P_{PV} = voltage * current (2)
- $P_{max} = V_{opt} * I_{opt}$ (3)
- $\eta_c = P_{max} / P_{in}$ (4)
- $P_{increase} = [(P_{cooled}-P_{ref})/P_{ref}]*100\%$ (5)
- Performance improvement (%) $= [(\eta_{PV/T}-\eta_{PV})/\eta_{PV}]*100\%$ (6)

3. RESULTS AND DISCUSSIONS

The current data were taken from June 2021 at three distinct volume flow rates 2 LPM, 4 LPM, and 6 LPM. Whenever the flow rate is 2 LPM and total solar radiation is 749.9655 W/m^2, the average power generated of the first PV/T system (serpentine form) is 61.438 W, which is 10.2 percent greater than the Photovoltaic cell module that isn't cooled, which is 55.6 W, and the average power output of the second PV/T system (rectangular helical form) by fins is 69.56 W, which is 24.8 percent more than the PV. the estimated value of photovoltaic system' energy generating efficiencies, the first PV/T AND second PV/T is determined to be 7.68%, 8.44%, and 9.57%, respectively. At a rate of 2 L/min, the power output of PV/T systems and photovoltaic modules varies as shown in figure (6), fig (7) shows PV/T systems and Modules for solar power have varying electrical efficiency, and fig (8) shows Variation in PV system electrical efficiency performance increase percentage.

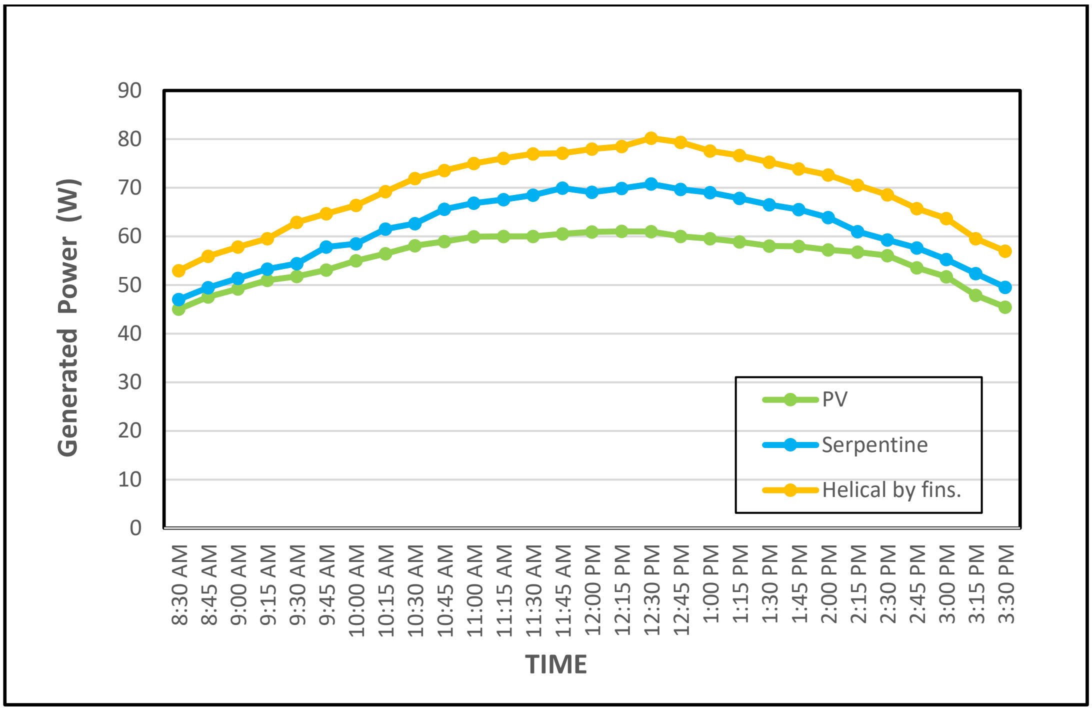


Fig. 6. At 2 LPM, generated power of PV module, serpentine form and helical by fins

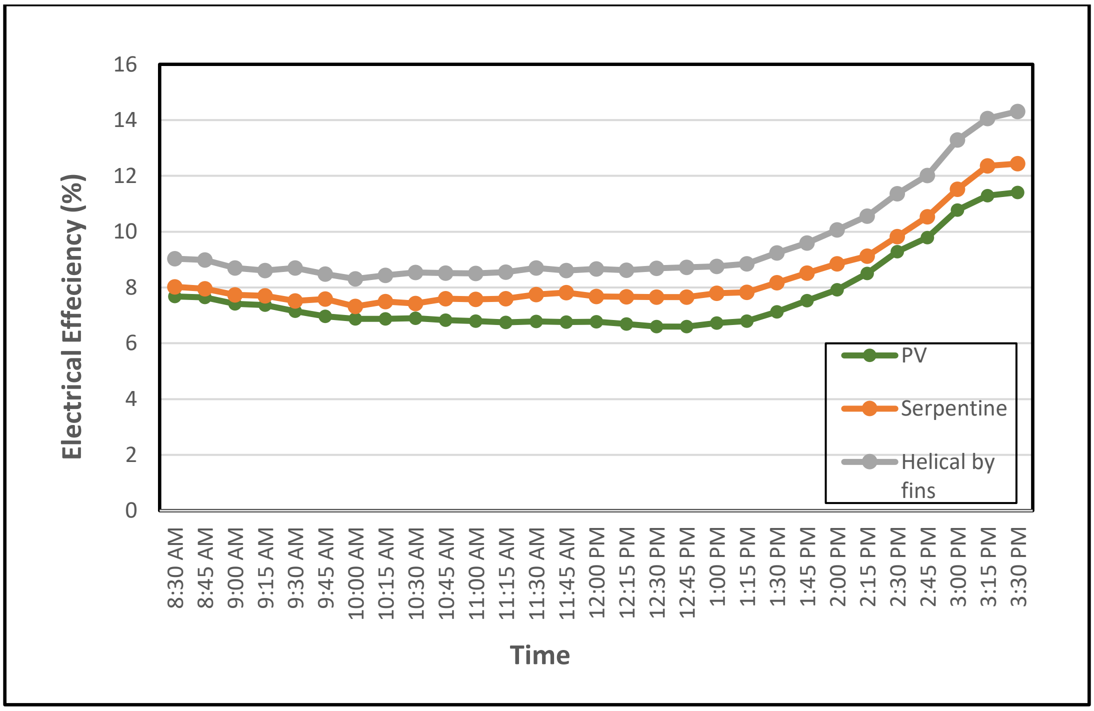


Fig. 7. During the daytime at 2 LPM, photovoltaic efficiencies of PV/T and PV modules were compared.

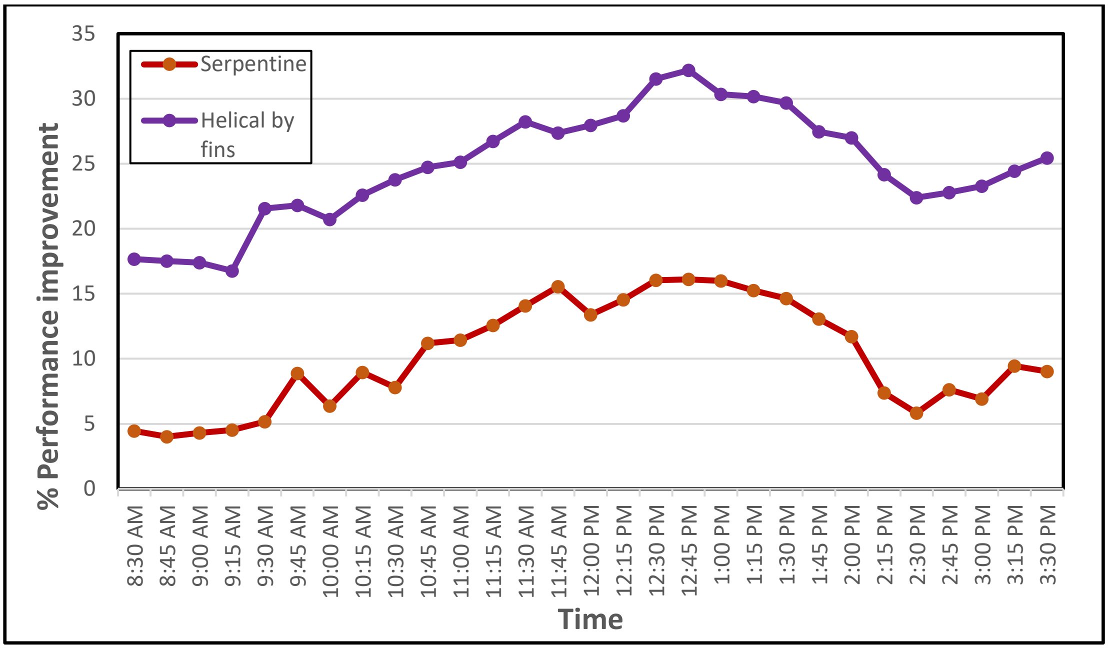


Fig. 8. Performance improvement in the electrical efficiency for serpentine shape and helical shape by fins at 2 LPM.

The average power output of first PV/T system (serpentine form) is 63.74 W when the flow rate is 4 LPM and overall solar radiation is 666.26 W/m^2, which is 16.16 percent more than the PV system's (no cooling) output of 54.75 W, the 2nd PV/T system's average output power (rectangular helical form) by fins is 70.86 W, which is 29.11 percent greater than Energy production efficiency for first PV/T, 2nd PV/T, and PV systems are 9.76 percent on average, 10.866 percent, and 8.44 percent, respectively. Figures (9) and (10) depict the variance in power output from PV/T systems and Photovoltaic panels at 4 LPM, as well as the variation in PV/T system and Photovoltaic modules' electrical efficiency the variance in performance boost percentage in the electrical efficiency of Solar systems at 4 LPM and the variance in performance boost percentage in the electrical photo voltaic systems at 4 LPM.

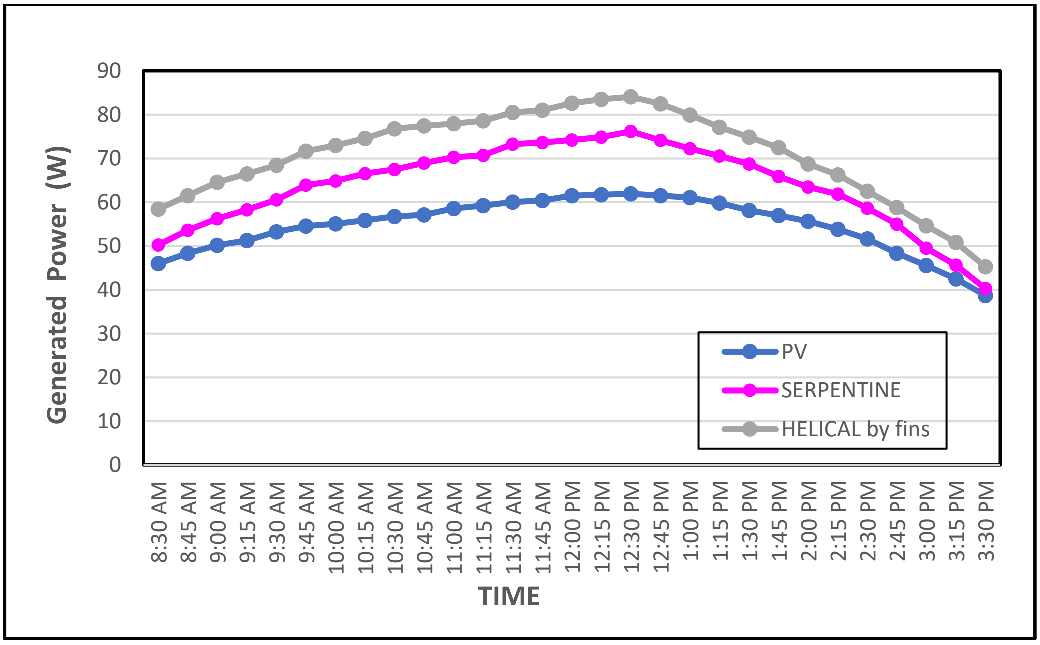


Fig. 9. PV module generated power, serpentine form and helical fins at 4 LPM.

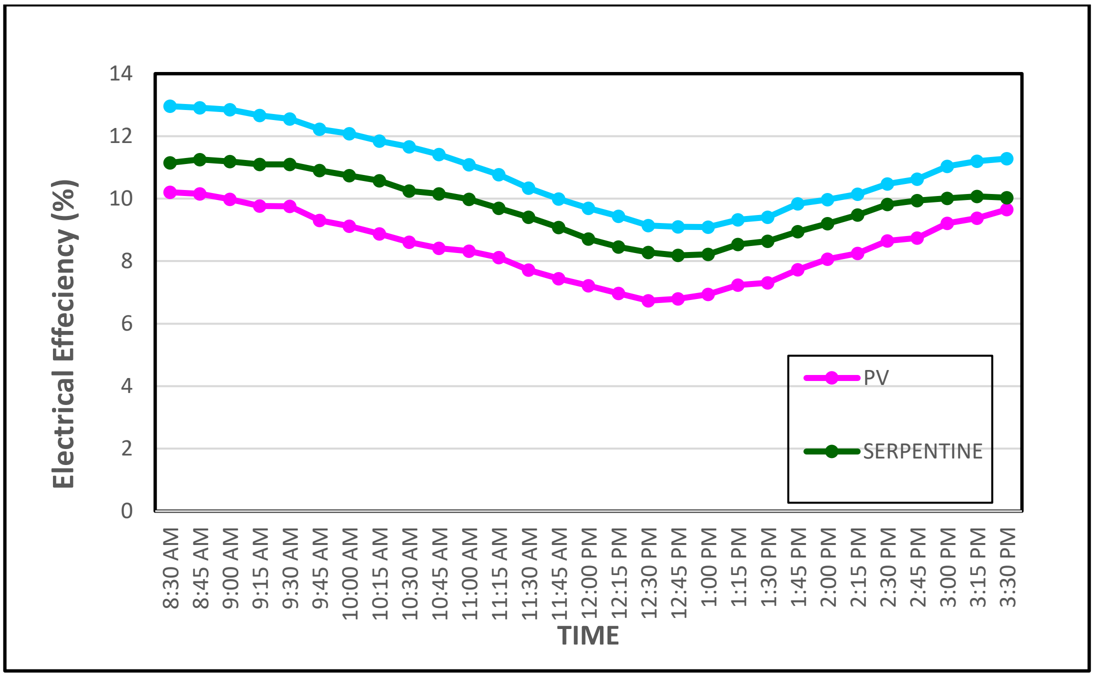


Fig. 10. During the day at 4 LPM, the photovoltaic efficiencies of the PV/T and PV modules were compared.

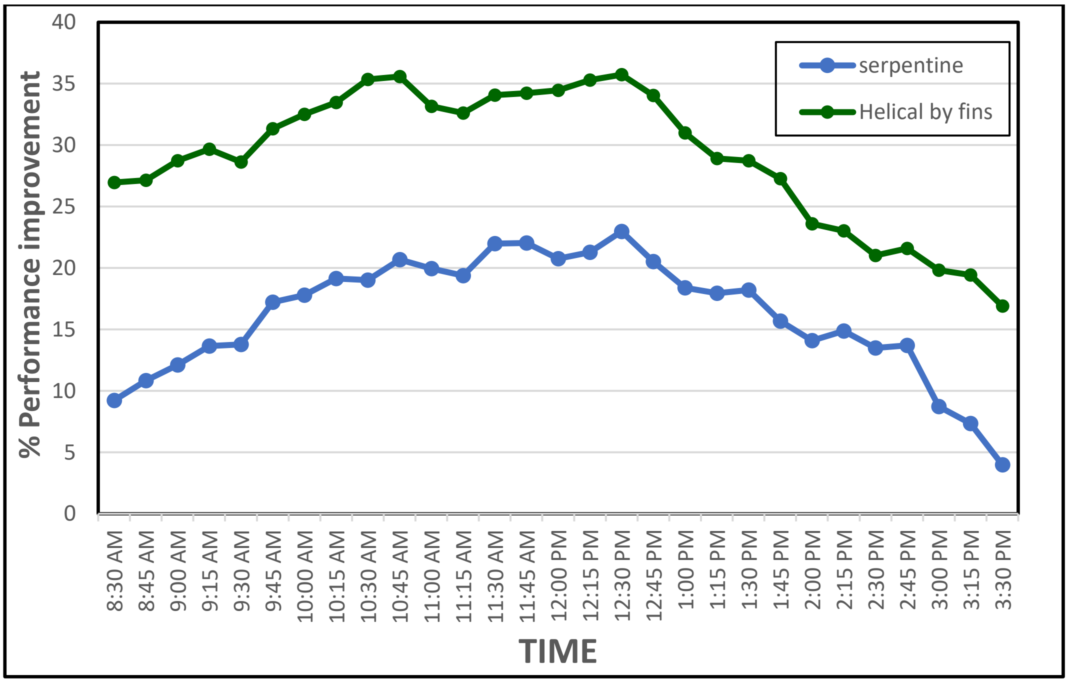


Fig. 11. Performance improvement in the electrical efficiency for serpentine shape and helical shape by fins at 4 LPM.

The averaged power output from first PV/T system (serpentine form) is 65.6 W when such flow rate is 6 LPM and overall solar radiation is 776.93 W/m^2, which is 18.5 percent greater than the solar power system's 55.27 W, the 2nd PV/T system (rectangular helical form) by fins produces a mean power output of 76.85 W, which is 38.7 percent higher than the PV system's 55 During the daytime, First PV/T, 2nd PV/T, and Photovoltaic systems had average power production efficiencies of 8.52 percent, 9.97 percent, and 7.2 percent, respectively. Fig (12) illustrates the fluctuation of power output from PV/T systems and Photovoltaics at 6 LPM, while Fig (13) shows the change of electrical efficiency of PV/T systems and Photovoltaic modules. and fig (14) shows the variation of the performance improvement percentage in the electrical efficiency of PV systems.

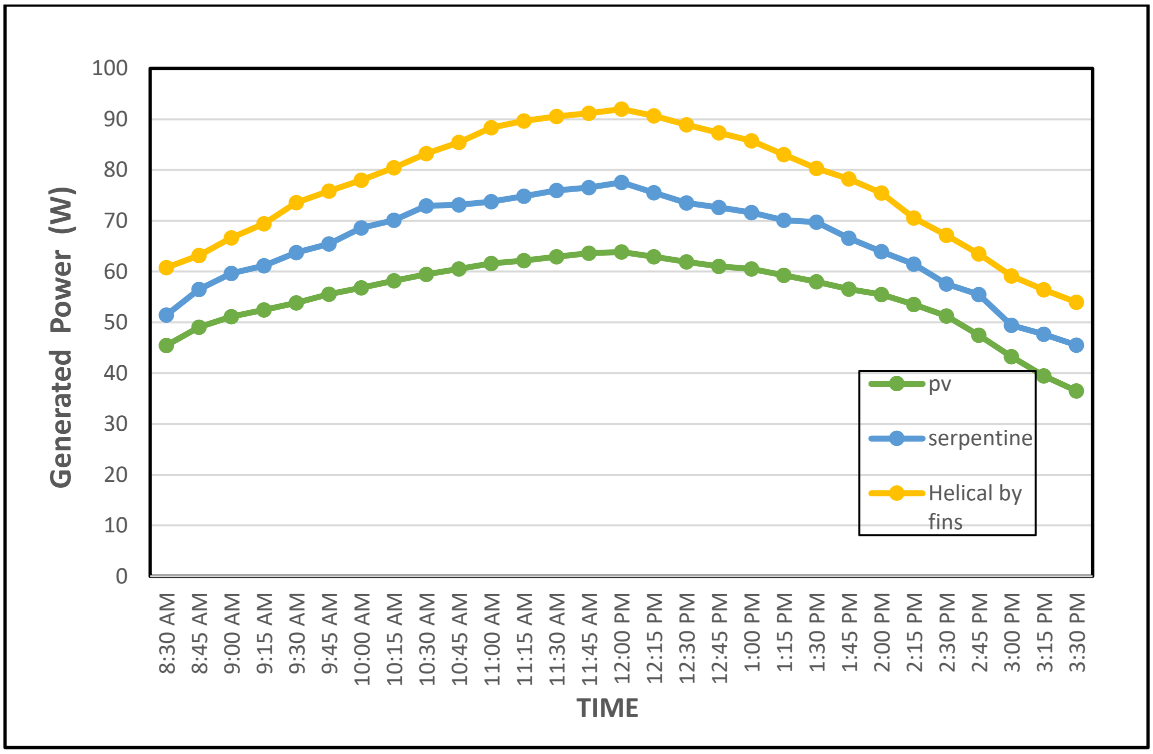


Fig. 12. PV module generated power, serpentine form and helical fins at 6 LPM.

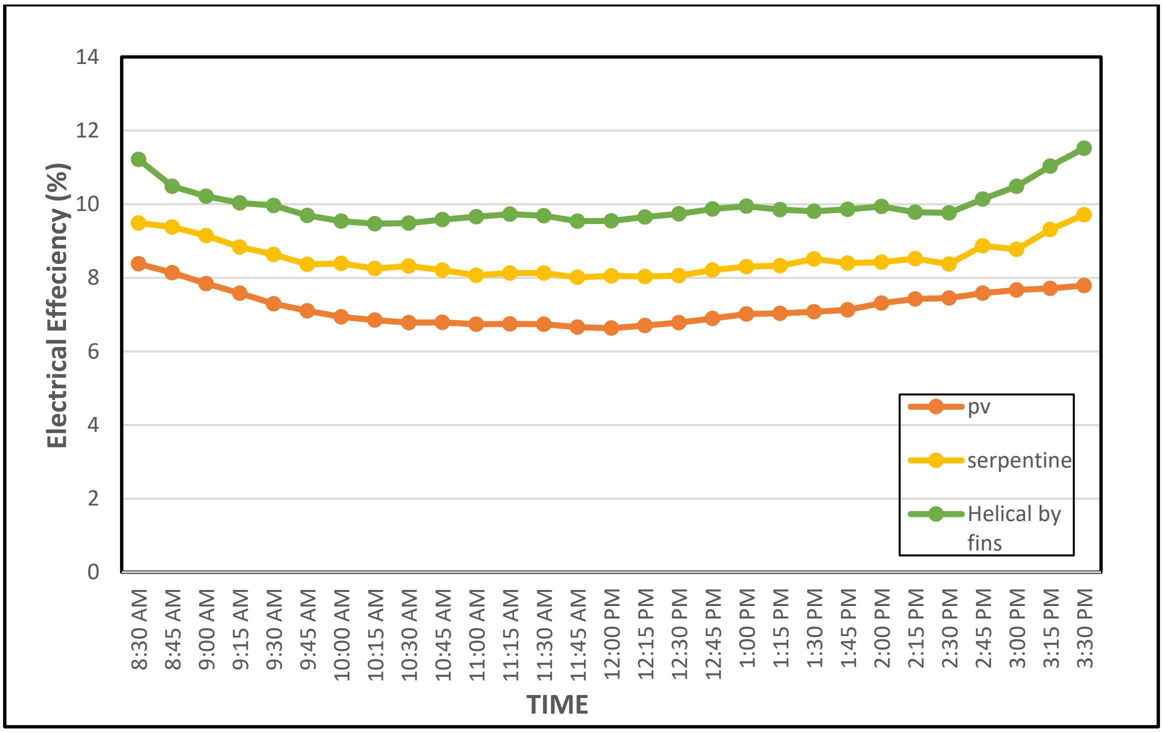


Fig. 13. During the day at 6 LPM, the photovoltaic efficiencies of the PV/T and PV modules were compared.

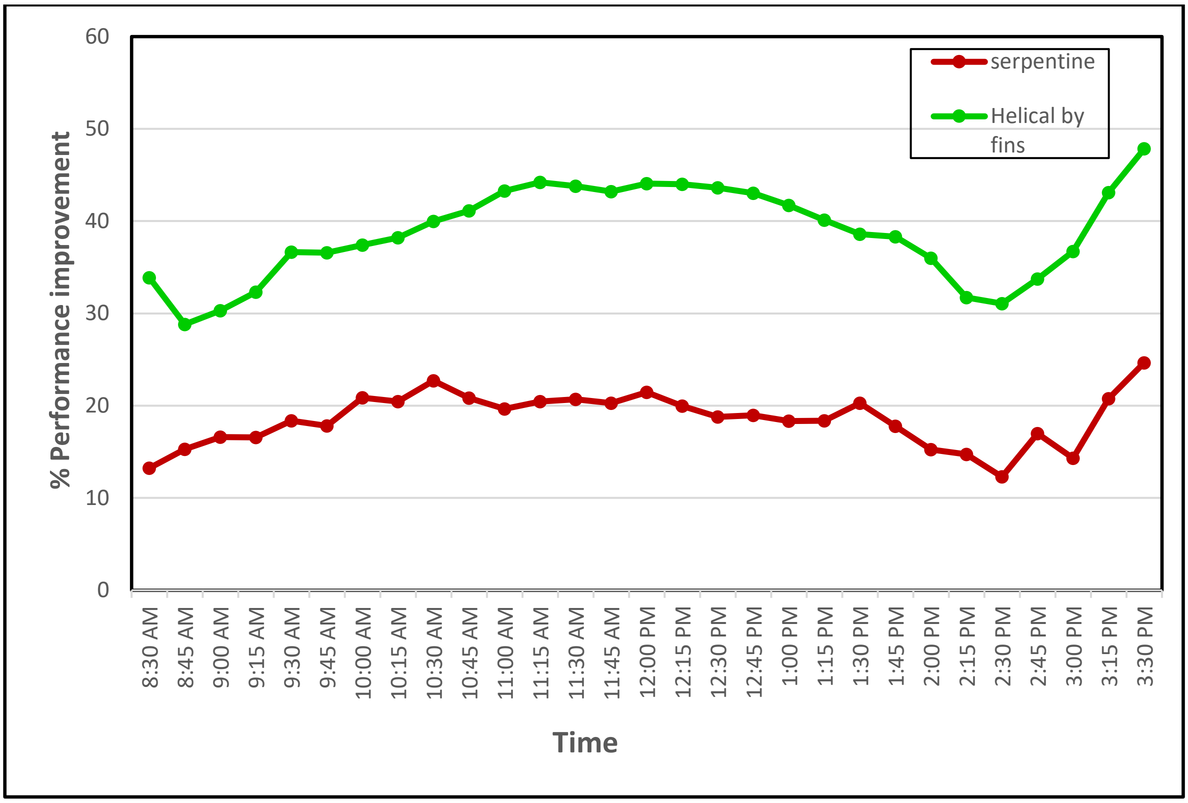


Fig. 14. Performance improvement in the electrical efficiency for serpentine shape and helical shape by fins at 6 LPM.

The rectangular helical flow PV/T system with fins has greater power than the serpentine flow PV/T system, as shown in Figures 6,9, and 12. Between 12:00 and 12:30 p.m., the largest values of electricity produced by solar panels modules and the two PV/T systems can be found, and the fluctuation of generation of electricity in these statistics follows the same trend as solar radiation. Furthermore, when the PV module's surface temperature rises, the module's output power drops drastically.

The electrical efficiency, as seen in Figures 7,10, and 13, represents the day-to-day variation in PV/T efficiency in terms of electricity systems and solar panels modules at varying flow rates. PV/thermal systems have a greater efficiency than solar panels modules as a result of cooling.

Figures 8, 11, and 14 illustrate the percentage performance increase in Solar systems' electrical efficiency throughout the daytime at varied flow rates.

based on these figures, During the peak working hours of the day, from 11 a.m. to 2 p.m., performance improved the most, due to cooling, the PV/T systems are at a low temperature, as contrast to the solar panel module, which has a high temperature due to strong solar radiation. At a water flow rate of 2 LPM, at 12:30 p.m., the best performing enhancement by fins in the first PV/T system (serpentine form) is 16 percent, with the first PV/T system's electric efficiency and PV module's electric efficiency being 7.66 percent and 6.6 percent, respectively, at 12:30 p.m., the greatest performance gain achieved by fins in the second PV/T system (rectangular helical form) is 31.5 percent, where the electric efficiency of the second PV/T system and photovoltaic module are 8.9 percent and 6.6 percent, respectively.

At a water flow rate of 4 LPM, at 12:30 p.m., the greatest performance gain achieved by fins in first PV/T system (serpentine shaped) is 22.98 percent, with the electric efficiency of its first PV/T system and PV system being 8.28 percent and 6.73 percent, respectively. At 12:30 p.m., the greatest performance improvement by fins in the 2nd PV/T system (rectangular helical form) is 35.7 percent, with the second PV/T system's electric efficiency and PV module's electric efficiency being 9.14 percent and 6.73 percent, respectively.

At a water flow rate of 6 LPM, at 12:00 p.m., the greatest performance gain achieved by fins in the first PV/T system (serpentine shaped) is 21.46 percent, with the electric efficiency PV/T system and PV module being 8.05 percent and 6.63 percent, respectively, At 12:00 pm, the greatest performance improvement achieved by fins in the 2nd PV/T system (rectangular helical form) is 44 percent, with the electric efficiency of the second PV/T system and PV system being 9.55 percent and 6.63 percent, respectively.

4. CONCLUSION

On October 6th, research was done in Cairo, Egypt, evaluated the impact of fin cooling on performance characteristics of silicon solar cells in order to increase their electrical performance under real-world.
The photovoltaic panel's temperature is greater without cooling, and solar boards can reach approximately 7.2 percent electrical efficiency. The temperature reduced dramatically when the Module of solar power was run in an active water-cooling condition. A first PV/T system (serpentine form). Solar cells' electrical efficiency improved by 8.5 percent, and when the Module of solar power (rectangular helical shape) was cooled by fins, the temperature plummeted even farther, and the electrical efficiency increased to 9.97 percent.
It has been discovered that raising the water flow rate increases electrical efficiency, with the largest improvement happening at a water flow rate of 6 LPM.

Whenever the flow rate is 2 LPM, the electrical efficiency improvements by fins 10.2 percent and 24.8 percent, respectively, in serpentine form and rectangular helical form.

When the rate of flow is 4 LPM, the electrical efficiency improvements by fins 16.2 percent and 29.1 percent, respectively, in serpentine form and rectangular helical form.
When the rate of flow is 6 LPM, the electrical efficiency improvements by fins 18.5 percent and 38.7%, respectively, in serpentine form and rectangular helical form.

REFERENCES

[1] Rahman, M. M., Hasanuzzaman, M., & Rahim, N. A. (2015). Effects of various parameters on PV-module power and efficiency. *Energy Conversion and Management*, *103,* 348-358

[2] Hudișteanu, S. V., Popovici, C. G., Mateescu, T. D., & Cherecheș, N. C. (2017). Efficiency analysis of BIPV systems for different locations in Romania. *Energy Procedia*, *112,* 404-411.

[3] Odeh, S., & Behnia, M. (2009). Improving photovoltaic module efficiency using water cooling. *Heat Transfer Engineering*, *30*(6), 499-505.

[4] Abdolzadeh, M., & Ameri, M. (2009). Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells. *Renewable energy*, *34*(1), 91-96.

[5] Farhana, Z., Irwan, Y. M., Azimmi, R. M. N., Razliana, A. R. N., & Gomesh, N. (2012, March). Experimental investigation of photovoltaic modules cooling system. In *2012 IEEE Symposium on Computers & Informatics (ISCI)* (pp. 165-169). IEEE.

[6] Zhu, L., Wang, Y., Fang, Z., Sun, Y., & Huang, Q. (2010). An effective heat dissipation method for densely packed solar cells under high concentrations. *Solar Energy Materials and Solar Cells*, *94*(2), 133-140.

[7] Hussien, H. A., Numan, A. H., & Abdulmunem, A. R. (2015, March). Improving of the photovoltaic/thermal system performance using water cooling technique. In *IOP Conference Series: Materials Science and Engineering* (Vol. 78, No. 1, p. 012020). IOP Publishing.

[8] Bahaidarah, H. M. (2015, June). Experimental performance investigation of uniform and non-uniform cooling techniques for photovoltaic systems. In *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC)* (pp. 1-4). IEEE.

[9] Bahaidarah, H., Subhan, A., Gandhidasan, P., & Rehman, S. (2013). Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. *Energy*, *59*, 445-453.

[10] Nehari, T., Benlakam, M., & Nehari, D. (2016). Effect of the fins length for the passive cooling of the photovoltaic panels. *Periodica Polytechnica Mechanical Engineering*, *60*(2), 89-95.

[11] Chandrasekar, M., & Senthilkumar, T. (2016). Passive thermal regulation of flat PV modules by coupling the mechanisms of evaporative and fin cooling. *Heat and Mass Transfer*, *52*(7), 1381-1391.

[12] Sedaghat, A., Karami, M. R., & Eslami, M. (2020). Improving performance of a photovoltaic panel by pin fins: a theoretical analysis. *Iranian Journal of Science and Technology, Transactions of Mechanical Engineering*, *44*(4), 997-1004.

[13] El Mays, A., Ammar, R., Hawa, M., Abou Akroush, M., Hachem, F., Khaled, M., & Ramadan, M. (2017). Improving photovoltaic panel using finned plate of aluminum. *Energy Procedia*, *119*, 812-817.

[14] Jobair, H. K. (2017). Improving of Photovoltaic Cell Performance by Cooling Using Two Different Types of Fins. *Int. J. Comput. Appl.*, *157*(5), 6-15.

[15] Cruey, B., King, J., & Tingleff, B. (2006). Cooling of Photovoltaic Cells. *Change*, *36*.

[16] Mojumder, J. C., Ong, H. C., Chong, W. T., Leong, K. Y., & Izadyar, N. (2017). An empirical analysis on photovoltaic thermal system with fin design by forced air circulation. *Journal of Mechanical Science and Technology*, *31*(5), 2549-2557.

[17] Salami, P., Ajabshirchi, Y., Abdollahpoor, S., & Behfar, H. (2016). A comparison among different parameters for the design of a photovoltaic/thermal system using computational fluid dynamics. *Engineering, Technology & Applied Science Research*, *6*(5), 1119-1123.

[18] Elsafi, A. M., & Gandhidasan, P. (2015). Comparative study of double-pass flat and compound parabolic concentrated photovoltaic–thermal systems with and without fins. *Energy conversion and management*, *98*, 59-68.

[19] Sethi, V. P., Sumathy, K., Yuvarajan, S., & Pal, D. S. (2012). Mathematical model for computing maximum power output of a PV solar module and experimental validation. *Journal of fundamentals of renewable energy and applications*, *2*(2), 1-5.

[20] Dubey, S., Sarvaiya, J. N., & Seshadri, B. (2013). Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world–a review. *Energy Procedia*, *33*, 311-321.

[21] Idoko, L., Anaya-Lara, O., & McDonald, A. (2018). Enhancing PV modules efficiency and power output using multi-concept cooling technique. *Energy Reports*, *4*, 357-369.

[22] Kaldellis, J. K., Kapsali, M., & Kavadias, K. A. (2014). Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece. *Renewable Energy*, *66*, 612-624.