



## PERFORMANCE EVALUATION OF SOLAR PANEL WITH REFLECTOR USING NANO FLUIDS

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### ARTICLE INFORMATION

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### ABSTRACT

This research evaluated the performance of solar panel with reflector using Nano Fluids in Kano State, Nigeria. An experimental setup was designed, consisting of a solar panel without modification PWM, solar panel with reflectors PWR, solar panel with reflectors and a water-cooling system (PWRC). The experiments were conducted at the optimum tilt angle of 12° in Kano State. Additionally, models were developed using SolidWorks of PWR and PWRC to simulate the thermal behavior of the panel with different coolant types, including water, ethylene glycol, and urea liquid using ANSYS. The results indicate that ethylene glycol exhibited the lowest rate of increase in the panel's surface temperature (ST), followed by urea liquid and then water. For an initial surface temperature (ST) of 27.5°C, 64.2°C, and 46.1°C, the panel using ethylene glycol experienced temperature increases of 22.072°C, 74.184°C, and 33.951°C, respectively, over a duration of 50 minutes. In the case of water, the panel's ST rose by 33.155°C, 80.388°C, and 59.698°C under the same initial ST conditions. Similarly, the panel using urea liquid witnessed surface temperature increases of 24.648°C, 74.282°C, and 35.498°C for the respective initial ST values of 27.5°C, 64.2°C, and 46.1°C.

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### 1.0 Introduction

Nigeria is fortunate to be located within the sunshine belt, receiving global radiation ranging from 3.5 kWh/(m<sup>2</sup> day) to 7 kWh/(m<sup>2</sup>day) across the country (Abdullahi, 2015; Aliyu et al., 2023). Additionally, Nigeria experiences an average of 6.25 hours of sunshine per day, with the southern region having around 3.5 hours and the far northern region enjoying up to 8.0 hours of sunlight (Abdullahi et al., 2017). According to a report from the Global Energy Network Institute, "If solar collectors/modules were deployed to cover just 1% of Nigeria's land space, it could generate up to 1850 × 10<sup>23</sup> GWh of solar electricity per year, which is approximately 100 times the current grid electricity consumption in the country" (Tukur et al. 2023).

Despite Nigeria's significant solar energy potential, there is currently no integration of solar energy into the national grid. Several challenges hinder the development of solar energy in the country, including high costs, limited awareness, and insufficient research efforts. Many researchers have made effort to improve the efficiency of PV panel by using reflective materials in other to increase the concentration of solar energy without even increasing the number of cells used (Bamisile et al., 2017) (Çamur,2023). (Kabeel et al., 2019), on their comprehensive investigation of an optimal cooling technique for improving the performance of PV module with reflectors under Egyptian conditions. On the Egyptian ambient condition, three different cooling methods are compared on a PV module in the presence of reflector that includes: Air force cooling system, Water cooling medium and Water- and air-cooling medium as case one, case two and three. It found that, the output electricity per day increases to 912, 1077 and 1010Wh/day for case one, two and three more than that of the Normal panels that record 832Wh/day. Moreover, the cost estimate in terms of KWh are

approximately 0.072, 0.061 and 0.0722\$/KWh. (Rakino et al., 2019), a passive cooling system for increasing efficiency of panel power output (PO). Water and a straight fin heat sink (SFHS) was used as the cooling medium, water passes through aluminum beam cuboid that was attached at the bottom of the panel (50W) and the SFHS are then attached to the cuboids to release heat to the air. This decrease the Surface Temperature (ST) of the panel by 21.66% in comparative with an ordinary panel. It was found that the  $V_{oc}$  increase by 21.49% compare to the normal panel, hence PO increase by 40%.

The research of (Hatmode et al., 2020), on Development and testing of PV panel for cooling under Natural condition, a wood will as put at the back side of the panel which also allow air to pass through it and exchange heat with the surrounding. The power output increase with 15% compare with the panel without cooling. Wang et al., 2020), on the study of the experimental and optical performances of a solar CPV device using a linear Fresnel reflector concentration, where by Monte Carlo Ray Tracing (MCRT) software is used to undergo simulation of solar concentration processes and a test rig of the linear Fresnel concentrator is developed. the finding shows that the test result of solar cell conversion efficiency under non concentration condition are 17.9% and 17.1% while for concentration condition are 14.7% and 13.6% which are both less than the parabolic v trough concentration test condition of (12.3% and 10.7%). (Rajagopal & Yadav, 2020), cooling Techniques for Performance Improvement of PV Systems. . Two types of cooling systems that include active and passive cooling systems. The active cooling systems yield better performance than that of the passive, this increases electrical efficiency with the maximum of 22% and reduces the panel temperature with maximum of 30°C. In the order hand, cooling systems that fall in the passive category, enhance electrical efficiency to 15.5% and we may see a reduction of 20 °C in the panel surface temperature. (Nader et al., 2020), on their study Assessment of Existing Photovoltaic System with Cooling and Cleaning System: Case Study at Al-Khobar City. The results found that for the Al-Khobar region, Eastern Province, Kingdom of Saudi Arabia, the Efficiency of the solar panels after cleaning was increased from 6% to an average of 12% at nominal temperature of 27 °C. moreover, the average power output was increased by 35% during the day Time. (Abizar & Nurtanto, 2021), on their studies to determines the effect of passive cooling for optimization of solar panel output. Where by two of solar panel (50W) with reflectors with and without cooling where used in Indonesia. It was found that the effect of cooling system increases the power output with average of 59.63 watt much greater than without cooling system that yield 47.68. It was also find out that both the module with reflector produced greater average power output 25.07% than that of a simple module. This paper determined a suitable coolant to use to regulate the operating temperature of a Panel in the City of Kano state Nigeria.

## 2.0 Materials and Method

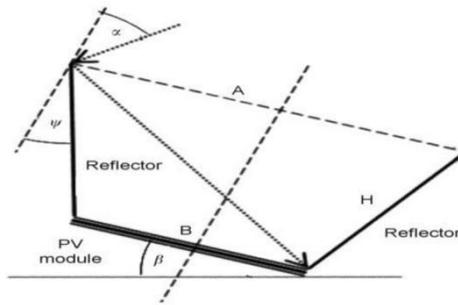
In the study conducted in Kano State, a 10W polycrystalline photovoltaic (PV) panels were utilized. The panel's electrical characteristics under standard test conditions are presented in Table I. The experimental investigation was carried out at centered city of Kano State. To intensify solar radiation, a reflective foil with an impressive reflectivity of 98% was employed. Measurements were conducted with electronic data logger, DC voltmeter and ammeter. Electronic data logger was employed to collect temperature, radiation, voltage, and current while DC voltmeter and ammeter was utilized to measure voltage drop and current flow within the system.

**Table I:** Electric data specification of the panel

Characteristics	Value
Panel types	Polycrystalline
Maximum power (W)	10
DC open circuit voltage (V)	21.8
DC max power current (V)	17.3
Operating Temperature (° C)	25
Panel size (L*W*H)mm	350*300*25
Life span (Years)	25

## 2.1 Design of Solar Reflector

Considering a panel with tilt angle of  $\beta$  with two reflectors attached to it as shown in Figure 1 below.



**Figure 1:** free body diagram of panel with two reflectors

From the equation 1 and 2 ((Burkhard et al., 1978)

$$C = \frac{D}{D_0} = \frac{\sin((2N+1)\alpha+\gamma)}{\sin(\alpha+\gamma)} \quad (1)$$

and

$$\frac{L}{D_0} = \frac{\sin((2N+1)\alpha+\gamma) - \sin(\alpha+\gamma)}{2 \sin(\alpha+\gamma) \sin \alpha} \quad (2)$$

where,

D= Width of the aperture

D<sub>0</sub>= Width of the panel

C= Concentration ratio

γ= angle of incidence

α= apex angle of the panel

L= length of reflector

At γ = 0 (radiation falling normal to the aperture area),

Chosen concentration ratio equals to 2, α equal to 30° and γ = 0 (radiation falling normal to the aperture area), D<sub>0</sub>=30 cm.

The optimum length L of reflector equals to 35cm

## 2.2 Cooling System Design

To enhance the cooling of the solar panel, an S-shaped copper pipe was meticulously installed at the bottom section of the panel, as depicted in plate 1. This design facilitates the passage of water through the pipe, allowing efficient heat exchange with the panel



**Plate 1:** The panel with cooling system

## 2.3 Experimental Procedure

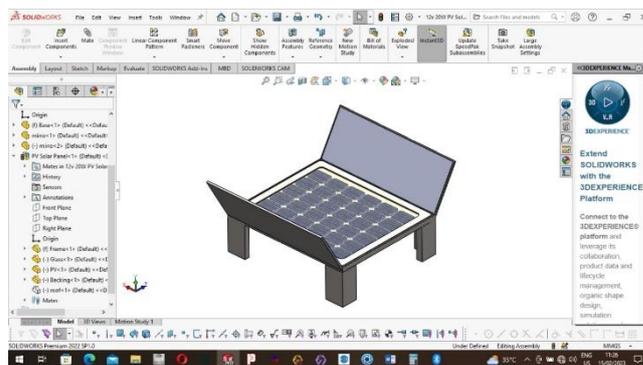
The experimental samples which include Panel Without Modification (PWM), Panel with Reflector (PWR) and Panel with Reflector and Cooling System (PWRC) were securely mounted on a stand located at the Oriental Hospital building in Kano State, Nigeria, as depicted in Plate 2. An electronic data logger was used to measure the Short-Circuit Current ( $I_{sc}$ ), Open-Circuit Voltage ( $V_{oc}$ ), and Standard Test Conditions (ST) of the panels. In the case of panel with reflector and water-cooling system, a rubber pipe was utilized to facilitate the flow of water, which then passed through an S-shaped copper pipe, allowing for heat exchange with the panel. The water was refilled on a daily basis to maintain consistent conditions. The duration of the experiments was 30 days in the month of March 2023.



**Plate 2:** Experimental samples during taking reading at oriental hospital

## 2.4 Modeling

The design and assembly of the panel, along with the attached reflector and cooling system, were accomplished using SOLIDWORKS 2020 software. The model consists of various parts, namely the Panel, Frame, and Cooling Medium Tubes. These individual components were combined and assembled together to form the complete Model, as illustrated in Plate 3.



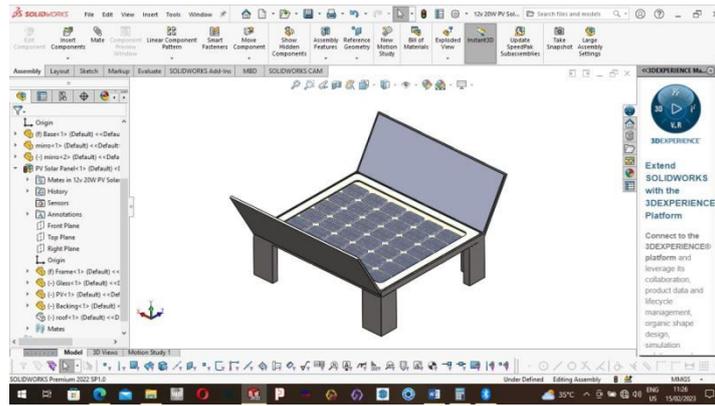
**Plate 3:** The Assembled Model

### 2.4.1 Solution Setup

The PV panel was assembled using four separate parts: backing, glass, frame, and cells. The construction process involved designing each part individually and then assembling them. To begin with, the backing was designed using SOLIDWORKS software. A new part design tab was opened, and a centered rectangle with dimensions of 300 x 350mm was selected. It was then extruded to a thickness of 5mm and saved in a specific folder. Next, the glass part was constructed. Another tab was opened in the part design section, and a centered rectangle with dimensions of 300 x 350mm was created. It was extruded to a thickness of 5mm and saved in a specific folder.

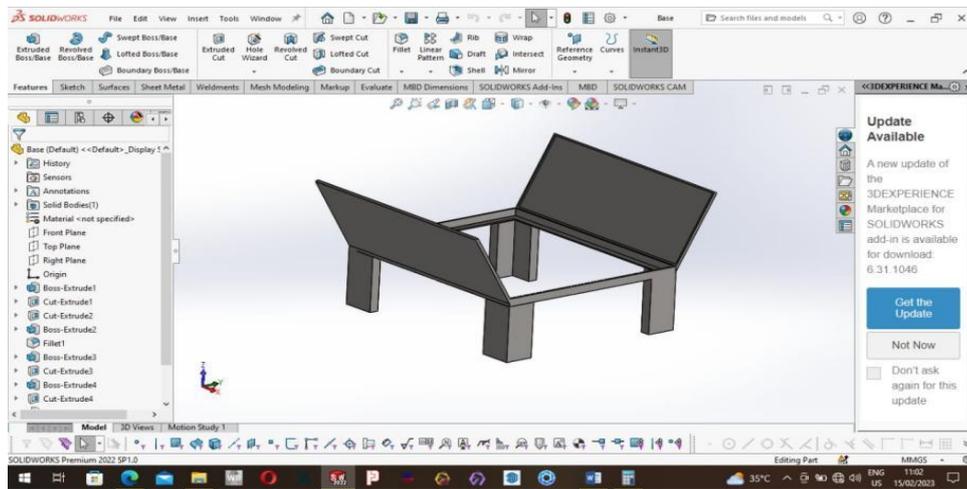
The frame of the panel was designed using the Swept Boss and Corner Rectangle features. A frame with dimensions of 300 x 350mm and a thickness of 25mm was formed on a new tab in the part design section. The file was saved in a specific folder. For the solar cells, the Corner Rectangle, Chamfer, Trim, and Extrusion features were used. The solar cell was created, and it was later duplicated using a linear pattern to fill the size of the frame (300 x 350mm). The file was saved in a specific folder.

To complete the PV panel, the assembly part tab in SOLIDWORKS was opened as shown in Plate 4 below. The backing, frame, cells, and glass parts created earlier in the part design section were imported to the workbench. Using the mate features, the parts were selected and assembled to form the PV panel.

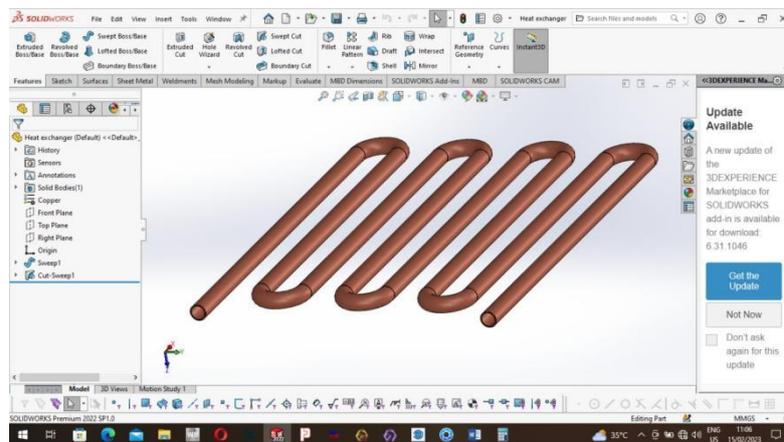


**Plate 4: PWR assembled Model**

Additionally, the panel holder and coolant tube were designed as shown in Plate 5. A new part tab was opened, and the part design section was accessed. The panel holder was constructed using the Corner Rectangle and Extrusion features, with its size matching the previously constructed panel. The file was saved in a specific folder. The coolant tube was also created in the part design section using the Circle as shown in Plate 6 below, Swept Boss, and Swept Cut features, ensuring it fit the panel size with two and a half circles. It was saved in a specific folder.



**Plate 5: PV panel holder**



**Plate 6: Construction of cooling medium**

### 2.4.2 Material Selection

The selection of materials for the various parts in the model was based on factors such as cost-effectiveness, availability, and their ability to fulfill specific functions within the context of Kano State, Nigeria. The chosen materials for each part are listed in Table 2:

**Table 2:** Items and their chosen Materials

	<b>Components</b>	<b>Material</b>
1.	Backing	Aluminum alloy
2.	Glass	pure glass
3.	Frame	Aluminum alloy
4.	Reflectors Reflectivity	98% reflectivity
5.	Stand	Steel
6.	Coolant Tube	Cooper

### 2.4.3 Coolant and Their Properties

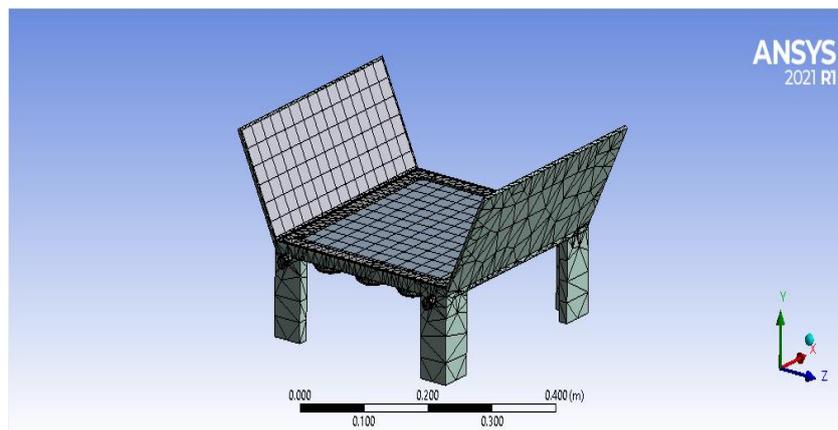
To investigate the impact of cooling on a solar panel in Kano State, Nigeria, three different coolants were employed which are water, ethylene glycol, and urea liquid. The properties of each coolant are presented in Table 3. These coolants were chosen for their specific properties and suitability for testing the cooling effect on solar panels in Kano State, Nigeria.

**Table 3:** Properties of the coolant used

S/N	<b>Properties</b>	<b>Water</b>	<b>Ethylene-glycol</b>	<b>Urea Liquid</b>
1	Density (kg/m <sup>3</sup> )	998.2	1111.4	1280
2	Cp (Specific Heat) (J/kg-k)	4182	2415	2375
3	Thermal Conductivity (W/m-k)	0.60	0.252	0.5
4	Viscosity (kg/m-s)	0.001003	0.0023	0.0157
5	Molecular Weight (W/m-k)	18.0152	0.252	0.5
6	Thermal Expansion Coefficient (/k)	0	0.00065	-

### 2.4.4 Grid Independence Test

The grid independence test was performed to evaluate the effectiveness of meshing methods on the Solar Panel, aiming to achieve grid independence. In this study, the surfaces of the Panel, cooling tube, and Stand were meshed using tetrahedral cells, as illustrated in Plate 4. Different grid systems were employed, considering three levels of mesh faces: Low, Medium, and High smoothing, applied to the same solar setup. Mesh quality was assessed for all three configurations, and the results, whether obtained numerically or experimentally, should be presented to demonstrate grid independence.



**Plate 7:** Meshing

For PWRC setup to be independent on mesh type; three cases were run on medium smoothing in order to choose the best in terms of computational time, number of elements and the result obtained. The meshing details are depicted in the Table 4.

**Table 4:** Grid Test Settings

PARAMETER	CASE 1	CASE 2	CASE 3
<b>Nodes</b>	118,074	122,047	131,112
<b>Elements</b>	56,651	58,442	64,175
<b>Mesh Quality</b>	0.19149	0.19285	0.1826
<b>Minimum Sizing</b>	0.21	0.225	0.19
<b>Curvature Angle</b>	9.40°	18.0°	7.8°
<b>Panel Temperature (°C)</b>	15.76	14.998	14.795

- i. **Case 1** has medium curvature angle, minimum sizing and has lowest number of elements and nodes in comparison with cases 2 and 3.
- ii. **Case 2** has the medium number of elements, nodes and mesh quality, minimum sizing is higher and also has the highest curvature angle among the three cases.
- iii. **Case 3** is also another modified medium smoothing mesh has the highest number of nodes, elements. It has least angle of curvature.

#### 2.4.5 Solution Setup

Step 1: From the toolbox, the steady-state thermal engineering analysis option was selected, which would allow for the analysis of thermal behavior under steady-state conditions.

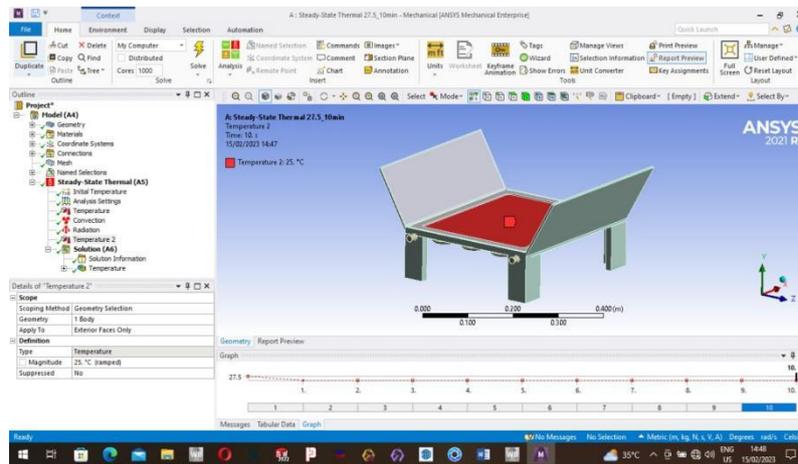
Step 2: Moving on to the second step, the geometry of the PWR (Panel with Reflector) model was imported from SOLIDWORKS software into the ANSYS workbench.

Step 3: Upon successful import, the imported PWR model geometry was displayed on the workbench. This was achieved by double-clicking on the PWR model in the workbench interface. By doing so, the user was able to visualize the imported model and further manipulate it for subsequent analysis.

Step 4: Progressing to the fourth step, a closer examination of the geometry and its constituent parts was carried out. By double-clicking on the geometry, all the parts that were assembled together to form the PWR model were displayed. At this stage, specific materials were assigned to each part based on their intended properties and characteristics. The materials utilized for the different parts of the PWR model are listed in Table 2. Assigning appropriate materials to the parts was crucial for accurate thermal analysis, as different materials possess varying thermal conductivity, heat capacity, and other properties that influence the model's behavior.

Step 5: In the final step, various input data and boundary conditions were defined to set up the thermal analysis for the PWR model. The input data included the information provided in Table 4, which specified relevant parameters and values related to the model. Additionally, the convective heat transfer coefficient, representing the rate of heat transfer through convection, was defined as  $2.5\text{W/m}^2\text{ }^\circ\text{C}$ . This coefficient played a vital role in capturing the cooling effect of convection on the PWR model. Moreover, the duration of the analysis was determined by setting the appropriate analysis settings, allowing the user to specify the desired time frame for the analysis to be conducted.

By following these steps, the PWR model was successfully set up for thermal analysis within the ANSYS workbench. The installation and configuration of the software, along with the importation of the geometry, assignment of materials, and definition of input data, provided a solid foundation for conducting a comprehensive thermal analysis of the PWR model.



**Plate 8:** ANSYS workbench for selection of panel surface temperature

### 2.5 Simulation Procedure

3D models of PWR and PWRC were developed using SOLIDWORKS software as discussed above, each panel was designed base on the design consideration of the panels used during the experiment in other to validate the simulated results. However, two other types of cooling apart from water that include ethylene and urea liquid. During the Simulation with Ansys software, the PWM experimental data found the month of March 2022 (Mean day) was used as the input data of the simulation. The panel ST and SR of PWM of before noon, noon and afternoon was selected. The selected data is shown in Table 5:

**Table 5:** Selected values from March, 2022

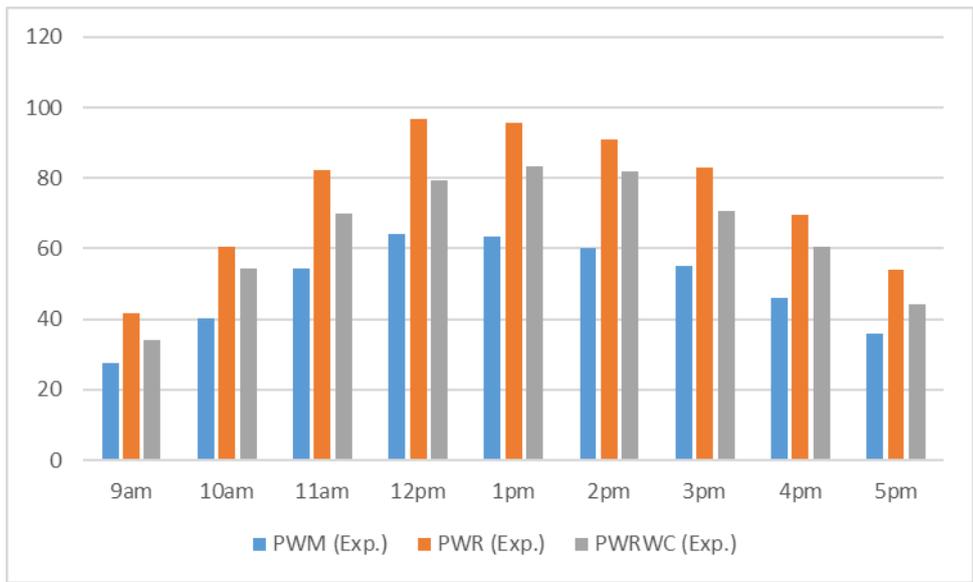
Time	Solar Radiation	Surface Temperature (°C)
9am	321	27.5
1pm	731	64.7
5pm	356	46.1

### 3. Results and Discussion

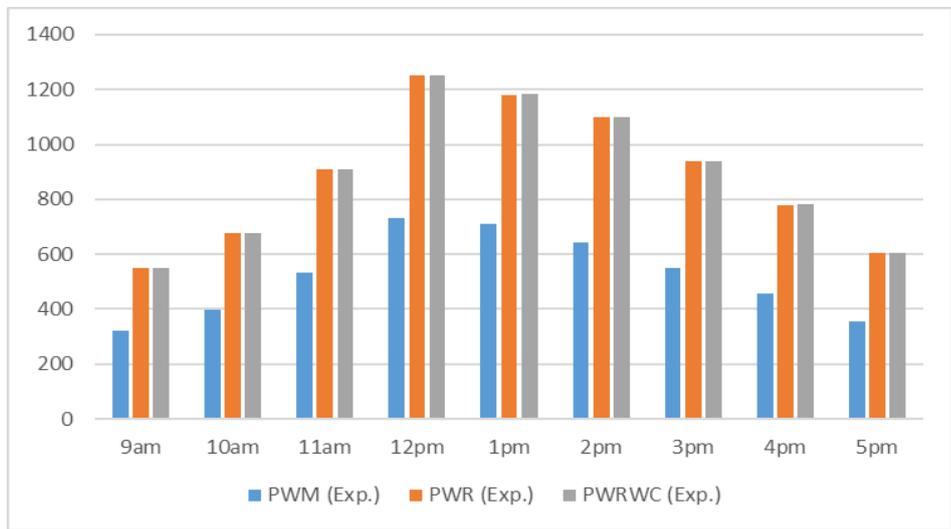
The results shown in Figure 2 and Figure 3 shows that despite PWR and PWRC are capturing the same amount of Solar Radiation (SR), the water-cooling system fixed at the back of the panel helped in reducing the Surface Temperature (ST) of the PWRC. The ST of the PWR and PWRC increased by an average of 39.19% and 23.50%, respectively, in comparison with the PWM. The maximum ST obtained on PWR and PWRC was found to be 96.9°C and 79.5°C, which is higher than that of PWM, at 64.2°C. The Panel operating temperature as stated from the manufacturer is 25° in other to obtained the stated power from the manufacturers, however, looking at the results in Figure 3 of surface temperature ST against time shows that even on the panel without concentration of more radiation PWM the surface temperature ST of the panel exceed 25° at around 9am in the morning where it reaches it maximum at around 1pm in the afternoon with surface temperature ST as 59.1°. Therefore, without even concentrating radiation, cooling regulator is needed to maintain the Surface temperature ST of the panel. In the other hand, the Surface temperature ST panel with reflector PWR system and panel with reflector and water-cooling system PWRC at that 9am in the morning is found to be 41.6° and 34.2° which is due to light concentration using reflectors.

The maximum SR found in the month of March 2022 captured by the PWR, PWRC, and PWM, is 731, 1250, and 1251 W/m<sup>2</sup>day and the minimum SR found are 718, 1160, and 1161 W/m<sup>2</sup>day.

The SR of the PWR and PWRC increased with an average of 71.26% in comparison with the PWM. However, the observed percentage increase in solar radiation (SR) did not reach the desired target of 100% increase. Several factors could contribute to this limitation, including the scattering of diffuse SR that reflects away from the panel, the inherent limitations of the solar cells in capturing SR, and the potential impact of air and dust on the panel's performance. Furthermore, when comparing the performance of the PWR (panel with reflectors) and PWRC (panel with reflectors and cooling system), it is notable that both setups captured approximately the same amount of SR. This suggests that the inclusion of the cooling system did not significantly affect the amount of SR captured by the panel.

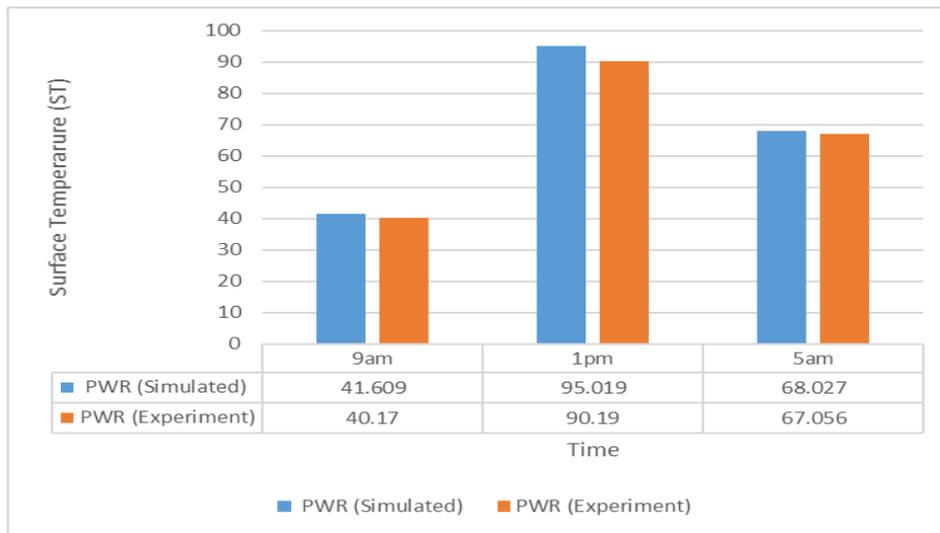


**Figure 2: SR against ST in March**



**Figure 3: Solar Radiation against Time in March**

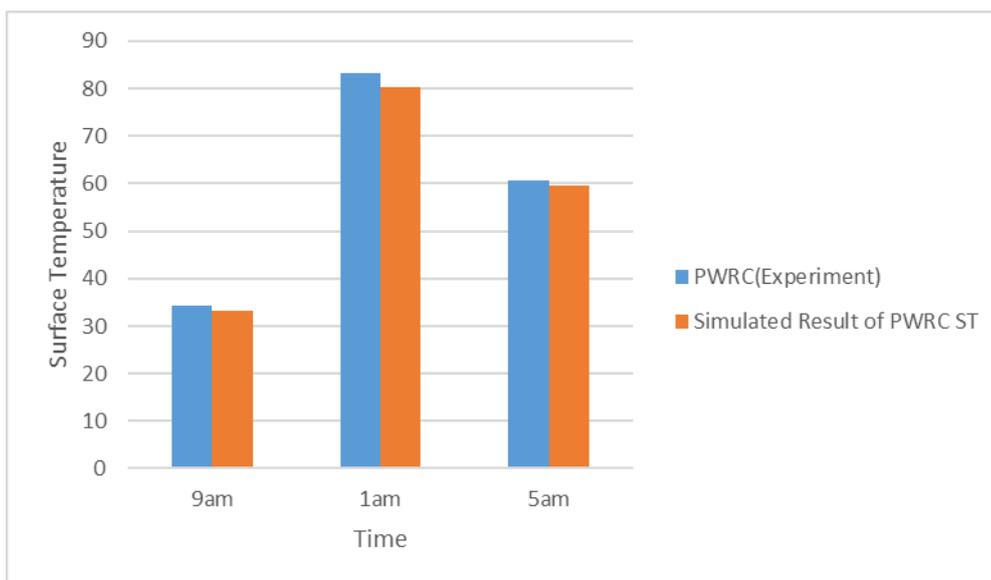
In the case of thermal simulation, the PWR (experiment) and PWR (simulation) were compared, along with the panel with reflector and water-cooling system (experiment) and panel with reflector and water-cooling system (simulation) to validate the analyses. Figures 4 and 5 below illustrate the comparison. Considering the PWR system, both the experimental and simulation results show that the surface temperature (ST) remains approximately equal at every point in time. At 9 am, the ST for both the experimental and simulation cases is 41.6°, while at 1 pm it is 96.9° and 95.0°, and at 5 pm it is 69.7° and 68.0°. Consequently, while the average deviation between the two approaches was approximately 3.31%, indicating good agreement overall, the observed differences underscore the inherent complexities and uncertainties involved in modeling and experimentation of real-world systems. These differences can be attributed to variations in heat transfer properties, inaccuracies in the model's assumptions, potential limitations in the experimental setup, and external environmental conditions. This highlights the importance of further investigation and refinement of simulation methodologies to improve accuracy and capture the nuances of the physical system under study. Moreover, comparing the simulation and experimental results of panel with reflector PWR in other to further validate the simulation methodologies as shown in figure 4 below, the graph shows that the two result are the same at 9am and approximately the same at other point.



**Figure 4:** Experimental ST and simulated ST (°C) against Time

On the other hand, the comparison between the panel with reflector and water-cooling system (experiment) and panel with reflector and water-cooling system (simulation) was conducted to further validate the simulation results and analyze the two different methods, as depicted in Figure 5. Both the experimental and simulated results were found to be approximately equal. At 9 am, the surface temperature (ST) of the simulated result was 33.2 °, while the experimental result was 34.2 °. The average percentage deviation between the experimental and simulated results was 3.12%. This deviation could be attributed to the inefficient experimental cooling system with pipes compared to the machine cooling system used in ANSYS software.

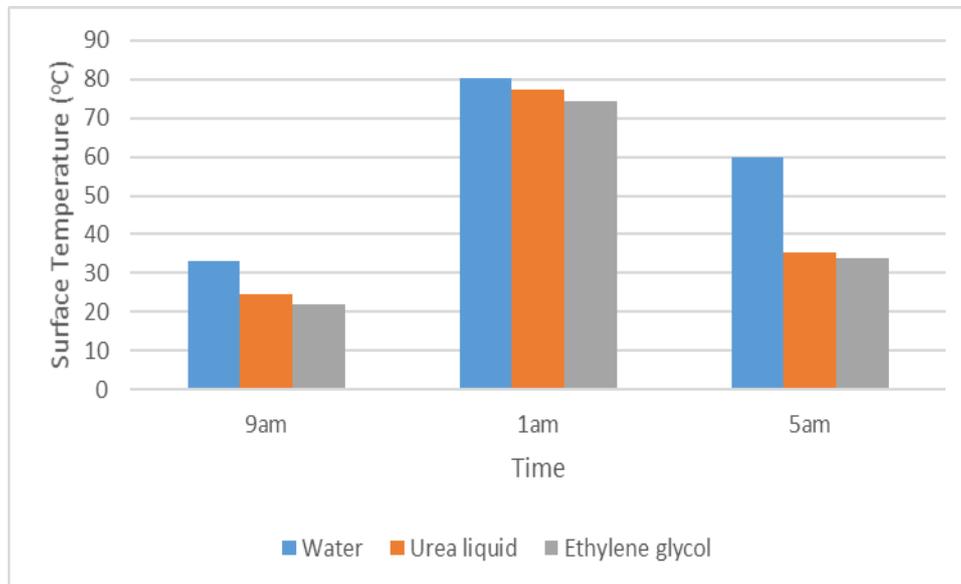
The small and acceptable deviation between the experimental and simulation methods suggests a good agreement in the thermal analysis of the panel with reflector and water-cooling system. The close alignment of surface temperature (ST) values at various times throughout the day indicates that the simulation accurately captures the thermal behavior of the experimental setup. This agreement enhances confidence in the validity and reliability of the simulation results, reinforcing the credibility of the findings. Overall, the negligible deviation between the two methods validates the analyses and demonstrates the effectiveness of the simulation in replicating the experimental conditions.



**Figure 5:** Simulated Result and Experimental Result of PWRC ST

Moreover, comparing the three different types of coolant were used as shown in Figure 6 below, ethylene glycol reduced the rate of increase of the panel ST followed by urea liquid and then water. The panel with ethylene glycol increased the ST of the panel by 22.072°C, 74.184°C, and 33.951°C when the initial ST was set at 27.5°C, 64.2°C, and 46.1°C for 50 minutes. In the case of water, the panel increased the ST by 33.155°C, 80.388°C, and 59.698°C when the initial ST was set at 27.5°C, 64.2°C, and 46.1°C, respectively. Moreover, the panel with urea liquid increased the ST of the panel by 24.648°C, 74.282°C, and 35.498°C when the initial

ST was set at 27.5°C, 64.2°C, and 46.1°C, respectively. This shows that both coolants used decrease the ST of the panel compared to the ST of the PWR. Even though when the temperature is at 27.5°C which is at 9am ethylene glycol and urea liquid decrease the ST less than the OT of the panel of 25°C from the manufacturer. This will cause a little bit under cooling of the panel, but in a little bit time the surface temperature ST will rise even above the operating temperature of the panel.



**Figure 6:** Graph of Output ST (°C) against Input ST (°C)

#### 4. Conclusion

Based on the comparison of surface temperatures at different time points (9am, 1am, and 5am), slight variations were observed between the simulated and experimental results. The simulated surface temperatures were slightly lower than the corresponding experimental surface temperatures, indicating some discrepancies. Despite these variations, the average deviation between the two approaches was approximately -3.31%, suggesting a good overall agreement. However, it is important to acknowledge that these variations highlight the inherent complexities and uncertainties associated with modeling and experimenting with real-world systems

In addition to the temperature comparison, the experiment also involved the utilization of three different types of coolants: ethylene glycol, urea liquid, and water. Among these, ethylene glycol demonstrated the highest rate of cooling the panel, followed by urea liquid and then water. The observed increases in ST varied based on the initial ST values and coolant type used. Notably, at some point in the before noon at 9am both ethylene glycol and urea liquid resulted in ST decreases below the manufacturer's specified operating temperature of 25°C when the initial temperature was 27.5°C, potentially affecting the power output by causing overcooling.

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