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Board 133: The Design, Implementation, and Lessons Learned of an Atmospheric Water Generator Device

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THE DESIGN, IMPLEMENTATION, AND LESSONS LEARNED OF AN ATMOSPHERIC WATER GENERATOR DEVICE

Abstract

It is estimated that four billion people worldwide experience water scarcity at least one month per year. At any given time, there are nearly 12,900 cubic kilometers of water present in the atmosphere. To develop a solution to water scarcity, we designed a system that extracts water from the air by condensing water vapor from humid atmospheric air using a heat exchanger. This heat exchanger is cooled by pumping water into the ground, using geothermal piping to reject heat into the soil. This closed-loop geothermal piping system was configured in a helical arrangement underground at a depth of 2.9 meters. Before implementing the system, we used Engineering Equation Solver (EES) and estimated the amount of water to be collected at 1.7 liters per hour when the soil temperature is at 18.0 °C. We conducted two pilot studies in Costa Rica as proof of concept based on a location selected by local collaborators. The first test site proved unworkable when the physical location had a soil and air temperature gradient that was too small. The team then set up another experiment at another location where we simulated a cool underground environment by mixing water and ice in a tank. The physical on-site system is now collecting an average of 0.45 L per hour of condensed water when the average atmospheric temperature is 28.3 °C, relative humidity of 81.64%, and a simulated cold underground temperature of 20.2 °C. Details of the design, implementation, instrumentation, future work, the educational experience of an international capstone, and lessons learned are also presented.

Keywords: Atmospheric Water Generators, Water Scarcity, psychrometrics, Water, Heat Exchangers, Instrumentation, Drinking Water, Irrigation Water, Geothermal Heat Exchanger, Underground Temperature Distribution. International Capstone Projects.

1. Introduction

The issue of water scarcity is a persistent problem affecting people worldwide despite revolutionary accomplishments in clean water generation. It is estimated that four billion people experience water scarcity at least one month per year [1]. While a few technologies like desalination, reverse osmosis, and refrigeration dehumidifiers are used effectively, these methods are intensive in energy consumption. The new cloud seeding technique has potential, but the environmental impact and economic cost-effectiveness need to be clarified.

A previous study [2] concluded that regions in the Middle East and Northern Africa face the highest level of water stress, defined as insufficient water to meet environmental and human demands. In these regions, the air temperature and humidity levels are relatively high and have the potential to be harvested and generate drinking water. Thus, their targeted stakeholders would be people from these areas (Figure 1).

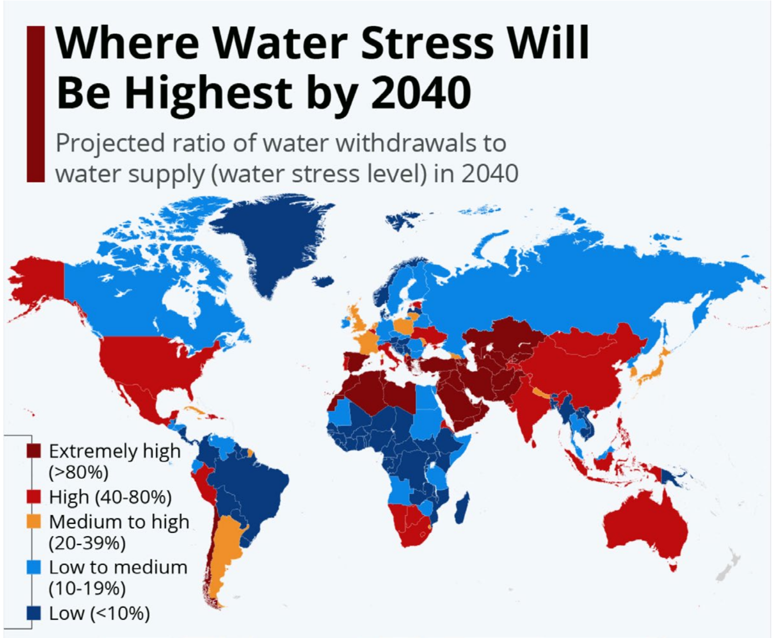


Figure 1: Map of Global Regions of Projected Water Stress by 2040 [2].

At any given time, nearly 12,900 cubic kilometers of water are in the atmosphere [3]. Suppose this humidity can be condensed economically and sustainably. In that case, it can be a great source of fresh water- especially in humid areas in the United States, such as Houston, Texas, or areas around the Persian Gulf, such as the United Arab Emirates.

A few studies attempted to collect water from the atmosphere [2, 4, 5, 6, 7, 8] using cold surfaces by heat exchangers and including the Peltier effect. With this principle of using condensation from humid air to produce water, a group of engineering students at James Madison University came up with two different designs [1] with a sustainable approach: using a Peltier device and a heat exchanger.

The results described here were part of a multi-year capstone project that two previous teams worked on and then were taken over and expanded upon by a third group of three students. The capstone educational experience in the ISAT program at James Madiosn University consists of a four-course sequence (6 credits) in the 3rd and 4th academic years. The courses follow the following sequence.

During the fall semester, students enroll in a one-credit hour course taught by two faculty members. The primary goal is to develop a research proposal on an engineering, science, or technological problem facing society. Students are responsible for identifying a problem, undertaking background research, deciding whether to form a team or work independently, and identifying one or more faculty advisors. Some projects are performed over multiple years, with one phase finished by one group and handed off to another group for continuation. Students then prepare a brief written proposal, and a memorandum of understanding (MOU) is signed by both the faculty advisor(s) and student(s).

A second one-credit course is taken in the spring semester of the junior year when students do a deeper dive into the relevant literature, develop a detailed plan for executing the project during their senior year, and prepare a poster on their project that is presented at a symposium.

Two faculty members co-taught this course, with the symposium poster and written proposal counting for 50 percent of their grade. This grade is given by the faculty advisor(s) who have signed the MOU with students.

In the senior year, students take a 2-credit hour course in the fall and spring, undertaking the research developed and proposed in their junior year. This sequence of courses is graded by the capstone advisor whom the students have signed an MOU with. For the project described here, students performed an independent research project in Costa Rica. Through this project, students will analyze a technology-based problem, develop alternative solutions, recommend the best solution, and provide a written and oral technical report. As part of this international experience, students will have the chance to demonstrate their ability to define and manage a project, identify goals, track, and report progress, deliver results on time; and clearly report results. Specifically, students have:

1. Develop innovative solutions to significant, real-world problems.
2. Work with others, such as team members, project sponsors, and faculty members.
3. Situate their work in the relevant social context(s).
4. Develop and deliver a clear, convincing oral presentation and
5. Write an extensive professional report.

Students' course grades are based on: 1. Professional management of their project and effective communication with all parties. 2. Quality of deliverables- both in implementation and report. 3. Timely achievement of project milestones and deliverables. 4. Professional behavior. 5. Peer and self-evaluation (see Table 1) were infused in the above grading scheme. One peer evaluation was done after the implementation of the project and another after the capstone presentation and report submission.

Table 1: Project Self and Peer Evaluation Form

Please highlight your name	**Name**	**Name**	**Name**
Level of Effort: *Indicate the % of the total team effort made by each team member. Use % values, so that the total across the row adds up to 100%*			
% of total team effort			
Quality of Effort: *Indicate the quality of each team member's contribution by rating their work on a scale of 1-10 (1 representing work that was useless; 10 representing work of high quality)*			
Quality rating (1-10)			
Teaming Contributions: *Consider how well each team member helped the team work well together. Rating their work on a scale of 1-10*			
Participation in team discussions and meetings			
Contributed useful ideas			
Helped keep the group focused on the task			
Preparation for assigned work			
Timely delivery of work			
Willingness to accept responsibilities			
Overall attitude			
Total score			

The team for this project consisted of three students (one female and two male students). Two of the three students had never been outside the United States, so cultural and extensive logistical preparations were made before the trip.

Starting in the fall of 2020, the team had weekly meetings with their faculty advisor to discuss progress, challenges, and next steps. This provided a sense of structure and accountability for the project. The team had the support of two advisors, a faculty member, and the manager of the resort, who provided guidance and facilitated connections with other experts when needed. The faculty advisor encouraged the team to be independent in finding solutions to their questions, which developed their problem-solving skills and sense of ownership of the project. The team members identified each other's strengths and weaknesses and assigned tasks accordingly, which created a sense of shared leadership and collaboration. The team was tasked with redesigning and implementing a system to address water scarcity, which required technical skills and creative problem-solving. The results of their efforts are reported here. The team was asked to consider the economic, environmental, and societal impact of their solution, which required a holistic approach to problem-solving. Finally, the team was asked to consider the global impact of their solution, which required an understanding of the broader context and implications of their project.

The focus of this team was to implement the work from the previous groups [2], [4] in which they investigated the optimal method to produce liquid water from humid air. The research and theory used were continued by the second group using the temperature differentials of the air temperature and underground soil temperature and improving the design based on specific system requirements [4].

To reduce the energy consumption and overall cost of an atmospheric water generator (AWG) system, the concept of using cool underground soil temperature to transfer heat absorbed above ground was crucial to this project. The previous work [9] summarizes the methods and results to estimate underground temperatures at various depths by correlating thermal diffusivity to the penetration depth of the soil. The authors concluded that at a depth of 6.4 m, the average temperature measured was 1.0°C during the period from May to December 2018. Their research mentions that factors like the thermal properties of the ground may vary based on the location, season, and rainfall amounts. Another paper [10] supported this: the ground temperature at a depth greater than 10 feet (3.05m) remains relatively constant throughout the year. In Houston, Texas, the observed temperature difference between ambient and subsurface locations is 8-17°F (4.4-9.4°C), which can be utilized to pre-heat or pre-cool ambient air for commercial and institutional facility use.

This research proves that hot and humid climates like Houston, Texas, have enough temperature difference between the ambient air and underground soil for condensation to occur.

The arrangement and total geothermal pipe length determined were grounded by a previous study [11]. In this study, the researchers compared the rate of heat exchange between three different coil arrangements: slinky, spiral, and U-shaped configurations. In their testing, they used copper coils rather than plastic resources due to their higher thermal conductivity values and tested the rate of heat exchange using different fluid mixtures.

Among the fluids they tested were water, ethelene glycol with water mixture, and methanol with water mixture [11]. This research concludes that circulating water through the coil was most effective due to the higher thermal and physical properties of water compared to the other mixtures. Furthermore, the coil arrangement had no significant difference in the heat exchange rate. The previous capstone group [4] adopted the spiral arrangement to minimize the total dimension of the trench to be excavated. This spiral arrangement forms a helical shape going horizontally to the ground with the intention of using plastic geothermal piping instead of copper for economic reasons.

The second group [4] focused on creating the energy calculations to set requirements for the system design apparatus built by the first group and comparing the measured results to their estimated calculations written in the Engineering Equation Solver (EES) software program. This software allows users to solve non-linear and differential equations quickly. The EES program allowed the team to scale up the project and get an estimate on the dimensions of the heat exchanger and the length required for the geothermal piping. This led them to purchase a larger heat exchanger to generate more water compared to the in-lab prototype to implement in Costa Rica in the Summer of 2020 [4]. Unfortunately, the trip was canceled due to the pandemic. In the winter of 2021, the study abroad program was given the green light, and the project implementation period in Costa Rica was three weeks.

During the program, each student was required to write two journals: a technical one to detail their daily work and accomplishments and a second to reflect on their international and cultural experience.

Writing a technical journal can be a valuable way for students to reflect on their daily work and progress. It can also serve as a record of their accomplishments, which may be helpful when preparing resumes or applications in the future. Students can use the technical journal to describe the tasks they performed, the challenges they faced, and the strategies they used to overcome those challenges. They can also reflect on what they learned and how they might apply it in future endeavors. The second journal, which focuses on the students' international and cultural experiences, can be equally valuable. This journal can help students to reflect on the ways in which their experiences in Costa Rica have broadened their perspectives and deepened their understanding of other cultures. For example, they might write about new foods they tried, people they met, or traditions they observed. By reflecting on their experiences, students can gain a better understanding of themselves and the world around them.

2. Materials and Methods

Based on previous groups’ design and laboratory testing, the decision to utilize a fin tube condenser coil, which acts as a heat exchanger, and geothermal piping will be the most efficient solution to our design. Using their work, our team finalized the design and implemented the prototype in Costa Rica during the winter session study abroad program in 2021. The aim of our project was to develop an operable and fully functional prototype of an (AWG) system. Furthermore, we integrated a data monitoring device that would measure and collect temperature and humidity readings necessary for system modeling in future work.

As shown in Figure 2, the AWG system consists of three parts: below-ground heat exchanger, above-ground heat exchanger, and data acquisition system.

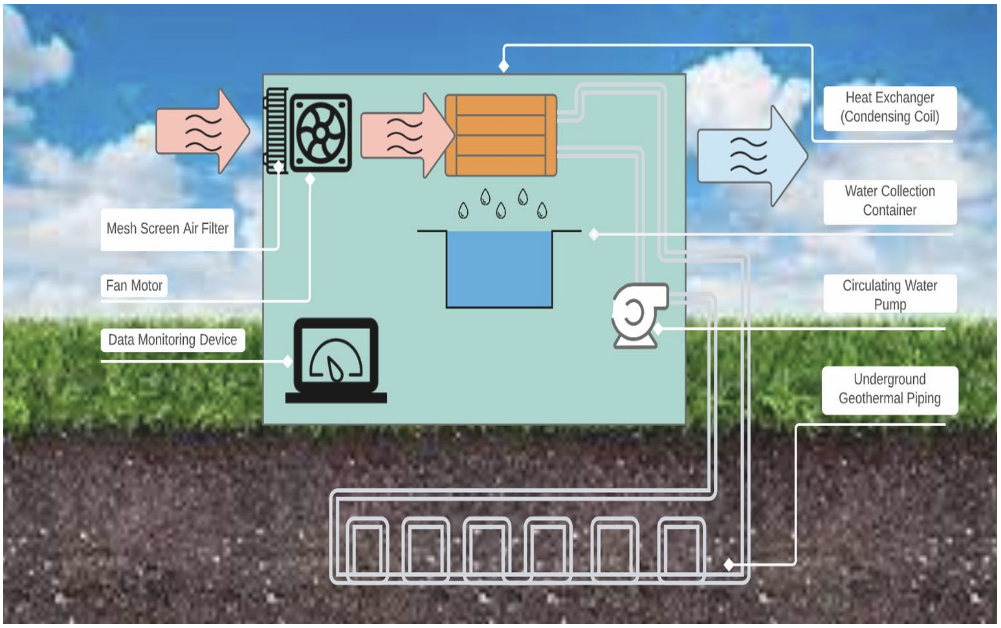


Figure 2: Schematic of the System.

2.1 Below-Ground Heat Exchanger

The spiral arrangement forms a helical shape going horizontally to the ground, as depicted in Figure 3 below, our intention of using high-density polyethylene (HDPE) geothermal piping instead of copper for economic and environmental considerations.

One distinguishing feature of our AWG design is our method of transferring heat using circulating water. Unlike many refrigeration systems and dehumidifiers that use a compressor to pressurize refrigerants, our approach comes from the idea of a geothermal heat pump. Geothermal systems utilize the underground soil as a heat sink to transfer the warmer fluid into the ground and return a cooler fluid to the heat exchanger above the ground.

Based on previous work, the team applied this concept to their design. While many other closed-loop geothermal piping configurations are laid flat on the ground, the piping coil was configured horizontally in a helical manner to minimize the size of the trench. Thus, we determined the distance between each roll, or the pitch, to be 0.10 m. The entire length of the geothermal piping purchased was 200 m. The dimension of the trench for the geothermal piping was 1.83 m by 6.10 meters long and 2.74 m deep, but the piping is 1.22 m in diameter and coils in 6.10 m in length (Figure 3).

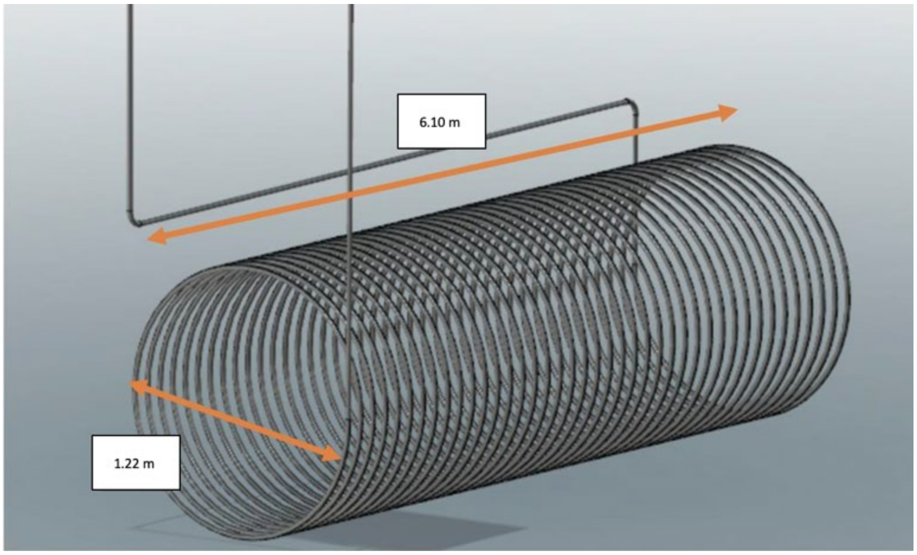


Figure 3: Cad Model of the Underground Geothermal Piping Configuration.

The entire piping of the system consisted of two materials: high-density polyethylene (HDPE) geothermal coils and PEX piping. The HDPE coil is a 2.54 cm diameter roll of piping used in most ground-source heat pumps. This material is semi-flexible and can be connected using push-lock connectors purchased from Georgia Underground Superstore [12]. This requires no soldering or cement solvent for easy installment during the implementation phase. To connect this geothermal piping to the above-ground heat exchanger, we transitioned the piping material to PEX piping, commonly used in new residential and commercial plumbing systems. The advantage of this material is that it is inexpensive, easily accessible, and has similar thermal properties to HDPE piping. Because HPDE piping is measured in Iron Pipe Sizing (IPS) standard and the PEX piping is measured in Copper Tubing Size (CTS) standard, we used SharkBite™ fittings to transition the two different piping standards without the need for welding or cementing. Figure 3 shows the schematic of the piping for the system and Table 2 shows the materials for the underground piping.

Table 2: List of Materials for Underground Piping

List of Materials- Underground piping		
Item Number	**Name**	**Quantity**
1	2.54 cm HDPE geothermal pipes	200 m
2	2.54 cm – 60.96 cm PEX pipe	5
3	1.91 cm – 60.96 cm PEX pipe	6
4	2.54 cm HDPE push lock connector	6
5	2.54 cm IPS to 2.54 cm CTS SharkBite fitting	2
6	2.54 cm threaded check valve	1
7	3.17 cm to 2.54 cm bushing	1

2.2 Above-Ground Heat Exchanger

Based on the in-lab setup used by the first two capstone groups, our team focused on developing a larger system with an integrated data monitoring device which we will implement in Costa Rica. The dimension of the above-ground heat exchanger was predetermined by the previous group, who purchased a 50.8 cm x 50.8 cm crossflow finned tube condensing coil. Constructing a housing was necessary to protect this heat exchanger from animals, insects, and the weather. Our team explored a plethora of different materials, such as plexiglass, plywood, and aluminum sheet metal. We also considered insulating the housing with materials such as spray foam insulation, polystyrene insulation boards, and bubble insulation.

A few prototypes were built. One is shown in Figure 4. The common theme to improve on previous work was to minimize the airflow loss from the duct fan to the heat exchanger. As a result, we chose to create a sheet metal diffuser to direct constant airflow from a duct fan across the heat exchanger. The fan will draw humid air from the surroundings, passes through the heat exchanger, and out the air exhaust vent.

When the humid air encounters the heat exchanger, condensation forms, and water is collected below with a rectangular funneled shape channel, which directs the water into the rain bucket meter, a La Crosse Technology® device, that measures water collection at a rate of inches per hour. The intention was to build a separate housing for the electronic components such as the pump and the data monitoring device. This concept of using sheet metal for the housing was disregarded after our team recognized the lack of structural integrity of the material to support the heat exchanger.

There were some design flaws that the team did not take into consideration until construction. The first issue was that the duct fan was on the outside of the housing, which raised concerns about water damage to the fan. Secondly, the air outlet vent was much smaller than the area of the duct fan. If the entire housing was sealed, it would create a positive pressure build-up. The third issue was that there was not enough space below the heat exchanger to effectively collect and store the condensate water. Therefore, the team modified the design of the above-ground housing to address these issues.

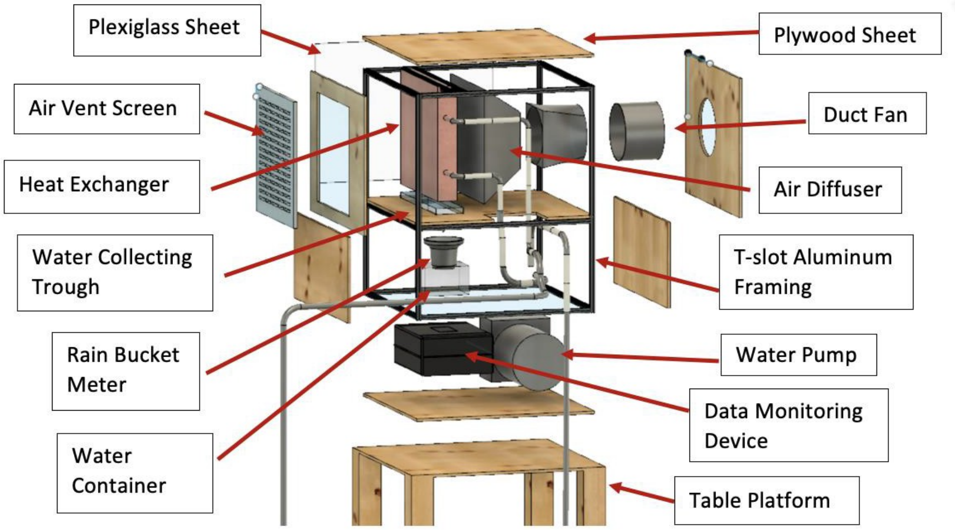


Figure 4: Exploded View of the Above-Ground Housing

2.2.1 Above-Ground Heat Exchanger- Final Design

We decided that the structure of the housing would be improved by using 80/20 T-slot aluminum framing. This material is commonly used for building shelving, CNC machines, and other structures that require strong framing [19]. This material does not require welding to secure objects, simplifying the assembly process. To fasten materials like the heat exchanger and the housing panels, we used 90-degrees corner brackets and other hardware designed specifically for T-slots. Holes were drilled into the frame of the heat exchanger, allowing it to be mounted to the T-slot frame. Once the dimensions of the final design of the above-ground housing were set, a CAD model was created to demonstrate the prototype before building it in Costa Rica (Figure 5). For the above-ground housing, the system will be placed on top of a table platform that is 89 cm wide by 89 cm long and 38.1 cm high.

The above-ground housing includes the heat exchanger and other components necessary for its operation. The top portion is where condensation occurs (Figure 4). As the duct fan draws in air from the surrounding, air flows through a fabricated sheet metal diffuser that covers the entire face of the heat exchanger. When the air contacts the cooler heat exchanger, the condensation of water vapor takes place and drips onto a plastic channel.

Using the T-slot aluminum framing, the dimensions of the above-ground housing frame were 81.3 cm wide by 81.3 cm long and 100 cm high. The dimension of the top portion is 81.3 cm wide by 81.3 cm long and 63.5 cm tall. For the housing panel, we used 1.27 cm (1/2") thick plywood and 0.95 cm (⅜″) Lexan™ sheets. The team chose these materials for their economic cost, durability, and aesthetics. For better visualization, using Lexan sheets would be suitable as it allows observation inside the system while in operation without needing to remove any of the panels.

Onto the components inside the housing, the duct fan the team purchased was a 25.4 cm diameter air booster with a rating of 0.307 m^3/s. The team connected the circular duct fan to the diffuser using a 10″ round-to-square duct transition. The team fabricated the diffuser by measuring out and cutting four sheet metal panels with a 25.4 cm to 50.8 cm square opening to cover the entire heat exchanger. To form the diffuser, one-inch tabs were bent on the ends, and S-cleat duct connectors secured them in place.

The bottom portion of the above-ground housing contains all the necessary components for system operation (Figure 4). In this portion, the placement of the water pump, monitoring device, rain bucket measurement device, water storage container, and electrical outlets were chosen. For this final design, the team created a top and bottom portion within the housing to separate the materials that may be affected by water using 81.28 cm by 81.28 cm plywood. For the pump, we chose a ½ hp shallow well circulator water pump for this project. Although it may be larger than required, it was chosen to compensate for any additional pressure needed to overcome head losses within the piping and economic cost. The La Crosse Technology® water bucket was selected to help measure collected water and has the capability to transfer the data wirelessly to an online account portfolio. Since the bottom of the rain bucket meter has a mesh screen, a plastic container was placed below to store the collected water. Lastly, the bottom portion was an area to house the monitoring device created for measuring temperature and humidity readings. Table 3 shows the list of materials used for the above-ground housing.

Table 3: Materials for Above Ground System

List of Materials- Above-Ground System		
Item number	Name	Quantity
1	T slot aluminum extrusion- 100 cm length	4
2	T slot aluminum extrusion- 77.3 cm length (10pcs)	2
3	1.22 m x 2.44 m plywood- 1.27 cm thickness	2
4	1.22 m x 2.44 m polycarbonate sheet	1
5	T slot hardware (corner brackets screws, nuts pack, etc.)	1
6	25.4 cm duct fan	1
7	50.8 cm x 50.8 cm Heat exchanger	1
8	Silicone caulking tube	3
9	Aluminum tape roll	1
10	25.4 cm duct transition	1
11	50.8 cm x 50.8 cm air vent grill	1
12	½ hp Shallow well water pump	1

2.3 Data Acquisition System

The optimization, performance, and modeling of this system require collecting data on temperature variation of solids, liquids, and air parameters that vary from one location to another. This device requires air parameters (temperature and relative humidity), water inlet and outlet temperatures as well as soil temperature variation. The WOTA-DAQ project [13] designed and implemented an inexpensive data acquisition system that utilizes off-the-shelf components. Twelve parameters are collected: air inlet and outlet temperature, relative humidity, water inlet and outlet temperatures, and soil temperature from 0.61 m to 2.44 m (2 to 8 feet) at one-foot increments. Raspberry Pi 4 with MCP-9600 chips, which runs on the I2C protocol, was used in this project. The I2C uses an address system that allows the Raspberry Pi to distinguish between multiple sensors. The sensors, setup, circuitry, and code details are presented in [13]. The team faced an issue with the saturation of the humidity sensors this WOTA-DAQ. When saturated, the sensor always read 100% humidity ratio and required that the sensor be dried and re-installed. This was not practical. The team also failed to obtain the required difference in temperatures between the atmospheric air and ground temperature, and hence, the team did not need to measure underground temperatures. The above saturation issue and the failure to obtain the required temperature difference prompted the team to use readily available components for data collection.

For the inlet and outlet atmospheric air temperature and relative humidity, the team used a SensorPush® device with WiFi Gateway [14]. It has an accuracy of ±1.5% in RH and ±0.1°C and a barometric pressure sensor with a typical accuracy of ±0.5 mb. To measure the cooling water flow rate, the team used a clamp on StreamLabs® Monitor [15]. This device has a 0.25 gpm low-flow detection.

For atmospheric temperature, relative humidity, pressure, wind speed and direction, and amount of water collected, the team used the La Crosse Technology® weather station. This model has a Pro 2019 Station Model display, a rain bucket, solar powered anemometer, and a thermo-hygro sensor. The rain bucket is a Rain 2.0 Sensor that is self-emptying and measures the amount of water collected by the WOTA system (LTV-R2 Rain Sensor, 2019). The solar-powered anemometer is an LTV-WSDTH01 Breeze Pro Sensor attached to the roof of the fencing at the highest point on site. It measures the outdoor air temperature, relative humidity, heat index, barometric pressure, and wind speed (LTV-WSDTH01 Breeze Pro Sensor, 2019). The display allows workers to check the data and updates on-site to ensure everything is working properly.

The display also connects all the other devices to the WI-FI through which the instruments update the data remotely (C79790 WiFi Weather Station, 2019). The LTV-TH2i sensor is in the raspberry pi housing case and is used to measure the temperature of the DCS housing case to ensure it does not get too hot for the raspberry pi (LTV-TH2 Thermo-Hygro Sensor, 2019).

The rain bucket provides data on the amount of water the system collects; a calibration was conducted to convert inches of water to milliliters. The rain bucket has a level in the middle that tips over when full, and the system registers this as 0.1″ of rain. Using a 5 mL syringe, water was poured onto the rain bucket in increments of 5 mL until 250 mL, and the readings from the rain bucket were recorded to get the calibration curve.

The above three devices are connected to WiFi and can be monitored remotely in real-time. Data can be downloaded for further analysis.

Finally, for inlet and outlet water temperature measurements, we used two inline K-type thermocouples that are connected to a datalogger [17]. Data for each experimental run can be stored and downloaded for analysis using Huato LogPro [18].

2.4 Project Implementation

Once the design was finalized and all the necessary materials were determined and purchased, the team started building the system. The majority of materials were purchased prior to arrival in Costa Rica due to the uncertainty of their availability. Items like plywood, Lexan sheets, geothermal piping, PVC tubing, and PEX piping were purchased in Costa Rica after confirming their availability. Many of the items, including all the pipe fittings, were purchased through local vendors. Material and hardware were packaged into boxes and luggage to prepare for the study abroad in Costa Rica from December 20th, 2021, to January 11th, 2022.

The team surveyed the resort for a site to install the system. Working with the resort management, the team selected a location at sea level, close proximity to the beach with an open flat field and visible from walking paths for educational purposes. This was a desirable location as it was large enough for the dimension of the trench required and has direct sunlight for a future installment of photovoltaic solar panels to power the system. The next day, the resort acquired a backhoe excavator to dig the trench.

Shortly after the excavator started breaking ground, the claw hit an underground water treatment pipe which caused flooding of the area. The pipe was fixed and digging continued. However, the team encountered another issue; underground water started accumulating in the trench after digging 5 ft, and this prompted the team to abandon this location. Maintenance suggested a different location that would not interfere with any of the pipelines and that would be less likely to experience underground water accumulation. Thus, the team changed the location. After the maintenance workers inspected the area of any potential concerns, such as pipelines or electrical lines, they began digging the trench, which was accomplished within a day (Figure 5).

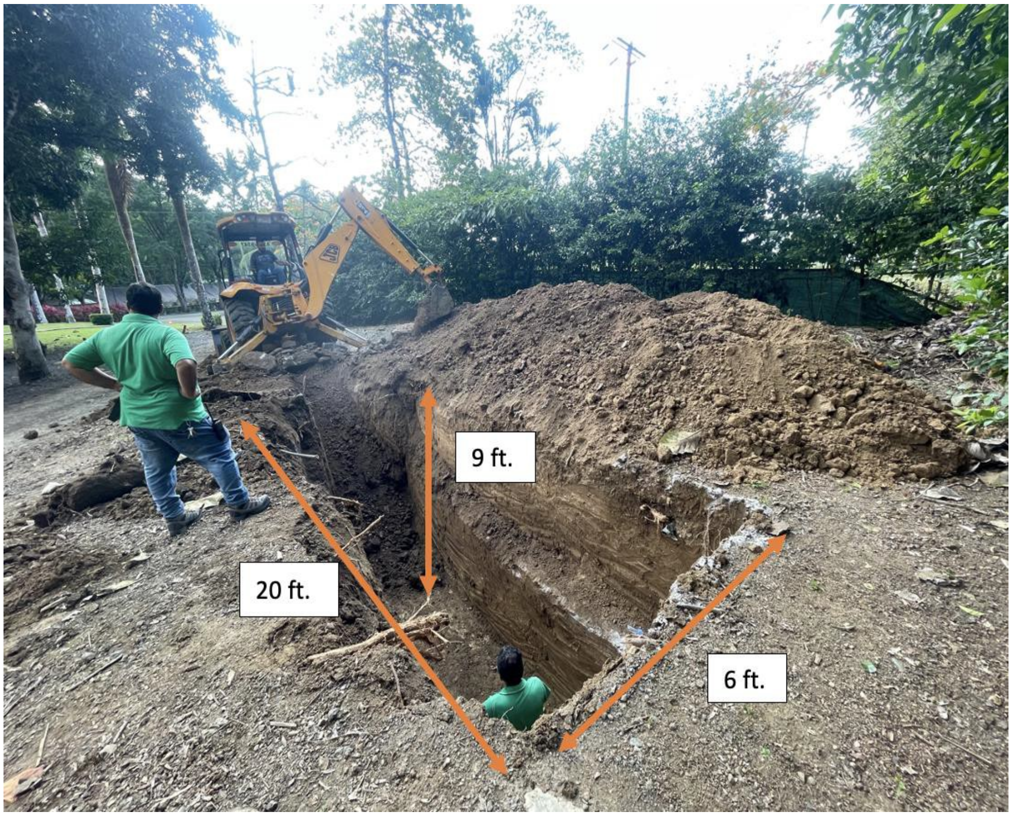


Figure 5: Initial Location of The Trench

After the trench was dug, the team installed the geothermal pipe inside the trench. To set the pitch between each coil, the team marked out thin strips of wood every 12.7 cm to allow 10.16 cm of spacing between the coils since the pipe diameter is 2.54 cm. After marking all the wood strips, one strip was placed at the bottom of the trench, and we would unravel the geothermal piping on top of the wood and zip tied the piping in place. Two other wooden strips would also be zip tied to the coil toward the top end. Figure 6 shows an image of the team installing the geothermal pipes. Afterwards, the trench was backfilled with dirt by hand until it covered the piping. This was done to avoid the risk of puncturing the pipes if large rocks were to fall. Once the entire geothermal piping was covered with dirt, the backend of the excavator compacted the dirt down and continued backfilling the trench until everything was flat. Then the team set up the above-ground housing system. After the plywood was cut to the correct dimensions, the team sanded the plywood before applying a polyurethane coating to protect the wood from scratches and water damage. This would also help keep the wood from warping in the humid environment.

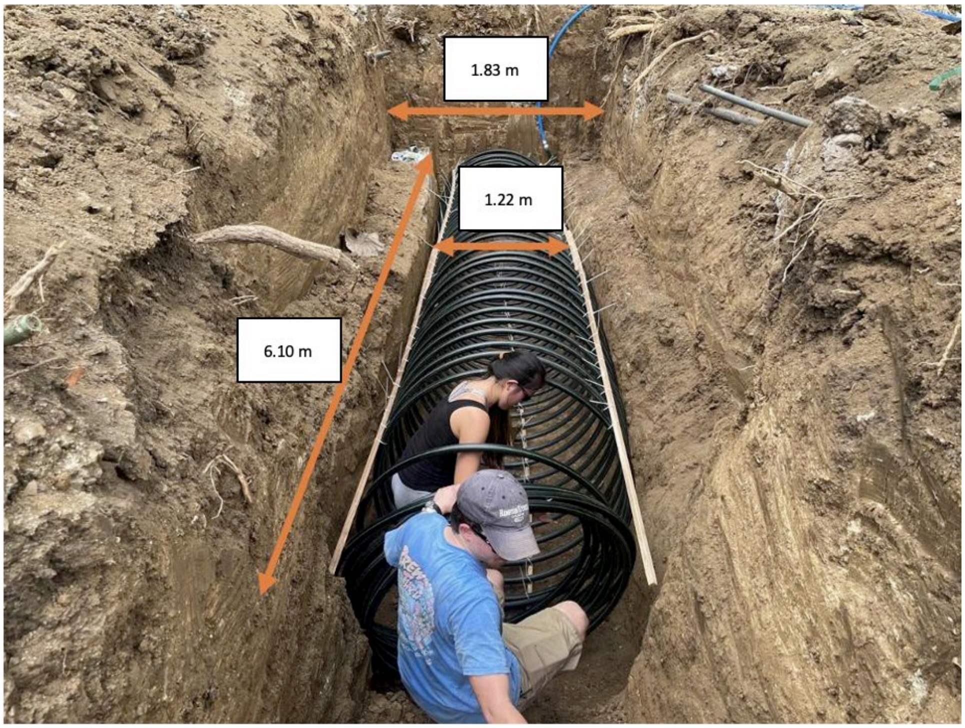


Figure 6: Installing the Underground Geothermal Piping

Following the completion of the above-ground component assembly, it was transported to the site using a truck with the help of the maintenance workers at the resort.

The resort workers assisted in constructing a concrete platform next to the site of the pipes so that the above-ground housing had stable platform to sit on. In addition, they built a metal table that the system will be placed on top of to prevent any water damage towards the bottom of the system. And lastly, the resort workers erected a metal fencing barrier around the area to protect against any unwanted disruption to our project and to keep wild animals such as iguanas, monkeys, and macaws from getting into the system. The final product of the fencing built by the resort is shown in Figure 7.

After the resort workers connected our system to the electrical outlets and WiFi connection, it was time to connect the geothermal piping to the above-ground heat exchanger. The team received external support from a local plumber to validate that the piping was done properly. Finally, the team integrated the data monitoring system to read the underground soil's temperature, the heat exchanger's inlet and outlet, and the entrance and exit airflow along with its relative humidity. The final product of the project is shown in Figure 7.

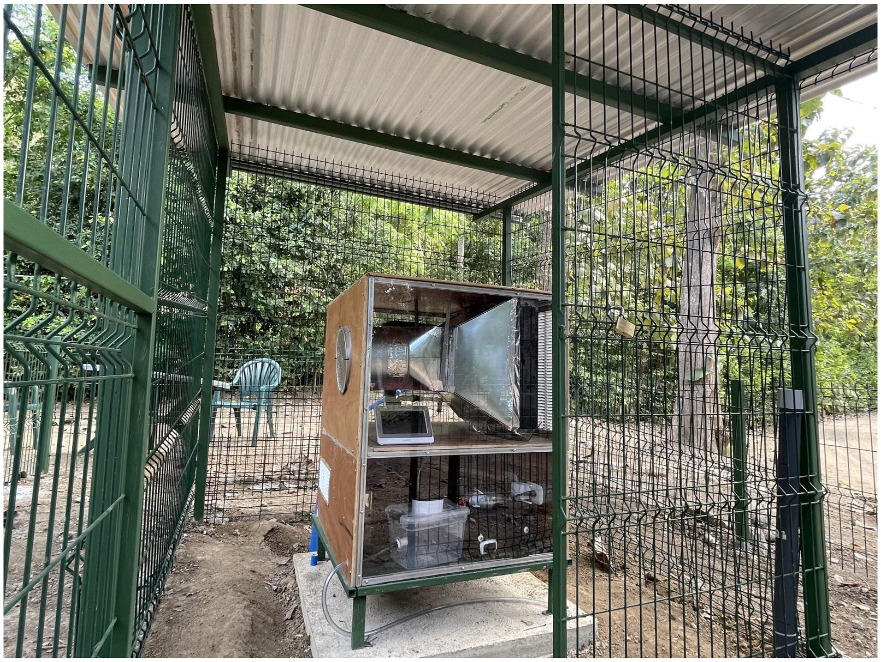


Figure 7: The Implemented Prototype.

2.5 System Modeling

The modeling was done using the Engineering Equation Solver (EES) Program. This program calculates the theoretical amount of water the system would collect depending on the variables input into it. The benefits of using EES are that it can use the data points from the environmental data acquisition system, and because it is real-time data from the site, it includes the daily fluctuations in temperature and relative humidity that will affect the daily amount of water collected. This allows calculations to be more realistic, and when the system is running, the model can be compared directly with the actual amount of water collected. The EES program can be adjusted if there are discrepancies between the model and actual data, but the hope in creating an accurate model is to then apply it to the environmental parameters of water-stressed regions around the world and see how much water would be collected there, and if it is worth it to build an AWG system given local conditions.

After the system was installed, the team encountered a major setback, the soil temperature was the same as the atmospheric air temperature. Many possibilities could cause that: the team did not go dig deep enough or possibly the new location is at a higher elevation than the sea level and the change was not accounted for.

A great deal of time, energy, and financial investment went into this multi-year project, and the team did not want to lose heart in this research. The final decision was to use this project as a proof of concept and as an educational tool for the resort. The system was relocated to a closer location to major walking paths, and adjustment to the system was made to simulate the cooling water by mixing water and ice in a tank. The AWG system at the new location is shown in Figure 8. The modified AWG system with an insulated tank is shown in Figure 9. Inside the tank, a pond fountain was used to enhance the mixing of ice and water.

Figure 8: The Prototype at the New Location.

Figure 9: Rear View of the System at the New Location.

3. Results and Discussion

Figure 10 shows the atmospheric air temperature readings captured by the La Crosse Technologies® weather station from March to April 2022. This behavior is a typical weather pattern in Costa Rica. This data, along with pressure and relative humidity data, is used as an input into the EES program. The EES program then determines the theoretical amount of water that would be collected based on the actual air temperatures and relative humidity on site. Similar available data can be used to model the system performance at other locations worldwide.

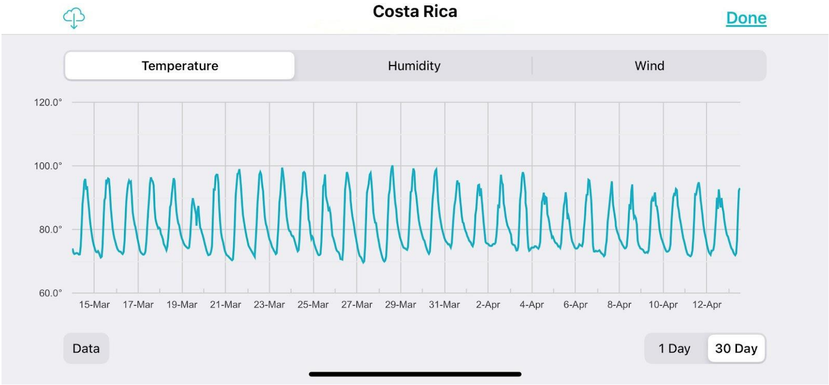
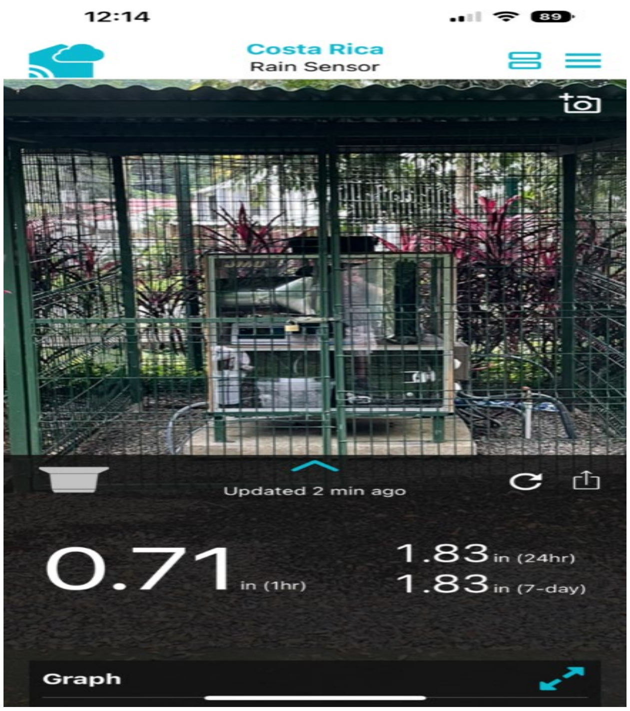


Figure 10: Temperature Data from the La Crosse View App.

Figure 11 shows the display of the lacrosse app. It shows the hourly and total accumulated condensed water in inches. This data is also physically recorded every 5 minutes while performing the experiment. Historical data can be downloaded from the La Crosse view stored in the cloud data system.



0.71 in (1hr)

1.83 in (24hr)

1.83 in (7-day)

Figure 11: Lacrosse Display of Rain Bucket Data From the La Crosse View App.

Figure 12 shows the calibration results of the rain bucket. As expected, it has a linear relationship. This data is used in calculating the amount of condensed water in milliliters.

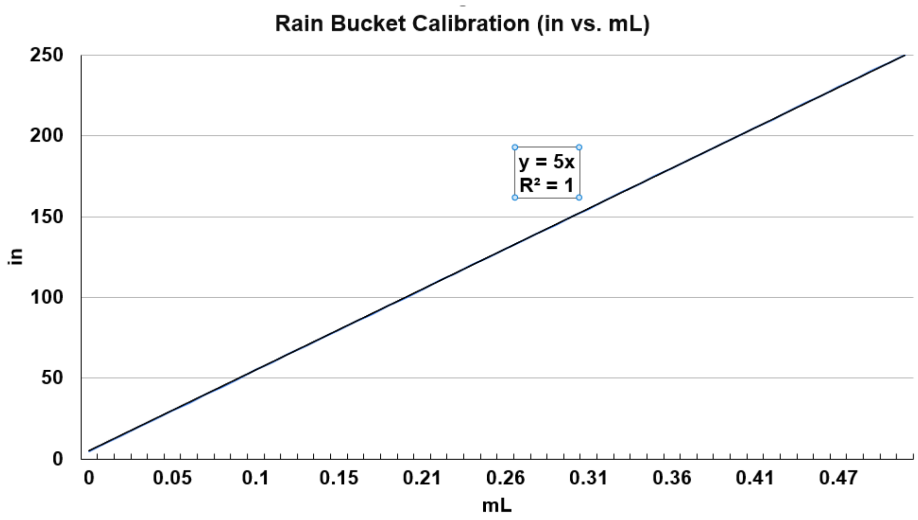


Figure 12: Rainbucket Calibration.

Figure 13 shows a typical display of the instantaneous inlet and outlet air temperature, relative humidity, and pressure measured by SensorPush® sensors. The historical data can be used in the EES program to compare the actual system performance to the theoretical.

Inlet Air

LAST READING: 10:29 AM   DAILY AVG: 26°C / 89% / 1,009mb / 24°C

TEMPERATURE 23.9°C RISING >

RELATIVE HUMIDITY 98.6% RISING >

BAROMETRIC PRESSURE 1,011.6mb RISING >

DEWPOINT 23.6°C RISING >

Outlet Air

LAST READING: 10:29 AM   DAILY AVG: 26°C / 89% / 1,009mb / 24°C

TEMPERATURE 16.6°C < FALLING

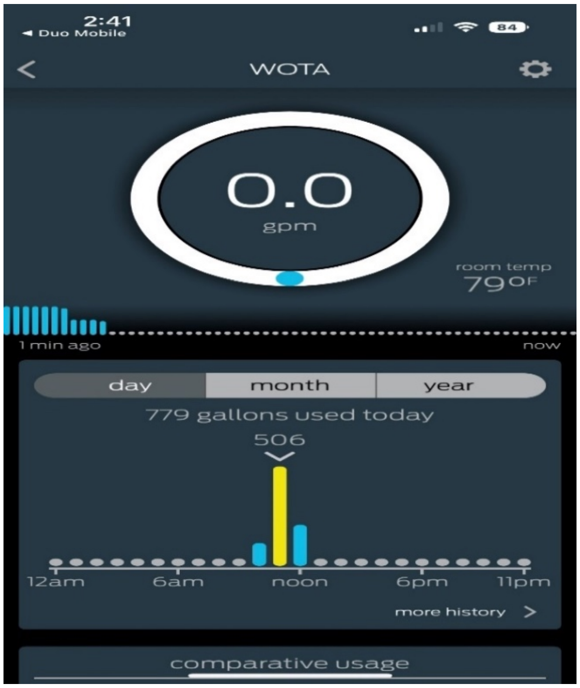
RELATIVE HUMIDITY 97.3% RISING >

BAROMETRIC PRESSURE 1,011.9mb RISING >

DEWPOINT 16.2°C < FALLING

Figure 13: Sensorpush Display of Inlet and Outlet Air Properties.

Figure 14 shows a typical display of the water flow rate. One can see that for this particular run (after the shutting off water), the total amount of water used in one hour was 1,537 liters (or 31.91 L/min). This will also be used in future modeling of the system and its performance.



779 gallons used today

Figure 14: Stramlabs Cooling-Water Flow-Rate Display.

Figure 15 shows the effect of soil temperature (or cooling water) on the amount of condensed water using the EES program. This program run is based on the collected air temperature and relative humidity over the months of January to February. The minimum air temperature was 20.5°F, the maximum was 35.5°F, and the average was 26.9°F. The program used an assumed soil temperature ranging from 18°C to 26°C to calculate the hourly amount of water collected. This graph clearly shows, and as expected, that the amount of condensed water increases as the soil temperature decreases. Depending on the site and other economic factors, the coolant temperature (or underground soil temperature) is recommended to be at 20°C or less.

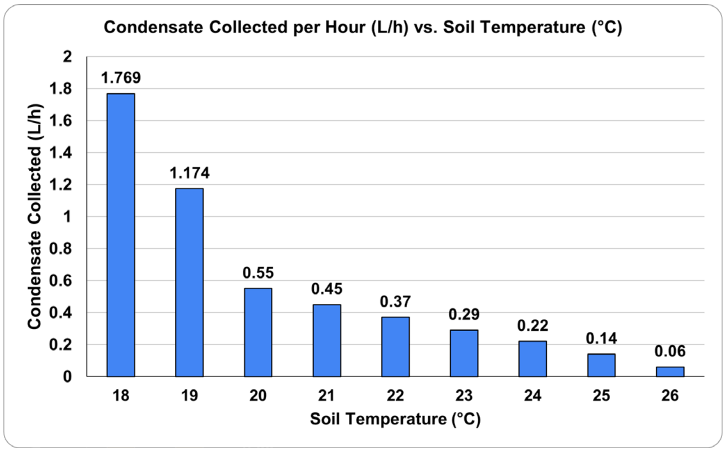


Figure 15: Effect of Soil Temperature on the Amount of Collected Water.

The physical on-site system is now collecting an average of 0.45 L per hour of condensed water when the average atmospheric temperature is 28.3 °C, relative humidity of 81.64%, and a simulated cold underground temperature of 20.2 °C. Figure 16 shows a photo of the collected water during one of the runs in August 2022.

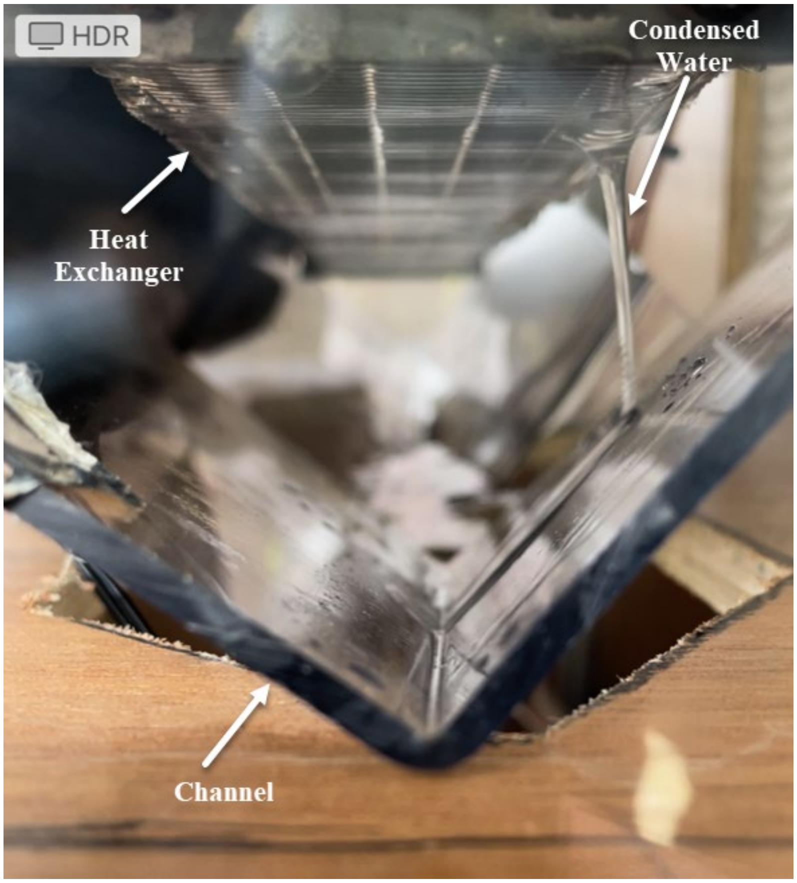


Figure 16: Collected Water During an Experimental Run.

3.1 Future Work

In the coming year, we are planning the following:

1. To collect a year's worth of data. This data will be used to model the performance of a scaled-up systems and at different locations around the world. For example, Houston Texas, Delhi, India, United Arab Emirates, and Basra, Iraq. We plan to use two modeling tools: EES and Stella. This will require underground temperature data at these locations.
2. Replace the clamp on the water meter with an inline meter to get an instantaneous rate rather than the average rate.
3. Install a video display explaining the system and its possibilities for hotel guests.
4. Install a small photovoltaic power station so that the system will be independent in its power.

3.2 Discussion and Lessons Learned

This multi-year project was a great educational and learning experience for all stakeholders: faculty, students, resort management, and employees.

There are important considerations for students participating in a study abroad program, especially one focused on a specific project like the one in Costa Rica. To expand on some points:

1. Cultural preparation is essential for any study abroad program. It's important for students to understand the culture, customs, and expectations of the place they are visiting. This can help avoid misunderstandings and cultural insensitivity. In addition, communicating with people from different cultures and languages is a valuable skill that can benefit students in many aspects of their lives. Learning how to appreciate and understand other cultures can help avoid misunderstandings and create more meaningful relationships.
2. This can also be applied to learning about different organizational cultures they may find themselves in during their careers.
3. Employability skills are also important for students to develop. Direct interaction with an international client can help students build skills in communication, negotiation, problem-solving, and project management.
4. Planning and preparation are key for any project, and even more so when resources are limited. Students who had to plan, purchase, and haul their own materials likely gained valuable experience in project management and resource allocation.
5. Learning from mistakes and planning for multiple scenarios is a crucial skill in any field. Students who experienced shortcomings in machinery or materials likely learned how to problem-solve and adapt to unexpected situations.
6. Sustainable solutions are becoming increasingly important in many fields, and learning about sustainable practices in the resort can help students become more environmentally conscious and responsible.
7. Time management is essential in any project, and students who had to complete their work within a three-week time frame likely gained valuable experience in prioritizing tasks and managing their time effectively.
8. Weather constraints can be unpredictable and difficult to manage, but learning how to plan for potential weather-related issues can help students become more prepared and adaptable.
9. Understanding the priorities and constraints of the client is important in any project. Students who learn to work within these constraints can gain valuable experience navigating complex professional relationships.

The team has made progress toward generating water from the atmosphere while utilizing geothermal properties. With assistance from resort facility workers, the team accomplished a proof of concept with potential for future research using our measured data and system modeling. The students successfully connected concepts and found solutions to each problem they encountered. Despite the team’s accomplishments, there were lessons learned that our team gained after the end of the project. This multi-disciplinary project challenged the team to broaden their focus to encompass every aspects from technical to project management skills. In this section, we will cover the items the team succeeded in as well as items that could be done differently.

As mentioned before, we have a proof of concept that the device can be used to address water scarcity and can be scaled-up. Before turning this concept into reality, the importance of understanding and applying basic mechanical systems cannot be overlooked. One of the challenges that the team faced when designing the prototype is applying their knowledge of fluid mechanics into plumbing and mechanical components. There were many questions as to what type of piping materials to use, how will they be connected, the number of fittings needed, what pressure to set the system at, how to control the flow rate, and how to fill and vent the system needed to be addressed. Several of these questions were unanswered, leading the team to develop a temporary solution. For example, the team did not take into consideration the process to fill and vent the system. Another concern the team had was how to control the flow rate of the system. The team approach was to utilize a basic ball valve to control the flow and to use an in-line pressure gauge. The flaw with this approach, that we discovered later, was that ball valves are not the best for making fine adjustments to the flow rate. Instead, the team should have investigated more into valves with throttling capabilities, such as needle valves since they can offer precise flow control. In hindsight, a thorough investigation into mechanical parts and processes would have prevented some technical setbacks during the implementation phase of the project.

The design process of the project had several complications. The first issue was to transform the design concept into a practical and scaled-up prototype. As mentioned before, there were several prototypes that the team considered but were never fully committed. This was due to the impracticality of the design as well as the appearance overall. Thus, the team struggled to come up with a design that complement the idea of being practical and upscaled until weeks before leaving for the trip. The second issue regarding the design process was figuring out the best layout of the internal components of the system. The sizes and dimensions of the heat exchanger, the water pump, the water collection tank, and the data acquisition system played a large role in defining the size of the housing but knowing its proper placement was ambiguous. It was not until the facilities workers installed the electrical box that the team could decide where to set internal components. For future researchers planning to recreate this project, having a strong understanding of design work, and planning every detail is critical to ensure that the delivery of the project will match the design intention.

Lastly, team management played an important role in delivering the project. Working together on this project is easier said than done. Coming from different backgrounds, there were many times that the team needed to share the same objective and have the same goals in mind. To mitigate these issues, communication was a big emphasis throughout the project to keep everyone informed on the progress and hold each other accountable for delegated tasks. The team held two weekly meetings to discuss the plan for the week and what to anticipate in the upcoming weeks. Although measures were taken to maintain communication, there were a few instances where support from team members was insufficient and work was not properly communicated. This led to several reworks and transfer of responsibilities. For example, one team member incorrectly calibrated a sensor and did not communicate the information, leading the rest of the team to read incorrect data. As a result, the entire team had to recalibrate the sensor and put on hold several other tasks. Although the team was ready to support each other, lack of communication delayed the progress of the project. This experience helped the team realize that having proper communication and forceful backup was necessary to ensure all the work was done correctly and hold each other accountable for their actions.

The overall experience of working on this project provided a multitude of important skills that could not be obtained from a classroom. The result of the project includes having stronger technical knowledge in mechanical system, instrumentation, and project management skills. After testing the prototype, it was made clear what ideas worked and which needed more investigation, such as how to properly fill and vent the system. The element of project management was the other area that the team learned to appreciate. Especially the importance of communication and support as it represents the connection between each other to the project. This project helped this team develop teamwork and problem-solving skills.

On the technical aspects, for any AWG system that plans to utilize geothermal energy to cool the system, soil temperature must be verified to be at 20°C or lower before implementation. Soil temp variation can be easily obtained in many parts of the US. However, it may not be available in other parts of the world and actual data must be measured. One can also look at cool underground water as a potential coolant in using the AWG.

4. Conclusion

A proof of concept for an AWG is presented here. The physical on-site system now collects an average of 0.45 L per hour of condensed water when the average atmospheric temperature is 28.3 C, relative humidity is 81.64%, and a simulated cold underground temperature of 20.2 °C. Before implementing such a system, a thorough modeling must be performed for the local atmospheric air temperature, relative humidity, and underground soil or water temperatures of 20°C or lower must be verified and modeled before installing the system.

Participating in an international capstone project can provide students with a unique and valuable educational experience that can help them develop important skills and prepare them for a globalized workforce.

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