# Deliverable G - Prototype II and Customer Feedback

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**Abstract**

This document provides an overview of Team Chad's second prototype for a geothermal heat exchanger, and their plans for their third and final prototype. Based on feedback from the client, results from our tests from last week's prototyping test plan 2, and feedback from potential users, we created prototype 2, which focuses solely on the heat exchanger. Our main purpose is to demonstrate our second prototype and plan for our third prototype.

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## 1.0 Introduction

The client's feedback, the results from our first prototype, and feedback from potential clients has helped us draft a second prototype. We provided an analysis of our second prototype and outlined how it does based on our prototyping test plan 2. We then created a prototyping test plan 3, which will be our final prototype.

## 2.0 Feedback from our client

The client provided minimal feedback, nonetheless, it was valuable and encouraging. He said that he was anticipating and waiting to see what we had in store. This was encouraging to us as we interpreted this as meaning that he did not see large red flags in our project so far. He also said that he thought that the temperature sensor above ground that automatically changes the system from a closed loop to an open loop and vise-versa, was a very good idea. We appreciate this feedback and feel encouraged.

## 3.0 Prototype II

Figure 3.1: Side-top view of prototype II

Figure 3.2: Internal view of prototype II

Prototype 2 focuses solely on the heat exchanger. We intended to build the entire heat exchanger. We wanted to put a layer of concrete in between the plastic layer and the heat exchanger box and we also wanted to add our pipes. Unfortunately, due to many circumstances including teammate availability and material availability (we don't have the pipes from the maker store yet), we were not able to accomplish these things this week. The prototyping objectives for this week were to get a better idea of how our heat exchanger will function and gain insight on the layout of the heat exchanger. We wanted more information on these things as we believe that the heat exchanger is the most crucial part of the design and we wanted to know what has yet to be done, and the materials we need to obtain to do it.

We are extremely satisfied with the way our heat exchanger box turned out. It was a lot of work and it turned out quite nicely, so as of now, we are very content with the way things are going and hope to finish the rest of the components of the heat exchanger this week. We also plan to leave the top of all layers completely open for observation so users can see all of the layers and the layout of the pipes on design day.We are aware of unforeseen circumstances as engineers that cause us to change plans or alter timelines. We have done a great job adjusting our plans and our timelines and have been very flexible with progress, but rigid with deadlines. Although our second prototype was not what we had planned on it being, we have full confidence in ourselves and our team that we will have no trouble meeting the deadlines for the final design and weekly deliverables.

## 4.0 Analysis of prototype II

Prototype two has two main components as of now: the heat exchanger box and the plastic layer. The heat exchanger box is completely made of scrap metal found in the maker lab. The brake was used to bend the sheet metal into the desired shape and the drill and the spot welder were used to seal pieces together. The scrap metal was cut using the shear and the holes were also made with the drill. The holes measure around 1.5 inches wide and are perfect for the 1.5 inch pipes the maker store sells. These are the pipes we plan on using in our prototype III. The box is almost completely sealed, however, in some corners, a small amount of air or water may be able to escape so we will be sealing the corners using epoxy glue. We will also be sealing the pipes to the heat exchanger box using epoxy glue. The plastic layer is fairly simple; it is simply a plastic box bought from the dollar store. A large part of the reason that we bought this box is because we plan on creating a cement exterior around the heat exchanger box, and we needed a plastic box to mold this layer of cement. The plastic layer plays a large role in keeping elements in the soil that may seep in with groundwater out of the heat exchanger, and also plays a large role in keeping the heat inside the heat exchanger. The plastic layer is absolutely crucial to the design, however, we do want this plastic layer to be relatively thin so that it allows the geothermal heat from the surroundings into the heat exchanger. As of now, our plastic layer is the plastic box and is a bit thicker than what we are comfortable with. Therefore, if time permits, once we secure the concrete layer around the heat exchanger box, we plan on removing the plastic box and replacing it with a thinner plastic layer. If time does not permit this, the box is also acceptable in our view.

## 5.0 Results from prototyping test plan 2

Test ID: 1,  Measure the efficiency of the heat exchanger.

Unfortunately, we were unable to carry out this test as we did not complete the pipes surrounded by the clay and water mixture.

Test ID: 2, Analyzing the integration of the heat exchanger in the system and the seals.

For this test we submerged the bottom portion of the heat exchanger in the bathtub. We did not submerge the entire thing as we plan to leave the top open for observation for our final design. The goal of the plastic is to protect the heat exchanger from groundwater. The plastic layer did it’s job very well.

Figure 5.1: The heat exchanger submerged in water.

The plastic layer protected the heat exchanger and no bubbles emerged. However, we also submerged the heat exchanger box itself and it did not fare well against the water. Water leaked in immediately. We drew the conclusion that the connections will need to be sealed by epoxy glue. Even though the heat exchanger box is protected from the groundwater by the concrete layer and the plastic layer, it will contain pipes surrounded by a mixture of clay and water, so it must not leak. If it leaks, our clay may dry out and shrink, potentially not surrounding the pipes completely. Another issue that may happen if it leaks is we may lose heat. The corners have not been sealed by epoxy glue just yet, but that will occur this week.

Test ID: 3, Analyzing the dimensions of the heat exchanger and determining the perfect dimensions

In order to do this, knowing information on the size of the pipes we had access to was very valuable. On the maker store website, we looked for pipes and found 1.5inch aluminum pipes for a great price. We decided to use these pipes and then we began comparing a diameter of 1.5 inch pipes to different things. We mostly used existing things we had around the house. We did initially want to create different sizes of heat exchangers and test them and note the pros and cons of each size, but we realized that this was not realistic so we just compared the diameter of the pipes we planned on using to arbitrary things, like boxes. For example, one team member compared it to a large box and decided that the box was far too large for 1.5 inch pipes.


Figure 5.2: We compared a large box to the diameter of the pipe.

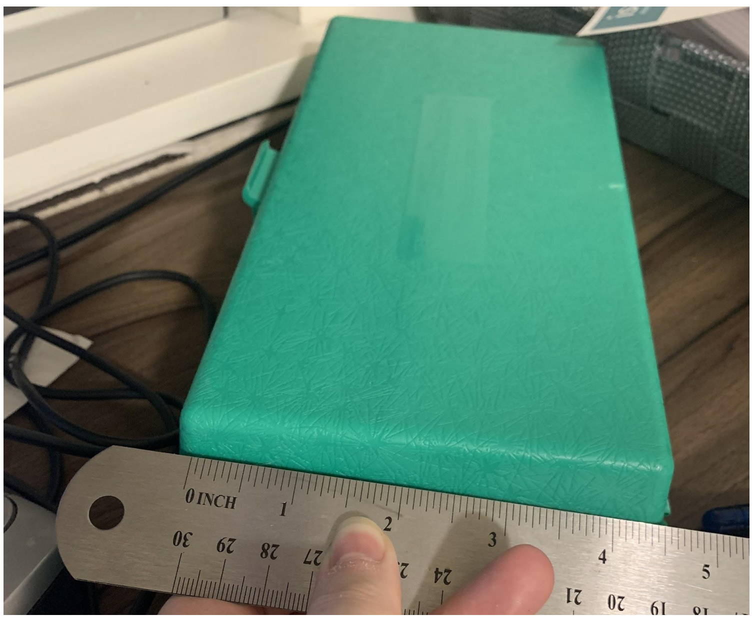

Figure 5.3: We compared a small box to the diameter of the pipe.

After comparing several different sized things, we decided that a heat exchanger box roughly the size of a shoe box would be the perfect size for what we want to accomplish. We want it to be fairly small, as we want a feasible prototype, but we also want our 1.5 inch pipes to comfortably snake through the heat exchanger box and leave space to be surrounded by a layer of clay and water. Therefore, the results of this test gave us the perfect size for our heat exchanger which ended up being 30cm long, 19cm wide, and 10.5cm deep.

Test ID: 4, Assessing structural soundness of the heat exchanger

In order to do this, we attempted to compress the four sides of the heat exchanger all at once. This is considered to be around 400 Newtons [1] on each side at one time. The heat exchanger held up just fine. Because the heat exchanger has an open top, we flipped it to simulate weight bearing down on the top of the heat exchanger, as shown in the image.

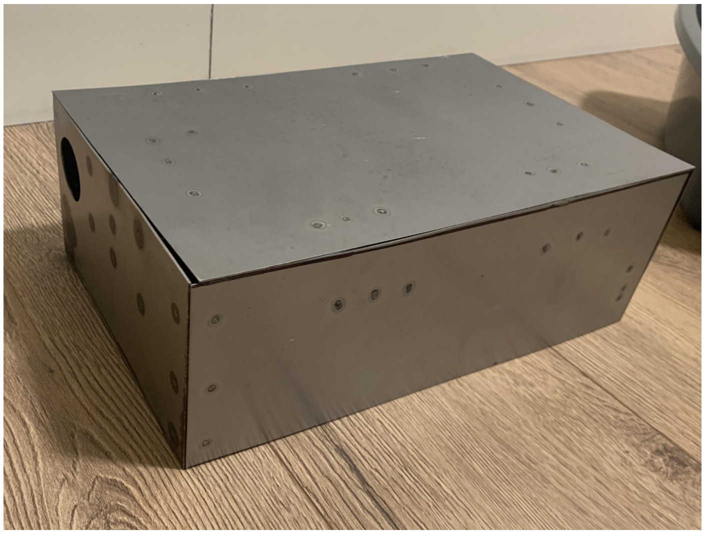

Figure 5.4: The position of the heat exchanger box before we put weight on the top

A 170 pound male stood on top of the heat exchanger and it withstood the weight. This is almost 1700 Newtons of force. Our heat exchanger box is very strong and will have no trouble withstanding the weight of the soil around it.

[1] “How many newtons is a push?,” *How many newtons is a push? | EveryThingWhat.com*. [Online]. Available: https://everythingwhat.com/how-many-newtons-is-a-push. [Accessed: 13-Mar-2022].

Test ID: 5, Getting feedback on the design

Just as we did for our prototype I, we wanted to obtain feedback from individuals who had no prior knowledge of the project. It is always so easy to make sense of your own project, but the real challenge is to show and explain it to a potential user and get feedback from them; ensuring that it is logical and that users would actually be interested.

The first bit of feedback that we received was general confusion. Without the pipes in the heat exchanger, many wondered how it was going to work. After a thorough and hopefully unbiased, factual explanation, the individuals that began as confused agreed that our heat exchanger made a lot of sense, and really liked the box that we had created. We also received feedback regarding how great of an idea it is to leave the top open for observation, which was encouraging. Other than the initial confusion, all individuals said that it made lots of sense and that they would be happy to invest in a product like this. We spoke to a couple of people that were more familiar with the ideas of conduction and convection, and they gave us valuable feedback regarding the layout of the pipes, which is something we were debating. The two individuals who felt qualified to comment on this both agreed that we should have our pipes snaking back and forth within the heat exchanger to create more surface area for conduction from the warmed clay and water to the pipes, and more area for convection from the warm pipes to the air circulating through them. This was extremely valuable as this was something that the team was on the fence about as creating pipes that snake back and forth is not super easy, but now we are confident that this is what we will do.

**6.0 Feedback from potential users**

"I like this box a lot. Now that you've explained the geothermal heat exchanger, I think that this box will do very well. I just have one question about the pipes. In your initial design, they are in the shape of an S and curve back and forth; how do you plan on accomplishing this?"
-Louis L
Thanks Louis, that's very kind of you! That's also a really great question! We have considered a few different options with two of the top contenders being to simply swap the curved pipes for a straight pipe since it is not easy to curve pipes when we don't have access to a large amount of resources for this. The other option we have thought of is to create the curved portion out of layers of aluminum foil and seal it to the pipes. The setup would look like the following:

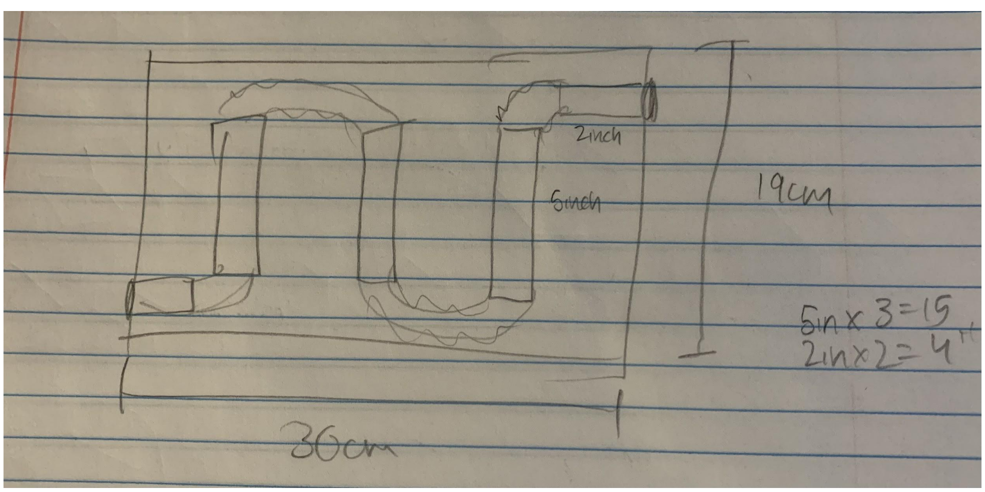


Figure 6.1: Potential option for setup of pipes in heat exchanger

"So far so good. I like it a lot and I think this is something I would buy. Does it require much attention? I am so busy with school lately, I don't have time to give anything else much effort or

attention.”
-Diana B
Thanks Diana! It does not require much attention at all. Once it is installed, the only attention it requires is to replace the fans every 10-20 years. We also have a temperature sensor near the air intake that triggers an automated valve which changes the system from an open loop to a closed loop, or vice-versa. This is super convenient and reduces the maintenance as nothing is manually changed in the system and does not require the user to monitor the temperature and change the valve that controls whether the system is in a closed loop or an opened loop.

“This looks like tough stuff. I’m so glad I’m in business. I do actually have a question though; if the heat exchanger is surrounded by so many layers, like there’s a plastic one on the outside, a concrete one and then the metal box, how does it even absorb heat from the earth?”
-Briana P
Good question Briana! The plastic layer on the outside is to ensure that moisture does not sneak in through the pores of the concrete. It is an extremely thin layer, as plastic is a poor conductor of heat, so it is mostly there to protect the system from moisture, and a large amount of geothermal heat will still continue through to the next layer. However, it also has the purpose of keeping heat in; the plastic layer, the concrete and the metal box of the heat exchanger work as a thermal storage medium to retain the warmth and transfer it to the air using conduction and convection. The next layer is the concrete layer. As concrete is a pretty good conductor of heat, the geothermal heat passes right through it. The next layer is the box made of metal. The heat also passes through the box made of metal and into the actual heat exchanger. Here, the heat is greeted by a mixture of clay and water that surrounds the pipes and transfers the heat by conduction to the pipes. The pipes are made of metal and will then transfer the heat by convection to the air circulating through them.

“I like all of what you have said so far. It’s great. I do have some feedback though; the top of your heat exchanger box comes off so easily, shouldn’t you guys weld it on to prevent hot air from escaping?”
-Dieunie D
We appreciate the feedback Dieunie! You have made a good point, and in the actual full size system, the box will be welded all around to prevent possibilities for warmth to escape, and the cement and plastic layers will also be on top. However, we have created a system with an open top for observation. On design day, we want individuals to be able to see all of the layers of the

system and also, the arrangements of the pipes in a mixture of clay and water within the heat exchanger. So this is why we've decided to leave the top off of this prototype.

## 7.0 Prototyping test plan 3

| ***Test ID*** | ***Test Objective (Why)*** | ***Description of Prototype used and of Basic Test Method (What)*** | ***Description of Results to be Recorded and how these results will be used (How)*** | ***Estimated Test duration and planned start date (When)*** | ***Stopping criteria*** |
|---|---|---|---|---|---|
| **1** | Test the operation of the system. | Prototype III:<br><br>Is the connection of all the system components.<br><br>Test Method:<br><br>Connect the system to the power supply. Turn on the supply fan. Check the air flow at the outlet pipe. Check the temperature at the outlet pipe. | The results are the airflow at the outlet pipe and the air temperature at the outlet pipe.<br><br>These results confirm whether or not the system works as it should be. | The estimated test duration is around 30 minutes. | If the air outlet temperature is lower than the air inlet temperature by a few or several degrees, stop the system. |
| **2** | Test the power supply unit. | Prototype III:<br><br>Is the connection of all the system components. | The results are the voltage and current. | The estimated test duration | The voltage and current should be within the |

| | | | | | |
|---|---|---|---|---|---|
| | | Test Method:<br><br>On a sunny day test the operation of the solar panel. Measure the voltage and current at the inverter level. | These results are used to check the electrical power needed for the supply fan. | is around 1 hour. | operation range. |
| **3** | Measure the water condensation in the pipe. | Prototype III:<br><br>Is the connection of all the system components.<br><br>Test Method:<br><br>Use a humidifier in the room and connect the return pipe to the room. Turn on the fan for one or two hours then measure the quantity of water collected at the sump pump level. | The results are the amount of water in liters collected at the sump pump for the operation time.<br><br>These results are used to confirm if the inclination of the pipe is sufficient to drain the condensed water to the sump pump level. | The estimated test duration is around 2 hours. | Operation time: 2 hours.<br><br>Quantity of water within the expected range. |
| **4** | Check the control unit of the shutoff valve of the | Prototype III:<br><br>Is the connection of all the system components. | The result is if the valve is closed during a cold day and open | The estimated test duration is around 30 minutes per | Visual inspection of the valve. |

| | | | | | |
|---|---|---|---|---|---|
| | outer door pipe. | Test Method:<br><br>On a cold day turn on the supply fan and check the valve if it is open or closed. On a warm day check again the valve openness. | during a warm day. The control unit operates as it should be.<br><br>These results are used to confirm the operation of the control unit of the valve. | day until the objective is fulfilled. | |
| **5** | Test the heat exchanger | Prototype III:<br><br>Is the connection of all the system components.<br><br>Test Method:<br><br>Determine the temperature going into the heat exchanger using a temperature gun, once the substance exits the heat exchanger measure the temperature once again at the exit using the temperature gun. | Once the prototype is active the temperature at the entrance and exit will be written down and will be used to determine the efficiency and to also determine if the exchanger is working properly as it was intended to. | The estimated test duration is around 10 minutes with 5 different trials deactivating then reactivating every for trial | Once all temperature is results are what were expected |

## 8.0 Wrike update

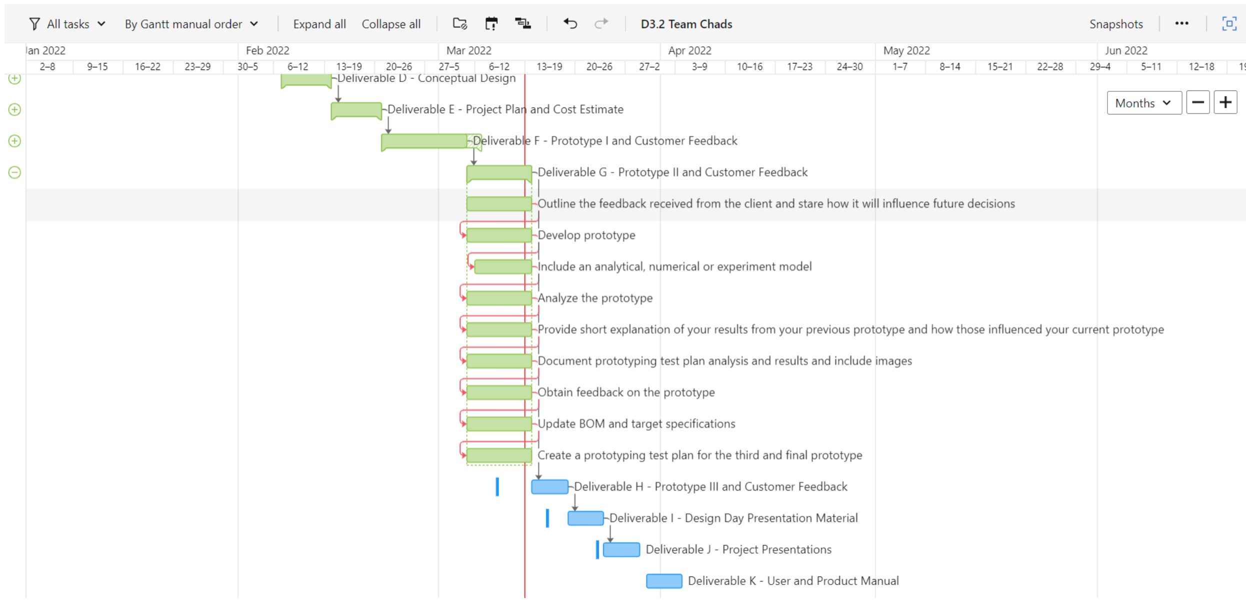


**Figure 8.1: Wrike Update**

https://www.wrike.com/frontend/ganttchart/index.html?snapshotId=vkUaQ1Mj0PW0ZqIL4gvnRkgZa4XdegrF%7CIE2DSNZVHA2DELSTGIYA

## 9.0 Conclusion

In conclusion, the client's feedback on our first prototype drove us to conclude with a better design for our second prototype. His feedback allowed us to iterate on the design and refine our solution. In this way, our client ultimately received a better solution, while our team learned and grew as a result of our client's positive feedback. The heat exchanger was researched intensively by our group to come to a conclusion to put a layer of concrete between the plastic layer. Throughout Deliverable G, we also answer some great questions about our prototype which help us look over our design from different perspectives and daily issues people may face. The more we improve our design, the more we look forward to seeing more questions to minimize any issues that may arise. Our tests mainly focused on the functionality of our prototype and gave us strong results that will help us in building our third and final prototype. This will help us conclude with our final design, with all aspects being at peak efficiency, environmentally conscious and economically smart.