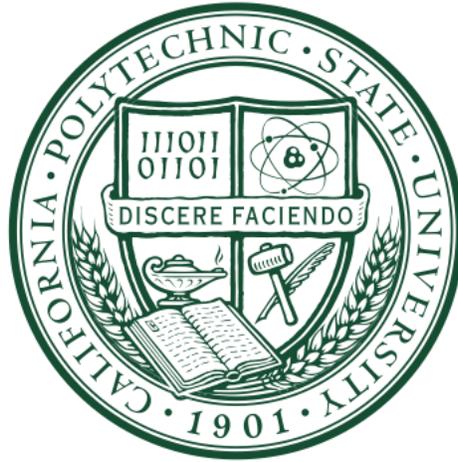# Final Design Review

Air to Water Capture in Support of UN Sustainable Development Goals

06/06/2025

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Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

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Table 1. Four Panel Chart

Project Overview	Design Description
Water scarcity is an increasing global concern which affects around 2.4 billion people worldwide. Water scarcity is linked to dry and/or remote locations, lack of water infrastructure, and/or natural disasters rendering current infrastructure inoperable. With help from Dr. Mohammad Noori, our senior project team has designed a device that can produce water from air using thermoelectric cooling. This design focuses on efficiency, low cost, reliability, and versatility in its efforts to produce clean drinking water.	Our project design uses an aluminum frame with acrylic and foam walls. This will house the thermoelectric cooling system, which consists of sixteen Peltier modules, sixteen hot-side heat sinks, and four cold-side fin arrays. These are the components that will work to condense water out of the air. The air flow will be controlled using a fan and filtered with a standard air filter. The water that condenses on the cold-side fin arrays will fall off and be funneled into a tube, where a bottle can be placed. The system will be powered by an external power source, but capable of running, for a limited time, independently on a battery. The cost of our current prototype is around $1500, with the most expensive components being the housing components and fans.
Design Image	**Design Verification**
	While we did not capture water with this device, we believe that we created a great foundation for water capture with additional refinement. We remained within the budget of $2,500, the prototype is portable and can be carried by two adults and can operate for sustained periods of time. The testing that we conducted provided valuable insights into how to improve the system. We found that a condensing panel with a smaller thermal mass, better cooling fans, and an improved thermal resistance network, water capture is well within the reach of this prototype.

Overview:

This Final Design Review (FDR) presents a comprehensive overview of the senior design project for an air-to-water capture device in support of the United Nations Sustainable Development Goals (UNSDG). This report details a summary of the project's design, its implementation, and how it fared against the specified requirements outlined in earlier reports. It also includes conclusions on the data related to the project's testing and recommendations for future work, assuming continuation of the project. The primary goal is to develop an accessible and reliable device that gathers water when operated in a variety of environments with different humidity conditions.

Our concept description section provides an overview of the solution that we decided would be best to meet the primary goals of this project, which forms the basis of our verification prototype design.

The implementation of major choices regarding the structure of the outer shell and interior layers remained largely unchanged from the conceptual designs in the Critical Design Review (CDR). The manufacturing involved for the shell in this project consisted mainly of sizing various materials we procured to be used in the assembly properly. Most parts were not modified beyond changing the shape to fit our project. The electrical implementation in our final prototype changed more from our CDR specifications than the mechanical section. Since the writing of the CDR, we made definite decisions about what electrical components we would need to hit our power goals in a safe and stable manner. The electrical components were not modified as largely as the mechanical components; however, some components were slightly altered to add fuses to the circuit or to make wire management easier.

Once built, the final design was tested against the design specifications that we had established over the year to ensure that we were reaching the goals of our senior project. Unfortunately, we were not able to produce water within our full verification prototype. Seeing as many of our original test designs were based around factors relating to water collection, we recognized that we could no longer conduct these tests and instead pivoted to design and conduct new tests to properly analyze why the system was operating but not collecting water.

After the design and execution of the new tests, we studied our collected data to draw conclusions about why our conceptual designs were not working as intended. From this analysis, we formed a plethora of changes that could be implemented to our prototype design to improve system operation and ideally produce water.

Finally, the appendices include the supporting documents necessary for a thorough review, including test procedures and results, design analysis, references, user manual, risk assessment, final budget, and references.

Concept Description:

The atmospheric water harvesting system we have developed, pictured in Figure 1 along with an exposed CAD view in Figure 2, is designed to produce about a liter of water per hour using a thermoelectric cooling (TEC) process. The TEC process makes use of Peltier modules, driven by an electric current, to cool down a large aluminum fin array on which the water vapor is intended to condense. The condensed vapor, now liquid water, would be dense enough to fall off the condensing array and into a water capture receptacle of the user's choice.

Figure 1. View of the outside of the verification prototype
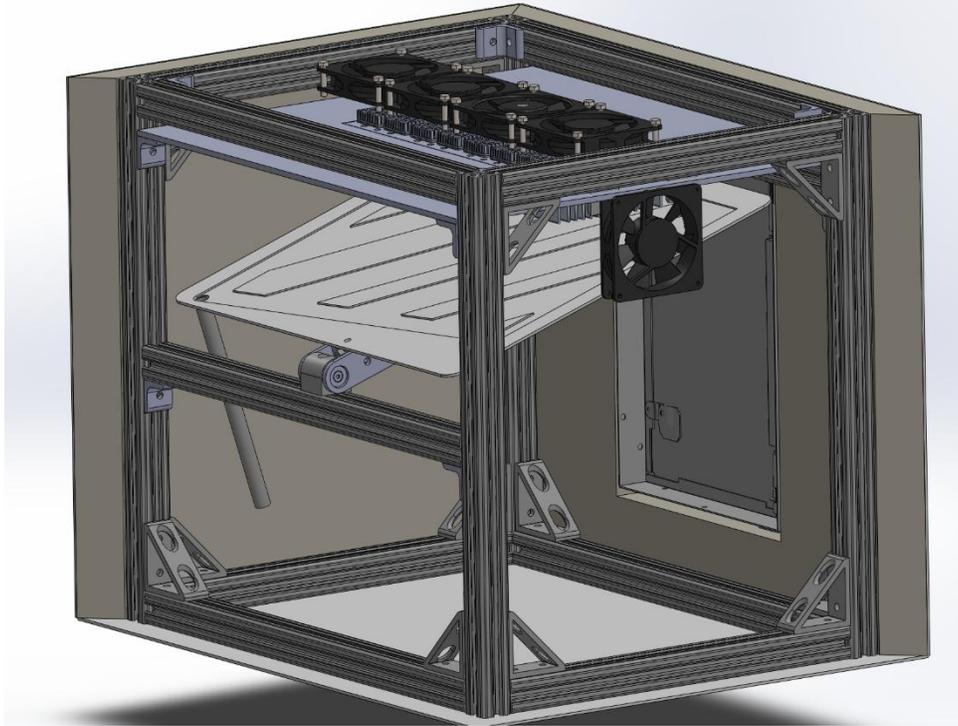
Figure 2. CAD of complete system with top and 2 lateral panels removed

The exterior design of the system features a frame, pictured in Figure 3, that is made from 6105-Aluminum T-slotted framing rails and is 1.5 feet in height by 1.5 feet in width by 2 feet in length. The frame is held together using gussets and brackets. The gussets are used in areas where strength is more critical and will be fastened using 5/16-18 flanged button screws. The brackets are used to mount internal components such as the fan and condensing array, and they are fastened using 5/16-18 flanged button screws as well. These framing rails were chosen because they are versatile, strong, and cost-effective.
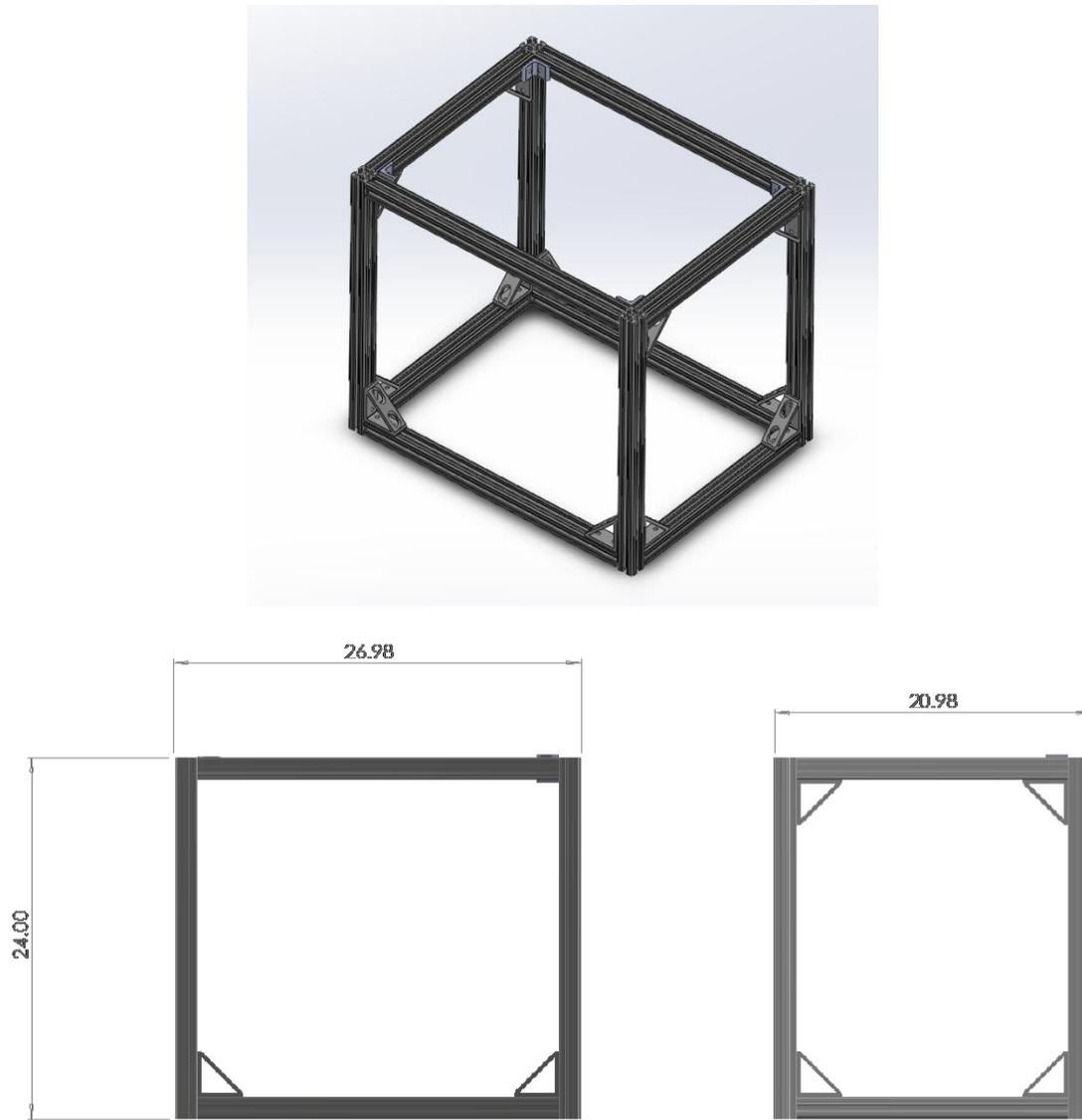
Figure 3. Frame and exterior protection

As shown in Figure 4, the four lateral sides of the frame are covered by insulation foam and thin plastic plates. The insulation is 1.5 inches of moisture-resistant low-temperature rigid polystyrene sheets, and the plastic panels are $1/16^{th}$ inch weather-resistant VHMW polyethylene. Both are attached to the frame using 1/4-20 screws. Together, these components offer a layer of rigid protection and minimize losses from heat transfer to the surroundings.
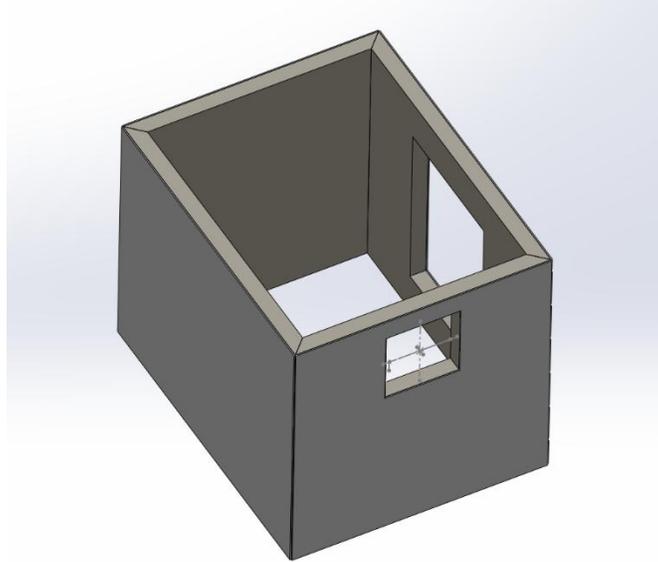
Figure 4. Lateral wall panels with insulation

The top and bottom panels of the system, seen in Figure 5, are fastened to the frame the same way as the lateral panels and are made of weather-resistant VHMW polyethylene. This material was chosen because of its weather and impact resistant properties. These panels are not accompanied by insulation like the lateral panels to help reduce the cost of our system. The top panel is designed to protect it from environmental conditions, such as dust and rain. The hot air from the system is pulled out through the top of the system via four fans. These fans are mounted to the top panel using 1/4-20-1.375 hex head bolts; thus, the panel needs to be strong enough for this mounting. Additionally, there will be substantial amounts of hot air flowing, via the fan, and rising, via natural convection, that the panel itself will conduct small amounts of heat out of our system. Therefore, the top panel is not accompanied by insulation to aid this heat rejection. For the bottom panel, heat transfer by conduction is not a concern because the polyethylene that we are using is relatively nonconductive and there will not be any incident radiation because our system rests on the bottom panel so the sun cannot hit it. Therefore, insulation is not critical for these panels.
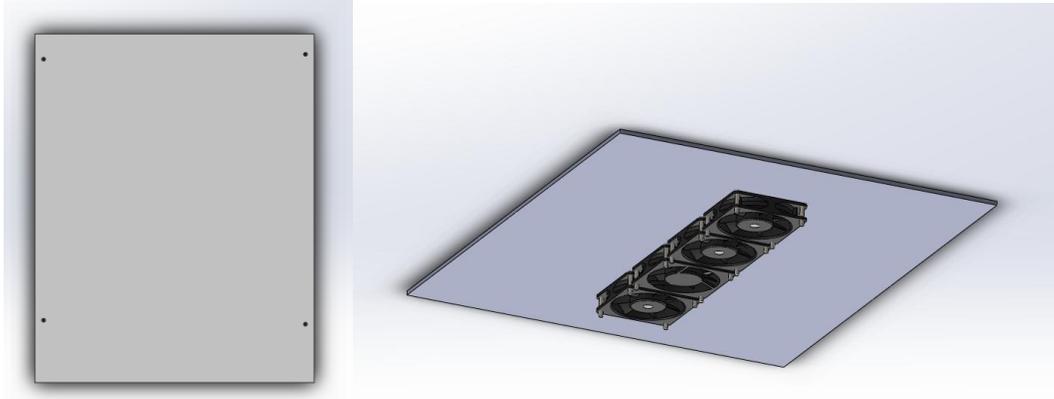
Figure 5. Bottom (left) and top (right) panels

Inside the frame, a two-by-eight grid of Peltier devices and heat sinks, displayed in Figure 6, will be the system through which we use electricity to cool down the condensing arrays, also shown in Figure 6. The full assembly is made up of four identical sub-assemblies. Each sub-assembly features four heat sinks, four Peltier modules, and one condensing array. The Peltier modules operate using the Peltier effect, where an electric current running through the device creates a temperature difference, causing one side to become cold and the other to become hot. The Peltier effect requires removal of the heat produced, because the devices create a temperature difference between the hot and cold sides and not a set surface temperature. If the heat is not sufficiently removed, it may be sent back through to the cold side, which negates the goal of the Peltier effect.
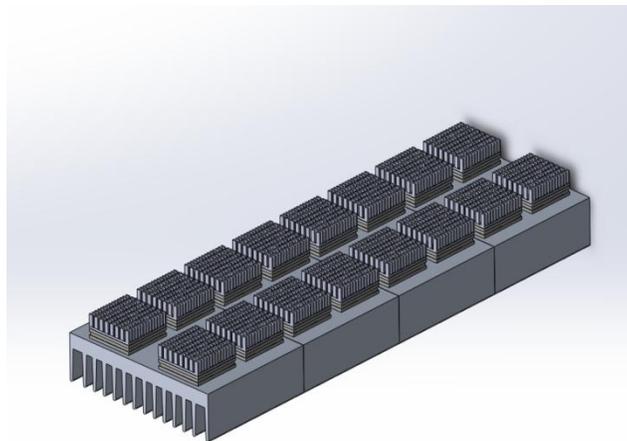
Figure 6. Configuration of Peltier devices, heat sinks, and fin arrays

Each Peltier module is attached to a small aluminum heat sink on its hot side using the provided adhesive that comes on the back of each heat sink. Similarly, each Peltier module's cold side will be adhered to a condensing array using thermal adhesive. To achieve and maintain a cold condensing array on which water can condense, it is critical that we pull off sufficient amounts of heat. Thus, 6063 Aluminum is the chosen material for both the heat sinks and condensing arrays because of its high conductivity. The vertical orientation of the cold side fin arrays ensures that gravity will help the water that collects fall down.

The configuration of Peltier devices, heat sinks, and fin arrays is situated on a mounting panel, displayed in Figure 7, which is made from a UV and scratch resistant acrylic panel. The panel is 21 inches by 27 inches so that all sides of the panel fit flush with the insulation. This effectively isolates the inner chamber into two sub-chambers. The panel has four cuts (1.5 inches by 1.5 inches) at each of the corners so that the frame and mounting panel do not interfere with each other. The panel is fastened to the main frame by mounting the top of four corner brackets with bolts. The height of the mounting panel is designed such that the heat sink on the very top will not interfere with the top panel or the fans mounted to it. The condensing arrays are fastened to the mounting panel with plastic zip-ties that go through both materials, thus pulling the condensing arrays flush to the mounting panel. To accomplish this, the mounting panel has holes intermittently spaced surrounding where the heat sinks will fit, as seen in Figure 7.
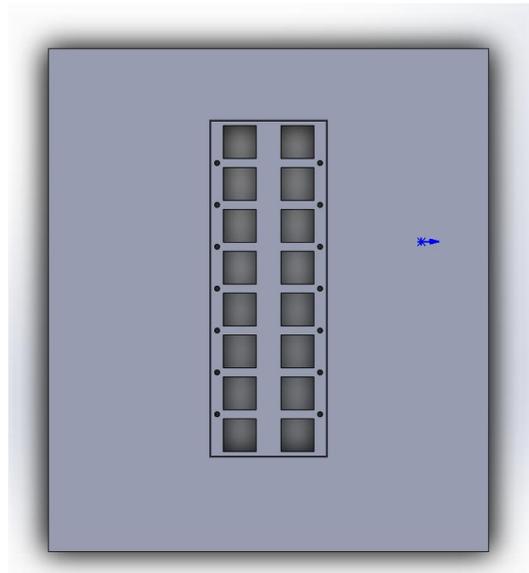
Figure 7. Mounting panel

The acrylic panel is not conductive, and it is ¼ inch thick. This way it also serves as an insulating barrier between the hot and the cold sides of the system by isolating the two different air masses. The condensing panels will create cold air, and the heat sinks will be surrounded by hot dry air. It is critical that we control the hot side temperature of the Peltier devices, since this is the only method to maintain the cold side at the dew point temperature of the air.

The air is brought through the system with the four 120-volt Alternating Current (AC) single phase fans, shown in Figure 8, that are mounted on the top panel. With these four fans, our system can move up to a maximum of 256 cubic feet per minute (CFM) of air.

Figure 8. 120-volt AC single phase Fan

It is an important requirement of our system that we can produce relatively clean water. To accomplish this, a six-by-six-inch pleated panel air filter, shown in Figure 9, is attached in front of the air intake fan. This filter can remove particulate matter down to 3 microns in size and is RoHS and REACH compliant, so the air coming through it is safe for consumption. This filter is press-fit into the wall of the system so it can be easily replaceable by the user when necessary.
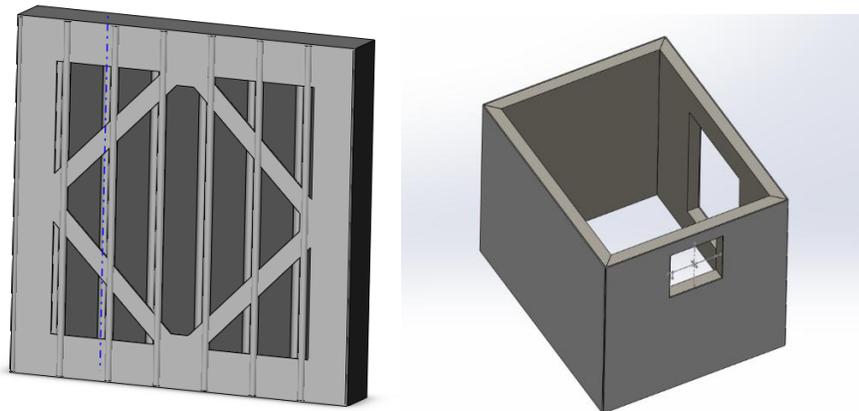
Figure 9. Pleated panel air filter and mounting location

The goal of the actual water collection system was simplicity and versatility, so we chose to allow the user to choose the container that the water will fall into. The only requirements are that the container must fit through the side door on the system and will sit flat within the system to collect water as the system operates.

Within our system there are two separate components that require power: the 120-volt AC single phase fans and the Peltier devices. Our initial calculations, which were based on psychometrics, predicted that we were going to need about 1 kW of power. This significant amount of power, as well as the extended operating times we planned to run the system at, were key factors in the decision to use AC grid power rather than a battery.

The fans are all powered with AC voltage, so they simply needed power cords to plug into the wall. The power cord to the intake fan is a quick-disconnect cord, which attaches directly to the quick-disconnect terminal on the fan. The power cords to the top four fans are pigtail power cords, meaning they have loose wire leads on one end. As the fans also have loose wire leads, the hot lead of each fan was connected in series with a fuse and then to the hot lead of the power cord, while the neutral leads were simply connected. These links were made with WAGO brand 221-412 lever nuts, seen in Appendix F Figure F.11, which join components in our circuit in series using clips that hold down inserted wires onto a metal bar that electrically unites each of the inserted ends. Fuses rated for 3A were added in these fan circuits to maintain safety and protect the fans if current were to spike, as the fans are only rated for 0.18A.

The Peltier devices run on Direct Current (DC) voltage, so the design of the Peltier circuits was a little more difficult than the fans. Each set of four Peltier devices is connected in series with WAGO connectors. These connectors allow the circuit to be easily altered, for example to contain only two or three Peltier devices in series instead, which proved to be advantageous for testing. The set of Peltier devices is then connected to the output of a voltage regulator, which allows both input and output voltage and current to be monitored. It also allows output voltage to be changed, which lets us try different power configurations during testing. A view of the top of our mounting panel with 4 sets of connected Peltier devices and voltage regulators is shown in Figure 10.
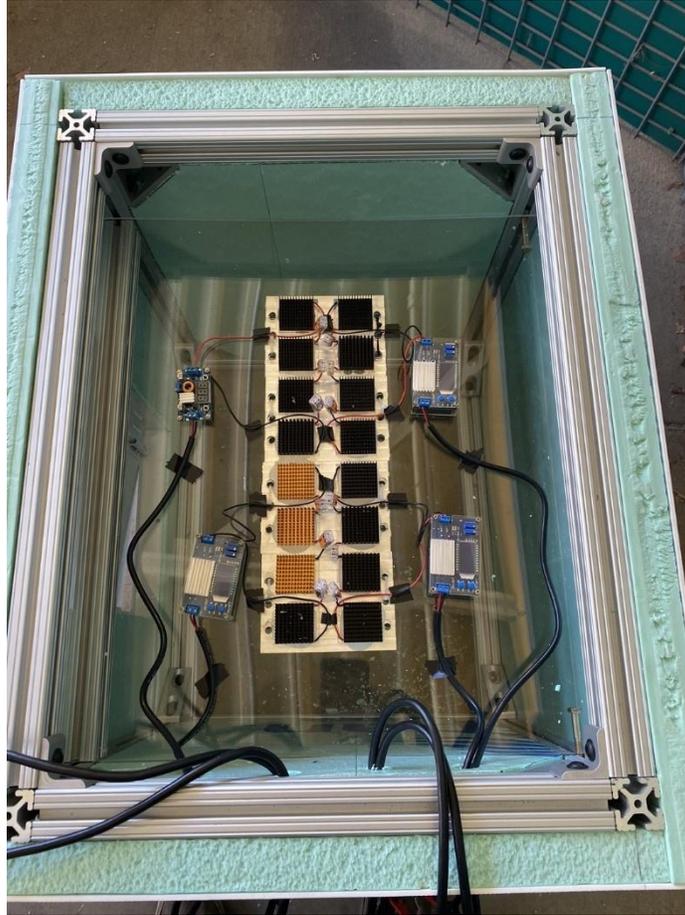
Figure 10. Top of mounting panel, pictured are the 16 Peltier devices in sets of 4 attached to a voltage regulators

The input of the voltage regulator is connected to a pigtail female barrel connector, which then connects to a male barrel connector on the AC-to-DC modules we chose. Once again, we inserted a fuse in series on the power cord side of each AC-to-DC module to protect the rest of the circuit from a current spike which is shown in Figure 11. These fuses are rated for 7.5A. The AC-to-DC modules produce an input voltage of 24VDC to the voltage regulators. The voltage regulators implemented in our system require a voltage difference of 0.8V between input and output, allowing us to power the Peltier circuits with a maximum of 23.2V. More information on all of these electrical components, circuit diagrams, and procedures can be found below in Appendix F. Finally, we plugged these nine total cords into an outlet strip rated for 15A and were very careful that our total added current could not go above 15A.

Figure 11. AC-to-DC converter with a fuse connected in series, adapter then connects to a voltage regulator set

The most important feature of our design is that it is ideal for people with little access to resources and/or capital. Overall, the thermoelectric cooling system that we have designed is relatively simple and robust. Our system's dimensions are 1.5 X 1.5 X 2 feet, and it weighs a little under 100 pounds, meaning it can be moved relatively easily with two able-bodied adults and is small enough to fit in most locations. Moreover, our system doesn't rely on refrigerant or any moving parts, making it durable and requiring low maintenance. If something ever breaks, the simplicity is advantageous to the user who may be trying to fix it. We also chose the simplest electrical system possible for the project scope. Our system does not have a sensor to tell someone when their bottle is full; instead, the user will have to physically assess when it is full. Our system can operate at a steady state condition as long as sufficient power is supplied and components do not overheat.

Implementation:

One of the main goals of this project was modularity, hence the construction was akin to a complex Lego project. We started by assembling the aluminum framing. Using brackets and nuts, that slide into the rails on the aluminum extrusions, we were able to use a Allen-key to create the frame. This way we were able to construct a strong frame that is capable of protecting and isolating the more fragile components on the inside. The exterior walls were made by cutting the plastic and insulation panels to size, with a skill saw, and then drilling holes in them so that

they could be attached to the outside of the frame using bolts. The top and two of the side panels required cutouts to be made for the air filter, door, handles, and top fans. These cuts were all made using a multitool. Two handles were bolted onto the top of the aluminum frame on opposite sides so that two people are able to easily pick up and carry the entire system. The fan on the lateral wall was press fit into the insulation, and the fans on the top panel were mounted using bolts, this way all the fans were fixed in place, but there orientations could be changed if desired. The air filter was press fit into the lateral wall outside the fan, so clean air would enter the system and the user was separated from what could be a hazard.
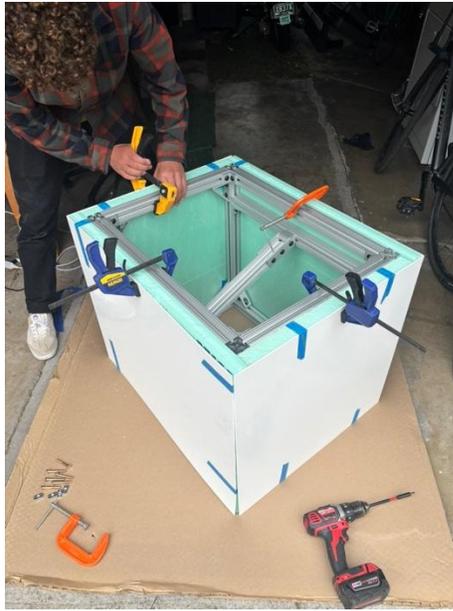
Figure 12. Assembling side panels, ensuring holes for bolts are aligned with rails on aluminum extrusions

Milling the base of the condensing arrays to try and reduce their thermal mass was an important step in the manufacturing process. We reduced this base by 0.25 inches, from 0.5 inches to 0.25 inches. We knew that the thermal mass was going to be large and did this as an attempt to reduce it; however, it ended up not being enough of a reduction. The acrylic panel upon which the condensing arrays, Peltier modules, heat sinks, and electrical wiring rested was cut out using a laser cutter.
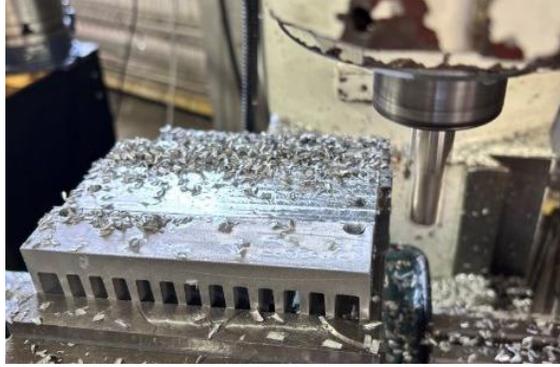
Figure 13. Milling of condensing arrays

        The electrical components were all procured either from McMaster-Carr or Amazon, as we needed reliable delivery times and trustworthy vendors. The only work needed to implement the top fan circuits was stripping the fan wire leads, power cord wire leads, and fuse holder wires to 11mm, which is the length recommended by the WAGO manufacturer, shown below in Figure 14. Beyond this, the desired connections were made with WAGO connectors and the fans plugged straight into the wall. The quick-disconnect power cord simply needed to be plugged into the quick-disconnect terminal of the intake fan.
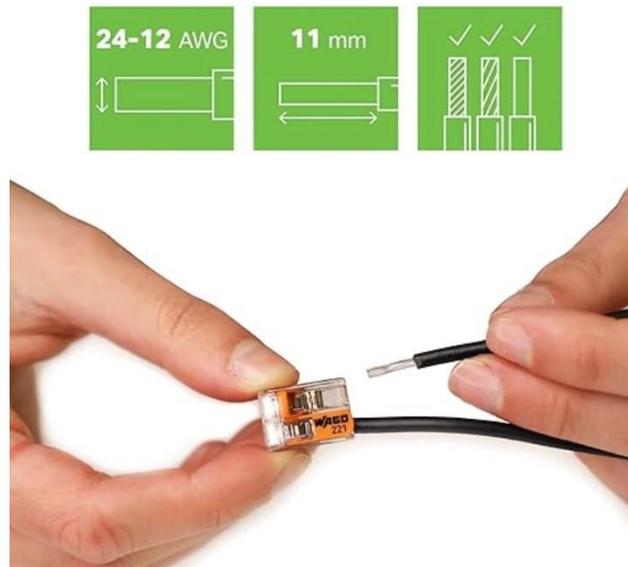
Figure 14. WAGO connector information including length that wires must be stripped to (11 mm), gauge of wires that can be used (12-24 AWG), and what types of wires can be used (solid or stranded)

        We spoke to both peers and faculty in the Electrical Engineering department to determine what the best approach was for the Peltier circuits. We decided to connect each set of four devices in series because that allowed us to split voltage and maintain a constant current across all four devices. We found that 24 V, 6 A AC-to-DC modules were more common and budget friendly than higher voltage modules, so we chose to build a circuit based on the assumption that

each Peltier device could receive 6 V (24 V split between 4) and about 3 A. We originally planned on connecting two sets of the four devices in parallel onto one power cord, which is where the 3 A comes from, as the input current would've split in the parallel connection. However, it proved to be less complicated and safer to give each set of four their own AC-to-DC module instead. The decision to add voltage regulators was made with the desire to monitor the voltage being sent into the Peltier devices during testing. Fuses were also added to both the cooling fan circuits and the power-side of the AC-to-DC modules to prevent components from being damaged if current were to spike.

The voltage regulators came in a few separate pieces and were easily assembled by connecting the acrylic top and bottom pieces to the main circuit board with the nuts and bolts provided in the package. The AC-to-DC module power cords first needed to be stripped of part of their outer wire covering to expose the lead wires inside. Then, the hot lead was cut and stripped to allow the fuse connection. The rest of the wires within the circuits were stripped to appropriate lengths to accommodate the WAGO connectors.

Initial electrical testing was done with the sets of Peltier devices connected in series on two breadboards and powered by a DC power supply in the Electrical Engineering student project lab, shown in Figure 15. This allowed us to get an idea of Peltier temperatures at certain monitored power inputs, but the data wasn't relevant to our final prototype since the system wasn't operating in the finished frame and housing. Once all the necessary components to safely connect to AC power arrived, the Peltier circuits were all transferred to AC power.
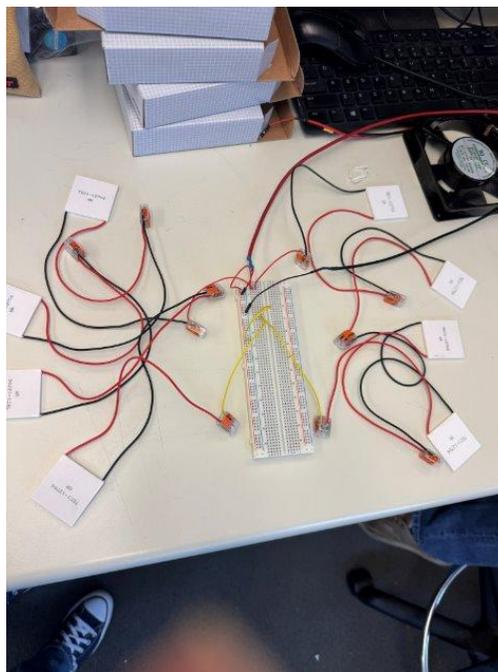
Figure 15. Initial testing of Peltier circuits with WAGO connectors done on DC power in EE lab

When manufacturing was finished, the Peltier devices were secured in the mounting panel on the condensing arrays using thermal adhesive. The devices were pressed down into the adhesive to ensure application on both surfaces, and then they were left to fully cure for 24 hours before the system was operated. To clean up the wiring of the system and ensure that wiring didn't interfere with the heat sinks or top fans, the Peltier wire leads were cut and re-stripped at much shorter lengths and parts of the fan wiring was duct taped to the top panel so the panel could still be raised and lowered without disturbing the electrical connections.

Holes were cut through the insulation and plastic panel on the wall opposite from the intake fan so that there would be space for the electrical components to be routed out of the interior without cutting through the roof or being unable to fully close the top. A total of four holes were cut and each hole had two wires pulled through and then plugged into the power strip which went into the wall outlet.

The implementation of our mechanical and electrical designs was successful according to the plans that we had set before the VP was manufactured; they allowed us to maintain consistent and safe power throughout our system. These implementation steps facilitated a variety of tests that we used to verify the state of our overall prototype when related to the initial project goals. Below is a more thorough investigation on what we tested, and the findings gained from those results.

Design Verification:

The primary goal of our design was to condense water vapor out of the air. However, upon testing, we found ourselves pursuing an intermediate objective that we previously assumed had been accomplished, being able to cool the aluminum condensing arrays below the dew point temperature. Because of this, we did not test water collection quantity or power use efficiency because those were all dependent on being able to collect water in the first place.

In lieu of the ability to collect water, we were still able to accomplish many of our other design requirements that, we believe, lays the foundations for a group to refine our design and achieve water collection in the future. Table 2 provides a summary of our design goals and which ones we achieved.

Table 2. Design criteria achieved

Design Goal:	Description:	Pass/Fail:
Water Collection	Collects 500 mL of water per hour	Fail
Modular	Components of Design are accessible and system is easily repairable	Pass
Cost	$2,447.85<$2500	Pass

Efficiency	Collect 500 mL of water in 1 hour using 1000 W of power	Fail
Reliable	System can run for 2 consecutive hours multiple times	Pass
Mobile	System can be moved by two average people	Pass
Versatile	Collects water at different humidities	Fail
Easy to Use	Simple start-up procedure	Pass

The notable goals are reliability and ease of use. During testing, we did have the system up and running for many extended time periods during which the electrical system never faltered. This means that should the system be collecting water, it could be operated for extended periods of time, enabling larger quantities of water collection. Additionally, the electrical system was designed to be very modular, allowing for parts to be switched out easily in case of failure. All of the electrical connections were designed with fuses so that electrical failure would not result in damage to the system as a whole or personal injury. While these are important parts of this prototype, we still needed to understand the reason for our inability to collect water.

To try and understand why we could not get the condensing arrays below the dew point temperature, we conducted a series of tests. Testing multiple configurations of the Peltier modules and the fans to try and find an optimal one that could be used for water collection. The results are presented in Figure 16 and 17.
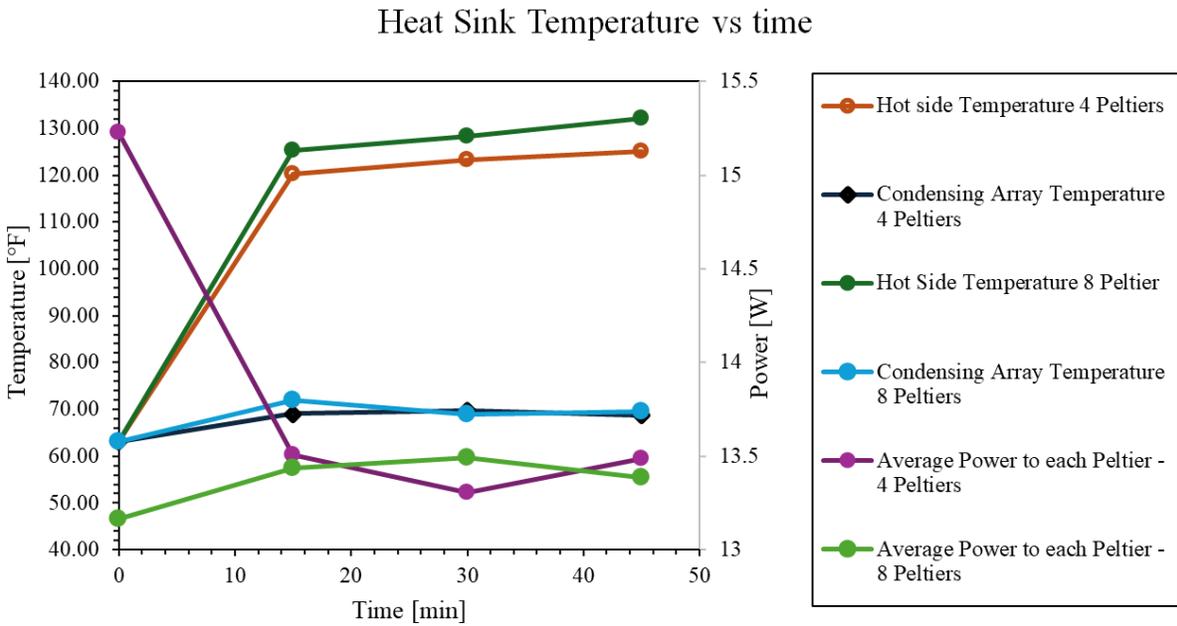
Figure 16. Test results showing the cold and hot side temperatures of two different Peltier configurations.
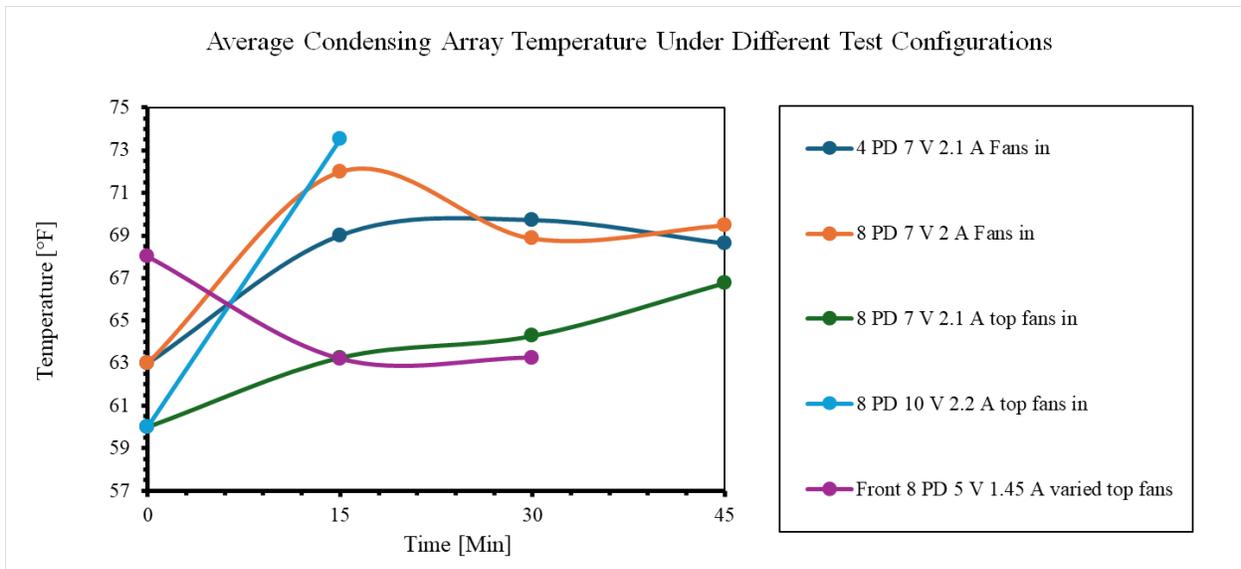
Figure 17. Test results showing the condensing array temperature over time with multiple Peltier and fan configurations.

These tests showed us that we were struggling to remove enough heat from the system for the condensing arrays to be cooled to the desired temperature. During these tests, the dew point temperature was roughly 51ºF, and as you can see from both Figures 16 and 17, the coldest temperature achieved was in the low 60s. In Figure 16, we can see that the hot side of the Peltier modules reaches upwards of 130ºF while the condensing arrays are being held at 63ºF. We conducted this test with both 4 and 8 Peltier modules. The test with 4 Peltier modules had 1 Peltier per condensing array while the 8 Peltier test had 2 Peltier modules per condensing array. This was done because we wanted to see if each condensing arrays corresponding fans were struggling to remove heat due to the quantity of Peltier modules that the fans had to remove heat from. We can see from Figure 16 that having more Peltier modules operating did result in a marginally higher condensing array temperature.

In Figure 17 we can see the condensing array temperature for multiple fan and Peltier configurations tested against each other. The best results came from 8 Peltier modules with a varied top fan arrangement. In this test, Peltier modules 1-8 were on[1], with fans 3 and 4 pulling air out, and the intake fan and fans 1 and 2 blowing air in. This created an environment with the largest amount of air movement and thus the most forced convection. These results showed us that the more heat removed from the Peltier modules the cooler the condensing arrays got.

To further understand why we couldn't remove the necessary heat from the system, we conducted a heat transfer analysis of the different components to try and draw conclusions and potential remedies for our shortcomings. The hypotheses that we derived from our testing and aim to address in this analysis are the following:

1.) The fans are not removing enough heat to allow the Peltier modules to cool the condensing arrays.
2.) The thermal mass of the condensing arrays is too large and therefore the air coming in that is to be cooled is heating them faster than they can be cooled.
3.) The thermal resistance network has too much thermal resistance and does not allow sufficient conduction and therefore sufficient heat removal.

Thermal Performance Analysis of Peltier Cooling System

To evaluate the cooling performance of the thermoelectric (Peltier) modules in our design, we conducted a quantitative analysis of their heat pumping capacity and the effectiveness of heat dissipation through the hot-side aluminum heat sinks.

Key Equations: Peltier Device Heat Balance

$$P_{elec} = V \cdot I \qquad\qquad 1$$

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[1] Labeled diagram in appendix A.9

$$COP_c = \frac{Q_c}{P_{elec}}$$
2

$$Q_h = Q_c + P_{elec} = P_{elec} \cdot \left(1 + \frac{1}{COP_c}\right)$$
3

Fin Heat Transfer Model (Hot Side)

$$Q_{fins} = \eta_f \cdot h \cdot A_{fins} \cdot (T_b - T_\infty)$$
4

$$\eta_f = \frac{\tanh(mL)}{mL}, m = \sqrt{\frac{2h}{kt}}$$
5

$$Q_{base} = h \cdot A_{base} \cdot (T_b - T_\infty)$$
6

$$Q_{total} = Q_{fins} + Q_{base}$$
7

Table 3. Theoretical necessary heat removal from a single Peltier module with different input power and COP using equations 1-3 calculated in MATLAB in Appendix B.4.

Voltage (V)	Current (A)	Power In (W)	Assumed COP	Q_c (W)	Q_h (W)
7.0	2.0	14.0	0.8	11.2	25.2
12.0	6.0	72.0	0.3	21.6	93.6
12.0	6.0	72.0	0.25	18.0	90.0
12.0	6.0	72.0	0.2	14.4	86.4

Table 4. Theoretical heat removal from the hot side fin arrays when the airflow is split between different numbers of Peltier modules using equations 4-7 and calculated in MATLAB which is in Appendix B.3.

Number of Peltier modules per fan	CFM per Sink	Air Velocity (m/s)	h (W/m²·K)	η_f	Q Removed (W)
1	64	7.71	39.4	0.910	42.7

2	32	3.85	22.6	0.946	24.7
3	21.5	2.59	16.5	0.96	18

As we can see from Table 3, operating the Peltier modules at their maximum parameters yields better heat removal only if the COP remains high, however that is not guaranteed and likely fluctuates over the course of operation. While the heat removal is less at the 14 W of input power, it is still acceptable. Now, using the value of 25.2 W of total heat that needs to be removed from the Peltier module, we can look at Table 4 to see how much heat we are removing with forced convection. Looking at the heat removed column, we can see that we can operate no more than 1 Peltier modules per cooling fan, or 4 Peltier modules in total given our system's design which gives us a margin of 17.5 W.

Additionally, even running our system with one Peltier module per fan/condensing array, we are then only removing 11.2 W from each condensing array and air chamber or 44.8 W of heat in total. This is far less than the estimated required heat removal of 500 W to get half a liter of water collection per hour. So, we know that we need to have better forced convection so that we can operate more of the Peltier modules to increase the amount of heat we are removing. However, we must be able to remove the latent heat from the condensing arrays before we can start cooling the air. This leads us to the second hypothesis, that the condensing array had too much thermal mass and was being rewarmed by the intake air before it could cool down.

Dynamic Thermal Interaction: Cold-Side Block vs. Air

The Peltier modules were tasked with cooling both the aluminum condensing blocks and the surrounding air. Each cold-side block segment (serving one Peltier) required over 5,100 J of thermal energy to be removed before even beginning to cool the air below dew point. Meanwhile, the air itself introduced additional thermal load — both sensible heat (from cooling to the dew point) and latent heat (from any potential condensation), totaling an additional ~60 J.

$$Q_{block} = m_{block} \cdot c_p \cdot \Delta T \qquad 8$$

$$Q_{sensible,air} = m_{air} \cdot c_{air} \cdot \Delta T \qquad 9$$

$$Q_{latent\ air} = m_{water} \cdot h_{\{fg\}} \qquad 10$$

$$Q_{air,total} = Q_{sensible,air} + Q_{latent\ air} \qquad 11$$

$$Q_{total} = Q_{block} + Q_{air,total} \qquad 12$$

At a cold-side cooling capacity of approximately 11.2 W per Peltier, the total time required to reach operating temperature exceeded 10 minutes. However, during this entire period, ambient air continued flowing over the surface, continuously reintroducing heat. This created a feedback loop in which the condensing blocks were constantly reheated by the air before they could fully cool down, resulting in a thermal equilibrium that remained above the dew point.

In effect, the large thermal mass of the condensing arrays coupled with the forced convection prevented the cold-side surface from approaching the dew point temperature. Thus, reducing cold-side thermal inertia is critical in future iterations.

Evaluating the Thermal Resistance

In order to better understand why our system performed the way it did we modeled the thermal resistivity of a system consisting of a Peltier module, a thermal adhesive interface, and an aluminum baseplate seen in Figure 18.
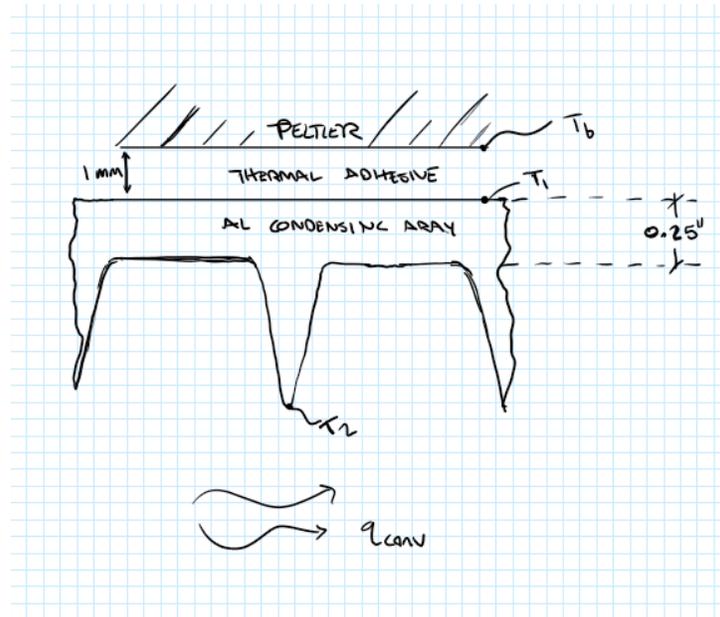
Figure 18. Schematic of thermal resistance network

The goal is to understand the temperature distribution and thermal resistance along the 1D path from the Peltier module to the fin tip. This is important since creating a more conductive path for the heat would allow for an even more effective system. For the heat transfer analysis, we modeled the system as being one dimensional, steady state, and having no internal heat generation. With these assumptions we were able to use a thermal resistance network.

The heat being removed from the air at T_∞ must move from the air into the tip of the aluminum condensing array (T_2) via convection. The heat then travels from point T_2 to the base of the condensing array where it interfaces with the thermal adhesive T_1. Then the heat flows through the adhesive into the cold ceramic plate of the Peltier module (T_0). The heat flux travelling between all of the temperatures encounters a unique thermal resistance between any two different temperatures or equivalently a different medium. The resistance network can be modeled as three resistors in series, the temperatures can be seen as voltage, and the heat flux as a current. Hence yielding equation 13

$$Q_c = \frac{(T_2 - T_0)}{(R_1 + R_2 + R_{fin})} \qquad\qquad 13$$

Where R_1 is the thermal resistance associated with the thermal adhesive,

$$R_1 = \frac{L_1}{(k_{ta} \times A)} \qquad\qquad 14$$

R_2 is the thermal resistance associated with the condensing array,

$$R^2 = \frac{L^2}{(k_{al} \times A)} \qquad\qquad 15$$

and R_{fin} is thermal resistance associated with the convection on the condensing array.

$$R_{fin} = \frac{1}{(\eta_f \times h \times A_{fin_{total}})} \qquad\qquad 16$$

The fin array is modeled using lumped fin efficiency theory.

$$\eta_f = \frac{tanh(mL)}{mL} \qquad\qquad 17$$

$$m = sqrt\left(\frac{hP}{(k_{al} \times A_c)}\right) \qquad\qquad 18$$

The total thermal resistance is the sum of the individual resistances.

$$R_{total} = R^1 + R^2 + R_{fin} \qquad\qquad 19$$

The temperature after the thermal adhesive (T_1) and the temperature at the base of the Peltier module T_0 were calculated as follows.

$$T^1 = T^0 + Q_c \times R^1 \qquad\qquad 20$$

$$T_0 = T_2 - Q_c * (R_1 + R_2 + R_{fin}) \qquad\qquad 21$$

T_0 is an important value because it tells us theoretically how cold the Peltier module would have needed to be in order for the condensing array to be at the dew point. In order to implement these

equations in MATLAB and solve for T_1 and T_0 we had to determine Qc, the heat flux created by the Peltier module. To determine Qc we were able use the performance curves provided by the manufacturer for the TEC1-12706 module in Figure 19.
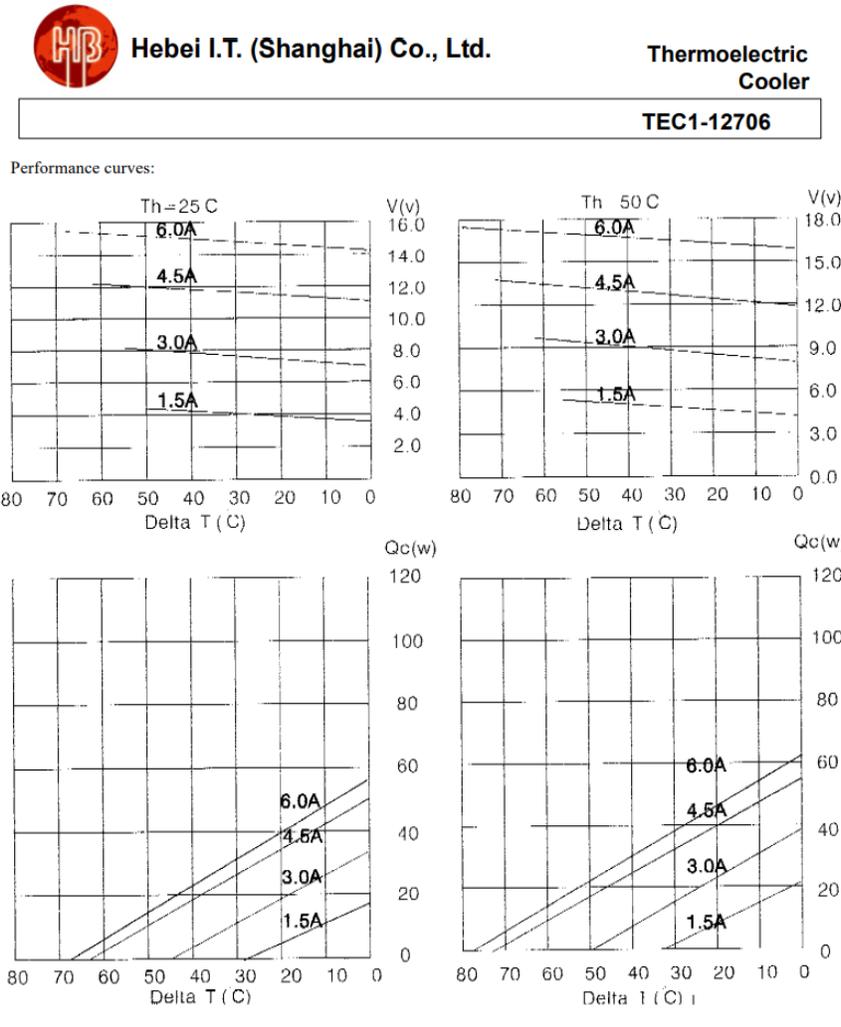
Figure 19. Peltier module spec sheet

Figure 19 provides 2 graphs per one temperature. One is for the hot side of the Peltier module at 25 °C and the other for 50 °C. These curves allows for a quick prediction of the amount of cooling power that can be expected for a certain current and voltage. Although we were interested in knowing more precisely what the cooling power (Qc) was for a given power input. Equations 22 and 23 below estimate cooling power and electrical requirements as a function of temperature difference (ΔT) and current.

$$Q_c = \alpha \times T_c \times I - 0.5 \times I^2 \times R - K \times \Delta T \qquad\qquad 22$$

$$\alpha: Seebeck\ coefficient\ [V/K]$$

$$R: Electrical\ resistance\ [\Omega]$$

$$K: Thermal\ conductance\ [W/K]$$

$$I: Electrical\ current\ [A]$$

$$\Delta T: Temperature\ difference\ across\ the\ TEC\ [K]$$

$$T\_c: Cold\ side\ temperature\ [K]$$

$$T\_h: Hot\ side\ temperature\ [K]$$

$$P_{elec} = IV = I(\alpha\Delta T + IR) \hspace{2cm} 23$$

Now we are able to cross reference the data sheets with these equations to determine operating points precisely.

In most tests we were running the Peltier modules at 2 amps and 7 volts, concurrently, we measured the heat sink to be about 123° F which correlates to 50° C. These conditions are annotated on the data sheet in Figure 20.
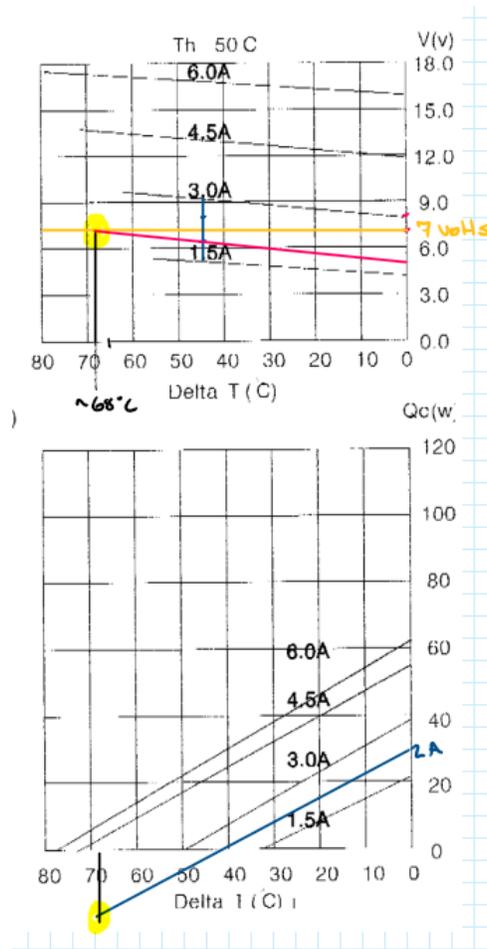
Figure 20. Annotated performance curve for TEC1-12706

Provided with the operating conditions above the expected temperature difference (ΔT) is about 68 ° C. We can then use this ΔT and current in the lower chart to see that the Qc is off the chart into what would be negative values, meaning that the cold side would be adding heat. To be sure this is accurate, we also used equations 22 and 23. The MATLAB in appendix B tells us that Qc = -34 W, thus confirming what the graphs are saying, that we would be adding heat with the cold side of the Peltier module. This explains how we saw the temperatures of the condensing arrays increase during testing. Next, we used the MATLAB code in appendix B. This allows us to work with equations 13 through 21 which model the thermal resistance network.

Furthermore, to see the theoretical value for how cold the Peltier module's cold side would have to be we entered the cooling power Qc, 10 W. This is an achievable value as seen in Table 3. Also entered was the necessary temperature of the tip of the condensing array 52°F, and the ambient air temperature T_∞ (76°F). For days at 76°F and about 68% relative humidity the dew point for air is 52°F. Therefore, this is the required temperature for water vapor to begin coalescing on the condensing array. The calculation yielded T_0 needs to be -15°F. Furthermore, it is important to note that this calculation was performed assuming a convection coefficient (h) to be 10 W/m^2-K, a typical value for natural convection. This is about the lowest possible heat load the condensing array will see given the same ambient air conditions, thus any amount of forced convection would require that the cold side of the Peltier module be even colder. The fault in our system is the poor thermal conductivity of the thermal adhesive (1.5 W/m-K). This model assumes a high-quality adhesion using thermal glue. If the glue is not as thin as possible and has any air pockets in it, both of which are potential imperfections when glueing by hand with little experience, then the thermal conductivity will be even lower than 1.5 W/m-K. The impact of this is that T_0 would need to be even colder than the -15°F predicted by the model.

The large thermal resistance is the primary driver for needing such a low temperature of the cold side of the Peltier module, therefore if we are not able to supply the required cooling to the hot side of the module, and/or sufficient current/voltage to achieve this low temperature our attention needs to be turned to the conductivity of this thermal system. This explains why we never saw the condensing arrays get nearly close to the dew point.

Conclusions and Next Steps:

While water capture was not achieved, we believe that we have created a great foundation for achieving water capture with this prototype in the future. We achieved the goals of making the device portable, using relatively low-cost components, easy to maintain and fix, and having an electrical system that can operate for extended periods of time. The testing of the system did yield valuable data that allowed us to conduct analyses as to why the system did not produce water.

The first wrong turn that was taken was that the psychometric analysis that was conducted told us how much heat we needed to remove from the air to be able to condense the water, however,

we did not take into consideration that the Peltier modules would also be creating heat that required removal. We were so fixated on the required heat removal from the air that we completely overlooked this vital part of the equation. This partly explains why the condensing arrays were not cooling, but rather, slightly warming. Additionally, we were not removing enough heat from the Peltier modules themselves, which meant they were unable to operate efficiently or operate at the temperature difference expected. Finally, the thermal resistance network made up of the condensing arrays and thermal paste proved to have too much thermal mass and thermal resistance respectively. The rate at which the air was heating the condensing arrays back up was faster than the heat was able to be removed from the condensing arrays.

These findings helped us to make the following recommendations for future iterations. The first and simplest change should be to exchange the condensing fin arrays for a thin aluminum plate. This will still conduct heat well, provide ample surface area for water collection, and reduce the thermal mass. The second change would be to use bigger heat removal fans while also moving the heat sinks closer to the fans. This can easily be done as the mounting panel is sitting on bolts that can be lowered or raised. Another change that we believe should be made would be finding a way to have temperature sensors permanently placed at each of the heat sinks and on the condensing arrays. This would dramatically streamline testing and provide more consistent and real time temperature data that would help with optimization. Lastly, we designed the electrical system so that it could be plugged into virtually any power source that can output 120V AC. This means that it could be run with solar if the solar array can supply the required power. This highlights the versatility and modularity of our system.

While those immediate changes could be made, there are parts of this project that were beyond our scope but would be useful for optimization. A flow analysis of the cooling fans could be done to optimize the airflow over the heat sinks as to be able to determine the best fan orientation. As we found in the testing, one of the most successful tests had the intake fan and two heat removal fans blowing in and 2 heat removal fans pulling air out. This is one example of the many components of this project that could likely be a whole project, which is part of the reason we found this project so challenging.

There were many different aspects that required learning and refining like the electrical system, heat transfer, thermodynamics, and airflow. This was an amazing opportunity to bring so many of the components of our mechanical engineering education together, but its breadth was also what made it so difficult. This could easily be a multi-disciplinary project and that would allow each group to optimize the many important variables that are needed for this system to work effectively. We are abundantly grateful to Dr. Noori, Lauren Rueda, and everyone else who supported us along the way and hope to see this project continue to be developed and learned from in the future.

Appendices

Appendix A

Test Procedures and Results

Below we have 9 different test procedures we will be completing once we have assembled the full project design to ensure we are reaching the goals we set out in the DVRP. These tests do not include assessments that would have required basic inspection when deciding if the parameters were met.

A.1 UNSDG Water Collection Test Plan

Test Name: Collected water volume

Purpose: Determining the quantity of water that can be collected over 2 hours

Scope: To evaluate the electrical needs of our Peltier devices while still maintaining condensation temperatures on the condensing arrays and a decent efficiency between electrical input and water collection

Equipment:

- Working prototype
- Water container
- timer
- Measuring tape
- Humidity and temperature sensor

Hazards:

- none

PPE Requirements:

- No necessary PPE

Facility:

- Hangar or Mustang 60

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

1. SETUP: Set desired temperature by setting Peltier power to pre-determined power-temp correlation
   a. Turn on heat removal fans
   b. Turn on peltier power
   c. Give 15 minutes to let condensing arrays reach a steady state temperature
   d. Turn on intake fan
   e. Start timer
2. TESTING: Record water quantity every 30 minutes

a. Take first data point when timer started and last at end of 2 hour period

b. Record humidity and temperature of outside at each 30 minutes interval

Results:

A success will be if we achieve within 10% of our 1 L goal for the 2 hours. The delta of water collection corresponding to recorded humidity and temperatures will give us a better idea of the best operating conditions.

The uncertainty will be found for the volume of water collected.

$$\sigma_V = V \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_W}{W}\right)^2 + \left(\frac{\sigma_H}{H}\right)^2}$$

- L = length
- W = width
- H = water height

Planned Test Date: N/A

Test Results: We were unable to gather water from the air, so the test regarding hitting certain levels for water production was not applicable to our situation.

Performed By: Entire Team

A.2 UNSDG Modular Test Plan

Test Name: Ensuring Modular design practice

Purpose: This test is to verify that the system is designed with the most accessible parts in mind to maintain straightforward repairs for users

Scope: To keep our components as simple and available as possible to keep the overall project design easy to repair and adjust

Equipment:

- None needed

Hazards:

- No hazards

PPE Requirements:

- No PPE needed

Facility:

- No facility needed

Procedure:

1. We will start with a completed system.

2. We will pose hypothetical scenarios: where each one will assess the feasibility of fixing a different component of the system

Results:

- This is a pass-fail test

- o If we can fix any part of the system in less than an hour- it is a pass

Finished Date: 05/13/2025

Test Results: For tests to be considered passed, the components must be repairable in less than an hour.

Potential component to break	Pass/Fail	Notes

Air filter	YES	The air filter can be easily exchanged from its position in the outer wall
Peltier module	NO	The Peltier modules are attached to the mounting panel using adhesive making it difficult to swap a specific Peltier module without removing a whole condensing array section.
Potential component to break	Pass/Fail	Notes
Voltage regulator	YES	The voltage regulators can be disconnected from the system while it is off and a different regulator can be placed in the same spot.
Condensing array	NO	The condensing arrays are attached to the Peltier modules using adhesive, so you wouldn't be able to swap one out without a fair amount of time and equipment, including a way to remove the adhesive and new adhesive to reapply Peltier modules.
Mounting panel	YES	The mounting panel can be removed from the system quickly once a side panel has been taken off and electric components disconnected.

Performed By: Entire Team

A.3 UNSDG Cost Test Plan

Test Name: Ensuring Cost of Project

Purpose: This test is to verify that the system is designed with the goal of staying within our budget.

Scope: To not overbuy things we don't need, to focus on thoroughly researching before we begin purchasing components. Also to keep up to date records of purchases to keep track of our spending.

Equipment:

- None needed

Hazards:

- No hazards

PPE Requirements:

- No PPE needed

Facility:

- No facility needed

Procedure:

1. Compare IBOM costs to our spending limit

Results: When we look at the updated IBOM for our project we are under the cost limit specified at the beginning of the project.

Planned Test Date: 5/21/25

Test Results: We were within the cost stipulated at the beginning of the project

Performed By: Entire Team

A.4 UNSDG Efficiency Test Plan

Test Name: Efficiency Test for Thermoelectric Water Harvester

Purpose: This test aims to evaluate the efficiency of the thermoelectric water harvesting system by measuring its water production rate and energy consumption. Since we will likely not have as much power as we would like to have due to safety concerns, we are more interested in how much water is produced compared to how much power was used.

Scope: The test will assess the ability of the thermoelectric cooling (TEC) system to condense water from the air. Specifically, this test will focus on how efficiently the system works since we know that it is going to work. This will provide us with a good idea of how much power our system is going to require.

Equipment:

- Thermoelectric Water Harvester Prototype

  o Aluminum frame

  o All panels

  o Peltier devices

  o Heat sinks

  o Condensing array

  o Mounting hardware

- Power supply (capable of delivering 1000 W)

- Humidity and temperature sensors (DHT22, DS18B20)

- Stopwatch/timer

- Standard air filter

- Measuring Beaker (1 L capacity)

- Thermocouples for monitoring hot and cold side temperatures

Hazards:

- Electrical hazards due to high power consumption

- Risk of burns from hot-side heat sinks

- Potential for overheating of components

PPE Requirements:

- Safety goggles

- Insulated gloves (for handling heat sinks)

- Closed-toe shoes

- Pants

Facility:

- Mustang 60

- Workbench with access to power outlets and ventilation

Procedure:

1. Set up the thermoelectric water harvester and ensure all components are securely assembled.

2. Verify that the air filter is clean and installed properly.

3. Connect the system to the power supply, ensuring correct voltage and current settings.

4. Place a clean, dry collection container beneath the water outlet tube.

5. Calibrate measurement equipment (scale, sensors, and thermocouples).

6. Record baseline ambient temperature and humidity levels.

7. Power on the system and start the timer.

8. Monitor water collection and power consumption in real-time.

9. After 1 hour, turn off the system and weigh the collected water.

10. Compare collected volume and power consumed to the theoretical values.

11. Repeat the test three times to account for variability.

Results:

- Pass Criteria: efficiency $\geq$ 0.7 mL/Wh (Water Collected $\div$ Power Input).

- Fail Criteria: efficiency < 0.7 mL/Wh

- **Number of Samples:** Minimum of 3 trials.

- **Uncertainty Analysis:** Measurement uncertainty will be evaluated using the resolution uncertainty of the power supply and measuring cup. Variations in environmental conditions (temperature, humidity) will be factored into the analysis.

Finished Date: N/A

Test Results: This test is not important to us since we were not able to collect any water and thus it does not make any sense to measure efficiency.

Performed By: Entire Team

A.5 UNSDG Reliability Test Plan

Test Name: Reliability Test

Purpose: This test aims to ensure that our system operates reliably in similar conditions for the same amount of time on different days so that we can be confident in our expected results.

Scope: This test is an extension of our water collection test to determine whether the results from the previous test can be relied on every time we run the system in certain conditions.

Equipment:

- Working prototype

- Water container

- Timer

- Measuring tape

- Humidity and temperature sensor

Hazards:

- No hazards

PPE Requirements:

- No PPE needed

Facility:

- Hangar (outside), Mustang 60

Procedure:

1. Record initial humidity and temperature readings

2. Set up system according to standalone water collection test

a. Turn on heat removal fans

b. Turn on Peltier power to pre-determined power-temp correlation using temperature outside

c. Allow 15 minutes of startup time to let condensing arrays reach a steady state temperature

d. Turn on intake fan

e. Start timer

3. Record initial water quantity

4. Record at each 30-minute interval:

a. Temperature

b. Humidity

c. Water quantity

5. At the end of the three-hour period, record final temperature, humidity, and water quantity

6. Inspect system for any visible issues

7. Repeat test twice in humidity conditions within +/- 5% and temperature conditions within +/- 10 degrees of initial test day, recording conditions and water quantity and inspecting after each five-hour period

Results:

Check system after each test to determine if any issues arose and note what the conditions were when the issues occurred. Ideally, we would see no issues and similar results from each test to prove that our system operates reliably when similar conditions are present.

Planned Test Date: Not planned yet

Test Results: While we were unable to determine reliable water gathering results, we ran the system for a 3-hour period and saw no changes from the electrical system output. So, while the reliability of the water gathering is not applicable the system is electrically reliable.

Performed By: Michael & Jordan

A.6 UNSDG Mobility Test Plan

Test Name: Mobility Test

Purpose: This test is to ensure that the entirety of the device could be lifted for the purpose of relocation by a two able-bodied individual

Scope: This test is designed to show that the device is an adequate weight for mobility

Equipment: scale, table and assembled system

Hazards: the individuals moving the device may drop it on themselves

PPE Requirements: closed-toed shoes

Facility: Anywhere with at least 5 sq-ft of space, a scale and a table

Procedure:

1) Place the device on a scale to see the total weight

2) Have two individuals pick up the device

3) Move at least 10 steps while carrying the device to ensure mobility

4) Set down the device

Results: The device should be moveable by 2 able bodied individuals and should be under 100 pounds in total weight

Test Date(s): 5/22

Test Results: We were able to comfortably move the full assembly with two individuals on either side holding the handles. The full system also weighed in at under 100 total pounds.

Pass criteria:	Results: Pass or fail
Under 100 pounds	Pass
Movable by two average people	Pass

Performed By: Entire Team

A.7 UNSDG Versatility Test Plan

Test Name: Versatility Test

Purpose: To test that our design works in a variety of different humidity settings

Scope: These different humidity levels would be done to ensure that our design still operates at reasonable water production levels within a range of environmental factors.

Equipment:

- Working prototype
- Water container
- timer
- Humidity and temperature sensor

Hazards:

- none

PPE Requirements:

- No necessary PPE

Facility:

- Hangar
- Outside under varying humidity conditions

Procedure:

1. Assemble our full project design
2. Run the design at a control humidity of around 50~60
3. Record results of test after an hour
4. Run the design again at a lower humidity level at least 30~40
5. Record results from the test after an hour
6. Compare to initial results to assess the device performance
7. Run the design at 10~20 percent humidity level to assess if the device will operate at in severely dehydrated environment

Results:

- Analyze results from severely dehydrated environment to make conclusions about production ability in extreme cases

- Ideally the test ran at the lower humidity will have at least 60% water production as the test ran at the initial humidity level

Planned Test Date: 5/16-5/18

Test Results:

Humidity level (RH%)	Production results after an hour (L)
50~60	0
30~40	0
10~20	0

We were unable to gather water under any humidity environments, so testing the project for versatility was no longer applicable.

Performed By: Entire Team

A.8 UNSDG Ease of Use

Test Name: Ease of Use

Purpose: This test is to ensure that the device could be operated simply and without need for technical knowledge.

Scope: This test is designed to show that the device is operable by a variety of users

Equipment: Fully assembled prototype, small flat-head screwdriver

Hazards: none

PPE Requirements: none

Facility: Anywhere with a wall outlet and enough space for the prototype

Procedure:

1) Place device near a wall outlet

2) Go through user manual for start-up procedure (mainly ensure wire connections)

3) Plug only wires from the mounting panel into the power strip that comes with the system

4) Plug the power strip into the wall outlet

5) Turn on power strip

6) Carefully push up top panel

7) Change power settings on the voltage regulators

8) Turn off power strip

9) Plug the remaining wires from the fans into the power strip

10) Turn on power strip

Results: The device should be considered easily operable and a user without technical experience should be able to make basic modifications to settings with just knowledge from the user manual.

Test Date(s): 5/18

Test Results: We were able to verify that the device is simple to operate and that a user doesn't need technical experience beyond the user manual to operate the device.

Performed By: Entire Team

A.9 UNSDG Peltier Configuration Test Plan

Test Name: Temperature Correlation between hot side of Peltier devices and condensing Arrays.

Purpose: The Purpose of this test was to try and understand why the condensing arrays were not cooling to the desired temperature. This test was created during the testing process to try and troubleshoot reasons for no water collection. It also helped with collecting vital information for analysis to aid with future project iterations and recommended design changes.

Scope: This test will provide essential information about the optimal Peltier configuration and power input to properly reduce the temperature of the condensing arrays to below due point.

Equipment:

- Thermoelectric Water Harvester Prototype
- Aluminum frame
- All panels
- Peltier devices
- Heat sinks
- Condensing array
- Mounting hardware
- Power supply (capable of delivering 1000 W)
- Humidity and temperature sensors (DHT22, DS18B20)
- Stopwatch/timer
- Standard air filter
- Thermocouples for monitoring hot and cold side temperatures
- Outlet Power consumption meter

Hazards:

- Electrical hazards due to high power consumption
- Risk of burns from hot-side heat sinks
- Potential for overheating of components

- Fans are exposed and caution must be used when manipulating prototype to avoid harming fingers or hands.

**PPE Requirements:**

- None

Facility:

- Mustang 60

Procedure:

- Record number of Peltier devices used in each test using the diagram and corresponding Peltier designations shown below.

- Record fan orientation.

- Record initial condensing array temperatures and hot side temperatures BEFORE plugging in system.

- Set timer for 15 minutes.

- Plug in system and record the voltage and amperage through each voltage regulator.

- Let system run until timer reaches 15 minutes.

- Once 15 minutes has passed, open access door and use the thermocouple to record condensing array temperatures based on their designations shown in the diagram below.

- Close access door and lift top with fans still running. Use electrical tape to tape thermocouple lead to the hot side heat sink of operating Peltier and then close lid. Wait 30-45 seconds for the temperature of the heat sink to go back down to operating temperatures as the temperature dramatically increases when lid is lifted and cooling airflow is removed. Record the temperature.

- Repeat this step for remaining Peltiers.

- Take photo of voltage regulator values to record them while waiting for the next 15 minutes run period.

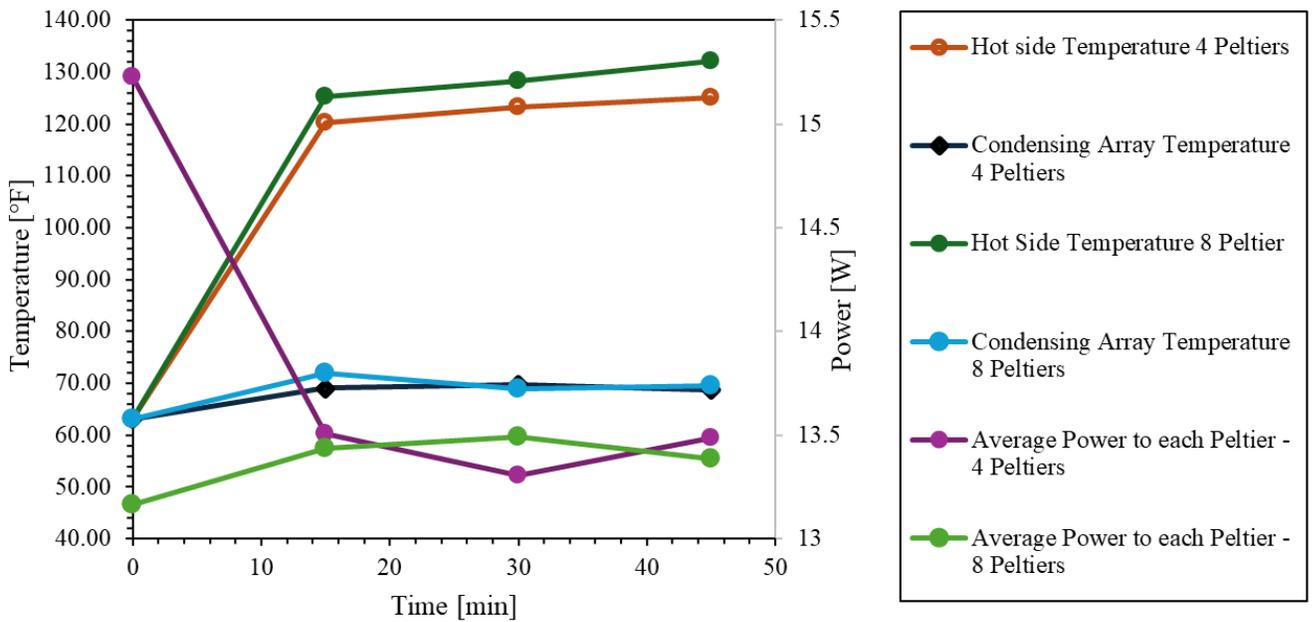- Repeat about steps 2-3 more times.
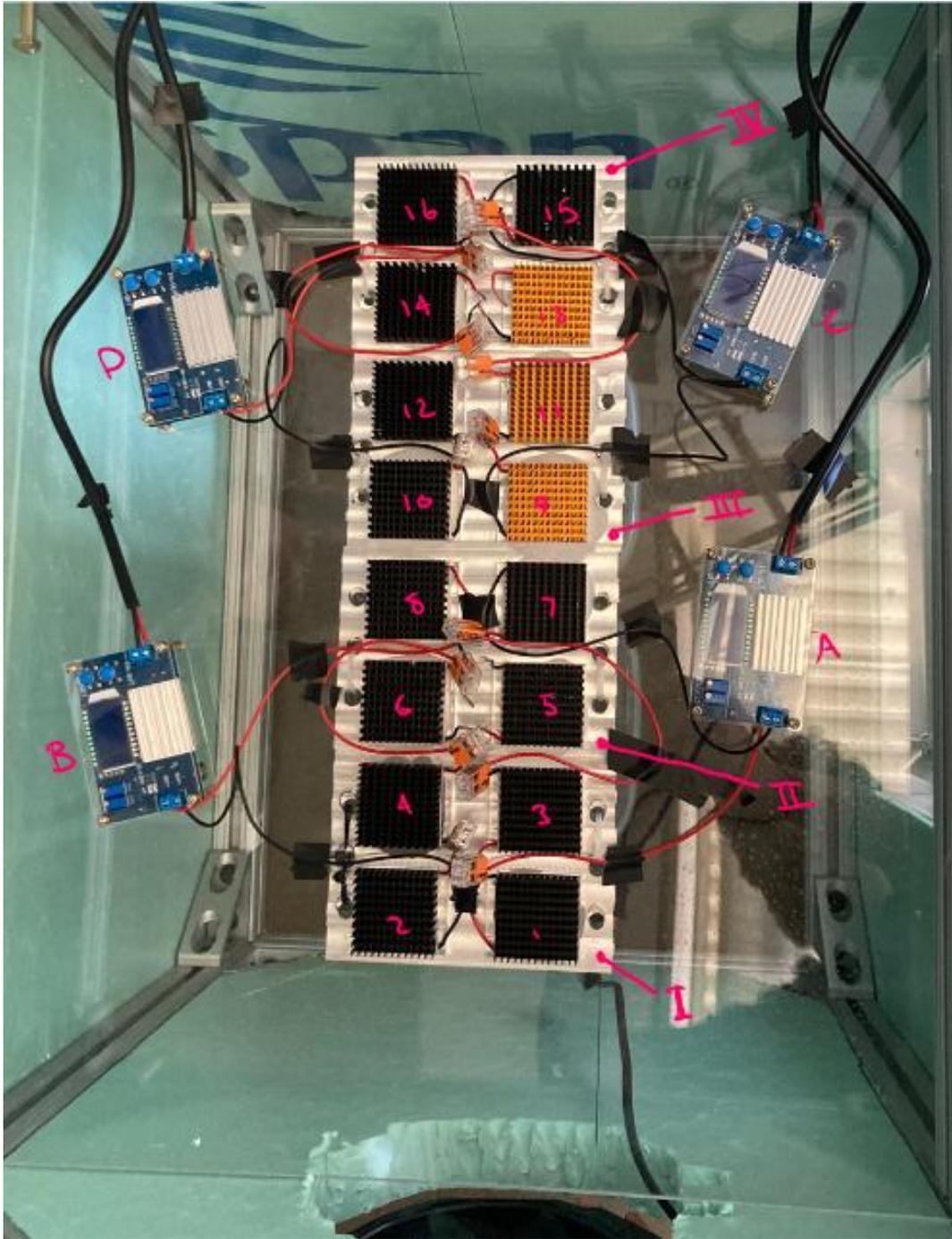
Figure A.1. Labels of electrical components to be used in recording data

Results:
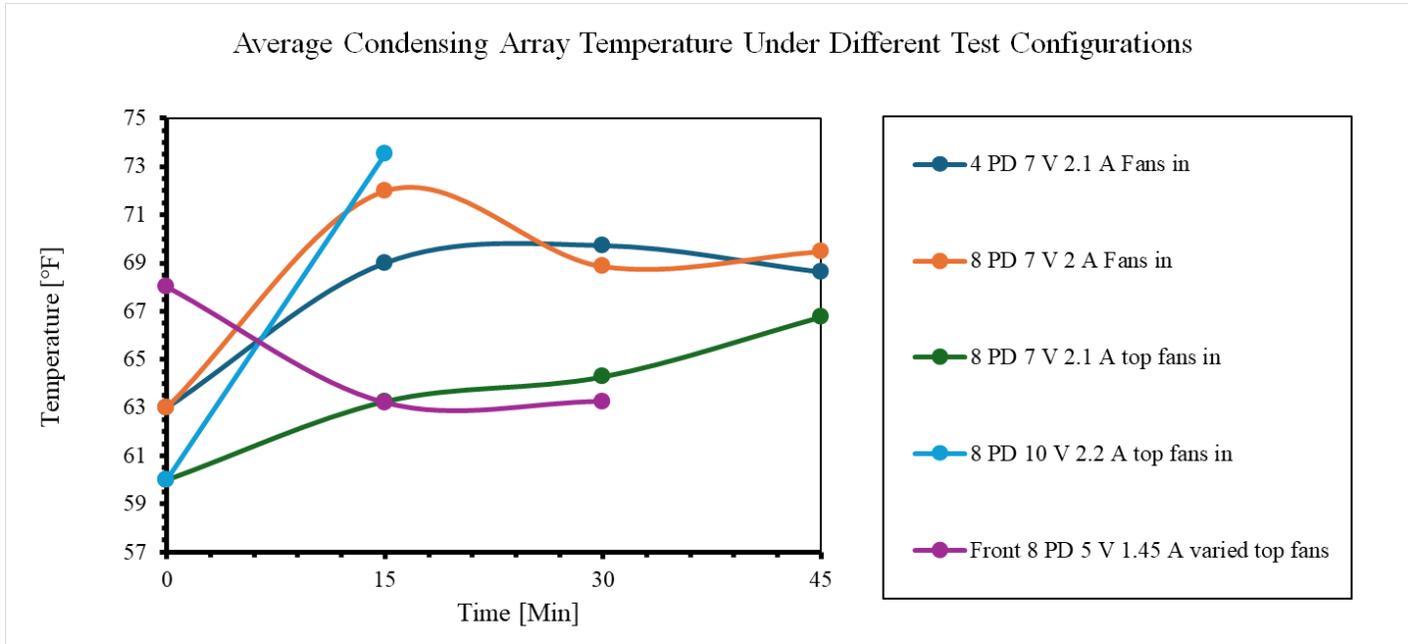
Figure A.2. Average Condensing Array temperature in different configurations

Figure A.3. Heat sink temperature in different configurations over time

We were able to collect data from our device that can help us to draw conclusions about why what we did didn't work and what sort of things that a future team could do to make improvements.

Performed By: Entire Team

A.10: DVPR

P&R - Design Verification Plan (&

Project:	UN SDG Water from Air Device		Sponsor:		Dr. Noori	

TEST PLAN

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Resp
1	Collects 1L/2hr (500mL/hr)	Run the system for an hour and measure the amount of water that is gathered	flowrate	collects within 10% of goal	stopwatch, measuring cup	VP	
2	Modular	components of design are accessible and system is easily repairable	Time	No more than hour to dissasemble /assemble entire system	stopwatch	VP	
3	Cost	Our design is within cost requirements	measure of cost	under $2500	none	VP	B
4	Efficiency	Collect 500 mL of water in 1 hour using 1000 W of power	flowrate versus power usage	within 10% of our desired efficiency goal	multimeter, stopwatch, measuring cup	VP	B
5	Reliable	We will run the system for 2 hrs on different days	check system for issues	No issues caused to system	stopwatch	VP	J
6	Mobile	system is moveable by two average people	weight	under 100 lbs	scale	VP	J

DVP&R - Design Verification Plan (

Project:	UN SDG Water from Air Device		Sponsor:		Dr. Noori	

TEST PLAN

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Resp
7	Versatile	run the system at 60% relative humidity and then 45% relative humidity for the same amount of time	relative humidity and dew point	water collection at 45% RH is within 25% of water collection for	Weather data, stopwatch, measuring cup	VP	M
8	Ease of use	Simple startup procedure	observation	No more than 2 switches and 2 power adjustment dials	none	VP	M

| 9 | Temperature of Condensing Arrays with varied Peltier Configurations | The system was operated as intended by a user, except for the number of peltier modules active | Temperature | Reaches the dewpoint for a given day | thermocouple | VP | |

DVP&R - Design Verification Plan (

| Project: | | UN SDG Water from Air Device | | Sponsor: | | Dr. Noori | | |

TEST PLAN

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Resp
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8	Ease of use	Simple startup procedure	observation	No more than 2 switches and 2 power adjustment dials	none	VP	M
9	Temperature of Condensing Arrays with varied Peltier Configurations	The system was operated as intended by a user, except for the number of peltier modules active	Temperature	Reaches the dewpoint for a given day	thermocouple	VP	

A.11: Test Data

Appendix B

Design Analysis

B.1: MATLAB of thermal resistance network

Below is the MATLAB code that was used to calculate the thermal resistance of the system and the cooling power of the Peltier module.

```matlab
% TEC1-12706 Thermoelectric Cooler Simulator
% Based on simplified thermoelectric equations

clear; clc;

% ---- Constants (approximate) ----
alpha = 0.051;          % Seebeck coefficient (V/K)
R = 2.3;                % Electrical resistance (Ohms)
K = 1.2;                % Thermal conductance (W/K)

% ---- User Inputs ----
Th_C = 50;                          % Hot-side temperature in °C
I = 2;                              % Current through TEC in A
deltaT = 0:1:80;                    % Range of ΔT values (K)
Th = Th_C + 273.15;                 % Convert to Kelvin

% ---- Preallocate Arrays ----
Qc = zeros(size(deltaT));
Tc = zeros(size(deltaT));
P_in = zeros(size(deltaT));

% ---- Calculations ----
for i = 1:length(deltaT)
    dT = deltaT(i);
    Tc(i) = Th - dT;

    Qc(i) = alpha * Tc(i) * I - 0.5 * I^2 * R - K * dT;      % Cooling power
    V = alpha * dT + I * R;                                  % Voltage across TEC
    P_in(i) = I * V;                                         % Electrical power input
end

% ---- Find values near 14 W ----
target_power = 14;          % Target power in W
tolerance = 0.1;            % Acceptable error range in W

idx = abs(P_in - target_power) < tolerance;

if any(idx)
    fprintf('Results near %.1f W input power (±%.1f W):\n', target_power, tolerance);
    fprintf('ΔT (K)\tT_c (°C)\tQ_c (W)\tP_in (W)\n');
    for i = find(idx)
        fprintf('%6.1f\t%7.2f\t%7.2f\t%7.2f\n', ...
            deltaT(i), Tc(i)-273.15, Qc(i), P_in(i));
    end
else
    fprintf('No values found near %.1f W input power within ±%.1f W tolerance.\n', ...
        target_power, tolerance);
end
```
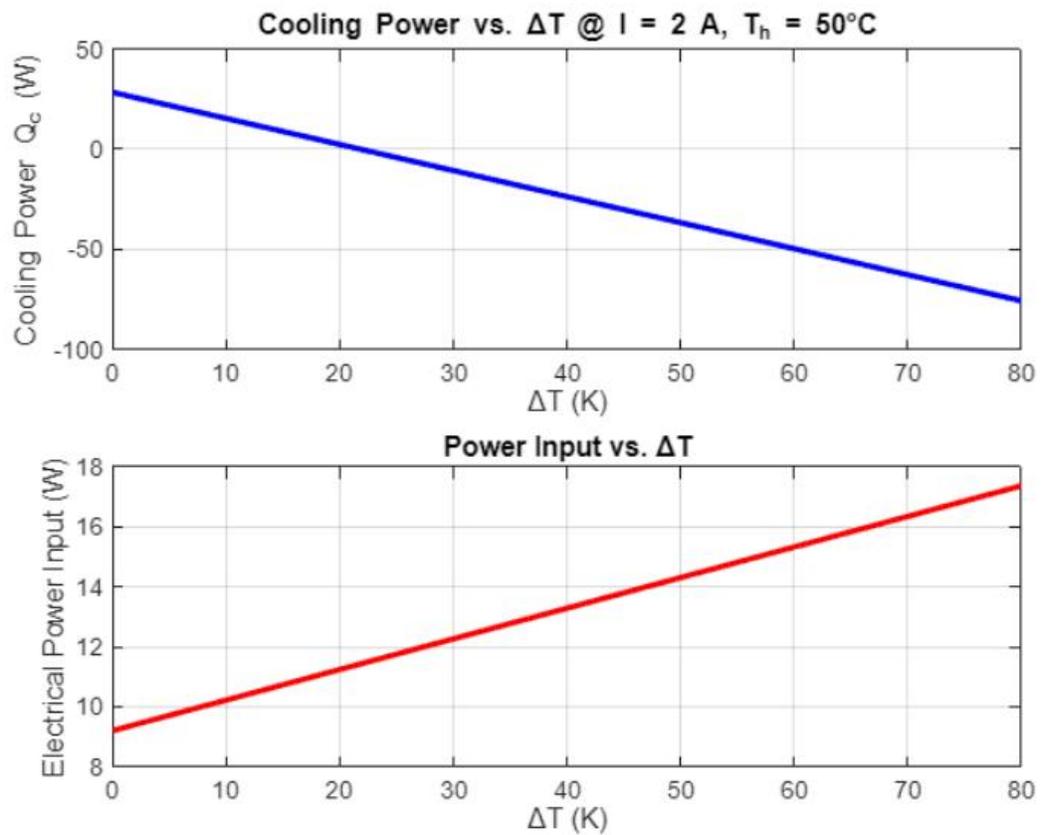
```
Results near 14.0 W input power (±0.1 W):
ΔT (K)  T_c (°C)      Q_c (W) P_in (W)
  47.0     3.00   -32.83   13.99
  48.0     2.00   -34.13   14.10
```

```matlab
% ---- Plot Results ----
```

```
figure;

subplot(2,1,1);
plot(deltaT, Qc, 'b', 'LineWidth', 2);
xlabel('ΔT (K)');
ylabel('Cooling Power Q_c (W)');
title(['Cooling Power vs. ΔT @ I = ', num2str(I), ' A, T_h = ', num2str(Th_C), '°C']);
grid on;

subplot(2,1,2);
plot(deltaT, P_in, 'r', 'LineWidth', 2);
xlabel('ΔT (K)');
ylabel('Electrical Power Input (W)');
title('Power Input vs. ΔT');
grid on;
```

```
% Corrected Thermal Model of Aluminum Fin Condensing Array (Qc as input)

clc;
clear;

% --- User Input ---
Qc = 10;                 % W, user-defined heat transfer rate
T2 = 284;                % K, cold side of Peltier
T_inf = 298;             % K, ambient temperature

% --- Material Properties ---
k_al = 205;              % W/m.K, aluminum
k_ta = 1.5;              % W/m.K, thermal adhesive
h = 10;                  % W/m^2.K, natural convection

% --- Geometry: Base and Adhesive ---
A_base = 0.04 * 0.04;  % m^2, contact area
L1 = 0.001;              % m, thermal adhesive thickness
L2 = 0.0125;             % m, aluminum base thickness

% --- Fin Geometry ---
N = 14;                  % Number of fins
L_fin = 0.028;           % m, fin height
t_fin = 0.001;           % m, fin thickness
w_fin = 0.04;            % m, fin width into page

P = 2 * (t_fin + w_fin);           % m, perimeter of fin cross-section
A_c = t_fin * w_fin;               % m^2, cross-sectional area
A_fin_single = 2 * L_fin * w_fin + t_fin * w_fin;
A_fin_total = N * A_fin_single;

% --- Fin Efficiency ---
m = sqrt(h * P / (k_al * A_c));
eta_f = tanh(m * L_fin) / (m * L_fin);

% --- Thermal Resistances ---
R1 = L1 / (k_ta * A_base);                 % Adhesive
R2 = L2 / (k_al * A_base);                 % Aluminum base
R_fin = 1 / (eta_f * h * A_fin_total);     % Lumped fin resistance

% --- Temperatures ---
T0 = T2 - Qc*(R1 + R2 + R_fin);
T1 = T0 + Qc * R1;

% --- Output ---
fprintf('--- Finalized Thermal Resistance Network Results ---\n');
```

```
--- Finalized Thermal Resistance Network Results ---
```

```
fprintf('Qc (user-defined)        = %.2f W\n', Qc);
```

```
Qc (user-defined)        = 10.00 W
```

```
fprintf('T0 (Peltier surface)     = %.2f K\n', T0);
```

```
T0 (Peltier surface)     = 247.31 K
```

```
fprintf('T1 (after adhesive)        = %.2f K\n', T1);
```

```
T1 (after adhesive)       = 251.48 K
```

```
fprintf('T2 (fin tip temp)          = %.2f K\n', T2);
```

```
T2 (fin tip temp)         = 284.00 K
```

```
fprintf('T_inf (ambient)            = %.2f K\n', T_inf);
```

```
T_inf (ambient)           = 298.00 K
```

```
fprintf('Fin efficiency η_f         = %.3f\n', eta_f);
```

```
Fin efficiency η_f        = 0.975
```

```
fprintf('R1 (adhesive)              = %.4f K/W\n', R1);
```

```
R1 (adhesive)             = 0.4167 K/W
```

```
fprintf('R2 (aluminum base)         = %.4f K/W\n', R2);
```

```
R2 (aluminum base)        = 0.0381 K/W
```

```
fprintf('R_fin (fin + conv)         = %.4f K/W\n', R_fin);
```

```
R_fin (fin + conv)        = 3.2143 K/W
```

```
fprintf('Total resistance           = %.4f K/W\n', R1 + R2 + R_fin);
```

```
Total resistance          = 3.6691 K/W
```

B.2: Psychometric Analysis of required heat removal to condensate 1 L of water

The EES code below was written to analyze the rate of water collection that could be achieved using the maximum power of our system in ideal conditions for the month of May in San Luis Obispo. As can be seen below, 1.152 kW of heat removed resulted in a rate of 1.325 kg of water per hour. 1 kg of water is equal to 1 L of water, so in an ideal system we could remove 1.15 kW of heat to produce 1.3 L/hr of water. This result allowed us to justify our goal of collecting 700 mL of water per hour, which considers losses that will occur in the actual system and the fact that we will likely be operating at a power lower than our system maximum.

Solution

Main

$AV_1 = 0.05117$ [m³/s] {3.07 [m³/min]}

$\delta_t = 30$ [C]

$\eta_{th} = 0.64$

$h_{a1} = 297.6$ [KJ/Kg]

$h_{a2} = 278.5$ [KJ/Kg]

$h_{v1} = 54.43$ [Kj/Kg]

$h_{v2} = 19.45$ [KJ/Kg]

$\dot{m}_{air} = 0.0597$ [kg/s] {3.582 [kg/min]}

$\dot{m}_v = 0.0003682$ [Kg/s] {1.325 [Kg/hr]}

$\omega = 0.006167$ [-]

$\omega_1 = 0.01191$ [-]

$\omega_2 = 0.005748$ [-]

$\phi_1 = 0.6$ [-]

$Power_{one,module} = 46.08$ [W]

$Power_{peltier,total} = 737.3$ [W] {0.7373 [Kw]}

$P_1 = 101.3$ [Kpa]

$P_{a1} = 99.51$ [Kpa]

$P_{g1} = 2.985$ [Kpa]

$P_{g2} = 0.872$ [Kpa]

$P_{v1} = 1.791$ [Kpa]

$P_{v2} = 0.872$ [Kpa]

$Q_{cv} = -1.152$ [Kw]

$T_\infty = 24$ [C]

$T_{out} = 5$ [C]

$v_{air,1} = 0.8572$ [m³/kg]

No unit problems were detected.

Compilation time = 141 ms   Calculation time = 187 ms

"may conditions"

T_infinity = 24 [C]   "ambient air conditions"
phi_1 = .60   "relative humidity"
T_out = 5 [C]   "assuming the air coming off of condesing array is at a temperature equal to that of the fins, which should be the dew point temp"
P_1 = 101.3 [Kpa]   "atmospheric pressure"
P_g1 = 2.985 [Kpa]   "saturaton pressure at t_infinity"
P_g2 = 0.872 [Kpa]   "saturation pressure at T-out"

"Guess the volumetric flow rate of air in"

{AV_1 = 0.0849 [m^3/s]}
Q_cv = -1.152 [Kw]

"From table A-2, or property look ups using EES"

h_a2 = enthalpy(Air,T=T_out)
h_a1 = enthalpy(Air,T=T_infinity)
h_v2 = enthalpy(AirH2O,T=T_out, w=omega_2 ,P=P_1)
h_v1 = enthalpy(AirH2O,T=T_infinity, w=omega_1 , P=P_1)

"1st law for the air blowing over condesing array"

Q_cv = m_dot_air*(h_a2-h_a1) + m_dot_v*(h_v2-h_v1)

m_dot_v = omega*m_dot_air

omega = omega_1 - omega_2

omega_1 = 0.662*(P_v1/(P_1 - P_v1))
omega_2 = 0.662*(P_v2/(P_1 - P_v2))

P_v1 = phi_1 * P_g1
P_v2 = P_g2

m_dot_air = AV_1/v_air_1

v_air_1 = volume(Air,T= T_infinity,P= P_a1)

P_a1 = P_1 - P_v1

"peltier Module- TECI- 12706"

Delta_t = 30 [C] "this is a conservative assumption, doubt delta t will be much larger than this"
Power_one_module = (6.4*14.4/2) [W]
Power_peltier_total = 16*Power_one_module

eta_th = Power_peltier_total*.001 [Kw/W] /abs(Q_cv)

B.3: MATLAB of Heat Transfer Analysis for hot side heat removal

```matlab
% Corrected Hot-Side Convection Analysis - Fan Flow Rate Sweep
% Baxter Mercy - Final Report Refinement

%% Constants
cp_air = 1005;           % J/kg·K
rho_air = 1.2;           % kg/m³
mu_air = 1.9e-5;         % Pa·s (dynamic viscosity)
k_air = 0.0262;          % W/m·K (thermal conductivity of air at ~25°C)
Pr = 0.71;               % Prandtl number for air (assumed constant)
cfm_values = [64, 32, 21.5];  % CFM per sink (1, 2, or 3 Peltiers per fan)
cfm_to_m3s = 0.00047194745;
T_base = 70;             % °C
T_inf = 25;              % °C
deltaT = T_base - T_inf;

% Fin Geometry
N_fins = 88;
t_fin = 1e-3;            % [m]
L_fin = 0.028;           % [m] updated from spec sheet
W_base = 0.140;          % [m] updated base width of heatsink
k_al = 205;              % [W/m·K]

% Heat transfer surface area
A_fins = N_fins * 2 * L_fin * t_fin;
A_base = W_base^2;

% Cross-sectional area (assuming flow through ~heatsink face)
A_flow = W_base * 0.028;  % [m²] frontal face area of heat sink

fprintf('\n--- Corrected Hot-Side Convection Table ---\n');
```

--- Corrected Hot-Side Convection Table ---

```matlab
for i = 1:length(cfm_values)
    cfm = cfm_values(i);
    m3s = cfm * cfm_to_m3s;
    velocity = m3s / A_flow;
    Re = rho_air * velocity * L_fin / mu_air;

    if Re > 4000
        Nu = 0.023 * Re^0.8 * Pr^0.3;  % Dittus-Boelter for turbulent
    else
        Nu = 0.664 * Re^0.5 * Pr^0.33;  % Laminar flat plate approx
    end

    h = Nu * k_air / L_fin;

    % Fin efficiency
    m = sqrt(2 * h / (k_al * t_fin));
```

```
    eta_f = tanh(m * L_fin) / (m * L_fin);

    Q_fins = eta_f * h * A_fins * deltaT;
    Q_base = h * A_base * deltaT;
    Q_total = Q_fins + Q_base;

    fprintf('CFM: %.1f | Air Vel: %.2f m/s | Re: %.0f | h: %.1f W/m²K | ηf: %.3f | Q: %.1f W\n', ...
        cfm, velocity, Re, h, eta_f, Q_total);
end
```

```
CFM: 64.0 | Air Vel: 7.71 m/s | Re: 13626 | h: 39.4 W/m²K | ηf: 0.910 | Q: 42.7 W
CFM: 32.0 | Air Vel: 3.85 m/s | Re: 6813 | h: 22.6 W/m²K | ηf: 0.946 | Q: 24.7 W
CFM: 21.5 | Air Vel: 2.59 m/s | Re: 4578 | h: 16.5 W/m²K | ηf: 0.960 | Q: 18.0 W
```

B.4: MATLAB of condensing array thermal mass

```matlab
%% Constants
cp_aluminum = 900;          % [J/kg·K]
rho_aluminum = 2700;        % [kg/m^3]
cp_air = 1005;              % [J/kg·K]
rho_air = 1.2;              % [kg/m^3]
mu_air = 1.9e-5;            % [Pa·s]
k_air = 0.026;              % [W/m·K]
h_fg = 2.45e6;              % [J/kg]
cfm_to_m3s = 0.00047194745;

%% Cold-Side Block and Air Load
width_block = 0.140;
height_block = 0.0405;
length_block = 0.075;
volume_block = width_block * height_block * length_block;
mass_block = rho_aluminum * volume_block;
mass_per_peltier = mass_block / 4;
deltaT_cold = 20;
Q_block = mass_per_peltier * cp_aluminum * deltaT_cold;
volume_air = 0.002;
mass_air = volume_air * rho_air;
deltaT_air = 10;
Q_air_sensible = mass_air * cp_air * deltaT_air;
mass_water = mass_air * 0.006;
Q_air_latent = mass_water * h_fg;
Q_air_total = Q_air_sensible + Q_air_latent;
Q_total_cold = Q_block + Q_air_total;
Q_dot_cooling = 11;
time_to_cool = Q_total_cold / Q_dot_cooling;
%% Print Cold-Side Results
fprintf('\n--- COLD SIDE ---\n');
```

```
--- COLD SIDE ---
```

```matlab
fprintf('Q_block: %.1f J\n', Q_block);
```

```
Q_block: 5166.8 J
```

```matlab
fprintf('Q_air_sensible: %.1f J, Q_air_latent: %.1f J\n', Q_air_sensible,
Q_air_latent);
```

```
Q_air_sensible: 24.1 J, Q_air_latent: 35.3 J
```

```matlab
fprintf('Total Q_cold: %.1f J\n', Q_total_cold);
```

```
Total Q_cold: 5226.2 J
```

```matlab
fprintf('Time to cool with 11 W: %.1f s (%.2f min)\n', time_to_cool,
time_to_cool/60);
```

```
Time to cool with 11 W: 475.1 s (7.92 min)
```

Appendix C

References

Listed below is a collection of the articles, papers, reports, regulations, patents and consumer products that our group has learned from while in the process of researching for this project. The website, title and author(s) are listed for each reference where applicable.

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Appendix D

Design Hazard Checklist

We have designed this system to minimize opportunity for harm wherever possible so that our system could ideally be operated by anyone in the world who needs it. We anticipate the main hazards in our system will involve the air intake fan, the electrical system design, and the heated elements used to process water out of air. Fans rotating at high speeds are a hazard while in operation, so we designed to have a mechanical filter at the inlet of our system which will block access to the fan while in place. To ensure that our electrical system is grounded and properly wired, we consulted with the electrical engineering faculty for advice and kept wiring properly organize and labeled in the manual so it can be understood by anyone. When our device is in operation, one side of the TEM and the corresponding heat sink heats up significantly, creating a potential burning hazard. To address this hazard, we used an insulating material for the housing of our system and part of this housing is designed to block direct access to the hot side of the system. In addition to each direct approach we have to these hazards, we also include appropriate hazard labels wherever possible in the user manual to ensure users are properly informed of any risks during operation.

Appendix E:

Project Budget

This Appendix includes an excel spreadsheet containing all of the products that we ordered and their corresponding costs. In the top left corner of the spreadsheet there are values for the amount that was spent and the amount that is remaining in our budget.

Appendix F:

User Manual

The user manual below documents initial startup and operation procedures for the system, as well as hazards to be aware of (Table F.1) and maintenance procedures for both the electrical and mechanical components. Additionally, it describes all the electrical components within the system, including links to their product websites and important notes for users (Table F.2). Finally, it contains specifications for the electrical components to be referenced when questions arise.

User Manual for Safe Operation of UNSDG Senior Project Device

HAZARDS

Table 1. Description and prevention instructions for possible hazards in system operation

TYPE	DESCRIPTION	PREVENTION	IMAGE
Rotating Machinery	There are multiple fans within the design that use high speed rotating blades.	Cooling fans and intake fan should be handled with care when in use. Fans and blades are exposed and pose a significant hazard.	
Electrical Shock	If electrical connections are not properly connected, there is a chance for electrical shock to occur to the user.	All connections should be verified before the system is activated. Personnel must not touch exposed wires while the system is plugged in.	

ELECTRICAL COMPONENTS

INITIAL SETUP:

To be performed each time system is operated, before system is turned on.

1. Lift top panel. Have someone hold panel up, as it cannot be fully removed due to wiring. Ensure fan wiring is not pulled loose when panel is moved.
2. Check electrical connections are made (see Figures 1 and 2), no wires are loose or disconnected.
3. Check electrical components for damage (cut or damaged wiring, signs of water damage, fuses blown, etc.)
4. Check that no wires are touching heatsinks or in the way of top fans when top panel is placed down. If wires are in the way, use electrical tape or duct tape to secure them to the mounting panel (Peltier circuits) or the top panel (fan circuits).

5.   Check intake and cooling fans for direction of air flow. For intake fan, the side that pushes air out has a guard. For the cooling fans, there is an indication on the side of the fan for which direction the air flows.
    a. To reverse direction of air flow for the intake fan, refer to fan replacement/rotation procedure below in mechanical components section.
    b. To reverse direction of air flow for the cooling fans, refer to fan replacement/rotation procedure below in mechanical components section.

OPERATION:

1. Plug outlet strip into wall, ensure switch is in the OFF position.
2. Plug Peltier circuits into outlet strip (up to 4).
3. Switch outlet strip ON.
4. Monitor display on voltage regulators, ensure output voltage is set to desired value. Voltage input-to-output difference must be 0.8V for DROK brand regulators.
5. If voltage output needs to be changed, use small screwdriver to twist the potentiometer screw. More specific info can be found by following item link in Table 2 or under the Electrical Component Specifications section, Figures 13 and 14.
    a. Note that the AC-to-DC modules provide a maximum input voltage of 24 V, so the DROK voltage regulators can operate at a maximum output voltage of 23.2 V.
6. Check to make sure Peltier devices are getting warm on the heat sink side (top) and cool on the condensing array side (cold). If reversed, wiring must be switched to fix this (information below in maintenance section).
7. Switch outlet strip OFF.
8. Plug four cooling fans and one intake fan in.
9. Replace door and top panel on frame. Ensure wires connecting to top panel fans have been pulled through so wires are not touching system or fans.
10. Switch outlet strip ON.
11. Monitor system as it operates. Follow water collection procedure in the mechanical components section below to collect water from the system.
12. When desired operation time is reached, switch outlet strip OFF. Remove water collection container from inside system.
13. Unplug all cords from outlet strip. Ensure that barrel connectors are disconnected and the AC-to-DC power cords are stored neatly. Ensure all remaining wiring still connected to the system is secured with a twist tie and stored on top of system so they are not stepped on and damaged while system is sitting idle.

MAINTENANCE:

- If a Peltier device is operating in reverse (i.e. heat sink side is cold, condensing array side is warm), user must first disconnect the wire leads from the circuit by lifting the corresponding WAGO lever up and pulling the wire out. To reverse the polarity of the device, which will switch the hot and cold sides, the user can swap which wire lead serves as the "in" terminal. Essentially, switching the leads will run the current through the device in the opposite direction, which will reverse the heating/cooling effect. Once switched, the wires can be inserted back into the appropriate WAGO terminals and the levers can be snapped back down into place. The device should not be operated with any Peltier devices disconnected from the system unless it is for testing purposes.

- If a Peltier circuit is not working or the voltage regulator readings seem off, the system should be powered off immediately and checked for external damage. If no external damage is found, the issue must be related to the Peltier devices or to some part of the voltage regulator circuit to the wall. To determine the issue, first disconnect the voltage regulator from the Peltier device circuit by using a small screwdriver to loosen the output wire pins until the Peltier wires can be removed. Connect this voltage regulator into another Peltier circuit to test for issues. If issues are detected, disconnect the voltage regulator from the input wires and test it again with a working input circuit to test for issues. Repeat this procedure with the barrel connector and AC-to-DC module to rule out issues with any of these individual components. If an issue is detected with any of these components, the component must be replaced. Note, the AC-to-DC module fuse should be checked before the entire component is replaced. See last bullet point in this section for further information.

  If no issues are detected from the input side of the circuit, the problem must lie within the Peltier devices. First, connect the Peltier devices to a working voltage regulator, barrel connector, and AC-to-DC module and test to make sure that the problem persists. Then remove one Peltier device from the circuit, so that only three are wired in series, and test again. If no issues are detected, the Peltier device that was pulled out of the system was the issue. If issues are detected, continue to remove Peltier devices until you narrow down which is broken. This device will have to be removed from the system and replaced; further details can be found in the Peltier replacement procedure of the mechanical components section. Note that, while rare, it is possible that multiple Peltier devices were damaged at once, so be sure to test the remaining three devices in series to ensure there are no persisting issues. If the issue does persist, repeat this process to further narrow down the problem.

- If any wires appear cut, damaged, twisted, or overly bent, they should be replaced. If damage has been done to any component, the entire component should be disconnected from the system and replaced. If damage has been done to a Peltier device wire lead, the entire Peltier device must be removed from the system and replaced. More information on this process can be found in the Peltier replacement procedure of the mechanical components section.

- If voltage regulators feel or appear overly hot at any point during system operation, the system should be powered off immediately and the devices should be given time to cool before being touched. Once cooled, the voltage regulators should be inspected for damage and then powered on to test if they have been damaged internally and now work incorrectly. If they do not seem to have been damaged (i.e. the input voltage is around 24V and the circuit board components all appear undamaged), they can continue to be used in the device but should be checked regularly to ensure they are still operating reliably. If they have been damaged, the component should be removed from its circuit and replaced. The user can remove a voltage regulator by using a small screwdriver to loosen the screws on the input and output wire terminals. Once loosened, the wires should slide out and the voltage regulator can be removed. Four additional voltage regulators (Valefod brand) have been provided with the system for easier replacement if damage were to occur. Note that our team did not experience any voltage regulators overheating during our testing windows, but the longest the system was run at one time was three hours, so for any prolonged operation longer than three hours the user should routinely check the voltage regulator temperatures to ensure they have not overheated.

- If the intake fan is not powering on, check to ensure the quick-disconnect prongs are secured completely in the terminal. If they are, check the wire for external damage, as it may need to be replaced.

- If the cooling fans are not powering on, check the power cord wire for external damage to determine whether it should be replaced. If it appears undamaged, check the fuse using the procedure described in the bullet point below. If the fuse is also undamaged, it can be assumed that there is an issue with the fan itself, and it should be removed from the system and replaced. To do this, refer to the fan removal procedure of the mechanical components section.

- If any fan circuits or Peltier circuits are not working and all the above options have failed to fix the issue, check to see if the fuse has blown. To do this, first disconnect the fuse from the circuit by pulling the appropriate WAGO connector lever up and pulling out the fuse holder wires. Then pull the cap of the fuse holder up and locate the colored fuse (3A fuse is bright pink, 7.5A is brown, refer to Figure 18). The fuses also have number labels on them. Pull the fuse out of the fuse holder and examine the fuse inside. If it appears to be damaged or burnt, it must be replaced. An example of a damaged fuse can be found in Figure 20. To replace the fuse, simply find another fuse of the same rating (match number and color) and press it into the slots of the fuse holder firmly until it is fully seated inside. Then, replace the black cap on the fuse holder and reconnect the wires to implement the fuse back into the circuit. Do not operate the device at all while any fuses are missing/being replaced.

CIRCUIT DIAGRAMS:

Before any operation, ensure the wiring is connected as shown below and connections are secure. Peltier devices should be wired in series in sets of four per voltage regulator and AC-to-DC converter. Fuses are connected in series with the live wire.
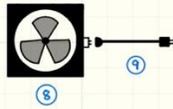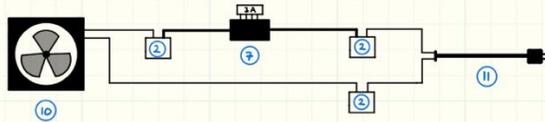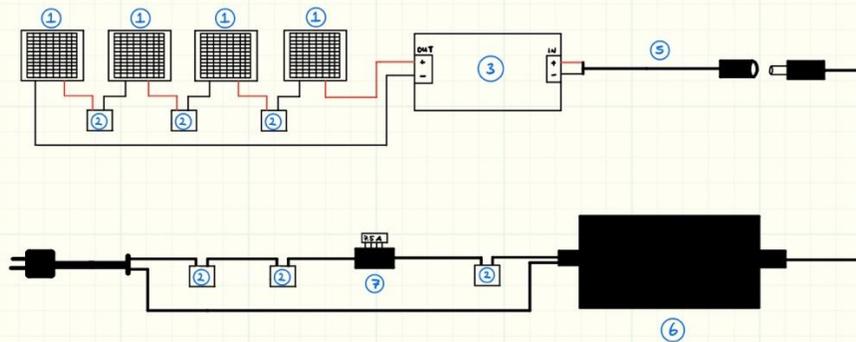
Figure F.1. Circuit diagrams for intake fan, top fans, and Peltier circuits. Component labels correspond to numbers in Table 2.
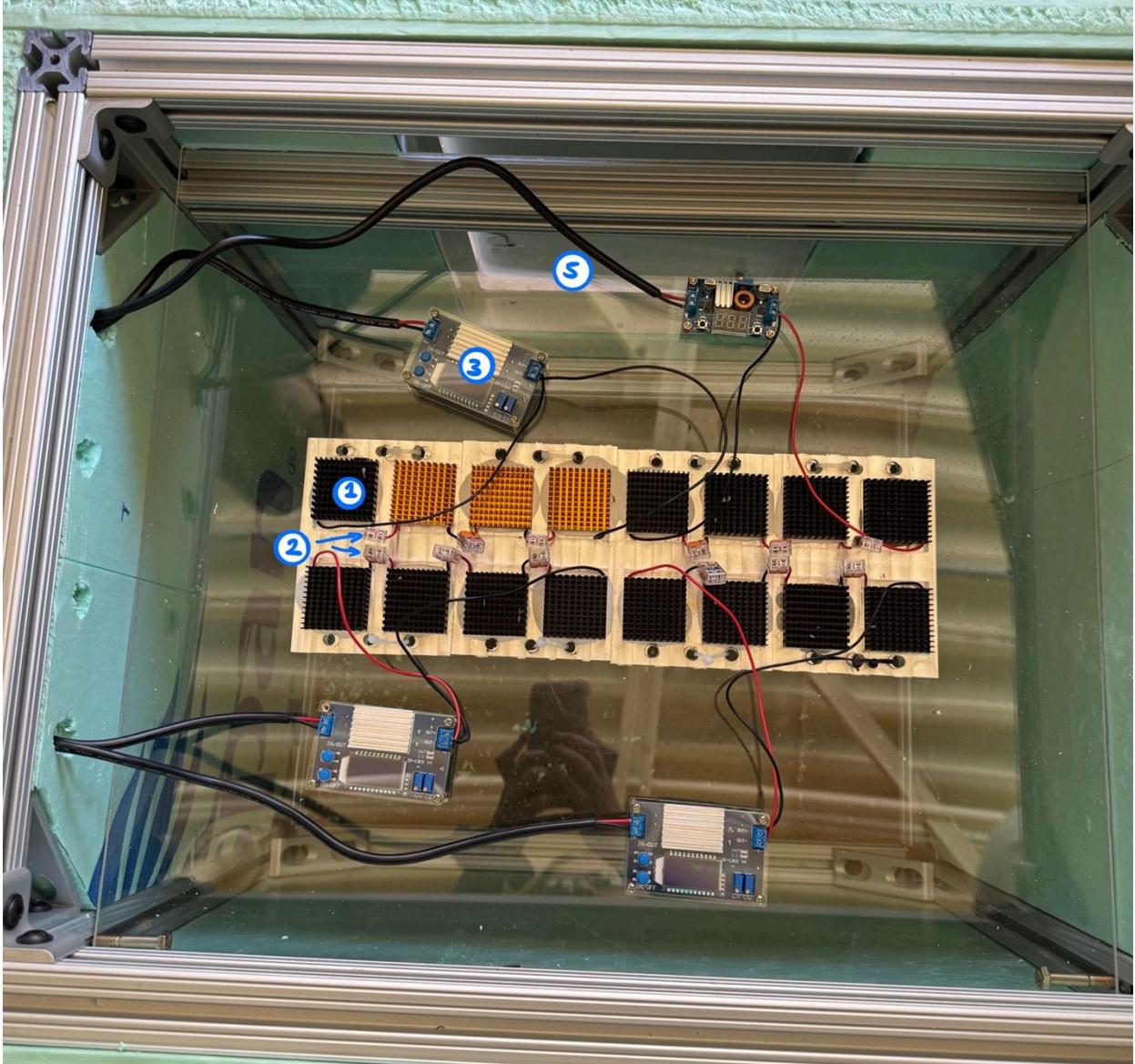
Figure F.2. Picture of mounting panel and Peltier circuits, components labelled to correspond with numbers in Table 2.

COMPONENTS:

Component numbers correspond with the circuit diagrams above. All important notes should be read before operating system. Relevant component information in the electrical component specifications section should also be reviewed.

Table F.2. List of electrical components with links, quantities, and important notes

| Component Number:	Component Name:	Quantity in System:	Link:	Important Notes:
1	Peltier devices with heat sinks	16	Link	Peltier devices are glued onto mounting panel with thermal adhesive (link). Peltier devices with gold heat sinks are wired backwards from the ones with black heat sinks. Specifications listed in Figure 10.
2	221-412 WAGO connectors	32 total; 20 for Peltier circuits (5 each), 12 for fan circuits (3 each)	Link	Wires must be 12-24 AWG solid or stranded, and stripped 11 mm before use. User information listed in Figures 11 and 12.
3	DROK DC voltage regulators	4	Link	Requires 0.8V difference between input and output. User must monitor temperature when the operation period is long; if these components get too hot, the system must be powered off. User information and specifications in Figures 13 and 14.
4	Valefod DC voltage regulators	4 (not in system)	Link	Backup devices, not currently used in system. Requires 1.5V difference between input and output. User must monitor temperature when the operation period is long; if these components get too hot, the system must be powered off. User information and specifications in Figures 15 and 1.
5	Barrel connectors with wire leads	4	Link	N/A
6	AC to DC converters	4	Link	Output is 24V, 6A. Fuses were added for extra safety. Specifications listed in Figure 17.

Component Number:	Component Name:	Quantity in System:	Link:	Important Notes:
7	Fuses and fuse holders	8 total; 4 in Peltier circuits (1 each), 4 in fan circuits (1 each)	Link	Fans are fused with the 3A fuse. Peltier circuits are fused with the 7.5A fuse. Specifications listed in Figures 18 and 19. Comparison of damaged vs. undamaged fuse in Figure 20.
8	Intake fan	1	Link	Rated for 120 VAC and 0.21 A; 190 cfm.
9	Quick disconnect power cord	1	Link	N/A
10	Top fans	4	Link	Rated for 120 VAC and 0.18 A; 64 cfm.
11	Power cords with wire leads	4	Link	N/A
12	Outlet strip with 10 outlets	1	Link	Rated for 15A. The sum of the currents of all circuits plugged into this strip MUST be under 15A. Considering the fan currents, this means the Peltier circuits should be run at no more than 3A each (3.5A absolute max).
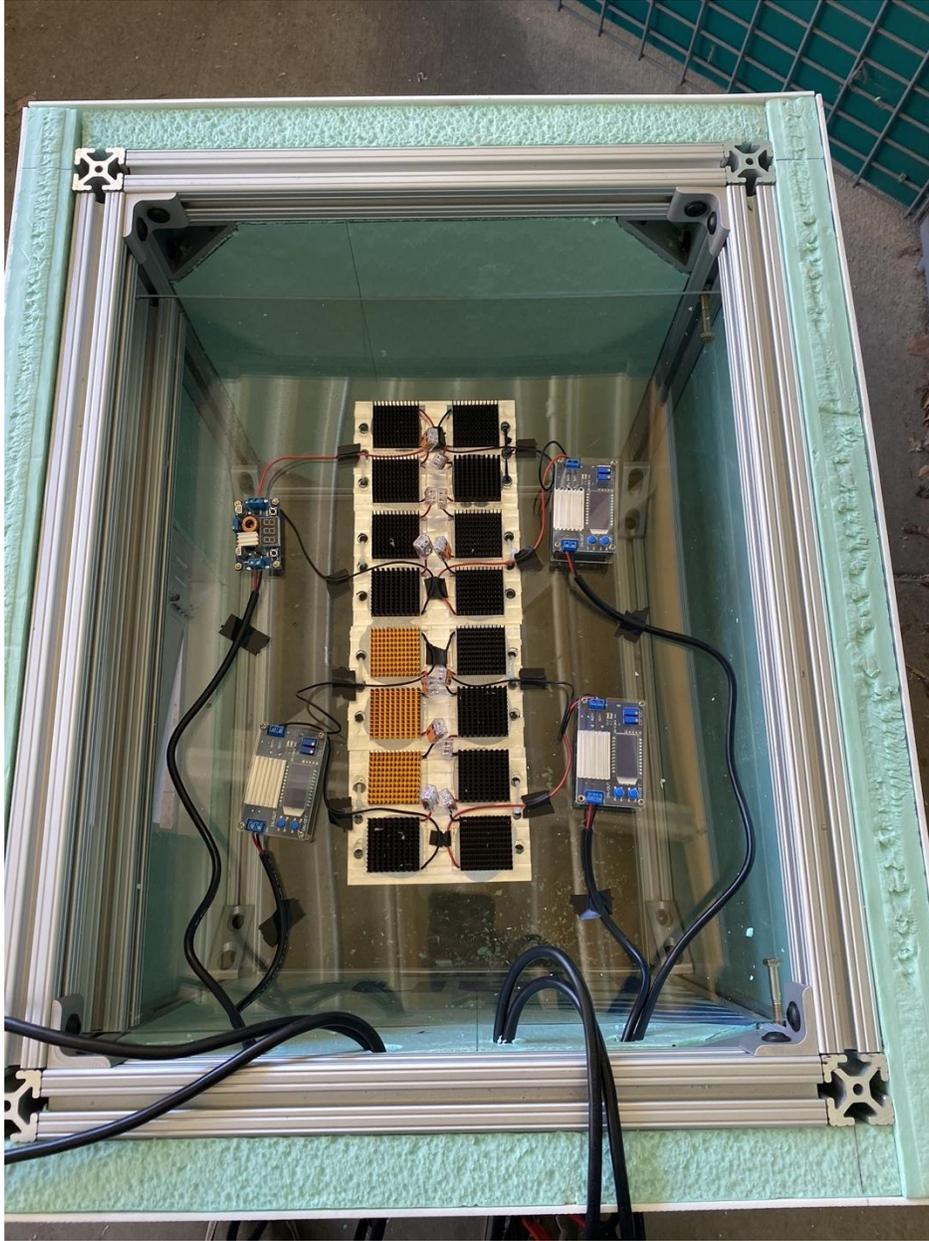
Figure F.3. Top of mounting panel, pictured are the 16 Peltier devices in sets of 4 attached to a voltage regulator

Figure F.4. AC-to-DC converter with a fuse connected in series, adapter then connects to a voltage regulator set
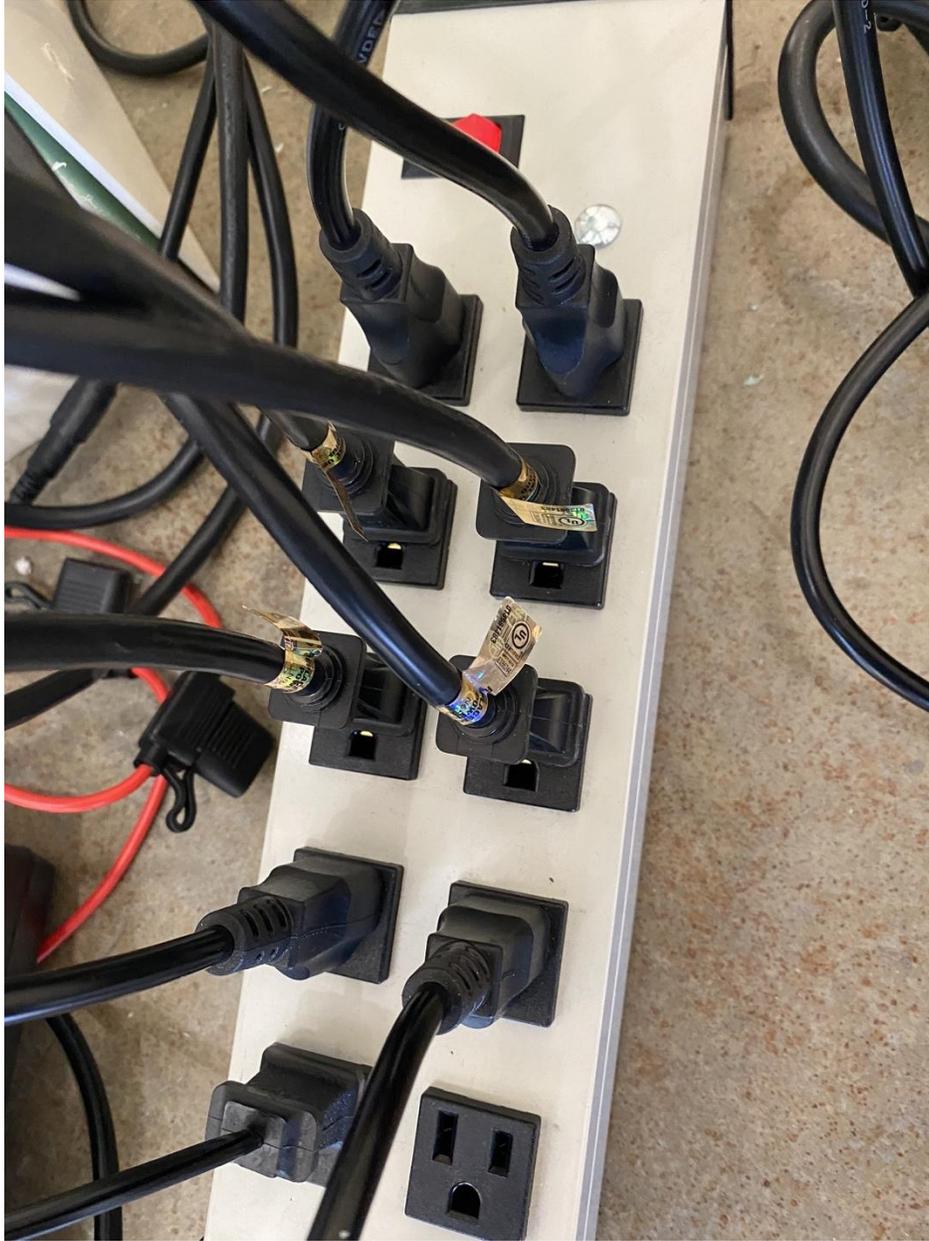
Figure F.5. Power cords from the 5 fans and 4 regulators/AC-DC converters plugged into a power strip that goes onto the wall outlet

FRAME AND MECHANICAL COMPONENTS

PANEL REMOVAL PROCEDURE:

Equipment

- Half-inch socket wrench

Steps

1. Using the socket wrench, loosen the four bolts holding the panel in place

Figure F.6. Bolt with half inch head

    a. NOTE: Only loosen until the bolt can be turned with hand, so it is loose enough panel can slide off but it the nut does not come off

    b. NOTE: If a nut comes of bolt holding a panel, continue with removal of panel, then see steps for re-attaching panel

PANEL SECURING PROCEDURE:

Equipment

- Half inch socket wrench

Steps

1. Check to see that the panel has 4 bolts through it and that every bolt has a nut on it
2. Push the bolts + nut configuration so the bottom of the bolt head is flush with the outside of the panel
3. Pick up the panel and slide it down into place
    a. Orient the nuts so they can slide into the grooves on the aluminum framing
4. Using ½ inch socket wrench to tighten the four bolts holding the panel in place
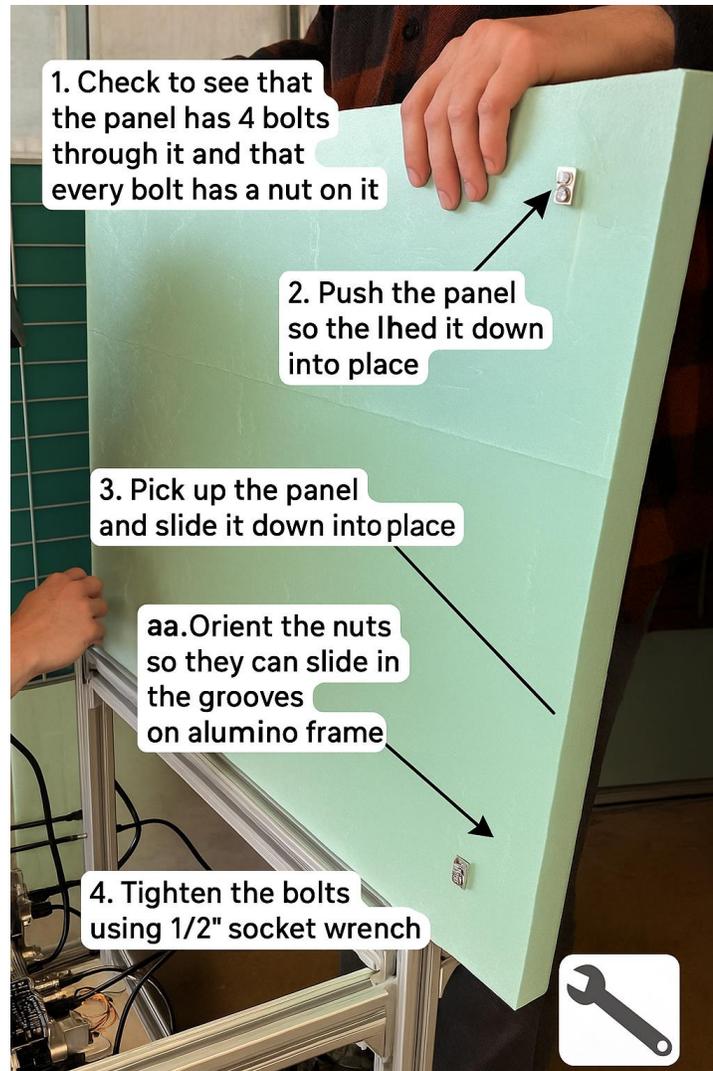
Figure F.7. Panel Replacement
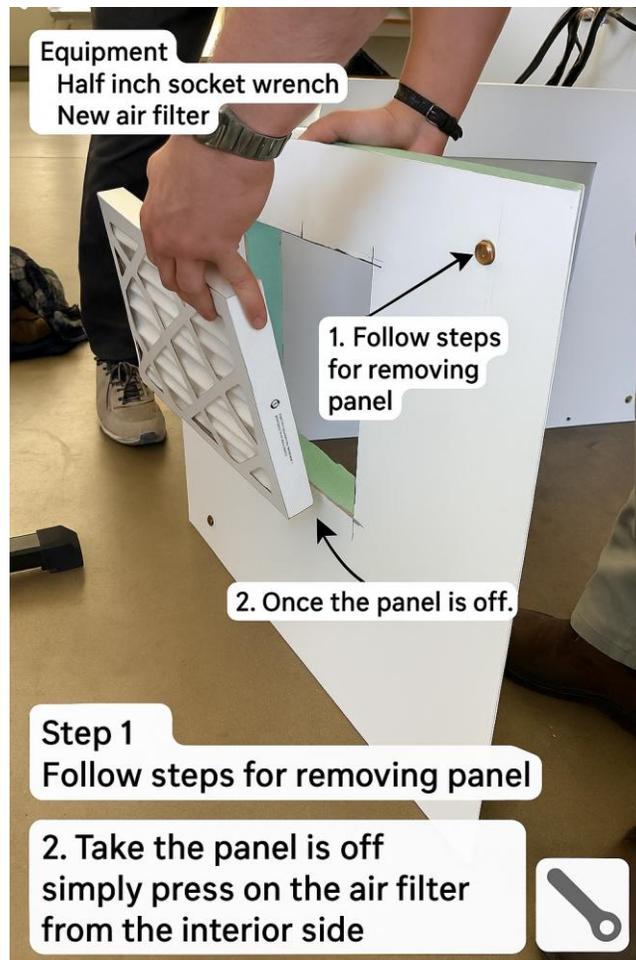
AIR FILTER REPLACEMENT PROCEDURE:

Equipment

- Half inch socket wrench
- New Air Filter

Figure F.8. Air Filter

Steps

1. Follow Steps for removing panel
2. Once the panel is off simply press on the air filter from the interior side of the panel until it slides out
3. Take the new air filter and press it into the slot in the opposite manner it came out

Figure F.9. Replacing air filter

FAN REPLACEMENT AND ROTATION PROCEDURE:

Equipment

- None

Intake Fan Steps

1. The intake fan is press fit into a hole in the insulation. To remove it, the air filter must first be removed (refer to section above for instructions).
2. Intake fan can be pulled out and flipped around.
    a. NOTE: the quick-disconnect terminal on the fan must still align with one of the slots on the right side of the insulation hole where the fan is placed.
3. Remove power cord.
4. Rotate fan to ensure proper airflow direction and correct alignment with insulation.
5. Reattach power cord.
6. Press fit the fan back into the system and replace the filter.

Cooling Fan Steps

1. Lift top panel up, ensuring that wire connections do not become loose in the process. Have someone hold the top panel upright.
2. Disconnect the wire leads of the fan you want to remove from the WAGOs it is connected to by pulling up the levers.
3. Locate the nuts and bolts holding the fans in place on the top panel.
4. Use your finger to loosen each nut (there are three per fan) while you or someone else puts pressure on the bolt head on the other side of the top panel. This ensures that the entire bolt doesn't spin as you try to loosen the nut.
5. Remove the nuts and pull the bolts through the holes in the top panel, making sure you don't lose any small pieces.
6. Remove the fan and either replace or rotate it depending on your need.
7. Align the new/rotated fan with the holes on the top panel and insert the bolts back in.
8. Hold (or have someone hold) the heads of the bolts on the opposite side of the top panel as you screw the nuts back on to each bolt until secure.
9. Reconnect the fan leads to their respective WAGO connectors.

PELTIER DEVICE REPLACEMENT PROCEDURE:

Equipment

- Thermal paste
- Q-tip or popsicle stick
- Sand paper

- Heat gun (optional)
- Scissors (optional)

Steps

1. Disconnect the Peltier device wire leads from its WAGO connectors by lifting the lever and pulling the wires out. Ensure the rest of the system is off and not connected to power.
2. The device is glued down on the condensing array with a thermal paste (product linked in Table 2). To more easily remove this attachment, the thermal paste can be warmed up using a heat gun for about 30 seconds, but this step is not mandatory.
   a. NOTE: another way to make the removal process easier is to remove the condensing array from the system to have better access to the Peltier device. This can be done by cutting the zip-ties securing the condensing array to the mounting panel with scissors, then pushing the Peltier devices down so the condensing array can be removed from the bottom of the mounting panel via the door. This step is not mandatory.
3. To the best of the user's ability, the Peltier device should be twisted free rather than pried. Warming up the thermal paste will significantly help this process along.
4. Once removed, the damaged Peltier device should be discarded and a new device should be acquired. A new heat sink for the hot side should also be acquired and stuck onto one side of the Peltier device using the sticky adhesive on the back of it.
5. The wires of the new Peltier device should be cut and stripped to the same lengths as the wires of the original device.
6. If there is excess thermal paste remaining on the condensing array, it should be sanded down with sand paper until the surface is flat enough for the new device to be installed. Removing the condensing array may make this process easier.
7. A 0.1-0.5 mm thick layer of thermal paste should be applied to both the Peltier device and the condensing array spot. A Q-tip or popsicle stick should be used to spread out the thermal paste so that the layer is thin and even.
8. The Peltier device should be pressed down onto the condensing array spot with the aluminum heat sink facing up and the wires facing into the middle of the system. It should be pressed down firmly for about five minutes and then allowed to dry and fully cure for 24 hours. The system should not be operated at all during this 24-hour period.
9. When the curing time has finished, reconnect the wire leads to their appropriate WAGO connectors and test to make sure the correct sides and getting hot or cold.

WATER COLLECTION PROCEDURE:

Equipment

- Any vessel of your choice that is able to hold water and is doesn't contaminate the water

Steps

1. Open the door
2. Place the vessel so it is underneath the aluminum fins on which water will be condensing
3. Wait and check intermittently until it is full

ELECTRICAL COMPONENT SPECIFICATIONS

Specifications and user instructions for electrical components. Refer to product links in Table 2 for further information.

Table F.3. Peltier device specifications

Parameter	Specification
Maximum Voltage	15.4 V
Maximum Current	6 A
Maximum Temperature ΔT	67 °C
Maximum Cooling Power	72 W
Dimensions	40 mm × 40 mm × 3.8 mm
Wire Colors	Red = Positive, Black = Negative
Notes	Reversed polarity for gold heat sinks (vs. black)
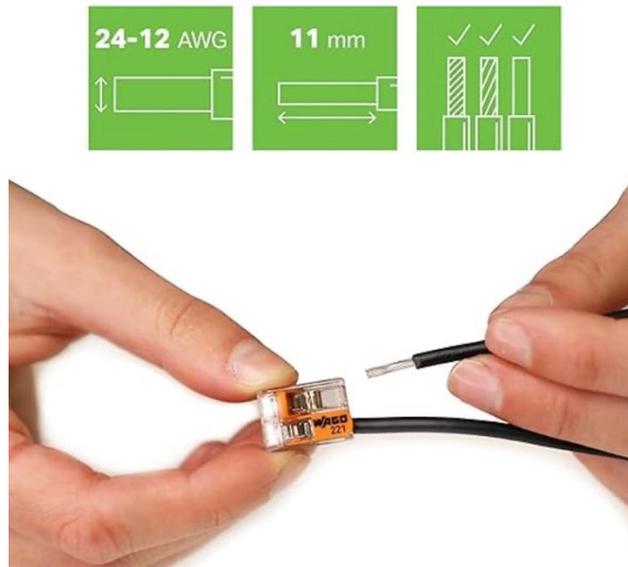
Figure F.11. WAGO connector information including length that wires must be stripped to (11 mm), gauge of wires that can be used (12-24 AWG), and what types of wires can be used (solid or stranded)
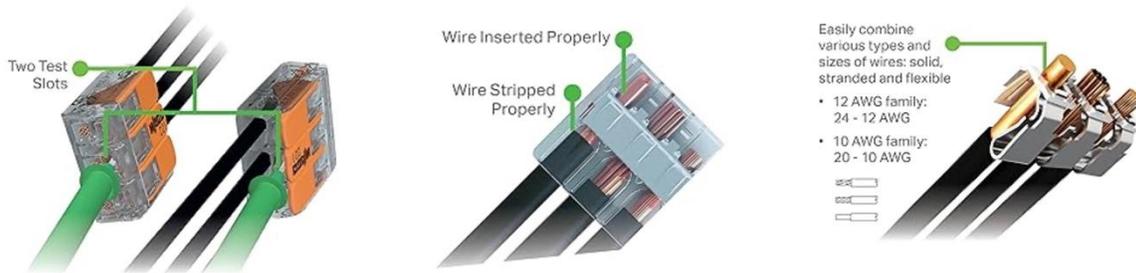
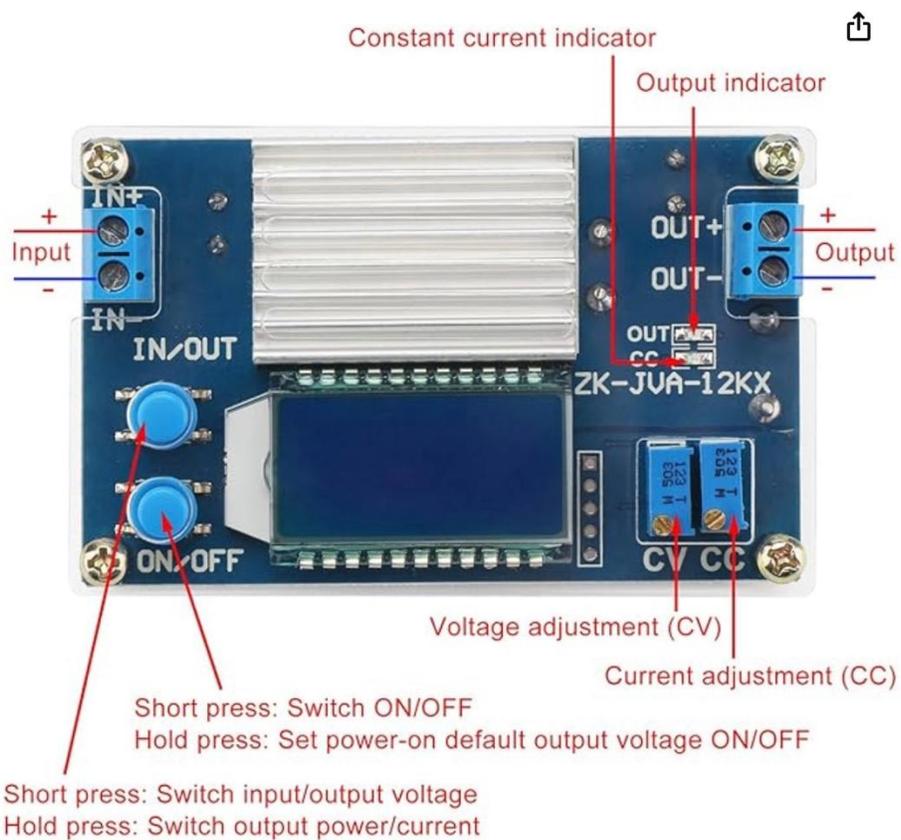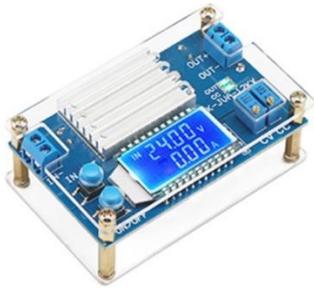**Figure F.12.** Further Wago connector information and pictures of proper use

Figure F.13. DROK voltage regulator user instructions/device diagram

DROK Buck Converter

Parameters:

Input voltage range: DC 5.3-32V

Output voltage range: DC 1.2-32V (input should be at least 0.8V higher than output)

Output current: 8A for long-term stable work. If strengthen heat dissipation can reach 12A.

Output power: natural cooling 120W (within 8A). If enhance cooling can reach 160W

- Can be used as an ordinary buck module with over-current protection.
- Can be used as a high-power LED constant current driver module.
- Can be used to diy a solar power controller.

DROK has been engaged in technical research, development, manufacture and sale of all kinds of buck converters for many years.

With acquisition of leading technology, we strictly enforce quality management system and improve operational management, dedicate to produce high performance meters for customers.

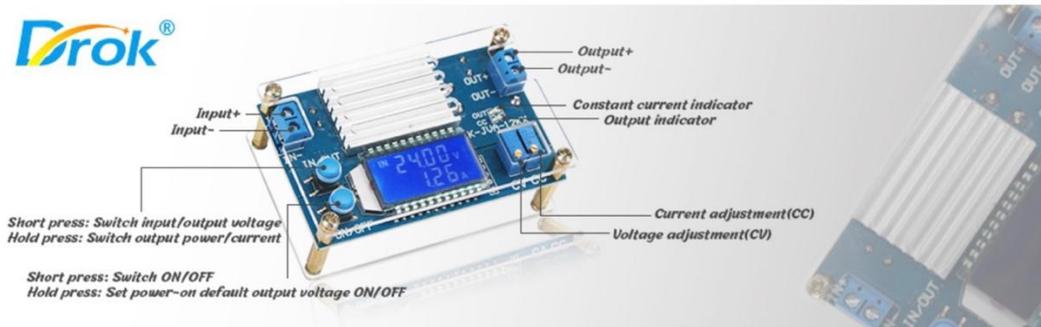"Integrity, Quality, Innovation, Customer" ----*DROK*

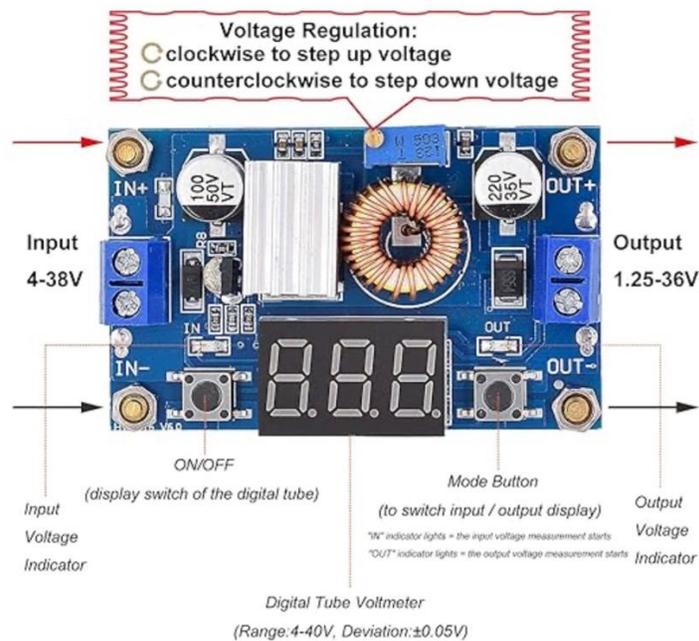**Figure F.14.** DROK voltage regulator specifications

Figure F.15. Valefod voltage regulator user instructions/device diagram

Kindly Note:

1. Input voltage must be 1.5 V higher than the output voltage, no boost

2. Do not reverse the input and output interface

3. Keep output under 5A (or 75W), and use a heat sink when for a long time working

4. The factory settings stay a high voltage, you may need to contrarotate the screw on blue potentiometer about 7-15 circles before the output voltage changes

How to Calibrate the Digital Tube Voltmeter

(Optional steps for the person who need a highly accurate voltage value)

1. Short press the left "ON/OFF" button to start up the digital tube voltmeter. Long press(>1s, <4 seconds) the left button to shut down the digital tube voltmeter.

2. Long press(>4 seconds) the left button to enter self-calibration of voltage measurement(calibration range: -0.5-0.5V, factory setting is 0.0).

"IN" indicator lights = input voltage measurement calibration starts. Then, long press(>2 seconds) the right "Mode" button, "OUT" indicator lights = output voltage measurement calibration starts.

Tap the left / right button to reduce / rise by one unit (since the voltage value of one unit is less than 0.1V, you need to 1-5 times tap the button continuously, so that the voltmeter can change by 0.1V)

3. After calibration, long press(>2 seconds) the right "Mode" button to preserve the adjusted value(no loss with outage) and back to normal voltage display.

Specifications:

- Model: Xl4015E / Digital Tube Voltmeter

- Input Voltage: DC 4V - 38V

- Output Voltage: DC 1.25V - 36V (adjustable)

- Output Current: 0-5A (recommended working current <4.5A)

- Conversion Efficiency: 96% (max.)

- Switching Frequency : 180KHz

- Operating Temperature: -45°C to +85°C

- Size(L x W x H): 62*38*14mm

- Weight: 32g

Parameter	Specification
Input Voltage Range	5.3 V – 32 V
Output Voltage Range	1.2 V – 30 V
Maximum Current	5 A (with heat sink)
Conversion Efficiency	Up to 96%
Switching Frequency	180 kHz
Operating Temperature	-40 °C to +85 °C
Dimensions	60 mm × 25 mm × 16 mm
Notes:	Requires 1.5V Δ between input and output

Figure F.16. Valefod voltage regulator specifications

Parameter	Specification
Input Voltage	100 – 240 V AC
Output Voltage	24 V DC
Maximum Output Current	6 A
Output Power	144 W
Certifications	CE, FCC
Cooling Method	Natural air cooling
Dimensions	110 mm × 78 mm × 36 mm
Notes:	Fuses added in series on power cord side for safety

Product Specification:

- Input Voltage: 100~240V AC
- Output Voltage: 24V DC
- Output Current: 6A max
- Output wattage: 144W max
- DC plug connector size: 5.5mmx2.5mm; 5.5mmx2.1mm compatible
- Polarity: internal "+", outside"-"
- Adapter body size: Please refer to the picture
- AC Cable length: about 120CM
- DC Cable length: about 110CM
- Safety Compliance: FCC/CE/RoHS
- Working Temperature: -20~50°C
- Ambient Humidity: 0~95% Non-Condensation
- **Package List:** 1x 24V 6A power supply adapter & 1x AC power cord

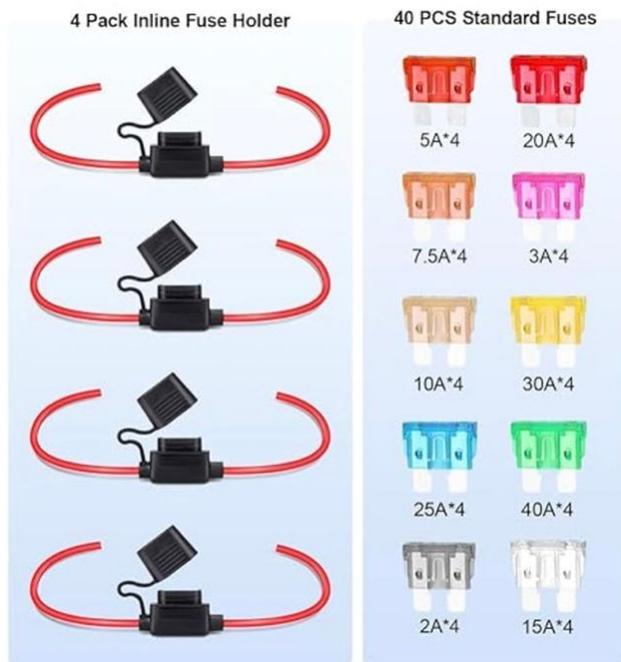**Figure F.17.** AC-to-DC converter specifications

Figure F.18. Image of fuse holders and corresponding fuses labelled with their current rating

Figure F.19. Fuse and fuse holder specifications and user guide

Figure F.20. Image of a blown out fuse on the left and an undamaged fuse on the right