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Solar PV Thermal Management System: A Case on Tembalang Village, Central Java, Indonesia

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***Abstract* - The increasing demand for cleaner energy solutions has led to the exploration of renewable energy sources, particularly solar photovoltaic (PV) technology. This research focuses on the thermal management of solar PV systems in Tembalang Village, Central Java, Indonesia, where the efficiency of PV panels is significantly affected by temperature fluctuations caused by environmental factors such as pollution, wind speed, humidity, solar radiation, and ambient temperature. The study highlights the importance of effective thermal management systems to enhance the energy efficiency of PV panels, which typically operate at an average efficiency of around 20%. As temperatures rise, the efficiency of these panels can drop by 10% to 25%, necessitating the implementation of cooling technologies.**

Keywords: Photovoltaic, Thermal Management, Heat Transfer, ANSYS, Solar PV, Thermal Management System, solar photovoltaic technology, solar PV systems, Renewable energy sources.

I. INTRODUCTION

Cleaner energy solutions utilizing renewable energy sources like wind and solar have been created in recent decades in response to the drawbacks of fossil fuel sources, including their fluctuating costs and environmental pollution [1-4].One of the most intriguing technologies for producing renewable energy is the solar photovoltaic (PV) cell [5].The capacity to generate power at various scales, ease of use and installation, comparatively cheap maintenance costs, and the availability of solar radiation in various locations are the key factors contributing to PV cells' appeal. Because of these benefits, solar cell systems are used for a variety of applications, such as electrifying buildings in remote locations and powering various devices like electrolyzers and desalination facilities [6-9].

PV panels, which are extensively used to generate electricity, have surface temperatures that are influenced by a number of external factors, including pollution, wind speed, humidity, solar radiation, and ambient temperature. These factors have a detrimental effect on the PV panel's energy efficiency. PV panels can have their temperature controlled using a variety of cooling methods. The two primary types of cooling technologies—passive and active cooling systems—differ in how they regulate the cells' working temperatures [10-11].

The average silicon photovoltaic cell has an efficiency of about 20%, meaning that solar panels are not entirely effective at turning sunlight into electrical energy [12-13]. The remaining energy is converted to heat, which significantly lowers the panel's efficiency and power production [14]. The majority of solar panels undergo testing at 25 °C under Standard Test Conditions. The output efficiency drops by roughly 10% to 25% as the temperature rises [15-17].

Hosouli *et al.*, [18] on their research presents a significant advancement in the design of Solar Photovoltaic Thermal (PVT) collectors, specifically targeting the issue of cell cracking caused by thermal expansion. The study found that a 2 mm H-pattern cavity design significantly reduces directional expansion, thereby minimizing breakage risks. Sohani *et al.*, [19] explores the performance and advantages of bifacial photovoltaic (bPV) panels compared to traditional monofacial photovoltaic (mPV) panels, focusing on their thermal, optical, and electrical characteristics. The bPV panels can harness sunlight from both sides, resulting in a 13.90% increase in annual energy production compared to mPV panels. Barbosa *et al.*, [20] investigates innovative cooling methodologies for photovoltaic (PV) systems which focused on a novel aluminum serpentine heat exchanger that allows direct contact between the cooling liquid and the surface of a PV-thermal panel, which is essential for maintaining optimal operating temperatures and enhancing system performance and highlighted that a wider PDMS serpentine significantly improved cooling performance over a narrower one, achieving an average increase in efficiency of 92% due to enhanced heat transfer surface area.

This research will focus on the heat transfer of photovoltaic solar panels in the Tembalang area in Central Java. This research will also use ANSYS software to carry out

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simulations and collect data experimentally every week from November 2023 to November 2024.

II. METHODOLOGY

Figure 1 shows a frequently used photovoltaic schematic and Table 1 details each function of the photovoltaic parts.When combined with PCMs, these systems' overall efficiency—which is the sum of their thermal and electrical performance—is higher than that of PV and thermal collectors used independently. The PCMs initially absorb the wasted heat from the PV panel as latent heat, which lowers the PV's surface temperature and increases electrical efficiency.

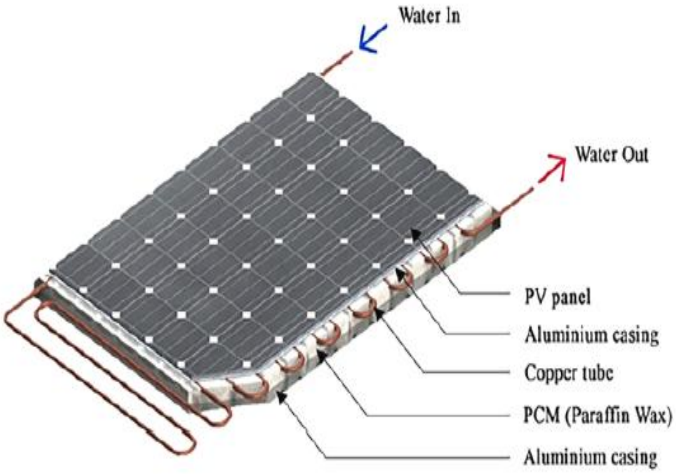

Figure 1: PV Schematic [21]

Table 1: PV Schematic Function

Component	Function
PV Panel	Converts sunlight into electrical energy
Aluminum Casing	Protects the PV panel and provides structural support
Copper Tube	Conducts water through the system and transfers heat
PCM (Paraffin Wax)	Absorbs and stores heat from the PV panel, releasing it when needed
Water In	Inlet for cold water entering the system
Water Out	Outlet for heated water exiting the system

Constituent materials such as tempered glass, EVA, PV, and PVF have main properties as shown in Table 2 [22]. These constituent materials are equipped with properties such as density, thermal conductivity, and specific heat.

Table2: Properties of EVA, PV, and PVF constituents

Material	Thermal Conductivity (K) (W/m.K)	Density (ρ) (kg/m³)	Specific Heat Capacity (Cp) (J/kg.K)
Tempered Glass	1.8	3000	500
EVA	0.35	960	2090
PV	148	2330	677
PVF	0.2	1200	1250

The main problem with solar panels in this simulation knows how the heat flux is distributed on the solar panel. In this simulation, we use data on the distribution of heat temperatures in Tembalang. In the data we have, it is found that every month and every week certainly has a different heat flux distribution. Table 3 shows calculations for determining heat flux in the Tembalang area.

Table 3: *n* value for determined the heat flux [23]

Month	*n* for *i*th Day of Month
January	*i*
February	31+*i*
March	59+*i*
April	90+*i*
May	120+*i*
June	151+*i*
July	181+*i*
August	212+*i*
September	243+*i*
October	273+*i*
November	304+*i*
December	334+*i*

Table 4 also shows the climate factors that occur in the Tembalang. This factor is used to calculate further heat flux.

Table 4: Correction Factors for Climate Types [23]

Climate Type	r_0	r_1	r_2
Tropical	0.95	0.98	1.02
Midlatitude summer	0.97	0.99	1.02
Subarctic summer	0.99	0.99	1.01
Midlatitude winter	1.03	1.01	1.00

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There are several parameters that must be met by PV in this simulation, including declanation (δ), horizontal collector ($\cos\theta_z$), atmospheric transmission (τ_b), and radiation (G_{on}) [23]. The declanation can be representing below:

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \qquad (1)$$

For a horizontal collector, the angle is the sun's zenith angle which will be given as in the following equation:

$$\cos\theta_z = \cos\varphi \cos\delta \cos\omega + \sin\emptyset \sin\delta \qquad (2)$$

Where:

ω = hour angle, where the angular displacement of the sun towards the east or west of the local meridian due to the rotation of the earth on its axis is 15 per hour; morning negative, afternoon positive.

φ = latitude, where is the north or south corner of the equator, north is positive.

The atmospheric transmission for radiation emission equation is as follows:

$$\tau_b = a_0 + a_1 exp\left(\frac{-k}{\cos\theta_z}\right) \qquad (3)$$

Where:

$$a_0 = 0.4237 - 0.00821(6-A)^2$$
$$a_1 = 0.5055 - 0.00595(6{,}5-A)^2$$
$$k = 0.2711 - 0.01858\,(2{,}5-A)^2$$

G_{on} is the incidence of extraterrestrial radiation in a plane normal to the radiation on the n-th day. The equation is as follows:

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \qquad (4)$$

Where:

$$G_{sc} = (1.000110 + 0.034221\cos B + 0.001280\,\sin B + 0.000719\,\cos 2B + 0.000077\sin 2B)$$

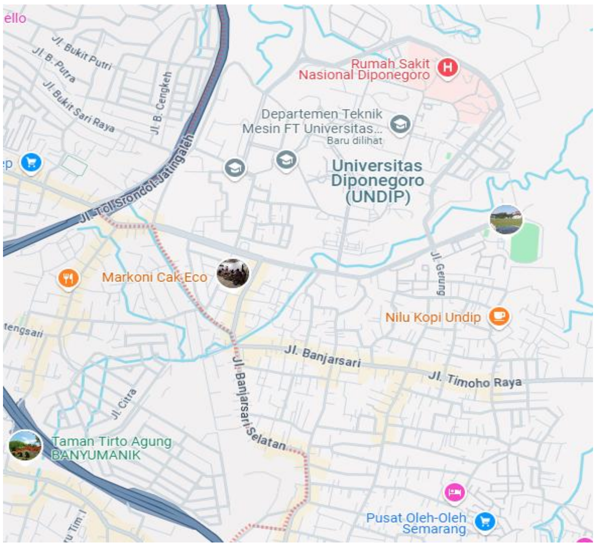

Figure 2: Map of Tembalang Region

Table 5 will show temperature data obtained from November 2023 to November 2024 in the Tembalang area.

Table 5: Collected Data Temperature

Month	Week	Temperature (℃)
November 2023	1	32.7
	2	32.71
	3	32.51
	4	32.49
December 2023	1	32.98
	2	32.87
	3	33.03
	4	32.89
January 2024	1	32.99
	2	32.87
	3	32.57
	4	32.74
February 2024	1	32.96
	2	32.98
	3	33.08
	4	33.31
March 2024	1	33.33
	2	33.41
	3	33.43
	4	32.94
April 2024	1	33.12
	2	34.09
	3	33.82
	4	33.79
May 2024	1	33.91
	2	34.08
	3	34.22
	4	34.21
June 2024	1	34.34
	2	34.73
	3	34.53
	4	34.12

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July 2024	1	34.82
	2	34.66
	3	34.56
	4	34.78
August 2024	1	34.52
	2	34.39
	3	34.83
	4	34.91
September 2024	1	34.85
	2	34.77
	3	35.01
	4	35.16
October 2024	1	35.04
	2	34.96
	3	34.42
	4	34.03
November 2024	1	33.69
	2	33.57
	3	33.89
	4	34.35

To solve this case, ANSYS Steady State Thermal will be used. The meshing obtained in the PV geometry is 280,625 elements with a skewness of 0.99 (Figure 3).

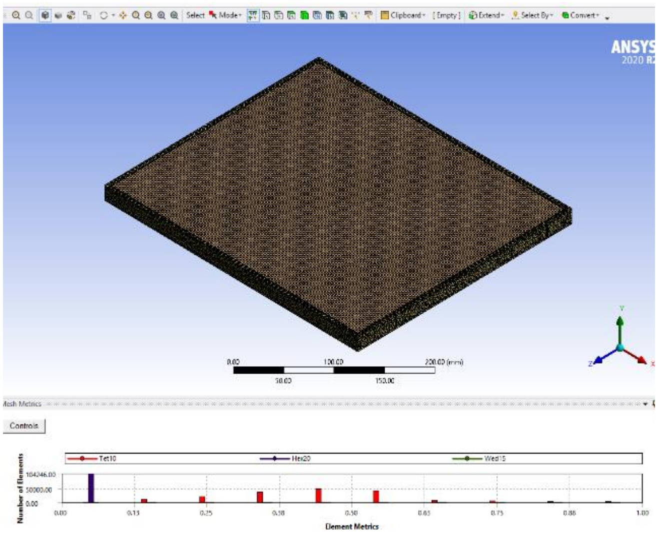

Figure 3: PV Geometry Meshing Setup

After Meshing and Setup have been carried out (inputting temperature according to the data obtained, calculating heat flux, etc.), the next step is to run a simulation to see the results of the PV.

III. RESULTS AND DISCUSSIONS

Table 6 shows the results obtained based on numerical simulations using ANSYS Steady State Thermal. This result consists of total temperature (the overall temperature of the PV), PV temperature (the temperature of the PV collector), and heat flux from the PV.

Table 6: Results from the Simulation

Month	Week	Total (°C)	PV (°C)	Heat Flux (W/m^2)
Nov-23	1	644.46	538.62	2.0815×10^{6}
	2	659.76	551.27	2.1335×10^{6}
	3	674.85	563.72	2.1856×10^{6}
	4	690.12	576.34	2.2376×10^{6}
Dec-23	1	705.9	589.47	2.2897×10^{6}
	2	721.08	602	2.3417×10^{6}
	3	736.52	614.8	2.3938×10^{6}
	4	751.3	626.93	2.4459×10^{6}
Jan-24	1	759.42	633.73	2.4719×10^{6}
	2	766.94	639.93	2.4979×10^{6}
	3	728.42	608.02	2.3678×10^{6}
	4	743.88	620.84	2.4198×10^{6}
Feb-24	1	767.03	640.02	2.4979×10^{6}
	2	772.4	644.46	2.5161×10^{6}
	3	782.44	652.78	2.55×10^{6}
	4	797.95	665.65	2.6021×10^{6}
Mar-24	1	803.32	670.09	2.6203×10^{6}
	2	809.29	675.04	2.6403×10^{6}
	3	811.45	676.83	2.6476×10^{6}
	4	805	671.41	2.6273×10^{6}
Apr-24	1	813.05	678.1	2.6541×10^{6}
	2	821.66	685.39	2.6802×10^{6}
	3	805.72	672.16	2.6268×10^{6}
	4	803.02	669.92	2.6177×10^{6}
May-24	1	806.5	672.82	2.6291×10^{6}
	2	807.89	674	2.6333×10^{6}
	3	808.42	674.46	2.6346×10^{6}
	4	808.25	674.32	2.6341×10^{6}
Jun-24	1	808.77	674.77	2.6354×10^{6}
	2	809.69	675.6	2.6372×10^{6}
	3	809.11	675.08	2.6359×10^{6}
	4	808.09	674.17	2.6338×10^{6}
Jul-24	1	809.93	675.82	2.6377×10^{6}
	2	809.39	675.34	2.6364×10^{6}
	3	809.21	675.18	2.6362×10^{6}
	4	809.82	675.71	2.6375×10^{6}
Aug-24	1	809.14	675.11	2.636×10^{6}
	2	808.89	674.88	2.6356×10^{6}
	3	809.97	675.85	2.6378×10^{6}
	4	810.1	675.97	2.638×10^{6}
Sep-24	1	810.1	675.88	2.6379×10^{6}
	2	809.76	675.67	2.6373×10^{6}
	3	810.4	676.23	2.6387×10^{6}
	4	810.73	676.53	2.6393×10^{6}
Oct-24	1	810.49	676.31	2.6389×10^{6}
	2	810.22	676.08	2.6382×10^{6}
	3	808.95	674.94	2.6357×10^{6}
	4	807.8	673.92	2.6331×10^{6}
Nov-24	1	805.56	672.01	2.6267×10^{6}
	2	805.29	671.76	2.6262×10^{6}
	3	806.45	672.78	2.629×10^{6}
	4	808.81	674.8	2.6355×10^{6}

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Based on Table 6, it can be seen that the temperature and heat flux values will increase as the month period increases, accompanied by the declanation and radiation parameters. Figure 4-6 will provide a further description of the distribution of temperature and heat flux based on each period.

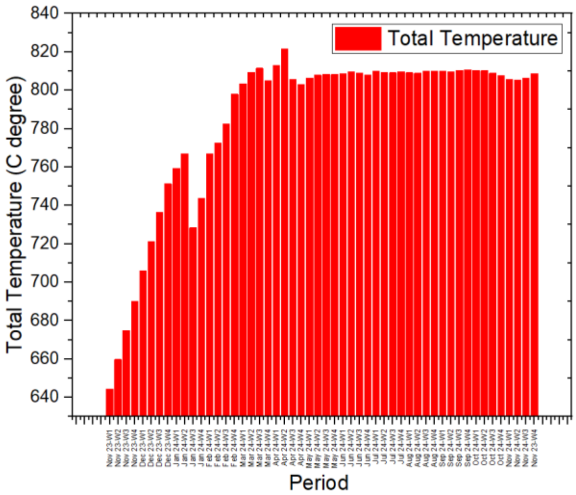

Figure 4: Total Temperature

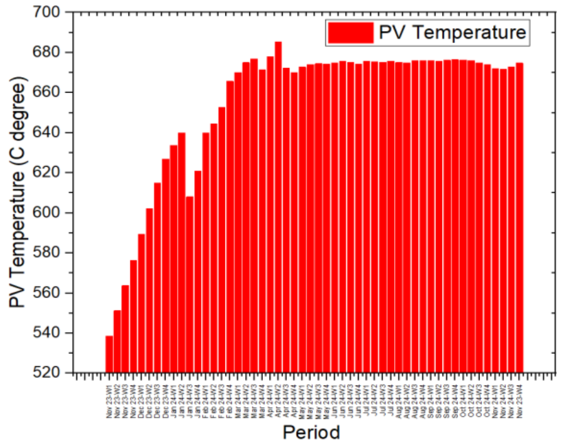

Figure 5: PV Temperature

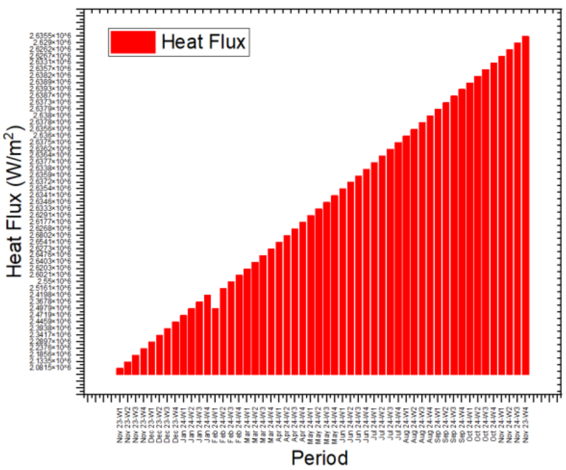

Figure 6: Heat Flux

Figure 7 shows the total temperature based on simulation results. In the provided ANSYS Steady State Thermal simulation, the temperature distribution appears to be concentrated in the center of the PV panel due to a localized heat source or sink. This could be caused by a manufacturing defect, such as a crack or a hotspot in the cell, can lead to increased heat generation.

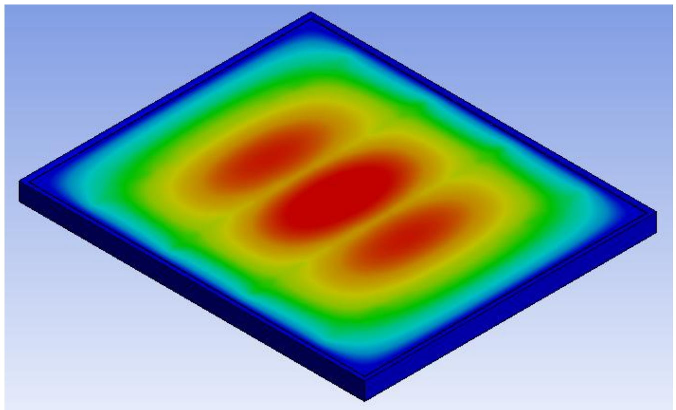

Figure 7: Total Temperature Result from Simulation

Figure 8 shows that the highest PV temperature is likely concentrated in the center due to a combination of factors of PV generate heat as they absorb sunlight and convert it into electricity. This heat is primarily generated in the photovoltaic cells themselves.

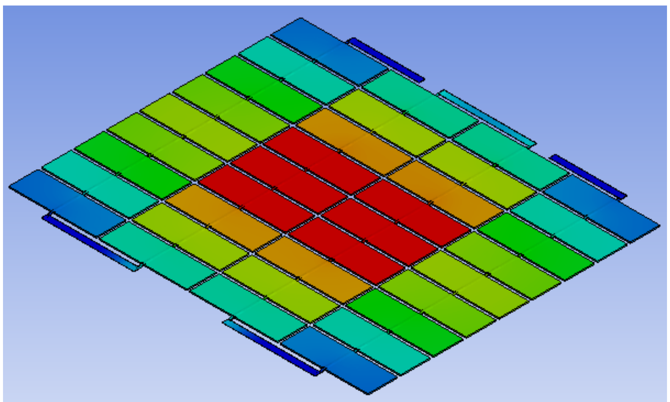

Figure 8: PV Temperature Result from Simulation

IV. CONCLUSION

The temperature of the solar cell will affect its conversion efficiency. The higher the temperature, the efficiency will generally decrease. Heat Flux is the rate of heat transfer per unit area. In the PV context, heat flux generally refers to the heat lost from the solar cell to the surrounding environment. Some of the solar energy that should be converted into electricity is instead converted into heat. This means more heat energy has to be dissipated by the solar cells. The temperature difference between the solar cell and the

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surrounding environment will be greater. This will increase the driving force for heat transfer, so the heat flux will also increase. Heat flux can occur through conduction, convection and radiation. Increasing temperature will increase the contribution of these three mechanisms. An increase in heat flux means the solar cell loses more heat. This indicates the need for a better cooling system to keep solar cell temperatures low and increase efficiency. Increasing the temperature value in the ANSYS Steady State Thermal simulation will cause an increase in the heat flux value in the solar cell. This is a natural physical phenomenon and can be explained by the basic principles of heat transfer. By understanding this relationship, we can perform better PV system design and optimization.

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