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The Effect of Reducing the Temperature of Photovoltaic Frame on its Efficiency: Case study in San Diego, California

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***Abstract*—** This study investigates the impact of the frame temperature on the solar panel performance with a focus on an aluminum frame cooled and maintained at 20°C. This study evaluates the potential of utilizing the frame as an active cooling mechanism for the panel. The results indicated that there is a strong significant relationship between the temperature of the frame and the various parameters. In the experiment it is concluded that the efficiency of the aluminum cooled frame was the highest with a 1.31% percent difference from the regular aluminum frame. Furthermore, the aluminum cooled frame maintained the highest efficiency level throughout the experiments which provides strong evidence that the frame can be utilized as a cooling mechanism for the panel.

***Keywords*—** Photovoltaic; Renewable energy; Efficiency analysis; San Diego; California.

1. INTRODUCTION

For the past few years, research in the renewable energy field has been directed to increase the efficiency of the Photo Voltaic (PV) systems and all its components, which include the PV panel, Wires, Inverters, charge controllers and the batteries. The PV panel temperature plays an important role in influencing the system where the increase in temperature of the panel decreases the photo voltaic panel's efficiency, and as a result the overall efficiency of the system.

PV modules are rated under standard test conditions (STC), which include an irradiance of 1000 W/m^2, solar spectrum of Air Mass 1.5, and a module temperature of 25 degrees Celsius [1]. Ratings provided from the manufactures for PV modules are always using the STC operating condition. PV modules however operate under varying environmental conditions when installed in the field, thus the information provided is not adequate to determine the actual performance of the panel in the field. When selecting a suitable PV technology for a specific location, some important factors must be considered including the annual solar intensity distribution, variations in the efficiency of the module with intensity, annual temperature distribution and module temperature coefficient, variations in the solar spectrum distribution and rate of power degradation of the PV modules with time [1-3]. Moreover, "the temperature effect on the PV module output and concluded that output decreases 0.469%/C with the temperature variation when other factors are controlled" as mentioned in [1].

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On the other hand, the efficiency of most types of renewable energy systems is relatively low, and the development of these systems along with the development of energy storage systems is one of the leading issues and limitations for the future of this field. As the efficiency of renewable energy systems increases the productivity and opportunities to exploit renewable and green energy available around us increases. One of these systems is renewable solar photovoltaic energy panels, which have an efficiency between 12% to 28%. The commercial market and the systems installed have the efficiency between 11% to 18%.

The authors in [4] stated that the solar PV technology converts solar energy directly into electricity, where extensive research done to improve its efficiency. Moreover, most of the new research is conducted to improve the produced power production and efficiency. A storage system was mentioned in [5] offers many advantages, such as extraordinarily high capacitance characteristics, on the order of thousands of farads, increased cycle life, low internal resistance, quick charging and discharging, extraordinary reversibility, excellent low-temperature performance, no destructive material, lower cost per cycle, and high cycle efficiency (up to 95%).

The authors in [6] gave a comprehensive review about solar PV technologies, architecture, and its applications to improved efficiency. They stated he associated challenges to improve the efficiency and to come over in the successful implementation of PV systems.

This research paper was carried out in San Diego, California where studied the temperature effect of the photovoltaic panel's frame on the efficiency, through applying the same methods of analysis stated for another frames. The system determined if the frame has a significant effect on the temperature of the panel. The aim of the research is to assess the possibility of using the frame to enhance the efficiency of the panel. This research paper aims to investigate the opportunity of using the photovoltaic panel's frame as a part of a cooling system for the photo voltaic panel. Moreover, the experimental investigation conducted to examine the impact of photo voltaic panels with various types of frames on its temperature and efficiency.

2. BACKGROUND

Recent research has increasingly focused on mitigating the temperature effect on PV module efficiency. For instance, the researchers in [7] proposed a configuration that utilizes both the latent heat of fusion of phase change materials (PCM) and the latent heat of evaporation of water to achieve effective cooling in a passive manner. Their study concluded that using PCM for cooling photovoltaic (PV) modules could reduce the module temperature by up to 10.14°C and 16.7°C, respectively. This cooling method resulted in a maximum power enhancement of 20.25%, with an average improvement of 8.57% compared to reference PV modules. Similarly, the authors in [8] examined the effect of nanofluids in cooling systems integrated with PV panels, demonstrating an efficiency improvement of up to 1.17% under optimal conditions.

In [9] the researchers installed their PV system in Cyprus. They analysed the effect of temperature on different grid-connected PV technologies. The results showed that over the evaluation period, the highest average thermal losses in annual DC energy yield were 8% for mono-crystalline and 9% for multi-crystalline silicon technologies, while for thin-film technologies, the average losses were 5%. Another study by [10] focused on Indian's tropical and humid environment, concluding that commercially accessible monocrystalline silicon has shown higher efficiencies among all the PV technology. Module efficiency is low at high module temperature and vice-versa.

In Japan, research indicated that PV systems operated over a wide temperature range and were strongly affected by the temperature coefficient of conversion efficiency when the module temperature became high. The results show that annual generation of PV energy was estimated to increase on average by 1.7% in 2030, 3.9% in 2050, and 4.9% in 2070 due to climate change [11].

Exploring innovative cooling techniques, recent studies have applied water- and air-cooling mechanisms, as well as advanced materials for the frame and back sheet, to enhance heat dissipation. For instance, the researchers in [12] conducted a study where they developed a hybrid photovoltaic and thermal solar energy collector integrating phase change material (PVT-PCM). The cross-season tests demonstrated that the system achieved an overall efficiency of 39.4% and an energy-saving efficiency of 64.2%. Moreover, the efficiency can be improved by different ways as mentioned in [13, 14].

In [15] the authors evaluate the influence of the performance of Poly-crystalline, Mono-crystalline, and Thin-film PV systems in Amman, Jordan regarding the temperature variations. Field data from three identical systems were analyzed to determine actual energy taken and temperature coefficients, revealing that Thin-film panels are less affected by temperature. The results inform optimal solar cell technology selection based on local climate conditions, enhancing project economics and efficiency.

Researchers in [16] examine the effects of high-temperature exposure on selective absorber samples prepared by using alternate and reverse plating techniques. It was tested using glazed flat plate collectors. The findings showed that increased temperatures, especially at 300°C, lead to a decrease in solar absorptivity and an increase in emissivity, reducing photothermal efficiency. The optical and thermal properties of the films highlighting temperature as a critical factor in absorbing stability and performance was significantly impacted by the degradation at elevated temperatures.

These studies underscore the critical role of temperature management in optimizing the efficiency of PV systems, particularly in hot and arid climates. As such, incorporating cooling mechanisms into PV system designs remains a promising approach to enhance overall performance. Moreover, Table 1 shows an in-depth comparison between the presented PV colling Techniques.

3. METHODOLOGY

This paper aims to study the effect of the panels frame regarding the panels various parameters. The experiment based on the analysis of six panels with different frame materials. The data generated from the panels under the same test conditions were analyzed to validate the hypothesis that the frame affects the parameters of the panels.

3.1. Experimental Work

The test modules for this research were comprised of six polycrystalline photovoltaic panels, each with a 50-watt rating. The surface area of the PV panel used for the experiment has dimensions of 550*630*30 mm. The surface area used to generate power, which used the name plate of the PV panel.

Table 1. Comparative analysis of PV cooling techniques.

Reference	Cooling Method	Experimental Conditions	Performance Improvement	Advantages	Limitations
[7]	PCM and Latent Heat of Water	Passive cooling	Max. 20.25% power enhancement, avg. 8.57%	Effective, passive, reduces module temperature	PCM cost, limited by PCM properties
[8]	Nanofluids in Cooling System	Active cooling	Up to 1.17% efficiency improvement	Improved thermal conductivity	Nanofluid cost, stability issues
[9]	Grid Connected PV system	Analysis of different grid-connected PV technologies in Cyprus	The highest average thermal losses were 8% for mono-crystalline and 9% for multi-crystalline silicon technologies, while for thin-film the average losses were 5%.	Stated the different losses in the grid-connected PV technologies.	Only measures for the specific grid PV technologies in Cyprus
[10]	India's humid enviroment	Analysis commerically accessible monocrystalline silicon PV module	Showed commerically accessible monocrystalline silicon PV module are more efficient.	Stated which module is more efficienct in humid environment.	Does not apply in arid or dryer environment.
[11]	Japan wide temperature range analysis	Estimated annual increase of 1.7% in 2030, 3.9% in 2050, and 4.9% in 2070	Annual PV enery production may increase over year of climate change.	Only provided Japan estimate increase in the future PV energy Production	Does not provide other location future increase
[12]	Hybrid PVT-PCM collector	Cross-season tests	39.4% overall efficiency, 64.2% energy-saving efficiency	High overall efficiency, energy-saving	System complexity, cost

The main goal is to evaluate the impact of the PV performance regarding the temperature which is transmitted through the bordering frame. Some factors were measured like open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), total temperature, and other factors of the solar panels, particularly those with a cooled aluminum frame. The specific electrical parameters for the polycrystalline modules are presented in Table 2 and shown in Fig. 1.

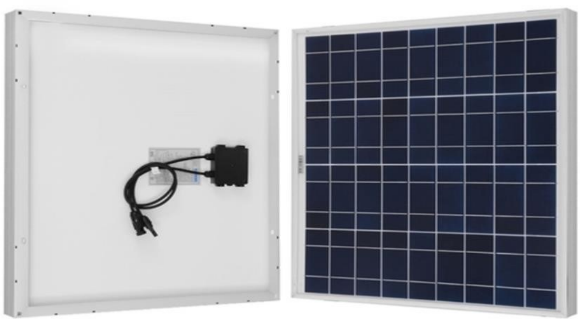

Fig. 1. Renogy Polycrystalline 50-Watt solar panel.

Table 2. Electrical characteristics for Polycrystalline.

Module Type	RNG-50P
Max Power at STC (P_{max})	50 W
Open-Circuit Voltage [V]	22.4 V
Short-Circuit Current (I_{sc})	2.95 A
Optimum Operating Voltage (V_{mp})	17.8 V
Optimum Operating Current (I_{mp})	2.84 A
Temp Coefficient of P_{max}	-0.44%/°C
Temp Coefficient of V_{oc}	-0.30%/°C
Temp Coefficient of I_{sc}	0.04%/°C
Max System Voltage	600VDC (UL)
Max Series Fuse Size Rating	15 A
Fire Rating	Class C
Weight	5kgs/11lbs
Dimensions	550x680x30mm / 21.6x26.7x1.2in
STC	Irradiance 1000 W/m², T = 25°C, AM=1.5

Test modules were installed in San Diego Vista at the coordinates 33.19 N Latitude and 117.27 W Longitude. The software that was used in the simulation was PVSYS. To maximize the angle of incidence, optimal tilt angles for application were determined to be 57°, 49°, and 41°. During the experiments, the panels were positioned at these angles to the south (zero azimuth). This location was selected because of the favorable wind conditions; the walls surrounding the court helped shield wind from the panels, eliminating most external influences on the temperature of the panels.

In the month of November, the average monthly global horizontal irradiance for San Diego was registered at 5.26 kWh/m²/day. This value reflects the global horizontal irradiance received by panels at their optimal tilt angles for solar panels with optimal tilt angles of 57°, 49°, and 41° for the period of the three experiments.

3.2. Experimental Work Procedures

The experiment consisted of six polycrystalline solar panels; each has a frame of different materials and color. Material selected for the frames were as follows; Steel (black coated), steel (white coated), Aluminum, Wood (white coated), and Wood (black coated). The selected materials and colors have different mechanical and heat properties which vary from low to high heat transfer and thermal conductivity values. This assisted in studying the effect of the various frames on the efficiency of the panel through the heat transfer from the frame to the PV panels. The results have been analyzed using two methods, first by comparing the parameters obtained through the experiment with the adjusted parameters provided from the manufactures using the temperature coefficients for the panels used. The second method was though studying the correlation between the parameters and determine if the correlation is statistically significant. The second phase of the experiment was utilizing the frame in cooling the panel. Through applying the same methods of analysis stated for phase I, the results have been stated have a significant effect on the panel temperature. The aim of the research is to assess the possibility of using the frame to enhance the efficiency of the panel. If a correlation is established, further research should be employed to use material with heat and mechanical properties capable of offsetting the effect of the temperature on the panel and increase efficiency and output.

The profile of the selected material for the frames was based on the frame provided by the manufacturer for the aluminum panels. Fig. 2 shows the dimensions and thicknesses details.

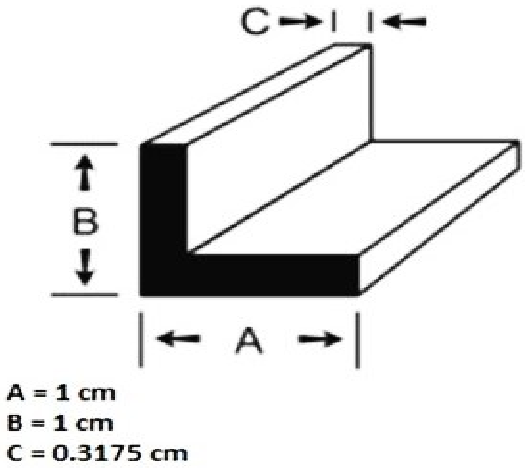

Fig.2. Dimensions and thickness of the angles.

The PV modules were mounted at 57°, 49° and 41° degrees, a plastic sheet was placed under the test subjects to limit the heat reflection and transfer from the ground. The panels were spaced at equal tilt angles and uniform spacing to eliminate the thermal and electrical inconsistency leading to temperature variations.

For this experiment the aluminum frame has been used as a reference point for the comparison of the various parameter results of the different frames. The parameters for the aluminum panel under standard test conditions were provided by the manufacturer. Thus, adjusted module values were calculated using the temperature coefficient to account for the effect of temperature. By comparing the experimental efficiencies of panels with different frames against the aluminum panel's efficiency and the theoretical value, this will assess to indicate the impact of frame materials on module performance.

3.3. Analysis Methodology and Data Generating

The experimental trials were held within a set period from 9:30 AM to 3:00 PM. The panels were mounted at 8:00 AM so that there was enough time for both the temperature of the panels and their surrounding frames to rise. The first set of readings was collected at 9:30 AM. After that, the different test modules were measured at 30-minute intervals. The parameters measured included solar irradiance obtained from the power meter, outdoor temperature, open circuit voltage supplied by a Fluke Clamp Meter, short-circuit current collected using a digital multimeter, and the temperature of the frame and the PV panel of each module as measured with a digital infrared thermometer.

4. EXPERIMENTAL RESULTS

The point of reference was the panel with the regular aluminum frame. The data represents the panel readings from the site. Noting that throughout the day the radiation highest value was 1150 and the lowest value is 700 W/m^2.

The fill factor (FF) is an important parameter which represents the ratio of maximum obtainable power (P_{max}) to the product of the open circuit voltage (V_{OC}) and short circuit current (I_{SC}). It is calculated by comparing the maximum power to the theoretical power as shown in Eq. (1).

$$FF = \frac{P_{max}}{V_{o.c} * I_{S.C}} \quad (1)$$

For the on-site efficiency it refers to the actual portion of energy in the form of sunlight that can be converted by photovoltaic panel into electricity, which was calculated using the on- site readings and parameters. It is derived from the maximum power (P_{max}), the solar radiation (E), and the aperture area of the solar panel A, as shown in Eq. (2).

$$\eta = \frac{V_{o.c} * I_{S.C} * FF}{E * A} \quad (2)$$

where the Voc, Isc and E are the readings from the site. The theoretical efficiency is calculated using actual radiation and the adjusted V_{oc} and I_{sc}, which is based on the temperature of the panel at that point as shown in Eq. (3).

$$\eta = \frac{Vadj * Is.c * FF}{E * A} \quad (3)$$

As shown in Fig. 3, it was expected for theoretical efficiencies to be higher than the onsite efficiencies as the parameters on the plate were generated in standard test conditions in labs where the environmental factors can be controlled. On site however, there were many environmental factors that could contribute to the deviation from theoretical power output and efficiencies.

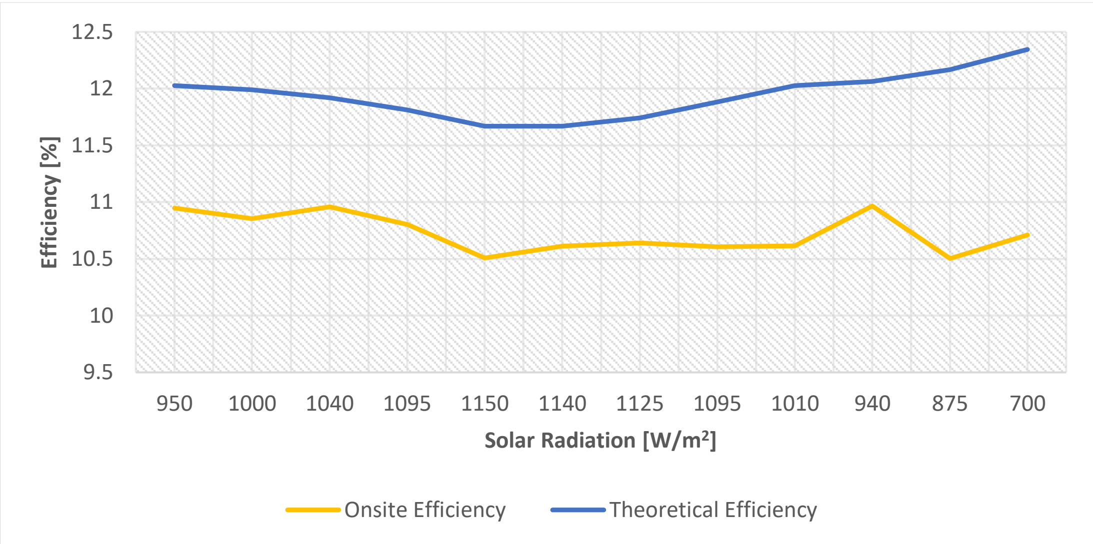

Fig. 3. The difference between the onsite and theoretical efficiency.

4.1. Cooled Aluminum Frame

Three experiments were conducted for the frame as following; the correlation for the wood black frame in experiment one indicated no correlation between the temperature of the frame and V_{oc}, in experiment 2 there was a correlation between the temperature of the frame and V_{oc}, and in experiment 3 there was no correlation for the temperature of the frame and the I_{sc} or the V_{oc}. Moreover, there were also variations for the aluminum frame as in experiment 1 there was no correlation between the temperature of the frame and any of the tested variables, however a strong significant correlation was shown in experiments 2 and 3.

An important criterion in evaluating the effectiveness and performance of a solar panel or solar technology is efficiency. Thus, efficiency was utilized in this experiment as a tool to study the differences among the various frames by studying the differences in the output efficiency. The Aluminum frame was used as the point of reference. As mentioned in the beginning of this section, the aluminum frame's onsite efficiency was compared to theoretical efficiency. The average onsite efficiency was around 10% while theoretical efficiency was 12%. The difference implies that though the temperature coefficient is provided to calculate the onsite expected values for the various panel parameters, environmental factors will never allow the panel to reach the full output efficiency calculated theoretically. Moreover, the values selected for the comparison between the various frames are the onsite value. The values for the Aluminum frame's efficiency for the three experiments were compared with the values of each frame separately.

Accordingly, the efficiency of the panel depends on the short circuit current and the open circuit voltage, thus these two parameters were measured and compared using the same method utilized for comparing the efficiency in which the aluminum frame used as a reference point for the comparison.

Figs. (4, 5, and 6) below represent the average efficiency of the various panels. The figures represent the values of various radiation and temperatures throughout the day for all the frames for the three experiments.

Comparing all kinds of frames and their performances within different solar radiations, it is noticed that the efficiency of the cooled aluminum frame exceeds the regular aluminum frame. As shown in the previous figures there is a difference between the efficiencies of the aluminum cooled frame and the aluminum frame, where the cooled aluminum frame panel's efficiency is higher than the aluminum frame by 1.54%, 0% and 2.39% for the experiment one, two and three respectively. The average of all experiments is 1.31%, which means that the aluminum cooled frame's efficiency is higher than the regular aluminum frame by 1.31%. Moreover, the figures showed in all cases that the lowest efficiency is referred to the steel frame which has large temperature coefficient. Table 3 represents the average of the values represented in the previous Figs. (4 to 6) for the three experiments.

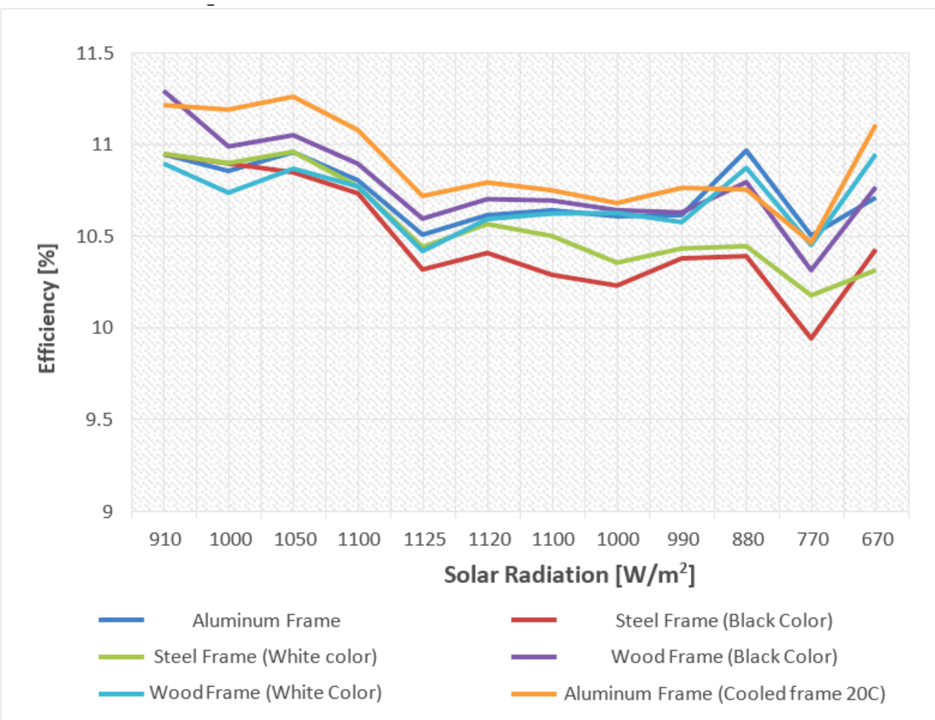

Fig. 4. Experiment one all types of frame efficiencies and radiation.

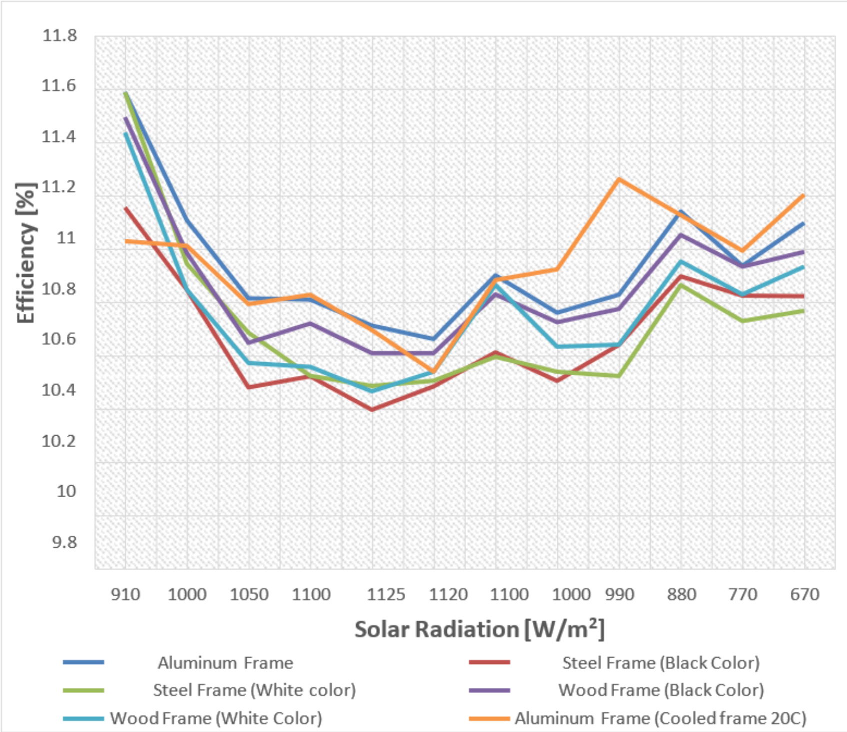

Fig. 5. Experiment two all types of frame efficiencies and radiation.

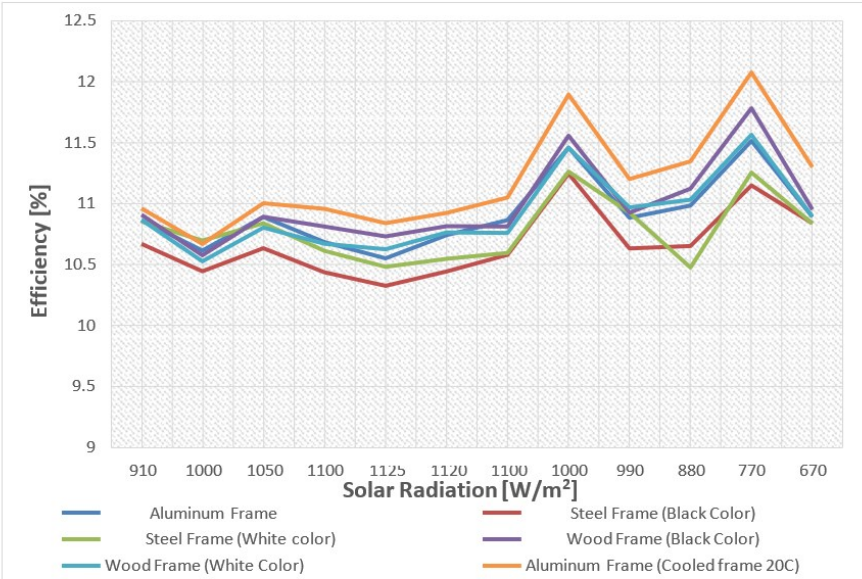

Fig. 6. Experiment of three types of frame efficiencies and radiation

Table 3. Average of all experiments open circuit voltage and efficiencies.

Average of all the Experiments	Voc. Difference			Efficiency Difference		
	Max	Min	Ave	Max	Min	Ave
Steel Frame (Black Coated)	1.34%	0.33%	0.74%	4.09%	0.39%	2.30%
Steel Frame (White Coated)	0.67%	-0.17%	0.26%	4.12%	-0.37%	1.57%
Wood Frame (Black Coated)	0.50%	-1.00%	-0.14%	1.29%	-1.82%	-0.14%
Wood Frame (White Coated)	0.85%	-0.17%	0.39%	1.49%	-0.86%	0.64%
Cooled Aluminum frame	-0.33%	-2.17%	-1.11%	2.09%	-4.19%	-1.34%

As presented, the efficiency of the Aluminum frame was higher than the steel black and white frames, and the wood black and white frames. The average differences across the three experiments were as follows for the frame in respective order: 2.3%, 1.57%, 0.14%, 0.64%. However, the efficiency of the aluminum cooled frame was higher than the efficiency of the aluminum frame by an average of 1.34% for the three experiments. It should be noted that the V_{oc} average value for the aluminum cooled frame was 1.11% higher than the regular aluminum frame. The other notable difference was between the steel black frame and the aluminum frame, in which the V_{oc} of the aluminum frame was higher by 0.74%.

4.2. Statistical Analysis Results

The aim of this analysis is to investigate the effect of the frame on the different parameters of the panel i.e. V_{oc}, I_{sc}, temperature of the panel, and efficiency. The method chosen for the analysis is generating the correlation value between all the parameters using the data gathered in the experiment.

The correlation value is utilized to measure the strength of the linear relationship between the different variables as done in [17]. The correlation denotes how close the values fall to a straight line thus quantifying both the strength and direction of the linear relationship between measured variables [17]. A correlation value equal or greater than 0.7 indicates that there is a strong correlation between the tested variables.

Furthermore, the statistical significance of the correlation values was tested using the regression analysis to generate the P-Value using the same data. For this research the null-hypothesis presented with no correlation/ relationship between the temperature of the panel's frame and the different variables. An alpha (α) value of 0.05 was used to determine the statistical significance, meaning that a P-value less than 0.05 will lead to rejecting the null hypothesis and thus accepting the alternative hypothesis that there is indeed a relationship/correlation between the temperature of the panel's frame and the tested variable. The analysis was performed for each experiment separately.

4.3. Correlation Testing

The correlation for the experiment was found using the correlation function. The correlation matrix allows for the correlation to be generated between all the variables as seen in Table 4. Correlation values higher than 0.7 represent a very strong correlation and thus were highlighted.

4.4. Significance

Though the correlation may suggest that there is a strong positive or negative relationship between the different variables, it is crucial to test the correlation to determine whether the correlation is statistically significant. The statistical significance was found using the P-Value method as shown in Table 4. The multiple R value is identical to the correlation value, as the multiple R is a measure of how close the different variables to the regression line. The higher the R value denotes a higher correlation or relationship between the variable. Moreover, P-Values less than 0.05 were highlighted to indicate a strong statistical relationship.

The following tables (Tables 5, Table 6, and Table 7) show the summary output - Aluminum Frame Temp of Panel and Temp of Frame.

Table 4. Correlation values for Aluminum frame.

Aluminum Frame	Radiation	T of atmosphere [C]	T of panel [C]	T of frame [C]	V o.c [V]	I s.c [A]	Efficiency
Radiation	1						
T of atmosphere	0.49141173	1					
T of panel	0.96815010	0.47061686	1				
T of frame	0.46233939	-0.169778	0.48731167	1			
V o.c	-0.86501809	-0.54207219	-0.9075565	-0.53142491	1		
I s.c	0.99491235	0.45149914	0.96621528	0.44075754	-0.86151762	1	
Efficiency	-0.1936834	-0.5203233	-0.2235067	-0.3998239	0.3767330	-0.104347	1

Aluminum Frame	Radiation	T of atmosphere [C]	T of panel [C]	T of frame [C]	V o.c [V]	I s.c [A]	Efficiency
Radiation	1						
T of atmosphere	0.49141173	1					
T of panel	0.96815010	0.47061686	1				
T of frame	0.46233939	-0.169778	0.48731167	1			
V o.c	-0.86501809	-0.54207219	-0.9075565	-0.53142491	1		
I s.c	0.99491235	0.45149914	0.96621528	0.44075754	-0.86151762	1	
Efficiency	-0.1936834	-0.5203233	-0.2235067	-0.3998239	0.3767330	-0.104347	1

Table 5. Aluminum frame P-Value test (a).

Regression statistics	
Multiple R	0.487311679
R Square	0.237472672
Adjusted R Square	0.16121994
Standard Error	5.22965711
Observations	12

Table 6. Aluminum Frame P-Value test (b).

ANOVA	df	SS	MS	F	Significance F
Regression	1	85.17353183	85.17353183	3.114284089	0.108071508
Residual	10	273.4931348	27.34931348		
Total	11	358.6666667			

Table 7. Aluminum Frame P-Value test (c).

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.09%
Intercept	53.359	5.305	10.058	0.000	41.539	65.179	41.539	65.179
T of frame [C]	0.227	0.128	1.765	0.108	-0.060	0.513	-0.060	0.513

5. RESULT ANALYSIS

The temperature of the frame had no effect on any of the variables for the aluminum cooled frame. However as indicated in the table below a strong correlation was appearing between the other variables which resembles the correlation pattern in the normal aluminum frame. Specifically, for experiments 2 and 3, the Aluminum frame presented a strong relationship between the temperature of the frame and the other variable as shown in Table 8.

Table 8. Correlation matrix for all parameters of experiments 1, 2 and 3.

Aluminum Frame (Experiment 1)	***Radiation***	***T of atmosphere***	***T of panel***	***T of frame***	***V o.c***	***I s.c***
Radiation	1.00					
T of atmosphere [C]	0.49	1.00				
T of panel [C]	0.97	0.47	1.00			
T of frame [C]	0.46	-0.17	0.49	1.00		
V o.c [V]	-0.87	-0.54	-0.91	-0.53	1.00	
I s.c [A]	0.99	0.45	0.97	0.44	-0.86	1.00
Efficiency	-0.19	-0.52	-0.22	-0.40	0.38	-0.10
Aluminum Frame (Cooled frame 20C) Frame (Experiment 1)	***Radiation***	***T of atmosphere***	***T of panel***	***T of frame***	***V o.c***	***I s.c***
Radiation	1.00					
T of atmosphere [C]	0.49	1.00				
T of panel [C]	0.96	0.53	1.00			
T of frame [C]	0.00	0.30	-0.03	1.00		
V o.c [V]	-0.88	-0.60	-0.95	-0.02	1.00	
I s.c [A]	0.99	0.38	0.95	-0.01	-0.87	1.00
Efficiency	-0.18	-0.80	-0.21	-0.02	0.27	-0.02
Aluminum Frame (Experiment 2)	***Radiation***	***T of atmosphere***	***T of panel***	***T of frame***	***V o.c***	***I s.c***
Radiation	1.00					
T of atmosphere [C]	0.71	1.00				
T of panel [C]	0.98	0.73	1.00			
T of frame [C]	0.95	0.60	0.94	1.00		
V o.c [V]	-0.95	-0.73	-0.97	-0.96	1.00	
I s.c [A]	0.99	0.65	0.97	0.95	-0.94	1.00
Efficiency	-0.68	-0.86	-0.72	-0.59	0.73	-0.59
Aluminum Frame (Cooled frame 20C) (Experiment 2)	***Radiation***	***T of atmosphere***	***T of panel***	***T of frame***	***V o.c***	***I s.c***
Radiation	1.00					
T of atmosphere [C]	0.71	1.00				
T of panel [C]	0.99	0.65	1.00			
T of frame [C]	0.28	-0.10	0.37	1.00		
V o.c [V]	-0.95	-0.60	-0.96	-0.45	1.00	
I s.c [A]	1.00	0.71	0.99	0.26	-0.94	1.00
Efficiency	-0.72	-0.46	-0.72	-0.51	0.83	-0.66
Aluminum Frame (Experiment 3)	*Radiation*	*T of atmosphere*	*T of panel*	*T of frame*	*V o.c*	*I s.c*
Radiation	1.00					
T of atmosphere [C]	0.50	1.00				
T of panel [C]	0.93	0.61	1.00			
T of frame [C]	0.82	0.48	0.94	1.00		
V o.c	-0.78	-0.72	-0.94	-0.90	1.00	
I s.c	0.99	0.56	0.93	0.80	-0.82	1.00
Efficiency	-0.48	0.04	-0.46	-0.52	0.23	-0.33
Aluminum Frame (Cooled frame 20C) (Experiment 3)	*Radiation*	*T of atmosphere*	*T of panel*	*T of frame*	*V o.c*	*I s.c*
Radiation	1.00					
T of atmosphere [C]	0.50	1.00				
T of panel [C]	0.92	0.45	1.00			
T of frame [C]	-0.07	0.11	0.00	1.00		
V o.c	-0.84	-0.33	-0.89	-0.06	1.00	
I s.c	0.98	0.58	0.91	-0.01	-0.81	1.00
Efficiency	-0.54	0.14	-0.51	0.25	0.64	-0.37

However, no comparable correlation was observed in any of the experiments conducted with the cooled frame. As shown from the results, there was a strong significant relationship between the temperature of the frame and the different variables for all the frames except the aluminum cooled frame. However, there were some variations among some of the frames in the three experiments.

The correlation for the wood black frame in experiment one indicated no correlation between the temperature of the frame and V_{oc}, in experiment 2 there was a correlation between the temperature of the frame and V_{oc}, and in experiment 3 there was no correlation for the temperature of the frame and the I_{sc} or the V_{oc}. Moreover, there were also variations for the aluminum frame as in experiment 1, also, there was no correlation between the temperature of the frame and any of the tested variables. However, a strong significant correlation was shown in experiments 2 and 3.

The correlation pattern was consistent for the steel black and white frames as well as the wood white frame. Noting that for the steel black frame there was a strong significant correlation between the temperature of the frame and the efficiency in experiment 2, while there was no such correlation present in the other two experiments, nor any similar correlation for any of the other frames in all the experiments.

Regardless of the minor variations in the results, the null- hypothesis was rejected due to the P-Value being less than the selected (α) value of 0.05, and thus there was an effect or strong relationship between the temperatures of the frame on the various variables. This effect however was not proven through this statistical analysis for the cooled frame as the correlation value was lower than 0.7 for all the variables. This could indicate to the maintained 20 degrees Celsius of the temperature where the temperature did not impact the performance of the other variables.

6. CONCLUSIONS

The aim of this work was to explore the effect of the panel's frame temperature on the performance of the panel, i.e. various parameters including the panel's temperature, V_{oc}, I_{sc}, and efficiency. Aluminum, cooled aluminum, black and white steel, black and white wood frames were used as the frame material for the panel. The aluminum frame was used as the reference point as it was the standard frame provided by the manufacturer.

In the experiment it was concluded that the efficiency of the aluminum cooled frame was the highest with a 1.31 % percent difference from the regular aluminum frame. The results suggested that the frame's temperature influences the performance of the panel though impacting the various parameters. This impact as seen through the various efficiency values varies based on the material, as each selected material has varying heat properties with aluminum yielding the highest efficiency, and the steel produced the lowest efficiency values. Moreover, for the aluminum cooled frame there was no correlation between the temperature of the frame and the various parameters, however the efficiency value was the highest among all the frames. This could suggest that because the temperature of the frame was set at a temperature of 20 degrees it did not impact on the other parameters and thus contributed to the higher efficiency values.

It was found that when compared to the regular aluminum frame the cooled frame produced higher efficiency though the two frames which were of the same material, this suggests that cooling the frame can be utilized to aid in counteracting the environmental effects and in turn improve the performance of the panel.

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