Project Deliverable F:
Prototype 1 and Costumer Feedback

Submitted by

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Abstract

This report documents the first prototype based on customer feedback, where the team plan is clearly outlining the feedback given by the client and how it will be used to improve our solution. Included in this report is of a prototype that has a small, targeted objective with specific test plan and measurable rules. This prototype includes diagrams and detailed images explaining its function. Additionally, we have included an analysis of critical components that must be included. Furthermore, as a form of testing, calculation was implemented using concepts such as heat transfer. Moreover, feedback was gathered from potential users/clients to further improved our prototype. The target specifications, detailed design and bill of materials were then update, as a result. Finally, we created a test prototyping plan for prototype 2 based on the feedback gathered.

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1 Introduction

A heating system is essential for buildings during winters in North America so, we designed a prototype of the conceptual design proposed. This prototype incorporated many components including hardware and software. In addition, it comprised of a physical design and a control system for the programming of the device. After multiple re-iterations, the first design of the prototype was built through the client feedback where it was broken down and used to improve our initial design. After building the prototype, the feedback is taken in consideration again to further refine the plan for the second prototype.

2 Customer Feedback from Deliverable D and E

After receiving customer feedback, it was evident that our initial design needed a lot more improvisions. The customer indicated that the design of the heat exchange chamber should promote heat transfer whereas our initial design was solely an insulated box filled with air. Therefore, the design was re-iterated to foster heat transfer so, that air will reach steady state at ground temperature. The heat exchanger will be filled with water as it is good for heat conduction and inside there will be several straight __ pipes connecting to the air inlet to the loop pipes to promote further heat transfer. In addition, the customer also stated that our design should focus on efficiency since it is low-tech. Therefore, it was decided that a compressor would be added into our re-iterated design after the looped pipes and above the sump pump. The purpose of the compressor is to increase pressure and consequently, increase temperature as well as increasing efficiency.

Figure 1. Proposed design from Deliverable D and E

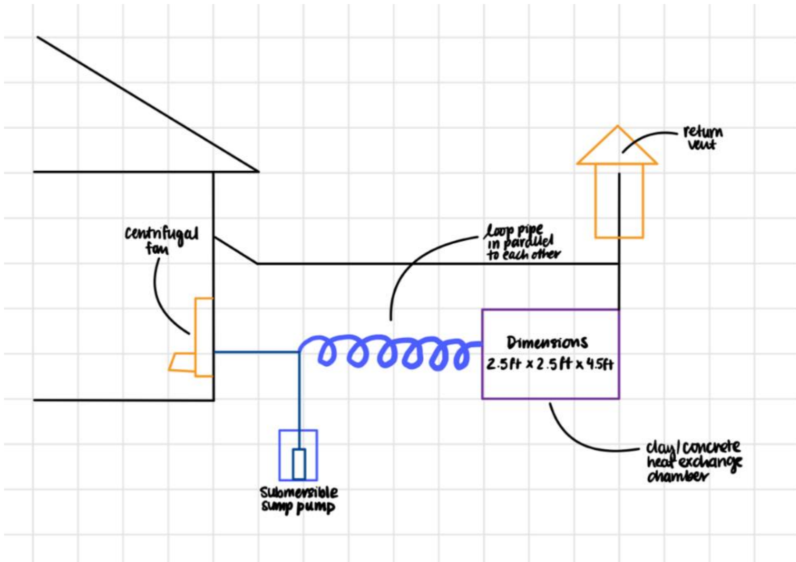
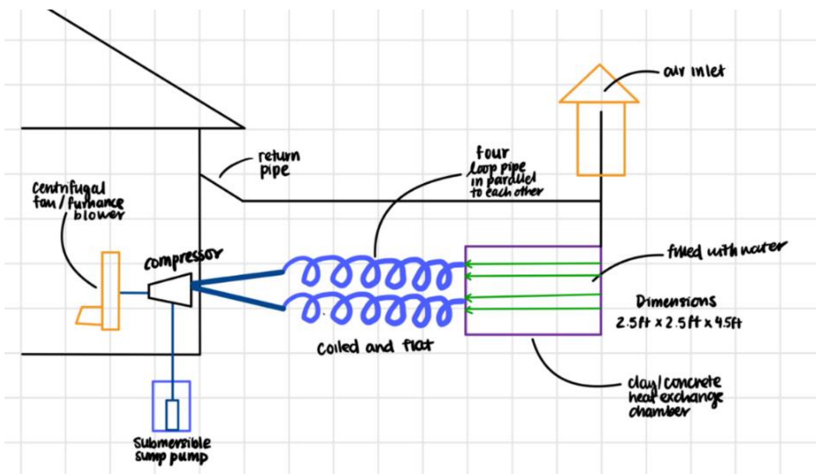


Figure 2. Design with Incorporated Customer Feedback



3 Prototype 1: Description and Test Plan

The purpose of prototype 1 is to determine if our HEC and piping network can obtain an outlet temperature of 20ºC and to ensure that the HEC does not fail when forces are exerted on it (0 deflection). In this prototype, we are testing and analysing the material properties of the HEC, piping network and compressor. The results will determine if we are using the correct dimensions and materials to achieve our desired design specifications and if a design re-iteration is required. Once our proof of concept is complete, we will obtain additional feedback so that the system may be further improved in future prototypes. The building and testing process took a duration of 2 days from March 5-6.

Table 1. Prototype 1 Test Plan

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)
1	To ensure that the HEC does not fail under the pressure of the ground	The outer layer of the HEC is a thick layer of concrete. A beam stress test will be used to determine the amount of pressure that can be applied to HEC's layer of concrete without failure.	Based on the result we will adjust the material being used for our piping network. This material needs to withhold the pressure from the ground.	2 days March 5-6
2	The concrete shell can support the weight of the contents inside the HEC.	The outer layer of the HEC is a thick layer of concrete. A beam stress test will be used to determine the amount of pressure that can be applied to HEC's layer of concrete without failure.	Based on the result we will adjust the material being used for our piping network. This material needs to withhold the pressure from the ground.	2 days March 5-6
3	To achieve a temperature of 20°C during the winter.	The heat transfer from the HEC to the piping network will be used to determine if the system's final outlet temperature can reach 20°C without the compressor.	Depending on the results from the calculations this will determine if our prototype meets the client's requirements. If not, we will adjust our ideas in the future prototypes.	2 days March 5-6

4 Analysis of Critical Components

Prior to the analysis on the HEC and the piping network, a detailed sketch was completed for each component to ensure that all dimensions required for the analysis are determined and the physical build is feasible.

Figure 3. Detailed Sketch of HEC

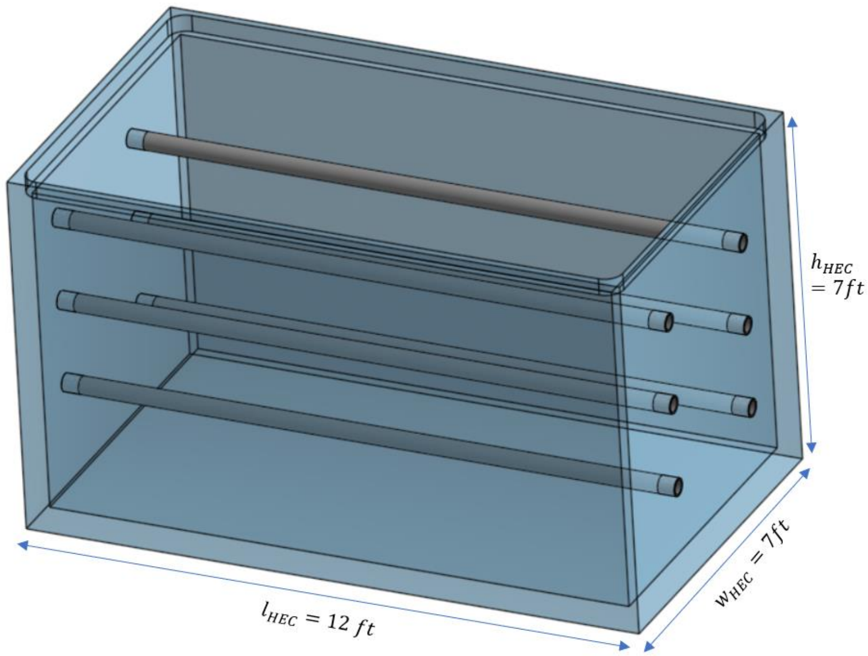
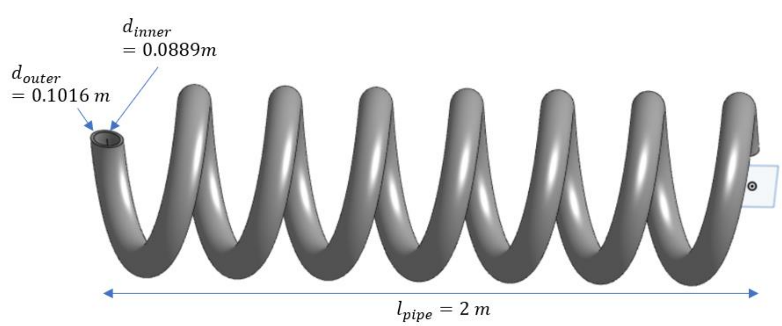


Figure 4. Detailed Sketch of Looped Pipe



4.1 Test ID 1: Uniform Distributed Load Deflection - Top of HEC

Assumptions:

- Neglect lateral earth pressure on the HEC
- Weight of soil is equally distributed on the HEC

- Maximum deflection occurs in the centre of the HEC lid
- Concrete has a thickness of 0.1m

Table 2. Test ID 1 Variables for Uniform Distributed Load Deflection - Top of HEC

Description	Variable	Value
Length of Concrete	l_C	$12ft = 3.6576\, m$
Width of Concrete	w_C	$7ft = 2.1336\, m$
Depth of Concrete	d_C	$10ft = 3.048\, m$
Thickness of Concrete	t_C	$0.1\, m$
Density of soil	ρ_{soil}	$1500\, kg/m^2$
Gravity	g	$9.81\, m/s^2$
Modulus of Elasticity	E_C	$30\, GPa = 3.0\, x\, 10^{10}$

<u>Volume of soil on HEC:</u>

$$V_{soil} = l_{HEC} w_{HEC} d_{HEC} = 11.9\, m^3$$

<u>Total distributed weight of soil:</u>

$$w_{soil} = \frac{g\rho_{soil}V_{soil}}{l_{HEC}} = \frac{(9.81\, m/s^2)(1500\, kg/m^2)(11.9\, m^3)}{3.6576\, m} = 47875.25\, N$$

<u>Moment of Inertia:</u>

$$I = \frac{w_C t_C^3}{12} = \frac{(2.1336)(0.1)^3}{12} = 1.78 \times 10^{-4}\, m^4$$

<u>Maximum deflection for top of HEC:</u>

$$\delta_{t,max} = \frac{5 w_{soil} l_C^4}{384 E_C I} = \frac{5(47875.25)(3.6576)^4}{384(3.0\, x\, 10^{10})(.78 \times 10^{-4})} = 0.02089\, m$$

4.2 Test ID 2: Uniform Distributed Load Deflection - Bottom of HEC

<u>Assumptions:</u>

- Neglect lateral earth pressure on the HEC

- Neglect the weight of the pipes in the HEC (they are supported by the HEC walls, not the concrete base)
- Weight of water in HEC is equally distributed on the concrete base
- Maximum deflection occurs in the centre of the concrete base
- Concrete has a thickness of 0.1m

Table 3. Test ID 2 Variables for Uniform Distributed Load Deflection - Bottom of HEC

Description	Variable	Value
Length of Concrete	l_C	$12ft = 3.6576\ m$
Width of Concrete	w_C	$7ft = 2.1336\ m$
Height of Concrete	h_C	$7ft = 2.1336\ m$
Thickness of Concrete	t_C	$0.1\ m$
Density of water	ρ_{H_2O}	$997\ kg/m^2$
Gravity	g	$9.81\ m/s^2$
Modulus of Elasticity	E_C	$30\ GPa = 3.0\ x\ 10^{10}$

<u>Volume of water in HEC:</u>

$$V_{H_2O} = (l_C - 2t_c)(w_C - 2t_c)(h_C - 2t_c)$$
$$V_{H_2O} = (3.6576 - 2(0.1))(2.1336 - 2(0.1))(2.1336 - 2(0.1))$$
$$V_{H_2O} = 12.927\ m^3$$

<u>Total distributed weight of soil:</u>

$$w_{H_2O} = \frac{g\rho_{H_2O}V_{H_2O}}{l_C - 2t_C} = \frac{(9.81)(997)(12.927)}{3.6576 - 2(0.1)} = 36566.82\ N$$

<u>Moment of Inertia:</u>

$$I = \frac{(w_C - 2t_c)t_C^3}{12} = \frac{(2.1336 - 0.2)(0.1)^3}{12} = 1.61 \times 10^{-4}\ m^4$$

<u>Maximum deflection of concrete base:</u>

$$\delta_{b,max} = \frac{5w_{H_2O}(l_C - 2t_c)^4}{384E_C I} = \frac{5(36566.82)(3.6576 - 0.2)^4}{384(3.0 \times 10^{10})(1.61 \times 10^{-4})} = 0.0176\, m$$

4.3 Test ID 3: System Heat Transfer and Output Temperature

4.3.1 Heat Transfer in the HEC

<u>Assumptions:</u>

- The temperature of water is $20°C$
- HEC inlet temperature is $10°C$
- Mass air flow is constant throughout entire system; mass air flow is $0.1\,\frac{kg}{s}$
- Temperature varies along 1 coordinate only (along x-axis)
- Temperature at every point does not change with respect to time

Table 4. Test ID 3 Variables for Heat Transfer in HEC

Description	Variable	Value
Temperature of HEC pipe = temperature of water	$T_{HEC.s}$	$20°C$
Inlet temperature of HEC	$T_{HEC.i}$	$10°C$
Outlet temperature of HEC	$T_{HEC,o}$	$17°C$
Pipe diameter	d_{pipe}	$4\, inch = 0.1016\, m$
Pipe length	l_{pipe}	$12ft = 3.6576\, m$
Heat transfer to air in HEC pipe	$\dot{q}_{HEC}$	N/A
Heat transfer coefficient of air	$\bar{h}$	$100\, \frac{W}{m^2K}$
Heat capacity of air	C_p	$1.006\, J/kgK$
Mass air flow	$\dot{m}$	$0.1\,\frac{kg}{s}$

Area of pipe:

$$A = \pi \cdot d_{pipe} \cdot l_{pipe} = \pi(0.1016)(3.6576) = 1.167\ m^2$$

Temperature Calculations:

$$\Delta T_i = T_{HEC.s} - T_{HEC.i} = 20 - 10 = 10°C$$
$$\Delta T_0 = T_{HEC,s} - T_{HEC.o} = 20 - 17 = 3°C$$
$$\Delta T_{lm} = \frac{\Delta T_0 - \Delta T_i}{\ln\left(\frac{\Delta T_0}{\Delta T_i}\right)} = \frac{3 - 10}{\ln\left(\frac{3}{10}\right)} = 5.81°C$$

Heat Transfer and Mass Air Flow Calculations:

$$\dot{q}_{HEC} = \bar{h}A\Delta T_{lm} = (100)(1.167\ )(5.81) = 678.5W$$

$$\dot{q}_{HEC} = \dot{m}C_{p,}(\Delta T_i - \Delta T_0)$$
$$\dot{m} = \frac{q}{(C_p(\Delta T_i - \Delta T_0)} = \frac{678.5}{1006(7)} = 0.01\frac{kg}{s}$$

The assumptions from the values tables gives an output temperature of $17°C$ for the HEC, so we can conclude that the specifications in this prototype are acceptable as the mass flow rate and the temperatures are within a realistic range.

4.2.2 Heat Transfer in Piping Network

Assumptions:

- Pipe surface temp = ground temp = $24°C$
- Inlet temperature of the piping network = HEC outlet temperature
- Mass air flow is constant throughout entire system; mass air flow is $0.1\frac{kg}{s}$
- Temperature varies along 1 coordinate only (along x-axis)
- Temperature at every point does not change with respect to time

- Assume pipe is straight (it is supposed to be looped, so the length of the pipe has been adjusted, but for the sake of the calculation we are assuming that the pipe is straight)

Table 5. Test ID 3 Variables for Heat Transfer in the Piping Network

Description	Variable	Value
Surface Temperature of piping network	$T_{PN.s}$	$24°C$
Inlet temperature of Piping Network	$T_{PN.i} = T_{HEC,o}$	$17°C$
Outlet temperature of Pipe Network	$T_{PN,o}$	$23°C$
Pipe diameter	d_{pipe}	$4\ inch = 0.1016\ m$
Length from pipe inlet to outlet	$l_{i,o}$	$6.56ft\ =\ 2m$
Heat transfer to air in HEC pipe	$\dot{q}_{HEC}$	N/A
Heat transfer coefficient of air	$\overline{h}$	$100\ \frac{W}{m^2K}$
Heat capacity of air	C_p	$1.006\ J/kgK$
Mass air flow	$\dot{m}$	$0.096\ \frac{kg}{s}$
Number of loops	n	7
Length of each loop	l_{loop}	$0.5\ m$

<u>Area of piping network:</u>

$$A = \pi \cdot d_{pipe} \cdot l_{pipe} \cdot n \cdot l_{loop} = \pi(0.1016)(2)(7)(0.5) = 2.23\ m^2$$

<u>Temperature calculations:</u>

$$\Delta T_i = T_{PN.s} - T_{PN.i} = 24 - 17 = 7°C$$

$$\Delta T_0 = T_{PN,s} - T_{PN.o} = 24 - 23 = 1°C$$

$$\Delta T_{lm} = \frac{\Delta T_0 - \Delta T_i}{ln\left(\frac{\Delta T_0}{\Delta T_i}\right)} = \frac{1 - 7}{\ln\left(\frac{1}{7}\right)} = 3.08°C$$

Heat transfer and mass air flow calculations:

$$\dot{q}_{PN} = \bar{h}A\Delta T_{lm} = (100)(2.23\ )(3.08) = 688W$$

$$\dot{q}_{PN} = \dot{m}C_{p,}(\Delta T_i - \Delta T_0)$$

$$\dot{m} = \frac{\dot{q}_{PN}}{(C_p(\Delta T_i - \Delta T_0)} = \frac{688}{1006(7)} = 0.01\frac{kg}{s}$$

To achieve a final outlet temperature of $23°C$ (which is higher than the minimum requested temperature from our client), our prototype will use the pipe specifications indicated in the table above. We can consider this prototype a success since the temperature and mass air flow values are within a realistic range.

5 Prototype #1 Feedback

Upon receiving feedback from various potential clients and individuals who would be interested in a heating system, changes were made accordingly to our prototype. The feedback received included the following: focusing more on the technological part of the system and as well as making the piping network as the main aspect. The potential client stated that the system is physical based and needs technological features to meet the requirements of heating a room to 20º C during the winter. For example, adding a heat sensor will control the heat levels of the system and it will ensure that the system will stay at that specific temperature. Another example the costumer provided is adding a pressure sensor to control the pressure underground. Additionally, the costumer suggested that we include a fan into the system to deliver high volume air output through the pipes, to the heat exchange chamber.

Our team's initial plan was to focus on the physical aspects of the system in prototype 1 and later focusing on the control system and sensors in our second prototype. We also were planning to include a centrifugal fan to blow air into the pipes. The primary focus of prototype 2 was the programming and technological components of the system. This feedback from the potential client helped us stabilize our test plan for prototype 2 and ensured us that we were on the right track.

6 Prototype 2 Test Plan: Control System

Table 6. Prototype 2 Test Plan

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)
1	The fan needs to be automated	It is important to make sure that the fan is automated with the correct instruction	It will be tested through the waveform diagram on Quartus II simulation	2 days March 12-13
2	Devices have a heat sensor and control system	The controlling system for heat sensor will be built with C language and later integrated into the Arduino.	It will be tested through the input-output simulation on VS Code software.	2 days March 12-13
3	Devices have a pressure sensor and control system	The controlling system for pressure sensor will be coded with C language and the output signal will be indicated on Arduino.	It will be tested through the input-output simulation on VS Code software	2 days March 12-13

7 Conclusion

The first prototype was created using the feedback received, in which it was later tested and completed. The team also labelled key components needed in our system in our proposed design. The test plan was carefully documented and additionally the feedback taken from the prototype assisted in the testing plan to build prototype 2. As a result, these recommendations were incorporated in prototype 2 test plan. The second prototype will be built accordingly to class material on how to build a prototype testing plan. We will then continue to build the design for prototype 2 and then test it in various ways. After doing so, the prototype 3 test plan will be finalized and therefore, the team will continue to assemble, program, design and test the various subsystems identified in the detailed design.

8 References

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