PHOTOVOLTAIC PANEL WATER COOLING SYSTEMS: A REVIEW OF THE DESIGN CONSIDERATIONS ON IMPROVING PHOTOVOLTAIC EFFICIENCY

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ABSTRACT

This paper reviews the design considerations that improve the overall efficiency and performance of photovoltaic panels. A literature search yielded more than 25 references which were narrowed to five recent documents on emerging new technologies and methodologies on improving photovoltaic panels through the use of water cooling systems. Some of the most frequent design factors that were considered included the structural aspect of the photovoltaic panel, the materials used and its environmental impact, and the reduction of the maintenance cost in operating these photovoltaic panels.

Keywords: *efficiency, literature review, photovoltaic, water cooling*

INTRODUCTION

The issue that this study focuses on is the photovoltaic (PV) panels' subpar performance as a result of too much heat buildup, which lowers PV efficiency. This study intends to analyze design factors and investigate how well water cooling systems work to increase PV panel efficiency. This study aims to pinpoint the main obstacles, constraints, and viable remedies for installing water cooling systems for PV panels by reviewing the pertinent literature and assessing the state of the art in PV panel cooling approaches. The main goal is to ascertain the viability and advantages of utilizing water cooling technologies to improve PV panel thermal management and increase their energy conversion efficiency. In this paper, the researchers review the design considerations on improving efficiency and performance of photovoltaic panels. Specifically, the researchers accumulate recent literature to formulate an effective list of photovoltaic panel design factors that industry designers should consider. The following were the most frequently identified design factors:

- Structural aspect of the photovoltaic design.
- Materials and environmental impact
- Maintenance cost reduction.

The following pages describe the researcher's methodology, literature cited, and the design considerations identified. Annotated references also offer specific information for each article, such as the issues addressed, their significance, a summary, and the design considerations noted.

METHODOLOGY

The researchers conducted keyword searches in numerous databases to identify the relevant literature:

- World Wide Web (Google), limited search
- National Renewable Energy Laboratory (NREL) publication database
- ResearchGate publication database

- Elsevier publication database
- IOP Science publication database

The researchers searched the databases using three main processes, albeit the structure of each database necessitated some variation in search techniques. The first procedure used the terms (*solar* or *photovoltaic*) and *design factor(s).* The second procedure used the terms (*solar* or *photovoltaic*) and *design consideration(s)*. The third procedure used the terms (*solar* or *photovoltaic*) and (*efficiency* and *performance*). Due to the rapid growth in the engineering industry, the researchers limited their searches to documents published in 2012 or later. The researchers accumulated 25 references.

The following criteria were used to reduce the full list of references:

- Document focusing on the effects of environmental factors on the efficiency of the photovoltaic panels.
- Documents focusing on new materials integrated to current photovoltaic designs that improves power output of the photovoltaic panels.
- Documents focusing on the relationship of the variations on the structural aspect in designing photovoltaic panels.
- Documents assessing the overall maintenance cost reduction of a specific design of a photovoltaic module.

Documents Reviewed

The five documents reviewed represent a range of sources. All of the documents address solar technologies, specifically on the effects of water cooling to photovoltaic efficiency and performance. The methods utilized to detect different design factors in the evaluated papers fell into two categories: analysis and feedback. Energy policy analysis is the most common type of analysis, which is usually seen in Energy Policy publications. Fuchs and Arentsen (2002), for example, use a "coevolutionary method" to examine electricity policy and its impact on renewable energy, which incorporates consumer and producer views as well as the importance of interactive learning in technology development. Other studies have been conducted in the fields of finance (Goldman et al. 2005), economics (Neuhoff 2005), and architectural design (Goldman et al. 2005). (Sozer and Elnimeiri 2003).

Design Considerations Identified

The list below contains the most frequent identified design factors to be considered when designing photovoltaic panels. The number indicated in the parenthesis, out of five, is the number of articles identifying the factors. For additional information, the following were the annotated references and the original sources.

- Structural aspect of the design (3)
- Materials and panel composition (3)
- Maintenance Cost Reduction (3)
- Environmental factors (2)

Structural aspect of the design. This aspect represents the components that are used to support the photovoltaic panels and the orientation of the materials and components used in the design in order to satisfy the structural requirements of the model due to the location, field configuration, necessary resistance to snow and wind loads, geotechnical studies, model, and weight of the panels.

Materials and panel composition. This includes recent technological advancements that aid in overall efficiency improvement. This includes newly developed photovoltaic circuit components as well as new design methodologies for creating the solar panel's circuitry.

Maintenance cost reduction. This includes design methodology that employs innovative and strategic planning to reduce the frequency of photovoltaic panel maintenance.

Environmental factors. This includes factors such as weather variations, changes in climate temperature, the impact on wildlife habitats, and potential changes in land structure and area vegetation.

Table 1. Summary of documents reviewed

TITLE OF THE STUDY	AUTHOR/(S):	SOURCE TYPE	SIGNIFICANCE	ISSUES
"Cost effective cooling of photovoltaic modules to improve efficiency"	Sajjad et al (2019)	Case Study	This report compares the power output, performance ratio, and efficiency of photovoltaic modules with cooling.	Installing photovoltaic modules on an air conditioner's chilled air duct improves performance, efficiency, and the construction of a cost-effective cooling system.
"Increasing the efficiency of Photovoltaic panels through cooling water film"	Dorobantu, L. & Popescu, M.O.(2013)	Experimental Study	The study was able to eliminate losses caused by the presence of deposits on the panel surface by installing a unique mechanism designed to disperse a water film on the panel surface.	High operating costs and lower energy efficiency as the surface temperature of the photovoltaic panel rises
"Enhancing Photoelectric Conversion Efficiency of Solar Panel by Water Cooling"	Musthafa MM (2015)	Research Article	To limit the growth in photovoltaic panel module temperature, the researchers used a sponge as a water absorption medium on the rear surface of the solar panel.	Reduction of temperature of solar cells for an increase in its electrical conversion efficiency.
"A Passive Cooling System for Increasing Efficiency of Solar Panel Output"	Sunarno A. Rakino et al (2019)	Journal Article	Solar panel cooling systems use both water and straight fins heat sink (SFHS) in the back side of the solar panel. Water is filled into an array of aluminum beam/cuboids. The cuboids are then attached at the back of the solar panel	Increased surface temperature of photovoltaic panels causes a decrease in efficiency.
"An Overview of Factors Affecting the Performance of Solar PV System"	Dr. K.V. Vidyanandan (2017)	Journal Article	The efficiency and power production of photovoltaic cells decreases as the temperature rises, thus, the module temperature creates significant impact. Considering floating photovoltaic systems in bodies of water solves land area spaces and will have more efficiency since modules are naturally cooled by bodies of water.	Identification of Factors affecting Solar photovoltaic Performance and Efficiency

Annotated References

1. Sajjad, U., Amer, M., Ali, H. M., Dahiya, A., & Abbas, N. (2019). Cost effective cooling of photovoltaic modules to improve efficiency. Case Studies in Thermal Engineering, 14, 100420. https://doi.org/10.1016/j.csite.2019.100420

Issues Addressed: Installing photovoltaic modules on an air conditioner's chilled air duct improves performance, efficiency, and the construction of a cost-effective cooling system.

Significance: This report compares the power output, performance ratio, and efficiency of photovoltaic modules with cooling.

Summary: The researchers examined the efficiency of two solar modules, one of which was water cooled and the other which was not. When compared to the module without cooling, the cooled module had a 7.2 percent increase in electrical efficiency and a 6 percent increase in performance ratio.

Design considerations identified

- **Maintenance cost reduction**: The photovoltaic modules were installed on the duct of cooled air of an air conditioner which provides additional cooling with the circulation of air on the module surface.
- **Structural aspect of the design:** Since the photovoltaic modules were installed on the air ducts, it reduces the space needed for installing both the air ducts and the photovoltaic modules. Thus, making the set-up consumes less space. Also, with this sort of cooling, the module's electrical efficiency and performance ratio increased by 7.2 percent and 6 percent, respectively.

2. Dorobantu, L. & Popescu, M.O. (2013). Increasing the efficiency of photovoltaic panels through cooling water film. UPB Scientific Bulletin, Series C: Electrical Engineering. 75. 223-232.

Issues Addressed: High operating costs and lower energy efficiency as the surface temperature of the photovoltaic panel rises

Significance: The study was able to eliminate losses caused by the presence of deposits on the panel surface by installing a unique mechanism designed to disperse a water film on the panel surface.

Summary: The researchers devised a method for increasing the efficiency of solar panels by using a mechanism that creates a water layer on the panels' surface. The output parameters were measured when a water film was applied to highlight the results. A thermo-vision camera was used to monitor the temperature of the panel during the experiment, with or without water coating.

Design considerations identified

- **Maintenance cost reduction:** A thin film of water running across the front of a photovoltaic module has been proposed as a cooling method, reducing the frequency of panel surface cleanup due to dust accumulation.

- **Materials and panel composition**: The electrical yield has increased by 9.5 percent as a result of the panel's front water cooling. This is sufficient to cover the energy required to pump water from the bottom of the panel to the top. For the investigation of permanent and transitory regimes, a thermic equivalent circuit can be created and employed. With the algorithm given in this research, the thermic resistances of this circuit may be empirically established, and the cooling process optimization and economic analysis will be the focus of future work.

3. Musthafa, M.M. (2015). Enhancing

Photoelectric Conversion Efficiency of Solar Panel by Water Cooling. J Fundam Renewable Energy App 5: 166. doi:10.4172/20904541.1000166

Issues Addressed: Reduction of temperature of solar cells for an increase in its electrical conversion efficiency.

Significance: To limit the growth in photovoltaic panel module temperature, the researchers used a sponge as a water absorption medium on the rear surface of the solar panel.

Summary: The researcher conducted a research development which further enhances the utilization of solar panels. Using the new set-up on the equipment, the photovoltaic module with water cooling reduces optimally by 4 degrees Celsius and averagely by 1.7 degrees Celsius at two liters per hour flow rate of water as compared to the ordinary set-up. This further implies that a cooling agent can be beneficial in prolonging the light emitted from a solar panel.

Design considerations identified

- **Environmental factors:** Musthafa (2015) improved the design using a novel sponge arrangement behind the solar panel which resulted in the reduction of temperature; thus, increased the efficiency of photoelectric conversion on solar panels. After the finalized set-up, the amount of real-time solar radiation intensity was measured through a solar meter.

- **Structural aspect of the design**: Absorbing sponge, 5 liter capacity water cane, hose with flow controlling knob, and drain pipe for water flow are some of the components used to improve the solar panel setup.

4. Sunarno A. Rakino et al (2019).A Passive Cooling System for Increasing Efficiency of Solar Panel Output. Phys.: Conf. Ser. 1373 012017

Issues Addressed: Increased surface temperature of photovoltaic panels causes a decrease in efficiency.

Significance: Solar panel cooling system uses both water and straight fins heat sink (SFHS) in the back side of the solar panel. Water is filled into an array of aluminum beams/cuboids. The cuboids are then attached at the back of the solar panel.

Summary: This paper suggests that the passive cooling method is the most cost-effective because active cooling absorbs the generated current. A cooling system with both water and heat sinks is being proposed. In terms of lowering solar panel surface temperature, the proposed technique outperforms water-only or heat-sink-only cooling systems. When compared to a standard solar panel, the output voltage rises by 21.49 percent on average, resulting in a reduction of 12.66 percent in average surface temperature. The output power rises by 40% as a result of this.

Design considerations identified

- **Materials and panel composition:** The structural design enhances the system by combining water and heat-sink configurations. This experimental implementation improves the efficiency of solar cells by continuously exposing their surface to the sun, resulting in a 12.66 percent decrease in average surface temperature when compared to standard solar panel use.
- **Materials and panel composition**: In consideration of the systems efficiency the passive cooling materials and components vary in their functionality in order to increase the voltage output. This system uses those passive components to increase the output

voltage with an average percentage of 21.49% and the output power exerts 47.71% higher than the basic solar panel.

- **Environment factors**: Solar panels are a non-polluting, gas-free power source that has an indirect impact on the environment by replacing and reducing the use of other energy sources. However, depending on the site, land use and loss of habitat, irrigation use, and the use of toxic components in manufacturing may vary significantly. Solar energy reduces the environmental impacts of other energy sources, such as combustion in fossil fuels, which emits air pollution.

5. Dr. K.V. Vidyanandan (2017). An Overview of Factors Affecting the Performance of Solar PV Systems. EnergyScan, A House of Journal of Corporate Planning, NTPC Ltd. Issue 27, pp. 2-8, Feb. 2021

Issues Addressed: Identification of Factors affecting Solar Photovoltaic Performance and Efficiency

Significance: Having been able to identify different factors provide us a better idea and understanding on various design criteria and considerations in terms of installation and materials selection

Summary: Many factors influence the output power and lifespan of a photovoltaic module, including the type of photovoltaic material used, the amount of solar radiation received, cell temperature, parasitic resistances, cloud and other shading effects, inverter efficiency, dust, module orientation, weather conditions, geographical location, cable thickness, and so on. The researcher examines a few of the most important aspects that influence solar photovoltaic system performance.

Design considerations identified

- **Structural aspect of the design**. Similar design as to automotive cooling systems but the type of pipe is variable since it is in experimental state, yet structural considerations such as mounting, types and sizes of frames are for determination, hence, the cooling purpose of which is met.
- **Maintenance cost reduction**. With minimal additional operational cost since the system will be relying on water

Synthesis

The researchers discovered that the effectiveness of photovoltaic panels is highly dependent on the real received sunlight in the surface of each solar module after analyzing several researches conducted in various parts of the world. As a result, any blockage in the path of the sunlight to the photovoltaic cells may have an impact on their electrical power output. Dust, for example, collects on the surface of the module, limiting the quantity of light that reaches each solar cells. Various surface panel cleaning techniques can improve the efficiency of photovoltaic modules. One of the most common methods of removing dust from solar panels is to use water as an automated cleaning agent. One of the primary advantages of this method is that, in addition to cleaning the surface of the module, it also provides additional cooling to the solar panel. As a result, it is normally recommended that water cooling methods be used to increase the efficiency of photovoltaic panels.

In their review of various photovoltaic panel water cooling methods, the researchers identified four major design considerations. The structural aspect of the photovoltaic design, maintenance cost, as well as the materials and panel composition, were clearly noticed from the annotated references listed in this review. The structural design of the photovoltaic module has a significant impact on the solar panel's efficiency. The photovoltaic module's potential energy intake is determined by the positioning, physical arrangement, and size of each solar panel. Similarly, the solar panel's components and materials determine the rate of energy conversion of each cell in the photovoltaic module. The cost of maintenance also plays a significant role in increasing the efficiency of a photovoltaic panel. Developing a smart method of cleaning solar panels not only increases their efficiency but also lowers the operating costs of photovoltaic modules.

Finally, in this review, the environmental factors were the least noticeable design consideration. The working temperature of photovoltaic panels can be affected by sudden changes in weather patterns. Furthermore, the loss of vegetation near the solar panel installation site is likely to raise the temperature of the photovoltaic modules. As a result, its efficiency decreases.

The applicability of water cooling technologies, specifically direct and indirect water cooling, for improving photovoltaic (PV) efficiency in residential, commercial and solar farm settings depends on several design considerations. When considering water cooling technologies for improving PV efficiency in residential settings, it is essential to carefully evaluate these design considerations. Direct water cooling involves circulating water directly over the surface of PV panels to dissipate heat. Consider the following design considerations for residential, commercial and solar farms applications such as roof space, system scalability, water supply and quality, maintenance and monitoring, and cost analysis. Indirect water cooling involves using a heat exchanger to transfer heat from PV panels to a separate water circuit. Consider the following design considerations for commercial applications such as heat exchange sizing, water circuit design, redundancy and reliability, maintenance and accessibility. Assess the available space, budget, water supply, and maintenance requirements to determine the most suitable water cooling technology for the specific residential PV system. Due to accessibility and digitalization, some of study proves that automating the process of photovoltaic (PV) panel water cooling can enhance efficiency and reduce the need for manual intervention.

In places like the Philippines, where rainy months are common, the viability of photovoltaic (PV) panel water cooling necessitates careful consideration of the climatic circumstances and unique problems offered by the rainy season. Given the length of the rainy season, the following is a discussion of the viability of PV panel water cooling in the Philippines:

Performance of cooling: Even in regions with a disproportionately high number of rainy months, water cooling can be helpful in reducing heat accumulation and enhancing PV panel performance. The cooling action of water can nonetheless improve the efficiency of PV panels during periods of sunlight, even when rain may momentarily lower solar irradiation levels.

When the sun is out, water can effectively remove heat from the panels, ensuring ideal performance and minimizing any potential efficiency loss brought on by the wet months.

Rainwater harvesting: In regions with a long rainy season, water cooling systems can incorporate rainwater collection devices. This makes it possible to collect and store rainwater during the rainy season so that it may later be used to cool PV panels with water during the summer when there is an abundance of sunlight. Rainwater collection lessens dependency on other water sources while supplying a steady supply of water for the cooling system.

Maintenance Considerations: It's necessary to think about the water cooling system's maintenance needs throughout the rainy season. Filter clogging or water circuit pollution are only two potential problems that could result from heavy rainfall and elevated humidity. Regular maintenance and cleaning should be scheduled to ensure the efficient operation of the system, particularly during and after the rainy months.

Monitoring and Control Systems: In places with rainy seasons, implementing cutting-edge monitoring and control systems can help optimize the water cooling process. These systems have the ability to consider weather predictions and modify the cooling process accordingly. For

instance, they can increase cooling when sunlight is present after a rainstorm while reducing or suspending cooling during heavy rain.
Reducing Water Consumption: It is crucial to take water consumption into account when designing a cooling system in locations where there is a lack of water or there are concerns about water scarcity. Utilizing strategies like water recirculation or water-saving approaches can assist reduce water usage while maintaining efficient cooling.

Alternative Cooling Techniques: In addition to water cooling, the design of a PV system may incorporate passive cooling strategies or natural ventilation. During the rainy season, when sunshine may be scarce, these techniques can offer extra cooling benefits. The overall cooling efficiency can be increased by mixing several cooling techniques, even when there is less sunshine.

In conclusion, even though the Philippines has a large number of rainy months, the use of PV panel water cooling can still be advantageous. The water cooling system may efficiently manage the obstacles brought on by the rainy season by taking into account rainwater collecting, maintenance considerations, cutting-edge monitoring systems, and complementary cooling techniques.

The ratio of water to solar panel for photovoltaic (PV) panel water cooling depends on various factors, including the cooling requirements, climate conditions, and design considerations. While there is no fixed ratio applicable to all scenarios, here are some general guidelines to consider such as cooling requirements, heat dissipation rate, flow rate and water velocity, water contact time, water loss and recirculation, and water availability and sustainability. It is recommended to consult with experts or engineers who specialize in PV panel water cooling systems to determine the optimal water-to-panel ratio for a specific installation. They can take into account a variety of project-specific elements, do thermal calculations, and offer a customized proposal to achieve the target cooling efficiency while optimizing water use.

RECOMMENDATIONS

The researchers recommend the following notes in improving the analysis and review of related literature about photovoltaic panel water cooling:

- Investigate the effects of using a cooling agent other than water and compare the results and findings to see if it improves the efficiency of the solar panel;
- Increase the number of database searches for information gathering, and gather data from physical libraries if the current situation allows; and
- Compare water cooling to traditional air cooling and conduct an in-depth analysis of its benefits and drawbacks.

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