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Biomimicry in Solar Energy Applications

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UNDER MY SUPERVISION BY

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ENTITLED

BIOMIMICRY IN SOLAR ENERGY APPLICATIONS

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BIOMIMICRY IN SOLAR ENERGY APPLICATIONS

By

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SENIOR DESIGN PROJECT REPORT

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Abstract

While solar power is one of the leading renewable energy sources today, current solar farms produce an amount of byproduct heat that is contributing to rising global temperatures and the deaths of many birds. Furthermore, solar panels that use water as a coolant through a sprinkler system use up a great amount of water that could be allocated somewhere else. Our project seeks to address both of these issues through a biomimetic design. Drawing inspiration from the ghost plant, our proposed solar panel cooling system is expected to reduce the amount of byproduct heat produced by panels, increase the overall efficiency of the panels, and reduce the amount of water used to achieve these goals.

Acknowledgments

We would like to thank our advisor, Dr. Maryam Khanbaghi, for her continued support and guidance throughout the course of this project. We would also like to thank the Latimer Energy Lab for providing us with a space to conduct research and perform testing and Santa Clara University's School of Engineering for bestowing us with the funds to complete this project. Lastly, we would like to thank graduate students Ahmed Saad, Saleh Dinkhah, and Daniel Mendoza for their mentorship and advice.

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1 Introduction

1.1 Statement of Project and Objectives

Byproduct heat emitted by solar modules contributes to negative effects on the environment such as global warming and poses a threat to the avian population. Solar farms in California alone kill an estimated 6,000 birds per year. To put the temperature significance into perspective, a study conducted by the University of Arizona showed the temperature differences between a PV farm and a parking lot in the desert, as seen in Figure 1 below[1]. The PV farm saw generally warmer temperatures of around 3^{o}C more than the parking lot.

Some recognize this temperature difference and try cooling the panels down using water. However, this may not be the most efficient use of water since farms consume an abundant amount of water for cooling and cleaning, and a lot of the water is lost to runoff or evaporation. Our objective is to reduce the byproduct heat generated by solar panels while keeping water consumption to a minimum. We also believe that turning towards nature and using biomimetic designs can help us reach our goals.

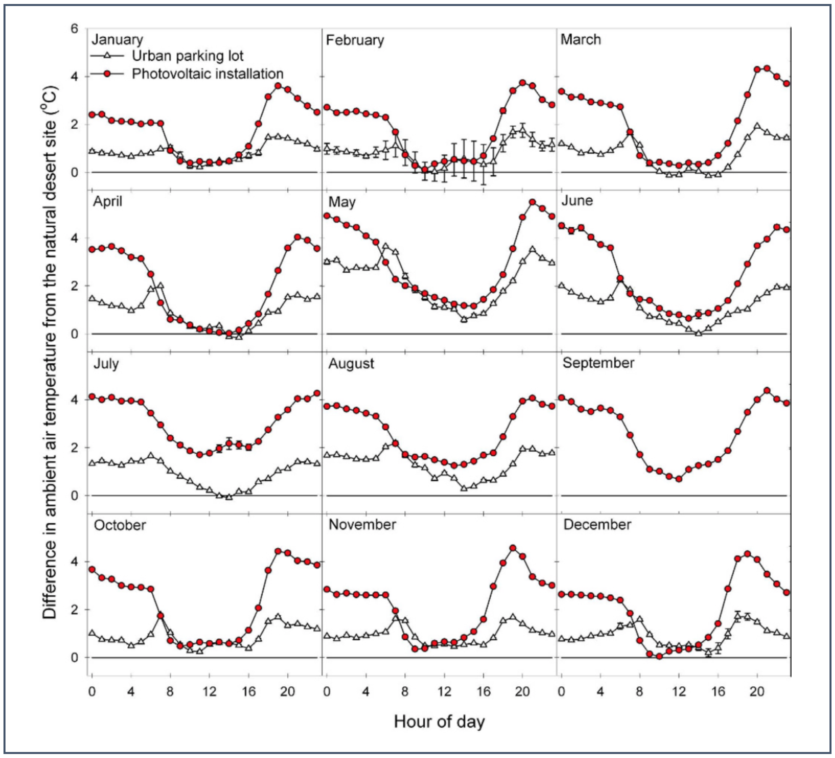

Figure 1: Solar Farm and Parking Lot Temperatures

1.2 Background and Motivation

The motivation for this project came from a TED talk by Janine Benyus on biomimicry and its applications to technical fields. Combining this and a passion for clean energy and environmental justice, the concept of higher efficiency biomimetic photovoltaic system was born.

Biomimicry is, as the name implies, the process of mimicking biological structures in human design; popular examples include mimicking the bill of a kingfisher for higher efficiency trains, copying the texture of shark skins for surgical gloves, and so forth. Generally, the motivation behind biomimicry is the rationale that nature can do it better - these structures and adaptations have evolved over millions of years and are hence more likely to have higher efficiency than man-made structures today[2].

Figure 2: SmartFlower Biomimicry Example

In power generation specifically, there have already been numerous applications of biomimicry: wind fans shaped like humpback whale fins, solar panel systems designed after sunflowers, shown in Figure 2, and more[3]. For our project, we chose to focus on creating a cooling system inspired by the Ghost Plant by mimicking the evapotranspiration patterns of the plant's stomata. Figure 3 accurately depicts this process: the plant only releases water through the pores on the bottom of its leaves, and due to the waxy coating, water can collect within the plant helping it maintain survivable temperatures in extreme heat. The goal of this project is to use water flowing in tubes along the back of the panels as a heatsink to cool the solar system and thus result in higher power generation efficiency. A blueprint of the proposed system design can be found in Figure 4.

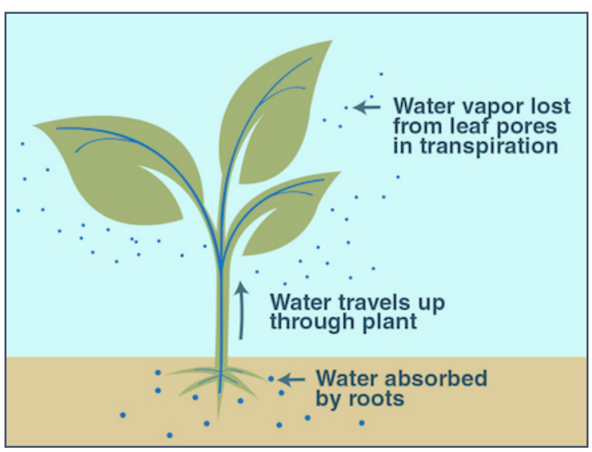

Figure 3: Visualization of Transpiration

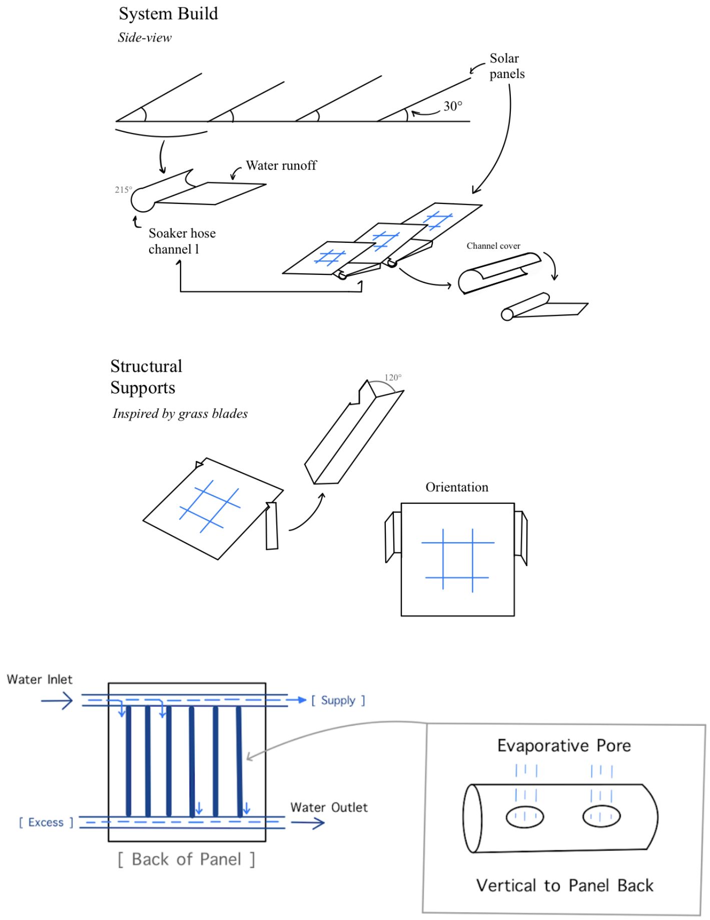

Figure 4: Biomimetic PV System Design

1.3 Project Plan

Starting with research, various plants in multiple extreme biomes were examined to determine not only which attributes evolved to be most beneficial for survival in these environments but also to see similar characteristics that could be implemented for a cooling system. From there, multiple biomimetic cooling systems were designed based on the observed natural structures; after a thorough review, the design based on the ghost plant was elected to be the basis for the project build (see Figure 4).

Next, simulations were conducted to establish a baseline for measurements to be expected from a non-cooled system. Following these simulations, the actual PV arrays were set up and tested first with and then without cooling. The data was aggregated and processed to show how the cooling system improved power generation and lowered ambient temperature.

1.4 Implementation Alternatives and Tradeoffs

A proposed implementation alternative is to have built two PV systems rather than one. In this scenario, one of the systems built would not have a cooling system and the other would be identical to the first but would include the cooling system. This may seem unnecessary at first glance because it would increase our expenses, but the main reason we would've considered this route is so that we could've gathered data about the two systems at the same time. With just one system, we are forced to run the PV system on different days since we need to test our panels with and without cooling. The irradiance may be different from one day to another and other factors may affect total system performance on a given day such as clouds, wind, rain, and dust. We are not able to control the weather and other external factors that may affect the PV system performance, so having two systems that can be tested at the same time each day would have been very useful. However, the cost to go down this path exceeds our given budget, so we stuck with the assembly of one system that we tested on alternate days with the cooling system on one day and off the next. This method allowed us to test the effectiveness of the cooling system without compromising the effects of the change in irradiance to the best of our ability.

1.5 Ethical Considerations

Conscious water usage was an essential ethical consideration for this project. By using soaker hoses over traditional hoses or even cooling via pouring water on top of the panels, water is conserved and any that does not evaporate is able to be funneled back into the reservoir. Also as previously mentioned, by cooling the solar panels the potential to curb animal deaths increases as well. In the United States alone, between 38k - 138k birds are killed per year by excess heat from solar farms[4]. Introducing cooling would be crucial to reducing this byproduct heat and as such its impact on the surrounding environment. Yet, if and/or when this system fails, the water used for cooling the PV arrays is wasted, which is in exact opposition to the intention of using soaker hoses.

1.6 Risk Analysis

Two major risks were identified for the building and testing phases of our project plan. Due to our planned workspace being the Sobrato Campus for Discovery and Innovation (SCDI) 4th Floor Balcony, these two risks were found to be falling and sun damage. Building our system outside on the top floor of SCDI proves a slight yet possible risk to workers and system parts falling off the balcony. This risk can be mitigated by working under the supervision of our advisor and monitoring the weather conditions for high wind speeds. Sun damage poses a risk since we will be working outside for long periods of time, directly exposed to sunlight (especially with high irradiance in Santa Clara). Sun damage can be hazardous to the eyes and skin and can cause heat exhaustion. This risk can be reduced through the use of sun protection (such as sunglasses, long sleeves, long pants, etc.), staying hydrated, and taking regulated breaks indoors. A table representing our risk assessment can be found below.

Table 1. Risk Assessment

Hazard	**Risk**	**Risk Control**
4th Floor Balcony of SCDI	Falling - Workers - Components	Work under the supervision of our advisor and when weather conditions/visibility are clear.
Sun/Heat	Heat exhaustion, skin damage, and eye damage	Working with sun protection such as sunscreen, long sleeves and pants, and sunglasses.

2 Project Process

2.1 Design Concept

After extensive research, the ghost plant was chosen to be the basis for the biomimetic cooling design. Ghost plants are unique in that transpiration happens only on the bottom of the leaf, and being an organism that grows in desert climates, this method of specific evapotranspiration was used as a reference for the cooling system. Ghost plants also face the sun perpendicularly to their leaves, and so generate as much energy as possible from the sunlight rather than trying to avert the sun rays like some cactus species that exist. The hydrophobic nature of the ghost plant's leaves also results in improved diversion of rainwater back into the soil, similar to the cyclical nature of the cooling system with the reservoir and water pump. All these factors were used as a reference to build the biomimetic cooling system[2].

2.2 Simulations

To better understand the behavior and output of the photovoltaic array that we had planned on building, we utilized Simulink and PVSyst in order to simulate and test our proposed system. When simulating a photovoltaic system, the main factors we were looking at were irradiance, panel temperature, and output power of our system. While PVSyst allows us to see the general amount of sunlight we can expect at the position of our panels throughout the day, we weren't able to simulate different outputs for varying levels of irradiation. PVSyst allowed us to see the big picture idea of how our system performed throughout the day, but we only planned on having our system running during peak sunlight hours (based on the panel position and orientation). In order to specifically check how our panels would perform during those times of day with varying weather conditions, Simulink was used to check the expected panel voltage and ultimately calculate the output power.

2.2.1 Simulating in Simulink

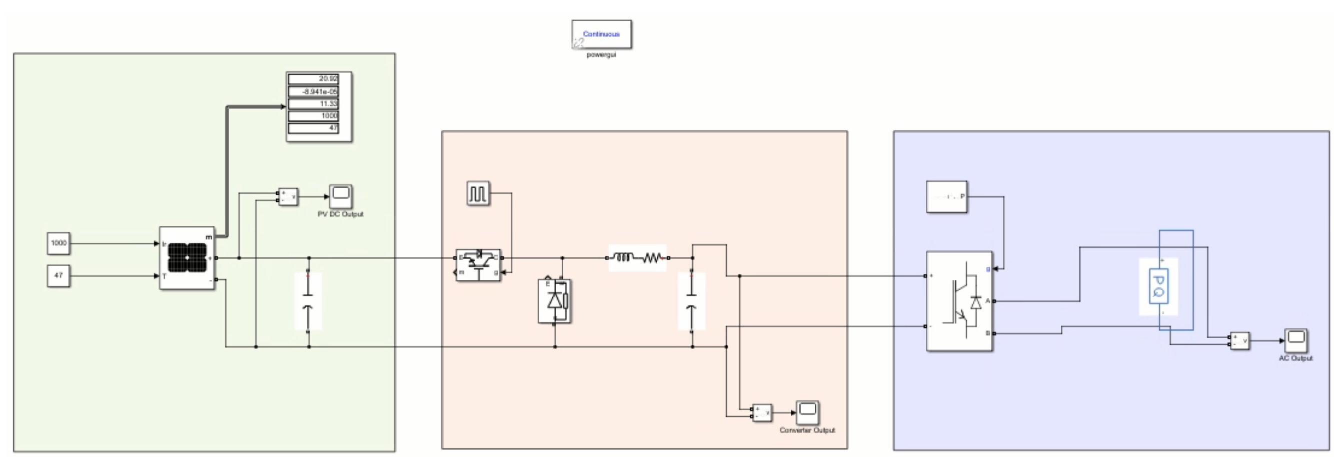

Figure 5: Simulink Model of PV Array

We modeled our solar panels in Simulink based on the ones that we were planning to build with. The array can be seen in the green section of Figure 5 and takes in two inputs: solar irradiance, and temperature (in Celsius). These characteristics determine the array output and efficiency. Furthermore, there is a capacitor added to reduce any ripple and smooth out the solar output. This helps with voltage regulation going into the converter seen in the red section. The red section represents our charge controller and is a DC-to-DC buck converter that steps down our output voltage to match that of our battery. Since we are using a 12V battery and our panel output is 18V, we needed to step down the voltage in our simulations before moving on to the inverter. As seen in the blue section, a universal bridge was used to model a single-phase DC to AC inverter that is connected to a constant power load that is modeled after a simple desk fan. At each section in the simulation, we are able to check the output voltage, but we mostly care about how our panels are performing with varying irradiances and temperatures.

The plots seen below show the I-V and P-V characteristics of our array at varying temperatures. For ease of understanding, each curve is shown at 1000 $\frac{W}{m^2}$, but other curves can be generated at different irradiances and temperatures. Figure 6a shows the plot at a zoomed-out view to get an understanding of the output behavior, while Figure 6b shows a zoomed-in portion of the plots that identify the points of highest possible efficiency given the temperature and irradiance.

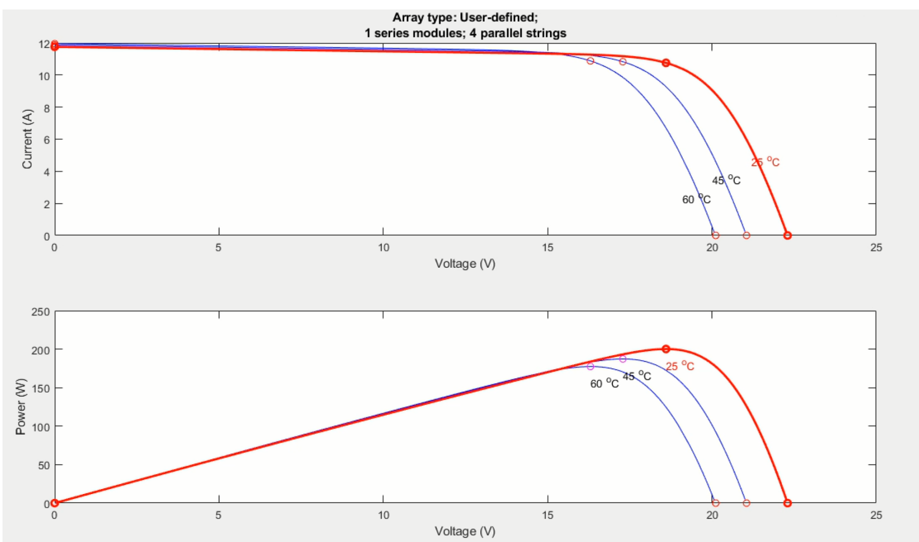

Figure 6a: Characteristics at Various Temperatures

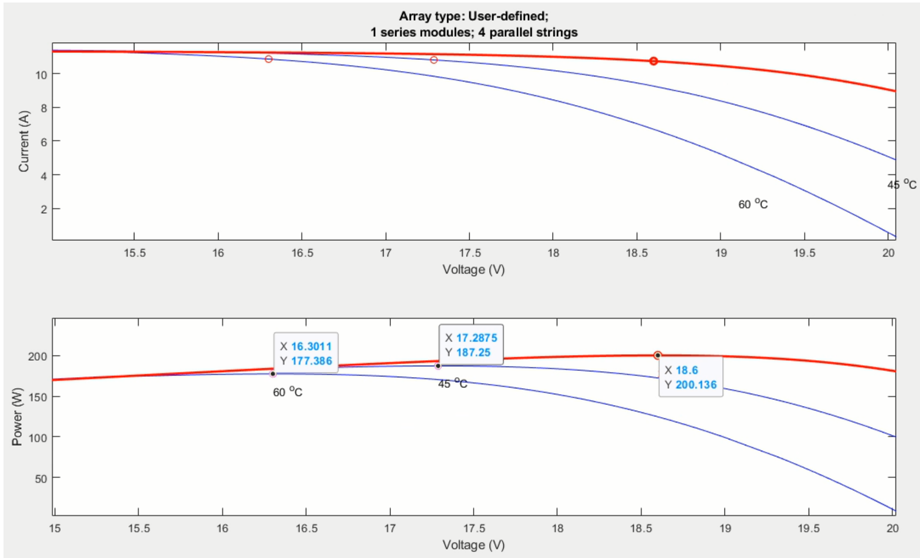

Figure 6b: The Most Power Efficient Points on Each Curve

Simulink is able to calculate these output values based on the inputs given and three equations that are used to calculate the power and efficiency[5]. These equations can be seen below:

$$V = V_{oc} - I_{sc}R_s - K(T_m - T_{ref}) \tag{1}$$

$$I = I_{sc}(\frac{G}{G_{ref}})(1 + a(T_m - T_{ref})) \tag{2}$$

$$\eta = \frac{P/G_{ref}}{A} * 100 \tag{3}$$

Symbol	**Parameter**
V_{oc}	Open Circuit Voltage
I_{sc}	Short Circuit Current
R_s	Series Resistance
K	Voltage Temperature Coefficient
a	Current Temperature Coefficient
T_m	Panel Temperature
T_{ref}	STC Temperature
G	Actual Irradiance
G_{ref}	STC Irradiance
A	Cross Sectional Area of PV Array
η	Efficiency

Equations 1 and 2 are used to calculate the output voltage and current of the array respectively. These values are multiplied together to obtain the output power of the array, represented by P. From there, equation 3 can be used to find the efficiency of the solar array at given values for irradiance and temperature.

2.2.2 Simulating in PVSyst

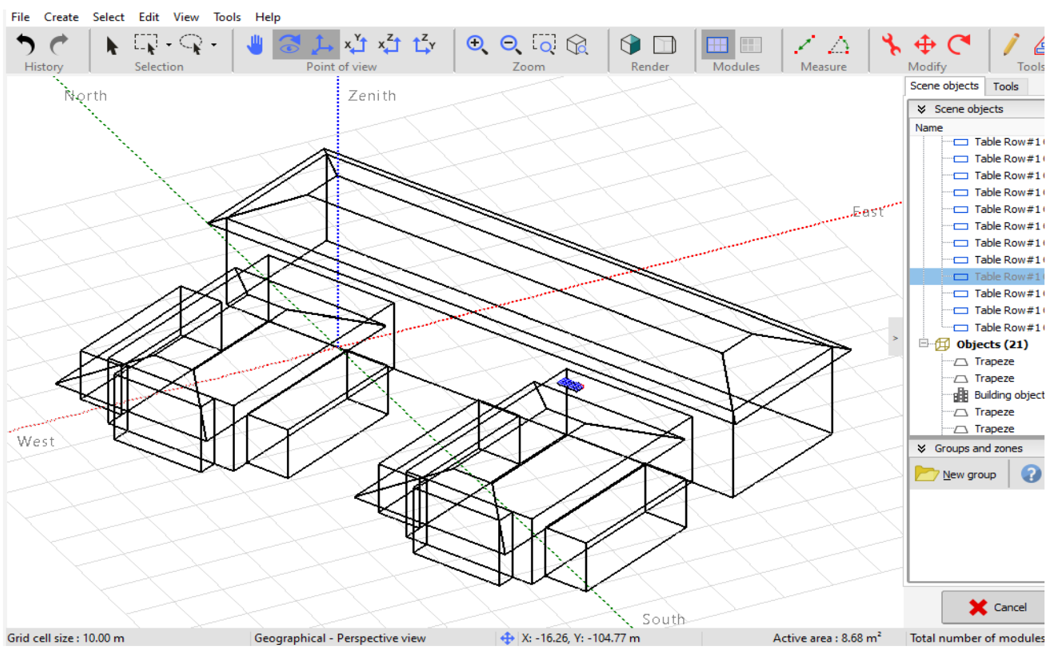

Figure 7: CAD Model of SCDI in PVSyst

PVSyst, a simulation/CAD software for analyzing photovoltaic (PV) systems, was used to complete parts of the research phase of the project. This includes modeling various PV cell materials (monocrystalline, polycrystalline, etc.), playing around with layouts and cell orientations, and getting familiar with the software as a whole. Figure 7 depicts a model of the Sobrato Campus for Discovery and Innovation (SCDI) building with the correct directional alignments. PVSyst also allows the user to select the site at which simulations are run in order to collect more accurate data for variables like general climate and patterns of overall Sun behavior. For the purposes of this project, the exact location of SCDI in Santa Clara, California has been selected.

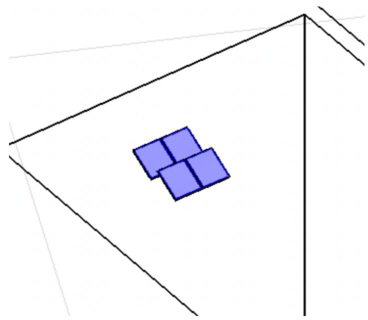

Figure 8: Proposed PV Array Setup

In Figure 8, the set of panels are modeled as if they were right on the balcony outside of the Latimer Energy Lab inside of SCDI, the location where all testing is planned to be conducted. They have been set up in a 2x2 layout facing towards the South in order to absorb the most amount of sunlight per day. To avoid partial shading and a subsequent decrease in efficiency, the top of the front row of panels has been placed a few inches ahead of the bottom of the back row of panels.

One of PVSyst's unique features is the ability to calculate the optimal tilt angle of the array that would generate the most power based on the specifications that it's given. There is the option to select the optimal tilt angle for summer months, for winter months, or for average year-round results. For this project, the year-round results have been chosen, yielding an ideal tilt angle to be 30 degrees. This tilt angle has thus been used in all of the simulations within PVSyst.

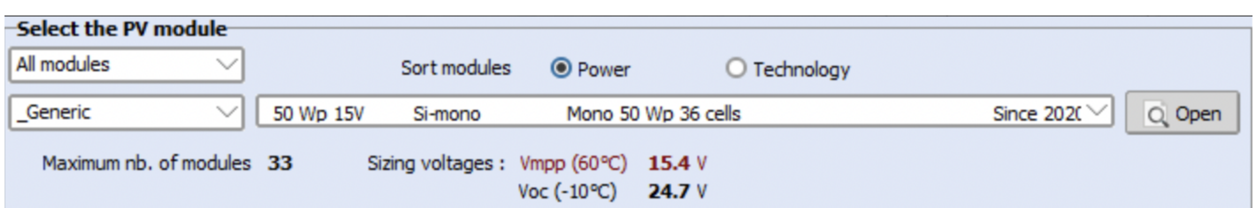

Figure 9: PV Module Specifications

The specifications of the PV panels that are being modeled are not exactly the same as the specifications of the panels that are being used to build the physical system, but it is the closest it can be due to the limited options of PVSyst. The specifications of the panels that are being used are rated at 50 watts and 12 volts, and there are a total of 33 cells within the panels. The dimensions of each panel are 22.9 x 20.0 x 1.2 inches. The specifications that are being modeled can be seen in Figure 9. It features a rating of 50 watts and 15 volts and a total of 36 cells within the panels. The dimensions of each modeled panel have also been adjusted to match the dimensions of the physical ones.

We have also finalized our decision to use monocrystalline silicon as the cell material to be modeled and used for our build. Though it's slightly more expensive than its main competitor, polycrystalline silicon, it has a greater efficiency and power output, which is the factor we value more for this project. There are also other cell materials in development at the moment that have a higher efficiency than monocrystalline silicon, but they are not available for purchase, are not widely used, and are not practical for the scope of this project.

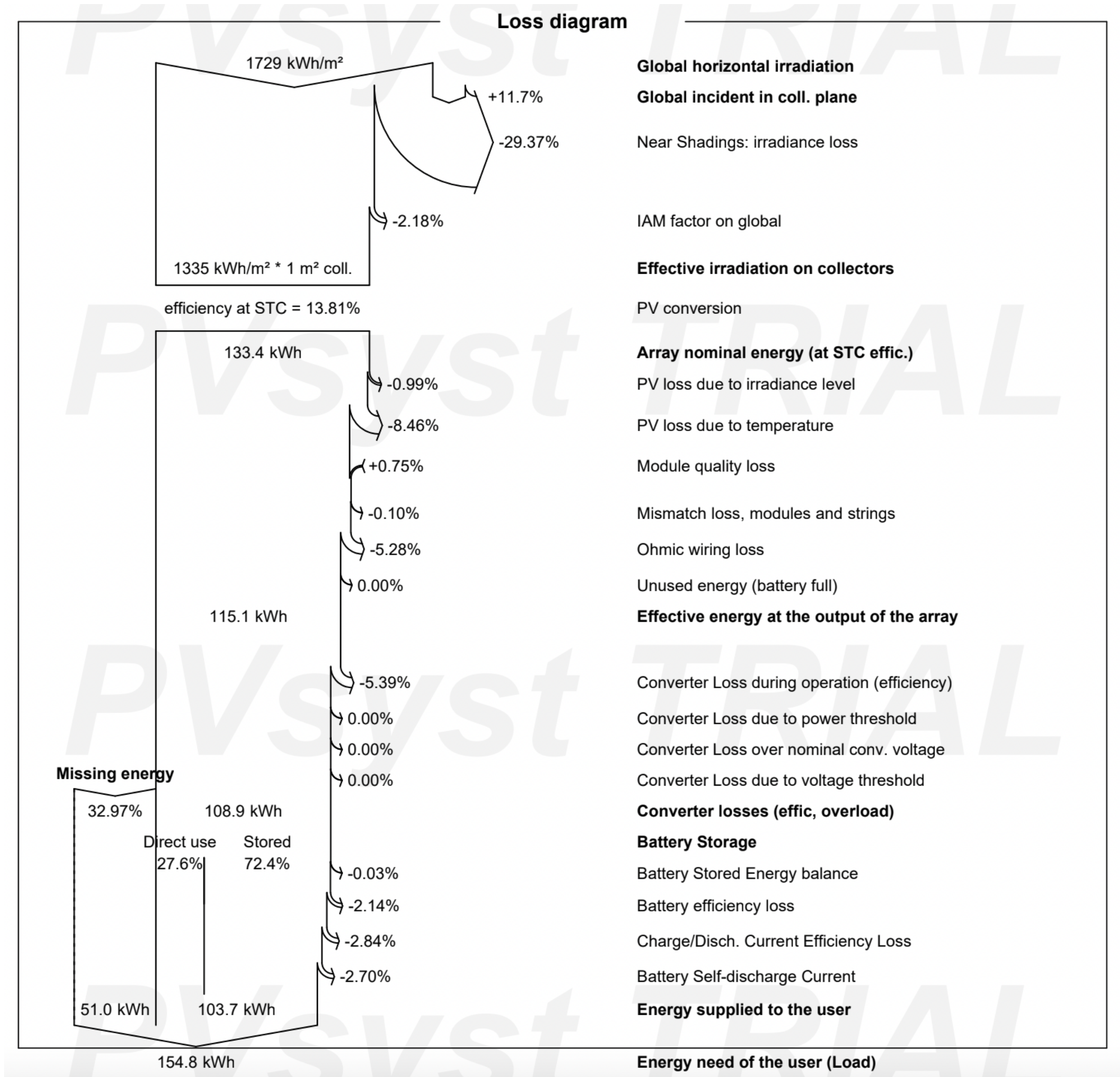

Figure 10: Loss Diagram Results of PV Array

Simulating our completed system yielded a loss diagram in the results report, provided in Figure 10. The loss diagram essentially details every kind of loss that the system is susceptible to. It is interesting to note that “PV loss due to temperature” is the highest contributing percentage at about 8.46%, so we hope to reduce that number with this project. Other important numbers include the operating efficiency of roughly 14%, which is expected of typical monocrystalline silicon cells. Another statistic that wasn’t included in the loss diagram was the expected usage at about 110 kilowatt-hours every year. While we understand that this number is extremely small, the project isn't designed so that we can produce the most amount of power, it's to simply reduce the ambient temperature around these panels in order to increase efficiency. This value will also be put into perspective later on in this paper.

2.3 Testing

Following the completion of the research and simulation phase, we moved on to building and testing the actual array. The next set of subsections will be focused on how the system was assembled and what important measurements were taken.

2.3.1 Physical Build

The final list of components that were used towards our physical build is displayed in Table 2 as follows.

Table 2. Final Component List

Item	Quantity
50 Watt Mono-Silicon Solar Panels [1]	4
Solar Panel Mounts	4
Water Pump	1
Water Reservoir	1
Soaker Hose	20 feet
PWM Controller	1
Panel-to-Controller Cables	2
Battery-to-Controller Cables	2
Battery-to-Inverter Cables	1
12V Battery	1
Kill-A-Watt	1
Wattmeter	1

Daystar Meter	1
Multimeter	1
Solar Inverter	1
Variable Load	1
Wooden Mount	1

[1] A junction box with bypass diodes was included with each of the four panels, so nothing was spent towards purchasing additional ones.

The build was assembled on the fourth floor balcony outside the Latimer Energy Lab of SCDI here on campus, also being the site where we ran all of the simulations. Subsequently, they were set up in a two by two configuration pointing towards the South, as displayed in Figure 11 below. This has also been modeled in our PVSyst simulation. To avoid the possibility of partial shading, the bottom of the back two panels were placed a few inches apart from the top of the front two panels. After putting together each of the individual panel mounts, we discovered that they weren't stable enough to hold up the solar panels themselves and were prone to falling over if lightly touched. Due to this, we ended up having to mount all four panels and drill the individual mounts onto a big wooden board so that they wouldn't topple over.

Figure 11: 2x2 Panel Configuration

Once the four panels were bolted to the wooden mount, we started to set up our proposed cooling system. As seen in Figure 12, we used a small recycling bin as our water reservoir and weaved the soaker hose channels through the holes of the individual panel mounts across all four panels. One end of the soaker hose was connected to our pump while the other simply looped back into the reservoir in order to preserve and reuse water. An alternative back view of the cooling setup can also be found in Figure 13 below.

Figure 12: Cooling System Setup

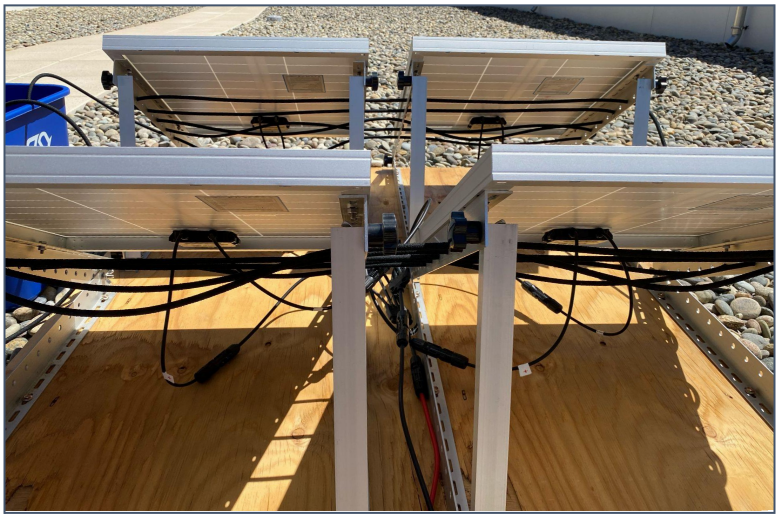

Figure 13: Back View of Cooling System

The appropriate cables and adapters were subsequently connected from all four panels to the Pulse Width Modulation (PWM) charge controller[1]. The charge controller was connected to the battery, which was connected to both the inverter[2] and the Wattmeter[3]. The inverter connected to our choice of a variable load, in this case a small desk fan, which was finally connected to a Kill-A-Watt[4] at the end. A more in-depth coverage can be found under Figure 14.

Figure 14: Measuring Tools and Components

[1] The charge controller is the rectangular box right underneath the desk fan

[2] The inverter is the rectangular yellow component to the right of the charge controller

[3] The Wattmeter is directly under the charge controller

[4] The Kill-A-Watt is located to the right of the yellow inverter

The orange rectangular component to the left of the charge controller is our multimeter, which measures our voltage at the charge controller, and directly above that is the daystar meter, which is used to measure irradiance of the Sun.

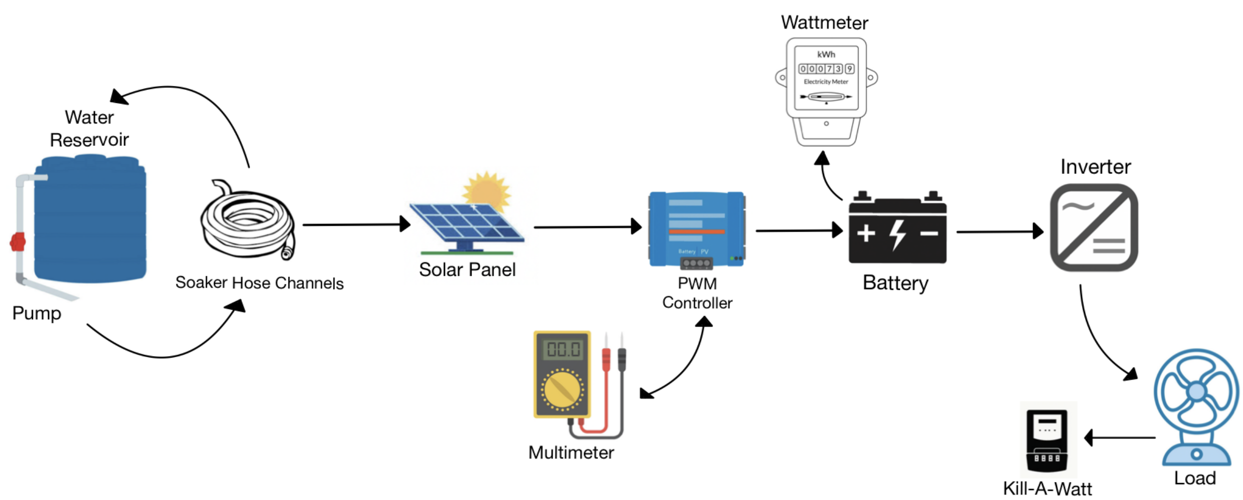

Figure 15: System Block Diagram

Figure 15 provides a more detailed visual representation of how each component is connected to each other. Starting from the water reservoir, water is pumped through the soaker hose channels that are lined up along the backs of the panels. Any excess water that is not being secreted through the pores of the hose flows back to the reservoir to be used later. From there, we have a standard solar panel setup. Our solar panels charge a battery and are regulated by our PWM charge controller. We are able to check the voltage of the panels and the battery at the charge controller. We also have a hall sensor attached to the battery to measure the current being drawn, which is multiplied by the voltage measured through the voltmeter in the wattmeter to show us the watts of the battery. This sensor allows us to check the wattage of our battery along with the capacity. Following the battery is a DC-AC inverter that leads to our load, which was chosen as a simple desk fan. The watts being drawn at this load can be checked using the Kill-A-Watt device. It should be noted that this fan is a constant power load, so the watts being drawn should remain relatively constant throughout the testing process. However, the Kill-A-Watt was still kept to monitor the watts drawn in case something went wrong, as it could serve as an indicator of whether or not the issue was with the inverter. Fortunately, we did not have any incidents with our inverter.

2.3.2 Testing Method

Starting in early April, measurements were taken every 15 minutes on our designated testing days from 11:15 AM to 3:30 PM. During these time intervals, we measured the voltage collected by the panels at the charge controller using a multimeter, the surface temperature of the panel using a standard temperature gun, as well as the irradiance of the Sun using a daystar meter. These measurements were all recorded on a spreadsheet for different days so that it could be utilized for analysis and plotting later on. Figure 16 shows an example of a section of data that is collected on the 26th of April. These values were used with equations 1, 2, and 3 to automatically calculate the efficiency at each time.

4/26		11:15 AM	11:30 AM	11:45 AM	12:00 PM	12:15 PM	12:30 PM
	V (V)	18.3	18.5	18.5	18.5	18.5	18.6
	T (deg C)	48	49	56	55	52	48
	Watts Produced (W)	173.5	165.2	144.8	147	156.7	164.7
	Watts drawn (W)	37.7	37.2	37.3	37.4	37.4	37.3
	Irradiance (W/m^2)	1000	1000	1000	1000	1000	1000
	Efficiency (%)	14.66714458	13.96548867	12.2409368	12.42691789	13.24692539	13.92322025

Figure 16: Sample of Collected Data

Due to time constraints and suboptimal weather conditions throughout the designated testing period, data was collected for nine days throughout the month of April. Only the measurements for six of those days were used for the final analysis, three with cooling and three without, since we encountered unexpected weather on the other three, marking them as outlier days.

Throughout the month, we had carefully hand-picked testing days for when we test with the cooling on and with the cooling off in order to establish similar weather conditions when testing for both scenarios. Using the National Weather Service government website, we were able to record temperature measurements and wind speeds at our location in Santa Clara during each of the fifteen minute intervals of testing. After observing weather patterns and taking measurements, we also noticed that the irradiance outside was at least 1000 W/m^2 from 11 AM to 3 PM on a typical sunny day. We leveraged this fact in addition to the outside temperature in order to match up days where we test with and without cooling. We decided not to factor in the outlier testing days, whether it was extremely windy or extremely cloudy, into our analysis since the varying weather would have made it harder for us to draw an accurate correlation. Ultimately, the average ambient temperature was 68.3°F on the days where cooling was tested as opposed to the 70.1℉ average on the days where cooling was turned off.

2.4 Analysis and Data Collection

Following the completion of the project's testing period, our group proceeded to use MATLAB to plot the collected data points in order to compare the desired testing variables. As shown in Figure 17, The MATLAB function "readtable" was used to take measurement values from the main data spreadsheet. Those rows of values were then assigned a variable in order to be graphed.

```
clc;
table = readmatrix('sddata1.xlsx');

v = table(1,:);
eff = table(2,:);
t = table(3,:);
p = table(4,:);
```

Figure 17: MATLAB Code for Reading Spreadsheet Values

```
figure;
plot(t,eff,'.','markersize',14)
grid on
title('Panel Temp vs. Efficiency (With)','fontsize',16)
xlim([25 60])
ylim([12 17])
xlabel('Temperature (Celsius)','fontsize',14)
ylabel('Efficiency (%)','fontsize',14)
```

Figure 18: MATLAB Code for Plot with Cooling

```
figure;
plot(t,eff,'.','markersize',14)
grid on
title('Panel Temp vs. Efficiency (Without)','fontsize',16)
xlim([25 60])
ylim([12 17])
xlabel('Temperature (Celsius)','fontsize',14)
ylabel('Efficiency (%)','fontsize',14)

```

Figure 19: MATLAB Code for Plot Without Cooling

The x and y axis limits as well as the size of the graphical points were kept the same for easier comparison, as seen in Figures 18 and 19. We had originally attempted to make different plots in order to showcase the results, such as power produced vs. efficiency or temperature vs. irradiance, but the graph depicting the relationship between panel temperature and overall efficiency ultimately ended up being the most favorable choice. Those plots can be found below in Figure 20.

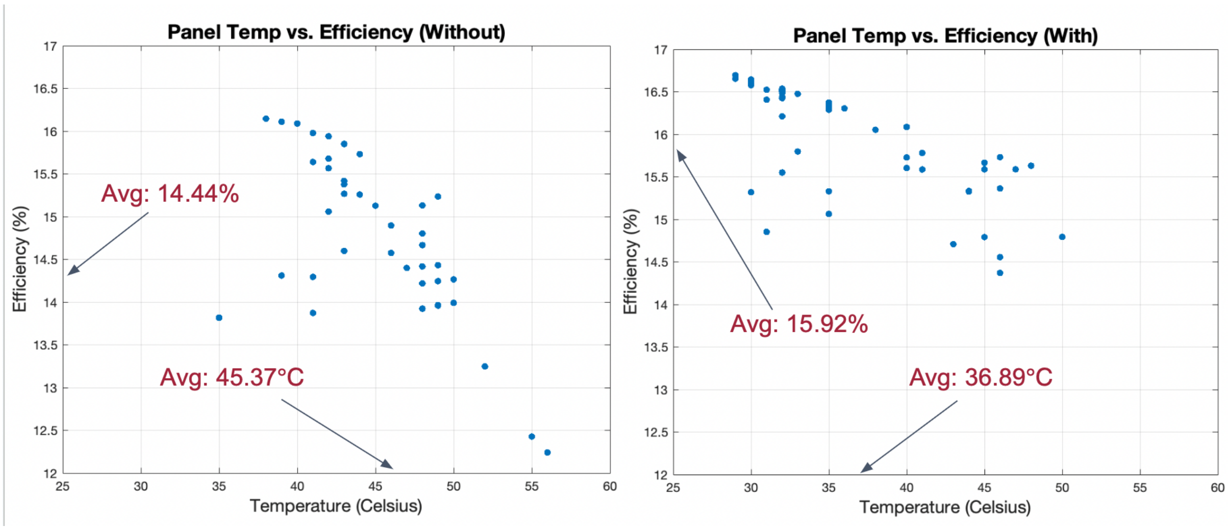

Figure 20: Temperature vs. Efficiency Plots Without Cooling (left) and With Cooling (right)

Given that the values were taken directly from the data spreadsheet, each blue point on the two graphs represents a moment in time when we took a measurement. As mentioned before, weather conditions were attempted to be closely matched in order to keep comparisons on an even playing field and to reduce the possibility of weather bias. The few outliers that are visible on the graph can be explained by the potential shading or possible gust of wind that occurred during the moment we took a measurement. Nevertheless, the average temperature for the days where we tested without cooling was 45.37℃ and the average efficiency was 14.44%. Conversely, the average temperature for the days where we tested with cooling was 36.89℃ and the average efficiency was 15.92%. To put this into perspective, according to our panel specifications, our highest possible efficiency is 16.9% at standard operating conditions. If we compare the two arrays, there is roughly a 1.5% increase in efficiency and an eight to nine degree difference in Celsius due to the cooling system, which roughly translates to a 15 degree difference in Fahrenheit. Although our smaller sample size isn't ideal, it can still be concluded from the plots that the evaporative cooling system does in fact succeed in both increasing the overall efficiency of the system while still keeping the panels nice and cool, fulfilling our main hypothesis.

3 Conclusions

3.1 Future Considerations

While the PV array did ultimately succeed in fulfilling our hypotheses in increasing efficiency while decreasing panel temperature, there is still room to improve and details to consider in the future. First of all, the project's original desired testing window had been cut short due to the suboptimal weather conditions during March of 2023, delaying it by several weeks. In an ideal scenario, testing would have been conducted over a much longer period of time, i.e. the entire year, so that we would be able to observe patterns and note behavior throughout the four seasons. Additionally, having a larger sample size for the data would have allowed for an even more reliable and accurate correlation between the desired testing variables.

The original plan had included the implementation of A/B testing, building two separate systems, one with cooling and one without, instead of one. This would have allowed the systems to be tested simultaneously, greatly reducing the error of day-to-day weather. However, only one system was assembled due to the monetary limitations of the project. In addition, having an automated temperature tracking system that is capable of automatically logging that data in set intervals would have helped reduce the possibility for human error.

As previously mentioned, the entire system had to be mounted on to a makeshift wooden board due to the unstable nature of the individual panel mounts, which may have affected the array's overarching performance. Generally speaking, wood is a very good heat-absorbing material which may have helped the panels maintain a cooler overall temperature compared to other materials. Since the majority of what panels are mounted on today aren't typically made of wood, there is room for research to be done in the future to observe how materials like ceramic or asphalt could impact the performance of this same array.

There are also a few improvements to be made to future iterations of this project, first of which would be the inclusion of a water trough that would run along the backside of each panel. This would allow the array to collect excess rainwater to be reused for cooling later on in the day, as well as the water that drips down from the soaker hose channels. Another addition that could be made would be a feedback-controlled water pump system. As it stands, the pump that is currently integrated with our system has a fixed flow rate and is incapable of turning on without manual instruction to. In the future, investing in a pump that has different speeds and is able to be paired with some sort of control loop would allow the system to recognize by itself when it needs more water but also when it has enough water.

3.2 Scalability

Due to the scope of the project being conducted and done on a smaller scale, it is valuable to consider broadening the results into a wider perspective. At the time of this analysis, the SCU Energy Data Hub states that SCU has 1.09MW of PV installed on campus that produces 1469 MWh per year[6]. With our current results (~1.5% improvement in efficiency), implementing our evaporative cooling system could help produce about 119 additional MWh per year. Based on Silicon Valley Power's electricity rates, this could save the school up to $14994 per year on electricity. Alternatively, this additional power would be enough to power SCDI for 19 days on its own. Another possible use of this excess electricity would be powering about 11 additional average American households for a year.

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