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A Study To Minimize Efficiency Loss In Solar Panels Due To High Temperatures Using Innovative Cooling Techniques

Dr. Pande Ashish Madhukarrao[1], Dr. Lande Yogesh Dileep[2], Dr. Arote Keshav Chandrakant[3]

[1,2,3]Lecturer, Department of Mechanical Engineering, Amrutvahini Polytechnic Sangamner, Maharashtra, India.

Renewable energy systems rely on solar photovoltaic (PV) technology, which is very inefficient when exposed to high working temperatures. Solar panels lose efficiency as a whole, have lower open-circuit voltage, and higher internal resistance when they become too hot. Both water and air cooling were used in this investigation. Air cooling using a DC fan mounted on the PV module's rear was the first cooling solution. In contrast, there are two distinct approaches to water cooling in the second method. One involves attaching two aluminium blocks to the back of the PV module to act as cooling elements; the other involves attaching a copper perforated tube to the front of the module to act as a water sprayer. When compared to other methods, the average of the testing data reveals that spraying water cooling achieves the greatest efficiency gain, especially at high photovoltaic temperatures.

Keywords: Solar panel, Water cooling, Spraying, Photovoltaic, Temperature.

I. Introduction

In recent years, solar power has grown in popularity as a viable alternative to fossil fuels and a powerful tool in the fight against climate change. At the heart of this transformation are solar photovoltaic (PV) cells, which use the photovoltaic effect to transform sunlight into energy. But changes in temperature have a dramatic effect on solar cells' efficiency.[1] Solar panels lose some of their efficiency and effectiveness when exposed to direct sunlight because their surfaces become quite hot. Research shows that the efficiency of solar cells made of silicon might decrease by 0.3 to 0.5 percentage points for every degree Celsius as the temperature increases. To keep solar cells working at their best performance, efficient cooling solutions are essential, since this efficiency loss is caused by temperature.[2]

Efficiency in converting solar radiation into usable electricity is the primary determinant of a solar cell's performance. A significant contributor to these losses is the buildup of heat, which raises the photovoltaic material's internal resistance, lowers the band gap, and influences the open-circuit voltage.[3] Solar cells have a poorer return on investment (ROI) and a shorter lifetime due to overheating, which also affects their efficiency of energy conversion.

Consequently, to guarantee the durability and efficacy of solar panels in producing energy over the long term, it is essential to create efficient cooling methods to control their temperature.[4]

There have been several attempts to improve solar cell efficiency by cooling, with the most common approaches falling into two categories: active and passive cooling. To actively cool anything, you may use things like fans, pumps, or phase change materials (PCMs) to remove heat from the system.[5] While these systems do a good job of controlling temperatures, they frequently use more energy, which may make the efficiency gains seem like a wash. In contrast, passive cooling doesn't involve actively controlling the temperature; instead, it makes use of natural phenomena like convection, radiation, and conduction to dissipate heat.[6]

Heat exchangers based on nanofluids, water spraying, cooling fins, thermoelectric cooling, and heat sinks all fall within this category.

Because of their efficiency in dispersing heat and excellent thermal conductivity, water-based cooling systems have become more popular. There are a few various ways to use water for cooling, including circulating it under the solar panels, spraying it on the surface of the panels, or using a heat exchanger system.[7] By regulating the temperature of the solar panels, these techniques increase their efficiency and electricity production. Nanofluid cooling is another solution that shows promise. It involves dispersing nanoparticles in a base fluid (such as water or ethylene glycol) to enhance heat transfer capacities. According to studies, solar panels may be made much more efficient and perform better all around by using cooling systems that are based on nanofluids.[8]

One further cutting-edge method of cooling is the use of phase change materials (PCMs), which are able to collect heat as they change phases (such as solid to liquid) and then release that heat when the temperature drops. PCMs are a passive cooling solution that stabilizes solar panels' performance over long periods of time by successfully regulating temperature variations. As an additional option, thermoelectric cooling systems that make use of Peltier devices have been investigated. These gadgets effectively disperse surplus heat by creating a temperature gradient using electrical energy. While thermoelectric cooling is a great way to regulate the temperature of solar panels, it's not always practical due to concerns about energy consumption and cost.[9]

Another potential passive cooling method for solar panels is radiative cooling, which entails dissipating surplus heat into space via the release of infrared radiation. To further reduce the total heat load on the solar cells, reflecting materials or specially formulated coatings may further this cooling effect. Solar panels may be even more efficient when subjected to high temperatures if they are coated with spectral-selective materials that reduce their absorption of infrared light while increasing their absorption of visible light.[10]

Many things must be considered while choosing a cooling system, such as the weather, budget, energy use, and complexity of the system. Hybrid cooling systems, which include active and passive cooling techniques, may provide the most effective performance for preserving the efficiency of solar panels in areas with high ambient temperatures and sun irradiation. In order to make solar cells that last longer and work better, scientists are always looking for new materials, better nanotechnology, and ways to include cooling.

II. Review Of Literature

Parthiban, Ravi et al., (2022)[11] Solar panels, which generate clean, renewable power, have recently risen in popularity among alternative energy sources. One unfavorable feature is that photovoltaic efficiency drops as the ambient temperature rises. There is a 0.33 percent drop in energy production for every degree Celsius above STC. The output of the solar panel may not be sufficient to power the load, however. Because of space constraints, it would not be feasible to install an additional solar panel to compensate for the decreased output power in certain applications, such freestanding electric automobiles. This extreme heat might be reduced with the help of the cooling solutions. A variety of cooling solutions, including both active and passive methods, have been used. This article provides a summary of methods for increasing the efficiency of solar panels by combining TEG with them and using different cooling strategies.

Sharaf, Mohamed et al., (2022)[12] Photovoltaic (PV) panels are among the most powerful methods for directly converting solar radiation into electrical power. The efficiency of solar panels is affected by both internal and external factors. Environmental factors like as wind speed, incoming radiation rate, temperature, and dust accumulation on the PV cannot be controlled by it. Controllable internal variables include things like PV surface temperature. Some of the light that reaches the photovoltaic cell's surface is transformed into electricity, while the remaining light is absorbed by the cell itself. This causes an increase in its surface temperature. Higher panel temperatures, worse conversion performance, and reduced reliability over the long run are all undesirable side effects. Consequently, several cooling systems have been researched and designed to effectively control temperature rise and enhance their functionality. Passive cooling, active cooling, phase change material (PCM) cooling using nanoparticles or porous metal additions, and PCM cooling with other methods are all viable options for reducing the temperature of solar cells. This study evaluates and analyzes the common methods used to cool PV panels, with a focus on the final techniques, and summarizes all the research that has dealt with cooling PV solar cells using PCM and porous materials.

Sorogin, A.S. et al., (2022)[13] Specialized cooling systems are necessary to maintain the coolness of solar panels throughout the scorching summer months. The most effective means of cooling include the use of a pump to enable the flow of liquid. Several potential approaches for cooling solar panels are described and evaluated in this article. The research is essential because during the hot season, it is necessary to reduce the temperatures of the solar panels in order to increase their output power. The main goal of this research is to find the most effective way to cool solar panels. Method: doing research and modeling using the ANSYS software package. The article compares the features of TEM, radiators, fans, and liquid cooling, and provides an example of how to use the former to spray a 29 l/min flow of liquid over a solar panel. It takes 4.7 minutes for the panels to cool down from 45 to 35 °C. A single 100 W EasySunSolar solar panel is included in the price.

Abbas, Ahmed et al., (2021)[14] The need for a new, sustainable, and ecologically friendly electrical energy source has been brought to light by the increased power use and serious global climate change issues. When dust forms on solar panels or other energy-generating surfaces, the efficiency of these devices drastically decreases. You can cool down and wash off with water. The Proteus and MikroC tools were used to construct the model and code. Do the experimental results back up the suggested cleaning and cooling solutions for photovoltaic (PV) modules in Ramadi, Iraq? The significance-decreasing effects of dust and heat will determine how this all starts. This was accomplished by displaying two almost similar solar panels side by side. After the basic unit had a model of the cleaning structure fitted, it was deemed standard. A more effective method of cleaning and cooling is yours with the data collecting framework. Vitality profitability increased by 12.4% as a result of less operational annoyances caused by residue buildup and heat of the board surface. Minimizing human stress, the system's cleaning procedure automatically washes the PV panel with low energy use.

Laseinde, Opeyeolu et al., (2021)[15] A large number of microgrids have been established to augment utility electricity in response to the continuously rising demand for power from main grids. Solar radiation is a sustainable and long-term renewable resource, which is why solar farms have recently gained popularity as an energy production method. As we enter the fourth industrial revolution, more and more countries are investigating this alternate power source, and the figures speak for themselves. Solar panels get heated as they absorb heat from the sun. The heat makes it harder for them to regulate their temperature, which slows down their power production. The intense heat from the sun limits the amount of energy that solar cells can generate. Focused photovoltaic (PV) systems rely heavily on solar panel collimation. The primary focus of this study is an optimization approach for a water spraying system that operates automatically. A major problem with solar panels in hot weather has been effectively addressed by this method. Using an Arduino board as part of a microcontroller-based thermal control water spraying system was discovered to increase the efficiency of the solar cells. According to the study's findings, a cooling algorithm for solar collectors may be designed and built using a thermal management feedback system, which can increase the array efficiency of solar panels by 16.65%.

Soliman, Aly et al., (2019)[16] The report describes an experimental analysis of solar cells' efficiency when used with a heat sink. We set up an indoor experimental setup to evaluate the effects of a heat sink cooling system on solar cell performance. The experiment is carried out under halogen lights that mimic different intensities of sunlight. The research heat sink is cooled using both natural and forced air. The results show that using a heat sink cooling method improves the performance of the solar cell. The temperature of the solar cells was reduced by around 5.4% when using a heat sink cooling system with natural air over it, and by about 11% when using forced air over it. The efficiency and output of the solar cell system are increased by about 16% when a heat sink cooling system is used.

Popovici, Cătălin-George et al., (2016)[17] Operating temperature is a crucial factor that dictates how efficient solar panels are in converting sunlight into usable energy. Maximum output power drops as working temperatures rise, even while solar radiation levels remain constant. An algorithm for cooling solar panels with air-cooled heat sinks is described in this computer study. Built from a highly thermally conductive substance, the heat sink has a ribbed wall shape. By changing the angle between the base plate and the ribs, several heat sink layouts are tested for cooling efficiency. Using the ANSYS-Fluent tool for turbulent flow, the numerical model was realized and the results for the average solar panel temperature are provided.

Thakur, Dharmendra et al., (2016)[18] As soon as photons from the sun reach a solar cell, they are converted into electricity. The most significant downside of the solar cell is its low efficiency. As the surface area of solar panels increases, its efficiency decreases. For photovoltaic modules, the sweet spot for conversion efficiency is about 15%. The solar system's operational temperature rises due to the released thermal energy, which affects the electrical power production of the PV modules. In addition to reducing the modules' conversion efficiency and longevity, this heat has the ability to harm their structures. Solar panels may have their temperatures down and their cell efficiency increased by submerging them in a liquid. Another option for keeping the panel cool is to attach a fan to its reverse side and run it continuously. This might make it work as a solar air heater, lowering the ambient temperature while raising the air temperature. In order to lower the inside temperature below the ambient temperature, heat must be transferred from one place to another or from one air to another. This is known as cooling. One major issue with concentrated solar cell arrays is keeping their temperature constant.

III. Experimental Setup

Utilized is a 36*30-centimetre monocrystalline solar module. The digital mustimeter and indicator both measure voltage and current to the nearest tenth of a milliampere. Measurement of solar radiation is done using a solar power meter (TES 1333R), and the temperature of the PV module is measured using an infrared thermometer ranging from -50˚C to 550˚C (-58˚F to 1022˚F). The following formula was used to compute the efficiency.

$$\eta = \left(\frac{P_{MAX}}{A * E_{STND}}\right) * 100\%$$

The variables PMAX, A, and ESTND stand for the solar cell's area, irradiance, and standard operating conditions, respectively. The efficiency formula takes into account the area of the PV module, the amount of solar radiation, and the current and voltages read from the devices, which are generated by varying the value of the variable resistance. The procedure for determining efficiency in measuring devices is shown in Figure (1).

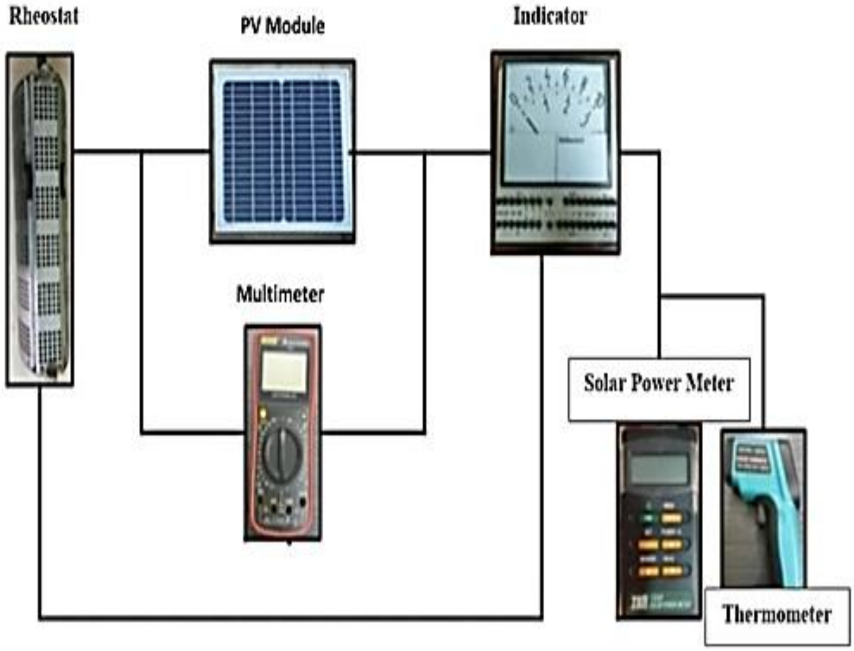

Figure 1: Schematic diagram of measuring efficiency

The cooling methods used in this research are: -

Air cooling

Figure 2 shows the air-cooling system that uses a DC fan technology. The fan, which is 12 volts, is installed at the back of the PV module to decrease heat and bring its temperature closer to that of the weather.

Figure 2: DC Fan

Water cooling

Two water cooling techniques were used as follows.

- **Water cooling blocks**

Installed on the reverse side of the PV module are two aluminum blocks with two holes punched into them for water exchange and transmission, as seen in Figure 3.

They get their water supply from a tank that has a pump that circulates the water in a closed system.

The closed cycle is illustrated by the following process: water is exchanged from the tank, via nylon tubes, to the first and second cooling blocks, and then back to the tank, where it is raised again by the pump.

This process continues until the closed internal cooling process is finished.

Figure 3: Water cooling blocks

- **Spraying water cooling**

Figure 4 shows the front surface of a PV module with a perforated copper tube fitted to cool the module using this method. The water is circulated in a closed system via two tanks, using a pump to increase the water level, and then it is sent to the copper tube that sprinkles water on the module's surface through nylon tubes, much like in the previous process.

Since the water that is left behind after spraying is often laden with dust and grime that has settled onto the module's surface due to environmental factors, this method incorporates a filter to remove these contaminants.

This method is thought of as simultaneously cleaning and cooling the PV.

Figure 4: Spraying water cooling

All three of the aforementioned cooling technologies—air cooling, water cooling, and heat exchangers—are powered by batteries (12 volt). Whenever the battery charger detects that the battery is low, it will begin charging the battery again.

Taking the PV's temperature is the most crucial test in this article as it tells us if the module requires cooling or not.

On test days, the average temperature is 35 degrees Celsius. Sunlight during the times of measurement was used to conduct the calculations in the months of April, May, and June, between the hours of 8 a.m. and 4 p.m. The angle of tilt for all measurements was 33˚.

IV. Results And Discussion

Table 1 displays the relationship between PV temperature and the power and efficiency of the PV module as a function of solar radiation.

Table 1: Performance of Solar Panel without cooling system

Time (hours)	**Solar irradiance (W/m2)**	**PV Temperature (˚C)**	**PMAX (W)**	**Efficiency %**
8:00-09:00	620	54.5	6.72	10.11
09:00-10:00	735	58.2	7.34	9.31
10:00-11:00	850	64.1	8.02	8.74
11:00-12:00	980	68.2	8.26	7.8
12:00-13:00	1050	71.4	8.43	7.41
13:00-14:00	835	63.5	8.2	8.01
14:00-15:00	760	59.4	7.51	9.17
15:00-16:00	570	52.2	6.21	10.21

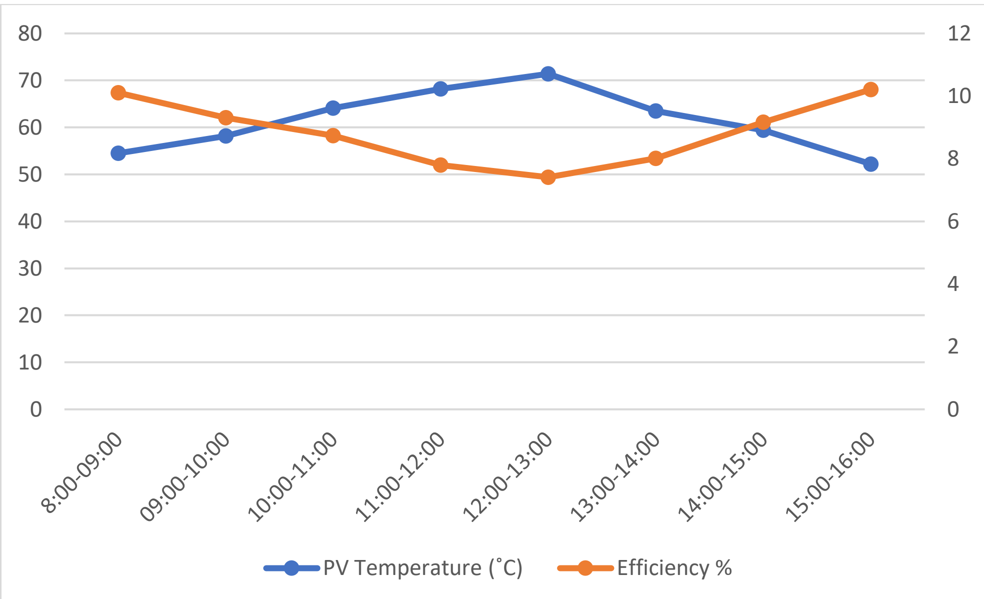

Figure 5: Performance of Solar Panel without cooling system

An obvious correlation between solar irradiation, panel temperature, and efficiency is shown by the solar panel's performance in the absence of a cooling mechanism. Solar irradiation peaks at 1050 W/m² at 12:00 PM, after rising from 620 W/m² at 8:00 AM, while the panel temperature reaches 71.4°C at the same time. While efficiency falls from 10.11% to 7.41%, power output (PMAX) rises from 6.72 W to 8.43 W during this time. The panel temperature reduces throughout the afternoon due to decreasing irradiance, leading to a modest improvement in efficiency. By 4:00 PM, this improvement had reached 10.21%. Even though the amount of light reaching solar panels increases, this trend shows that efficiency decreases as temperatures rise.

Table 2 show the results of using DC fan for cooling.

Table 2: Performance of Solar Panel with DC fan cooling

Time (hours)	PV Temperature (˚C)	PMAX (W)	Efficiency %
8:00-09:00	38.2	7.47	11.14
09:00-10:00	42.1	8.14	10.12
10:00-11:00	48.1	8.42	9.64
11:00-12:00	52.2	9.1	8.58
12:00-13:00	55.2	9.33	8.15
13:00-14:00	47.6	8.73	9.7
14:00-15:00	43.4	8.21	10.08
15:00-16:00	36.5	7.01	11.42

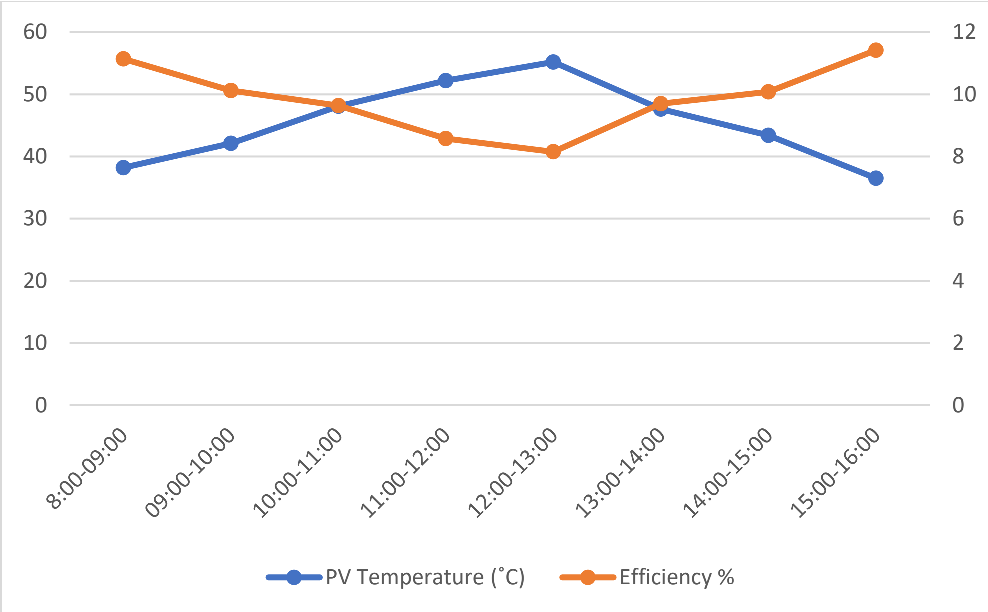

Figure 6: Performance of Solar Panel with DC fan cooling

A DC fan cooling device greatly enhances the performance of the solar panel. Compared to the uncooled system, the panel temperature stays lower all day, reaching a midday high of 55.2°C. Consequently, PMAX power output is continuously greater, peaking at 9.33 W at 12:00 PM. By 4:00 PM, efficiency had also improved to 11.42%, maintaining values over 8% even at peak temperatures. When compared to a panel without cooling, one with cooling significantly improves power production and efficiency by reducing the detrimental effects of heat.

Table 3 displays the outcomes of the experiment involving the use of water-cooling blocks made of aluminum.

Table 3: Performance of Solar Panel with water cooling blocks

Time (hours)	PV Temperature (˚C)	PMAX (W)	Efficiency %
8:00-09:00	44.4	7.15	10.54
09:00-10:00	48.2	7.82	9.75
10:00-11:00	55.0	8.2	9.21
11:00-12:00	59.5	8.72	8.20

12:00-13:00	63.2	9.2	8.04
13:00-14:00	54.5	8.4	9.21
14:00-15:00	50.1	8.1	9.7
15:00-16:00	42	6.74	11.04

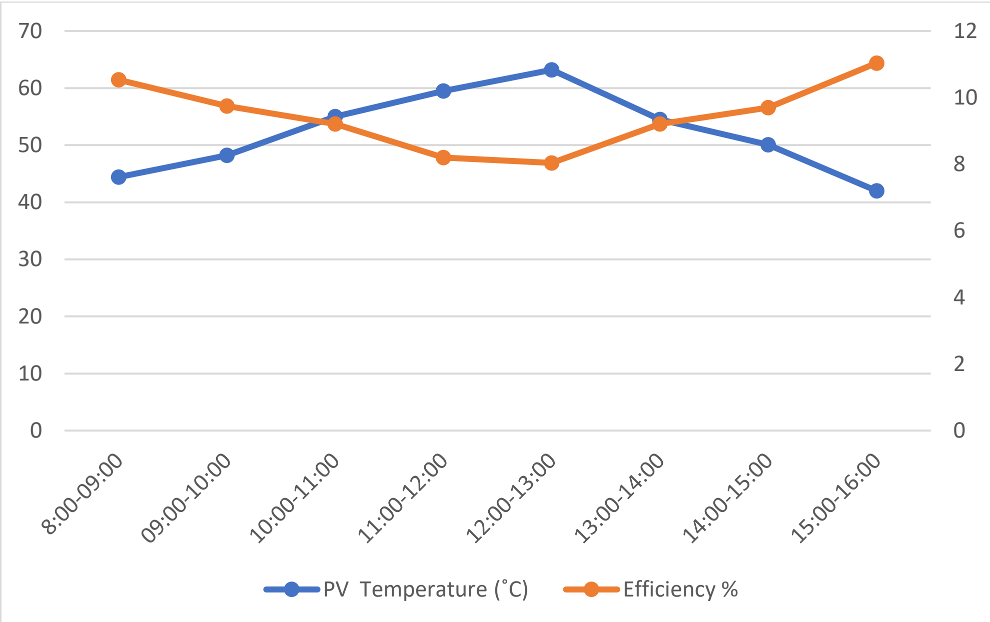

Figure 7: Performance of Solar Panel with water cooling blocks

Solar panels that use water cooling blocks outperform those without cooling, although they still fall short of DC fan cooling systems. Even during midday, the panel temperature reaches a mild high of 63.2°C. Efficiency varies but stays greater than the non-cooled system, and power output (PMAX) reaches a maximum of 9.2 W at this peak. Midday efficiency is 8.04% and by 4:00 PM it has risen to a respectable 11.04%. Despite being somewhat less efficient and producing slightly lower maximum power output than the DC fan cooling system, the water cooling system stabilises performance and improves overall efficiency by reducing temperature.

The outcomes of using the spray water cooling approach are shown in Table 4.

Table 4: Performance of Solar Panel with spraying water cooling

Time (hours)	**PV Temperature (˚C)**	**PMAX (W)**	**Efficiency %**
8:00-09:00	32.2	7.79	11.33
09:00-10:00	37.0	8.35	10.54
10:00-11:00	43.7	9.04	10.12
11:00-12:00	48.3	9.32	8.58
12:00-13:00	51.2	9.62	8.64
13:00-14:00	43.0	9.07	10.1
14:00-15:00	38.2	8.50	10.32
15:00-16:00	30.5	7.21	11.81

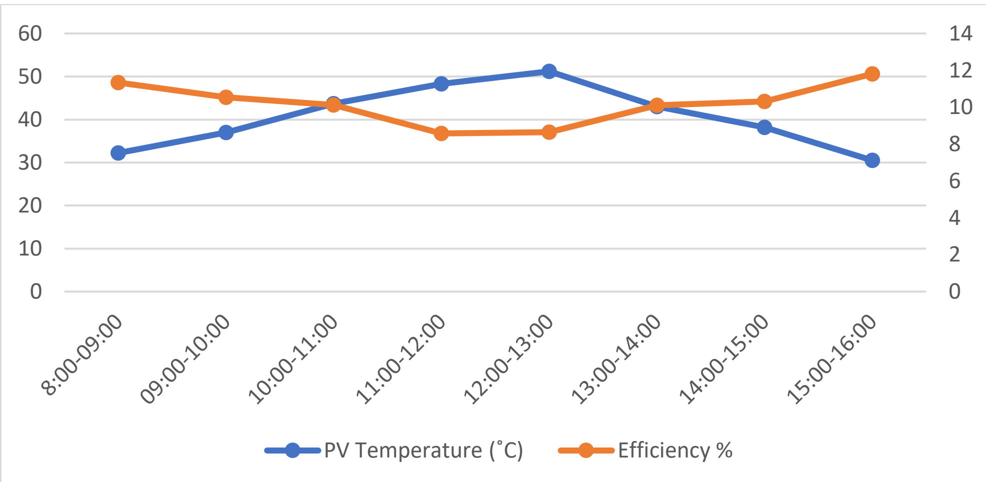

Figure 8: Performance of Solar Panel with spraying water cooling

Solar panels equipped with water spray cooling systems outperform all other technologies that were examined.

At midday, the panel temperature reaches a low of 51.2°C, and it stays there throughout the day. This efficient cooling keeps efficiency fairly constant all day long and results in a maximum power output (PMAX) of 9.62 W.

During peak circumstances, efficiency values remain over 8.5 percent and peak at 11.8 percent by 4:00 in the afternoon. The spraying water system is superior to the DC fan and water block cooling techniques in terms of temperature control, power output optimization, and overall efficiency.

V. Conclusion

Cooling solutions are needed since the findings show that power production and efficiency are significantly affected by growing PV module temperature. The most efficient and successful way for decreasing module temperature and boosting efficiency was spraying water cooling, but air cooling with a DC fan and water cooling with aluminum blocks were also considered. It was determined that the spraying water approach for cooling is the most effective and appropriate way for hot areas.

The research verifies that the best way to maximize energy production is to use cooling solutions that mitigate efficiency losses caused by temperature. In order to make hybrid cooling systems that use various approaches more effective and scalable for real-world applications, future research should concentrate on improving these systems.

By guaranteeing more dependable and efficient PV module performance in high-temperature circumstances, these results assist to improving the sustainability of solar energy.

References: -

[1] T. V. R. Sekhar, G. Nandan, R. Prakash, and M. Muthuraman, "Investigations on viscosity and thermal conductivity of cobalt oxide-water nanofluid," Materials Today: Proceedings, vol. 5, no. 2, pp. 6176–6182, 2018.

[2] T. V. R. Sekhar, R. Prakash, G. Nandan, and M. Muthuraman, "Pressure drop characteristics & efficiency enhancement by using TiO_2-H_2O nanofluid in a sustainable solar thermal energy collector," International Journal of Environmental Sustainability and Development, vol. 17, no. 2/3, pp. 273–294, 2018.

[3] J. Vadhera, A. Sura, G. Nandan, and G. Dwivedi, "Study of phase change materials and its domestic application," Materials Today: Proceedings, vol. 5, no. 2, pp. 3411–3417, 2018.

[4] N. Milind, M. Antony, F. Febin, J. Francis, J. Varghese, and S. K, "Enhancing the Efficiency of Solar Panel Using Cooling Systems," International Journal of Engineering Research and Applications, vol. 7, no. 3, pp. 05–07, 2017.

[5] T. V. R. Sekhar, R. Prakash, G. Nandan, and M. Muthuraman, "Preparation of CO_3O_4-H_2O nanofluid and application to Cr-60 concentrating solar collector," Progress in Industrial Ecology: An International Journal, vol. 11, no. 3, p. 227, 2017.

[6] Z. A. Haidar, J. Orfi, H. F. Oztop, and Z. Kaneesamkandi, "Cooling of solar PV panels using evaporative cooling," Journal of Thermal Engineering, vol. 2, no. 5, pp. 928–933, 2016.

[7] L. Lin, H. Yu, and Q. Ronghui, "Parameter analysis and optimization of the energy and economic performance of solar-assisted liquid desiccant cooling system under different climate conditions," Energy Conversion and Management, vol. 106, pp. 1387–1395, 2015.

[8] S. Mehrotra, P. Rawat, M. Debbarma, and K. Sudhakar, "Performance of a solar panel with water immersion cooling technique," International Journal of Science and Environment Technology, vol. 3, no. 3, pp. 1161–1172, 2014.

[9] K. Moharram, M. Abd-Elhady, H. Kandil, and H. El-Sherif, "Enhancing the performance of photovoltaic panels by water cooling," Ain Shams Engineering Journal, vol. 4, no. 4, pp. 869–877, 2013.

[10] L. Zhu, R. F. Boehm, Y. Wang, C. Halford, and Y. Sun, "Water immersion cooling of PV cells in a high concentration system," Solar Energy Materials and Solar Cells, vol. 95, no. 2, pp. 538–545, 2011.

[11] P. Parthiban and P. Ponnambalam, "An Enhancement of the Solar Panel Efficiency: A Comprehensive Review," Frontiers in Energy Research, vol. 10, no. 1, pp. 1–15, 2022.

[12] M. Sharaf, M. S. Yousef, and A. Huzayyin, "Review of cooling techniques used to enhance the efficiency of photovoltaic power systems," Environmental Science and Pollution Research, vol. 29, no. 18, pp. 26131–26159, 2022.

[13] A. S. Sorogin and R. N. Khamitov, "Ways to Increase the Efficiency of Solar Panels Operating in Isolated Power Supply Systems," Resource-Efficient Technologies, vol. 4, no. 1, pp. 1–9, 2021.

[14] A. Abbas, K. W. Abid, O. Ibrahim, Y. Al Mashhadany, and A. Jasim, "High performance of solar panel based on new cooling and cleaning technique," Indonesian Journal of Electrical Engineering and Computer Science, vol. 24, no. 2, pp. 803–814, 2021.

[15] O. Laseinde and M. Ramere, "Efficiency Improvement in Polycrystalline Solar Panel Using Thermal Control Water Spraying Cooling," Procedia Computer Science, vol. 180, no. 3, pp. 239–248, 2021.

[16] A. Soliman, H. Hassan, and S. Ookawara, "An Experimental Study of the Performance of the Solar Cell with Heat Sink Cooling System," Energy Procedia, vol. 162, no. 2, pp. 127–135, 2019.

[17] C.-G. Popovici, S. V. Hudisteanu, T. Mateescu, and N.-C. Chereches, "Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks," Energy Procedia, vol. 85, pp. 425–432, 2016.

[18] D. Thakur, A. Arnav, A. Datta, and E. V. V. Ramanamurthy, "A Review on Immersion System to Increase the Efficiency of Solar Panels," International Journal of Advanced Research, vol. 4, no. 3, pp. 312–325, 2016.