

Atmospheric Vapor Extraction Device

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Final Report

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1. Introduction

The team wishes to put into practice an idea proposed by Chris Allender who is a biological sciences graduate student at NAU. Chris wishes to build a device that will help in the study of vapor extraction from the atmosphere. A constant supply of fresh water, coupled with an ever increasing human population has resulted an unprecedented fresh water shortage among developing nations as well as developed nations. Approximately two point five percent of the earth's water supplies are freshwater (National Geographic 2015). While approximately one percent of these freshwater is easily accessible, the remaining one half percent remains an untapped potential which contributes to the global clean water crisis.

Over extraction of freshwater from the world's reserves has resulted in unprecedented constraints on the supply of fresh water. Despite the numerous advances in the technologies that signify our modern world, such as desalination plants, the overall constraints in the freshwater supply is still a recurring issue among nations. Couple this with non-conservative habits that are common for most households, institutions, and business organizations, the need a for new methods of mining freshwater. As such, innovative techniques like vapor extraction possesses the ability to counteract some of the rising needs for water

2. Problem Statement

The client, Mr. Christopher J Allender, is looking for a device that is capable of extracting water from the atmosphere. Mr. Allender would like the device to collect data in order to find the optimal condition for which a maximum amount of water can be extracted. Though water vapor extraction devices do exist, there has not been enough research to find the optimal conditions. This project will serve as a teaching tool for future devices, and will possibly be used to aid communities that lack a potable water supply. The team's goal is to create a working

atmospheric vapor extraction device that will be tested in different conditions, including: pressure, temperature, elevation, humidity, etc.

The frame and lid have been completed and only the electronics remain unfinished. All of the necessary components have already been purchased and are nearly wired in. The largest task left is coding the electronics to operate properly.

3. Concept

The team identified three main functions of the device as shown in Figure 1. First, it needs to have a power source; second, it needs to have a condensing process; and lastly, it must have sensing equipment to detect and log the ambient weather conditions.

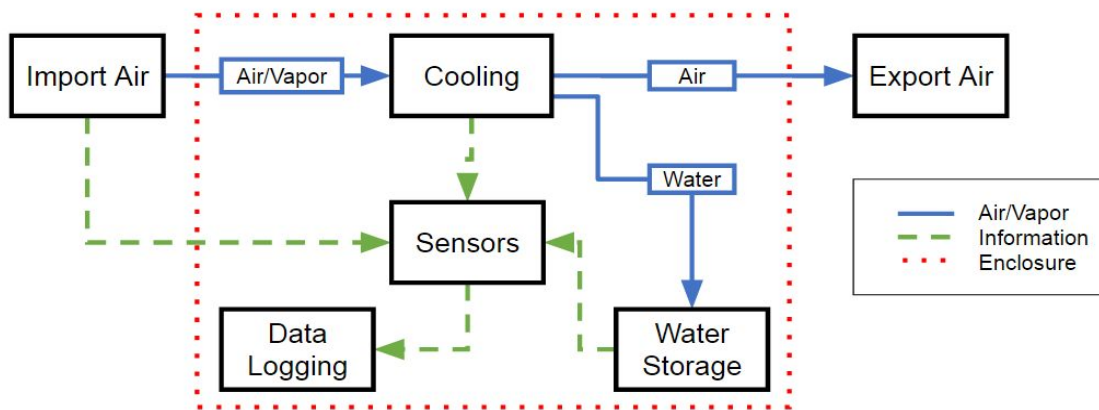


Figure 1 - The Functional Diagram

The condensing process cools the air by dissipating the heat. Many refrigeration devices are available on the market to do this, we chose to use koolatron 12 volt cooler which can cool down up to 22°C below the ambient temperature.

Condensation results when air is cooled to its dew point temperature for its current pressure and relative humidity. Considering the average annual temperatures, elevation, and relative humidity of Flagstaff, the team estimates that the dew point temperature of the ambient air can be reached by cooling the air by 15 or fewer degrees fahrenheit.

The koolatron is expected to perform about three times as well as required. Because the air inside the cooler can be so cold, it allowed the team to design a continuous air system where ambient air is passed through the system and cools enough to condense out most of its water before leaving. To cool the ambient air, they made use of an aluminum heat exchanger that is cooled by air recirculated in the koolatron. Water was allowed to collect at the bottom of the cooler before being pumped out. The intended design is shown in Figure 2.

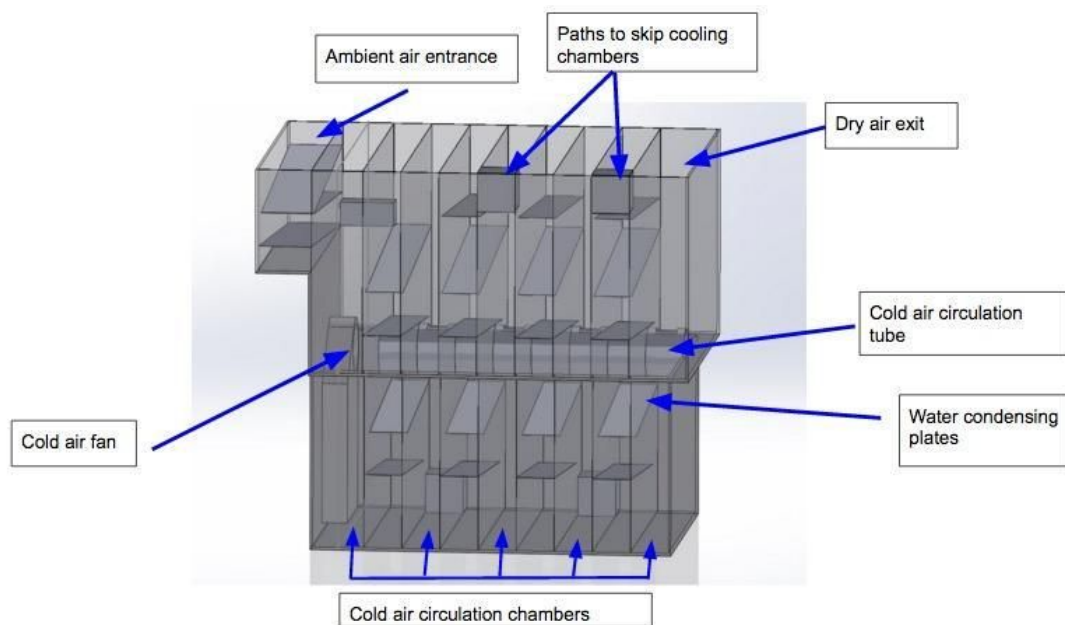


Figure 2 - Design of Heat Exchanger Assembly

4. Cooling Calculations

The following section outlines the calculations for the temperature at which the water vapor in the air will precipitate out as dew. The calculations were done using the Magnus Formula which is illustrated in Figure 3. Temperature and relative humidity of the air are necessary. For these values, it was assumed that the average annual temperature of Flagstaff, Arizona was about 16°C and that the average annual relative humidity was about 53%. These values indicate that the air must be cooled to near 6.43°C in order to extract the air. Therefore, the team required a cooler that was capable of reducing the ambient air temperature by approx. 10°C. The selected koolatron cooler is rated at over double (22°C) the required amount.

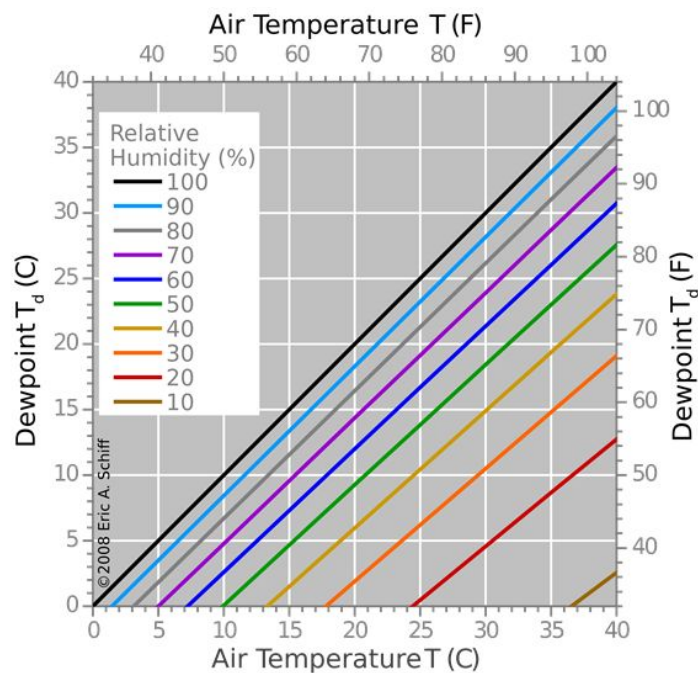


Figure 3 - Diagram of the Magnus Formula to Estimate Dew Point Temperature

5. Electronic Devices

The Arduino runs on an open-source platform capable of reading inputs, and returning an output. For the Atmospheric Vapor Extraction Device, the Arduino is used to control the following components: DHT11, Fans, Peristaltic Liquid Pump, and Liquid Level Sensor. The DHT11 is a humidity/ temperature sensor that is capable of reading data through Arduino. For this project 2 DHT11 sensors are used, one for the ambient air conditions and one for the exhaust. This allows the user to determine the change in humidity before and after the air goes through the device. Since this project requires a form of data storage, an SD card module is used. The SD module utilizes a 2GB SD card, which can be read through a computer. Furthermore, since the Arduino does not have an internal clock, a Real Time Clock module (RTC) is also required to establish a time and date. With the RTC, the collected data can be correlated with a time and day.

The fans used in this project are 12V DC PC fans in series. The Functional Diagram (Figure 1) is used to portray this process, where the import air can be attributed to the inlet fan and export air can be attributed to the exhaust fan. Depending on the humidity, the fan will either turn on/off. Additionally, if the fan is on, its speed will be dependent on the humidity. For instance, if the humidity is under 20%, the fans will turn off; on the other hand if the humidity is above 20% the fan will turn on. As the humidity increases above 20%, the fan will decrease in speed, in order to push less air through the system. This will give the system enough time to cool the moister air in an efficient manner.

The peristaltic liquid pump and liquid level sensor are used to measure the amount of water collected on a daily basis. With the RTC, the pump can be set to turn on once a day. The pump begins by pumping water into a pipe where the liquid level sensor is housed. The liquid level sensor reads the height, and with the known pipe diameter the volume of water can be determined. The water is then pumped out of the pipe and into a reservoir. Due to the liquid

level sensor's height limit, this process must be repeated until the water within the system has been depleted. Figure 4 displays the pump housing and the liquid level sensor inside of its measurement pipe.



Figure 4 - The Pump Assembly

6. Lid Assembly

Instead of the original lid, the team decided to use a high density polystyrene that was purchased from HomeCo, so it can be customized as the project needed. A vertical band saw was used to cut the polystyrene, as well as the box cutter to cut 1 inch by 1 inch indent. The lid presses into the heat exchanger panels by 0.5 inch to prevent air leaking between channels, as well as outside the cooler. The polystyrene lid (Figure 5) contains handles, piping, and the electronics housing. Handles were needed to remove the lid easily and were secured while using 1 inch diameter aluminum washers on the underside (Figure 6). There were two holes drilled in the lid for the air pipes. Pipes were needed to ensure the ambient air goes in and out the cooler. Two fans has been used to circulate the air. A small bracket was fabricated to attach the humidity sensors in the flow of the pipes. To increase the airflow rate, funnels were used to concentrate the air into

the pipes. A 0.1 inch hole was drilled in the lid to insert the water pump tubing. Lastly, a housing box used to contain all the electronic devices was installed. There are two holes in the sides of the box for wiring the fans, sensors, and the water pump.

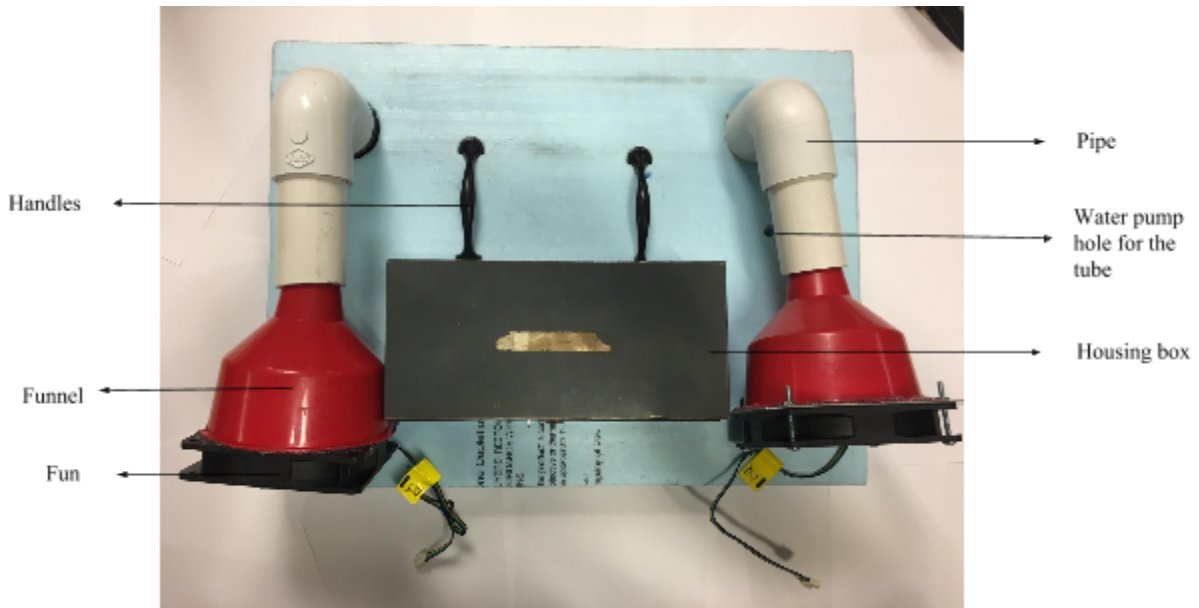


Figure 5 - Top View of the Lid Assembly



Figure 6 - Bottom View of the Lid Assembly

7. Design

Three coolers were taken into consideration. The first option, the Igloo 40-Quart, is a cooler to store food and beverages of maximum 40 quarts. It was rejected because there were negative reviews published about the product. The second option, the Dometic 15-quart, is a cooling facility that can be used at picnics, dorms etc. It was rejected due to its capacity issues as it is the smallest in size. Lastly, the Koolatron 52 - Quart was chosen because it was the best product to fit the needs of the team.

The Koolatron cooler was chosen because of several features that satisfy the design criteria. The appliance is capable of cooling 40 degrees Fahrenheit below the surroundings temperature. It is light in weight and weighs about 17.4 pounds. The appliance has good size for a portable refrigerator measuring 20 x 15.5 x 20 inches. It has a 12V outlet fitted with 120V AC adapter.

The traditional lid will be replaced by a customized polystyrene foam lid 2 inches thick. The system will use the concept of ambient air cycle. The lid will have a piping system. The input pipe will ensure ambient air input and the output pipe will release the dry air outside. On the surface of the lid, fans will be introduced to circulate the air.

There will be a combination of fans that will be on under the lid. The operation of the fans will depend on atmospheric conditions. The speed of the fan will be controlled and adjusted by an arduino, a microcontroller, and an air sensor. The maximum level of air flow to be maintained by the device will be 57.67 CFM. The fan speed will be around 1500 revolutions per minute (RPM) with a upper and lower bound of 10%. The fans will be connected to the funnel which in turn will be linked to tube assembly.

8. Manufacturing

In order to manufacture the cooling channels 22-gage aluminum sheet metal was purchased from Boyer Metal Co in Flagstaff, AZ. The team decided aluminum was the best choice to make the channels because of its low weight, resistance to corrosion, affordability, and flexibility. Two plate templates were made in order to make the cooling assembly. One template was made for plates separating the cool air chambers from the ambient air chambers. Another template was made for plates going between the first plates. The function of these pieces was to redirect the air back and forth so that the ambient air has more time and cold aluminum surfaces to come in contact with thus causing condensation. The team used a large piece of paper to trace the outline of the inside of the cooler. This method proved to make a plate that had a snug fit. A picture of the plate can be seen below in Figure 7.



Figure 7 - Heat Exchanger Assembly

The tools used to cut the plate to size were tin snips and electric metal shears. The electric shears were used to cut the rough outline of the plate then fine tuned with the tin snips. After one good metal plate was made seven reproductions were created. The plate inserts were intended to redirect the air and separated the cooling chambers. In order to connect the rectangular inserts to the plates the team created four notches on the outside of the rectangular inserts. Using a Dremel, slots were machined into the plates for the notches to slide into and then bent to secure them. A picture of the inserts before being installed can be seen below in Figure 8.



Figure 8 - Templates of Inserts in Air Chambers

To circulate the cool air being produced from the cooler, a 2 inch stainless steel pipe was purchased from Boyer Metal Co. The pipe was then machined to size using a horizontal band saw. Using a Manual Mill $\frac{1}{4}$ inch holes were drilled into the pipe. Each set of holes is 2 inches apart and has 4 holes separated equally around the circumference of the pipe. The holes in the

pipings line up with the cold air chambers to circulate the cold air around the system with one end of the pipe closed off and one end open for the cool air to be pumped into via the fan provided in the cooler. In order for the ambient air to skip through the cold air chambers, 1 inch aluminum square tubing was purchased from HomeCo and cut to size. To connect the square tubing to the plates a thin metal strip was cut and then pushed through the tubing and bent on either side of the bypassed air chamber. Using super glue, the bent pieces of sheet metal were glued to the plates. The manufacturing of the cooling assembly took 6 weeks. Below is the final cooling assembly (Figure 9). The total cost of the cooling assembly was \$555.49.



Figure 9 - Finished Heat Exchanger Assembly

9. Results

The device was then tested through four days with slightly different conditions. The tests were conducted in both a low and high humidity environment, and with one and two fans running. The two separate humidities were to show that it could collect water in both of those environments, and to show the difference in water collected. The trials with different amounts of fans running was because our initial airflow calculations only called for one fan to be necessary to move the air at a desired speed, but the team believed that with all of the air resistance from the frame more air throughput would be needed. Both were tested to ensure that increasing the airflow would in fact increase the water production.

Table 1 - water collected

Humidity (RH%)	Temp. (°F)	Fan(s) Running	Time (hr)	Water (mL)
65	70	Both	24	300
35	70	Both	24	80
65	70	Inlet	24	250
35	70	Inlet	24	30

These numbers reinforce both of the assumptions that a higher relative humidity would lead to more water production, and that using both fans would increase the water output. The system could be scaled up to reach the goal of 2 L per day.

10. Bill of Materials

Besides the main components, the team decided to purchase aluminum sheets, fans, a styrofoam insulating lid, and pipes. The aluminum sheet was used in the manufacturing of the cooling chambers, the styrofoam lid was used as an insulated lid in which holes can be drilled through. The inlet and outlet were installed on the styrofoam lid. The fans were placed near the inlet and outlet, in order to maintain airflow.

The team purchased the aluminum sheets, styrofoam lid, and pipes from Home Depot due to its convenience and low price. Since computer fans proved to be sufficient, we purchased a 3-pack on amazon for \$11. For this project no additional labor was considered because it was all done in house. The final Bill of Materials is shown below in Table 2.

Table 2 - Bill of Materials

Parts	Price
Portable Cooler	\$169.00
Metal and Tools	\$105.00
Lid Assembly	\$88.00
Electronics	\$193.49
Total	\$555.49

11. Future Modifications

To better improve the performance of the device, the team would first aim to increase the flow of the ambient air by improving the fan power. This would increase the amount of water in the system by providing a greater supply of higher relative humidity air. This is the primary addition that would improve water collection. In addition to increasing the fan power, the team would also look into sealing the edges of the heat exchanger to reduce the loss in flow due to unnecessary mixing. Furthermore, with enough airflow, the heat exchanger could possess more plates to increase surface area and allow more heat transfer. Lastly, the cooler could be scaled up into a larger (but less portable) device, such as a stand alone freezer. This would allow for colder temperatures to take the relative humidity of the outlet air lower, as well as provide room for a much larger heat exchanger and more powerful fans.

12. Conclusion

The prototype was expected to take measurement of the ambient air, to cool that air to its dew point temperature, and to condense water out of it using an air to air heat exchanger cooled by a koolatron portable cooler. Special considerations were taken to preserve the insulating properties of the cooler by replacing the lid with a polystyrene foam board which allowed easy modifications such as installation of airflow pipings and water tubing. The microcontroller was installed with sensors to monitor and regulate the amount of air and water passing through the system. The prototype remained well under budget. The team will move forward by finishing the coding and beginning data collection. With experimental data, they will optimize the system for maximum liquid water output.

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