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DESIGN AND DEVELOPMENT OF NOVEL COOLING ARRANGEMENT FOR PV CELL

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ABSTRACT

The demand for sustainable energy has highlighted the importance of photovoltaic (PV) Cells in power generation. However, polycrystalline PV cell efficiency is hindered by temperature sensitivity. This leads to design a novel cooling system using cooling medium. The cooling system with and without baffles are preferred for experimentation. The ethylene glycol is in demand due to its availability and miscible nature in water at all concentration. The concentration of ethylene glycol is varied from 5%, 10%, 15% and 20% to study the evaporation rate of water. The requirement of water for cooling PV is also studied with and without adding ethylene glycol. With the help of ethylene glycol, the efficiency enhancement without compromising rate of evaporation is achieved. The outcome of the present paper indicates that efficiency of polycrystalline PV Cell is increased by 1.725% using novel cooling system with 20% of ethylene glycol concentration.

I. INTRODUCTION

Sunlight is open source of energy. The poly-crystalline photovoltaic cells (PV) are used to collect and convert this energy into electrical energy [1]. The solar energy is just the procurement of the sun's energy. It is noticed that 70 % to 80% solar radiation is wasted for heating of the environment and 5% to 20 % of the sun radiation is only converted to electricity for consumption and rest of is reflected to the environment [2]. The polycrystalline PV Cell have wide applications including Off-grid energy inception, businesses, manufacturing, as well as in domestic usage. The photovoltaic was first seen in plant life and its usage as food source converting the radiance into consumable energy. Later the various materials were studied which absorbs the radiance and converts the energy into electric energy. The mostly preferred materials used in solar panel are Gallium Nitride, Silicon, Cadmium telluride, Copper Indium Gallium Selenide (CIGS), and amorphous silicon. However, silicon is widely used for its remarkable properties in terms of efficiency up to 25% with perovskite-silicon heterojunction [3] and also due to availability [4]. The PV panel comes with different crystal structures of mono-crystalline, poly-crystalline, thin-film or perovskite and its selection depends on the working condition of surroundings [5]. The mono-crystalline silicon grants remarkable properties of imperishability and efficiency. The polycrystalline cells are made by melting silicon crystals together. In Thin-Film cell, the substrate is deposited with thin layer of Silicon. The perovskite consists of hybrid organic and inorganic material which mainly include methylammonium lead halides[6],[7].

The PV construction includes a variety of layers. When the sunlight strikes the surface of first layer the energy transfer take place in form of electrons this movement of electrons from one layer to another is cause of electric generation [8]. The highly sensitive nature of monocrystalline photovoltaic cell towards the temperature's variation as compared with amorphous and polycrystalline photovoltaic cells make it limited use in power generation. Also the fill factor and efficiency decrease with increase in temperature [9]. The limitation of PV cell is that when rise in temperature diminishing the output reduces the efficiency led to improvement of system. One of the major causes among all of them is heating and dust saturation on the panel.

The temperature change occurred on the surface of the PV cell is due to continuous exposure to sunlight and generation of electricity. This overheating phenomenon of PV cell leads to decrease overall efficiency of power generation. The overheating of the panel led to slackening of power output and life of panel. Consistent with review 1°C upsurge in surface temperature cause lessening of 0.5% efficiency [10]. The overheating PV cell is ended by the application of chilling systems and which leads to rise in output, reliability and longevity of the PV cell. This cooling effect could be achieved with various methods some of the techniques are active, passive cooling.

The natural factors affecting the heating of the panel are wind velocity, moisture, sunlight, atmospheric temperature and dust contained nearby. To apply restriction on the heating of panel the variety of cooling techniques are implemented [11]. The active cooling techniques includes coolant (usually fluid), this method of cooling also involve extrinsic mechanisms and systems such as fans. The active cooling techniques increases overall efficiency by consuming some energy in drawing fluid The passive cooling techniques are further sorted into three category's passive cooling with air, water, and conductive cooling. Passive would need supplementary equipment such as heat pipes and sinks to drive natural convection. Therefore, it is found be more implementable as compared to active cooling [12].

Many researcher focuses on use of nanofluids as coolant, however, nanofluids suffer from aggregation issues [13]. The combination of paraffin jelly and perlite segment improves the desired output [14]. In air-based cooling the effective amount of flow rate will assure desired temperature changes, this system assures an average reduction of temperature by 9°C. The temperature difference varies with flow rate of air, the enhancement of efficiency varies between 7 to 12.6 %. Overheating problems of solar panel are reduced by using air-based cooling system [15]. The liquid based cooling system include continuous flow of fluid through the system. A thin film of coolant is passed through system cause increase in efficiency and overall efficiency of solar panel observed to be 13.9% [16]. According to Li Zhu, Robert F Boehm, et.al. experimentation temperature of system liquid immersion cooling maintained temperature up-to 45°C, where 30°C inlet water temperature [17]. The sprinklers sprays on the water P.V. modules increasing the efficiency up to 13.5% in extreme weather environments [18]. Spraying on the solar panel cell reduces heating and improves performance by 1.35 – 3.26%. Application of heat pipe results in increment of efficiency 3.11% as compared to conventional system [19]. Materials used for heat pipes include copper, aluminum, etc. The fins in the systems usually fit at some angle which ranges from 0 to 40 degrees, this ensures more energy output. Electric efficiency achieved by system is 29% and temperature reduction occur is 28.95% [20]. In Evaporative cooling various fluids can be implemented but the most feasible one is silica gel. The reduction in temperature by silica gel came across 16%, and upscaled the panel efficiency by 8.76% [21]. Other methods involve Materials such as copper or aluminum must be stick behind the PV panel so that the heat gets distributed in all thermoelectric generators . The overall solar conversion efficiency was 40% [22]. There exists variety of gap in the field of cooling technology for photovoltaic cell.

The impact of cooling system on photovoltaic cell is studied reports suggested that there is need for better and efficient cooling system that can improve the performance. The first parameter raises concern towards durability and longevity of the cooling system. The next important criteria are use of water as coolant can increase efficiency at the cost of high evaporation rate. There are several studies available on cooling methods with natural or forced convection in the back of the panel. The mixture of water with ethylene glycol forms a coolant.

The use of ethylene glycol with water as coolant is favourable coolant medium due to it availability and thermal exergy efficiency. Several researchers varied different concentration of ethylene glycol in water from 50% to 60% to check the impact on PV cell efficiency [23-26]. The limited literature is available on consumption of water and its evaporation rate during cooling of PV cell. The present study focuses on water with ethylene glycol as coolant. The objective is to minimize evaporation rate by finding optimize concentration of ethylene glycol with water. The proposed setup integrates the usage of baffles on panel back and use of evaporative techniques to cool the reused coolant.

II. MATERIALS AND METHODS

The setup of cooling system is shown in Figure 1. The polycrystalline PV cell panel of capacity 75W was taken for study. It consists of polycrystalline PV panel with cooling system attached back of the panel. The cooling system arrangement consists of 45 baffles as shown in Figure 2. The cooling system is fitted at the panel back. The earthen vessel is customary made to ensure cooling of coolant coming after cooling the PV cell. The present solar panel efficiency = 14.17%. The three cases are considered for testing. The case 1 shown in Figure 3 is dry testing setup without any cooling system to examine the behaviour of panel efficiency with respect to increase in surface temperature of panel. The case 2 shown in Figure 4 consist of cooling of PV Cell with using water as a coolant to examine increase in the efficiency of panel. The case 3 shown in Figure 5 consist of cooling of PV cell with using ethylene glycol as a coolant to examine increase efficiency of the panel. The specification of components used is enlisted in table 1.The design calculation is tabulated in Table 2.

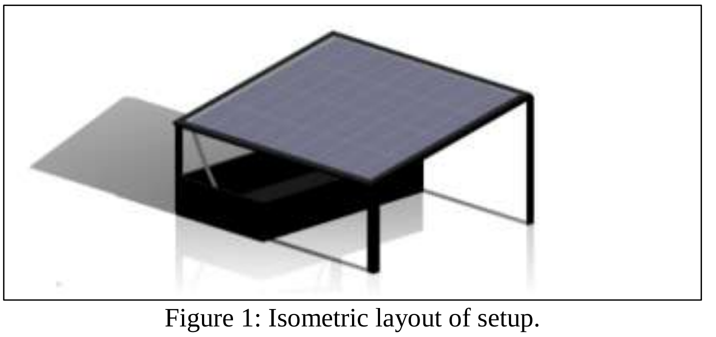

Figure 1: Isometric layout of setup.
Source: Authors, (2025).

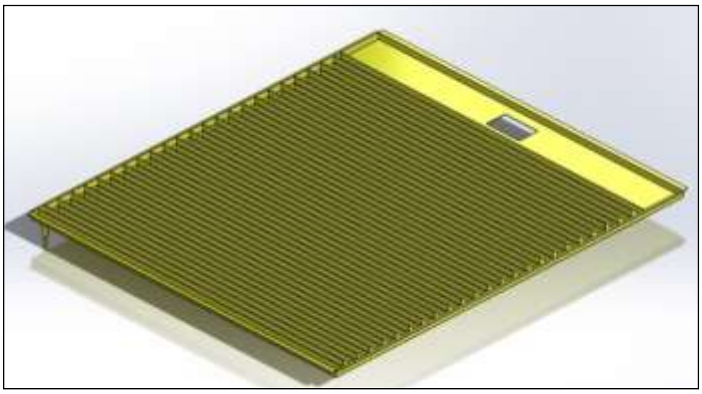

Figure 2: Cooling system with baffles.
Source: Authors, (2025).

Table 1: Specification of Components.

Sr. No.	Components	Specification
1	Polycrystalline PV Panel	75W, Size –780x670x30mm,8Kg Vmax -18.22V, Imax -4.29A
2	Frame	Mild steel
3	Panel Back with baffles	GI Sheet with zinc coating
4	Push connectors	Polybutylene Terephthalate
5	Tubes	Polybutylene Terephthalate
6	Water pump	12V DC solar water pump
7	Coolant Reservoir Tank	Terracotta Water Reservoir Tank
8	Synthetic Primer	Zinc chromate primer
9	Temperature Sensor	DS18B20 resolution up to 12 bits over a range of -55°C to +125°C
10	Arduino Uno	Arduino Uno R3 with ATmega328P microcontroller chip with Ju
11	Coolant	Ethylene Glycol • Solubility: Soluble in water and Miscible in all proportions • Boiling point:197.30C. • Specific Heat capacity: Ethylene glycol 30% by volume /water,700C (3.87) KJ/kg-K • Thermal Conductivity: 0.254 W/m-K at 300C

Source: Authors, (2025).

Table 2: Design Calculations.

Sr. No.	Design Parameters	Ref.
1	Heat gain by Water, $q = m\, C_p\, dt$	[27]
2	EVA silicon specific heat (C_p) =3135 J/Kg K	[27]
3	Flow rate, Q = A x V **For Water,** Water specific heat (C_{pw}) = 4180 J/kg k. $\dot{m}$ = 6 lps q = 150480 J Diameter of pipe for water will be 61.644 mm **For Ethylene Glycol:** $\dot{m}$ = 0.0556 lps Diameter of pipe for Ethylene Glycol will be 8.822 mm	[28]
4	V = 0.91 m/s²	[28]
5	Efficiency $= \frac{\text{Panel Power (in kW)}}{\text{Panel Length x Panel Width (in m)}} \text{x } 100\%$	[29]
6	power output efficiency: Efficiency, $\eta_P = \frac{P_{mean} \text{ (in kW)}}{P_{max}(in\ kW)} \text{x } 100\%$	[29]
7	Performance ratio: Performance Ratio, PR $= \frac{P_{mean} \text{ (in kW)}/P_{max}(in\ kW)}{E_{mean}(in\ kW)} \text{x } 100\%$	[29]
8	Maximum Power: $P_{max} = V_{max} \times I_{max}$ Measured Power: $P_{mean} = V_{mean} \times I_{mean}$	[30]

Source: Authors, (2025).

Figure3: Dry Testing Setup.
Source: Authors, (2025).

Figure 4: Wet Testing Setup with water
Source: Authors, (2025).

Figure 5: Wet Testing Setup with Ethylene Glycol.
Source: Authors, (2025).

III. RESULTS AND DISCUSSIONS

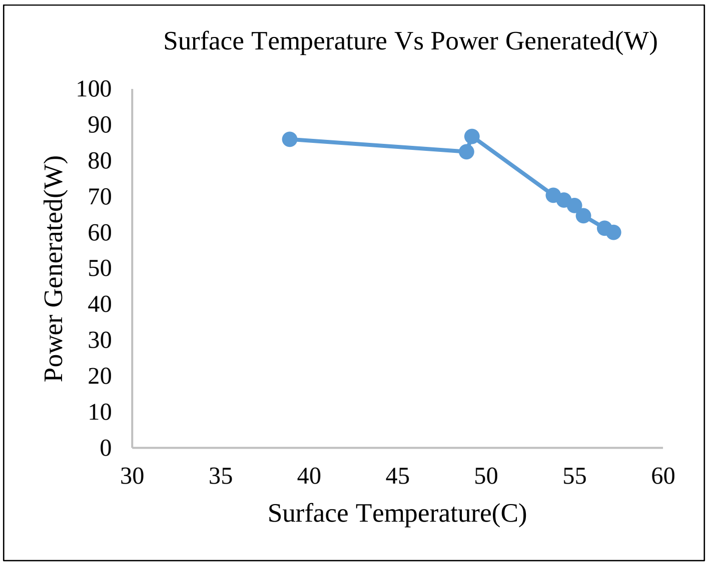

Figure 6: Surface Temperature Vs Power Generated.
Source: Authors, (2025).

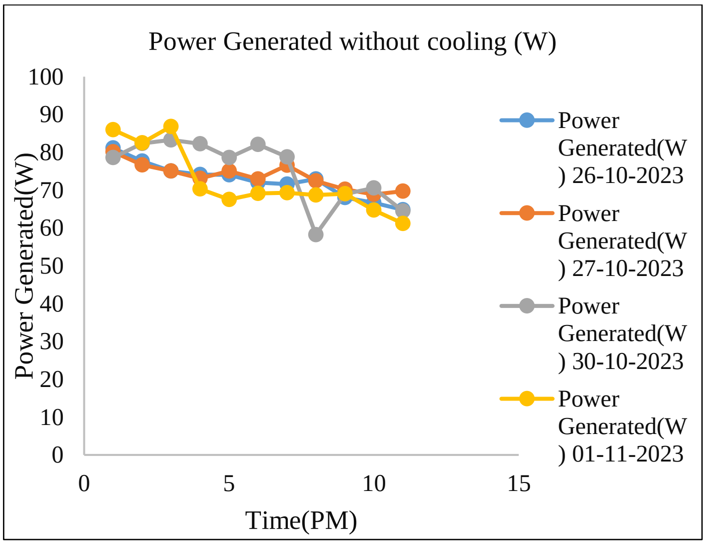

Figure 7: Power Generated without cooling.
Source: Authors, (2025).

The power generation data was recorded from month of Octomber 2023 to May 2024. On 26/10/23, 27/10/23, 30/10/23, 4/4/24 data without cooling arrangement and data with cooling arrangement was recorded on 15/04/24, 17/04/24, 18/04/24, 19/04/24, 20/04/24, 21/04/24, 22/04/24, 23/04/24, 24/04/24, 25/04/24, 26/04/24, 27/04/24, 28/04/24. The Figure 6 indicates that power generation decreases with an increase in surface temperature. At lower surface temperatures (~35°C), power generation remains high (~100 W). As surface temperature rises to 55°C, power generation declines significantly (~60 W). This suggests that the system's efficiency is inversely proportional to surface temperature. Effective cooling mechanisms are crucial to maintaining higher power generation levels.

The Figure7 indicates that power generation without cooling decreases gradually over time during the day across all dates (26-10-2023, 27-10-2023, 30-10-2023, and 01-11-2023). Peak power generation (~90 W) occurs early in the day but declines to ~60 W later in the afternoon due to rising ambient and surface temperatures.

Table 3: (Test Data from 24/04/24, 25/04/24,28/04/24 With Cooling Arrangement).

	24/04/24 (20% Concentratio)		25/04/24 (20% Concentration)		28/04/24 (5% Concentration)	
Time(PM)	Surface Temp.	Power(P=I^2*R)	Surface Temp.	Power(P=I^2*R)	Surface Temp.	Power(P=I^2*R)
8:15 AM	38.46	12.9	-	-	38.86	20.0
8:30 AM	40.56	4.67	39.6	12.67	40.56	29.4
8:45 AM	42.63	9.28	41	15.03	43.2	32.7
9:00 AM	44.69	9.95	38.13	38.20	41.3	33.2
9:15 AM	46.19	33.1	37.75	43.28	39.19	41.2
9:30 AM	48	41.6	37.88	45.95	39.94	47.3
9:45 AM	45.25	38.7	38.63	51.22	41.44	50.0
10:00 AM	48.6	39.4	39.38	53.91	38	54.9
10:15 AM	50.75	40.8	41.69	57.51	38	60.5
10:30 AM	53.54	45.9	40.13	62.24	38.13	63.1
10:45 AM	56.74	44.7	41.25	64.17	39.13	64.8
11:00 AM	58.5	63.1	41.36	67.29	39.13	67.2
11:15 AM	52.5	66.7	41.96	68.92	42.02	69.0
11:30 AM	41	70.8	43.63	70.99	43.2	71.0
11:45 AM	42.25	71.7	45.19	71.65	44.2	70.9
12:00 PM	42.25	72.3	45.19	72.06	44.38	71.2
12:15 PM	42.85	60.0	45.19	71.84	46.1	71.3
12:30 PM	43.88	31.5	44.6	76.81	46.25	70.8
12:45 PM	43.25	58.4	45.04	74.74	47.06	71.9
1:00 PM	43.25	70.9	45.17	77.17	47.25	68.6
1:15 PM	43.69	73.22	45.23	79.98	46.6	69.1
1:30 PM	43.76	75.33	45.23	80.85	45.2	63.4
1:45 PM	44	70.41	45.86	76.86	47.75	64.5
2:00 PM	44.23	77.469	45.53	62.04	45.8	51.8
2:15 PM	44.23	69.92	45.16	59.61	46.13	55.9
2:30 PM	44.69	62.25	44.5	57.61	42.85	16.5
2:45 PM	44.2	66.47	41.32	55.34	42.5	57.5
3:00 PM	43.67	53.55	43.67	53.09	43	46.0
3:15 PM	43.55	49.26	43.55	48.98	43.96	55.6
3:30 PM	43.13	46.67	43.13	46.42	44.25	56.3
3:45 PM	43.13	42.49	43.13	42.20	45	57.3
4:00 PM	42.89	41.94	42.89	41.69	45	54.2
4:15 PM	42.62	40.46	42.62	40.46	45	52.0
4:30 PM	41.9	44.09	41.9	44.01	44	47.2

Source: Authors, (2025).

The Table 3, 4 and 5 gives an ideology that sun radiance heats the panel with energy conversation and lead to the degradation of efficiency. Also, with use of alternative cooling methods the conversion of energy from radiance to useable energy could be converted. Here the application of Ethylene Glycol with water in different percentage had increase the efficiency and power output on a scalable factor. The different percentage of concentration of Ethylene Glycol is used to reduce the evaporation rate of water as seen rate of evaporation is decrease by 25% for 5% Ethylene Glycol with water. Alternatively, the combination of Ethylene Glycol and Water at different concentration are studied 10%, 15% & 20%. From which the 20% concentration of Ethylene Glycol is mention and efficiency is calibrated.

Table 4: (Consumption of Cooling Fluid).

Date	Total water used for test (L)	Concentration of Ethylene glycol (%)	Total Fluid after end of the day (L)	Loss of fluid (L)
21/04	40	5	30	10
22/04	40	10	32	8
23/04	40	15	33.5	6.5
24/04	40	20	35	5
25/04	35	20	30	5
26/04	40	15	33.5	6.5
27/04	40	10	32	8
28/04	40	5	30	10

Source: Authors, (2025).

Table 5: (Consumption of Water and Ethylene Glycol).

Date	Remaining Water (L)	Remaining Ethylene glycol (L)	Consumption of Water (L)	Consumption of Ethylene glycol (L)
21/04	28.5	1.5	9.5	0.5
22/04	28.8	3.2	7.2	0.8
23/04	28.475	5.025	5.525	0.975
24/04	28	7	4	1
25/04	24	6	4	1
26/04	28.475	5.025	5.525	0.975
27/04	28.8	3.2	7.2	0.8
28/04	28.5	1.5	9.5	0.5

Source: Authors, (2025).

5% Concentration: On 21-04-2024 and 28-04-2024, the total fluid loss is 10 L per day, with 30 L remaining at the end of the day. This indicates a consistent rate of fluid loss. Daily water consumption is 9.5 L, and ethylene glycol consumption is 0.5 L. This suggests a higher water-to-glycol consumption ratio compared to other concentrations.

10% Concentration: On 22-04-2024 and 27-04-2024, the fluid loss increases to 8 L per day, leaving 32 L at the end of the day. The slightly higher fluid retention compared to 5% concentration might suggest improved system efficiency. Daily water consumption decreases to 7.2 L, and ethylene glycol consumption rises to 0.8 L. The increased glycol consumption indicates better thermal performance and reduced water evaporation.

15% Concentration: On 23-04-2024 and 26-04-2024, fluid loss reduces to 6.5 L, with 33.5 L remaining at the end of the day. This concentration achieves the lowest fluid loss among all tested values. Water consumption further decreases to 5.525 L per day, with ethylene glycol consumption at 0.975 L. The ratio indicates an optimal balance, resulting in lower fluid loss overall.

20% Concentration: On 24-04-2024 and 25-04-2024, fluid loss is 5 L, with 35 L remaining at the end of the day. The least fluid loss observed at this concentration highlights its effectiveness in minimizing coolant consumption. Water consumption reduces to 4 L, while ethylene glycol consumption increases to 1 L. This concentration achieves the most efficient water usage, with higher glycol

Power generation plots without providing cooling are plotted with the help of experimental data to get insights such as maximum power generated and behavior of power generation with respect to time.

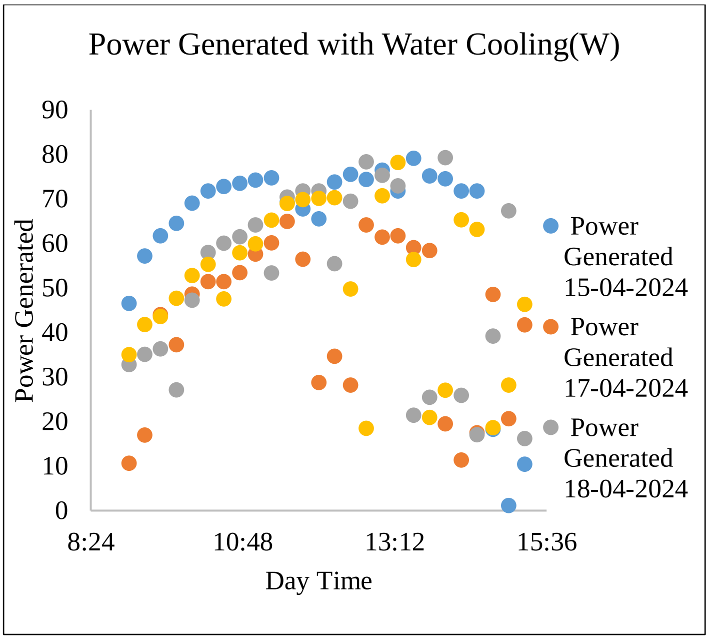

Figure 8: Power Generated with water cooling.
Source: Authors, (2025).

This Figure 8 represents power generation with water cooling across different times of the day on two dates: April 15, 2024, and April 17, 2024. Power generation increases gradually in the morning (starting from around 8:24) and reaches its peak during midday (near 13:12). A decline in power generation is observed as the day progresses into the afternoon (by 15:36). April 15, 2024 (Blue Data Points): The power generated consistently trends higher, with values reaching closer to 80–90 W during peak hours. April 17, 2024 (Orange Data Points): Power generation appears lower overall, with fewer instances exceeding 70 W and scattered data points indicating more variability. Water cooling may influence peak power generation positively, as seen with the higher outputs around midday. The variability in data between the two days could suggest external factors like environmental conditions (e.g., temperature, sunlight availability) affecting the system.

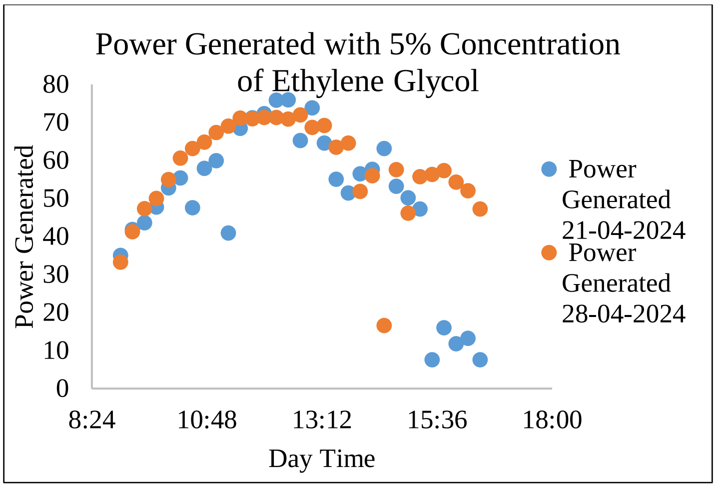

Figure 9: Power Generated with 5% Concentration of Ethylene Glycol
Source: Authors, (2025).

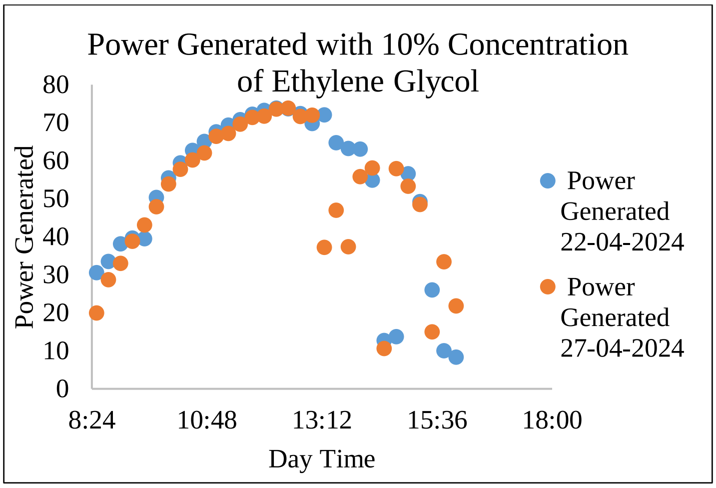

Figure 10: Power Generated with 10% Concentration of Ethylene Glycol
Source: Authors, (2025).

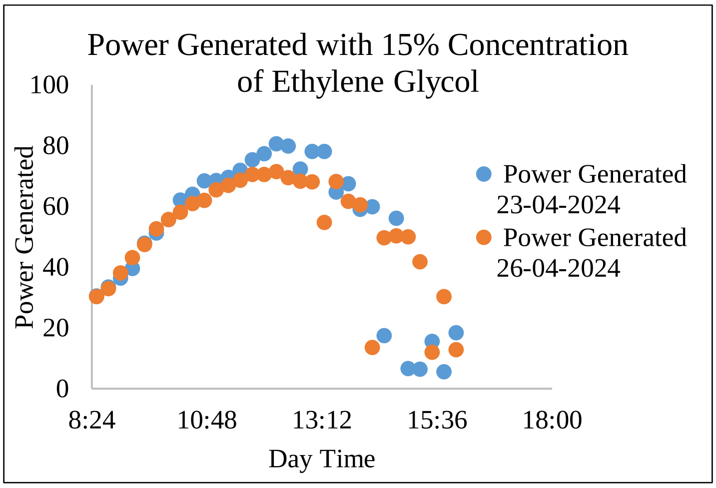

Figure 11: Power Generated with 15% Concentration of Ethylene Glycol
Source: Authors, (2025).

The figures 9,10 and 11 illustrate the power generated at varying concentrations of ethylene glycol (5%, 10%, 15%, and 20%) over two distinct days for each concentration.

5% Concentration: Power generation peaks between 10:48 and 13:12 for both days (21-04-2024 and 28-04-2024), with values reaching approximately 70 W.A sharp decline in power generation is observed after 13:12.Power generation on 28-04-2024 is lower across the day compared to 21-04-2024.

10% Concentration: The peak power generation increases slightly compared to the 5% concentration, reaching approximately 75 W. Similar temporal trends are observed, with a peak around 13:12 and a decline thereafter. Power generated on 27-04-2024 is consistently lower than on 22-04-2024.

15% Concentration: Power generation reaches nearly 90 W, indicating a further increase with higher ethylene glycol concentration. The trend of power peaking around 13:12 is consistent. Power generated on 26-04-2024 is slightly lower than on 23-04-2024.

20% Concentration: The highest power generation is recorded at this concentration, peaking near 100 W. The decline in power generation post-peak is more gradual compared to lower concentrations. Data for 25-04-2024 shows slightly reduced power compared to 24-04-2024.

Increasing the concentration of ethylene glycol from 5% to 20% results in higher peak power generation, demonstrating a positive correlation between concentration and power output. Across all concentrations, power generation follows a consistent diurnal pattern, peaking during midday and declining in the late afternoon. For each concentration, the second day consistently shows reduced power generation compared to the first, potentially due to variations in environmental factors such as temperature, sunlight intensity, or system efficiency.

IV. CONCLUSIONS

Fluid loss decreases as the concentration of ethylene glycol increases, with 20% concentration exhibiting the least loss (5 L/day). The reduced fluid loss suggests that higher glycol concentrations are more effective in reducing evaporation and leaks. Water consumption decreases progressively from 9.5 L/day at 5% concentration to 4 L/day at 20% concentration. Ethylene glycol consumption increases proportionally, with higher concentrations ensuring better thermal performance and fluid retention. The 20% concentration demonstrates the best results in terms of minimal fluid loss and efficient consumption of both water and ethylene glycol. While the 15% concentration also shows promising results, it slightly underperforms compared to 20%.

The study also highlights that the influence of ethylene glycol concentration on power generation efficiency. The 20% concentration yields the highest power output, suggesting it as the most effective concentration within the tested range. However, environmental and operational conditions appear to impact daily performance, necessitating further investigation to optimize the system for consistent power generation. The future research focuses on optimizing cooling designs, evaluating environmental impacts, and exploring advanced technologies to achieve consistent and efficient performance.

VI. AUTHOR'S CONTRIBUTION

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Resources: Vedant Jiraffe.
Supervision: Laxmikant Jathar,Sagar Shelare.
Approval of the final text: Keval Chandrakant Nikam, Amit Umbrajkar, Sandesh Solepatil, Vandana Patil, Chetan Pawar,Vedant Jirafe,Piyush Bhosale,Dhruv Res,Ayush More, Laxmikant Jathar,Sagar Shelare

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VIII. REFERENCES

[1]. Kalogirou, S.A.: Chapter 1 - Introduction to Renewable Energy Powered Desalination. Presented at the (2018). https://doi.org/https://doi.org/10.1016/B978-0-12-815244-7.00001-5.

[2]. Tripanagnostopoulos, Y.: 3.08 - Photovoltaic/Thermal Solar Collectors. Presented at the (2012). https://doi.org/https://doi.org/10.1016/B978-0-08-087872-0.00308-5.

[3]. Nikitina, V., Reichel, C., Erath, D., Kirner, S., Richter, A., Rößler, T., De Rose, A., Kraft, A., Neuhaus, H.: Shingling meets perovskite-silicon heterojunction tandem solar cells. Sol. Energy Mater. Sol. Cells. 263, 112590 (2023). https://doi.org/https://doi.org/10.1016/j.solmat.2023.112590.

[4]. Xu, C., Isabella, O., Vogt, M.R.: Future material demand for global silicon-based PV modules under net-zero emissions target until 2050. Resour. Conserv. Recycl. 210, 107824 (2024). https://doi.org/https://doi.org/10.1016/j.resconrec.2024.107824.

[5]. Preet, S., Smith, S.T.: A comprehensive review on the recycling technology of silicon based photovoltaic solar panels: Challenges and future outlook. J. Clean. Prod. 448, 141661 (2024). https://doi.org/https://doi.org/10.1016/j.jclepro.2024.141661.

[6]. Li, A., Zou, S., Peng, C.-W., Ni, M., Dai, L., Han, W., Lu, Z., Chen, Z., Su, X.: Improving the light trapping ability and flexural strength of ultrathin monocrystalline silicon wafers with submicron pyramid textures. Sol. Energy Mater. Sol. Cells. 271, 112847 (2024). https://doi.org/https://doi.org/10.1016/j.solmat.2024.112847.

[7]. Maalouf, A., Okoroafor, T., Jehl, Z., Babu, V., Resalati, S.: A comprehensive review on life cycle assessment of commercial and emerging thin-film solar cell systems. Renew. Sustain. Energy Rev. 186, 113652 (2023). https://doi.org/https://doi.org/10.1016/j.rser.2023.113652.

[8]. Lu, Y., Hao, Z., Feng, S., Shen, R., Yan, Y., Lin, S.: Direct-Current Generator Based on Dynamic PN Junctions with the Designed Voltage Output. iScience. 22, 58–69 (2019). https://doi.org/https://doi.org/10.1016/j.isci.2019.11.004.

[9]. Ouédraogo, A., Zouma, B., Ouédraogo, E., Guissou, L., Bathiébo, D.J.: Individual efficiencies of a polycrystalline silicon PV cell versus temperature. Results Opt. 4, 100101 (2021). https://doi.org/https://doi.org/10.1016/j.rio.2021.100101.

[10]. Siecker, J., Kusakana, K., Numbi, B.P.: A review of solar photovoltaic systems cooling technologies. Renew. Sustain. Energy Rev. 79, 192–203 (2017). https://doi.org/https://doi.org/10.1016/j.rser.2017.05.053.

[11]. Sohail, A., Rusdi, M.S., Waseem, M., Abdullah, M.Z., Pallonetto, F., Sultan, S.M.: Cutting-edge developments in active and passive photovoltaic cooling for reduced temperature operation. Results Eng. 23, 102662 (2024). https://doi.org/https://doi.org/10.1016/j.rineng.2024.102662.

[12]. Elnaby Kabeel, A., El Hadi Attia, M., Abdelgaie, M., Khelifa, A., Abdel-Aziz, M.M.: Experimental study on energy and exergy assessments of a new PV system with a concave cover for active cooling and self-cleaning. Renew. Energy Focus. 47, 100512 (2023). https://doi.org/https://doi.org/10.1016/j.ref.2023.100512.

[13]. Shu, L., Zhang, J., Fu, B., Xu, J., Tao, P.: Ethylene glycol-based solar-thermal fluids dispersed with reduced graphene oxide. 10282–10288 (2019). https://doi.org/10.1039/c8ra09533g.

[14]. Govindasamy, D., Kumar, A.: Experimental analysis of solar panel efficiency improvement with composite phase change materials. Renew. Energy. 212, 175–184 (2023). https://doi.org/https://doi.org/10.1016/j.renene.2023.05.028.

[15]. Patil, M., Sidramappa, A., Shetty, S.K., Hebbale, A.M.: Experimental study of solar PV/T panel to increase the energy conversion efficiency by air cooling. Mater. Today Proc. 92, 309–313 (2023). https://doi.org/https://doi.org/10.1016/j.matpr.2023.05.007.

[16]. Sainthiya, H., Beniwal, N.S.: Different Types of Cooling Systems Used in Photovoltaic Module Solar System : A Review. 1500–1506 (2017).

[17]. Zhu, L., Boehm, R.F., Wang, Y., Halford, C., Sun, Y.: Water immersion cooling of PV cells in a high concentration system. Sol. Energy Mater. Sol. Cells. 95, 538–545 (2011). https://doi.org/10.1016/j.solmat.2010.08.037.

[18]. Ashok Kumar, L., Indragandhi, V., Teekaraman, Y., Kuppusamy, R., Radhakrishnan, A.: Design and Implementation of Automatic Water Spraying System for Solar Photovoltaic Module. Math. Probl. Eng. 2022, 7129610 (2022). https://doi.org/https://doi.org/10.1155/2022/7129610.

[19]. Nakkaew, S., Chitipalungsri, T., Ahn, H.S., Jerng, D.-W., Asirvatham, L.G., Dalkılıç, A.S., Mahian, O., Wongwises, S.: Application of the heat pipe to enhance the performance of the vapor compression refrigeration system. Case Stud. Therm. Eng. 15, 100531 (2019). https://doi.org/https://doi.org/10.1016/j.csite.2019.100531.

[20]. Torbatinezhad, A., Rahimi, M., Ranjbar, A.A., Gorzin, M.: Performance evaluation of PV cells in HCPV/T system by a jet impingement/mini-channel cooling scheme. Int. J. Heat Mass Transf. 178, 121610 (2021). https://doi.org/https://doi.org/10.1016/j.ijheatmasstransfer.2021.121610.

[21]. Hamed, M.H., Hassan, H., Ookawara, S., Nada, S.A.: PV thermal regulation and water harvesting hybrid system using evaporative cooling of silica gel layer. Process Saf. Environ. Prot. 181, 243–265 (2024). https://doi.org/https://doi.org/10.1016/j.psep.2023.11.009.

[22]. Parthiban, R., Ponnambalam, P.: An Enhancement of the Solar Panel Efficiency : A Comprehensive Review. 10, 1–15 (2022). https://doi.org/10.3389/fenrg.2022.937155.

[23]. Kazemian, A., Hosseinzadeh, M., Sardarabadi, M., Passandideh-Fard, M.: Experimental study of using both ethylene glycol and phase change material as coolant in photovoltaic thermal systems (PVT) from energy, exergy and entropy generation viewpoints. Energy. 162, 210–223 (2018). https://doi.org/10.1016/j.energy.2018.07.069.

[24]. Sandhya, M., Ramasamy, D., Kadirgama, K., Harun, W.S.W., Saidur, R.: Experimental study on properties of hybrid stable & surfactant-free nanofluids GNPs/CNCs (Graphene nanoplatelets/cellulose nanocrystal) in water/ethylene glycol mixture for heat transfer application. J. Mol. Liq. 348, 118019 (2022). https://doi.org/https://doi.org/10.1016/j.molliq.2021.118019.

[25]. Upadhyay, V., Rashmi, Himanshu Khadloya, P., Raja Sekhar, Y., D Sai Anoop Reddy, A., Reddy, B.: Experimental studies on solar flat plate collector with internally grooved tubes using aqueous ethylene glycol. Appl. Sol. Energy. 53, 222–228 (2017). https://doi.org/10.3103/S0003701X17030112.

[26]. Hemmat Esfe, M., Saedodin, S., Mahian, O., Wongwises, S.: Thermal conductivity of Al2O3/water nanofluids. J. Therm. Anal. Calorim. 117, 675–681 (2014). https://doi.org/10.1007/s10973-014-3771-x.

[27]. Ruiz-reina, E., Sidrach-de-cardona, M., Piliougine, M.: Heat Transfer and Working Temperature Field of a Photovoltaic Panel under Realistic Environmental Conditions. COMSOL Conf. 1–26 (2014).

[28]. Ciano, T., Ferrara, M., Babanezhad, M., Khan, A., Marjani, A.: Prediction of velocity profile of water based copper nanofluid in a heated porous tube using CFD and genetic algorithm. Sci. Rep. 11, 10623 (2021). https://doi.org/10.1038/s41598-021-90201-x.

[29]. Jean, J., Brown, P.R., Jaffe, R.L., Buonassisi, T., Bulović, V.: Pathways for

solar photovoltaics. Energy Environ. Sci. 8, 1200–1219 (2015). https://doi.org/10.1039/C4EE04073B.

[30]. Ogbulezie, J.C., Njok, A.O., Panjwani, M.K., Panjwani, S.K.: The impact of high temperature and irradiance source on the efficiency of polycrystalline photovoltaic panel in a controlled environment. 10, 3942–3947 (2020). https://doi.org/10.11591/ijece.v10i4.pp3942-3947.