Performance Improvement of Solar Photovoltaic Modules through Advanced Passive Thermal Management Strategies

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ABSTRACT

Reducing reliance on fossil fuels and mitigating climate change requires enhancing the efficiency of Photovoltaic (PV) systems. One great challenge is thermal limitation, where increased operating temperatures reduce electrical output and conversion efficiency. This study investigates passive cooling techniques using water, vegetation, and coconut fiber layers to mitigate the thermal effects on PV modules. The system performance was investigated through module surface temperature measurements, electrical power output, and efficiency metrics. The results demonstrate that floating water and hybrid floating-vegetation configurations substantially improved PV performance, with power output gains of up to 55.5% and efficiency increases of approximately 63.5%. Vegetation-only cooling yielded modest improvements (~7.34%), while coconut fiber layers showed inconsistent results, sometimes decreasing performance. These passive cooling approaches, especially the floating water system, offer sustainable, energy-free solutions for optimizing PV operation, with the potential for widespread application in sustainable energy infrastructure.

Keywords-passive cooling; temperature; renewable energy; photovoltaic; floating

I. INTRODUCTION

The use of fossil fuels is bound to decline over time and become unreliable because of their limited availability [1]. In this regard, the shift to renewable energy from water, wind, solar, biomass, marine, and geothermal resources has become imperative [2]. Of these alternatives, solar power is considered the most cost-effective and ecologically friendly, as supported by the fact that the sun is capable of providing ample and virtually unlimited energy [3]. Although sunlight is available in all climate zones, the irradiation levels are highly variable by region, with tropical regions receiving consistently high daily global irradiation throughout the year [4]. Despite this enormous potential, the conventional Photovoltaic (PV) modules can only convert about 15% of incident solar radiation into electrical energy [5]. However, the efficiency of traditional ground-mounted PV systems is often restrained by high module temperatures, which lower the power output as a result of the negative temperature coefficient of silicon-based solar cells [6, 7]. These challenges highlight the need to enhance PV thermal management as one of the key research priorities to advance energy yield and ensure dependable system performance.

Floating PV (FPV) systems, which employ PV panels mounted on water surfaces, such as reservoirs, canals, and lakes, have gained increased interest owing to their potential for increased energy production. The water beneath the modules cools them naturally, resulting in notably lower operating temperatures and higher performance compared to land-mounted PV systems [8, 9]. Indeed, empirical and modeling studies support such performance gains. For instance, in [10], a comparative study was conducted, demonstrating that FPV systems exhibited module temperatures significantly below those of the ground-based system, resulting in considerably higher energy yield and energy efficiency. It was shown that FPVs display lower irradiance-weighted module temperatures and enhanced performance in two different climate zones, compared with nearby land-based references [11]. FPV energy gains commonly fall in the single to low-double percent range at temperate sites, with higher benefits-often up to about 10% or more-under particularly favorable conditions, which depend on water temperature, system layout, and local climate [12]. Improved thermal stability can thus translate into statistically significant power increase, as confirmed by site-specific reservoir studies in tropical/shallow water settings [13]. The cases where water-cooled FPV installations yield double-digit improvements in annual energy output compared with equivalent ground installations, as documented by field investigations and techno-economic assessments, further highlight FPV's potential as a thermally advantageous, land-efficient renewable option [14]. This study emphasizes the promise of FPV as a thermally advantageous, land-efficient, and sustainable renewable energy source.

Even though FPV installations enjoy certain advantages due to cooling from water, under high solar irradiance and low wind speeds, often experienced in tropical regions, the module temperature increases and electrical output decreases. Therefore, passive cooling techniques have been considered in several studies to further improve FPV's intrinsic thermal benefits. Field experiments and modeling confirmed that certain passive methods can significantly reduce the module operating temperature while enhancing the power output. For example, fin-assisted designs with partial submergence can achieve ~19% operating temperature reduction and an electrical output increase of up to ~24% compared to reference FPV systems [15]. Three different passive fin geometries have been applied to PV modules: pin fins, Y-shaped fins, and spring fins. The results showed that pin fins provided the most effective thermal amelioration. Fully saturated pin-fin configurations considerably reduced the module temperature while increasing the electrical performance, giving about a 4% increase in efficiency and a 0.8 V increase in open-circuit voltage [16]. Submerging PV modules in shallow water provides an effective passive cooling mechanism because direct contact with water maximizes heat removal. Optimal depths of 4-5 cm have been reported, which can increase electrical efficiency by 15-18%. However, deeper submersion reduces power output due to stronger light absorption from water, making shallow, partially submerged FPV configurations the most practical for enhancing performance without compromising optical transmission [17]. A pilot study on the membrane-based FPV system of Ocean Sun showed that, owing to better heat transfer, placing PV modules in direct thermal contact with the water surface results in 5-7% higher energy output than air-cooled modules, confirming the significant passive cooling benefit of water-based FPV designs [18].

Although previous studies have shown that a range of passive cooling methods, such as fin-assisted designs, coconut-coir cooling, shallow-water submersion, and membrane-contact FPV, can successfully decrease module temperature and enhance power output, most research so far has focused on issues related to temperature reduction and electrical power gains. However, few studies have presented a comparative assessment of passive cooling techniques in terms of the variation in critical performance indicators, such as the Fill Factor (*FF*) and overall PV efficiency. This lack of comparative performance-based assessment restricts the understanding of which passive cooling method is most capable of providing the most effective thermal–electrical enhancement to FPV systems under a range of environmental conditions. Therefore, the present study examines the performance improvements in FPV systems using advanced passive thermal management strategies. It evaluates module temperature reduction, energy-yield enhancement, and the practical viability of each passive cooling method under real environmental conditions, providing technical insights to support more efficient and reliable FPV deployment.

II. RESEARCH METHODOLOGY

A. *Photovoltaics*

PV cells are semiconductor-based solar energy converters with the ability to directly convert solar radiation into electric energy by exploiting the PV effect [19]. By measuring the output parameters generated by the PV, such as voltage, current, and power, the performance of the panel can be determined. In power generation systems, PVs have the characteristics of voltage currents that are used to represent the power obtained. Factors that can affect the characteristics of the voltage–current include the operating temperature of the PV and the intensity of solar radiation. If the level of irradiation received by the PV is high, then the amount of electrical energy produced will be greater [20]. However, only approximately 15-20% of the energy received can be converted into electric current [21]. The remaining solar energy generates heat, increasing the surface temperature of the panel. The increase in temperature decreases the output power produced [22].

The PVs used in this study were 30 Si-polycrystalline panels with a capacity of 30 pieces assembled in series and parallel, as shown in Figure 1 (a). Although the efficiency of Si-polycrystalline PVs is approximately 12-14%, which is lower than that of monocrystalline PVs, they are preferred because they are more affordable. Additionally, the polycrystalline panels have the advantage of being able to produce electricity in cloudy conditions or lack of sunlight [23].

B. Floating Cooling System

An FPV system is shown in Figure 1 (b). FPVs are an emerging approach in PV applications, where the PV modules operate while floating on a water surface. As depicted in Figure 1 (b), the studied systems consisted of several components, including (a) polycrystalline PV modules, (b) a floating cooling system, (c) a plant-based cooling system, and (d) a coconut fiber cooling system designed to enhance thermal management and improve the overall performance of the PV modules. FPVs have high potential, especially in densely populated areas, where land development is hampered by limited availability and high costs [24]. Additionally, FPVs can be used to reduce the growth of algae that need sunlight. In addition, FPVs can reduce evaporation in stagnant areas, thereby conserving water. Evaporation rates can be reduced by up to 50% in artificial water pools and 30% in lakes [25]. FPV modules show an efficiency of more than 10% compared to land-mounted or conventional PV modules [26]. However, there are economic drawbacks. That is, the initial installation cost of FPV modules is about 15% more expensive than conventional installations, but the operational and maintenance costs tend to be lower than the initial installation costs [27]. By floating the PV module over a body of water, the panels can be effectively cooled, and the water evaporation rate can be reduced by up to 70% [28]. The operating temperature of PV modules tends to be lower due to the cooling effect of evaporating water, which leads to the increased efficiency of solar panels [29].

C. Plant Cooling System

The proposed plant cooling system is illustrated in Figure 1 (c). The plants provide natural air circulation by blocking direct solar radiation. In addition, plants are used to reduce humidity levels and improve the efficiency of solar panels. The plant cooling system provides better temperature regulation and a considerable power increase of 7.34% [30]. In this study, 10 plants were placed around the solar panel with a minimum plant height equal to the panel frame. The plants used were not limited to a specific type of plant.

D. Coconut Fiber Cooling System

Coconut fiber is a natural fiber that can be used in products such as mattresses, brushes, and footwear. Besides this, coconut fiber can also be used as a planting medium. The former is composed of lignin, hemicellulose, cellulose, and ash. When coconut fiber is soaked in water and placed under the PV module, it can absorb excess heat from the latter, thereby lowering the surface temperature. Coconut coir has an indefinite shelf life after moistening, but it is best to replace it within three to four months [31]. The coconut coir installed at the bottom of the panel was soaked for a few hours or overnight. The PV installation with the coconut cooling system is presented in Figure 1 (d).

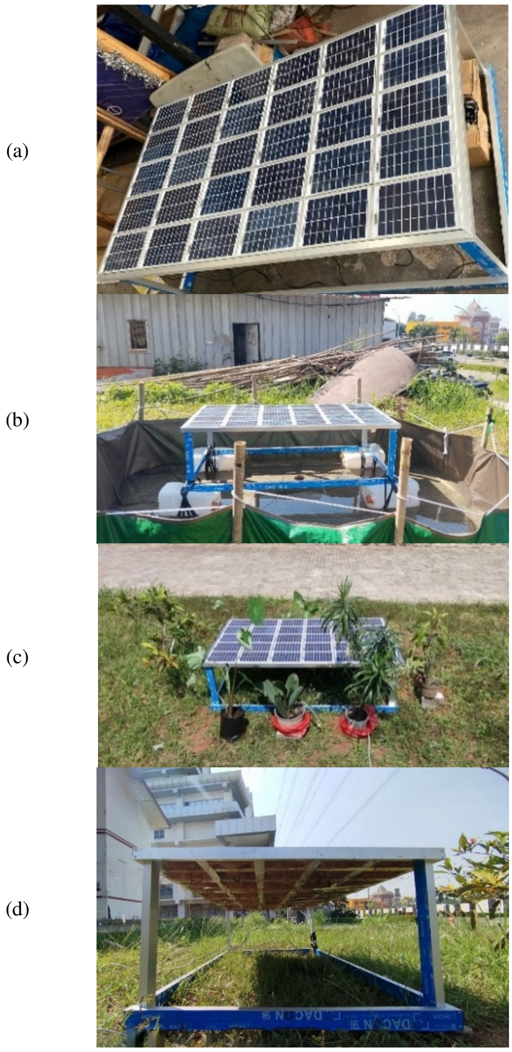

Fig. 1. (a) Si-polycrystalline PV modules, (b) floating cooling system, (c) plant cooling system, and (d) coconut fiber cooling system.

E. Experimental Method

The solar panels with and without cooling were exposed to sunlight. Solar irradiation, panel surface temperature, ambient temperature, voltage, current, and panel power were recorded simultaneously. Fluctuations in the temperature, power gain, and electrical efficiency were calculated to conduct a performance analysis of each system used in this study. To facilitate a comparison of the experimental results without the risk of differences in weather conditions, performance measurements were conducted under comparable solar irradiance values to assess the impact of the cooling techniques. Each test was carried out for three days. Then, a comparison between the proposed systems that include cooling functions and the uncooled panels was conducted.

The characteristics of the PV have several energy parameters at a given radiation. The theoretical maximum power ($P_{max\text{-}th}$) is the result of the short-circuit current (I_{SC}) and open circuit voltage (V_{OC}). The actual maximum power (P_{max}) is the result of the maximum current (I_m) and maximum voltage (V_m) generated by the PV module [32]. The ratio of actual power to theoretical power is called the *FF*, which can be calculated using:

$$FF = \frac{P_{max}}{P_{max-th}} = \frac{V_m I_m}{V_{OC} I_{SC}} \quad (1)$$

The greater the *FF* value and closer to 1, the better the performance of PV, which is given by [33]:

$$n_e = \frac{P_{max}}{IA}\, x\, 100\% \quad (2)$$

where *I* is the solar radiation and *A* is the illuminated area.

III. RESULTS AND DISCUSSION

In this section, the operational performance of polycrystalline PV modules under different thermal management conditions, namely without cooling, with floating water cooling, with vegetation-based cooling, and with coconut fiber layers, is systematically evaluated and compared. The analysis encompasses variations in surface temperature, voltage, current, power output, and electrical efficiency to elucidate the influence of each cooling approach. The comparative discussion presented here provides a detailed understanding of the thermal–electrical behavior of the PV modules, highlighting the relative effectiveness and practicality of each cooling configuration in mitigating temperature rise and improving overall energy conversion performance.

A. Uncooled vs Floating Cooling

The analysis was performed by comparing the data of the uncooled and floating solar panels (Figure 1). The parameters used for the comparison were power and temperature at the same light intensity. In this case, the data were collected in real time for 30 min from 09.00 to 15.00. The highest solar irradiation recorded in the test system was 137400 lx, as shown in Table I. This cooling system can lower the maximum temperature by 12.5 °C. When the temperature drop remains stable during the day, the amount of power increase produced decreases further, and when the power increase is negative in the afternoon, the temperature decrease in the panel is still positive albeit lower. This indicates that the floating cooling system contributes to a decrease in temperature, even though the power is relatively lower in the afternoon. Overall, the floating cooling system was able to lower the average temperature by 13.6%. The high surface temperature of the panel contributes to a decrease in the performance of the solar panel; hence, a cooling system is required to improve the performance of the system and extend the life of the solar panel.

The electrical energy generation with an average output power gain for the floating cooling system was recorded. The floating cooling system solar panels produced a peak power of 93.1 W, while without a cooling system, they produced 66.3 W. The highest power increase was 41.3 W (81.4%), with an average power increase of 19.81 (38.5%), as presented in Table I. Overall, the test data of this cooling system can be used to confirm that the floating cooling system is highly effective in increasing power by decreasing the surface temperature of the panels.

B. Uncooled vs Plant Cooling

The plant cooling system in this study was implemented by placing plants around the solar panels, as displayed in Figure 1 (c). A comparison of the data between the cooling and unrefrigerated systems is presented in Table II, which consists of the power, temperature, increase in power, decrease in temperature, and intensity of sunlight when the test was conducted. By comparing the test results with and without the plant cooling system, data on fluctuations in temperature, power, and sunlight intensity were obtained. The lowest temperature with the plant cooling system was 39 ºC or 8.13% lower than that of a system without cooling. The average temperature drop that occurred with this cooling system was 16.33%, decreasing the initial temperature of 51.42 ºC to 43.02 ºC, as presented in Table II. This confirms that maintaining a low panel surface temperature can improve the efficiency of solar energy conversion into electrical energy.

TABLE I. FLOATING COOLING SYSTEM

Time	**Power without cooling (W)**	**Floating cooling power (W)**	**Power increase (W)**	**Temperature without cooling (°C)**	**Floating cooling temperature (°C)**	**Temperature drop (°C)**	**Light intensity (lx)**
09.00	43.30	81.0	37.7	47.6	38.6	9.0	122400
09.30	50.73	92.0	41.3	50.9	38.4	12.5	121500
10.00	60.52	93.1	32.5	50.3	40.5	9.8	124600
10.30	66.30	87.6	21.3	48.2	40.6	7.6	121700
11.00	63.47	72.3	8.9	55.0	43.5	11.5	130300
11.30	58.53	79.2	20.7	48.5	47.7	0.8	137400
12.00	54.29	77.1	22.8	48.5	47.9	0.6	125500
12.30	48.24	64.6	16.3	52.3	46.3	6.0	121500
13.00	41.29	61.3	20.0	52.1	46.1	6.0	113100
13.30	33.00	51.9	18.9	52.1	46.4	5.7	129600
14.00	40.03	57.5	17.4	54.2	47.2	7.0	123400
14.30	57.84	61.1	3.3	51.7	44.3	7.4	125900
15.00	49.84	46.4	-3.5	47.2	41.2	6.0	102500
Average	51.34	71.15	19.81	50.66	43.75	6.9	123030.7

TABLE II. PLANT COOLING SYSTEM

Time	**Power without cooling (W)**	**Plant cooling power (W)**	**Power increase (W)**	**Temperature without cooling (°C)**	**Plant cooling temperature (°C)**	**Temperature drop (°C)**	**Light intensity (lx)**
09.00	43.20	45.25	2.05	49.2	44.2	5.0	95720
09.30	51.50	46.22	-5.29	47.3	42.9	4.4	94360
10.00	54.09	52.95	-1.14	51.2	42.4	8.8	107100
10.30	57.68	61.17	3.49	53.4	43	10.4	106200
11.00	60.14	75.08	14.94	52.1	45.2	6.9	111400
11.30	59.16	66.59	7.43	56.1	41.8	14.3	110800
12.00	63.10	70.81	7.70	56.3	47	9.3	118600
12.30	54.10	60.48	6.38	54.6	44.4	10.2	117700
13.00	46.37	49.36	2.99	50	44.8	5.2	90770
13.30	39.12	48.88	9.76	51.8	43.6	8.2	85800
14.00	34.46	39.90	5.44	55.5	40.4	15.1	71340
14.30	58.75	37.36	-21.39	43	39.5	3.5	64960
15.00	49.73	34.57	-15.16	47.9	40.1	7.8	66110
Average	51.65	52.97	1.32	51.42	43.02	8.4	95450.77

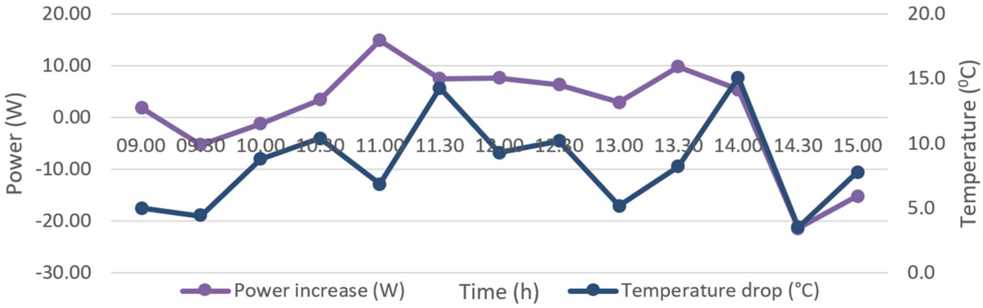

Fig. 2. Correlation between temperature variations and power generation in the plant cooling configuration.

TABLE III. COCONUT FIBER COOLING SYSTEM

Time	**Power without cooling (W)**	**Floating coconut cooling power(W)**	**Power increase (W)**	**Temperature without cooling (°C)**	**Floating coconut cooling temperature (°C)**	**Temperature drop (°C)**	**Light intensity (lx)**
09.00	43.20	53.75	10.55	49.2	34.7	14.5	90450
09.30	51.50	61.78	10.27	47.3	41.5	5.8	101000
10.00	54.09	70.47	16.38	51.2	43.5	7.7	114600
10.30	57.68	72.71	15.02	53.4	43	10.4	105400
11.00	60.14	73.64	13.49	52.1	49.8	2.3	104100
11.30	59.16	23.18	-35.99	56.1	53.3	2.8	123500
12.00	63.10	41.18	-21.93	56.3	46.5	9.8	116300
12.30	54.10	33.36	-20.74	54.6	48.1	6.5	116600
13.00	46.37	37.47	-8.90	50	43.1	6.9	96490
13.30	39.12	36.09	-3.03	51.8	43	8.8	87830
14.00	34.46	34.40	-0.06	52	37.9	14.1	74500
14.30	58.75	28.51	-30.24	43	37.5	5.5	65900
15.00	49.73	25.34	-24.39	47.9	36.4	11.5	61310
Average	51.65	45.53	-6.12	51.42	42.95	8.5	96767.69

In general, the benefits of cooling to improve the performance of solar PVs using plant cooling systems are evident from the temperature data. The highest sunlight intensity was 118600 lx. This cooling system consistently lowered the surface temperature of the panels. The introduction of a plant cooling system was recorded to increase the peak power obtained by 24.84% compared to that of the uncooled PV, reaching 75.08 W. The average increase in the power obtained using a plant cooling system was 2.55% higher compared to that of a system without cooling. Generally, a decrease in temperature is associated with an increase in the power produced by the panels when the intensity of sunlight reaches its peak. However, this is not always linear because other factors, such as wind and conversion efficiency, also play a role. In addition, a power decrease occurred at the beginning and end of the test, as shown in Figure 2. This directly corresponds to the decrease in temperature in the solar panel, which indicates that the main cause is the reduction in solar radiation received by the solar panel.

C. *Uncooled vs Coconut Fiber Cooling*

The coconut coir cooling system was operated by placing coir on the bottom of the panel that was previously soaked for several hours or overnight, as portrayed in Figure 1 (d). The comparison made with the power and temperature parameters of the dominant intensity of sunlight is the same as that presented in Table III. Both tests, with and without cooling, were conducted from 09.00 to 15.00.

The highest temperature of 53.30 °C was recorded at 11.30 a.m. for the coconut coir-cooled panels. This is due to the increase in sunlight intensity, which increases the surface and bottom temperatures of the panel. The coconut coir cooling system showed up to a 29.47% temperature reduction compared to the system without cooling. The average temperature recorded for the coconut-cooled panels was 8.5 °C, equivalent to 16.53%, which, as a whole, can lower the surface temperature but is not always linear with the increase in electrical power produced. A comparison between the coconut coir cooling system and a system without cooling is presented in Table III. The comparison of power without the cooling process and the floating coconut cooling power indicates that, for certain periods, the power values for the coconut cooling process are lower than the values for the power without the cooling process; hence, the negative values. This happens because of the heat vapor accumulation beneath the PV module, leading to an increase in the bottom side temperature; thus, reduced power generation.

D. Cooling System Efficiency

The parameters used for calculating the effectiveness of solar panels without a cooling system and with a floating cooling system, plants, and coconut fibers were in the form of voltage and current of the solar panels. Equations (1) and (2) were used, and the results are presented in Table IV.

TABLE IV. COOLING SYSTEM EFFICIENCY

Parameter	Uncooled	Floating cooling	Plant cooling	Coconut fiber cooling
FF	0.357	0.617	0.421	0.413
n_e (%)	0.074	0.121	0.10	0.105

FF is used as a performance indicator for the device. A higher *FF* value indicates that the solar panel can convert most of the sunlight it receives into usable electrical energy. The higher the *FF* value or the closer it is to 1, the better the performance or charging efficiency of the system. In this study, the highest *FF* value was recorded for the solar panel with a floating cooling system at 0.617, with an energy efficiency of 0.121%. Next is the plant cooling system with an *FF* value of 0.421 and an efficiency of 0.10%. The coconut husk cooling system had a filling factor value of 0.413 and an efficiency value of 0.105%.

Each cooling system increased the *FF* and efficiency. The ranking based on the highest *FF* values is: floating cooling system, plant cooling system, and coconut husk cooling system, with values of 72.8%, 17.9%, and 15.7% higher, respectively, than the system without cooling. The efficiency values of each system were 63.5%, 41.9%, and 35.1% higher, respectively, compared to the system without cooling.

IV. CONCLUSIONS

This research demonstrates that the use of passive cooling systems, such as floating, plant-based, and coconut fiber systems, significantly enhances the performance of solar panels. The floating and combined floating-plant systems achieved a maximum power increase of up to 55.5% and an energy efficiency of approximately 63.5%, both of which were higher than those of systems without cooling. Plant-based cooling provides a moderate power gain of around 7.34%, with effectiveness depending on plant arrangement and proximity, while coconut fiber cooling exhibits limited performance and may reduce output due to insufficient heat dissipation and localized heat accumulation beneath the module.

The novelty of this work lies in the integrated experimental evaluation of multiple natural-material passive cooling methods applied to a Floating PV (FPV) system, offering new insights beyond conventional land-based or single-panel studies. These findings contribute to the development of low-cost and environmentally friendly cooling solutions for floating solar applications. Future work will focus on long-term performance assessment, scaling to larger FPV arrays, and integrating adaptive cooling strategies under varying environmental conditions.

DECLARATION OF COMPETING INTERESTS

Not applicable to this work.

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DATA AVAILABILITY

Data acquisition and processing are described within this paper. No external dataset was used. Further details can be granted by the corresponding author upon request.

REFERENCES

[1] S. Zhironkin and F. Abu-Abed, "Fossil Fuel Prospects in the Energy of the Future (Energy 5.0): A Review," *Energies*, vol. 17, no. 22, Nov. 2024, Art. no. 5606, https://doi.org/10.3390/en17225606.

[2] S. Nadalipour Kaldeh, H. Yousefi, Y. Noorollahi, and M. Abdoos, "Integration of renewable sources in buildings: A review of energy savings, feasibility, and challenges," *Energy Reports*, vol. 14, pp. 3905–3934, Dec. 2025, https://doi.org/10.1016/j.egyr.2025.10.046.

[3] N. S. M. N. Izam, Z. Itam, W. L. Sing, and A. Syamsir, "Sustainable Development Perspectives of Solar Energy Technologies with Focus on Solar Photovoltaic-A Review," *Energies*, vol. 15, no. 8, Apr. 2022, Art. no. 2790, https://doi.org/10.3390/en15082790.

[4] F. A. Suwadana *et al.*, "Solar Irradiance Estimation in Tropical Regions Using Recurrent Neural Networks and WRF Models," *Energies*, vol. 18, no. 4, Feb. 2025, Art. no. 925, https://doi.org/10.3390/en18040925.

[5] M. A. I. Khan *et al.*, "An Experimental and Comparative Performance Evaluation of a Hybrid Photovoltaic-Thermoelectric System," *Frontiers in Energy Research*, vol. 9, Sept. 2021, Art. no. 722514, https://doi.org/10.3389/fenrg.2021.722514.

[6] S. M. Hashim and R. I. Hassan, "Impact of high temperature on PV productivity in hot desert climates," *Green Technology, Resilience, and Sustainability*, vol. 2, Dec. 2022, Art. no. 9, https://doi.org/10.1007/s44173-022-00009-9.

[7] A. R. Jatoi, S. R. Samo, and A. Q. Jakhrani, "Comparative Study of the Electrical Characteristics of Different Photovoltaic Modules in Outdoor Environment," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4600–4604, Oct. 2019, https://doi.org/10.48084/etasr.2976.

[8] L. Essak and A. Ghosh, "Floating Photovoltaics: A Review," *Clean Technologies*, vol. 4, no. 3, pp. 752–769, Aug. 2022, https://doi.org/10.3390/cleantechnol4030046.

[9] M. Al-Smairan, H. A. Khawaldeh, B. Shboul, and F. Almomani, "Techno-enviro-economic analysis of grid-connected solar powered floating PV water pumping system for farmland applications: A numerical design model," *Heliyon*, vol. 10, no. 18, Sept. 2024, Art. no. e37888, https://doi.org/10.1016/j.heliyon.2024.e37888.

[10] V. Keskin, "Performance evaluation of water-based and soil-based photovoltaic systems: energy, exergy, environmental, and economic perspectives," *Clean Technologies and Environmental Policy*, vol. 27, no. 10, pp. 5249–5270, Oct. 2025, https://doi.org/10.1007/s10098-025-03166-0.

[11] M. Dörenkämper, A. Wahed, A. Kumar, M. de Jong, J. Kroon, and T. Reindl, "The cooling effect of floating PV in two different climate zones: A comparison of field test data from the Netherlands and Singapore," *Solar Energy*, vol. 219, pp. 15–23, May 2021, https://doi.org/10.1016/j.solener.2021.03.051.

[12] A. Majumder *et al.*, "Cooling Methods for Standard and Floating PV Panels," *Energies*, vol. 16, no. 24, Dec. 2023, Art. no. 7939, https://doi.org/10.3390/en16247939.

[13] P. Yang, L. H. C. Chua, K. N. Irvine, M. T. Nguyen, and E.-W. Low, "Impacts of a floating photovoltaic system on temperature and water quality in a shallow tropical reservoir," *Limnology*, vol. 23, no. 3, pp. 441–454, Aug. 2022, https://doi.org/10.1007/s10201-022-00698-y.

[14] Y. Karatas and D. Yilmaz, "Experimental investigation of the microclimate effects on floating solar power plant energy efficiency," *Clean Technologies and Environmental Policy*, vol. 23, no. 7, pp. 2157–2170, Sept. 2021, https://doi.org/10.1007/s10098-021-02122-y.

[15] N. A. S. Elminshawy, A. Elminshawy, and A. Osama, "An innovative cooling technique for floating photovoltaic module: Adoption of partially submerged angle fins," *Energy Conversion and Management: X*, vol. 20, Oct. 2023, Art. no. 100408, https://doi.org/10.1016/j.ecmx.2023.100408.

[16] O. A. M. Adil, A. Y. Ali, and B. S. Sumait, "Comparison between the Effects of Different Types of Membership Functions on Fuzzy Logic Controller Performance," *International Journal of Emerging Engineering Research and Technology*, vol. 3, no. 3, pp. 76–83, Apr. 2015.

[17] A. Mahdavi, M. Farhadi, M. Gorji-Bandpy, and A. Mahmoudi, "A review of passive cooling of photovoltaic devices," *Cleaner Engineering and Technology*, vol. 11, Dec. 2022, Art. no. 100579, https://doi.org/10.1016/j.clet.2022.100579.

[18] T. Kjeldstad, D. Lindholm, E. Marstein, and J. Selj, "Cooling of floating photovoltaics and the importance of water temperature," *Solar Energy*, vol. 218, pp. 544–551, Apr. 2021, https://doi.org/10.1016/j.solener.2021.03.022.

[19] A. S. Al-Ezzi and M. N. M. Ansari, "Photovoltaic Solar Cells: A Review," *Applied System Innovation*, vol. 5, no. 4, July 2022, Art. no. 67, https://doi.org/10.3390/asi5040067.

[20] E. Nurdiana, R. Riza, I. Ifanda, and A. A. Basharah, "Performance of 10 kWp PV Rooftop System Based on Smart Grid in Energy Building PUSPIPTEK," in *2019 International Conference on Sustainable Energy Engineering and Application (ICSEEA)*, Oct. 2019, pp. 193–200, https://doi.org/10.1109/ICSEEA47812.2019.8938615.

[21] A. U. Chandavar, "Quantifying the performance advantage of using passive solar air heater with chimney for photovoltaic module cooling," *International Journal of Energy Research*, vol. 45, no. 2, pp. 1576–1586, 2021, https://doi.org/10.1002/er.5782.

[22] V.-S. Hudișteanu, N.-C. Cherecheș, F.-E. Țurcanu, I. Hudișteanu, and C. Romila, "Impact of Temperature on the Efficiency of Monocrystalline and Polycrystalline Photovoltaic Panels: A Comprehensive Experimental Analysis for Sustainable Energy Solutions," *Sustainability*, vol. 16, no. 23, Dec. 2024, Art. no. 10566, https://doi.org/10.3390/su162310566.

[23] M. Benghanem *et al.*, "Evaluation of the Performance of Polycrystalline and Monocrystalline PV Technologies in a Hot and Arid Region: An Experimental Analysis," *Sustainability*, vol. 15, no. 20, Oct. 2023, Art. no. 14831, https://doi.org/10.3390/su152014831.

[24] A. Sohail, M. S. Rusdi, M. Waseem, M. Z. Abdullah, F. Pallonetto, and S. M. Sultan, "Cutting-edge developments in active and passive photovoltaic cooling for reduced temperature operation," *Results in Engineering*, vol. 23, Sept. 2024, Art. no. 102662, https://doi.org/10.1016/j.rineng.2024.102662.

[25] F. R. dos Santos, G. K. Wiecheteck, J. S. das V. Filho, G. A. Carranza, T. L. Chambers, and A. Fekih, "Effects of a Floating Photovoltaic System on the Water Evaporation Rate in the Passaúna Reservoir, Brazil," *Energies*, vol. 15, no. 17, Aug. 2022, Art. no. 6274, https://doi.org/10.3390/en15176274.

[26] S. Sujay (Desai) Patil, M. M. Wagh, and N. N. Shinde, "A Review on Floating Solar Photovoltaic Power Plants," *International Journal of Scientific & Engineering Research*, vol. 8, no. 6, pp. 789-794, June 2017.

[27] P. Ranjbaran, H. Yousefi, G. B. Gharehpetian, and F. R. Astaraei, "A review on floating photovoltaic (FPV) power generation units," *Renewable and Sustainable Energy Reviews*, vol. 110, pp. 332–347, Aug. 2019, https://doi.org/10.1016/j.rser.2019.05.015.

[28] H. D. M. R. Perera, "Designing of 3MW Floating Photovoltaic Power System and its Benefits over Other PV Technologies," *International Journal of Advances in Scientific Research and Engineering*, vol. 6, no. 4, pp. 37-48, Aug. 2022, https://doi.org/10.31695/IJASRE.

[29] H. M. Pouran, M. Padilha Campos Lopes, T. Nogueira, D. Alves Castelo Branco, and Y. Sheng, "Environmental and technical impacts of floating photovoltaic plants as an emerging clean energy technology," *iScience*, vol. 25, no. 11, Nov. 2022, Art. no. 105253, https://doi.org/10.1016/j.isci.2022.105253.

[30] B. Ramkiran, C. K. Sundarabalan, and K. Sudhakar, "Sustainable passive cooling strategy for PV module: A comparative analysis," *Case Studies in Thermal Engineering*, vol. 27, Oct. 2021, Art. no. 101317, https://doi.org/10.1016/j.csite.2021.101317.

[31] E. Bellini, "Cooling solar panels with bio-inspired coconut fiber," *pv magazine International*, Feb. 27, 2023. https://www.pv-magazine.com/2023/02/27/cooling-solar-panels-with-bio-inspired-coconut-fiber/.

[32] A. Malvika, U. C. Arunachala, and K. Varun, "Sustainable passive cooling strategy for photovoltaic module using burlap fabric-gravity assisted flow: A comparative Energy, exergy, economic, and enviroeconomic analysis," *Applied Energy*, vol. 326, Nov. 2022, Art. no. 120036, https://doi.org/10.1016/j.apenergy.2022.120036.

[33] A. H. Siregar and P. Harahap, "Effect of Wind Temperature on Solar Panels and Efficiency," *Jurnal Teknik Elektro dan Komputer*, vol. 13, no. 2, pp. 97–102, 2024.