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# Preliminary Study on Enhancing Solar Panel Efficiency through Hydroponic Cooling

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**ABSTRACT**

*This study introduces a dual-purpose solar roof system that combines hydroponic agriculture with photovoltaic (PV) energy generation to enhance land use efficiency and address food and energy challenges. The system was designed, built, and tested using three 100W polycrystalline solar panels capable of tracking the sun's path to optimize energy capture. The research aimed to evaluate how integrating hydroponics beneath solar panels affects their thermal performance and energy output. Temperature sensors and performance monitoring tools were used to compare panels with and without hydroponic systems. Results showed that plant evapotranspiration cooled the solar panels by 2–5°C, leading to a 3–4% increase in energy efficiency. Simultaneously, the hydroponic system benefited from the shading effect of the panels, which moderated the microclimate, reduced water loss, and improved plant growth. These outcomes highlight the mutual benefits of combining solar energy and hydroponic farming, demonstrating the potential of agrivoltaics systems to support sustainable development in both urban and rural settings.*

**Keywords:** Dual-purpose solar roof, Hydroponics, Solar panel efficiency, Agrivoltaics, Renewable energy

## 1. INTRODUCTION

The increasing global population, projected to reach 9.7 billion by the year 2050, is expected to result in a 70 % rise in the demand for food production [1]. At the same time, the global energy sector is under pressure to transition from conventional fossil fuels to renewable energy sources in order to mitigate climate change and reduce greenhouse gas emissions. These parallel challenges underscore the necessity for integrated solutions that address both sustainable food production and clean energy generation. Solar photovoltaic (PV) systems have become a widely adopted technology for renewable energy generation due to their scalability and operational reliability. However, a significant limitation of these systems is the decline in energy conversion efficiency at elevated temperatures, with studies indicating a reduction of approximately 0.4 % to 0.5 % for every 1 °C increase above the optimal operating temperature [2]. In parallel, hydroponic agriculture has emerged as a highly efficient method of food production, offering improved crop yields and reduced water usage when compared to conventional soil-based agriculture [3].

The integration of solar PV systems with hydroponic agriculture has been proposed as a promising strategy to enhance land-use efficiency and support sustainable development goals.

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A dual-purpose solar roof system, in which photovoltaic panels provide shade for hydroponic cultivation, may offer mutual benefits: shading can reduce water evaporation and help regulate the microclimate for plant growth, while the evaporative cooling from the hydroponic system may contribute to lowering the operating temperature of the solar panels, potentially improving their overall performance [4,5]. Despite the theoretical advantages of such systems, empirical studies on the thermal interactions and performance impacts within integrated PV–hydroponic configurations remain limited. Recent studies have investigated combining solar panels with agricultural systems, especially hydroponics, to optimize land use efficiency. A dual-purpose solar roof creates renewable energy while offering shade for the hydroponic system, perhaps supporting a mutually beneficial ecosystem. The shading provided by the panels can reduce water evaporation and regulate temperatures within the hydroponic system, while the cooling effect from evaporated water from plants can decrease the temperature of the solar panels, therefore improving their performance [6]. Although this promising potential, research on the temperature changes caused by solar panels in integrated systems is limited compared to traditional systems.

The concept of dual-purpose solar roofs integrates PV systems with hydroponic agriculture to optimize land use and enhance sustainability. This approach allows for simultaneous electricity generation and food cultivation within the same spatial footprint. Semeraro et al. [7] reported that integrating PV systems with agriculture can reduce land use by up to 40%, making it particularly beneficial in densely populated areas. Additionally, Williams et al. [8] found that hydroponic systems placed beneath PV panels can reduce panel surface temperatures by 2–5°C through plant evapotranspiration, resulting in a 3–4% improvement in energy efficiency. Ravishankar et al. [9] further observed a 20% increase in crop yield under solar-integrated hydroponic systems compared to open-field hydroponics, due to better control of temperature and humidity. However, adequate design is required to ensure sufficient light reaches the crops. Novaldo et al. [10] evaluated a solar-powered hydroponic system with PV panels and AC pumps, confirming stable voltage output and consistent system performance. Their methodology and component specifications align closely with the present study, offering a validated model for dual-purpose system design.

This research aims to address the knowledge gap through developing a dual function solar roof system that combines energy production and hydroponic cultivation within the same physical unit. This study aims to examine changes in temperatures and their effects on solar panel efficiency to establish a system to ensure sustainable and effective resource utilization in the agriculture and energy sectors.

## 2. MATERIAL AND METHODS

This study implements a solar-powered hydroponic system designed to operate independently of grid electricity as shown in Figure 1. The system begins with solar panels that capture sunlight and convert it into direct current (DC) electrical energy, which serves as the primary power source. The generated DC power is directed at a solar charge controller that regulates voltage and current to safely charge a 12 V battery. This controller plays a crucial role in preventing overcharging and deep discharging, thereby ensuring battery longevity and system reliability. Once stored, the DC energy is converted into alternating current (AC) using a DC-to-AC inverter to power a submersible water pump, which requires AC input for operation. The pump circulates nutrient-enriched water from a reservoir to the hydroponic channels, where plant roots are submerged in the solution. The hydroponic setup is tilted to allow gravitational recirculation of the nutrient solution back into the reservoir, enabling a closed-loop system. This configuration ensures continuous nutrient delivery and water flow, even during periods of low solar irradiance or night-time, as the battery provides backup power.

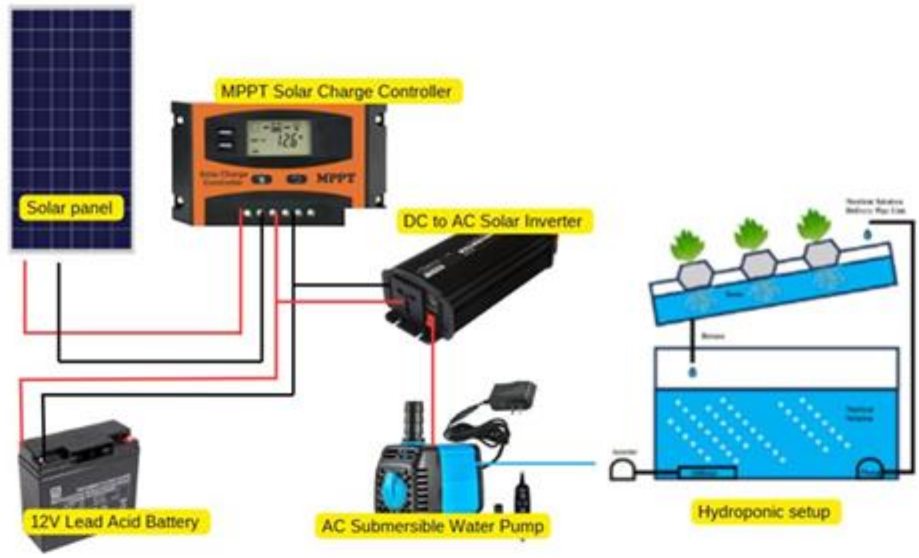


**Figure 1.** Circuit diagram of the system

A working physical prototype to support the feasibility of the dual-purpose solar roof system, including panel arrangement and system connections, were constructed and tested as shown in Figure 2. This ensures that this prototype can function in a real-world environment. The prototype combines solar panels with hydroponic system placed beneath them. Essential components such as water pumps, battery storage, solar charge controller, and project circuit were assembled to simulate full system integration. The design was optimized for space-saving and dual-functionality, offering simultaneous solar energy generation and crop cultivation within the same footprint. In this setup, three polycrystalline 100 W solar panels are employed as the energy source, with dimensions of each panel are 53.5 cm by 133 cm, providing sufficient surface area for effective solar energy harvesting.


(a) (b)

**Figure 2.** Actual (a) prototype and (b) electrical setup of the system

## 3. RESULTS AND DISCUSSION

The performance of the solar-powered water pump system is considered a crucial element to determine the effectiveness of integrating hydroponic systems with solar PV panels. There are several parameters to be emphasized during this study such as the weather condition, the water pump running hours and the battery performance. The weather condition is determined during the peak sunlight intensity for the solar panel to receive and produce electric charge mostly around 1.00 PM. The sunlight duration is estimated hourly each day. The water pump running hours are set to have 30 minutes delay before starting to pump again for 30 minutes every hour daily. The battery voltage is recorded daily at the end of each day at around 6.00 PM using a digital multimeter.

Table 1 presents the environmental and operational data recorded throughout the study period. The findings indicate a clear correlation between daily sunlight duration and the performance of the solar-powered water pump system. The average sunlight exposure was approximately six hours per day. On days with higher solar irradiance, such as Day 8 and Day 9, the battery voltage reached a peak of 12.5 V, enabling the pump to operate at its full 12-hour capacity. In contrast, reduced sunlight on Day 13 resulted in a lower battery voltage of 11.8 V and a shortened pump runtime of 10.5 hours. Minor declines in battery voltage were also observed on days with limited solar input due to light rainfall or partial cloud cover. These results underscore the critical role of solar availability in maintaining consistent system functionality. The average sunlight duration observed during the study was sufficient to sustain stable pump operation, indicating that the system design is well-suited for typical daily solar conditions. Overall, consistent performance throughout the testing period provided reliable data, enabling accurate evaluation of the system's operational efficiency and its suitability for integration with hydroponic agriculture.

**Table 1** Weather condition, sunlight hours, battery voltage

| Day | Weather Condition | Average Temperature (°C) | Sunlight Hours (hrs) | Pump Runtime (hrs) | Battery Voltage (V) |
|---|---|---|---|---|---|
| 1 | Partly Cloudy | 32.4 | 5.5 | 12 | 12.1 |
| 2 | Sunny | 33.1 | 6 | 12 | 12.4 |
| 3 | Mostly Sunny | 32.8 | 6 | 12 | 12.2 |
| 4 | Light Rain | 31.0 | 6 | 11 | 12.0 |
| 5 | Cloudy | 30.5 | 4.5 | 11 | 11.8 |
| 6 | Sunny | 33.1 | 6 | 12 | 12.3 |
| 7 | Partly Cloudy | 31.7 | 5 | 12 | 12.5 |
| 8 | Sunny | 33.0 | 6 | 12 | 12.5 |
| 9 | Sunny | 33.5 | 6.5 | 12 | 12.5 |
| 10 | Partly Cloudy | 32.6 | 6 | 12 | 12.4 |
| 11 | Partly Cloudy | 31.9 | 5.5 | 12 | 12.3 |
| 12 | Cloudy | 30.8 | 4.5 | 11 | 12.0 |
| 13 | Light Rain | 30.2 | 4.5 | 10.5 | 11.8 |
| 14 | Sunny | 33.2 | 6 | 12 | 12.5 |

Evaluation of solar panel temperature behavior under varying environmental and structural conditions is conducted using three panels: Panel 1 without hydroponic shading, and Panels 2 and 3 equipped with hydroponic systems beneath. Table 2 shows a critical insight into the hydroponic plant behaviour towards the thermal changes on the solar panels, During the first week, which is from Day 1 to Day 7, there are minimal temperature differences between the panels indicating the hydroponic plants are too immature to significantly influence the panel surface temperature. The difference in temperature from Day 1 to Day 7 ranges below 1 °C. For example, on Day 3, the panel temperature reading for Panel 1 is 56.8 °C while Panel 3 reached the temperature 56.5 °C. This temperature difference is considered significantly small to be counted to support this study. As the hydroponic plant grew and density from Day 8 onwards, the impact towards the solar panels becomes more visible and can be counted evident. For instance, on Day 10, Panel 1 reached 56.7 °C, while Panel 2 and 3 dropped to 54.6 °C and 54.7 °C respectively. From this observation, the delayed impact of the hydroponic plants towards the thermal behaviour of the solar panels requires sufficient plant development before it can impact the thermal behaviour of the solar panels. However, after the plants developed from Day 8 onwards, the change on the thermal behaviour becomes visible and showed consistent reduction in panel temperature which further reflects on the benefits of plant evapotranspiration and climate improvement.

**Table 2** Solar panels temperature analysis result

| Day | Average Ambient Temperature (°C) | Temperature of Panel 1 (without hydroponic setup) (°C) | Temperature of Panel 2 (with hydroponic setup) (°C) | Temperature of Panel 3 (with hydroponic setup) (°C) |
|---|---|---|---|---|
| 1 | 32.4 | 56.3 | 56.2 | 56.3 |
| 2 | 33.1 | 57.2 | 57.1 | 57.0 |
| 3 | 32.8 | 56.8 | 56.4 | 56.5 |
| 4 | 31.0 | 54.1 | 54.1 | 54.2 |
| 5 | 30.5 | 53.6 | 53.5 | 53.4 |
| 6 | 33.1 | 57.0 | 56.9 | 56.6 |
| 7 | 31.7 | 55.8 | 54.2 | 54.1 |
| 8 | 33.0 | 56.9 | 54.6 | 54.8 |
| 9 | 33.5 | 57.2 | 55.8 | 56.1 |
| 10 | 32.6 | 56.7 | 54.6 | 54.7 |
| 11 | 31.9 | 55.6 | 53.5 | 53.3 |
| 12 | 30.8 | 53.4 | 52.9 | 52.8 |
| 13 | 30.2 | 53.1 | 52.9 | 53.0 |
| 14 | 33.2 | 57.0 | 55.6 | 56.0 |

Figure 3 illustrates the thermal reduction effect of hydroponic shading under solar panels towards the panel surface temperature. The graph provides a visual representation of the growing impact of shading hydroponic plants towards the solar panels' thermal behaviour. Initially, from Day 1 to Day 7, the difference in temperature differences between panels are small showing small effects of the hydroponic plants towards the solar panels. Starting from Day 8, the separation of the temperature for Panel 1 and Panel 2 and 3 becomes more distinct, highlighting the increase in cooling effectiveness towards the solar panels with hydroponic setup shading below it. On Day 12, the difference between Panel 1 and Panel 2,3 shows maximum difference which supports the effectiveness of matured hydroponic crops in temperature behaviour of solar panels and further supports the solar panels efficiency enhancement.

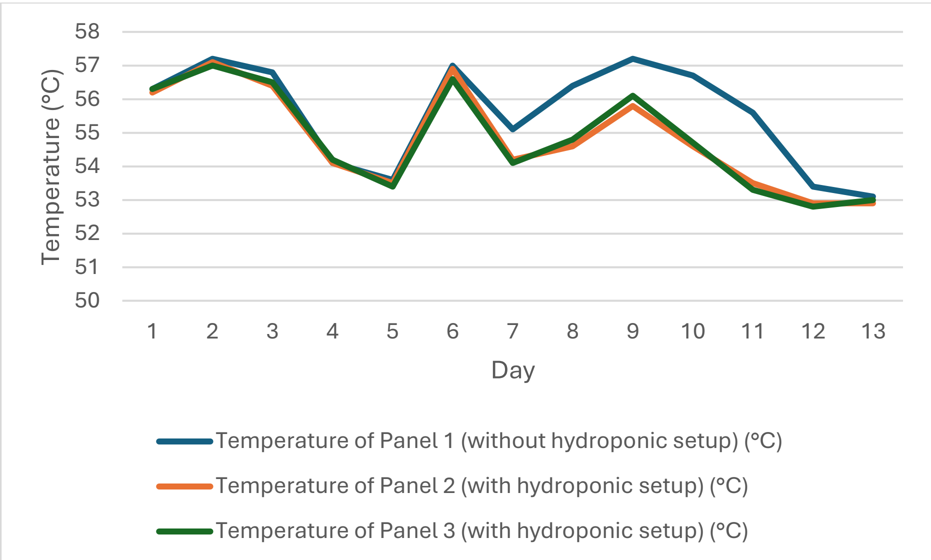


**Figure 3.** Daily solar panel temperature comparison

Assessment of solar panel efficiency is conducted to evaluate the impact of hydroponic plant shading on photovoltaic performance. Efficiency for each panel was calculated using its maximum power output, $P_{max}$ and the corresponding solar irradiance, measured daily with an irradiance meter. This method enabled comparative analysis across panels with and without hydroponic setups, as well as across different days, to determine the influence of plant development on panel performance. Table 3 presents the calculated efficiency values for each panel throughout the study period. From Day 1 to Day 8, efficiency remained relatively consistent across all panels, with differences below 0.2 %. This minimal variation is attributed to the early growth stage of the hydroponic plants, which had limited impact on panel temperature and performance. However, from Day 9 onwards, a noticeable improvement was observed in Panels 2 and 3, which were shaded by hydroponic systems. On Day 10, for instance, Panel 2 and Panel 3 achieved efficiencies of 7.4 8% and 7.55 %, respectively, compared to 7.25 % for Panel 1. These results confirm the performance benefits of hydroponic shading, which contributes to reduced thermal operating temperatures and enhanced energy conversion efficiency.

**Table 3** Solar panels efficiency result

| Day | Irradiance ($W/m^2$) | Efficiency Panel 1 (%) | Efficiency Panel 2 (%) | Efficiency Panel 3 (%) |
|---|---|---|---|---|
| 1 | 820 | 7.85 | 7.86 | 7.88 |
| 2 | 860 | 7.52 | 7.52 | 7.54 |
| 3 | 870 | 7.43 | 7.47 | 7.45 |
| 4 | 71. | 8.82 | 8.84 | 8.82 |
| 5 | 690 | 8.98 | 9.00 | 8.98 |
| 6 | 860 | 7.44 | 7.44 | 7.44 |
| 7 | 800 | 7.97 | 8.03 | 8.04 |
| 8 | 900 | 7.25 | 7.36 | 7.38 |
| 9 | 920 | 7.27 | 7.33 | 7.45 |
| 10 | 890 | 7.25 | 7.48 | 7.55 |
| 11 | 830 | 7.67 | 7.95 | 7.88 |
| 12 | 670 | 9.24 | 9.33 | 9.35 |
| 13 | 660 | 9.26 | 9.43 | 9.37 |
| 14 | 910 | 7.19 | 7.45 | 7.41 |

## 4. CONCLUSION

In summary, the dual-purpose solar roof system demonstrated effective energy generation, thermal performance, and agricultural support over a 14-day monitoring period. Surface temperature analysis revealed that hydroponic setups shading under solar panels began having a cooling effect on the solar panels starting from Day 8, which directly contributed to improved power output and energy conversion efficiency for Panels 2 and 3. The system's energy performance closely correlated with daily weather conditions, with all electrical parameters stabilizing during peak sunlight periods. The system operated reliably throughout the period, with no recorded faults, battery undervoltage, or irrigation failures, confirming the feasibility of autonomous operation. The overall results validate the system's design concept, proving that a hybrid solar-agriculture solution can be both technically sound and agriculturally productive, while offering environmental benefits such as temperature moderation and land-use optimization.

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**REFERENCES**

[1] About FAO In Action Countries Themes Media Publications Statistics Partnerships (2020).
[2] Bahaidarah, H., Subhan, A., Gandhidasan, P., Rehman, S. Energy. vol 59, issue 1 (2013) pp. 445-453.
[3] Mamta, D. S., Shraddha, V. A., Int. J. Res. Eng. Technol. vol 2, issue 3 (2013) pp. 299–304.
[4] Barron-Gafford, G. A., Minor, R. L., Allen, N. A., Cronin, A. D., Brooks, A. E., Pavao-Zuckerman, M. A., Sci. Rep. vol 6, issue 1 (2016) pp. 35070.
[5] Sarkar, S., Rahman, M. M., Trans. Electr. Electron. Mater. vol 21 (2020) pp. 377–383.
[6] Chandel, S. S., Nagaraju Naik, M., Sharma, V., Chandel, R., J. Ren. Ene. vol. 78 (2015) pp. 193–202.
[7] Semeraro, T., Scarano, A., Santino, A., Emmanuel, R., Lenucci, M. (2022)., J. Eco. Ser. vol. 56 (2022) pp. 101450.
[8] Williams, H. J., Hashad, K., Wang, H., Max Zhang, K., J. Ap. Energy. vol. 332 (2023) pp. 120478.
[9] Ravishankar, E., Charles, M., Xiong, Y., Henry, R., Swift, J., Rech, J., Calero, J., Cho, S., Booth, R. E., Kim, T., Balzer, A. H., Qin, Y., Hoi Yi Ho, C., So, F., Stingelin, N., Amassian, A., Saravitz, C., You, W., Ade, H., … O'Connor, B. T. Cell Reports Physical Science, 2(3). (2021).
[10] E. V. Novaldo, T. Dewi, Rusdianasari. "Solar energy as an alternative energy source in hydroponic agriculture: A pilot study", in Proc. - IEIT 2022: 2022 International Conference on Electrical and Information Technology, Malang, Indonesia, (2022) pp. 202-20.