

GNG 1103 - Engineering Design
Group 3.4

University of Ottawa

Deliverable G: Prototype II and Customer Feedback

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Introduction

In this deliverable for prototype 2, our team took the feedback our client gave us from the meeting for prototype 1 to further enhance our design and expand on certain aspects that needed more detailed explanations. Our client had no initial questions or feedback to give besides a minor confusion on the role of the radiator, which was ultimately explained in better detail and concluded. For the first prototype of the project we wanted to display a simple circuit for our electrical subsystem, entailing how this circuit would function under a set temperature. Building off of this idea, we enhanced the idea of the circuit implementing the different parts of the subsystem instead of a simple ON/OFF signal as well as writing the code in more detail while providing instructions for each line.

Furthermore, we modelled the ventilation and thermal subsystems in accordance with the given size constraints and with respect to measurements of our pipes. A series of tests conclude this deliverable emphasising on pressure, heat loss and running the code for our electrical subsystem. The tests outlined in this document will help the team understand whether each part of this prototype works or needs further tuning or refining. Lastly, we had to update our BOM as we encountered a small number of obstacles that required different parts or to ultimately scrap some from the initial BOM.

Updated Arduino Code

The thermostat is programmed in a way to turn on or off (HIGH or LOW signals) various components depending on the temperature being read by a TMP36 temperature sensor. At all times, the sump pump has a constant input of power to ensure the level of condensation in the pump is constantly being monitored. The pump is then activated when this level reaches a certain height.

The code initially defines four variables; PIN_TEMP, PIN_FAN, PIN_HEATER and PIN_PUMP, as well as their analog pins. Our initial PIN_TEMP is defined to be the input inside our void setup while the remaining three become our outputs and the PIN_PUMP is then defined to always be active.

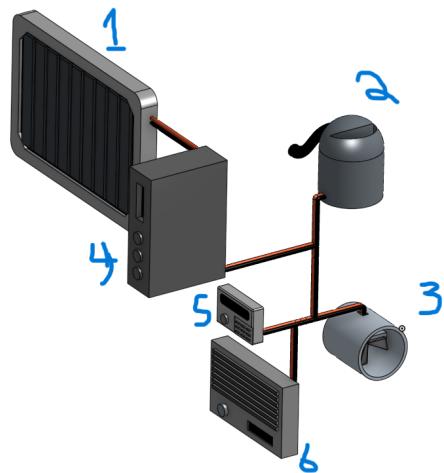
We define room temperature to be between 20°C and 21°C while the temperature of the ground is a constant 16°C. As such, the THEC can help cool down air temperatures to room temperature, and increase the temperature to 16°C. However, the THEC is unable to increase the temperature from 16°C to 20°C. As such, in this range, the external heater is activated.

The code begins by reading the temperature from the TMP36 temperature sensor and checking an if-else statement for our heater/radiator. If the temperature is between the range of 16°C to 20°C, the code instructs the heater to turn on (HIGH) and if it is outside of that range the heater remains off (LOW). After checking the heater we move onto the fan, which will operate if the temperature is above 21°C the fan will turn on to cool the system and if the temperature goes below 16°C the fan should operate under a closed loop, controlled by a manual hatch and an inlet inside the building. The optimal temperature of the building should reside within the range of 20°C to 21°C.

The code along with the circuit for the electrical subsystem is displayed in the Appendix.

Electrical Subsystem

Below is a visual representation of our electrical subsystem, as depicted in our sketches from Deliverable E, along with a legend of all its parts.



- 1 : Solar Panel for power
- 2 : Sump Pump
- 3: Intake fan
- 4: Inverter, battery, charge controller and arduino sensor equipement box
- 5 : Thermostat
- 6 : Radiator

<https://cad.onshape.com/documents/dd5ffc3d1ac1c873cc50c221/w/8299622647c61a6a20aa064c/e/1c50f4e981a1084fea749915?renderMode=0&uiState=622e487bda5cb11d804e631d>

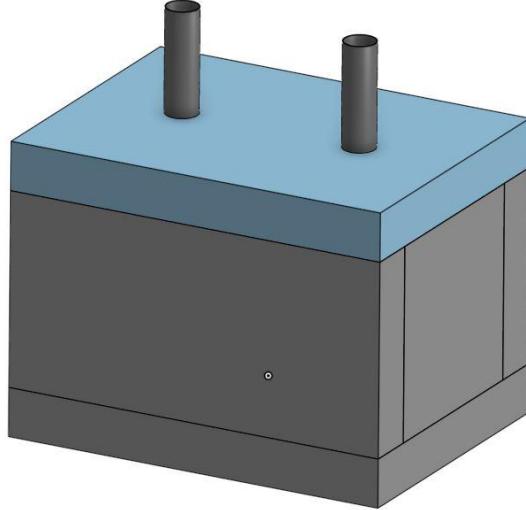
Thermal/Ventilation Subsystems

For the thermal and ventilation subsystems, a 3D model was built using Onshape. This 3D model used highly specific measurements for each part, ensuring the different parts would fit together in the full assembly. This 3D model can be viewed in full detail by clicking the link shown below and clicking on the assembly tab.

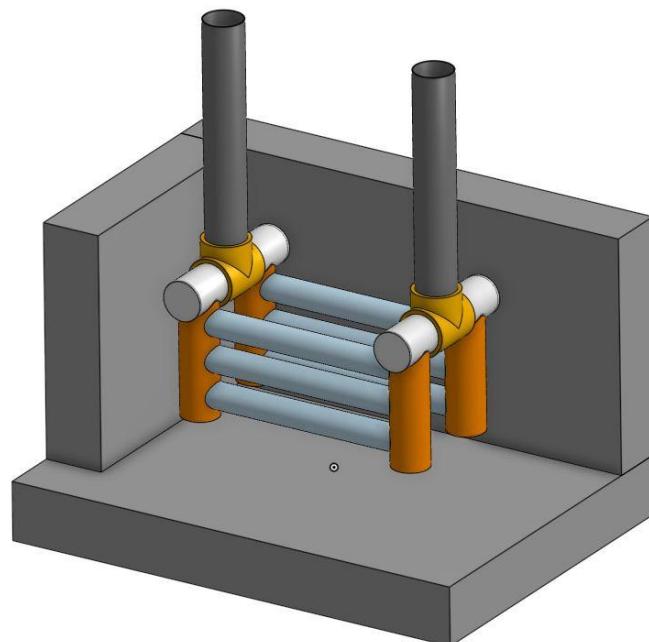
<https://cad.onshape.com/documents/798aec5689e19b05061dfe38/w/4ee653bedda8d19865d81350/e/bfed30a6b32fd81727e25ad1?renderMode=0&uiState=622e540d2f0edf459cac7665>

Once in the assembly tab, the inner apparatus can be seen by making various parts of the assembly transparent. A part can be made transparent by clicking the eyeball icon for that

part on the “Instances” menu. The full assembly consists of a box entirely sealed except for two 2” pipes sticking in and out of the box. In the full system, air travels in through one such pipe, moves through the system of pipes in the box, exchanges heat with the thermal exchange medium, and exits through the other pipe. The final dimensions of the chamber itself in this prototype design ended up being 2ft long, 1.5ft wide, and 1.5ft tall.



Once the walls of the chamber are made transparent, the inner system of pipes is revealed. This system consists of a 2” inlet pipe connected via a t-diverter to a horizontally oriented 2” pipe, sealed on both of its sides. This horizontal 2” pipe has a hole cut into it to allow it to connect to the vertical 2” pipe, and two other holes cut into it to allow for it to connect to two vertically oriented 1.5” pipes. These 1.5” pipes are sealed on one end, and open on the other to allow air flow to pass from the horizontal 2” pipe to them. These 1.5” pipes each have 3 holes cut into them allowing them to connect to 3 horizontally oriented 1” pipes which then connect to the other half of the symmetrical apparatus.



The space inside the box not occupied by the pipes is filled by the thermal exchange fluid, which at the moment is water due to cost constraints. The pipe apparatus is designed on all sides to have at least a 5cm separation between it and the walls. This way, all pipe surfaces are ensured to have optimal heat transfer with the thermal exchange fluid, thereby maximising the efficiency of the overall system.

To find the exact pipe dimensions needed, the standard used by each of the pipes was identified. Using documents and charts outlining the various standards—these sites and documents are listed in the appendix—a table was constructed displaying the various pipes used, their inner diameter, their outer diameter, and their lengths. This information is shown below.

Name	Pipe Standard	Nominal Diameter (in.)	Outer Diameter (in.)	Inner Diameter (in.)	Length (ft.)
Large Vertical Pipe	ASTM F 2158	2	1.935	1.935	1
Large Horizontal Pipe	ASTM F 2158	2	2.000	1.935	0.65
Intermediate Vertical Pipe	Schedule 40	1.5	1.900	1.590	0.5
Small Horizontal Pipe	ASTM D2241	1	1.315	1.195	0.85

Conscious Design Decisions

For the second prototype, a myriad of different design choices were made for a variety of reasons. Some of these choices and reasons are listed below.

To begin with, our group was debating on the secondary method of heating in wintertime. The choice was between an external heater which would be placed near the outside of the outlet fan in the house and a set of resistors lining the pipes near the fan. Both the external heater and set of resistors would be controlled by the arduino and would activate at certain temperatures to achieve thermal comfort when the THEC alone is not sufficient to achieve this task. Ultimately, the external heater unit was chosen due to efficiency concerns—while the heater unit would be producing heat in the well-insulated house, the set of resistors would be conducting a large amount of heat into the ground due to them being attached to the pipe walls. As such, if the resistors were chosen, a lot more energy would be required to yield the same thermal effect for the air being expelled into the house.

There were also various options of pipe materials to choose from. On one hand, metallic pipes provide heat transfer advantages which would improve the rate at which air exchanges heat with the thermal exchange medium. This is significant as this whole system is built on the principle of optimising heat transfer properties. Additionally, metallic pipes are inherently more sturdy in terms of resisting pressures than plastic pipes. On the other hand many metallic pipes are susceptible to corrosion. Furthermore, plastic pipes are cheap and holes can be easily cut into them. As such, a system designed with plastic pipes could connect pipes by cutting holes into a pipe, inserting the other pipe, and sealing the gap with adhesive. Due to this, pipes can easily be split into systems of many smaller pipes which optimises surface area contact with the thermal exchange medium, and by extension, optimises heat transfer. To construct similar systems with metallic pipes, many more joints and connectors would need to be purchased, and cutting holes would be significantly more difficult to perform and vastly more expensive. As such PVC pipes were the chosen type of pipe for this system. A graph demonstrating heat loss in relation to diameter is found in the Appendix for additional reference.

Finally, when designing the THEC, there were a variety of different pipe designs and heat transfer fluids to choose from. However, while there were many different heat transfer fluids to choose from, they were all highly expensive, and for that sole reason, water was the chosen heat transfer fluid. For the pipe design, many options were available such as coiled pipes and straight pipes. While on the surface, coiled pipes offer more surface area for a certain horizontal distance in a chamber, straight pipes can easily achieve a stronger effect since more and smaller pipes can be used. Furthermore, a higher density of straight pipes can be achieved since these pipes pack together much better than coiled pipes. Finally, it is much more difficult to construct a system of coiled pipes than a system of straight pipes. Therefore, while coiled pipes may offer superior heat transfer properties when looking at a single pipe, a system of coiled pipes has worse heat transfer properties and is much harder to construct.

Tests and Benchmarking

Prototype II Tests

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)
HVAC System	To be able to test the overall functionality of the HVAC system through the toggling of the thermostat. This to ensure safety and check if the automation of the individual parts are running properly.	Prototype for the HVAC will be virtually designed on TinkerCAD with simplified representations of the systems with Arduino Hardware, wired through the UNO and multiple transistors and relays. The testing will be done through running a script through the Arduino IDE and toggling of the temperature sensor to call different subsystems.	Results will include whether the functionality of each of the individual components in the HVAC runs smoothly. The results will be used as instant feedback on what to tweak in the design, whether that be the code or the physical system	Start Date 3/12/2022 Duration Almost instantaneously to a couple minutes based on the simulation duration.
Structural Analysis	The structural analysis helps to determine the cause of a structural failure. The purpose of the structural analysis is to design a structure that has the proper strength, safety, and rigidity.	Simulations in Onshape.	Results will include if the concrete box can withstand force of the soil mixture and its weight underground (6ft deep)	Start date: 3/12/22 Duration: 5 hours

Prototype II Test Results

Test ID	Results (Successful/Failure)	Future Development (feedback)
HVAC System (successful)	<ul style="list-style-type: none"> ● Sump pump is always activated as long as the system is as well. ● Fan works as expected, through the built in TMP36 temperature sensor and code to immediately boot up as the temperature is toggled to drop under 20°C. ● Heater works as expected, through the built in TMP36 temperature sensor and code to immediately boot up as the temperature is toggled to the range of 16°C to 20°C. 	<ul style="list-style-type: none"> ● To further develop the sump pump and have it automated based on a certain fill level. This will call to the rest of the system to drain it. For example: this can be done through attaching an Arduino water level detection sensor attached to a rod submerged underground. Which could be programmed to send updates to the serial monitor/plotter as a warning on the IDE to immediately start. ● Find a more suitable and specific piece of hardware to better represent components like the heater with limited resources. This could be done with bought physical components rather than an online resource or rather a different online source.
Structural Analysis (successful)	<p>The results were successful. From our testing we can conclude that the concrete box can endure a significant amount of force applied on it, and shows us that it will be safe under extreme measures.</p>	<p>No further feedback is required.</p>

- Reference the Appendix for visual representations of the results.

Updated Bill of Materials

Updated bill of materials after the construction of prototype 2:

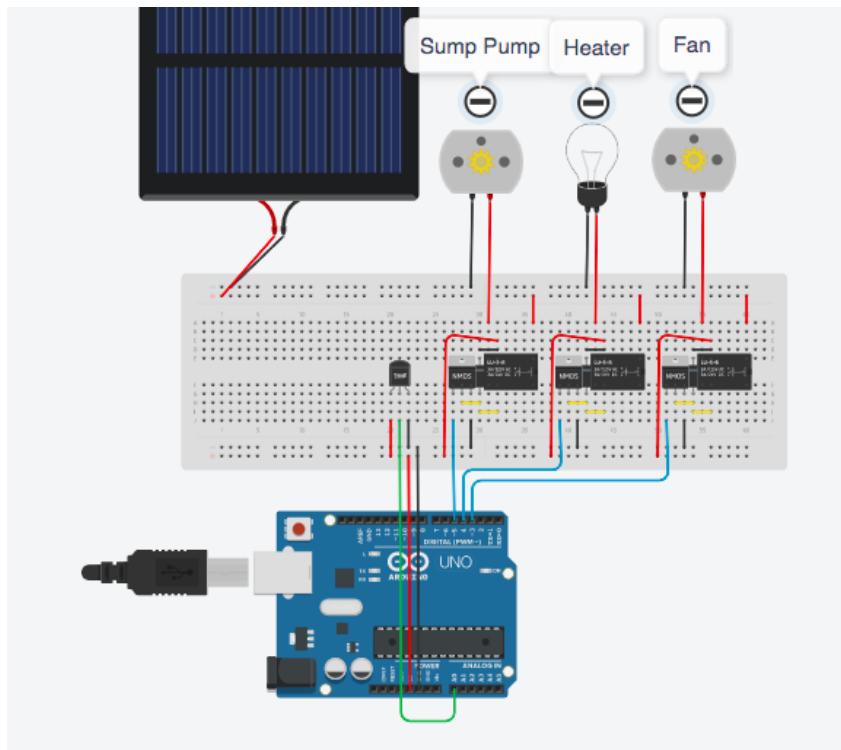
<https://docs.google.com/spreadsheets/d/1ZFL6iPO7CPeat8pi4nXPiKrb-0GiwXMwSPCX8PW27T4/edit#gid=0>

Conclusion

To conclude, a multiple amount of things were done such as the circuitry and model for the electrical subsystem as well as laying the foundation for the 3D model of the thermal and ventilating subsystems. We accomplished a major milestone in this document towards our final design and we look forward to the client's feedback to help guide us in the development of the third and ultimately final prototype.

Appendix

Appendix 1 : Updated arduino code and electrical subsystem circuit



```
#define PIN_TEMP A0
#define PIN_FAN 3
#define PIN_HEATER 4
#define PIN_PUMP 5

void setup() {
    // Temperature Sensor
    pinMode(PIN_TEMP, INPUT);

    // Output Devices
    pinMode(PIN_FAN, OUTPUT);
    pinMode(PIN_HEATER, OUTPUT);
    pinMode(PIN_PUMP, OUTPUT);

    digitalWrite(PIN_PUMP, HIGH);
}

void loop() {
    // Read the temperature sensor and map it
    float temp = analogRead(PIN_TEMP) * 5;
    temp /= 1024;
    temp -= 0.5;
    temp *= 100;

    // Check if we should turn on the heater
    if(16 < temp < 20) {
        digitalWrite(PIN_HEATER, HIGH);
    } else {
        digitalWrite(PIN_HEATER, LOW);
    }

    // Check if we should turn on the fan
    if(temp > 20 or temp < 16) {
        digitalWrite(PIN_FAN, HIGH);
    } else {
        digitalWrite(PIN_FAN, LOW);
    }

    delay(10);
}
```

Appendix 2 : Additional reference for thermal and ventilation subsystems

ASTM F 2158 Standard Document:

<http://www.tiptopparts.ca/content/TipTop/pdf/ASTM/ASTM.pdf>

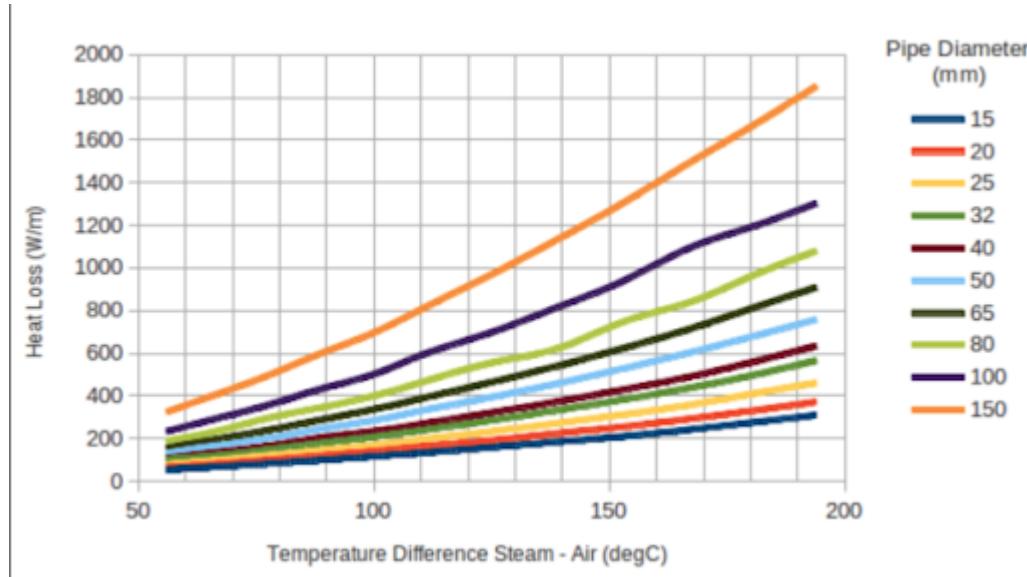
ASTM D2241 Standard Document:

https://www.napcopipe.com/sites/default/files/media/PL-PS-002-US-EN-0521.1_D2241.pdf

Schedule 40 Standard Chart:

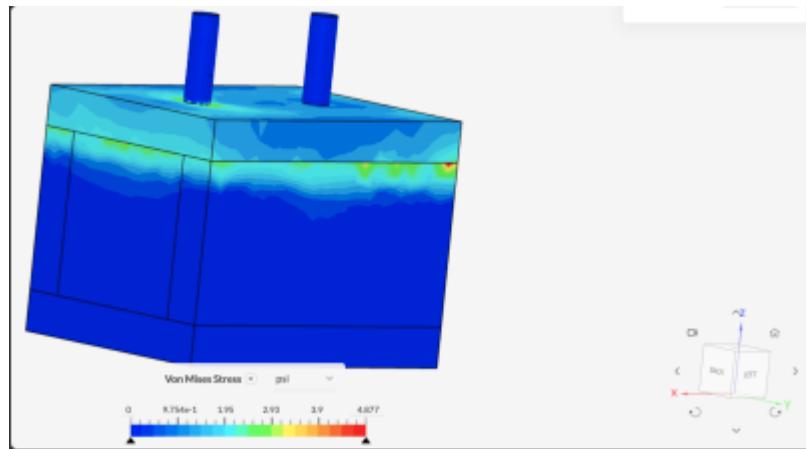
<https://www.commercial-industrial-supply.com/wordpress/wp-content/uploads/2020/11/sch40-pvc-piping-dim-chart.jpg>

Appendix 3 : Heat loss graph for PVC pipes

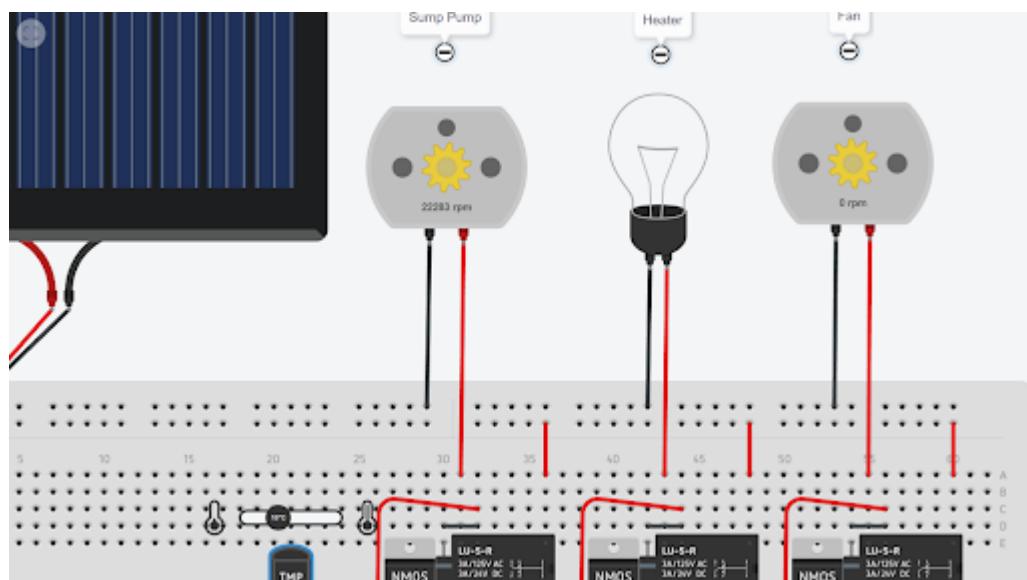


Appendix 4 : HVAC system and electrical subsystem circuit test results

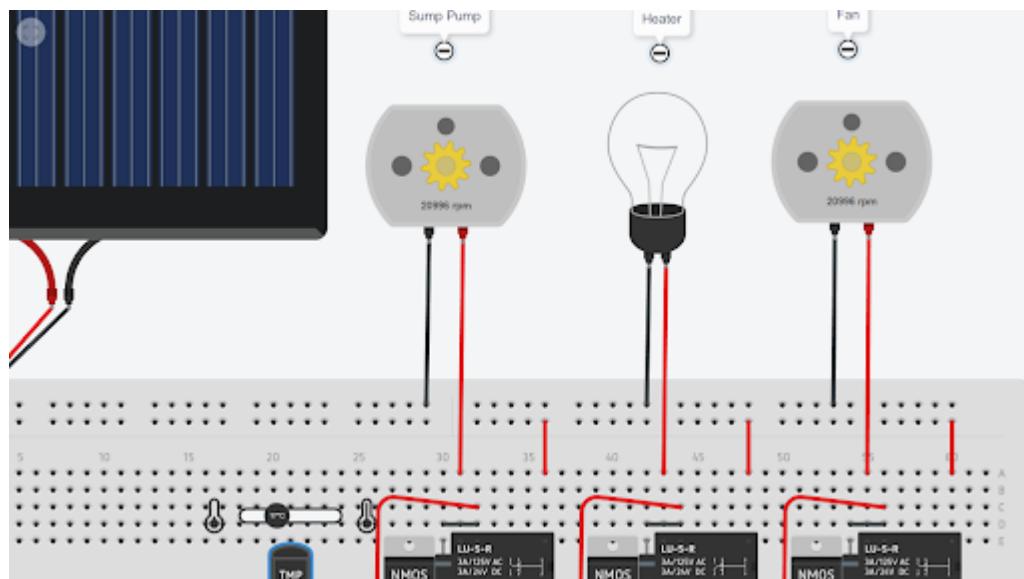
Concrete at 1000N downwards (6ft in the ground, covered with dirt mixture), estimated force the ground will act upon the concrete body, concrete can withstand around 1450 psi to 5800 psi, analysis has shown us that under 1000N the stress of the concrete stays below 5psi.



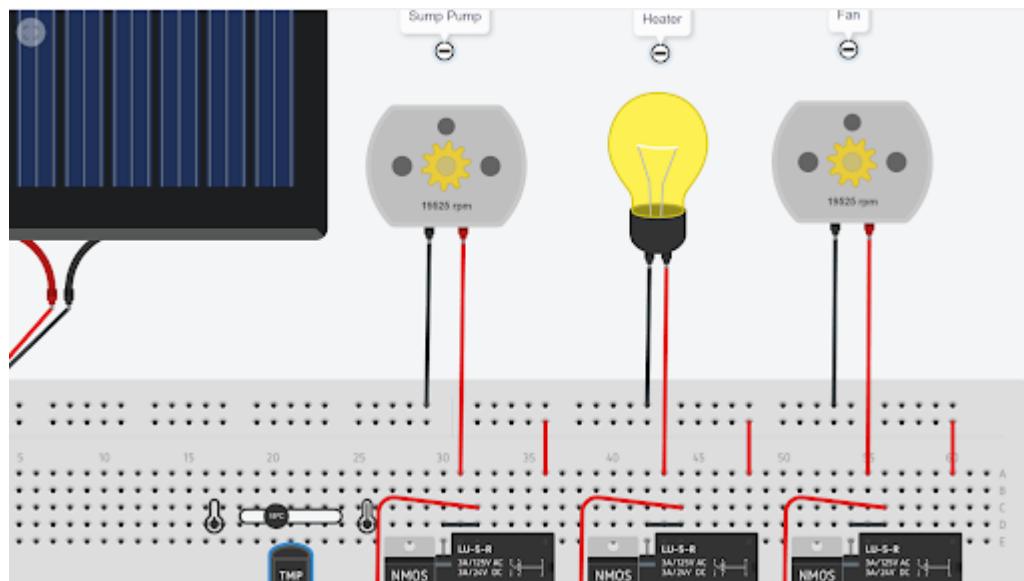
Initial state (temperature = 20-21°C)



Check fan RPM (temperature = below 16°C or above 21°C)



Check heater activation (temperature = between 16°C to 19.9°C)



Appendix 5 : Energy Consumption/Production Item Specifications

Fan: Air Flow = 49.6 CFM (cubic feet/minute)

Power = 1.8W

Voltage Range = 90-270VAC

Submersible Pump: Max Flow Rate = 300 L/H

Power: 4W

Voltage Range = 110-120 V @ 60Hz

Solar Panel: Power = 2W/6V