The Effect of Non-Recirculating Front Surface Air Cooling on the Amount of Electricity in Volts Produced by a Photovoltaic Solar Panel System

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The low efficiency of photovoltaic panels has limited its commercial use and its ability to convert clean energy into electricity. To increase photovoltaic panel efficiency by decreasing surface temperature and improving voltage production, non-recirculating front surface air-cooling was proposed. It was hypothesized that if an air curtain is installed over a photovoltaic solar panel, then the number of volts produced would be greater than a plain solar panel configuration. The final curtain design was built of two propellers, controlled by 3-volt motors, held by balsa wood, and powered by a DC supply. The photovoltaic panel was built in a circuit using a 1,000-ohm resistor, LED light, breadboard, wire, and a halogen light as the power source. The controlled test, completed without the air -cooling, had 20 trials, each four hours long. Another 20 trials of 4 hours were completed with the cooling system. The experiment was conducted in a closed setting, with no other source of light or air. Temperature (°C) and voltage (V) data were collected through a LabQuest 2. The data were statistically analyzed using a paired t test with a 95% confidence interval. The results show that, on average, the air-cooled setup generated 2.720% more voltage than the controlled test. The air-cooled setup was 35.801% cooler than the controlled setup. The changes in voltage and temperature are statistically significant, as the p-values were less than 0.010. Therefore, the solar panels with air curtains were demonstrated to be more efficient in producing electricity, meaning the hypothesis was supported.

Introduction

Since the Industrial Revolution in the mid-1700s, humans have burned fossil fuels as the primary source of energy. This has led to environmental pollution and the depletion of raw materials[1]. To avoid these issues, humans need to decrease their consumption of fossil fuels. Sources such as the Sun provide free, clean, and unlimited energy[2]. According to Mekhilef et al., solar energy hitting the Earth in one hour is equivalent to a year's worth of energy used on Earth[2]. As a result, researchers and companies have begun to invest in finding ways to efficiently capture solar energy using photovoltaic solar panels[1]. Also, commercial solar panels are becoming more popular and electric utility companies are constructing solar farms. Despite the amount of energy the Sun provides and the efforts being made to increase solar panel efficiency, most of today's commercial photovoltaic panels convert less than 20% of solar irradiance, the output power of light energy from the sun, into electricity[3].

Photovoltaic solar panels demonstrate the photovoltaic effect, where photons from sunlight transfer their energy to electrons, creating a current. Solar panels have a low conversion efficiency since most of the irradiance is reflected and converted into heat energy[2]. Furthermore, solar panels are known to decrease in efficiency due to the panel heating up and the build-up of dust on the surface. A hybrid photovoltaic panel set up can have different types of configurations, such as an air or water cooling system, to mitigate these issues. Air-curtain cooling may be the most ideal method of cooling since it does not require a constant supply of water, which must be cooled and recirculated continuously. Also, air-curtain cooling eliminates both issues by blowing away most dust particles and pushing warm air away from the panel. Air cooling systems, when installed on a photovoltaic solar panel, should not only increase the number of volts generated but also keep the surface temperature lower when compared to a bare solar panel.

The number of volts produced by the hybrid solar panel system depends on the cooling setup. This is because the photovoltaic panel stays constant, while a cooling system is added for the manipulated tests. Voltage (V) is the pressure in a circuit that causes electrons to flow. In this experiment, voltage production was measured from the photovoltaic panel using a Vernier voltage probe and a LabQuest 2. The solar panel surface temperature (°C) also depends on the hybrid solar panel system set up. Most of the light from the 500-watt halogen light is reflected off as heat energy. As a result, the panel surface temperature rises the longer it is exposed to the light. Installing an air curtain causes most of the warm air reflected by the solar panel to travel downwards and away from the panel. The solar panel surface temperature (°C) was measured using a Vernier stainless steel temperature probe, connected to the same LabQuest 2.

It has been found that solar panel efficiency can decrease up to 20% when the panel temperature increases, making them less applicable[1]. According to a previous study by R. Hosseini, N. Hosseini, and Khorasanizadeh, a proper method of heat extraction needs to be installed to photovoltaic panels so they can operate in optimal conditions. The study tested running a film of water across the surface of the solar panel. Cooling the panel with the fluid water resulted in an increase of 1.6% in electrical efficiency[4]. However, it must be taken into consideration that the researchers used some of the generated power for a water pump and water cooler. A much more simple and cheap method would be replacing the water-cooling system with an air-curtain. This system would not need a constant supply of water and only require minimal power. This study revealed a possible advantage of using a non-recirculating air-cooling system for a hybrid solar panel.

Mekhilef et al. found that dust can also have a profound effect on the performance of solar panels[3]. According to their study on the effect of dust on the efficiency of photovoltaic panels, solar panel voltage production decreases up to 4.7% in the United States, and up to 65% in other major countries [3]. As wind speed increases, more dust, defined as minute particles less than 500 μm in diameter, settles on solar panel surfaces. As the dust increases, the voltage produced by the panel would decrease exponentially. Installing a strong fan and motor to the photovoltaic panel should reduce this issue. The fan would constantly blow the settled dust away from the panel, keeping the efficiency and voltage production of the panel more consistent. However, it must be considered that this project's non-recirculating air-cooling system was not tested against dust, as the trials were done indoors. This study by Mekhilef et al. revealed a possible advantage of using a non-recirculating air-cooling system for a photovoltaic panel.

Tonui and Tripanagnostopoulos conducted a similar study to this research project. A back-surface non-recirculating system was constructed using an air pump and insulation material as the channel[6]. The insulative material was wrapped around the panel so that a small channel of space was available for air to pass through and conduct heat. Toni and Tripanagnostopoulos tested different air inlet temperatures and flow rates to determine which best increases efficiency. Using two types of constructed back-surface cooling systems, the efficiency of the solar panel was found to increase by 12% and 20%[6]. Although the method of cooling will not be the same, this study suggests that air, although a relatively poor heat conductor, can increase solar panel efficiency significantly. As a result, front-surface cooling is hypothesized to have some kind of cooling ability.

The purpose of this project was to identify a more efficient hybrid solar panel configuration that produces more voltage. Due to the lack of efficient ways to use alternative sources of energy, humans continue to burn fossil fuels and emit greenhouse gasses. This is demonstrated by photovoltaic solar panels which are inefficient at collecting solar energy. Adding an air curtain to a photovoltaic panel would increase its efficiency by circulating the hot air away from the panel and keeping it cool[1]. In turn, this would reduce the need for other energy sources. This purpose is relevant because global warming, climate change, depletion of fossil fuels, and mass consumption of raw materials are threatening the environment and its organisms[1]. As a result, alternative measures, such as engineering a hybrid solar panel system, need to be taken.

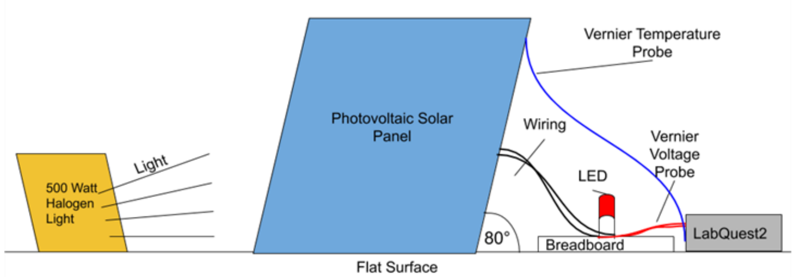
It was hypothesized that if an air curtain is installed over a photovoltaic solar panel, then the number of volts produced by the hybrid system would be greater when compared to the plain solar panel configuration. The experiment was designed to measure the voltage productions of two different hybrid photovoltaic panel systems. During the experiment, the different systems were tested 20 times each, with every trial lasting 4 hours. The first 20 trials used a photovoltaic panel alone, powered by a 500-watt halogen light. The second set of 20 trials measured a photovoltaic panel paired with a non-recirculating surface air curtain. The air curtain was constructed using two mini fan blades, each 89mm in length, and two 3-volt DC motors. Voltage production and solar panel surface temperature data were used to determine if a non-recirculating air curtain improves the efficiency of the photovoltaic panel.

Methods

The 33.528 x 20.574 x 1.778 cm photovoltaic solar panel was acquired and propped up using household objects so that it receives most of the surrounding light. The panel was always tilted up 80° from the ground. The method of propping up the panel did not matter if the angle of the panel was kept constant with the halogen 500-watt work light throughout all the trials. In addition, the size of the panel did not matter if the cooling system covered the length of the panel and the same panel was used in all the trials. A positive and negative wire was attached to the appropriate ports of the solar panel and connected to the breadboard. The single 5-millimeter LED light bulb and the Vernier 30 volt-voltage probe were also connected to the breadboard so that a circuit, powered by the photovoltaic panel, was formed. The LED light was used solely to indicate that the solar panel was functioning properly and producing a current. This controlled setup is shown in Figure 1. The 830-point, 5-hole row terminal strip breadboard setup is shown in Figure 2; only the first row of the breadboard was used.

The sensing tip of the Vernier temperature probe was glued to the right-side, back surface of the panel using carbon-based high-performance thermal paste and tape; thermal paste ensured that the probe was getting an accurate reading of the back-surface temperature of the panel. The other ends of the voltage and temperature probes were attached to the ports of the LabQuest 2 to collect data. The LabQuest 2 was configured so that it collected and graphed voltage and temperature (°C) data once every second for 4 hours. Twenty trials of 4 hours each were completed with this plain photovoltaic solar panel set up. Using the temperature probe, time was given between each trial to ensure that the surface of the panel returned to around 21°C.

Figure 1. Controlled experiment photovoltaic solar panel setup. This illustrates the construction of the controlled, plain photovoltaic solar panel set up. The 500-watt halogen light is shown powering the solar panel circuit.



Another twenty trials were completed and measured the same way using a constructed air-curtain attached to a solar panel. To construct the cooling system, a heavy density balsa wood strip was cut to construct a frame for holding the two fans. A single strip, the main beam, ran the length of the panel and was 33.528 cm long. Four smaller strips, 97mm in length, were used to hold up the main beam, two motors, and fan blades, as shown in Figure 3. Two of the short strips were placed on the ends of the main beam and connected to the panel. The other two short strips connected the mid -section of the main beam to the panel. The short strips were hot glued to the main beam and duct taped to the panel. The motors were fastened on the main beam using 20.2 cm long zip-ties. The entire setup needed to be powered by one power source, a switchable DC power supply. To do this, the motors' electrical wires were soldered together using an iron and tin-lead rosin core solder wire. One lengthy piece of wire had to be added to connect the two positive ends from the two motors to the power supply; the same was done for the negative ends. The Xs in Figure 3 represent places where the wires were soldered together. The angle between the panel top and wooden frame was 120° and was kept constant during all twenty trials. The 89mm in length fan blades were already designed to fit tightly onto the motor shaft, so the fan was inserted onto the motor shaft. The solar panel was set up exactly like the controlled test, shown in Figure 1; the only additional components were the fans. The breadboard was also configured like the controlled experiment, shown in Figure 2. Again, the LabQuest 2 was setup so that it collected and graphed voltage and temperature (°C) data once every second for 4 hours. This meant 14,401 data points of both temperature and voltage were collected. Time was given between each trial to ensure the panel always started around 21°C to 22°C.

The temperature and voltage averages of the 20 trials were then calculated and compared to determine the effect of non-recirculating front surface air cooling on photovoltaic panel voltage production. The percentage differences between the configurations were also calculated. Voltage production and surface temperature were measured and statistically analyzed using a paired t test with a 95% confidence interval. The paired t test was conducted on Minitab.

Figure 2. Eight-hundred-thirty-point, 5-hole row terminal strip breadboard setup. This illustrates the first row, the only row used, of the breadboard for the photovoltaic panel circuit. The Vernier voltage probe was added to the circuit to collect voltage potential data.

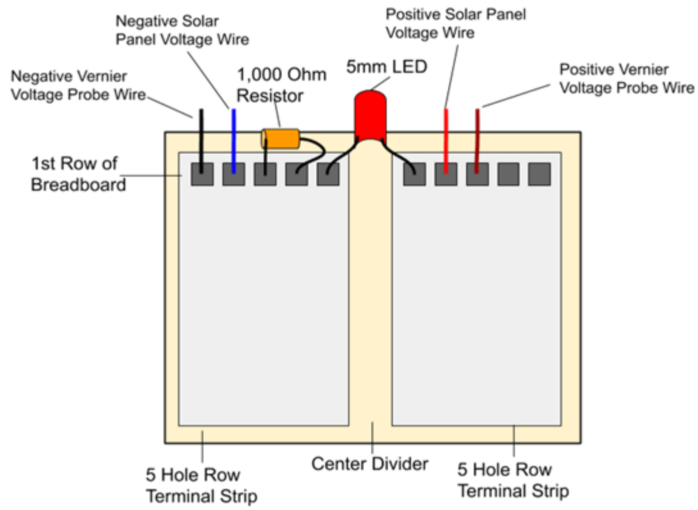
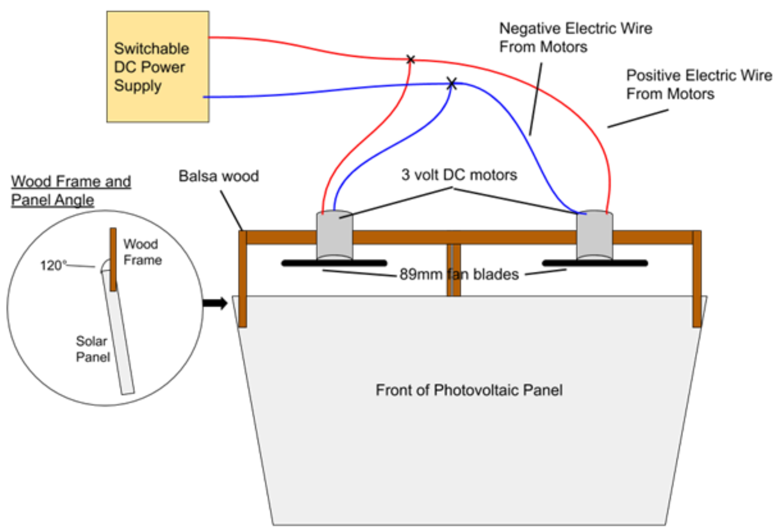


Figure 3. Photovoltaic solar panel with front non-recirculating surface cooling setup. This illustrates the construction of the photovoltaic solar panel with the front non-recirculating surface cooling setup. This setup would also include the breadboard from Figure 3. The panel was powered by the halogen light as shown in Figure 1. Data were collected with the LabQuest 2. Xs, symbolize places where the wires were soldered together.



Results

The results of the experiment show that, on average, the air-cooled setup generated 2.759%, or 0.059V, more voltage throughout the 4 hours of the trial. This is shown by the different columns in Appendix A. It can also be seen that the air-cooled setup generated 2.186V while the controlled setup generated 2.127V, on average. This is graphically shown in Figure 4.

When looking at the average statistics for both trials, the voltage tended to decrease as time passed. Specifically, during the controlled test, the voltage decreased 0.288V, or by 11.944%, during the 4 hours. During the air-cooled test, the voltage decreased 0.132V, or by 5.718%. The air-cooled panel had a smaller drop in voltage as time passed. These changes in voltage can be seen in the voltage columns of Appendix A. The cooled panel produced more voltage for 14,384 out of the 14,401 seconds of the trial. This can be seen in the time and voltage columns of Appendix A. The maximum voltage for the air-cooled trial was 2.247V while the minimum was 2.179V; for the controlled trial, the maximum was 2.279 while the minimum was 2.120. These summary statistics are displayed in Table 1.

When looking at the temperature statistics, on average, the air-cooled setup was 14.414°C cooler than the plain solar panel configuration throughout the 4-hour trial, meaning there was a 30.655% difference. This difference in temperature is graphically shown in Figure 5 and can be seen in Appendix B. On average, the air-cooled panel increased by 12.53°C or by 36.858%, from start to finish, while the controlled panel increased

Figure 4. The air-cooled setup constantly produces a higher voltage throughout the four hours. Looking at both trials, there is a very small decrease in voltage produced as time passed.

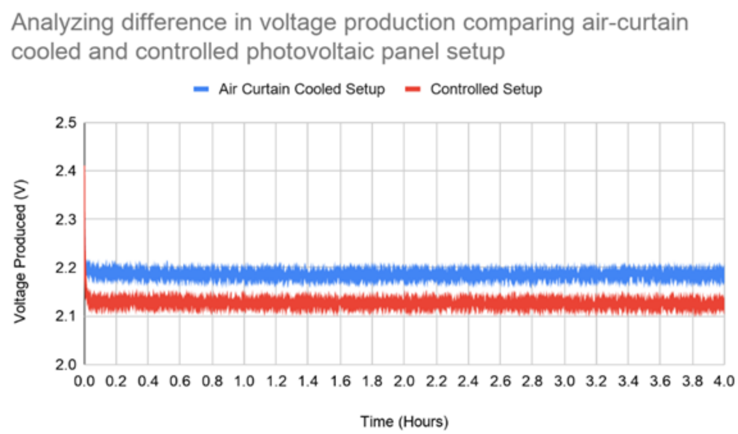
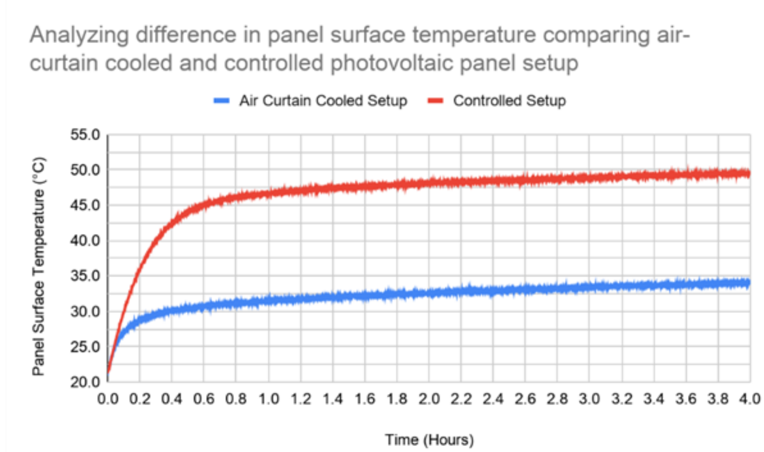


Table 1: Panel voltage production average data summary table

	Air-cooled setup	Controlled setup
Average voltage produced	2.186 V	2.127 V
Decrease in voltage during the 4 hours	0.132 V	0.288 V
Starting voltage	2.312 V	2.411 V
Ending voltage	2.810 V	2.123 V
Maximum voltage	2.247 V	2.279 V
Minimum voltage	2.179 V	2.120 V

These are important figures gathered after analyzing voltage data. The data provide further evidence that the air-cooled panel produced more voltage than the controlled setup

Figure 5. The air-cooled setup constantly has a lower panel surface temperature right after 0.1 hours. In both trials, the temperature increased as time passed.



27.995°C, or by 56.544%. The air-cooled panel had a smaller rise in temperature. These statistics can also be viewed in Appendix B. The temperature difference between the two trials tended to increase with time. The difference grew from 0.05°C to 15.59°C (see difference column in Appendix B). In addition, it can be seen that during both configuration tests, the temperatures tended to increase as the time increases. When looking at the average data, the controlled test started at 21.515°C and ended at 49.51°C. Meanwhile, the air-cooled test started at 21.465°C and ended at 33.995°C. The controlled test maxed out at 49.550°C while the air-cooled test maxed out at 34.040°C. These statistics can be seen in both temperature reading columns of Appendix B. The air-cooled test has a lower maximum temperature. These summary statistics can be found in Table 2.

The raw data tables for the controlled trials are in Appendix C and E. The raw data tables for the manipulated trial are in Appendix D and F. Appendix C and D include voltage readings while Appendix E and F include temperature readings.

To start the inferential test, the data were first tested for normality. The null hypothesis was that all the data values followed a normal distribution. The Kolmogorov Smirnov Normality test was conducted and reported p-values < 0.05 for both the voltage and temperature. The p-values from this test are shown in Table 4. Because the p-values were less than the alpha value of 0.05, the temperature and voltage data are considered to not be normal. Box plots of the voltage and temperature data were also made. The box plots, graphically displayed in Figure 6, have contrasting whisker

Table 2: Panel surface temperature average data summary table

	Air-cooled setup	Controlled setup
Surface temperature increase over time	12.530°C	27.995°C
Starting temperature	21.465°C	21.515°C
Ending temperature	33.995°C	41.51°C
Maximum temperature	34.040°C	49.550°C
Minimum temperature	21.425°C	21.45°C
Temperature difference growth between two setups	0.050°C to 15.590°C	

These are important figures gathered after analyzing surface temperature data. These provide further evidence that the air-cooled panel was significantly cooler than the controlled setup.

Table 3: Kolmogorov Smirnov normality test p-values (**α** = 0.05)

Controlled temperature data	< 0.010
Air-cooled temperature data	< 0.010
Controlled voltage data	< 0.010
Air-cooled voltage data	< 0.010

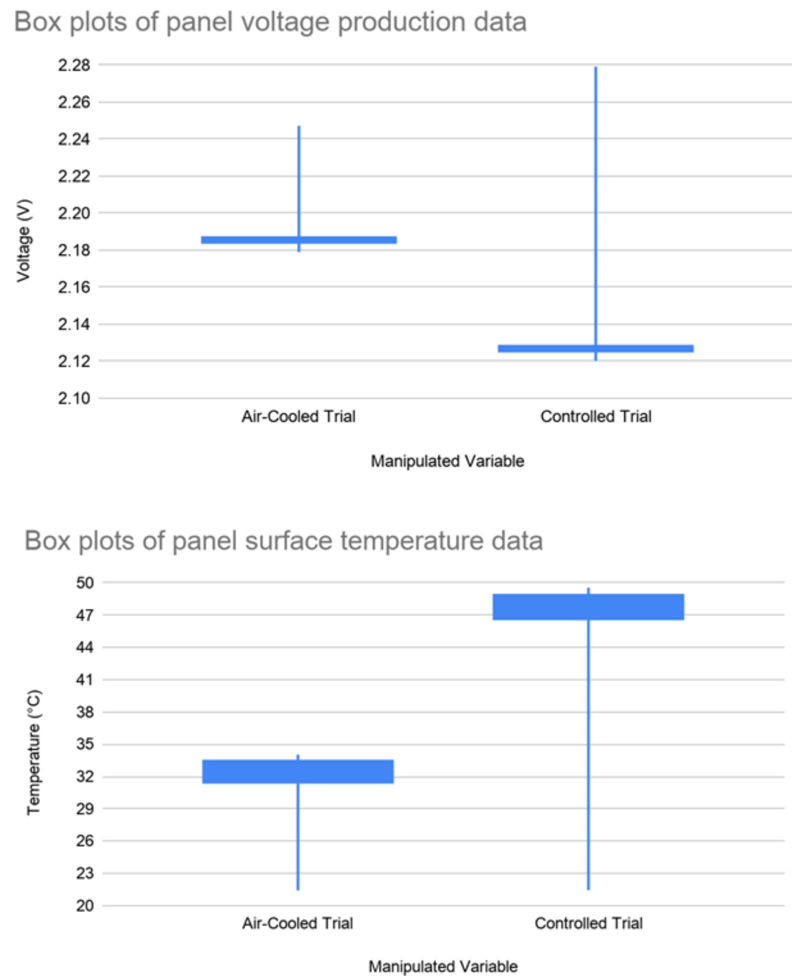
The null hypothesis was that all data sets follow a normal distribution. $p < \alpha$, meaning the null hypothesis was rejected. This indicates that the voltage and temperature data were not normal.

Table 4. Results of statistical testing

Paired t test for voltage production	
t-test statistic	**-1672.31**
p-value	**< 0.001**
Degrees of freedom	**19**
Confidence interval	**95% or α = 0.05**
Paired t test for panel surface temperature	
t-test statistic	**585.28**
p-value	**< 0.001**
Degrees of freedom	**19**
Confidence interval	**95% or α = 0.05**

p < alpha meaning there is a significant difference between the voltage means and surface temperature means of the controlled and air-cooled trials. This is sufficient evidence that the solar panel with an air curtain is more effective than the controlled setup.

Figure 6. The box plot of the voltage data are not symmetrical; the whiskers are not close to equal in length, meaning the data are not normal.



lengths and are not symmetrical. There appear to be numerous outliers. This again suggests the voltage and temperature data are not normal. Although the data were not normal, paired t tests were done as they are robust statistical tests.

Voltage production and surface temperature were measured and statistically analyzed using a paired t test with a 95% confidence interval. The null hypothesis stated that there was no significant difference in the voltage and temperature means of the controlled and manipulated tests. Table 3 displays the paired t test for voltage production and surface temperature. Because p is less than alpha in both tests, the null hypothesis was rejected. There is sufficient evidence to support that air cooling a photovoltaic panel leads to a significantly lower panel surface temperature and significantly higher voltage production.

Discussion

The purpose of this project was to identify a more efficient hybrid solar panel configuration that produces more voltage when compared to the plain setup. This purpose is relevant because global warming and climate change are threatening the environment and its organisms[1].

To reach the engineering goal of developing a more efficient photovoltaic panel system, multiple designs were designed and constructed. The first design attempted to pair a photovoltaic panel with a thermoelectric generator and a cooling system. Thermoelectric generators (TEGs) can be used to absorb excess and wasted heat energy. They demonstrate the Seebeck effect since the heat-induced temperature difference between the two types of semiconductors produces a current[5]. So, the design planned for the wasted heat from the photovoltaic panel to be converted to usable energy. The design was further improved by adding a cooling system or device, such as a water pump system or an aluminum heat sink. It was later deemed that this design would not be very efficient since the voltages would need to be split and added using a voltage adder paired to a resistor. Using these electronic components would decrease the already small voltage gained from the thermoelectric generators. Furthermore, when the TEGs' cooling abilities were tested, the entire system heated up in just a few minutes. For the test, the TEGs were glued to an aluminum heat sink using carbon thermal paste and paired with a fan to push away the heat that traveled down the fins. The heatsink and fan were not strong enough to cool a side of the TEGs.

The second attempted design primarily used 4 rotary pumps, surgical tubing, and polyvinyl chloride pipe that underwent a chlorination reaction (CPVC). Five-millimeter holes were drilled in a straight line, 2 centimeters apart, across a CPVC pipe 2 centimeters in diameter. The pipe, as long as the length of the panel, was taped to the top of the panel so that the holes were parallel to the surface. Four rotary pumps were then acquired and electrically connected using a soldering iron and tin-lead rosin core solder wire; the airways were connected using surgical tubing barbed, brass 3-way pipe connectors. The airways were all directed into one surgical tube, which was then connected to the CPVC via a small drilled hole. The switchable DC power supply was used as the power source and supplied 9V to the system. During testing, it was deemed that the system, despite the provided voltage and number of mechanical parts, could not provide enough air to cool the entire panel. Minimal amounts of air traveled about halfway down the panel. The third successful design, used for the 20 trials, involved a fan blade. The drawback to this design was that it involved a relatively large, exposed moving part.

The results of the fan-blade generated air curtain experiment show that, on average, the cooled setup generated 2.759% more voltage throughout the 4 hours of the trial. The average difference in voltage production was 0.059 volts. The cooled panel produced more voltage for 13,384 out of the 14,001 seconds of the trial. When looking at the average temperature statistics, the air-cooled setup was 30.655% cooler than the plain solar panel configuration throughout the 4-hour trial. The temperature difference between the two trials tended to increase with time. These statistics show that the fans cooled the photovoltaic panel significantly.

The hypothesis stated if an air curtain is installed over a photovoltaic solar panel, then the number of volts produced by the hybrid system would be greater when compared to the plain solar panel configuration. The data were statistically analyzed using a paired t test with a 95% confidence interval. It was determined that there is a significant increase in voltage production and a significant decrease in panel surface temperature, as the p-value was < 0.001. As shown by the statistical analysis, the hypothesis was supported since the fans installed on the photovoltaic panel significantly decreased the surface temperature, also leading to an average 2.759% increase in voltage production.

Tonui and Tripanagnostopoulos conducted a similar study to this research project. A back-surface non-recirculating system was constructed using an air pump and insulation material as the channel[6]. Two setups were primarily tested. One setup forced air through a double membrane channel. The other setup forced air through a channel lined with thermocouple fitted metal fins. The double membrane channel and the fin fitted channel improved photovoltaic panel efficiency by 12% and 20%, respectively[6]. Compared to the design of this research project, the double membrane channel and fins are more complicated and expensive. In addition, their experiment was completed using a much larger panel outdoors. The two primary reasons why the increase in panel efficiency varies between the two experiments is cost and panel size. A complex and costly addition to a solar panel will not make it ideal for commercial use because it raises the construction and installation cost. However, it is evident that the efficiency will be higher compared to a cheaper cooling system. In addition, it was determined that the larger the panel, the more it is affected by an increase in surface temperature and a cooling system. Tonui and Tripanagnostopoulos' research is similar to this project because it too suggests that an increased panel temperature means a decrease in panel voltage production. They both also suggest that air, although a poor heat conductor, has the ability to carry away some excess heat. Lastly, both propose working cooling devices for commercial use in solar panels.

A procedural improvement could be controlling the constant variables better. For example, the experiment room temperature was hard to control since it was dependent on the air conditioning setting of the building as well as the outside temperature. Another improvement would be determining a way to view and check on the experiment without opening the door to the controlled environment; this often exposed the setup to the outside temperature and air. The LabQuest 2, fans, and light had to be constantly checked during trials to make sure they were running properly.

There were two main uncertainties during the experimentation. The degradation of the photovoltaic solar panel was unknown. The relatively small solar panel was exposed to 500-watts, coming from a light source only 41cm away, for 200 plus total hours. The decrease in voltage caused by the weakening of the solar panel was unknown throughout the experiment. This uncertainty could affect the voltage production data, meaning it could have also affected the analysis statistics and conclusions made about the voltage produced. Another source of uncertainty was the decrease in performance of the DC motor. The motors were also constantly used for over 220 hours. Whether the speed and performance of the motor stayed constant was unknown. This uncertainty could affect the voltage production and surface temperature data, meaning it could have also affected the analysis statistics and conclusions made for voltage and temperature.

In the future, a much larger scale solar panel should be tested. The panel should be closer to the size used on solar farms or community houses. Furthermore, the sun should be used instead of a 500-watt halogen light to power the solar panel. Both adjustments would make the experiment much more reliable to apply to commercial solar panels. It is hypothesized that these changes to the solar panel will result in a greater decrease in voltage production over time, meaning the air curtain system should have a more profound effect on panel performance. Also, experiments like this should be conducted outside so that natural disturbances, such as the build-up of dust, can be tested against different configurations. For instance, the air-cooled solar panel would not have any dust build-up, keeping the voltage production of the panel higher than the plain photovoltaic panel setup.

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Notes and References

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Supplemental Information

Experimental Design Diagram

Hypothesis: It was hypothesized that if an air curtain is installed over a photovoltaic solar panel, then the number of volts produced by the hybrid system would be greater than the plain solar panel configuration.

Independent Variable: The hybrid solar panel system configurations: Solar panel and solar panel + air curtain setup using two fan blades and two 3-volt DC mini motors.

Levels of Independent Variable	Bare solar panel	Solar panel + air curtain set up
Number of Repeated Trials	20 trials – 4 hours run times each	20 trials – 4 hour run times each

Dependent Variable: The number of volts (V) produced by the hybrid solar panel configuration. This measured the overall electricity generated.

Constants:

- solar panel angle to receive equal light intensity
- Breadboard used to connect the photovoltaic panel, LED light, and voltage probe
- ambient temperature around solar panel
- brand and type of solar panel
- location of solar panel during experimentation
- Thermal paste used to attach temperature probe to the photovoltaic panel
- LabQuest 2 interface used to collect voltage and temperature data
- Vernier temperature probe ranged from -200°C to 1400°C used to measure temperature data
- Vernier 30 volt-voltage probe used to measure voltage
- amount of light received from the Halogen 500-watt work light by the photovoltaic panel

Control: The controlled experiment was testing the photovoltaic panel by itself.

Appendix A	
Voltage Comparison Table	https://bre.is/A3uWZ6CE
Includes a table that compares the analyzed and averaged voltage data from the controlled and manipulated tests.	

Appendix B	
Temperature Comparison Table	https://bre.is/d6mx9mAM
Includes a table that compares the analyzed and averaged temperature data from the controlled and manipulated tests.	

Appendix C	
Raw Voltage Data from Controlled Test	https://bre.is/EWS767Ad
Includes a table that contains the raw voltage data for the controlled test. The different trials run across the spreadsheet while the time goes down the spreadsheet.	

Appendix D	
Raw Voltage Data from Air-Cooled Test	https://bre.is/PUEBtgFy
Includes a table that contains the raw voltage data for the manipulated, air-cooled test. The different trials run across the spreadsheet while the time goes down the spreadsheet.	

Appendix E	
Raw Temperature Data from Controlled Test	https://bre.is/vma6Ds6Z
Includes a table that contains the raw temperature data for the controlled test. The different trials run across the spreadsheet while the time goes down the spreadsheet.	

Appendix F	
Raw Temperature Data from Air-Cooled Test	https://bre.is/PEfSqUkk
Includes a table that contains the raw temperature data for the manipulated, air-cooled test. The different trials run across the spreadsheet while the time goes down the spreadsheet.	