Deliverable F: Prototype I and Client Feedback

Team Jeff

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1 Introduction

This document outlines the plan of the first prototype and the critical components using detailed descriptions, scientific calculations, 3D modelling from OnShape. The plan of the first prototype and the critical components according to the client feedback which was obtained during the second client meeting. A brief section for the client feedback is included in this document. This document also includes sections for the potential user feedback and the second prototype plan. The potential user feedback section explains how our prototype plans were presented to a civil engineer/construction manager and a civil engineering student, and what they thought about our prototype plan. The second prototype plan section briefly explains our plan for our second prototype will be made. Appendix A contains extra images if needed.

2 Prototype I Plan

Our first prototype is an analytical model comprised of a virtual 3D model and calculations. That is to analytically confirm the efficiency of the system depending on the length of the pipes and the underground temperature in Ottawa during winter. The prototype will encounter a measuring of the rate of heating starting from quantifying the mass of energy the system provides. Afterwards, a theorical heating test will be done in order to measure the temperature change, this will be made assuming that the prototype will run in a room in which temperature is around 20C for a period that ranges between 4 to 6 hours with availability of good sunlight exposure.

3 Feedback From Client

The client noted an interest in our presented design concepts the favored version being developed into the current prototypes. The client recommended ensuring solar water heater be place in high points where snow and debris will not cause the heater to be covered. Additionally, the client commented on the design of the inlet and was intrigued using what the group calls a thermal battery. Of all the designs presented at the time the client believes the current design is likely the most efficient but encouraged implementation of other designs, particularly their energy generation methods.

4 Critical Components

Our prototype will include the THEC, an air inlet, a thermal battery, a solar water heater, a fan, a water pump, a thermostat analog, and a pipe layout as its main subsystems and components.

The THEC is filled with water and the fan is attached to the larger lower exit hole by using electrical tape and hot glue. The pipe layout is connected to the larger holes and is used as the main airflow pipe for the system. The lower hole will be drilled to the pipe and watertight sealed. We will also use hot glue for this part to make sure that there are no leaks between the pipe and the THEC. The upper hole will be cut in a lid, so there will be no adhesive of permanent fixation used to make sure the THEC can be opened if modification or transportation is needed.

The smaller holes of the THEC will be used for the vinal tubing that will coil around the larger airflow pipe. The vinal tubing will connect to either end of the thermal battery, the upper and lower small holes on the THEC, and the circulation pump. We will use hot glue to seal this.

The pump will circulate water from the coil exit up to the solar water heater. The solar water heater is made from vinal tubing, which is held in place by two or more Styrofoam blocks. There will be no need for adhesives, as the blocks are there to rigidity.

All the outflow from the bottom of the solar water heater travels through the tubing to the thermal battery. The battery is a plastic box, similar to the THEC, but is insulated using Styrofoam insulation glued to all of the edges of the box. The box also has two holes which allow for tubing to be made in order to connect the solar water heater to the THEC.

The system will be powered using a thermostat that runs the pump and fan using a wall adapter with a temperature switch. This is because the pump and fan have higher power requirements than what an Arduino can supply, and the temperature switch is an easy and effective way of controlling the system.

5 Prototype I

As stated above this prototype was analytical, creating a final 3D model and analyzing some of its heating capabilities and requirements. The prototype includes THEC, the fan, air pipes and the heating system. The purpose being to create a final detailed plan of all integrated systems and gain an idea as to whether it would be functional.

6 Prototype I Results

6.1 3D modeling

The result of the modeling in the CAD software OnShape was a complete assembly of what should be the final prototype. Figure 1**Error! Reference source not found.** is an isometric of the complete assembly, Figure 2 outlines the heating system.

For further images of the prototype please see Appendix A.

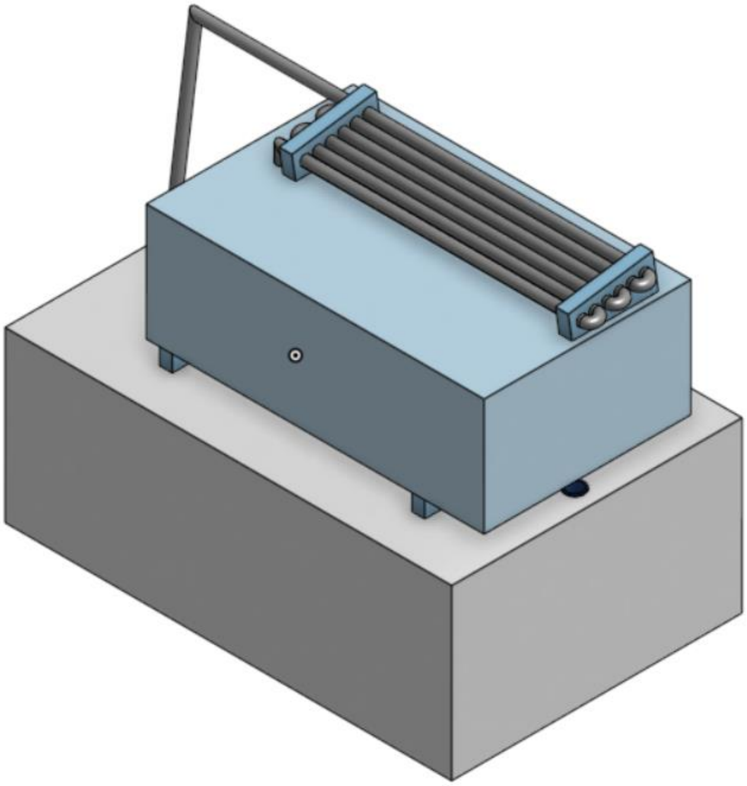

Figure 1: Isometric of Prototype

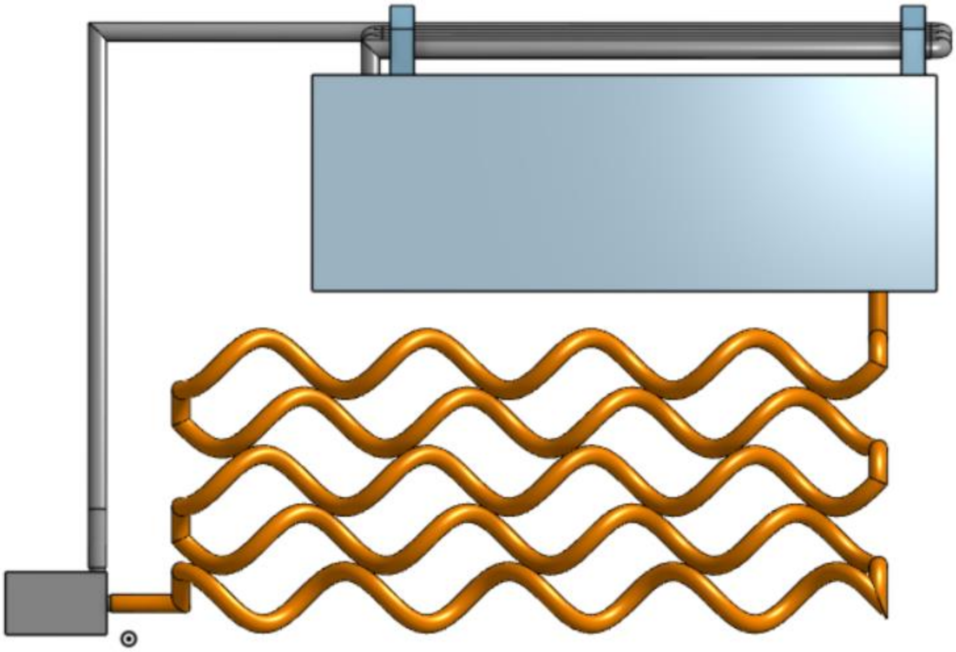

Figure 2: Prototype Heating

For further images of the prototype please see Appendix A.

6.2 Calculation

$q = mC_p(T_{m,o} - T_{m,i})$ $\quad T_s - T_m$

$q = mC_p(\Delta T_i - \Delta T_o)$ $\quad \Delta T = T_s - T_m \begin{cases} \Delta T_i = T_{s,i} - T_{m,i} \\ \Delta T_o = T_{s,o} - T_{m,o} \end{cases}$

Newton law of cooling: $q = hA\Delta T_{lm}$

$\Delta T_{lm} = \dfrac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}}$ $\quad A \rightarrow$ Surface Area

$\Delta T_i \rightarrow$ the inlet mean temperature

$\Delta T_o \rightarrow$ the outlet mean temperature

length of the pipes = 12X6 inch

= 1.83m

diameter = 0.0095 m

the average heat transfer coefficient is $100 W/m^2$-k

via analysis/estimation and research: the inlet mean temperature is -5°C

the outlet mean temperature is 13 °C

$\Delta T_s \rightarrow$ the surface temperature of the pipe is 15 °C

$\Delta T_i = \Delta T_{s,i} - T_{m,i} = 15 - (-5) = 20°C$

$\Delta T_o = T_{s,o} - T_{m,o} = 15 - 13 = 2°C$

$\Delta T_i - \Delta T_o = 20 - 2 = 18$

$$\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}} = \frac{2-20}{\ln \frac{2}{20}} = 7.817\ ^\circ C$$

$$q = (100\ W/m^2 \cdot k) \cdot \pi \cdot \underset{(1.85m)}{(\text{length})} \underset{(0.0095m)}{(\text{diameter})} (7.817^\circ C)$$

$$= 43.16 \quad W$$

mass flow rate:

$$m = \frac{q}{C_p(\Delta T_i - \Delta T_o)} = \frac{43.16 \quad w}{4184 \frac{J}{kg \cdot k} \ (18^\circ C)} = 5.73 \times 10^{-4}\ kg/s$$

2nd part

$T_{hot} = 40^\circ C \qquad T_{cold} = 20^\circ C$

$Area = \frac{\pi \cdot D \cdot L}{2}$

diameter: 0.0095m

length $\quad 12 \times 8 = 72\ inch = 1.83\ m$

The heat transfered by process of radiation

$$Q = \sigma\ (T_{hot} - T_{cold})\ A$$

$$= 5.67 \times 10^{-8}\ W m^{-2}\ k^{-4}\ (40 - 20)\ \frac{0.0095 \times 1.83\pi}{2}$$

$$= 3.096 \times 10^{-8} \quad W$$

The length and diameter are from the estimation of our prototype.

The average underground temperature is 10-16C degrees in Canada (from the Project Description). We choose 15C because Ottawa is in the warmer part of Canada.

The inlet temperature is -5C degree, the average temperature in winter in Ottawa is around -5C.

Through analysis, we believe when the air exit the system, the temperature will be around 13C degrees.

In the end, we calculated the energy the system brings to the house per unit time and mass flow rate of our prototype, the result is 43.16 W(J/s) and 5.73*10^-4 kg/s

This means there are 43.5 joules of energy the system brings to the house per second and 73*10^-4 kg of air pass through the system per second.

These results prove our prototype plan works.

In the second part of the calculation, we calculated the heat transferred by the process of radiation since the prototype test will be conducted under sunlight. The room temperature is around 20C degrees, after 4-6 hours of exposure of sunlight, we expect the temperature would increase to 40C degrees. In the end, we get the result of 3.096*10^-8 W, which proved our prototype plan is good.

7 Potential User Feedback

As part of the development and refinement process the team contacted a couple of outside sources that may have useful perspectives on the project and prototype.

7.1 Civil Engineer and Construction Manager

We got in touch with a civil engineer/construction manager. Bowen presented our design with detailed graphs and data. The engineer really liked our designs, he believes our design is innovating and practical. He thinks the geothermal heating system is very reliable with low maintenance requirements. He mentioned that there is potential risk associate with the system including pipe leaks which may result insects get into the system and reduce system efficiency, water leaks of the solar water heater due to winter low temperature damaged the solar water heater and its pipes. He also said it may have corrosion on the heat exchange coils, corrosion prevents the system from being able to exchange heat. He suggested that we use filtered water for the solar water header system to prevent the incrustation built up.

7.2 Civil Engineering Student

Additionally, we got in touch with a civil engineering student and an employee at an Ottawa based property development. The student was told about the project and the team's prototype and asked for comments and feedback. The first bit of feedback was regarding the flow rate through the solar water heater panel. The comment was in relation to the pitch of roofs in Ottawa being very steep and may not provide ample time for the water to get up to temperature. The second was regarding the location of the solar water heater, completely covering the roof or only on a segment. This thought also lead to them mentioning the possibility of standardizing or prefabricating the roof elements for easier installation. They were also asked about the possibility of this product being used in new developments, to which they responded that property developers in the Ottawa region are not likely to use this product. The main reason being there is no incentive for developers to include the product in designs, and the level of development makes other heating and cooling systems cheaper to install. In the end, they found the project and prototype to be interesting and feasible but, point to several areas of more research and concern.

8 Prototype II Plan

Prototype 2 will be a partially complete physical model of the heating system comprised of the unmodified pump and the tubing that creates the solar water heater panel. The purpose of the prototype is to analyze and confirm the heat gained that was calculated in this prototype, related to weather and length of tubing. The prototype will encounter one test measuring the rate of heating using a thermometer to periodically measure the temperature of the water in the system. The prototype will be placed indoors in an area with large availability to sunlight and the pump will be able to run continuously over a 3-hour period. The test will be run several times with different levels of sunlight and area of tubing exposed. Each test will conclude after each 3-hour period, or if the temperature of the water in the pipe nears 60 degrees Celsius the maximum temperature rating for the pump.

9 Conclusions

Currently, the team has developed a 3D model and analysis of the final prototype and has interviewed several potential clients for our product. The calculations of the heat requirements of a house and the projected energy collection of our prototype suggest feasibility of our design. Additionally, the interviews have identified several areas of consideration for our final concept and have reinforced the potential of the team’s ideas.

10 Appendix A: Further Images of Prototype I

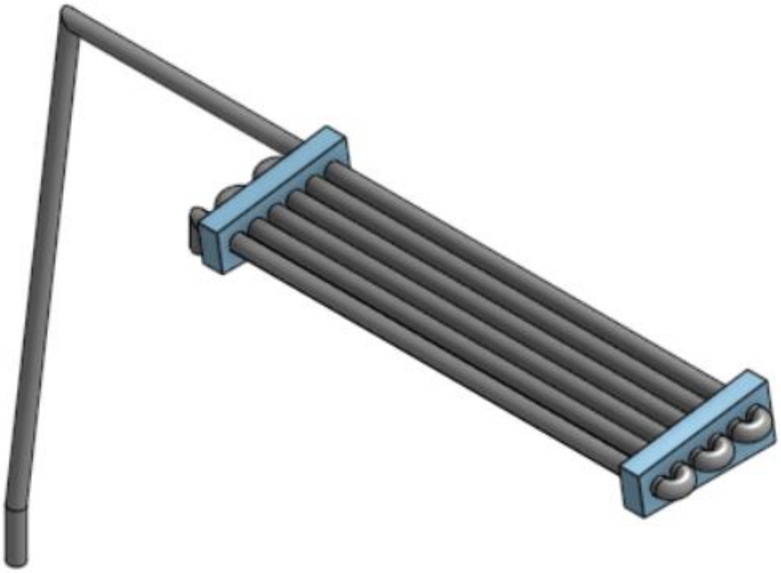

Figure 3: Solar Water Heater Panel

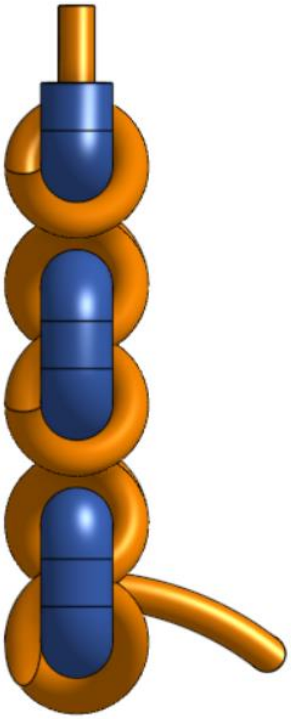

Figure 4: Air Pipe and Heating Coil