GNG 1103

Design Project User and Product Manual

The Heat Exchange Chamber (THEC)

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Table 1. Acronyms

Acronym	Definition
BOM	Bill of Materials
GCHE	Ground-Coupled Heat Exchange
THEC	The Heat Exchange Chamber
DRHS	Dynamic Resistor Heating System

Table 2. Glossary

Term	Acronym	Definition

1 Introduction

This User and Product Manual (UPM) provides all the required information necessary to construct and operate this implementation of THEC. The manual contains detailed information on the design of the project, a startup guide for the system, a guide on how to use the system and its subcomponents, along with potential upgrades to the system. Along with this, this document provides step-by-step guides to build the subsystems of this project, and the necessary materials required for its construction. This document will also highlight the thoughts and considerations that went into the design process. Any testing conducted along with the errors produced by the testing will be documented. The conclusion of this document will provide an overview of the skills and tools that our group learned throughout this design process as well as potential upgrades/design choices that would have been made had our group not been constrained by time or budget.

2 Overview

The Heat Exchange Chamber (THEC) is a sustainable and environment friendly product with zero emissions. It is a Ground-Coupled Heat Exchange (GCHE) system with an emphasis on portability. It can be installed as a retrofit in existing buildings or in new construction. It functions on the principle that the ground temperature 6 ft below ground is between 10 C to 16 C year round. The heat exchange chamber is buried at least 5 ft below ground, and is connected to a fresh air inlet pipe, an air outlet pipe, and finally to the regular furnace blower inside a house. The furnace blower is activated by a thermostat, triggering the movement of air into the house through the chamber. A vent shutter is installed on the fresh air inlet so that this inlet may be closed during severe winter. Heat is exchanged by conduction and convection between the air being drawn in and the pipes within the chamber.

The current model for THEC cannot maintain a temperature higher than 15 degrees in cold situations. This presents a problem for the general Canadian population, due to temperatures dropping below -10 degrees during winter time. Therefore to appeal to the Canadian market THEC must be modified to allow the system to heat the air above 15 degrees centigrade during the Canadian winters. Along with this, the system has the following fundamental needs; The overall size of the system will be scalable for all different types of households and buildings. The system will be able to act as an open-loop and closed-loop system depending on the temperature. The system will have a condensation removal system which will prevent mold from forming in the pipes. The system will provide the functionality to keep the heating/cooling area at the constant required temperature. The system will be easily maintainable (low maintenance cost).The system will be environmentally friendly (low environmental cost). The system will be sustainable for the duration of a normal HVAC system (15-25 years). The system's energy consumption to heat or cool down system will be $1kW/100ft^2$. The system will use a storage chamber enclosed in a layer that has heat/cold storage capability. The system will use a network of pipes to exchange the outside air and the air inside the thermal storage medium.

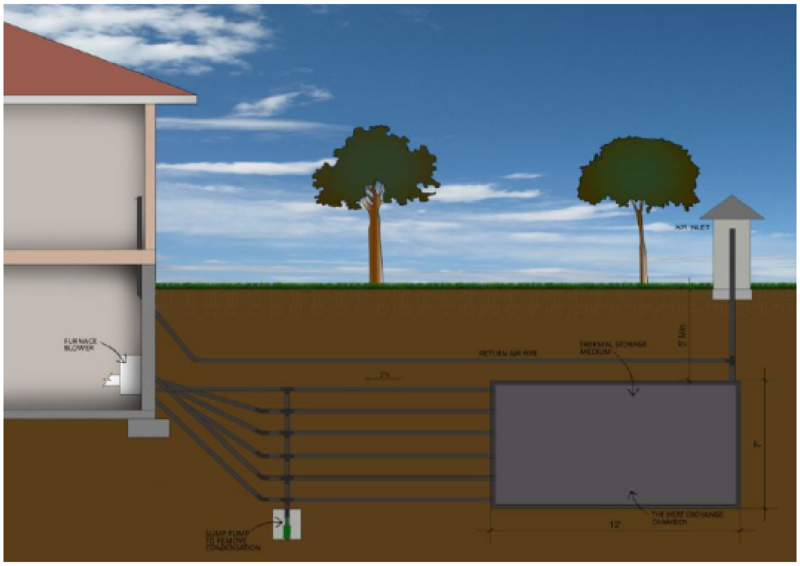


Figure 1 - THEC model provided by the client

Our product employs the same overall pipe and heat exchange chamber configuration as outlined by the client, with an added emphasis on compactness and portability.

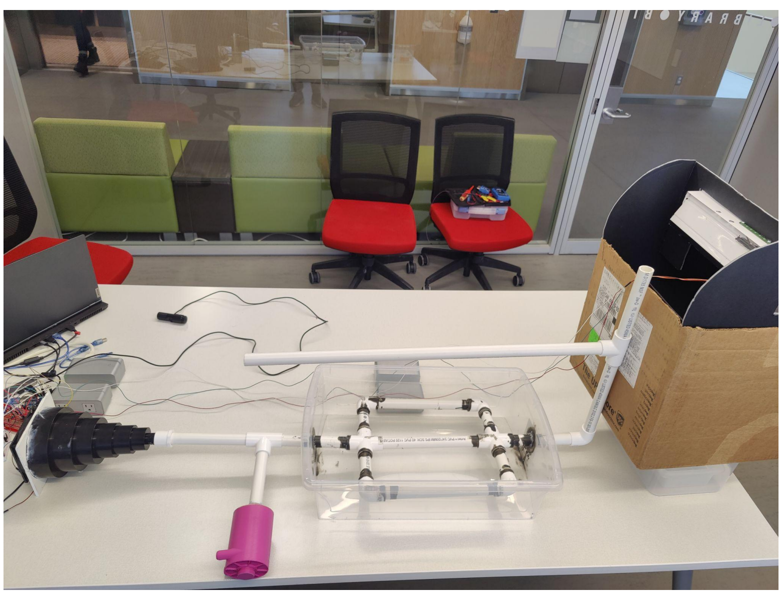


Figure 2 - Entire System and Assembly

Our product features many functions that allow for ease of accessibility along with functionality. The intake of the system employs a button to control A sump pump will be installed within the system to collect any excess condensation. Additionally, temperature sensors are installed at the intake, output, and the main THEC chamber to enable dynamic fan speed change depending on intake temperature using the Arduino Uno microcontroller.

The intake system consists of a cardboard housing, a servo motor, and a HVAC register. The THEC and piping system consists of the various PVC pipes and joints used in the system, along with a plastic container used as the THEC chamber. The sump pump of the system was created by 3D printing. The heating subsystem consists of the resistor ring, the temperature sensors, the intake fan, and the step-reducer used as housing for the heating system. The entire device is controlled using an Arduino Uno microcontroller, with temperature sensor inputs.

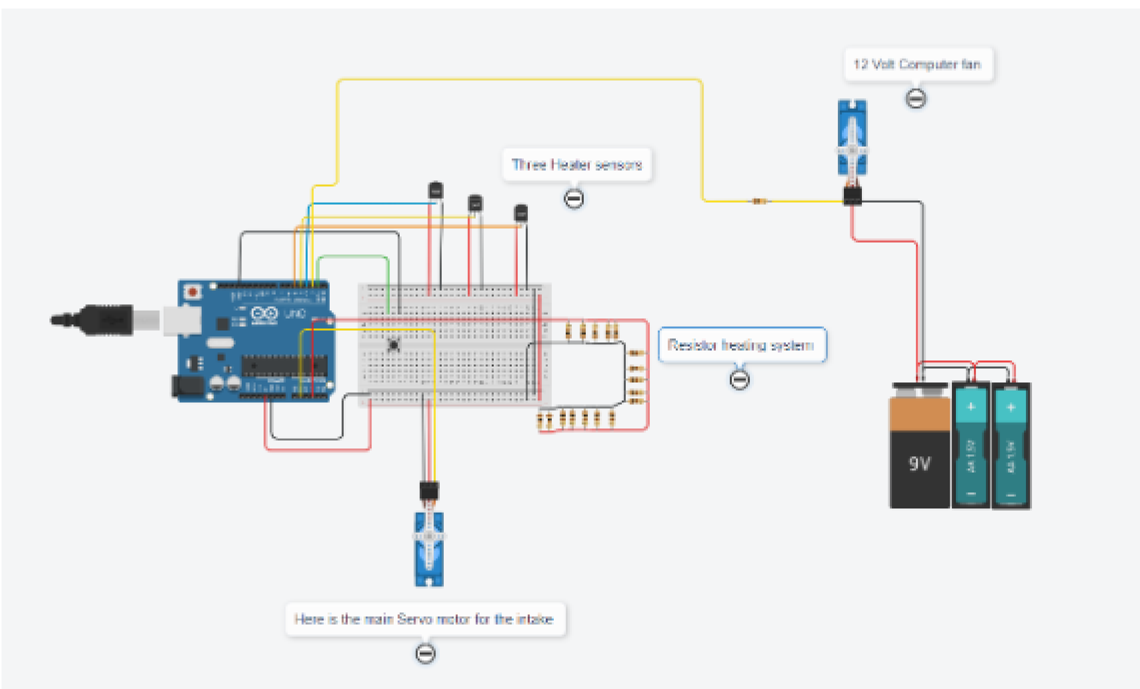


Figure 3 - Block Diagram of Microcontroller and Components

2.1 Conventions

Table 3. Conventions

Convention	Description	Example
#define	If applicable, the format used to define I/O pins in the arduino. #define is a c++ component which allows a programmer to give a name to a constant value in the program before it is compiled.	**#define** servoPin 8;
const	If applicable, the format used to define other constants not related to I/O pins in the arduino. const is a keyword which stands for constant. It is a qualifier that makes a variable "read-only" (immutable).	**const** float dryAirDensity = 1275;
Mode	If applicable, the format used for methods which alter the functionalities (fan, resistive heating, etc) of the system.	**CoolingMode();** **HeatingMode();**
Temp	If applicable, the format is used to define mutable temperature variables such as sensors or target variables. Temp is a keyword which stands for temperature. The temperature stored in these variables are in degrees celsius.	float **targetTemp** = 25;

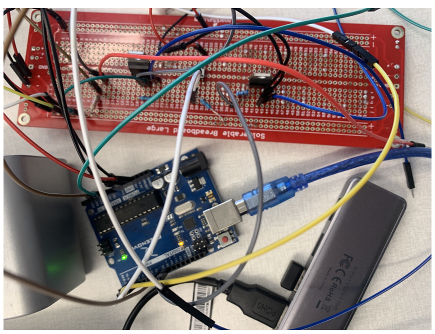
Threshold	If applicable, the format used to define variables that are used to determine the extent that has to be reached for a change in mode.	targetThreshold = 1;
		
		if(abs(temp1 - temp2) <= targetThreshold) {
		StandbyMode();
		}

2.2 Cautions & Warnings

- Do not touch the fan, intake system or wires directly. This could injure your hand or break down the system.
- Do not allow water or any liquid to enter the system.

3 Getting started

After bringing the parts of the system together and connecting them to a power source, there is no need to do anything additionally, except use the button.



The system has the function to heat the houses in an environmentally-friendly way by using geothermal energy.In Canada's cold winter months below -10 celsius degrees, the system starts to transfer the geothermal heat to the houses with just one button according to the set degree and turns itself off with a function depending on the situation.

Figure 4 - Arduino and Breadboard Wiring

The intake system turns on and off by pressing the button on the breadboard where the cables are connected.When the intake system is operated with a button, the air carried by the PVC pipes starts to flow through the sump pump and towards the intake system.

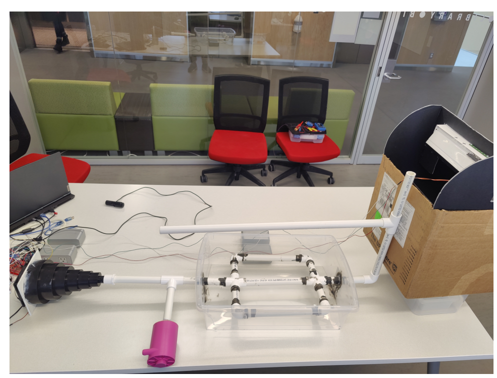


Figure 5 - Entire System Assembly

3.1 Configuration Considerations

The use of this heating unit for a house is very simple and is intended to be a simple user navigation system. First the air intake is powered by a simple arduino button, the user can press the button and the intake will open to allow air to enter the system, once the air makes its way through the pvc pipes that are designed to warm it up. A sump pump is connected to the pipes to ensure no moisture is also being pushed through the system. After passing the sump pump the air will reach the dynamic resistor heating solution. At this point the temperature sensors will read the temperature and will heat up the 17 resistors to the desired temperature inputted by the user, once the air is heated up, the air will reach the second set of temperature sensors to then know whether the air was heated to the right temperature. If It was, the fan would blow out the hot air into the house. The intake, temperature sensors, fan, and resistors will all be powered by one arduino uno. Overall this system is the future of heating a house.

3.2 User Access Considerations

The potential users of this system consist of homeowners or landlords and any potential tenants or renters. The only requirement is the necessary space for the installation of the system. All users may access this system as there are no restrictions placed on any users.

3.3 Accessing/setting-up the System

Due to this system's emphasis on the use of geothermal energy, the setup of this system is simple. With the intake system set up outside the house, and the THEC enclosure buried in the ground, the piping system will connect the intake to the enclosure and the enclosure to the furnace inside the house. Operating the system consists of the button to open or close the vent on the intake.

3.4 System Organization & Navigation

The system has 2 major components that interact with the system. These components are the intake button that turns the intake valve on and off, and finally the DRHS computer interface which adjusts the temperature and shows its progressive rise.

3.4.1 The Button

Simple button input that turns the valve on and off for the intake is attached to the main soldering panel to be connected with the main system.

3.4.2 DRHS Interface

Was made using a python interface to input and demonstrate all of the cooling information. Including a slider to help the user input.

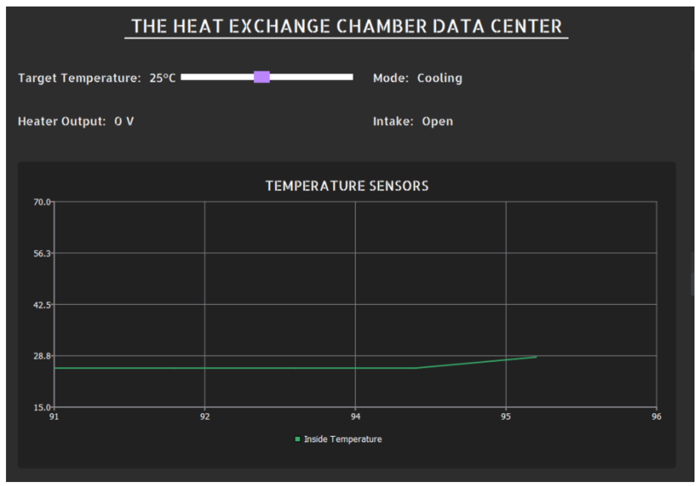


Figure 6 - Screenshot of DRHS Interface

3.5 Exiting the System

The system is designed to maximize the usage of geothermal energy. For storage for a long period of time, it is recommended to disconnect the power supply simply by taking off the cable and plugging it out.

4 Using the System

The following subsections provide detailed information and step-by-step instructions on how to use The Heat Exchange Chamber (THEC). Each function or feature is described under a separate subsection header corresponding to the various subsystems of the product.

4.1 Intake System

The intake system that we have incorporated into the Heat Exchange Chamber (THEC) is a vent powered by a microcontroller that is hooked up to a switch. The microcontroller will actuate the servo motor that will open the metal vent to allow for airflow to occur or not.

The image on the left shows the intake vent with a servo motor on the side of it to open and close the vent. Wires connect the servo motor to the microcontroller with a button to allow the user to open or close the vent when needed.

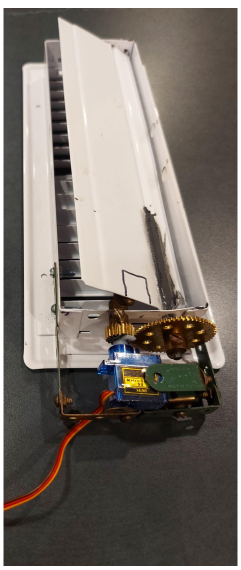


Figure 7- Intake control and servo

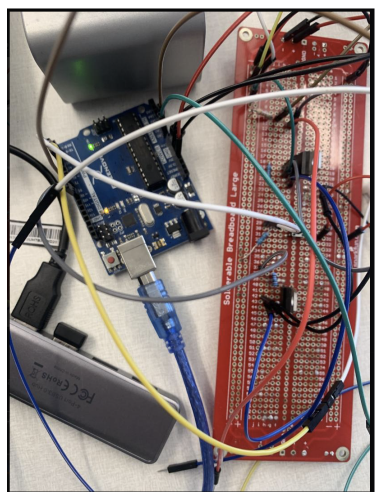


Figure 8 - Wiring for microcontroller

To protect the intake system from potential external damage like weather we have housed the intake vent in a high-density foam model. An image of the housing is below:

Figure 9 - Intake Housing

Overall this intake system is geared toward ease of use by the user. The intake system will open at a push of a button and if any component malfunctions refer to the support section of this user manual or the maker repo where all the information for user assistance will be located.

4.1.1 Register Control

The vent control function is used to remotely open and close the HVAC register of the intake system. A servo motor physically opens and closes the register, being wired to a button for remote control. The HVAC register along with the servo motor controlling it are both contained within the intake housing. To prevent the gearing system axle interfering with the vent itself, a notch cut was cut out of the vent to allow for the clearance of the axle. Although this creates a hole in the vent door, this greatly improves the seal of the vent, thereby improving the system's efficiency at operating under a closed-loop.

Figure 10 - Servo control for register

4.2 Sensor System

The sensor system is the logic which is used to determine which mode to activate and provide the necessary alterations to the components for the activation of that mode. It makes use of the different temperature sensors to determine the mode. From that point, it uses them again to determine the output of the fan and/or heating system.

4.2.1 Standby Mode

When the absolute difference in temperature between the room temperature and the target temperature is below the temperature threshold, the system goes into standby mode. Standby mode is a mode which intends to keep the temperature at the same level. The system operates with the fan at half power and the heat system turned off.

4.2.2 Cooling Mode

When the absolute difference in temperature between the room temperature and the target temperature is not below the temperature threshold and the temperature inside is bigger than the target temperature, the system goes into cooling mode. Cooling mode is a mode that intends to reduce the temperature of the room. This is accomplished by using the THEC and controlling the speed of the fan. The system operates based on how much it needs to cool down the room.

4.2.3 Standard Heating Mode

When the absolute difference in temperature between the room temperature and the target temperature is not below the temperature threshold and the temperature inside is smaller than the target temperature, the system goes into heating mode. From that point, if the system does not need additional heating, it goes into standard heating mode which makes use of the THEC to heat the room. This mode only controls the fan output depending on the heat provided by the THEC, in other words the case temperature.

4.2.4 DRHS Mode

When the absolute difference in temperature between the room temperature and the target temperature is not below the temperature threshold and the temperature inside is smaller than the target temperature, the system goes into heating mode. From that point, if the system does need additional heating, it goes into standard heating mode which makes use of the THEC and the DRHS to heat the room. This mode calculates the voltage needed depending on the inside temperature and the target temperature. If the voltage necessary is too high the target temperature is adjusted to the maximum level it can heat. The system determines how much it can heat given a

5V output to the DRHS and the target temperature will be scaled down to that value. The fan operates at full power to distribute the heat to the system.

5 Troubleshooting & Support

The following section provides a detailed explanation of any error conditions that may be generated by the system, as well as any potential solutions. This section is split up into the following subsection: error messages or behaviors, special considerations, maintenance, and finally the support subsection. Any corrective action that must be taken will be clearly outlined and detailed step-by-step.

5.1 Error Messages or Behaviors

Table 4. Error Message and Behaviors

Error/Behavior	Actions
An error occurred while uploading the sketch avrdude: ser_open(): can't open device "\\.\COM3": The system cannot find the file specified.	● Make sure the connection from the arduino to the computer is reliable ● Make sure that in the Tools/Port dropdown, the correct port is selected
Sensor sending irregular values	● Check the pin and power connections for the sensor ● Wait around a 1 minute for values to settle down
Servo intake state inversed	● Set servo state in EEPROM using EEPROM.write(0,0) and make sure the intake is open to recalibrate it.

5.2 Special Considerations

Consider the following for as reasons of system failures:

- Please make sure All water or conductive sources are away from the DRHS at All Times
- Avoid installing the system in Humid conditions.
- Make sure the temperature output is between 15 ℃ and 27 ℃

- If no temperature changed between 1 hour -2 hours, please check the intake vent is still open
- If the fan isn't spinning please contact the technician for further help.

5.3 Maintenance

To ensure the continuous operation of the device and the system, make sure that dust does not enter the fan. Make sure nothing is blocking the intake section. If there is dust inside the pipes, it is recommended to clean them with compressed air. Clean the junction points with a microfiber cloth at regular intervals to prevent dust from entering the system. Before using the system, make sure there is no disconnection.

5.4 Support

In the event of needed customer service for any component of the Heat Exchange Chamber you can refer to this user manual and the specific subsections of the overall system. Another way to seek support would be the Team AvoCADoes maker repo account where we have provided all the team members accounts so that we can give the best possible customer service.

6 Product Documentation

The following section provides a detailed explanation of how the final prototype was constructed. Each subsection will cover one of the subsystems of the final prototype, and will detail the subsystem's BOM, a list of equipment required for construction, and step-by-step instructions on how to build the subsystem. This section is split into the following subsections: Intake System, THEC and Piping, Heating, and the Sump Pump. These subsections will also explore some of the design choices made during the construction of the final prototype, and if applicable, explore the feasibility of alternative solutions.

6.1 Intake System

6.1.1 BOM (Bill of Materials)

Table 5. Intake System Bill of Materials

Item Name	Description	Quantity	Unit Cost	Extended Cost	Link
HVAC Register	Steel HVAC vent	1	$8.99	$8.99	HomeDepot
FoamCore Board	Foam Board for the intake body	1	Owned	Owned	Owned
Hardware	Gears and Bolts	4	$1.99	$1.99	HomeDepot
Servo Motor (Intake)	SG90 9g Micro Servo	1	$4.29	$4.29	PCBoard

6.1.2 Equipment list

The following is a list of tools/equipment needed to construct the intake system:

- Screwdriver
- box cutter
- JB weld

6.1.3 Instructions

<u>Step 1:</u> Construct the housing for the intake system. The intake system requires housing for the pipes drawing air into the THEC chamber, the pipes that recycle air from within the house back into the system, and mounting space for the HVAC register that will be used to remotely open and close the intake. The intake chamber/housing assembly can be further modified to include an overhang, which will protect the intake from the elements. Attached below is an image of the intake chamber/housing with the combined intake and return PVC piping.

Figure 11 - Housing assembly for intake system

Step 2: Modify the HVAC register and install the servo motor. To prevent the gearing system axle interfering with the vent itself, make a cut out of the register to allow for the clearance of the axle. Creating this hole in the vent door greatly improves the seal of the vent simultaneously improving the system's efficacy at operating under a closed-loop. Once this notch has been made, the servo motor can be installed as seen in the figure below.

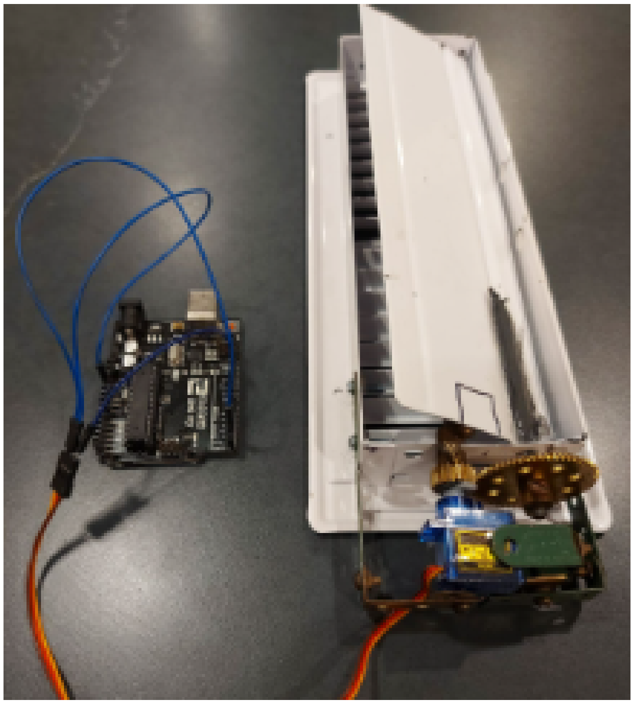


Figure 12 - Servo configuration and HVAC register

Step 3: Final assembly of the subsystem. Place the HVAC register and the servo in their designated locations on the housing. Make sure to connect the servo to the Arduino microcontroller. After testing the functionality of the servo motor, the intake system can be connected to the intake and return pipes and be connected to the overall system.

6.2 THEC and Piping

6.2.1 BOM (Bill of Materials)

Table 6. THEC and Piping System Bill of Materials

Item Name	Description	Quantity	Unit Cost	Extended Cost	Link
PVC Pipe	Broan 3/4-in x 15-ft PVC Tubing	1	$15.41	$15.41	Home Depot
PVC Joint T	NIBCO - K09825CA C4811 2 HXHXH Sanitary TEE PVC, White, 3/4 Inch	2	$0.98	$1.96	Home Depot
PVC Joint L	Bow ABS/DWV 90-Degree Elbow, 3/4-in	5	$1.18	$5.90	Home Depot
PVC Joint Cross	PVC Plumbing Cross - 3/4" Slip (All Sides)	2	$1.25	$2.50	Home Depot
PVC Cement	Cement 118ml	1	$7.32	$7.32	Home Depot
25L Container	type A Clarity Container, 25-L	1	$12.99	$12.99	Canadian Tire

6.2.2 Equipment list

The following is a list of tools/equipment needed to construct the THEC and piping systems:

- Mallet (to ensure pipes are snugly fit)

6.2.3 Instructions

Step 1: Prepare the plastic container by creating two holes opposing each other on the narrow ends of the container. The diameter of these holes should be the width of the PVC pipes that will be used, in this case 1 inch. The plastic box is used instead of concrete due to the excessive weight of the system preventing portability should it be built out of concrete.

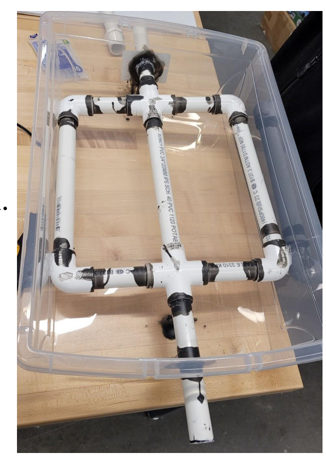


Figure 13 - THEC system

Step 2: Assemble the piping subsystem within the container as outlined in the adjacent image. Ensure that the piping splits into (at least) three channels within the container. This serves to maximize the surface area of the piping, thus improving the efficiency of the system. In larger containers, more channels can be added to improve efficacy. Additionally, clay is applied to the joints of the pipes to make them waterproof. The waterproofing of the pipe system was tested by placing the pipe system under water.

Step 3: Once the assembly of the other subsystems is complete, connect this subsystem to the sump pump, the intake, and the heating subsystem. Pictured below is the final assembly.

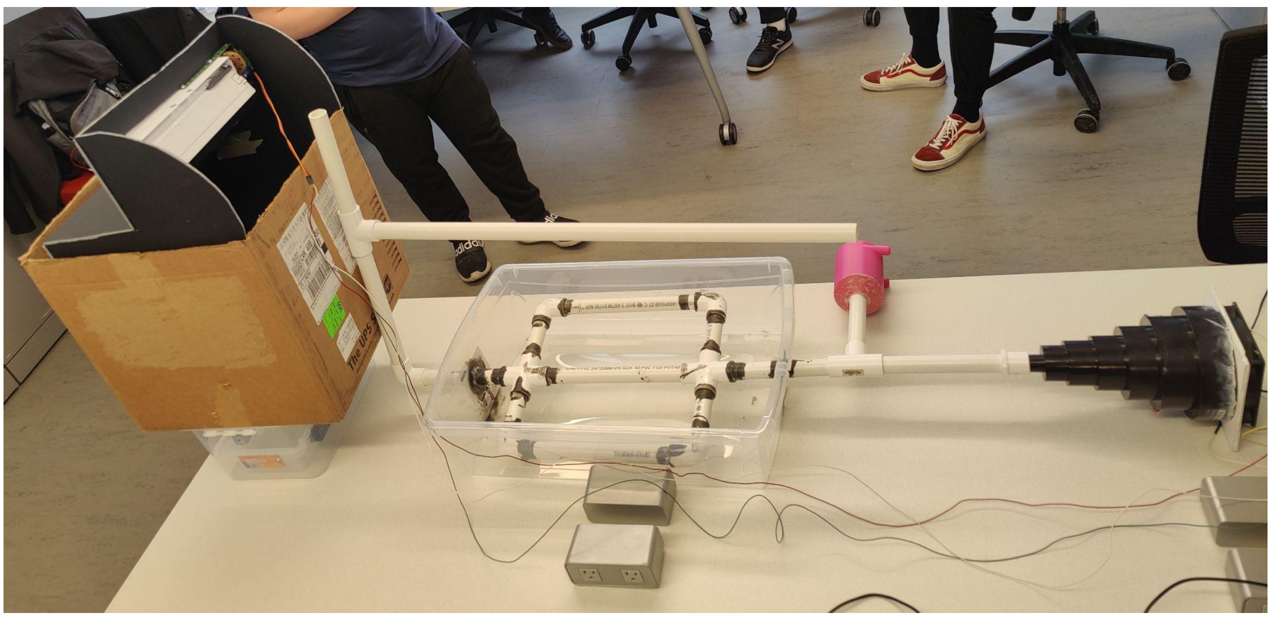


Figure 14 - Entire THEC System

6.3 Heating

6.3.1 BOM (Bill of Materials)

Table 7. Heating System Bill of Materials

Item Name	Description	Quantity	Unit Cost	Extended Cost	Link
Temperature Sensor	LM61BIZ/NOPB	3	$2.65	$7.95	Digi-Key
Fans	120mm Cooling Case Fan	1	$15.99	$15.99	Amazon
7 Step Universal Reducer	6 to 1 Inch Universal PVC Extender-Reducer	1	$20.99	$20.99	Home Depot

6.3.2 Equipment list

The following is a list of tools/equipment needed to construct and install the heating system:

- drill and various bits
- soldering iron
- hot glue gun

6.3.3 Instructions

Step 1: Construct the resistor ring that will be used for heating. As seen in the adjacent image, the resistors were soldered to 2 copper wires, forming 2 concentric rings. As the copper wire being used was stripped, it had multiple strands of copper hanging out, as such, more solder was applied to the wire so all the copper wire didn't unravel. Then, the male-male wires were soldered to the ends of each section. The PVC reducer was then drilled in at the 4 inch section as the resistor ring snuggly fit into that part of the reducer. To secure it, small holes were drilled and paper clips were put in and wrapped around the resistor wire circuit. These were isolated and glued to this PVC reducer by hot glue. Testing was done by running voltage through it and it was able to demonstrate that the soldering and wiring were all competent.

Figure 15 - Resistor ring and housing

Step 2: Installation of the sensors. The LM61BIZ/NOPB temperature sensors were hot glued with the pins sticking out of the PVC reducer. A sensor was placed at the base of the PVC reducer, along with another sensor at the end of the PVC reducer. This was done by drilling the reducer with 1/36 inch drill bits and then using hot glue to to not only insole these holes but to keep the sensor in place. These were then wired with male-female wires to the proto board and tested accordingly. Pictured below is the sensor with protruding pins installed at the end of the reducer.

Figure 16 - Temperature Sensor with protruding pins

Step 3: The final step is the installation of the fan. To power the fan, a 12 volt power bank was used, with its wires being connected to the respective wires of the fan. A piece of foam was then cut to match the interior fan section further insulating the air heating chamber. This was done to simultaneously provide a mount for the fan and prevent any potential air loss by removing gaps between the PVC reducer and the fan. Once that was done, this was super glued to the heating chamber and had the resistor heating rings wires sticking out so that there was access to it. Pictured below is the final assembly of the heating subsystem.

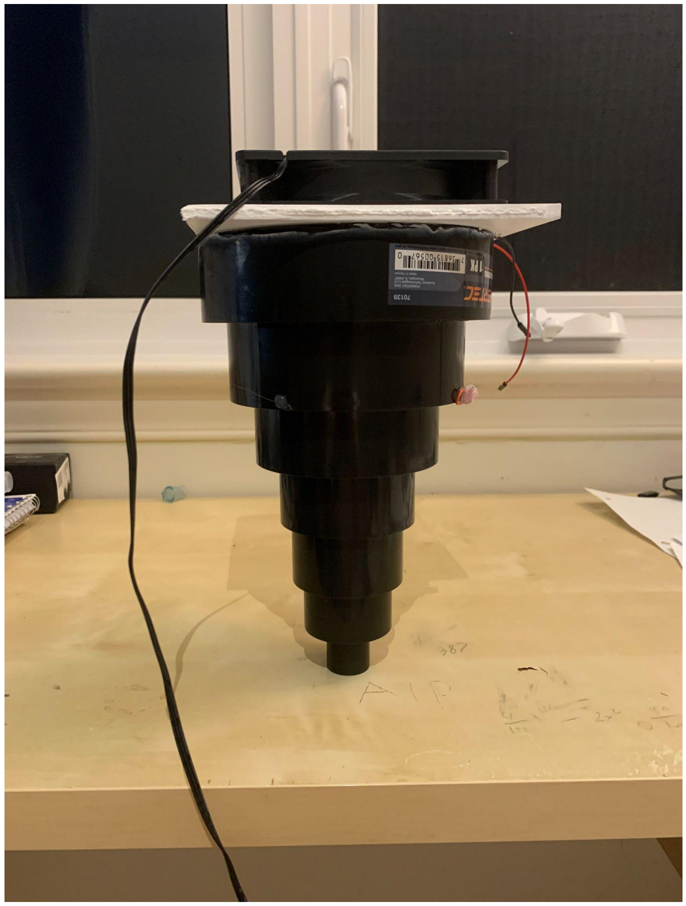


Figure 17 - Heating system assembly built in step-reducer

6.4 Sump Pump

6.4.1 BOM (Bill of Materials)

Table 8. Sump Pump System Bill of Materials

Item Name	Description	Quantity	Unit Cost	Extended Cost	Link
Filament	Cost of 3D printing	-	-	-	MakerSpace

6.4.2 Equipment list

The following is a list of tools/equipment needed to print and construct the sump pump:

- drill and various bits
- 3D Printer
- CAD software

6.4.3 Instructions

Step 1: Acquire a design for the sump pump. This can be accomplished by designing a unique pump, or by using the same design for the sump pump as our team used for our final design. This design can be found under the 'project files' section of our MakerRepo here.

Step 2: Upload the sump pump design to your 3D printer and print it. The cost and time required to print may vary depending on the filament and model of 3D printer used. The pump used in the final design was printed using PLA filament.

Step 3: After printing the sump pump, all that remains is preparing the pump for installation. The design for the pump contained support structures that were put in place to create operating holes. These support structures need to be drilled out to allow the pump to function. Lastly, the top of the sump pump needs to be sealed with gorilla glue so that the sump pump won't release water from the top when used in the system. Below is the final print of the sump pump with operating holes.

Figure 18 - 3D printed sump pump used in final design

6.5 Testing & Validation

There were two experimental tests, one for the THEC water system and the DRHS. Every other system was done empirically where the intake clearly opened and closed.

The THEC system data below shows the consistency to maintain a cool temperature under geothermal conditions. As it can clearly be seen after the water reached equilibrium with the room temperature, the interior of the pipe was very close to the room temperature. Demonstrating its tendency to maintain the temperature under geothermal conditions. Empirically no major problems of leakage or damage to the pipes were seen. Demonstrating that this subsystem worked flawlessly .

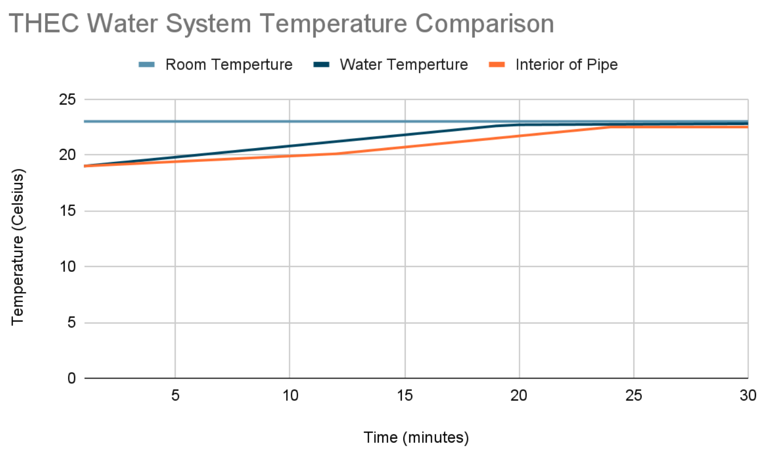


Figure 19 - THEC water system testing

DRHS Testing data can clearly show that the temperature of the heating box rises and reaches the requested temperature compared to the General room temperature. As it can be seen over a period of 5-6 minutes the desired temperature of the interior of the box was reached. As it can bee seen it was able to quickly and efficiently heat up an insulated box to solve it.

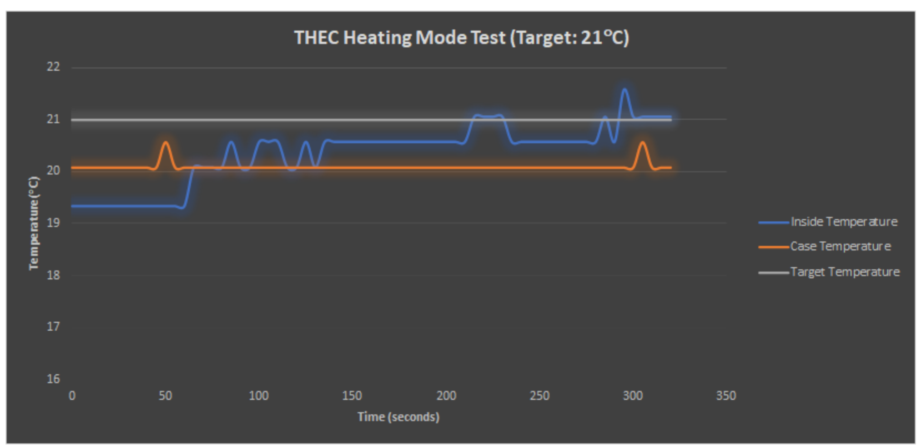


Figure 20 - DRHS testing data

7 Conclusions and Recommendations for Future Work

Through the process of designing and building this project, our team has learned how to use a variety of tools and acquired new skills that may be valuable for aspiring engineers. The variable requirements of this project allowed our group to learn and hone skills such as Arduino development and programming, designing and modeling using CAD software, and the usage of a 3D printer. This project also allowed us to explore and learn some basic manufacturing and construction skills. Throughout this project our team faced a variety of challenges and problems. These challenges led our team to develop more interpersonal skills such as communication, while simultaneously encouraging our group to discuss and fully understand the problems to develop the ideal solution. The deliverable process for this project assisted our team in correctly listening to the needs of the user and conceptualizing those needs into a product using the design process. From prototyping, our team learned how to build, test, and iteratively update the various subsystems. This meant that all the subsystems were tested under the right conditions that were outlined by the client, while also ensuring that the final prototype was both functional and portable.

This project was extremely valuable in developing interpersonal and team skills. As a group, we learned to work together efficiently by creating a Discord group to hold weekly meetings, work upon project deliverables, schedule work for members, as well as itemizing and documenting various receipts and design files. Had our team not been constrained by the timeline and budget of this project and been given a few more months, we would have improved some aspects of the design. The biggest improvement would be the construction of a scale THEC enclosure using concrete, as well as the use of glycol as the thermal medium due to its heating properties. Various aesthetic changes could also be made to the design.

APPENDICES

8 APPENDIX I: Design Files

Table 9. Referenced Documents

Document Name	Document Location and/or URL	Issuance Date
7_step_Universal_ Reducer.stl	THEC MakerRepo (Find in project files)	2022-03-30
Testing File.zip	THEC MakerRepo (Find in project files)	2022-03-30
Resistive Heating Calculator.xlsx	THEC MakerRepo (Find in project files)	2022-03-30
sensorCode.ino	THEC MakerRepo (Find in project files)	2022-03-30
Updated BOM.xlsx	THEC MakerRepo (Find in project files)	2022-03-30

9 APPENDIX II: Other Appendices

10.1 Sensor Activity Diagram

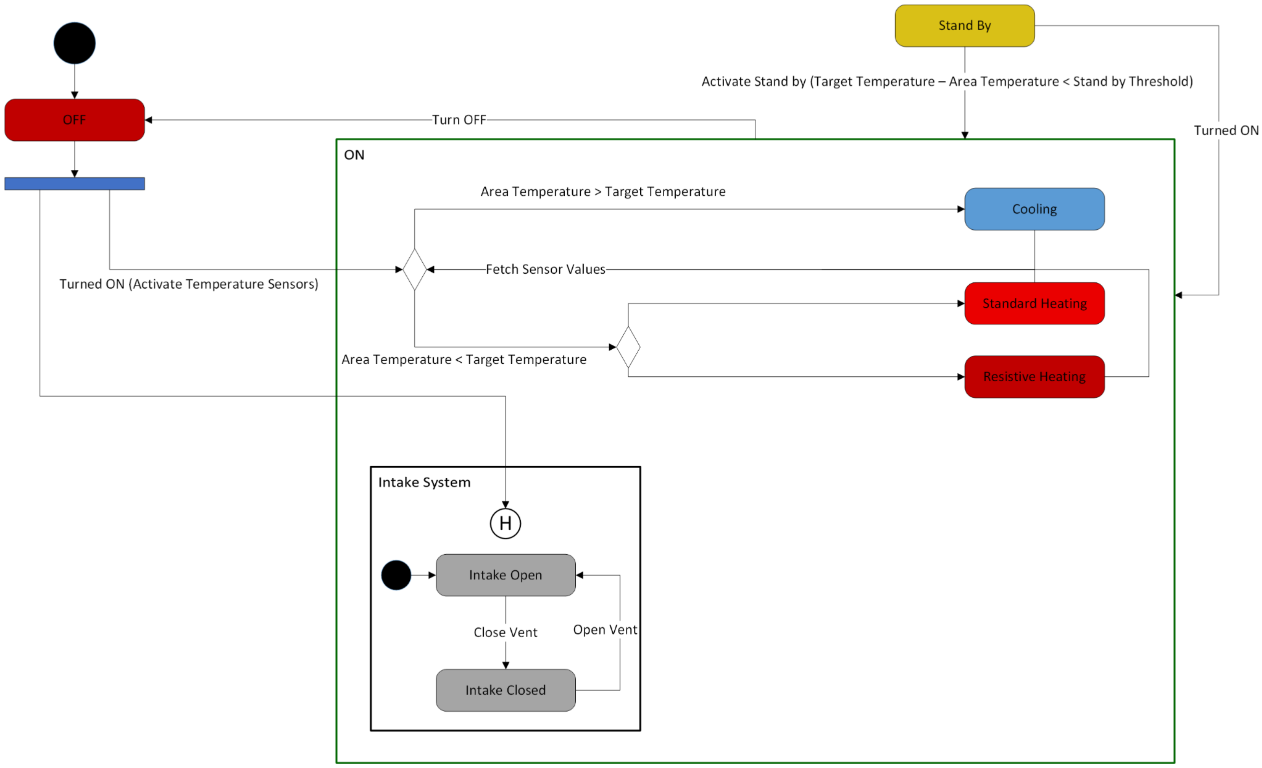


Figure 21 - Sensor Activity Diagram