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Effect of thermal collector configuration on the photovoltaic heat transfer performance with 3D CFD modeling

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Abstract: The shape and material of the collector configuration in photovoltaic thermal collectors (PVTs) are adjusted to alter the effectiveness of thermal conductivity. Good thermal conductivity between units plays an important role in heat absorption, and photovoltaic modules can increase electrical and thermal efficiency. In this study, a 3D computational fluid dynamics simulation of collector design in PVTs was carried out using Solidworks. The modeling was carried out on variations in the shape of boxes, pipe boxes, and triangle boxes with aluminum, copper, and mild steel materials on the thermal collector. The triangular box shape made of copper in the collector had a minimum temperature of 301.01 K when the heat generated was $1,000 \text{ W/m}^2$ and the flow volume was $0.0005 \text{ m}^3/\text{s}$. The difference in the heat generation rate and volume flow rate in each collector variation affects the collector temperature.

Keywords: photovoltaic, thermal collector, heat absorption, computational fluid dynamics

1 Introduction

The operation and maintenance of photovoltaic (PV) power generation modules have become increasingly important, as the number of such modules has increased to ensure maximum power generation throughout their life cycle [1]. The utilization of solar energy by combining PV and thermal collectors (T) can produce electricity and

heat simultaneously [2]. The use of combined devices, namely photovoltaic thermal collectors (PVTs), makes it possible to convert solar energy more effectively, with the aim of increasing PV efficiency [3]. PV technology has an efficiency value of solar energy utilization of 15–20%, which decreases as the PV temperature increases [4]. The use of cooling allows the temperature of the PV panels to be maintained at 38°C and the efficiency to be increased by 12.7% [5]. The thermal collector in a PVT acts as an active PV coolant and produces hot fluid that can be utilized [6].

In recent years, the number of publications regarding the use of PVTs has increased. PVTs use water as an active coolant that is flowed to the thermal collector for heat transfer in PV systems [7]. Both types of energy are environmentally friendly, which means that PVTs can be integrated into industrial and residential water pipelines [8]. It is known that the thermal efficiency of PVTs is in the range of 28–45%, and the electrical efficiency is in the range of 10.6–12.2% [9]. Parameters that can affect PVT performance include design parameters, operating parameters, and climate parameters. It can be concluded that the collector parameter design factors that directly affect the heat transfer of the PV module itself have a significant impact on the PV module. This effect not only drains fluid for the PVP module itself but also affects its performance [10,11]. Many designs have been considered in efforts to optimize PVT performance [12].

In efforts to improve the bonding quality and heat transfer of PVT collectors, several alternative designs of thermal collectors, including a flat box structure made of aluminum alloy, have been proposed, as shown in Figure 1. This study considers the aluminum alloy flat box design as the first alternative to the reference case with regard to loss coefficient; it displays a lower heat by up to 15.7%. Moreover, in PVTs, copper is the most widely used solid material, and the sheet-and-tube arrangement is the most common absorbent exchange design found in the literature and used in commercially available PVT collectors [13]. The shape

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Figure 1: Schematic of the box configuration of the photovoltaic thermal collector [14].

and material of the collector configuration are adjusted to alter the effectiveness of thermal conductivity [14,15].

Three-dimensional numerical analyses of PVT modules with a flow channel design, carried out under various environmental and operating conditions to estimate thermal and electrical performance, have been reported. The results of numerical analyses show that for aluminum and copper, an increase in the inlet speed causes a decrease in the battery temperature by 37%, while electrical efficiency and output power increase by 2 and 26%, respectively. When the inlet velocity increases from 0.0009 to 0.05 m/s, the overall efficiency of the PVT collector increases by 14.6% for aluminum and 16.3% for copper. When the inlet temperature is increased from 20 to 40°C, the efficiency of aluminum is reduced by 13%, and the efficiency of copper is reduced by 12.7% [16]. Gupta et al. determined the thermal performance of PVT panels at solar radiation levels of 500–1,000 W/m² [17]. They performed fluid flow analysis and studied the temperature distribution on solar panels using experiments and computational fluid dynamics (CFD). Fayaz et al. reported that in the overall performance of the PVT system with lower sunlight intensity and lower ambient temperature, lower water flow rates are more suitable [4]. In 2019, Misha et al. reported that the maximum average thermal efficiency of PVT systems was 59.6%. The highest average values for the electrical efficiency of PV panels and PVT water systems were found to be 10.86 and 11.71%, respectively, at a mass flow rate of 6 L/m. From various studies that have been carried out, it has been shown that heat transfer in thermal collectors plays an important role in increasing PVT efficiency [13].

The main objective of the research reported in this article is to propose a thermal collector that has the

lowest heat transfer temperature. Thermal collectors are investigated based on shape and material configuration. This research was conducted using 3D CFD modeling using Solidworks 2017 software [8,13,14,18]. In addition, this article discusses the effect of radiation intensity and flow rate on changes in the shape and configuration of materials regarding heat transfer in PVTs. The magnitude of the effect was investigated using the single-factor ANOVA method [19–21].

2 Methodology

This article examines the effect of the number of collectors on the operating temperature of PV panels during a sunny summer day, with the highest temperature of 307 K and static pressure of 101,325 Pa [22]. Coatings with the characteristics of PV panels are considered by direct radiation to the base of the collector. This research was conducted using a laptop with Intel (R) Core (TM) i3-6006U CPU @ 2.00 GHz 1.99 GHz specifications and the Solidworks 2017 application. The application was used to design and simulate CFD. The flow chart of the research carried out is shown in Figure 2.

There are several literature studies to date that are related to the relationship between thermal efficiency and electrical efficiency, which are improved by changing the design of the thermal collector based on the effect of heat transfer. Research on thermal collectors is typically carried out via simulation or experimental methods. The research in this article was carried out using research benchmarks reported by Herrando et al. in 2018 regarding the shape and material of the collector used [14], Misha et al. in 2019 regarding the fluid flow rate in the collector in simulation and experimental conditions [13], Abdullah et al. in a simulation in 2019 regarding heat transfer in thermal collectors based on the mass flow rate and radiation intensity [16], and Zabihi Sheshpoli et al. in 2021 regarding the shape and angle of the collector. The purpose of benchmarks is to adjust the design of the thermal collector that is being studied [23].

Solidworks 2017 software allows researchers to understand the thermal behavior of materials or designs without having to conduct experiments directly. This is very useful for experimenting and checking for errors in designs, as it means that the number of errors in experiments can be reduced. In this study, modeling was carried out as shown in Figure 3; the thermal collector was designed with a thickness of 1.95 mm, a hole surface area of 248.69 mm², and a thin plate was added, with a thickness of 0.4 m. The

Figure 2: Research flowchart.

number of collectors used was 10 grooves [23]. The variation of the box shape was used to determine the effect of the configuration shape on the thermal temperature of the

Table 1: Material specifications

Specification	Aluminum	Copper	Steel (Mild)
Density (kg/m^3)	2688.9	8,960	7,870
Conductivity type	Isotropic	Isotropic	Isotropic
Electrical conductivity	Conductor	Conductor	Conductor
Melting temperature (K)	933.4	1356.2	1673.15
Specific heat ($\text{J}/(\text{kg K})$)	951	322.6	472
Thermal conductivity ($\text{W}/(\text{m K})$)	240	393	51.9

PV collector; the various shapes used for the box were a box, pipe, and triangle. This research also examined the effect of the configuration material on the thermal temperature of the PV collector. The specifications of the materials used are shown in Table 1. The use of these materials is possibly the reason for the occurrence of temperature differences based on thermal conductivity [24]. However, this research focuses on materials that can be adapted to the thermal configuration of the designed collector.

The initial simulation that aimed to determine the effect of the configuration shape was carried out using a material with the type of aluminum. Meanwhile, a box-shaped thermal collector was used to determine the effect of the configuration material. Simulations were carried out with an XYZ direction range of 0.5 m and a speed of 0 m/s, as shown in Figure 4 and Table 2. On the top surface of the thin plate base, the collector had a heat generation rate of $1,000 \text{ W/m}^2$. The water flow was fed into one of the collector inputs with a flow rate of $0.0005 \text{ m}^3/\text{s}$ at a temperature of 300 K. At the final output, a static

Figure 3: Thermal configuration of collector: (a) square box, (b) pipe box, and (c) triangular box.

Figure 4: The scope of simulation.

pressure of 101,325 Pa with a temperature of 300 K was shown, as shown in Tables 3 and 4. All conditions other than those that varied were treated the same. To determine the effect of the number of collectors, research was also carried out using variations in the heat generation rate and flow rate. The heat generation rates used were in the range of 700–1,300 W/m², and the flow rates used were in the range of 0.0005–0.005 m³/s [4,13].

A grid was made to increase the accuracy of the CFD simulation results. The mesh generation was standardized, and the same operation was performed for each variant. The grid created at the collector was automatically executed in the Solidworks CFD simulation to produce the same grid, as shown in Figure 5. The created grid automatically simulated heat transfer to the collector, so that the number of collectors corresponded to the PV collector temperature. Meshing was performed to increase the accuracy of the contact point simulation, and a finer finite element was selected [11].

A homogeneity test was carried out using ANOVA studies to determine the effect of the heat generation

Table 3: Boundary conditions: inlet volume flow 1

Conditions	Information
Type	Inlet volume flow
Faces	Face<1>@LID1
Coordinate system	Face coordinate system
Reference axis	X
Flow parameters	Flow vectors direction: normal to face Volume flow rate: 0.0005 m ³ /s Fully developed flow: No Inlet profile: 0
Thermodynamic parameters	Temperature: 300.00 K
Turbulence parameters	Boundary layer parameters
Boundary layer type	Turbulent

rate and flow rate on the shape and configuration of the thermal collector material regarding temperature changes. The hypothesis H₀ used is that the effect of the heat generation rate or flow rate does not result in changes in the collector temperature. The hypothesis H_a used is that the effect of the heat generation rate or flow rate causes changes in the collector temperature. The test criteria were based on the hypothesis that if the *P* value < 0.05 with an α of 5%, hypothesis H₀ can be accepted. Meanwhile, if the *P* value > 0.05 with an α of 5%, hypothesis H_a can be accepted [19–21].

3 Results

3.1 Heat transfer contours in PVTs

The simulation results are presented as temperature contours of the entire collector domain in the form of various forms of thermal collector configurations. Figure 6 illustrates the temperature contour of the changing collector

Table 2: Ambient conditions

Conditions	Information
Thermodynamic parameters	Static pressure: 101325.00 Pa Temperature: 307.00 K
Velocity parameters	Velocity vector Velocity in the X direction: 0 m/s Velocity in the Y direction: 0 m/s Velocity in the Z direction: 0 m/s
Solid parameters	Initial solid temperature: 307.00 K

Table 4: Boundary conditions: static pressure 1

Conditions	Information
Type	Static pressure
Faces	Face<2>@LID2
Coordinate system	Face coordinate system
Reference axis	X
Thermodynamic parameters	Static pressure: 101325.00 Pa Temperature: 300.00 K
Turbulence parameters	Boundary layer parameters
Boundary layer type	Turbulent

Figure 5: Results of mesh: (a) square box, (b) pipe box, and (c) triangle box.

Figure 6: The contour of simulation results for solid temperature: (a) square box, (b) pipe box, and (c) triangle box.

Table 5: Temperature simulation results from the thermal configuration of the collector

Collector configuration variations	Goal name	Value (K)	Averaged value (K)	Minimum value (K)	Maximum value (K)
Square box	Max temperature (solid)	303.33	303.33	303.33	303.34
Pipe box	Max temperature (solid)	304.41	304.42	304.41	304.44
Triangle box	Max temperature (solid)	301.43	301.43	301.43	301.44

configuration with top and bottom views. A red line indicates a high temperature, while a dark blue line indicates a low temperature. The difference in color profile in one configuration indicates that the shape of the thermal configuration of the collector affects the heat transfer absorbed. As can be seen, the triangular box has a blue color temperature contour and a uniform contour profile.

The triangular-box-shaped collector with aluminum material produced the lowest average temperature value of 301.43 K at a heat generation rate of $1,000 \text{ W/m}^2$, and a volume flow rate of $0.0005 \text{ m}^3/\text{s}$, as shown in Table 5. The low average temperature is also indicated by the number of blue and evenly distributed contours in the simulation results. The low and uniform temperature that was produced in the use of a triangular collector box is influenced by the distance between the sides and the surface

area that coincides with the thin plate [14]. This indicates that more heat can be extracted from the PV panels so as to increase the thermal and electrical efficiency of the PVT.

Figure 7 presents the shape of the water flow in the collector; it is observed that the different edge angles produce different temperature contours, as shown in Figure 6. The use of a triangular box thermal collector produces a denser and more directed flow, reaching more collector contours. A triangular box with a larger surface area on a thin plate has a wider range of water flow so that it can make cooling a more even process. When compared to pipes, the surface area has an important role in heat transfer [25]. This is indicated by the lower average temperature of the collector using a triangular box compared to using a pipe box with a temperature difference of 2.98 K.

Figure 7: Water flow at the corner of the collector edge: (a) square box, (b) pipe box, and (c) triangular box.

Table 6: Simulation results of alloy variations in the shape and thermal collector material

Triangular box collector configuration material variations	Goal name	Value (K)	Averaged value (K)	Minimum value (K)	Maximum value (K)
Square box – aluminum	Max temperature (Solid)	303.33	303.33	303.33	303.34
Square box – copper	Max temperature (Solid)	302.59	302.6	302.59	302.6
Square box – steel (mild)	Max temperature (Solid)	306.95	306.95	306.91	306.97
Pipe box – aluminum	Max temperature (solid)	304.41	304.42	304.41	304.44
Pipe box – copper	Max temperature (solid)	303.09	303.1	303.09	303.11
Pipe box – steel (mild)	Max temperature (solid)	309.42	309.43	309.42	309.45
Triangle box – aluminum	Max Temperature (solid)	301.43	301.43	301.43	301.44
Triangle box – copper	Max temperature (solid)	301.01	301.01	301.01	301.02
Triangle box – steel (mild)	Max temperature (solid)	303.67	303.69	303.67	303.7

Figure 8: Collector temperature vs. heat generation rate.

3.2 Temperature change simulation results

In addition, to study the effect of materials on the temperature of the PVT, the three previous collector designs were modeled using three materials, namely aluminum, copper, and mild steel. Different materials affect the PVT

due to their different physical and mechanical properties. As shown in Table 6, the use of a triangular box shape with a copper material on the thermal collector provides the lowest average temperature of 301.01 K. Triangular alloys that have a higher surface area and less spacing between connectors and materials with high thermal conductivity can transfer heat better [26].

Table 7: Data summary of the results of the heat generation rate on variations in the shape with temperature

Groups Heat generation rate (W/m ²)	Count	Sum	Average	Variance
700	9	2727.1	303.01	3.9839
800	9	2730.1	303.34	4.9615
900	9	2733	303.67	6.011
1,000	9	2735.9	303.99	7.1448
1,100	9	2738.8	304.31	8.2811
1,200	9	2741.7	304.64	9.6724
1,300	9	2744.7	304.96	11.083

Table 8: ANOVA heat generation rate on variations in the shape with temperature

Source of variation	SS	df	MS	F	P value	F crit
Between groups	26,462	6	4.4103	0.6037	0.7262	2.2656
Within groups	409.1	56	7.3053			
Total	435.56	62				

Figure 9: Collector temperature vs. volume flow rate.

3.3 Effect of radiation intensity on variations in the shape and material of the collector configuration

Figure 8 shows the maximum temperature for each variation of the shape and material of the collector under the heat generation rate. The increased heat generation rate contributes to an increase in the collector temperature. The use of a copper, triangular-box-shaped collector always displayed a lower temperature than the use of other collector variations at any given heat generation rate. The temperature in the copper, triangle collector box can be maintained for any heat generation rate in increments of less than 0.7 K.

Table 7 shows the simulation results with regard to the collector temperature at each heat generation rate.

Table 9 : Summary data on the heat generation rate results of variations in the shape with temperature

Groups volume flow rate (m ³ /s)	Count	Sum	Average	Variance
0.0005	9	2733.1	303.68	7.2115
0.0006	9	2732.7	303.63	7.218
0.0007	9	2732.3	303.59	7.2356
0.0008	9	2732.1	303.56	7.1346
0.0009	9	2732	303.55	7.12
0.001	9	2731.9	303.54	7.1296
0.002	9	2732.1	303.57	7.0841
0.003	9	2733.4	303.71	7.0814
0.004	9	2735.4	303.93	7.0513
0.005	9	2738.1	304.24	7.007

It is known that the use of a heat generation rate of 1,300 W/m² produces the highest average temperature of 304.96 K. After the summary data were obtained, the ANOVA test was carried out using predetermined variables. The results of the ANOVA test show that the resulting *P* value is 0.72, as shown in Table 8. Therefore, the *H*_a hypothesis can be accepted, as the heat generation rate causes a change in the temperature for each variation in the shape and the material of the collector. It can be seen that the use of collector shapes and materials increases with each heat generation rate.

3.4 Effect of flow rate on variations in the shape and material of collector configuration

Figure 9 shows the effect of each change in flow velocity on the shape and material of the collector on the temperature of the collector. According to the graph shown, for each change in the collector used, the flow rate does

Table 10 : ANOVA heat generation rate on variations in the shape with temperature

Source of variation	SS	df	MS	F	P value	F crit
Between groups	3,991	9	0.4434	0.0622	0.9999	1.999
Within groups	570.18	80	7.1273			
Total	574.17	89				

not significantly affect the temperature; the flow rate of $0.001 \text{ m}^3/\text{s}$ causes the lowest temperature value for each change in the collector. The trend line shows that the flow velocity between 0.0005 and $0.005 \text{ m}^3/\text{s}$ increases in temperature. This indicates that the working fluid needs more time to absorb heat from the PV panel than it does at higher flow rates.

Table 9 shows the simulation results regarding the collector temperature obtained for each flow volume. It is known that by using a volume flow rate of $0.001 \text{ m}^3/\text{s}$, the lowest average temperature is achieved, at 303.54 K . After the summary data were obtained, an ANOVA test was performed with predetermined variables. The ANOVA test results show that the P value obtained is 0.99 , as shown in Table 10. Therefore, the hypothesis H_a can be accepted, as it was proven that the volume flow rate causes a change in the temperature of each collector.

4 Conclusion

In this study, we succeeded in studying the effect of the number of collectors and different edge angles on PVTs regarding changes in the temperature of collectors. The study was conducted using CFD simulation using the Solidworks 2017 application. The shape and material of the collector configuration affect temperature changes in the collector. The copper, triangular-box-shaped collector causes a minimum temperature of 301.01 K when the heat generated is 1000 W/m^2 and the flow volume is $0.0005 \text{ m}^3/\text{s}$. The larger the surface area of the collector, the smaller the distance between the collectors, which can make the temperature distribution of the collector more uniform. Materials with high thermal conductivity have better heat absorption performance. The difference in the heat generation rate and volume flow rate in each collector variation affects the collector temperature. The effect of heat generation is justified based on the P value in the homogeneity test using ANOVA, which is 0.72 above the standard value. As for the volume flow rate, it causes temperature changes in each collector variation because the P value is 0.99 above the standard value.

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References

- [1] Kilikevičienė K, Matijošius J, Kilikevičius A, Jurevičius M, Makarskas V, Caban J, et al. Research of the energy losses of photovoltaic (PV) modules after hail simulation using a newly-created testbed. *Energies*. 2019;12(23):4537. doi: 10.3390/en12234537.
- [2] Widyolar B, Jiang L, Ferry J, Winston R, Kirk A, Osowski M, et al. Theoretical and experimental performance of a two-stage (50X) hybrid spectrum splitting solar collector tested to 600°C . *Appl Energy*. 2019;239(January):514–25. doi: 10.1016/j.apenergy.2019.01.172.
- [3] Aste N, Leonforte F, Del Pero C. Design, modeling and performance monitoring of a photovoltaic-thermal (PVT) water collector. *Sol Energy*. 2015;112:85–99. doi: 10.1016/j.solener.2014.11.025.
- [4] Fayaz H, Rahim NA, Hasanuzzaman M, Nasrin R, Rivai A. Numerical and experimental investigation of the effect of operating conditions on performance of PVT and PVT-PCM. *Renew Energy*. 2019;143:827–41. doi: 10.1016/j.renene.2019.05.041.
- [5] Al-Shamani AN, Alghoul MA, Elbreki AM, Ammar AA, Abed AM, Sopian K. Mathematical and experimental evaluation of thermal and electrical efficiency of PV/T collector using different water based nano-fluids. *Energy*. 2018;145:770–92. doi: 10.1016/j.energy.2017.11.156.
- [6] Fu Z, Li Y, Liang X, Lou S, Qiu Z, Cheng Z, et al. Experimental investigation on the enhanced performance of a solar PVT system using micro-encapsulated PCMs. *Energy*. 2021;228:120509. doi: 10.1016/j.energy.2021.120509.
- [7] Al-Shamani AN, Sopian K, Mat S, Abed AM. Performance enhancement of photovoltaic grid-connected system using PVT panels with nanofluid. *Sol Energy*. 2017;150:38–48. doi: 10.1016/j.solener.2017.04.005.
- [8] Lari MO, Sahin AZ. Design, performance and economic analysis of a nanofluid-based photovoltaic/thermal system for residential applications. *Energy Convers Manag*. June 2017;149:467–84. doi: 10.1016/j.enconman.2017.07.045.
- [9] Khanjari Y, Pourfayaz F, Kasaeian AB. Numerical investigation on using of nanofluid in a water-cooled photovoltaic thermal system. *Energy Convers Manag*. 2016;122:263–78. doi: 10.1016/j.enconman.2016.05.083.
- [10] Abdullah AL, Misha S, Tamaldin N, Rosli MAM, Sachit FA. A review: Parameters affecting the PVT collector performance on the thermal, electrical, and overall efficiency of PVT system. *J Adv Res Fluid Mech Therm Sci*. 2019;60(2):191–232.
- [11] Makarskas V, Jurevičius M, Zakis J, Kilikevičius A, Borodinas S, Matijošius J, et al. Investigation of the influence of hail mechanical impact parameters on photovoltaic modules. *Eng Fail Anal*. 2021;124(December 2020):105309. doi: 10.1016/j.engfailanal.2021.105309.

- [12] Ibrahim A, Sopian K, Othman M. Simulation of different configuration of hybrid photovoltaic thermal solar collector (PVTs) designs. *Sel Pap Commun & Inf Technol.* 1976;2008:1–3.
- [13] Misha S, Abdullah AL, Tamaldin N, Rosli M, Sachit FA. Simulation CFD and experimental investigation of PVT water system under natural Malaysian weather conditions. *Energy Rep.* 2020;6:28–44. doi: 10.1016/j.egy.2019.11.162.
- [14] Herrando M, Ramos A, Zabalza I, Markides CN. A comprehensive assessment of alternative absorber-exchanger designs for hybrid PVT-water collectors. *Appl Energy.* 2019;235(November 2018):1583–602. doi: 10.1016/j.apenergy.2018.11.024.
- [15] Miller A, Carchman R, Long R, Denslow SA. Energy consumption of spray dryer machine for producing red natural powder dye and its stability. *AIP Conf Proc.* 2019;2097(April):1–7. doi: 10.1063/1.5098251.
- [16] Abdullah AL, Misha S, Tamaldin N, Rosli MAM, Sachit FA. Hybrid photovoltaic thermal PVT solar systems simulation via Simulink/Matlab. *CFD Lett.* 2019;11(4):64–78.
- [17] Gupta P, Sahu A, Prasad S, Sinha VK, Bakhla AK. Experimental study of combined transparent solar panel and large Fresnel lens concentrator based hybrid PV/thermal sunlight harvesting system. *Energy Sustain Dev.* 2021;63:33–40. doi: 10.1016/j.esd.2021.05.008.
- [18] Arifin Z, Prasetyo SD, Prabowo AR, Cho JH. Preliminary design for assembling and manufacturing sports equipment: A study case on Aerobic Walker. *Int J Mech Eng Robot Res.* 2021;10(3):107–15. doi: 10.18178/ijmerr.10.3.107-115.
- [19] Anders K. Special issue: Responsible writing in science resolution of students *t*-tests, ANOVA and analysis of variance components from intermediary data Lessons in biostatistics. *Biochem Med.* 2017;27(2):253–61.
- [20] Al-Alwani MAM, Ludin NA, Mohamad AB, Kadhum A, Baabbad MM, Sopian K. Optimization of dye extraction from *Cordyline fruticosa* via response surface methodology to produce a natural sensitizer for dye-sensitized solar cells. *Results Phys.* 2016;6(August):520–9. doi: 10.1016/j.rinp.2016.08.013.
- [21] Khoshvaght H, Delnavaz M, Leili M. Optimization of acetaminophen removal from high load synthetic pharmaceutical wastewater by experimental and ANOVA analysis. *J Water Process Eng.* 2021;42(April):102107. doi: 10.1016/j.jwpe.2021.102107.
- [22] Dannemand M, Perers B, Furbo S. Performance of a demonstration solar PVT assisted heat pump system with cold buffer storage and domestic hot water storage tanks. *Energy Buildings.* 2019;189:46–57. doi: 10.1016/j.enbuild.2018.12.042.
- [23] Zabihi Sheshpoli A, Jahanian O, Nikzadfar K, Aghajani Delavar M. Numerical and experimental investigation on the performance of hybrid PV/thermal systems in the north of Iran. *Sol Energy.* 2021;215(December 2020):108–20. doi: 10.1016/j.solener.2020.12.036.
- [24] Abbas N, Awan MB, Amer M, Ammar SM, Sajjad U, Ali HM, et al. Applications of nanofluids in photovoltaic thermal systems: A review of recent advances. *Phys A: Stat Mech Its Appl.* 2019;536:122513. doi: 10.1016/j.physa.2019.122513.
- [25] Yu Y, Yang H, Peng J, Long E. Performance comparisons of two flat-plate photovoltaic thermal collectors with different channel configurations. *Energy.* 2019;175:300–8. doi: 10.1016/j.energy.2019.03.054.
- [26] Popovici CG, Hudișteanu SV, Mateescu TD, Cherecheș NC. Efficiency improvement of photovoltaic panels by using air cooled heat sinks. *Energy Proc.* 2016;85:425–32. doi: 10.1016/j.egypro.2015.12.223.