A Novel Water Based Cooling Approach to Increase Solar Panel Efficiency

Grant Proposal

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Executive Summary

The aim of this project is to study the effects of using thermoelectric generators (TEG) on subsidizing the power draw of a photovoltaic panel (PV) water cooling system and increasing the power efficiency of a solar panel. Solar panels lose a dramatic amount of efficiency when operating at higher temperatures, and as much as 0.5% efficiency can be lost for every 1°C temperature increase above 25°C (Salehi et al., 2021). As a result, cooling systems are needed to maximize system output. Thus, a mathematical model, a computer-based model, and a physical model of a PV-TEG system will be constructed to test and analyze the effectiveness of using thermoelectric generators in conjunction with closed loop water cooling. This project aims to address a significant knowledge gap as little research has been carried out in compensating for the power draws of photovoltaic water-cooling systems, especially cooling systems that contain thermoelectric generators. Thorough background research suggests that this system will raise the efficiency of a PV by a notable percent by reducing operating temperatures and, in turn, increase cell performance. This project works to improve the efficiency of a clean energy source, contributing to a cleaner global future. The lead researcher is a motivated student at The Massachusetts Academy of Math and Science and believes strongly in the importance of clean energy. As a result, to the author, this project is a highly interesting and valued pursuit of scientific advancement.

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As populations rise and technology advances, there is a continuous need for more energy. Unfortunately, more fossil fuels are consumed to offset the increased global power draw. Fossil fuels are actively destroying the environment through the emission of greenhouse gases, including carbon dioxide. As a result, it is paramount to our planet that advances be made to increase the output of renewable energy, such as solar, to reduce dependence on fossil fuels. Solar energy is a clean, renewable energy source that uses photovoltaic cells to convert solar radiation into electrical energy. This process releases no greenhouse gases and is a popular option for those looking to reduce their dependence on fossil fuels and reduce their carbon footprint.

Only about 15% of the solar irradiance[1] that reaches solar panels is converted to energy; the rest is lost as heat (Salehi et al., 2021). As the solar panels heat up, they lose a significant magnitude of power output. In fact, for every 1℃ increase in temperature (above 25℃), there is a 0.08 to 0.45 percent drop in power output efficiency (Alktranee & Péter, 2023). With operating temperatures as high as 70℃ (Akal & Türk, 2022), this is detrimental to electrical output. It is crucial that panels operate at the lowest possible temperatures to produce the most electricity. If more energy can be harvested by solar energy, fewer fossil fuels must be burned to support power grids worldwide.

Previous Research

Several studies have been conducted to address solar panel cooling, and they can be divided into two main categories: active cooling and passive cooling. Active cooling requires an input of electricity, whereas passive cooling does not. Previous studies have utilized various cooling methods including water cooling (Chanphavong et al., 2022; Terashima et al., 2023; Zubeer & Ali, 2022),

[1] Radiation that hits the surface of an object.

nanofluids, forced and passive air circulation (Rahman et al., 2023), thermoelectric modules (Salehi et al., 2021), heat sinks, and many others. While most studies with active water-cooling solutions use pumps to circulate coolant, few consider the associated power draws. Furthermore, fewer try to subsidize this power draw. A significant knowledge gap arises when thermoelectric generators are put into consideration. Thermoelectric generators convert heat flux (temperature differences) into electricity via the Seebeck effect (Jaziri et al., 2020). There is a clear lack of knowledge regarding how thermoelectric generators can work in conjunction with photovoltaic (PV) water cooling systems.

Researchers based in Laos, led by Lemthong Chanphavong, created an active cooling system consisting of a thin layer of continuously flowing water over the surface of a panel to keep it cool. Two solar panels were set up. One had no specialized cooling system, while the other had a custom water-cooling system. This system consisted of a few PVC pipes oriented so that a DC pump could transport water to the top of the panel. As the water left a distribution PVC pipe, it formed a thin, flowing film over the surface. During testing, climate conditions (ambient temperatures, relative humidity, windspeeds, and solar irradiances) as well as electrical outputs of the panels and panel surface temperatures were measured every thirty minutes. Results suggest an approximate exergy (usable energy) efficiency increase of 9.8% as a direct result of lowering panel temperatures by as much as 29.2℃, see Figure 1 below (Chanphavong et al., 2022).

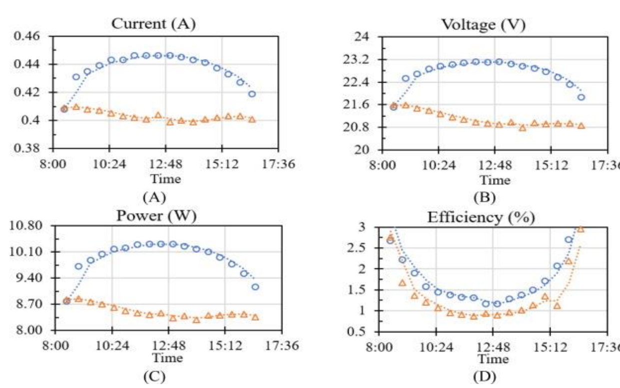

Figure 1. Parts A and B show current and voltage vs. time which, when multiplied equal power output (C). Along with efficiency, all four measurements were higher in the cooled PV (Chanphavong et al., 2022).

A study in Japan, led by Terashima et al. (2023), aimed to compare two different water based solar PV/T or photovoltaic thermal systems using both a CIS (copper, indium, selenium) and a m-Si (monocrystalline silicon) panel type. A water block was placed on the rear side of the panel, where flow rates were controlled to change the output temperature of the coolant. These output temperatures corresponded to two use cases: space heating and cooling. Instead of a traditional pumping method, a decompression-boiling heat collector was used, boasting lower power draw, and higher efficiency. Results suggest that the CIS PV/T system was able to convert 73.5% of the solar energy at a 40℃ water output and 45.9% of the solar energy at a 60℃ water output, whereas the m-Si panel type, in the same conditions, showed to operate at a dramatically lower efficiency (Terashima et al., 2023).

A Malaysian research group, led by Noor Muhammad Abd Rahman, utilized a custom cooling system consisting of a customized plenum[2] and specially designed aluminum heat sinks to transport cool air from a heat pump through the back of the panel and back down to the heat pump where the heat can be recycled. The findings suggest an impressive 12.35% increase in panel efficiency (as compared to the nominal operating cell temperatures, NOCT) and a comparatively low, 17% decrease from the standard testing conditions (STC) (Rahman et al., 2023).

A research group, led by Salehi et al. (2021), studied the use of thermoelectric modules to pump heat from the rear of a solar panel to corresponding anodized aluminum heat sinks. This system reduced the overall temperature of the panel by an average of 10.04℃, allowing for a 10.50% increase in energy output (Salehi et al., 2021).

Similarly, another group researched the use of thermoelectric generators in improving solar efficiency by reducing panel temperatures and in turn producing electricity through the Seebeck effect.

[2] An air intake device to direct airflow in a controllable manner.

The Seebeck effect is a natural phenomenon that states that whenever there is a temperature difference between two different electrical semiconductors/conductors, a voltage is produced between those two materials. Thirty thermoelectric generators, fitted with aluminum heat sinks, were put on the back of a solar panel to reduce panel temps and increase output electricity. Results suggest an average of 8.4% more electrical energy was produced by the TEG than the standard PVs (Akal & Türk, 2022).

According to research done by a group from the Indian Institute of Technology, operating temperatures of photovoltaic cells are crucial to their longevity. When the temperatures within the cells vary too significantly, delamination can occur, resulting in the deterioration and shortened lifespan of PV cells. To model this situation, a conduction based thermal model was designed to analyze the thermal interactions between a PV with and without a rear mounted heat sink. Results suggest that hotspots, which cause delamination, tend to occur on the outer edges of the PV. With the addition of a simple, passive cooling system, this model was able to find an approximate 1% increase in PV efficiency (Laha et al., 2021).

The proposed design works to include concepts from each of these studies including conduction-based water cooling and the use of thermoelectric modules to effectively cool a PV system.

Implications

Solar panel efficiency defines global sustainability. As of 2023, 3.4% or 144,000,000,000 KWh of the United States' power is produced by solar. If solar panels can be made universally more efficient by just 5%, the United States' power grids could become 0.3% less dependent on fossil fuels such as petroleum. While this may not sound significant, roughly 3.1 million barrels of petroleum liquids would remain unburned annually, reducing carbon dioxide emissions by roughly 1.4 million metric tons per year (U.S. Energy Information Administration, 2023). The effect on the planet and global CO2 emissions would be profound. Any improvement to the efficiency of PVs can be an improvement to the condition of the planet and the sustainability of the world’s power grids.

Section 2: Specific Aims

The overall objective of this project is to reduce the temperature of a PV and, in turn, increase panel efficiency. Through research, design and revision, the desired outcome is a cooling system that can increase the power output of a PV system. Thus, the primary goals of this project are threefold: reducing PV temperature, reducing cooling system power draw, and increasing overall PV power output. Once all three grounds have been properly addressed, the project will be deemed a success. The expected outcome of this project is an effective, retrofittable active cooling system with a net positive effect on the power output of a solar panel.

2.1 Reducing Overall Panel Temperatures

The first specific aim of this project is to reduce the PV temperatures as excessive panel temperatures reduce power output and lifespan. Several factors are responsible for heat-based performance degradation, including delamination, where the internal components of a panel begin to separate due to excessive pressure in the cells. Additionally, for every 1°C temperature increase, each cell tends to lose 2.2mV, resulting in an inherent loss in power output (Laha et al., 2021). Therefore, it is key that this project produces a device to aid in reducing the temperature of a PV to combat PV degradation and mitigate thermally triggered reductions in PV power output.

2.2 Reducing Net Power Draw of Active Cooling System

A cooling system will be designed to address the aim described in Section 2.1. An active cooling system can oftentimes cool at higher, more controllable magnitudes (Rahman et al., 2023; Terashima et al., 2023). By nature, active cooling systems require input energy, creating the potential for a reduction in overall panel efficiency (Zubeer & Ali, 2022). Any energy consumed by the cooling system detracts from the energy collected by the PV, reducing overall exergy efficiency. Therefore, to maintain a net positive impact on the overall panel performance, the power draw of the PV cooling system must be mitigated.

2.3 Increasing Panel Power Output

For most, the sole purpose of solar panels is to produce usable electricity. Thus, this system must increase the overall power output of the panel. After all, the only metric aside from longevity that matters to most panel users is power output. Therefore, by reducing the temperature of the panel and mitigating the power draw of the cooling system, the overall power output must be improved. Otherwise, this project would have no meaning for improving PV efficiency and reducing large scale dependence on fossil fuels. The primary purpose of solar panel cooling systems is to increase PV performance; this system must do the same (Salehi et al., 2021).

Section 3: Project Goals and Methodology

3.1 Project Significance

The creation of an effective PV cooling system is essential to the optimization of solar energy as both power output and photovoltaic cell longevity are defined by the operating temperature of a panel

(Laha et al. 2021). This project aims to put forth a device to combat overheating panels through active cooling and, in turn, increase PV output power and increase panel lifespan.

3.2 Innovation

A novel active cooling system will be created to address the three project aims described in Section 2. The first aim of reducing panel temperature will be achieved through the creation of a closed loop water block fixed to the rear of the panel. The second aim of reducing the net power draw of the water loop will be achieved through thermoelectric generators, which will both reduce panel temperature and provide electricity for the recirculation pump (Farhani et al., 2022). The overall objective of increasing panel efficiency will be achieved through the culmination of all apparatus components and subsequent adherence to the rear of the panel. So long as the TEGs successfully subsidize the power draw of the recirculation pumps and the water block effectively draws heat from the PV, the project will meet its objectives.

3.2.1 Rear mounted water loop

Several studies have examined the effectiveness of PV water cooling and have generally found water[3] cooling systems highly effective. Based on these studies, two categories of water cooling can be identified: closed loop and open loop. Closed loop water cooling systems are sealed off and, if built properly, will not lose an impactful quantity of coolant through normal operation. These systems require the water to be cooled after passing through the heat source to return and efficiently draw heat from a PV (Chanphavong et al., 2022; Terashima et al., 2023). If the coolant returns hot, it will have a weaker cooling effect as justified by the specific heat formula. Open loop cooling, on the other hand, does not

[3] "Water" and "coolant" will be used interchangeably as water is the coolant in a water-cooling system.

necessarily reuse the coolant and does not fully encapsulate the coolant. Open loop PV water cooling often requires a constant water source and a method to dispose of used coolant. If used coolant is recirculated, it is generally more at risk to factors such as evaporation or contamination from outside elements such as dust or other debris (Zubeer & Ali, 2022; Alktranee & Péter, 2023). Consequently, open loop cooling systems often have a larger resource and maintenance requirement. With this in mind, a closed loop PV water cooling system will be used in the proposed apparatus to take advantage of the cooling abilities of water while not requiring a considerable amount of maintenance or resource input.

To contain the water and effectively transport heat, an aluminum water block will be used. Aluminum was chosen because it has a high specific heat capacity of 0.89 J/g℃ and will be able to effectively transfer heat from the PV to the coolant (A. Powell, personal communication, November 7, 2023). A high surface area will be necessary to ensure consistent cooling across the PV to mitigate risks of delamination (Laha et al., 2021). An aluminum container will span the rear of the PV, as shown in Figure 2, with angling towards the water recirculation port to direct coolant in the proper outflow direction. Other materials, including copper and stainless steel, were considered for use in the backplate but were deemed to be too expensive for practical application.

Figure 2. SolidWorks model of aluminum water block on the rear of a PV (iteration 1). The right side represents the lower half of the PV.

Water recirculation will occur with the help of a small aquarium sized pump and copper tubing. Water will return to the top of the block where it can flow back through the block. While the water flows through the aluminum container, it will flow through aluminum fins, shown in Figure 3, which aid in the heat distribution into the coolant (Terashima et al., 2023; Zubeer & Ali, 2022). Using angled fins is hypothesized to allow for more effective heat transfer while promoting smooth coolant flow. The top of the block will then be sealed with another sheet of aluminum. It is expected that this water block will effectively conduct the heat from the PV to the water.

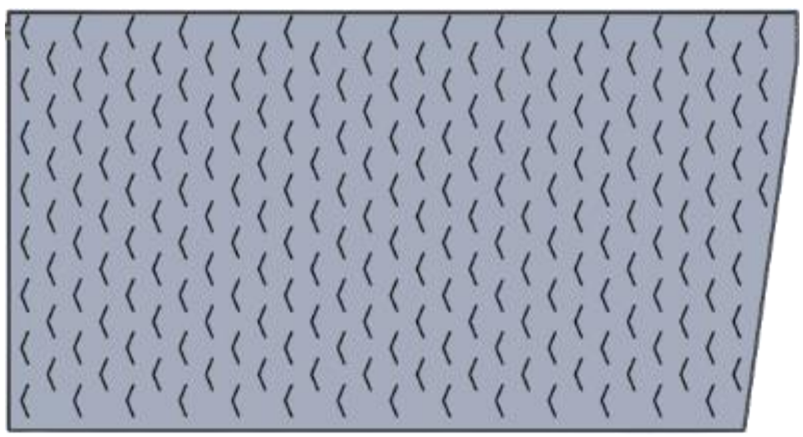

Figure 3. SolidWorks model of aluminum water block with angled fins (iteration 1).

3.2.2 TEG powered water recirculation

Pumps used in water cooling systems can draw somewhere in the range of 12 volts and 3 amps (Chanphavong et al., 2022). Resultantly, using PVs to power their own cooling reduces their net power output. The use of thermoelectric generators is proposed to offset this power draw. Thermoelectric generators, otherwise known as Peltier modules in the Seebeck mode, are devices that convert heat energy into electrical energy (Jaziri et al., 2020). In this model, roughly 10 TEGs will be placed on the rear of the panel, below the water block modeled in Figure 2. The power output of these TEGs will be wired directly to the power input of the recirculation pump so that the TEGs supply all of the pump's power draw. Heat sinks will be placed on the cold side of the TEGs to help maintain a temperature gradient

(Gopinath & Marimuthu, 2023). Data from a previous study suggests that TEGs placed on the rear of a panel can produce electricity (see Figure 4) and reduce panel temperatures (Akal & Türk, 2022). This same logic is applicable to the proposed apparatus and will be used to supply the power for the recirculation pump. As the temperatures of the PV lower, so will the output voltage of the TEG, reducing the speed of the pump. A reduction in pump speed is acceptable because once the panel is cooler, it requires less cooling and lower coolant flow rates. It is hypothesized that this system will be able to subsidize the majority if not all of the power required to run the pump.

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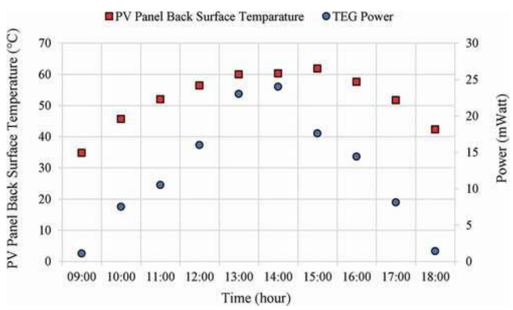

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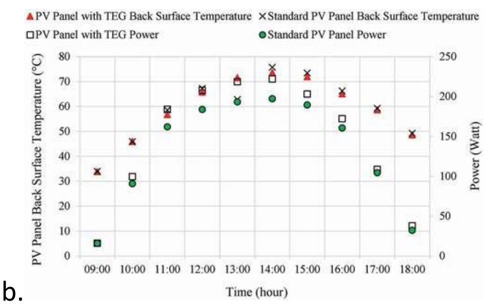

Figure 4. a. Graph showing TEG power output in mW from the heat of a PV over the course of 9 hours. b. Graph showing a TEG fitted panel temperature and output power compared to a control without TEGs, suggesting a slight reduction in temperature and an increase in power output (Akal & Türk, 2022).

3.2.3 All in one PV cooling apparatus

When put together and fixed to the rear of the PV, this system is expected to effectively cool the PV. The aluminum backplate will be fixed to the rear of the panel, assuring full contact with the PV back panel. The copper recirculation pipes will be cut, put together, and attached to the water block/pump with the help of silicon sealant. The TEGs will be fixed to the lower portion of the PV with the help of a silicon thermal glue to aid in the transfer of heat from the PV to the TEGs and the same glue will be used to adhere aluminum heat sinks to the cold sides of the TEGs (Alktranee & Péter, 2023). The TEGs will be wired in parallel and connected to the recirculation pump. Once put together, the PV-TEG (photovoltaic based thermoelectric generator) will be put on a stand and will be fully functional.

3.3 Methodology

Three different forms of apparatus representation will be designed and analyzed. Mathematical models for this project will consider the thermal properties of the apparatus materials and environmental conditions and will output the power production and efficiency of the solar panel. The CAD model will serve as a visual representation for to-scale design and will define the exact material needs and apparatus arrangement. The final testing method will take place outside, where one standard solar panel and one water cooled PV-TEG will be set up. Power output, solar radiation, and panel and ambient temperatures will be measured in increments over the course of a whole day. These three testing methods will provide a well-rounded understanding of the proposed apparatus and its effectiveness.

3.3.1 Computer Simulation

To fully understand the interactions between the flowing coolant and the PV, computer-based flow simulations will be conducted (Laha et al., 2021). SolidWorks Flow Simulation will be used to model the fluid dynamics and thermodynamics involved in the cooling block. This software will not be used to simulate any interactions within the PV; it will take only an input heat from the aluminum plate, which will be adhered to the rear of the PV and will simulate the heat transfer from the plate, through the coolant and to the other side of the water block.

The coolant, water, will enter the PV water block through the top intake hole and will flow through a series of angled aluminum fins until it is directed to the lower exit hole. At the intake, the water will enter at a flow rate comparable to that of a small aquarium pump. The bounds of the flow model will end at the exit hole. The flow in return pipes will not be simulated for the sake of time and energy. In addition, the mesh size (density of measuring points in the model) will be reduced from the maximum with minimal impact on model accuracy (Laha et al., 2021).

The results of the model will include coolant pressure, water block pressure, coolant temperature, water block wall temperature, water block fin temperature, coolant velocity, and coolant turbulence. These factors will be analyzed, and the model adjusted to optimize the heat transfer from the PV backplate to the coolant.

Some weaknesses involved in this testing method include the assumptions that must be made to proceed. The PV backplate temperature will be assumed to be 70 degrees Celsius, and so will the temperature of the water block wall that comes into contact with the PV backplate (Terashima et al., 2023). This assumption will be made to simplify the model and reduce computation time and the electricity required for the computation. Additionally, the return pipe fluid dynamics and the resultant reduction in flow rates will be neglected for the same purposes. Even so, the results of the SolidWorks Flow Simulation will be useful in understanding how the coolant fluid interacts with the rest of the water block and how effective it will be in the cooling of the PV.

Preliminary results, represented in Figure 5 below show the coolant flow patterns and temperatures as it travels through the backplate. Results provide insight into the weaknesses in the design and where revisions must be made. The results also show a notable improvement from the first iteration which can be seen in Figure 6. Improvements in the consistency and predictability of waterflow have been made. The backplate is still in the designing phase and factors such as over pressurization in the container and inequitable flow rates are being addressed in upcoming iterations.

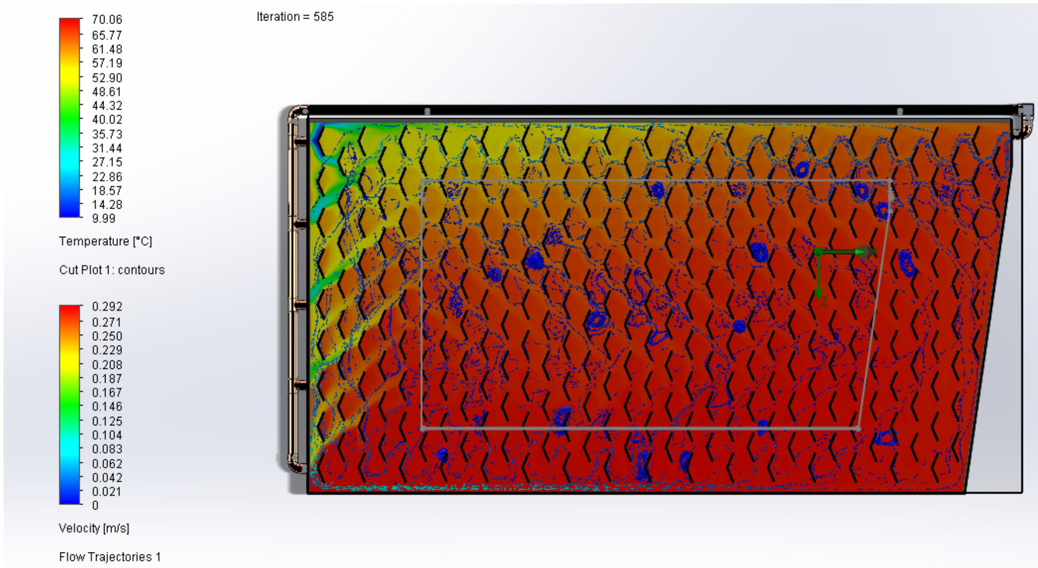

Figure 5. A visual of the flow simulation results after iteration 2. The background color signifies coolant temperature and arrows represent velocity direction and intensity. Significant improvement was made from the results displayed in iteration 1, Figure 6. The addition of additional exhausts is proposed to further introduce uniformity in coolant flow.

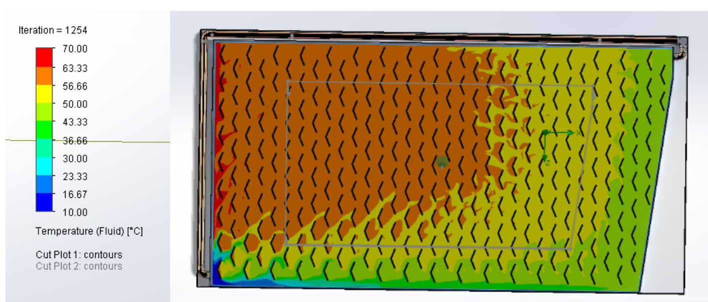

Figure 6. A visual of the flow simulation results after iteration 1. Coolant appeared to flow with significant bias down the edge of the apparatus (pictured in green) with significant dead-zones in the opposing corner. Temperature uniformity was not achieved in iteration 1, but iteration 2 offers a significant improvement.

3.3.2 Mathematical Representation

Mathematical models for this project will take in the solar radiation, ambient temperatures, and the heat transfer characteristics of all components and, through several physics-based equations, will output an approximate power output and efficiency of the solar panel. Additionally, the PV rear panel temperatures will be calculated, and the output electricity of the thermoelectric generators will be estimated.

The proposed mathematical model will account for the energy transfer between all surfaces within the apparatus, including the PV front glass, solar cells, PV back plate, and the materials within the water block which include two layers of aluminum sheets and water coolant. Through consideration of free convection from the apparatus to the air and reflection from the sun, the majority of the external and internal factors in this system will be accounted for.

The use of mathematics will provide another basis by which the apparatus can be analyzed and understood. To have a well-rounded understanding of a design, theoretical models based on physics can be created to supply an additional perspective (Laha et al., 2021). Through consideration of the results of a mathematical model, which will be carried out with MATLAB, an improved understanding of the interactions within the system will be achieved. Based on the results of the mathematical model, weaknesses in the cooling system can be identified and strengths quantified.

Factors such as coolant turbulence, air pressure, humidity, and wind speed are important factors that modify the energy exchanges within a PV system (Chanphavong et al., 2022). These variables will not be accounted for, as doing so would increase model complexity by a significant amount. By not considering the aforementioned factors, the accuracy of the mathematical model will lessen, but the meaning behind the results will not. Analysis of power output and PV efficiency will be conducted with simplifications considered.

3.3.3 Experimental setup

To truly understand whether the apparatus works in real world applications, it must be tested in the field. Once all materials have been acquired (see Section 4), a control PV and a PV with the cooling system will be set up according to Section 3.2.3. The two PV systems will be mounted above an array of incandescent lightbulbs with uniform angles of incidence.

After the set-up phase is complete, data collection will begin and last four roughly two hours. Multimeters will be connected to the power output cables on the PVs and output voltage and current. The temperature on the front and back of both panels as well as the cold side of the TEGs and the rear of the water block will be measured by Arduino every 5 minutes. Solar irradiance will be measured in the same interval by the Arduino and power outputs will be measured every 10-15 minutes manually.

Once the data collection is complete, and the analysis phase can commence. The panel power outputs and efficiencies will be calculated and compared, along with the voltages, currents and temperatures to assess the effectiveness of the cooling system. A reduction in PV temperatures and an increase in panel efficiency/power output on the modified PV will signify a successful design.

Section 4: Facilities, Resources and Equipment

4.1 Facilities

All testing will be completed either indoors or on a computer. Computer testing will be hosted by the Worcester Polytechnic Institute and The Massachusetts Academy of Math and Science for free. Testing in the field will happen in a garage or open indoor environment. These testing locations will provide no additional expense. No labs will be required for testing.

4.2 Materials

The materials that will be used in this project are as follows:

- Two 175W solar panels
- Two PV stands
- One aluminum sheet (dimensions correspond to approximately thrice the surface area of the PV)
- 10 thermoelectric generators (40mm by 40mm)
- 10 Aluminum heat sinks (40mm by 40mm by 20mm)
- Approximately 2.5 meters of ½” to ¼” diameter piping
- A low voltage aquarium pump
- 20ft of copper wiring
- 5 Thermocouples
- Thermal adhesive
- 1 Multimeter
- 1 Arduino uno with 6 temperature probes and a light detector
- 24 x 72W incandescent lightbulbs

This list covers all materials that will be used in the project and estimated expenses can be found in Section 6.1.

Section 5: Ethical Considerations

5.1 Safety

The proposed testing methods do not pose any significant threats to human safety. As solar panels can be heavy, caution must be used when moving the panels around. Low amperages and voltages (no more than 10A, 24V) will be used with all electronics and are not a significant threat to human health. Caution will be taken when handling/modifying any electrical components to reduce the risk of electrocution. So long as the materials are not consumed, there are no other risks to human health.

5.2 Moral Implications

There are no negative moral implications in the aforementioned testing methods. All materials will be repurposed following testing and this procedure will not produce a significant quantity of waste. No organisms will be tested on and thus, no further considerations in that field are required. Conclusively, there are no violations of common environmental/organism related ethics.

Section 6: Budget and Timeline

6.1 Finances

The required materials include two solar panels, two aluminum sheets of the approximate length and width of the panel, roughly ten thermoelectric generators, a low-power aquarium pump, a solar panel stand, and copper piping to recirculate coolant. The total expense for the purchase of these materials will be approximately 1130 dollars (USD) and is broken down in Table 1.

Table 1. Breakdown of price per component used in this experiment.

Material	Quantity	Expected price per unit (USD)
175W PV	2	200
Thermoelectric generator	10	40
Aluminum heat sinks	10	2
Copper piping	10ft	50 total
Low voltage aquarium pump	1	20
Copper wiring	20ft	15 total
Thermocouples	5	10
Thermal adhesive	250mL	15 total
Multimeters	4	25

PV stand	2	50
Arduino System	1	60
72W Incandescent light bulbs	24	80
	Total Expected Price:	1270 USD

The expenses associated with mathematical modeling and computer-based models are negligible as they will be conducted using licenses from Worcester Polytechnic Institute and The Massachusetts Academy of Math and Science. Additionally, the operating expense of computers used for both models is negligible.

6.2 Project duration

The proposed project will take approximately four months to execute. This duration begins at the start of preliminary testing in November of 2023 and ends with the final documentation/conclusions which are anticipated to terminate in February of 2024. Interpretations of preliminary data will occur between the end of November and mid-December while final data is anticipated to be collected between the end of December and mid-January. Subsequent interpretations of data will take approximately one month to produce and upon completion in February, the project will terminate.

Section 7: Appendix

The Office of Energy Efficiency and Renewable Energy (EERE) is a government organization that funds research in clean energy. Grants are given out via a merit-based system based on the quality and potential implications of research projects. The EERE aims to reduce the cost of renewable energy and expand access through funding of research projects. Each year, the EERE gives several millions of dollars in funding for research projects such as this one and larger scale research projects. As there are a few different solar based grant opportunities on the EERE website, it makes the perfect fit for the target of this grant proposal (Solar Energy Technologies Office, n.d.).

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