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Proceeding Paper

Experimental Study of Amorphous Photovoltaic Systems in Indoor Performance with Different Coolants †

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† Presented at the 8th Mechanical Engineering, Science and Technology International Conference, Padang Besar, Perlis, Malaysia, 11–12 December 2024.

Abstract: The aim of this research is to investigate the performance of indoor amorphous photovoltaic systems with PVC water cooling and compare them with those using heatsink cooling. The amorphous approach used in this study involves water flowing through a PVC pipe and a heatsink cooler. The circular heatsink that was used has fins all around it. The water flow through the pipe is pumped from the reservoir to the PVC pipe. The study found that a PVC water flow-based active cooling system is the most effective at preserving thermal stability and improving the performance of amorphous PV modules under high light intensity circumstances, providing insights for future advancements.

Keywords: amorphous; indoor photovoltaic; coolant

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Academic Editors: Noor Hanita Abdul Majid, Agus Dwi Anggono, Waluyo Adi Siswanto, Tri Widodo Besar Riyadi, Mohammad Sukri Mustapa, Nur Rahmawati Syamsiyah and Afif Faishal

Published: 29 January 2025

Citation: Pratiwi, D.A.; Soumi, A.I.; Wicaksono, G.; Nugraha, N.A.; Fatmawati, A.; Ahmad, R.N.; Kurniawan, W.; Anggoro, C.J. Experimental Study of Amorphous Photovoltaic Systems in Indoor Performance with Different Coolants. *Eng. Proc.* **2025**, *84*, 84024. https://doi.org/10.3390/engproc2025084024

1. Introduction

Photovoltaics have been applied in various materials [1]. One photovoltaic material is amorphous silicon. Amorphous materials have made significant contributions to energy enhancement [2,3]. Amorphous materials hold potential in both mechanical and electronic applications. Amorphous-phase silicon carbide can serve as a layer in solar cells [4]. Amorphous films consist of a silicon and hydrogen glass alloy [5].

Amorphous materials include two types, single-junction solar cells and multijunction solar cells. The single-junction type of amorphous material is a type of solar cell with a n-i-p or p-i-n configuration, which depends on the deposition on the doped and intrinsic layers. Meanwhile, the multijunction type consists of stacked cells as an effort to improve the light stability of the solar cells. Light that is not absorbed can be reflected back through the rear reflection [6]. Higher efficiency can be achieved in the heterojunction type by reducing doping in the emitter and eliminating the buffer [7].

One of the factors affecting photovoltaic efficiency is temperature [8]. In improving photovoltaic energy conversion efficiency, addressing the temperature issue can be a solution for photovoltaic systems. The cooling process for photovoltaics can be one of the considerations when enhancing photovoltaic efficiency [9]. Cooling can be divided into two types: passive cooling and active cooling [10]. Active cooling refers to cooling that uses energy consumption such as pumps and fans [11]. Meanwhile, passive cooling refers to cooling that uses the concepts of natural convection and conduction in heat extraction.

Studies on the cooling of solar cells with various solar cell materials and cooling methods have been conducted in previous studies. Bai et al. [12] conducted research on the cooling of monocrystalline photovoltaic cells. Their study used a water flow cooler. The results of their research show that the photovoltaic efficiency, after accounting for the cooling power, increased by 12%. Shahsavar et al. [13] conducted a study on a photovoltaic cooling system applied to the exhaust and ventilation air of buildings. The air from the building that exits is used to cool the PV panels. The results of the cooling research show that the ventilation and exhaust air from the building can serve as a cooler for the PV panels, which can enhance the efficiency of the PV panels. Kumar et al. [14] conducted research on water cooling for crystalline and amorphous PV systems. The results of the study showed that photovoltaic panels with water cooling have better performance than simple photovoltaic panels.

In the context of previous research, there is still little information regarding the performance of amorphous-type photovoltaic systems with water flow cooling and in indoor conditions. In this study, the concept of PVC pipes, which are often used in residential buildings, is employed for indoor amorphous cooling. In addition to using PVC water cooling, photovoltaic systems were also tested with another cooling device, namely, a heatsink. The aim of this research is to investigate the performance of indoor amorphous photovoltaic systems with PVC water cooling and to compare the performance of photovoltaic systems with heatsink cooling. This research is expected to contribute to improving the performance of amorphous photovoltaic cells with water flow cooling in PVC pipes.

2. Research Method

For this research, photovoltaic testing was carried out in indoor conditions. Figure 1 is a schematic of this research. The photovoltaic module used in this study is an amorphous module with a specification of 3 V, as shown in Figure 2a. The photovoltaic lighting system uses 1 halogen lamp, as shown in Figure 2b. The halogen lamp is turned on with electrical power from the power supply. The measuring instrument used is based on an Arduino data logger to store data on temperature, voltage, and photovoltaic current as well as light intensity. The temperature data measured are the photovoltaic surface temperature, the inlet, and the outlet water temperature of the pipe. The temperature data are measured with a MAX 6675 sensor, and photovoltaic output voltage and electrical data are measured with a MAX 471 sensor. The light intensity on the photovoltaic surface is measured with an LDR sensor. The water flow in the pipe is measured with a YF-S401 sensor to determine the mass flow rate.

In this research, an amorphous system is installed, using a heatsink cooler and water flow through a PVC pipe. The heatsink used is round and has fins surrounding the heatsink circle, as shown in Figure 2c. Meanwhile, the PVC pipe is 5/8 inch in size. A heat spreader with steel-plate material was applied on top of the pipe. The heat spreader was used to attach the photovoltaic module and act as a surface contact between the photovoltaic material and the pipe. The water flow in the pipe was pumped so that it flowed from the water reservoir to the PVC pipe. The PVC water flow returned to the water reservoir. The pump used in this study is a pump with a DC 12 V electric voltage.

The photovoltaic output power corresponds to the following equation.

$$\mathrm{Pm} = \mathrm{Im} \times \mathrm{Wm} \quad (1)$$

where Pm is the photovoltaic output power, Im is the photovoltaic electric current, and Vm is the photovoltaic voltage.

Photovoltaic efficiency is the percentage of electrical output power from the light intensity absorbed by the photovoltaic module. The efficiency calculation uses the ratio of the highest power, Pmax, with E, light intensity, and surface area (Ac) [15]. The efficiency equation can be written as follows:

$$\mu = \frac{P\max}{EA_c} \quad (2)$$

where Pmax is the maximum output power of photovoltaic, E is the light intensity, and Ac is the surface area of the photovoltaic.

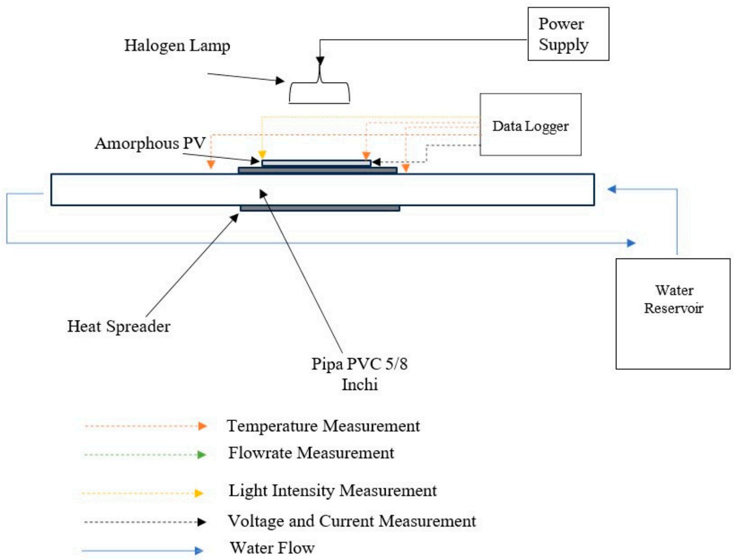


Figure 1. Schematic of the research.

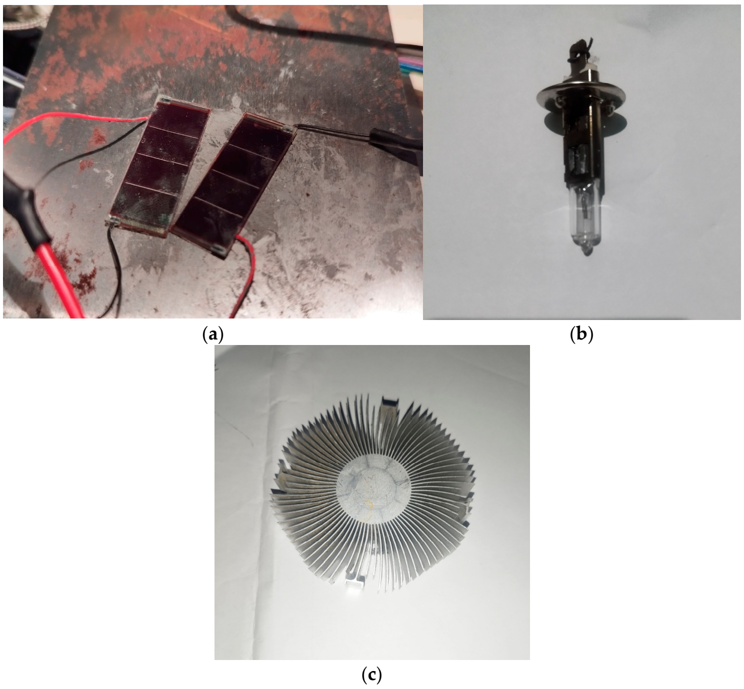


Figure 2. (**a**) Amorphous PV. (**b**) Halogen lamp. (**c**) Heatsink.

3. Result and Discussion

The performance of amorphous photovoltaic (PV) modules was methodically assessed under three separate thermal management conditions: absence of cooling, implementation of a heatsink, and application of water circulation through a PVC pipe as an active cooling system. The main aim of this study was to evaluate and compare the effectiveness of these cooling methods in improving the operational efficiency of photovoltaic modules, while clarifying the heat transfer mechanisms that affect their thermal behavior and performance metrics.

Figure 3a illustrates that the cooling method significantly influences the temperature of amorphous PV modules. The temperature rose along with light intensity (W/mm^2) under all situations, with the uncooled modules exhibiting the maximum temperature. This signifies the module's vulnerability to overheating, which diminishes its efficiency. The incorporation of a heatsink reduced the module temperature by around 3–4 °C relative to the absence of cooling, particularly at moderate light intensities. The PVC water flow-based cooling system demonstrated superior efficacy, maintaining a steady temperature of approximately 32–33 °C even under elevated light intensities more than 600 W/mm^2, and exhibiting a reduction in temperature at an intensity of 800 W/mm^2. This efficacy illustrates the water flow's superior capacity to dissipate heat compared to passive convection through the heatsink.

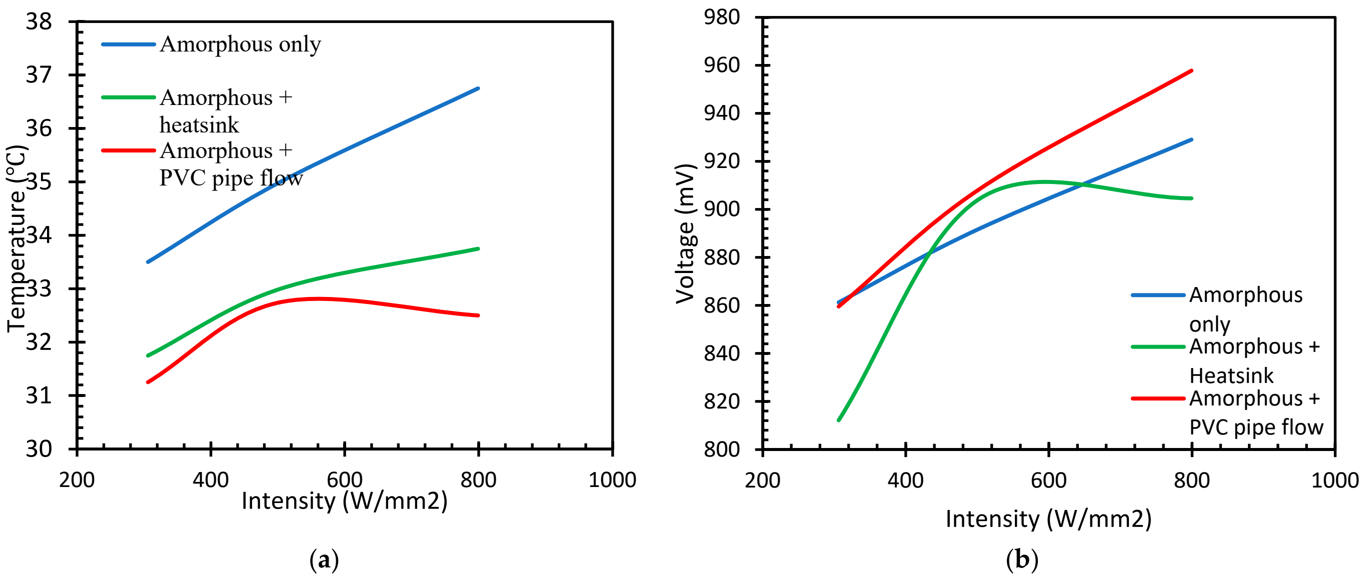
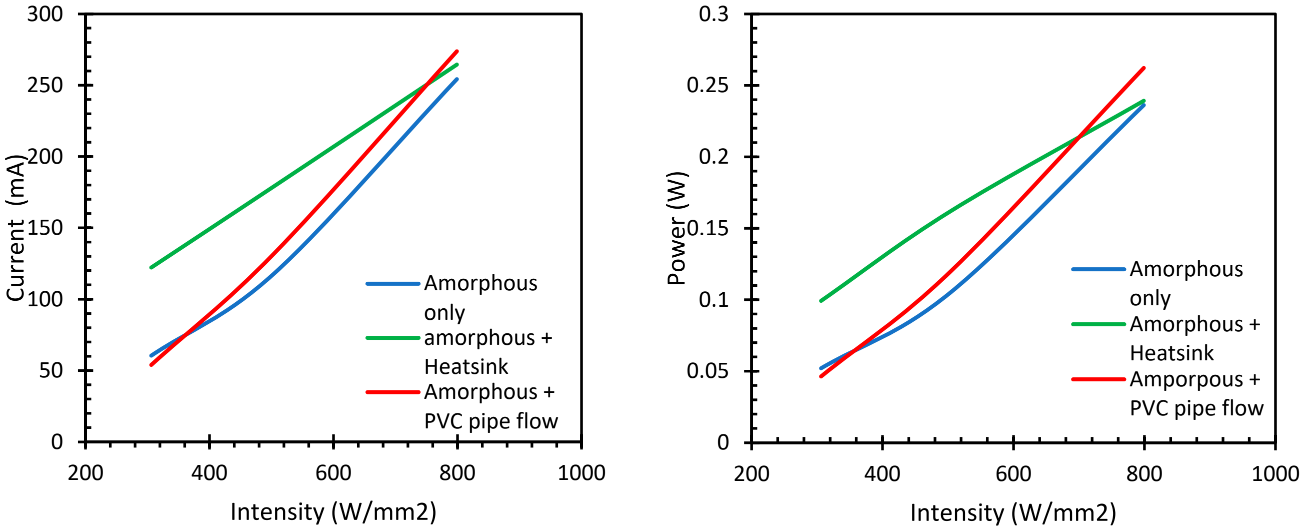


Figure 3. (**a**) Temperature against intensity. (**b**) Voltage against intensity.

The correlation between voltage and light intensity is depicted in Figure 3b, with the PVC water flow system generating the maximum voltage of 960 mV at an intensity of 800 W/mm^2. This results from the system's capacity to maintain a low module temperature, hence enhancing electrical efficiency. The heatsink system ranked second, with the voltage stabilizing at 900 mV after the intensity exceeded 500 W/mm^2. The module without cooling exhibited the lowest voltage, which grew progressively with light intensity; however, it remained low due to the internal resistance being elevated by the high temperature.

The effect of PVC water flow cooling guarantees good temperature stability, enabling the module's voltage to remain elevated even under high intensities. Conversely, heatsinks are efficient at low-to-medium intensities but are less capable of managing heat at high intensities.

Figure 4a depicts the correlation between light intensity and current, exhibiting a comparable trend, with the PVC water flow cooling system generating the maximum current of 250 mA at an intensity of 800 W/mm^2. The heatsink system demonstrated superior performance compared to the uncooled module, particularly at low-to-medium intensities (300–500 W/mm^2), but its effectiveness diminished at high intensities.



(**a**) (**b**)

Figure 4. (**a**) Current against intensity. (**b**) Power against intensity.

In the uncooled module, the rise in current transpired gradually as elevated temperatures impeded the energy conversion efficiency. Conversely, the PVC water flow-based active cooling sustained an ideal temperature, enhancing electrical conductivity and yielding an increased current.

Figure 4b illustrates the correlation between light intensity and output power, indicating that the PVC water flow-based cooling system yields the maximum power of approximately 0.25 Watt at an intensity of 800 W/mm^2. This technology regulates the module temperature, enabling the power output to rise despite the elevated light intensity. The heatsink system demonstrated considerable power enhancements at low-to-medium intensities, but its efficacy diminished at high intensities due to the constraints of passive convection. Modules lacking cooling generated the least power, as elevated temperatures diminished the energy conversion efficiency.

This study establishes that a PVC water flow-based active cooling system is the most efficient method for sustaining thermal stability and enhancing the performance of amorphous PV modules, particularly under conditions of elevated light intensity. Heatsinks enhance performance relative to modules lacking cooling; however, they are less effective than the PVC flow system. These findings offer significant insights for the advancement of more effective cooling methods to enhance the thermal stability and electrical performance of photovoltaic modules under diverse operational situations.

4. Conclusions

This research presents prospects for additional investigation, particularly concerning the impact of fluctuations in light intensity and ambient temperature on the efficacy of photovoltaic (PV) modules. In addition, this research can be extended to examine the effectiveness of cooling systems on various types of PV systems, including crystalline PV modules, to better understand their cooling mechanisms. The cooling system significantly influences the performance of photovoltaic (PV) modules; in the absence of cooling, module temperature rises sharply with increasing light intensity, resulting in diminished efficiency and a reduced electrical output (voltage, current, and power). The incorporation of heatsinks proved helpful in lowering module temperature and enhancing electrical performance, particularly under low-to-medium light intensities. Nonetheless, at elevated intensities, the efficacy of heatsinks diminishes due to the constraints of passive convection. The PVC flow-based cooling system showed considerable advantages in maintaining module temperature stability, leading to increased voltage, current, and power, even under high intensities. The PVC flow system features an active cooling mechanism that enhances module efficiency, rendering it an optimal choice for thermal stability and higher photovoltaic performance in high light intensity applications. Moreover, subsequent studies may concentrate on the development of alternate cooling materials, such as mineral oil with an elevated specific heat capacity, to enhance cooling efficiency in photovoltaic modules.

Author Contributions: Conceptualization, D.A.P., A.I.S., and N.A.N.; methodology, W.K. and C.J.A.; software, R.N.A. and A.F.; validation, G.W., D.A.P., and A.I.S.; formal analysis, A.I.S.; investigation, D.A.P.; resources, A.I.S. and R.N.A.; data curation, A.I.S., N.A.N., and A.F.; writing—original draft preparation, A.I.S. and D.A.P.; writing—review and editing, G.W.; visualization, D.A.P.; supervision, N.A.N.; project administration, D.A.P.; funding acquisition, D.A.P. All authors have read and agreed to the published version of the manuscript.

Funding: We are grateful to Universitas Muhammadiyah Surakarta for financing this research through Rikom funding No. 125.18/A.3-III/LRI/IV/2024.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets in this article are not accessible to the public due to their involvement in current research. Requests for access to datasets should be sent to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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