Red Feather- Team B12

Final Proposal Report

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1 DISCLAIMER

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2 EXECUTIVE SUMMARY

Red Feather Development group would like a design for a thermal storage device that can provide heat for the home at night. The goal for this team is to develop a solar thermal storage device that captures heat from the sun's rays and stores that heat. The heat will then be released during a cold winter night. The materials for the device should be locally available materials. They should be within the price range set by the Red Feather group and their customers. The final design selected for prototyping was the cumulative result of the concept generation and selection process, as well as several weeks of deliberation and consultation both amongst the teams and with outside advisors. This design uses a buried polyethylene storage tank to contain the thermal storage fluid, and two separate pipe networks for charging and discharging the thermal storage device. These networks and their driving turbomachines (a pump and blower) are managed by the control system, which monitors temperature of the house and the storage fluid to determine flow rates needed to ensure consistent heating to the home. This system is powered by a solar panel during the day, and by a charged battery at night, to ensure continual operation. In order to examine the operation of each element of this system, it is useful to divide them into five main subsystems: the air pipe network, the fluid heating network, the storage tank, the control system, and the power supply. After weeks of research and budgeting the total cost of the final design is approximately $1,200.00 according to the bill of materials. The next step to take for next semester is to prototype as much as possible and ensure the device passes all testing procedures before presenting the final product to the Red Feather Development group.

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4 BACKGROUND

4.2 Introduction

Red Feather is an organization that primarily does work on the Hopi Reservation and Navajo Nation. A problem that is currently faced is that there is not an adequate heating source for a lot of homes on the reservation. On the Navajo Nation and Hopi Reservation they have been primarily using wood and coal stoves as the main heat source. This creates problems due to the lack of coal, which makes an inconsistent heat source. Another problem is that coal and wood stoves create a poor air quality which can increase the amount of asthma cases. Since it can hurt the lungs of the families living there, it can make it worse if COVID is caught. Another type of heat that is used is propane or natural gas, which can be expensive for long term use. Red Feather Development group has been installing solar furnaces on several homes however those only heat the homes during the day when the sun is shing, which still creates the problem of having an adequate heating source at night.

4.3 Project Description

Previous capstone groups have designed solar furnaces that are reliant on the sun to produce heat for daytime use, however this left the problem on how the house would be warmed at night. In order to solve some of these problems Red Feather Development group would like a design for a thermal storage device that can provide heat for the home at night. The device is meant to store heat in a medium to then release it at night. The materials for the device should be locally available materials. Everything used for the system needs to be easy to transport to the home location. The design needs to be durable and able to handle the weather conditions that it will be exposed to. Lastly, the system should be within the price range set by the Red Feather group and their customers.

5 REQUIREMENTS

This part of the report will contain the customer needs from the client as well as the engineering requirements. Statements from the customer were recorded from a meeting with the client. These were then interpreted to create customer needs. With the customer needs the engineering requirements were derived and given a unit of measurement. A table of the customer needs and engineering requirements are displayed in this chapter. A brief description of how the engineering requirements will be measured and what equations will be used given the measurements is also included. A total of ten customer needs will be displayed in the tables below and from these, nine engineering requirements will be derived.

5.2 Customer Requirements (CRs)

Using the questions, the team had asked Terry, they began to design a set of Customer Needs. These needs ranged from information regarding the functions of the device and the kind of setting the device would be set in. The contact from red feather, Terry, had a lot of information for to expand on. The two most crucial pieces of info involved the temperatures the device would need to accommodate and the exact parameters of what the team needed to develop. With this information in hand ten customer needs shown in table 1 below were developed.

Table 1: Customer Needs

Question/prompt	Customer statement	Interpretation/Need
What is the main problem?	"A solution is still required to keep the home comfortable throughout the night."	Device should provide consistent heat source to keep houses warm at night, storing heat during the day and releasing at night.
What is the scope of the project?	"Current solar furnace is Arctica solar. Run by solar panel that runs the thermostat inside and monitors the temperature. System without electricity. Runs thermostat, fan, takes care of all electrical needs."	Device should store heat during the day and release it at night.

Where do you primarily work on homes in the reservation?	"Predominantly doing Hopi and western side of Navajo, includes major Navajo areas. Tuba City, Cameron, Leupp, Bird Springs. Currently, temperature drops into 40 degrees in the evening, 100 degrees all the way down into the 40's and 30's. June and July are 100-60. Gets colder as progress into fall. In the summer it is 100-50 degrees. In the fall it is 100-40 degrees. In the winter, goes down to 20's."	Device should be suited to functioning in Western Agency Council and Hopi Mesa regions.
How warm does the device need to keep the house?	"The design of thermal storage devices to be used in conjunction with thermal furnace solutions to keep indoor temperatures at or above 50+ deg F are the product deliverables."	Device should maintain comfortable indoor temperature throughout night.
What is the budget?	"Comfortable with $1200/$1500 per unit." [Although this is likely in tandem with Arctica Solar Air Furnace, for $500/unit]	Device should be within purchasing capabilities of Red Feather and the relevant clients.
Are there any readily available resources?	"Could ask Arctic solar if they would consider donating one [of the solar furnaces] to us to look at. Resources available would be donations." [Needs to be easily understood by donators]	Design should be straightforward.
What are our limits to size and dimension?	"If you start drilling holes in the roof, though, you could cause enormous problems. Exterior wall mounted systems work. Even in those systems, avoid a roof-mounted system. Any attempt to mount something on the roof will present a problem."	Device geometry should fit a variety of housing situations (no roof cave-ins).
What are the limits to the available materials?	"Device should be constructed with locally available materials"	Materials should be readily available in the region.
Will the device be reliable?	The device needs to consistently work for people in homes without maintenance.	Design a reliable design.
Will the device remain intact if dropped or damaged?	The device needs to withstand normal, everyday conditions, including different applications of force and different ranges of weather.	Create a durable and robust design.

The most important needs were that the device should provide consistent heat, store heat during the day and release it at night and should be capable of keeping a comfortable indoor temperature. It's worth noting that the customer needs that had the highest importance were those pertaining the effectiveness of the device. Next were qualities about the device's functionality on the reservation based on material availability in the Hopi region. This includes it being easy to operate, straightforward, low cost, be reliable.

5.3 Engineering Requirements (ERs)

The team derived nine engineering requirements shown in table 2 below from the ten customer needs. There needs to be an engineering requirement measuring the temperature inside the home and outside the home. This ensures the device can keep the home at a comfortable, warm temperature, as one customer need presents. It also checks for the usefulness of the device in different climates, from the information that the Navajo Nation and Hopi reservations climates range from an outside temperature of 20 degrees to 60 degrees when the device would be heating during the night. Another important measurement is heat output from the device, taken by applying the heat equation, simplified to:

$$Q = mc_p\Delta T \tag{1}$$

In which Q is the Heat Energy in BTUs, m is the mass of the medium fluid, in pounds, is the specific heat in BTU/°F/lb., and is the change in temperature, in Fahrenheit. If is negative, heat is lost, and if is positive, heat is gained. The target ER is 10,000 BTU/h.
Other engineering requirements include that the budget be within $1,500, which is the target ER, for the device alone. This comes from a desire for the device to be affordable and reliable for the Navajo and Hopi reservations. To create a straightforward design which is not too complex, the team required the device to have a maximum of 12 unique parts. For this purpose, the fewer the parts required indicates a better mechanical design. Due to the need for a device that adapts and functions on a variety of styles of homes, the team requires the device to meet certain device dimensions and weight, so that it is not unavailable to certain types of homes. The target ER is for the device to be within 4 ft. by 8 ft., which is the size of a typical truck bed, and less than 500 lbs.

Because resources are difficult to deliver to the customers' locations, and to address the customer need of using readily available materials, the team uses distance as a metric for how justifiable it would be to use different resources for our device. Later the team will also look at how often a resource is needed for the device, thus determining how often this delivery time will occur as a barrier to the customer. The target ER is a maximum of 150 miles, which can be measured using an odometer.

Another important engineering requirement is for the device to be durable and robust, withstanding different weather conditions. This is tested by submerge the electronic components case within a bucket of water to see if the water is sealed out. The target ER for the amount of water that the case can be submerged in is 5 gallons.

Table 2: Engineering Requirements

Engineering Requirement	Derived from this Customer Need	Method of measurement	Unit of Measurement	Target ER	Testing Procedure

Device maintains consistent house air temperature (60deg F)	Device should maintain comfortable indoor temperature throughout night	Thermometer or Temperature Sensor for temperature of air	Fahrenheit BTU/h	60F 10,000 BTU/h	Over a 14-hour period, the device outputs 10,000 BTU/h
Device works in environments with outside temperatures ranging from 20 degrees to 60 degrees Fahrenheit.	Device should provide consistent heat source to keep houses warm at night, functioning within standard season range of Navajo Nation and Hopi Reservation temperatures.	Thermometer or Temperature sensor	Fahrenheit	20-60F	Run device for several day/night cycles with projected lows around 20 F; if device maintains minimum heat output over 20 or sub 20 F nights, it passes the test
Device stores heat in an effective method.	Device should provide consistent heat source to keep houses warm at night AND device should store heat during the day and release it at night.	Heat equation, using mass, material qualities such as the specific heat of the medium fluid, and a measured change in temperature	Fahrenheit	175F	Measure the temperature of the water of the storage tank. Over 14 hours, does it maintain 175 F?
Device budget is within $1,500	Device should be within purchasing capabilities of Red Feather and the relevant clients.	Pricing	Dollars	$1,500	Bill of materials
Device has no more than 12 unique parts.	Design should be straightforward.	Counting	Unitless	<=12	Bill of materials
Device able to install onto a variety of homes.	Device geometry should fit a variety of housing situations (no roof cave-ins)	Device dimensions and weight	Feet, Lbs.	4ft.x 8ft <500 lbs.	Measuring tape Bill of materials
Materials should have minimal delivery (transit) time	Materials should be readily available in the region	Transit time of materials	Miles	<150 miles	Odometer
Device should work without interruption or maintenance.	Design a reliable design.	Amount of time device works without stopping	Days	7 days	Device functions without stopping for at least one week
Device should be able to withstand all weather conditions.	Create a durable and robust design.	Amount of water on the electronics case that can be withstood over time.	Lbf, Volume of water	5 gallons of water	Submerge the electronic components case within a bucket of water to see if the water is sealed out.

5.4 Functional Decomposition

As a functional decomposition, the team created a black box model to show a basic concept of what the device should be doing. Furthermore, the team created a Functional Model to show the broken-down components at each step of the process in our system. The functional model changed significantly between this report and the preliminary report. One reason for this is that the design has been compacted and simplified to have both heat exchangers inside the storage tank. Another reason is that there is now a loop of cold air and cold air recycled and blown into the house and then back into the tank when the air cools.

5.4.1 Black Box Model

The Black Box Model shows sunlight and water as physical inputs. Sunlight comes in naturally to the solar panel without a physical interaction. Water remains available in a closed loop system where the water is recycled after first being heated to transfer heat to the air and then cooled down and recycled. There is a signal input in the form of temperature data from the Arduino. The function of our system is to store thermal energy throughout the day to dispense during the night. The physical output of the system is heat in the form of warm air to be provided to the home. The signal output is temperature data from the Arduino. The Black Box Model can be seen below in **Error! Reference source not found.**.

Figure 1: Design Black Box Model

5.4.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The process starts with a liquid pump that pumps a heating fluid, propylene glycol, into copper piping that is heated with heating tape and a heating element, such as a thermal solar panel. This copper piping leads to an insulated storage tank which keeps fluid heated at 175 degrees Fahrenheit throughout the night. During the day, this fluid is heated with the heating tape so long as there is thermal energy provided through means such as the solar panel. Then, at night, this fluid is exchanged with water in the tank to make the fluid even hotter, then the fluid goes through a second liquid-to-air heat exchanger which takes cold air recycled from the house and makes the air hot through heat transfer of the hot fluid. Then, this hot air is blown through a blower into the house. Liquid is recycled back into the pump at the beginning of the cycle. Meanwhile, electricity is provided to the blower to blow hot air into the house through a subsystem with an electric solar panel which stores electricity in a battery throughout the day to be provided to the blower during the night when the solar panel is not actively providing electricity. This source of electricity, the solar panel, and the battery also provide constant monitoring of temperature at four different points in the system using thermocouples and an Arduino. The first part monitored by the Arduino is the liquid going from the pump into the storage tank, before it is being heated up. It should not be a high temperature yet. The next thermocouple is placed in the storage tank to monitor how hot the fluid is inside the tank, which should be 175 degrees Fahrenheit. The third thermocouple is placed at the blower which blows hot air into the house. This hot air should be up to 70 degrees Fahrenheit. The last thermocouple position is inside the house. The air in the house should be at least 60 degrees Fahrenheit.

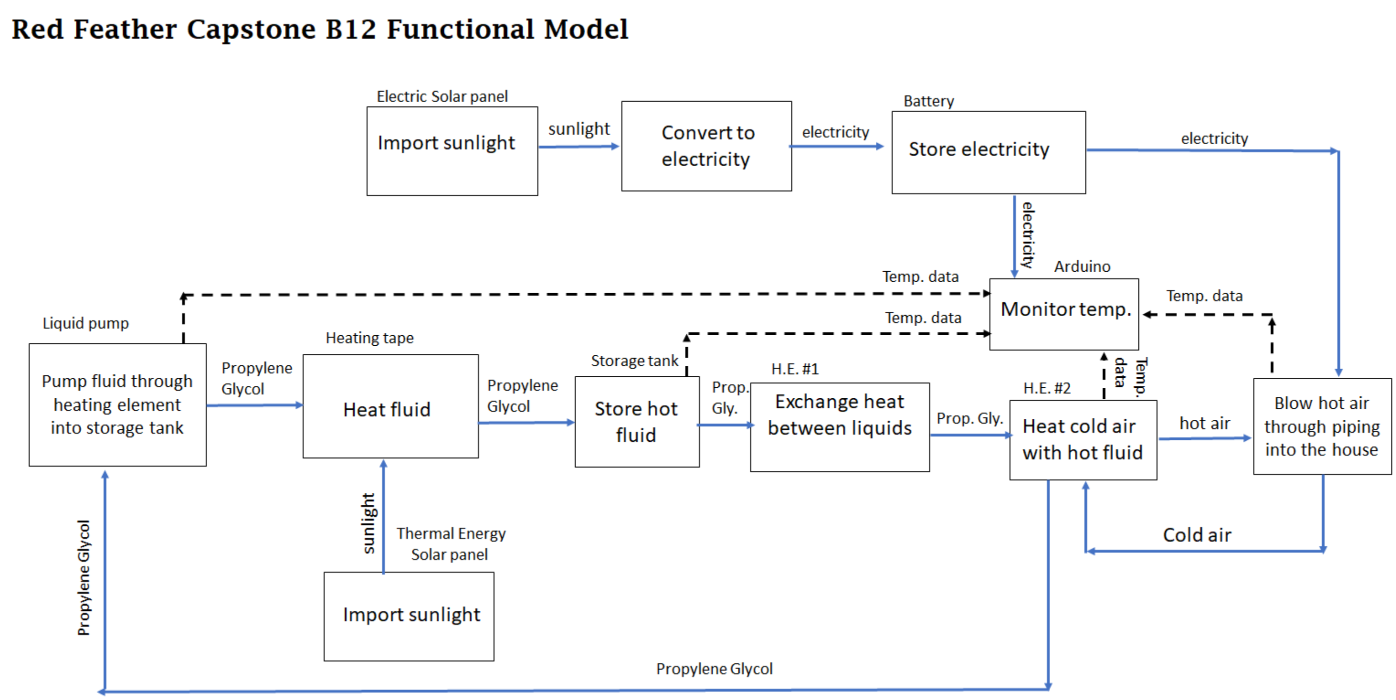

Figure 2: System Functional Model

5.5 House of Quality (HoQ)

The House of Quality presented all the customer needs and weighed them alongside corresponding engineering requirements to find which engineering requirements weigh most heavily in the concept selection stage. A figure of the House of Quality can be seen below in Error! Reference source not found.. The results were that the most weighted engineering requirement is the heat transfer rate of the device with an Absolute Technical Importance (ATI) of 186, and a Relative Technical Importance (RTI) of 0.1862. The second most weighted engineering requirement was the device cost, with an ATI of 148 and an RTI of 0.1481. Following these, the next most weighted engineering requirements were, in order, the outdoor temperature range, indoor air temperature, cycles without failure, number of parts, dimensions and weight, force withstood, and finally, max material delivery time as the least weighted engineering requirement.

Table 3: House of Quality

House of Quality (HoQ)													
Customer Needs	Customer Weights	Engineering Requirement	indoor air temp. (°F)	heat transfer rate (BTU/h)	Temperature of storage tank liquid (°F)	Device cost ($)	Number of parts (unitless)	Dimensions (ft^2)	Weight (lb)	Max material delivery distance (mile radius)	Outdoor temp. range (°F)	Volume of Water withstood (gal)	Cycles without failure (Days)
1. Consistent heat source at night	5		3	9	9	3		1	1		3		9
2. Store heat during day	5		3	9	9	3		1	1		9		1
3. Maintain comfortable indoor temperature throughout night	5		9	9	9	3		1	1		3		1
4. Device should be within purchasing capabilities of Red Feather and the relevant clients	5		0	0	0	9	6	3	3	3		1	1
5. Design should be straightforward.	3		0	0	0	3	9	1	1			1	1
6. Functions within standard season range of Navajo Nation and Hopi Reservation temperatures.	4		3	6	3	3					9	3	
7. Device geometry should fit a variety of housing situations	4		0	0	0	1	6	9	9			1	
8. The device should be efficent as possible.	3		6	9	3	3	1	1	1		3		6
9. The device should be durable	4		0	0	0	3	1	1	1			9	6
10. Materials should be readily available in the region	2		0	0	3	6	1			9			
Absolute Technical Importance (ATI)			105.00	186	162	148	90	76	76	33	120	60	105
Relative Technical Importance (RTI)			0.09044	0.1602	0.1395	0.1275	0.08	0.065	0.07	0.03	0.103	0.052	0.09
Target ER values			60	10,000	175	1200	<=12	4'x8'	<500	<150	20-60	5	7
Tolerances of Ers			(+-) 10	(+-200)	(+-5)	(+) 500	(+-)1	(+)0.1	(+)10	(+)10	(+)3	0	0
Testing Procedure (TP#)			#1	#1	#3	#4	#5	#6	#6	#7	#2	#9	#8

Table 3

3: House of Quality

5.6 Standards, Codes, and Regulations

Table 4 below provides the standards, codes, and regulations that apply to this project. Standards and codes vary from the ASME, IEE, Mechanical residential code (MRC), International residential code (IRC), and the International plumbing code (IPC). These codes and regulations must be considered for this project to ensure the safety of our clients. Since water will be heat to approximately 175 degrees Fahrenheit then the storage tank must be safe and under code to withstand the water temperature. The type of piping material for the heat exchangers cannot degrade or build residue from the high-water temperatures. Also, the air temperature cannot exceed temperature values of 250 degrees Fahrenheit.

Table 4: Standards of Practice as Applied to this Project

Standard Number or Code	Title of Standard	How it applies to Project
ASME BPV Code, Section VII Division I	Design and Fabrication of Pressure Vessels.	Helps in the design of selecting the right type of heat exchanger that is safe and effective.

IEE 937	Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems	Helps ensure the PV solar panel is installed correctly and safely.
2018 IRC Chapter 16	Duct systems	Making sure the duct system is safe, proper installation, and is durable for the warm air.
2018 IRC Chapter 23	Solar thermal energy systems	For choosing the correcting heating fluid for the heat exchangers.
2018 MRC Section 1003	Pressure vessels	Choosing the right material to withstand the pressure for the heat exchangers and be accessible.
2018 MRC Section 1202	Hydronic piping	Choosing the proper material for the piping within the tank.
2018 MRC Section 1404	Heat Transfer Fluids	To ensure the heat exchangers have leak protection.
2018 IPC Section 504	Safety Devices	Providing a pressure and temperature relief valve for the hot water storage tank.

6 Testing Procedures (TPs)

Once prototyping is accomplished the team must analyze the device under a series of different tests. These tests are derived from the engineering requirements in table 2. Some of these tests can be done before prototyping such as meeting the budget and number of parts. However, for the other tests they range from using thermal couples and a data acquisition device. Most of the tests will be conducted once the device is built or parts have arrived after being purchased. Data from all testing procedures will be stored in an excel file and will be discussed with the team's capstone mentor.

6.2 Testing Procedure 1: Consistent air temperature

A constant air temperature must be achieved to ensure the client is comfortable during cold 14-hour winter night. This testing procedure was derived from the first engineering requirement. Thermal couples and thermometers will used to measure the air temperature. A calculated 10,000 Btu/hr output of heat is desired to ensure the customer will be comfortable.

6.2.1 Testing Procedure 1: Objective

The device will be put into a room for 14- hours and will operate when ambient temperature drops below 60F. This procedure is testing the performance of the device and making sure the device works consistently. Testing the performance of this device will let the team know if any flaws are present.

6.2.2 Testing Procedure 1: Resources Required

Thermal couples, thermometers, laptop, and Microsoft excel will be needed for this testing procedure. Thermal couples and thermometers will measure the temperature. The laptop and Microsoft excel will record the measurements.

6.2.3 Testing Procedure 1: Schedule

For this test only a 14-hour night in a room is how long this test will take. Running this test will be conducted once the device is built. Scheduling this test can be done halfway through the semester.

6.3 Testing Procedure 2: Achieving heat output outdoors

For the device to be successful a heat rate of 10,000 btu/hr or more is desired. This testing procedure was developed from the second engineering requirement. Performance of the device must be consistent with the heat rate output. Thermal couples will be used to measure the ambient and device temperature difference.

6.3.1 Testing Procedure 2: Objective

This test will be done by placing the device outdoors with ambient temperatures less than 60F and allowed to operate. The thermal couples will measure the temperature of the air from the device so the heat output can be calculated. Measuring the temperature difference will determine if the device has a heat output of 10,000 Btu/hr or more.

6.3.2 Testing Procedure 2: Resources Required

Thermal couples, laptop, and Microsoft excel are the resources required for this testing procedure. A cold room on campus can be used for this procedure.

6.3.3 Testing Procedure 2: Schedule

Conducting this testing procedure can be accomplished halfway through the semester or once the device is built. If the device fails, this test then redesign, and retesting will be accommodated.

6.4 Testing Procedure 3: Thermal storage tank

The fluid stored in the storage tank must be heated to 175F to achieve the desired heat output. While the device is heated during the day and stored at night, reducing the amount of heat lost is the goal for this procedure. This procedure came from the third engineering requirement, thermal couples will be used to measure the fluid temperature. Insulation will also be accounted for during this testing method.

6.4.1 Testing Procedure 3: Objective

This testing procedure will test the amount of heat loss from the storage tank and if the fluid stays at a consistent temperature throughout a 14-hour period. This test will let the team know if the tank needs to be insulated more or need to redesign.

6.4.2 Testing Procedure 3: Resources Required

Thermal couples, laptop, device storage tank, and Microsoft excel will be needed to conduct this testing procedure. Data from the thermal couple will be stored in a excel file.

6.4.3 Testing Procedure 3: Schedule

Conducting this test can be accomplished once the storage tank is purchased and received. This could be during the early part of the semester and testing at the machine shop on campus.

6.5 Testing Procedure 4: Making sure device is within budget

This test came from the fourth engineering requirement, the device must be $1,500 or less, and this can be tested by referring to the bill of materials once every part has been purchased and put together. Resources required will just be the BOM and receipts.

6.5.1 Testing Procedure 4: Objective

Testing whether the product meets budget constraint will be done by reviewing the BOM. This testing procedure will determine if the device is affordable to the client but also efficient.

6.5.2 Testing Procedure 4: Resources Required

Resources required is the BOM, laptop, and receipts. Not a lot of resources are needed to test this procedure as this test was accomplished this semester.

6.5.3 Testing Procedure 4: Schedule

This test can be accomplished before the start of the semester at any location. According to the BOM the device is within budget.

6.6 Testing Procedure 5: Limit number of parts.

The device should contain no more than 12 unique parts, and this can be tested by reviewing the bill of materials. This testing procedure was developed from the fifth engineering requirement. Scheduling this test will be done towards end of the semester once the product is working properly.

6.6.1 Testing Procedure 5: Objective

Conducting this test will determine if assembling time can be reduced. Limiting the number of parts ensures a straightforward design and less maintenance.

6.6.2 Testing Procedure 5: Resources Required

For this test only the Bill of materials will be needed to determine if the device passes, which it did according to the team's bill of materials.

6.6.3 Testing Procedure 5: Schedule

Scheduling this test can be done before the start of the semester in the spring and this report contains those results. The results are in the bill of materials section and the total number of parts is eleven.

6.7 Testing Procedure 6: Testing Geometry

6.7.1 Testing Procedure 6: Objective

The objective of this testing procedure is to ensure that the device can be installed in a way that has no chance of obstructing the homes it is being installed into. In particular, it revolves around having a light enough and properly dimensioned device so that it does not compromise the home its built to work with.

6.7.2 Testing Procedure 6: Resources Required

The only recourse required for this procedure is measuring tape to allow us to better understand how much space the fully assembled device will need. Along with this the Bill of Materials will provide enough information about each part to give a reliable weight for the system.

6.7.3 Testing Procedure 6: Schedule

This test would be performed as the system is being assembled. The whole assembly will be made up of three distinct systems. Due to this the measuring will be done in four stages. Once per assembly of each subsystem and a final time when the system is complete.

6.8 Testing Procedure 7: Time in Transit

6.8.1 Testing Procedure 7: Objective

The objective of this experiment would be to explore the ability of the device as a whole system to be taken to the home that it will be installed in. The main purpose of this procedure is in order to ensure that the device can be delivered easily to the homes it needs to be installed in.

6.8.2 Testing Procedure 7: Resources Required

The only required resources for this analysis are an average vehicle for transporting the system and an odometer to measure the distance the chosen vehicle will need to travel in order to deliver all of the parts.

6.8.3 Testing Procedure 7: Schedule

This could be taken in several steps. The first run of this test would take place by understanding the actual distance between point A and point B. From there the device as a whole or by subsystem would be measured against the chosen vehicle to see if multiple trips would be required in order to get the device as a whole to the place it needs to be set up at.

6.9 Testing Procedure 8: Reliability of Design

6.9.1 Testing Procedure 8: Objective

This testing procedure is straight forward. It only requires seeing if the device is able to function experimentally for an extended period without having any malfunctioning elements.

6.9.2 Testing Procedure 8: Resources Required

The design of this procedure has two possibilities. On one hand all that would be required is a space to hold the device while it runs for a period of time and the system is under surveillance to see how it is operating. Another option would be to find a building that fits a standard design and test the machines operating system on it.

6.9.3 Testing Procedure 8: Schedule

This testing would take place nearly at the end of the spring semester when the whole system is put together. It would be run for approximately a week to test whether or not the system could operate continuously without any malfunctions.

6.10 Testing Procedure 9: Durability of Design

6.10.1 Testing Procedure 9: Objective

The objective of this testing procedure is to see how well the device could handle snow and water building up around it. This would be to simulate the types of weather the device would have to deal with during the primary months of usage.

6.10.2 Testing Procedure 9: Resources Required

The resources required for this testing would include a bucket of water and a weighted material. The electronic components of the device would be placed into the bucket full of water to see if they are safe from water. The weighted materials would be placed onto the piping components to ensure they could support the weight of snow.

6.10.3 Testing Procedure 9: Schedule

This testing would occur in multiple stages. The first process would be fairly short and could take place at any time after the electronic components are assembled. The second test would be undertaken once the whole device is assembled and would take place in several stages to see how each section of piping could handle weight.

7 RISK ANALYSIS AND FMEA

By considering all the components of the design, we can analyze the potential risks and failures that can occur with these components. The components of the system include the heating fluid pump, liquid-to-liquid heat exchanger, liquid-to-air heat exchanger, heating band, copper piping, storage tank, fan, battery, electricity solar panel, Arduino, and thermocouples. Most risk involves corrosion, because this is a piping system with heated liquids travelling at a velocity above still water. Other forms of failure involve fatigue, chemical damage, or thermal shock. First, we discuss the 10 most concerning critical failures gathered from the score of the RPN, from a full FMEA calculation. The full FMEA sheet can be found in the Appendix.

7.2 Critical Failures

The ten greatest critical failures are sorted by RPN. The greatest critical failure is corrosive wear of the electricity solar panel, where weathering causes cracks in the cells, therefore making the panel not output the full amount of power as it did before the critical failure. This failure mode has an RPN of 48, and the recommended action involves regular maintenance and check-ups on the panels. This includes cleaning the panels monthly, performing a maintenance check annually, and covering the panels with a tarp or protective layer if there is a hailstorm or damaging storm coming.

The second greatest critical failures are tied, both involving thermocouples with an RPN of 42. One critical failure is thermal fatigue, where temperature changes within the thermocouples eventually cause expansion and contraction of the metal, weakening the thermocouples. Eventually, this may cause the thermocouple to break, where it cannot read temperatures properly. The other critical failure involving thermocouples is hydrogen damage, where oxygen gets into the sealed thermocouple, reacting with the metal and damaging it. This would cause the temperatures of the thermocouple to be inaccurate. The recommended action for this is to switch out the thermocouples on a routine basis.

The fourth highest RPN, at 40, has critical failures for the liquid to liquid and liquid to air heat exchangers, both failing from thermal fatigue. This could occur from high temperature differentials of liquids or from freezing from the outside environment if the tank is not insulated properly. If the heat exchangers were to fail, the liquid would not be heated, the piping would break with holes or cuts in the material. The recommended action is to choose a heat exchanger with increased temperature limits.

The next most likely critical failures, with RPN values of 32, involve the heating band or heating tape. One critical failure is crevice corrosion, where moisture builds and is trapped between sheets of metal on the heating band. This causes the heating band to be overwhelmed by moisture and fail. The recommended action is to make sure the heating band is properly protected from the elements and weather conditions. Another heating band critical failure is high cycle figure, caused by the wire diameter being reduced over time, which melts and breaks down the insulation of the wire. This would cause power shorts in the heating band, causing it to no longer work. The recommended action is to use the lowest wattage necessary. The last critical failure for the heating band is thermal fatigue, where the low or high temperature affecting the efficiency of heat transfer. This is often caused by the heating band or tape being at too high of a power over a short period of time. The recommended action is to make sure the heating band is tightened and properly fitted, using as low an amount of wattage, as necessary.

The final critical failures making up the 10 most concerning critical failures regard the copper piping. These two critical failures have an RPN of 27. One critical failure is erosion corrosion of the copper piping. This happens because of electrical-chemical reactions or bacteria causing corrosion. It creates holes in the piping, making the liquid leak or spray into either the storage tank or the surroundings, depending on the location of the leak. The recommended action is to check and confirm that the piping system is properly grounded, to check the pH levels of the water to see if they are lacking balance, and then to consider adding phosphate or algae to the water to combat chemical or bacterial damage on the piping.

7.3 Risk and Trade-offs Analysis

The different types of critical failures exist around high temperatures and high temperature differentials in fluids causing damage, as well as corrosion from the weather, high velocities of water, and chemical reactions. The team originally chose high temperature resistant components so they could operate at 175 to 200 degrees Fahrenheit for the liquid in the storage tank. Thus, there are not many trade-offs in design for choosing high temperature components. All the modifications to decrease risk work synchronously with each other. The only trade-off is with the budget and maintenance time. By making additions to the piping, such as adding phosphate or algae to the water, or adding thicker material to the piping, the cost of the system increases. To reduce risk, the owners should check up on components annually or monthly and maintain them by cleaning them. To reduce the damage from high velocity in the pipe, the team chose a 1-inch diameter piping, which is a larger diameter compared to some HVAC systems, where the piping diameter is ¾ inch or ½ inch. The diameter could possibly be further increased if necessary, but this is a low possibility failure.

8 DESIGN SELECTED – First Semester

This section examines in detail the design selected for prototyping at the end of the Fall 2020 semester. To do this, it first describes the various physical details of the design, including the various key subsystems, before providing a detailed diagram intended to explain the operation of the device, how it works, and when it performs the tasks necessary to its operation. Once that is done, this section then describes the implementation plan for the device, including both the stages of the design and prototyping process as well as a detailed bill of materials.

8.2 Design Description

The final design selected for prototyping was the cumulative result of the concept generation and selection process, as well as several weeks of deliberation and consultation both amongst the teams and with outside advisors. This design, as shown in the CAD model below (**Figure *3***), uses a buried polyethylene storage tank to contain the thermal storage fluid, and two separate pipe networks for charging and discharging the thermal storage device.

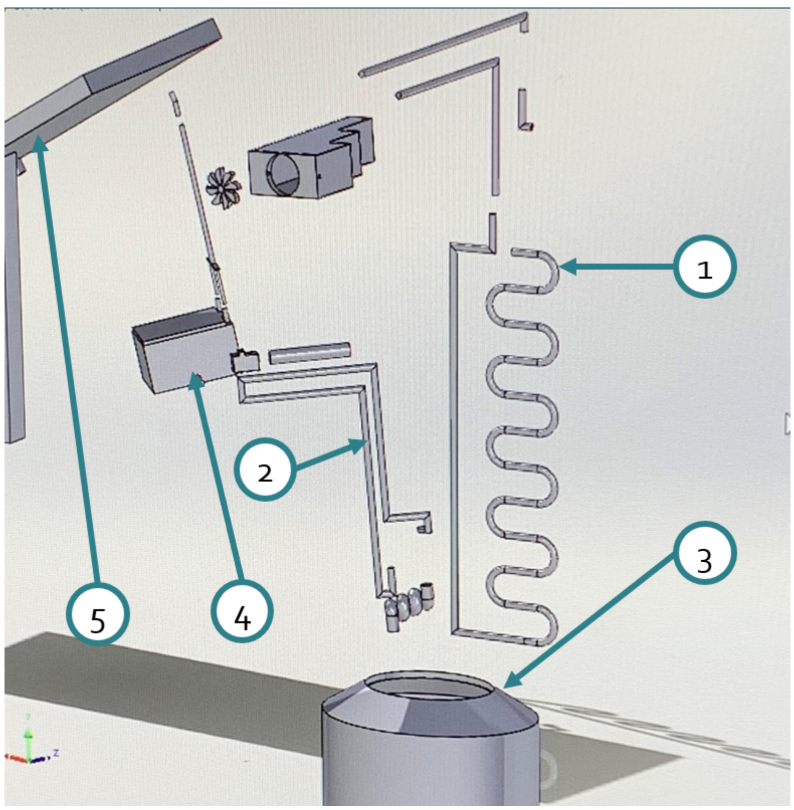

Figure 3: CAD Model Exploded View with Numbered Subsystems

1: Air Pipe Network, 2: Fluid Heating Network, 3: Storage Tank, 4: Control System, 5: Power Supply

These networks and their driving turbomachines (a pump and blower) are managed by the control system, which monitors temperature of the house and the storage fluid to determine flow rates needed to ensure consistent heating to the home. This system is powered by a solar panel during the day, and by a charged battery at night, so as to ensure continual operation. In order to examine the operation of each element of this system, it is useful to divide them into five main subsystems: the air pipe network, the fluid heating network, the storage tank, the control system, and the power supply.

8.2.1 Air Pipe Network

When the thermal storage device is discharging, this subsystem is responsible for moving the air through the storage device. It does this by first pulling air from the house with a blower and pushing that air through the pipe network and into the thermal storage tank. Once there, the air is heated in a liquid-gas heat exchanger submerged in the tank fluid, before being returned to the house via more copper piping. This subsystem only operates at night and is necessary for delivering heat from the thermal battery to the house as it discharges. During this time, the blower operates on battery power. This subsystem does not operate during the daytime, while the system is charging.

Originally, the Air Pipe Network used a fan at the end of the network (the outlet to the house) to drive airflow. However, after suggestions to do so from both advisors, the team decided to replace this with a blower at the inlet to the pipe network.

8.2.2 Fluid Heating Network

The Fluid Heating Network performs a similar role to the Air Pipe Network, albeit during the day. In this subsystem, heat transfer fluid is circulated through the pipes, transferring heat from a section of pipe wrapped in heating tape to a liquid-to-liquid heat exchanger inside the thermal storage tank. This process is used to heat the storage device throughout the day, ensuring that it is at the desired temperature when the sun sets. A small, temperature-resilient pump is used to drive this flow, the current desired temperature of which is 230 °F. The transfer fluid used will be some concentration of propylene glycol solution of at least 20% concentration.

In order to determine the necessary thermal output of this system, the team first evaluated the necessary amount of heat stored by the device by comparing the heat loss of a simulated building to the heat produced by a comparable thermal device currently used on the Navajo Nation and Hopi Reservation [1]. To calculate heat loss, the following equation was used:

$$Heat\ Loss = \frac{A_{surf} * \Delta t}{R_{surf}}$$

Where A_{surf} and R_{surf} are the area and thermal resistivity of the surface, and Δt is the desired temperature changed. This determined a necessary heat output of 10,000 BTU/hr, with a total of 140,000 usable BTUs needed to heat the house over a 14-hour night. Since this system will be used to charge the thermal storage device, it is reasonable to assume that it must output 140,000 BTU during the charging process. Since this is based on a 14-hour night, it follows that this must be done during a 10 hour day; as such, the required thermal output of the Fluid Heating Network was determined to be 14,000 BTU/hr. This should be achievable with the 8' heating tape selected for the project [2].

Note that the heating tape heating system is a stand-in, used in lieu of a different source of heat for the purpose of creating a functional proof of concept prototype. The team had originally intended to include a solar thermal water heating panel, with the intension that it would allow the device to be fully autonomous, requiring no grid electricity. However, this led to the team being far overbudget, and as such it was decided that, for the purpose of the prototype, it would be best to use the tape heating system instead.

8.2.3 Storage Tank

The storage tank is perhaps the most critical subsystem in the design, largely because it is responsible for the thermal storage component of the thermal storage device. It is filled with thermal storage fluid and is heated up by the Fluid Heating Network during the day, before discharging the heat via the Air Pipe Network at night. The subsystem itself is simple, being composed only of a polyethylene liquid storage tank and storage fluid, with holes in the lid of the tank for the heat exchangers and pipes involved in the two pipe networks. The current storage fluid selected is a 20% concentration propylene glycol, much like the heat transfer fluid. These concentrations may vary according to the needs of the project.

In order to determine the necessary amount of heat transfer fluid, the following equation was used:

$$Q = cm\Delta t$$

Where Q is the amount of heat stored, m is the mass of fluid, c is the specific heat, and Δt is the desired temperature change of the fluid. This equation was used to compare the thermal properties of a variety of candidate thermal fluids, using an assumed Q = 140,000 BTU to determine the necessary volumes of each fluid. The results of this analysis are tabulated below (Table 5).

Table 5: Required Mass and Volume of Different Thermal Storage Fluids

Name	Density	Specific Heat	delta T (F)	Q (BTU)	mass (lb)	volume (ft^3)	volume (gallon)
Fresh Water	62.4	1	115	140000	1217.391	19.50947603	145.9410256
Salt Water (Sea)	63.93	0.938	115	140000	1297.859	20.30124407	151.8638623
Ammonia (176°F)	38.55	1.29	115	140000	943.7142	24.48026432	183.1251068
20% Propylene Glycol Solution	62.7	0.968	115	140000	1257.636	20.05798477	150.0441562
20% Ethylene Glycol Solution	63.8	0.96	115	140000	1268.116	19.87642542	148.6859979

The results of this analysis suggested that the ideal thermal storage solution was a 20% propylene glycol mix. This is for a variety of reasons, chief of which are that it is relatively affordable, has properties that reduce corrosion, it will not freeze or boil at operating temperatures, and most importantly it is not as toxic as ethylene glycol (with which it shares many properties) [3-5].

8.2.4 Control System

The control system is responsible for ensuring that the each of the subsystems performs its role as needed, and to monitor various parameters of the system in order to ensure that the system operates as intended. It uses thermocouples to determine the temperature at various key steps within the process, such as the air outlet and the pump inlet, as well as the tank itself. It also controls the blower, pump, and heating tape, in order to ensure that the system discharges heat at the appropriate rate without overheating or becoming too cool. This component is crucial for the continued operation of the device, as it ensures that the correct charging or discharging cycle is running at the correct time. Additional information on these cycles is included below.

8.2.5 Power Supply

This subassembly is relatively simple, being only responsible for ensuring that certain other components remain powered throughout the duration of the device's operation. It consists of two major components- a battery, which shares a waterproof container with the control system, and a solar photovoltaic panel. During the day, the solar panel charges the battery, while also providing power for the control system and pump. At night, the battery provides power for both the blower and the control system, to ensure continual operation of both. Note that neither of these are responsible for powering the heating tape; this is because this component is a "stand-in" for a different heater that will not require electricity. As such, the heating tape will be powered by grid power for this prototype.

8.2.6 Full System Schematic

In order to demonstrate how each subsystem works together, it is helpful to use a schematic that details the full extent of the system. Said schematic is included below (Figure 4)

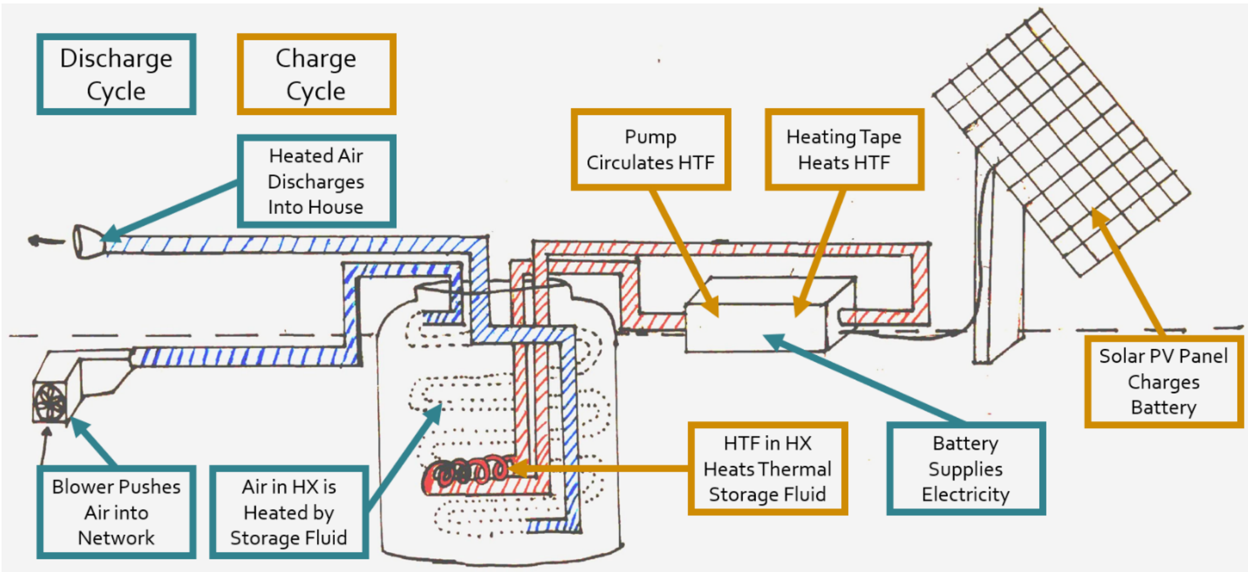

Figure 4: Full System Schematic

The system goes through two different cycles while in operation, one during the day and one at night. These are distinguished by color in the image shown.

During the day, the system goes through the charge cycle. In this cycle, the pump circulates "cool" heat transfer fluid (HTF) through the heating tape section of fluid heating network, where it is heated. From there, it moves through the pipe network into a fluid-to-fluid heat exchanger (HX) immersed in the tank. Here, heat moves from the transfer fluid to the storage fluid, "charging" the thermal battery. This cycle continues until the tank reaches a pre-determined temperature threshold.

At night, the system goes through the discharge cycle. In this cycle, a blower pushes air from the house into the air pipe network. Here, air passes through the heated thermal storage tank, where it is warmed in a liquid to gas heat exchanger. From there, it flows through the remainder of the pipe network out of the tank, and back into the house. This cycle continues throughout the night, with air speed and heat transfer varying according to the inputs of the control system.

8.3 Implementation Plan

8.3.1 Implementation Break Down

This design will be implemented in several stages. The first stage has already been taken. This involved developing a three-dimensional model of the system. From this point most of these stages will have to do with the process of collecting parts, assembling the design, and then testing the system both as subsystems and as a total system. The total amount of parts for this design can be seen in figure 1 below. While most of these parts will be bought from suppliers. One of the required heat exchangers and the piping will require more extensive work in order for them to be able to be best integrated with the rest of the system. This prototyping is predicted to take most of the semester. This is due to both the extensive nature of our design and the need to run experiments on the system and likely rework parts of the design that prove ineffective when assembled. It is also important to understand that in order to create a prototype for this system a different heating source is required that will be different when the device is applied on the Navajo nation. This is also explored further in the next section.

8.3.2 Bill of Materials

Below in **Table 6** is the bill of materials that was developed to account for all of the materials required for the device to be constructed. It's worth noting that the device will also include two different sources of liquid. The first liquid source is water that could be easily accessible to the inhabitance of the Navajo nation. The second liquid is used for heating and is called propylene glycol. This liquid would make up 20 percent of the total liquid solution. The budget given to develop this device was approximately 1500 dollars. Taking into account the cost of all the materials required to design this device the total cost came out to a total of 1251.51 dollars. This means that the current estimate of expenses falls comfortably 248.49 dollars below budget. This is useful as it gives the capstone team breathing room to more easily take care of setbacks or any elements of the design that end up requiring more resources then initially projected.

Table 6: Bill of Materials

Part #	Part description	Manufacturer	Dimensions	Weight	Quantity	Unit Cost	Total Cost for Part
1	Heating Fluid Pump	Ferroday	10.2 x 7.6 x 6 inches	4.59 lbs.	1	$79.99	$79.99
2	Liquid to Liquid Heat Exchanger	Duda Energy	7.5" x 2.9" x 2" 2.58 ft2	N/A	1	$57.55	$57.55
3	Liquid to Air Heat Exchanger	Outdoor Furnace Supply	24" x 24"	N/A	1	$225.00	$225.00
4	Heating Band	Omega	8 ft length, 1 in width	N/A	1	$93.49	$93.49
5	Copper Piping	Cambridge-Lee	10' and 1" dia.	N/A	1	$34.77	$34.77
6	Storage Tank	Norwesco	32" dia. x 67"H and 210 gallons	65 lbs.	1	$276.00	$276.00
7	Fan	Ridgid	13 x 12.3 x 10.6 in	12.25 lbs.	1	$79.97	$79.97
8	Battery	Crown	12.19 × 7.19 × 14.13 in	92 lbs.	1	$235.00	$235.00
9	Electricity Solar Panel	Canadian Solar	3.44 ft x 6.92 ft	N/A	2	$71.88	$143.76
10	Arduino	ELEGOO	3.15 x 2.36 x 0.39 in	2.24 oz.	1	$12.98	$12.98
11	Thermocouples	Aideepen	3.7 x 3.1 x 0.3 in	0.81 oz.	5	$2.60	$13.00

8.3.3 CAD Model and Drawings

For the three-dimensional modeling it was decided that the system should be split up into three pieces. The first can be seen in figure 2 below. This is the model of the entire system. The two main subsystems for this device are displayed on their own in order to make their designs clearer. This is needed due to the way that the size of the tank hides the majority of the piping. These two subsystems are displayed in figures 3 and 4.

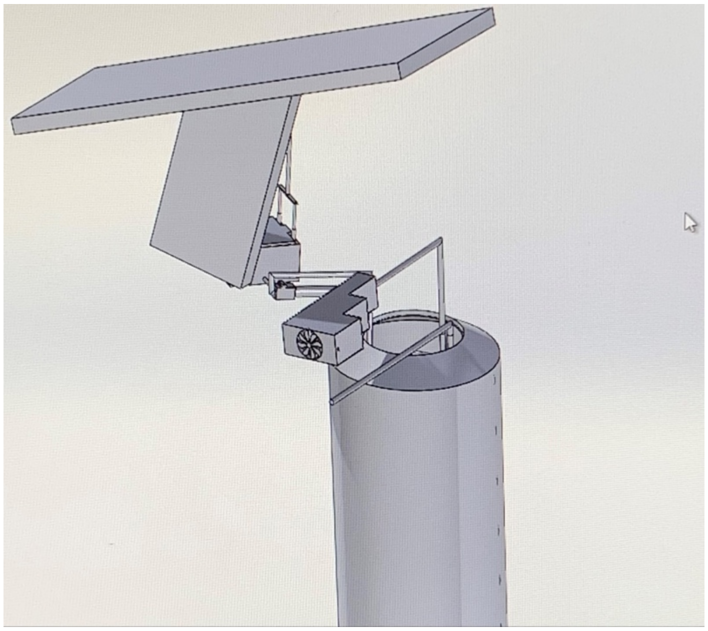

Figure 2: Thermal storage device

Displayed blow in figure 3 is the liquid heating subsystem responsible for heating the water. For the sake of experimentation, a heating tape is used in order to generate the watts comparable to the heat that might come from a solar furnace. This design utilizes the use of a pump to pull the heating liquid (propylene glycol solution). Finally, the piping is designed in order to extend the amount of time the heating liquid will be in the water.

Figure 5: Heating system

Below in figure 5 the air heating system is displayed. This piping system has one inlet and one outlet. This section of piping carry's the air from the house into the piping and then delivers it back into the home. The inlet piping provides a path for the cold air to enter the system. From there the piping is designed to extend the amount of time that the air would spend inside the tank. Then the air is pulled through the pipe and then pushed back into the home through the action of the fan.

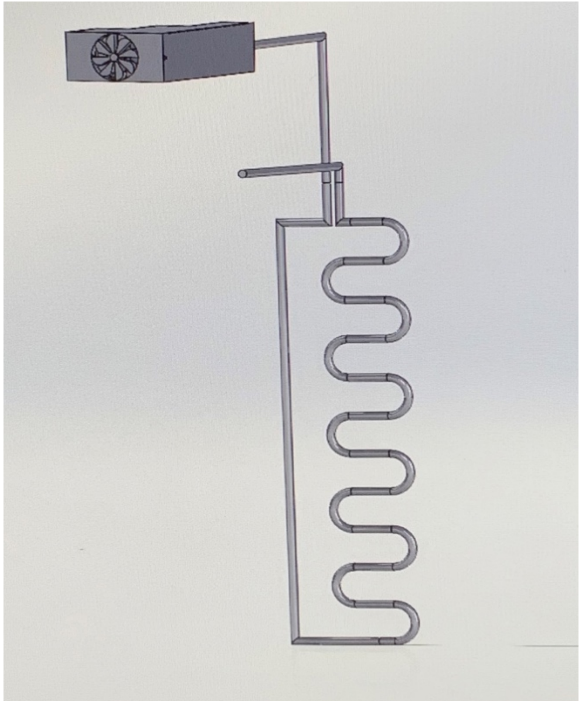

Figure 5: Air Heating

What's useful about these two systems is that neither are running at the same time as the other. This means the system as a whole is never running all at once. While one system is running to build up the heat that will be stored in the water, the other subsystem is silent waiting to move into action once it becomes nighttime. Once it does become dark out the day subsystem will turn off and the system responsible for heating the home begins its own operations.

In figure 6 the exploded view of the entire system can be seen. This was accomplished by first pulling the main systems out of the tank. Then each part is pulled apart to make up the exploded view of the design. What's interesting about this design is the range of part sizes that make it up. While there are massive pieces like the Tank. There are also small pieces comprised of wires and piping that are all integral to the proper functionality of the device.

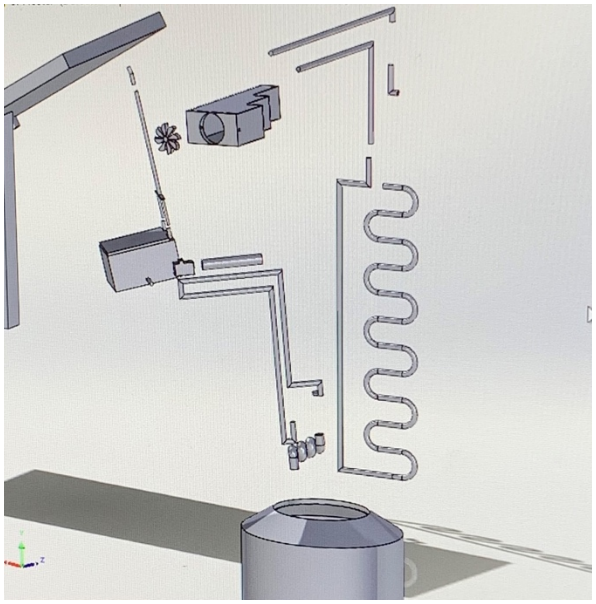

Figure 6: Exploded view

8.3.4 Next semester's schedule

In figure 5 the planned schedule for next semester is laid out. Within this schedule are all the requirements that are needed in order to finish the prototype, have a finished report discussing the final product, and a website that properly displays everything accomplished for this capstone. It is worth noting that due to the current pandemic worsening, having a precise schedule is challenging. However, this current outline gives an approximate look at what needs to be accomplished, when parts of the capstone project will be started, and when they are intended to be finished.

Table 7: Next Semester's Schedule

Task	Plan Start Date	Plan End Date
Finalizing and Purchasing Parts (including Testing Procedure parts)	1/11/2020	1/25/2020
Meet with Clients	1/15/2020	1/29/2020
Website Development Check-up	1/27/2020	2/3/2020
Concept Check-up	2/3/2020	2/5/2020
Building Prototype	2/5/2020	2/12/2020
Parts Analysis	2/17/2020	2/26/2020
Testing Procedures	3/5/2020	3/13/2020
Testing Procedures Results/Analysis	3/17/2020	3/27/2020
Meet with Clients	3/31/2020	4/2/2020
Preliminary Report	3/31/2020	4/11/2020
Final Report	4/14/2020	4/25/2020
Website Final Check-up	4/21/2020	4/25/2020

9. CONCLUSIONS

Red Feather Development group is requesting a design for a thermal storage device that can provide heat for the home at night. The device is meant to store heat in a thermal medium during the day and then release it at night. It needs to provide a consistent heat source. The materials for the device should be locally available materials. The parts of the system need to be readily available with a minimal delivery time. The design needs to be durable and able to handle the adverse weather conditions that it will be exposed to. Lastly, the system should be within the $1500 price range set by the Red Feather group and their customers. After months of research and analysis the team decided on a buried insulated polyethylene storage tank to contain the thermal storage fluid, which is a 20% propylene glycol solution and two separate pipe networks for charging and discharging the thermal storage device. During the day, the pump circulates "cool" heat transfer fluid through the heating tape section of fluid heating network, where it is heated. From there, it moves through the pipe network into a fluid-to-fluid heat exchanger immersed in the tank. The heat then moves from the transfer fluid to the storage fluid, "charging" the thermal battery. This cycle continues until the tank reaches a pre-determined temperature threshold. At night, the system goes through the discharge cycle, in which a blower pushes air from the house into the air pipe network. The air then passes through the now-heated thermal storage tank, where it is warmed in a liquid to air heat exchanger. Once heated, it flows through the remainder of the pipe network out of the tank, and back into the house. This cycle continues throughout the night, with air speed and heat transfer varying according to house temperature. The total cost for this design is a total of $1,251.51. This means that the current estimate of expenses falls comfortably $248.49 below budget.

10 REFERENCES

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[5] J. Chant, "The Difference Between Propylene Glycol and Ethylene Glycol in Antifreeze," Monarch Chemicals, 5 December 2018. [Online]. Available: https://www.monarchchemicals.co.uk/Information/News-Events/700-/The-difference-between-Propylene-Glycol-and-Ethylene-Glycol-in-antifreeze#:~:text=The%20main%20difference%20between%20propylene,any%20human%20or%20animal%20exposure.. [Accessed 25 October 2020].

11 APPENDICES

11.1 Appendix A: Descriptive Title

11.2 Appendix B: Full FMEA Sheet

Solar Thermal Storage Heating Device		Northern Arizona Unviersity Red Feather Capstone B12 Team				Page No 1 of 3 7-Nov-20			
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
#1 Heating Fluid Pump	Corrosion fatigue	Liquid not heated, leaking of liquid into storage tank	3	Loose/Broken Belt	3	Run system nonstop for 7 days	1	9	None
	Stress Corrosion	Liquid not heated, leaking of liquid into storage tank	3	Impeller Shaft Failure	3	Run system nonstop for 7 days	1	9	None
	Fretting Corrosion	Liquid not heated, leaking of liquid into storage tank	2	Liquid Leaking	5	Run system nonstop for 7 days	2	20	None
#2 Liquid to Liquid Heat Exchanger	Thermal Fatigue	Liquid not heated, leaking of liquid into storage tank	8	High Temperature differentials of liquids.	5	Run system nonstop for 7 days	1	40	Choose a heat exchanger with increased temperature limits
	Thermal Shock	Heat exchanger breaks, causing fluid to not flow	8	Freezing from outside environment	1	Run system at cold, 20 degree temperatures	3	24	Make sure the storage tank is properly insulated
	High Cycle Fatigue	Liquid not heated, leaking of liquid into storage tank	8	Higher fluid velocity than manufacturer's stated maximum causing vibrations	2	Run system nonstop for 7 days	1	16	Maintain a lower velocity of the fluid throughout the H.E.
	Erosion Corrosion	Liquid not heated, leaking of liquid into storage tank	8	Electrochemical potential from chemical reactions	3	Run system nonstop for 7 days	1	24	None
	Pitting Corrosion	Liquid not heated, leaking of liquid into storage tank	8	Higher fluid velocity than manufacturer's stated maximum	3	Run system nonstop for 7 days	1	24	Maintain a lower velocity of the fluid throughout the H.E.

	Erosion Corrosion	Liquid not heated, leaking of liquid into storage tank	8	Electrochemical potential from chemical reactions	3	Run system nonstop for 7 days	1	24	
	Pitting Corrosion	Liquid not heated, leaking of liquid into storage tank	8	Higher fluid velocity than manufacturer's stated maximum	3	Run system nonstop for 7 days	1	24	Maintain a lower velocity of the fluid throughout the H.E.
	Thermal Shock	Heat exchanger breaks, causing fluid to not flow	8	Freezing from outside environment	1	Run system at cold, 20 degree temperatures	3	24	Make sure the storage tank is properly insulated
#4 Heating Band	Crevice Corrosion	Heat band fails	8	Moisture builds and is trapped between sheets of metal on the heating band	2	Power on the heating band and turn it to high wattage for long period of time	2	32	Make sure the heating band is properly protected from the elements and weather conditions
	High Cycle Fatigue	Power shorts, heating band no longer works	8	Wire diameter reduced, melting and breaking, wears down insulation	2	Power on the heating band and turn it to high wattage for long period of time	2	32	Use the lowest wattage necessary
	Thermal Fatigue	Heat band will die	8	Heat not transferred efficiently,too high wattage over short period of time	2	Power on the heating band and turn it to high wattage for long period of time	2	32	Make sure the heating band is tightened and properly fitted, on the lowest wattage necessary
#6 Storage Tank	Erosion Corrosion	The storage tank has a leak of hot liquid	10	Electrical-Chemical reaction or bacteria causing corrosion	1	Run the system for 7 days and check to see if there is any build up in the tank	2	20	Make sure the tank has regularlly scheduled maintanence
	Thermal Fatigue	The storage tank has a leak of hot liquid	10	If the material of the storage tank does not have a high enough melting point, the high temperatures may wear away the material	2	Run system nonstop for 7 days, check integrity of the tank	2	40	Make sure the tank's material has a high melting point, far above the max temperature of 175 F

Solar Thermal Storage Heating Device		Northern Arizona Unviersity Red Feather Capstone B12 Team				Page No 3 of 3 7-Nov-20			
	Low Cycle Fatigue	Battery dies.	8	The battery is undercharged (not fully charged after use) causing sulfation, where sulfate builds up on the battery electrodes, making it less effective	2	Run system nonstop for 7 days	1	16	
	Thermal Fatigue	Battery dies.	8	Battery overheats, causing overcharging.	2	Run system nonstop for 7 days	1	16	Keep battery out of direct sunlight
#9 Electricity Solar Panel	Corrosive wear	Solar Panel does not output fully	8	Weathering causes cracks in the cells	2	Run system in cold, 20 F temperatures for a long period of time	3	48	Clean the panels on a monthly basis. Cover the panels with a tarp if there is a hail or damaging storm incoming. Perform maintenance check annually.
	Thermal Fatigue	Junction Box stops working, panel does not work	8	Junction box frozen by humidity freezing or other types of freezing. Cells crack from the thermal stress	3	Run system in cold, 20 F temperatures for a long period of time	1	24	None
#10 Arduino	Thermal Shock	Arudino shorts, stops working. Temperature can no longer be monitored and pumps/fan cannot be controlled	8	Freezing or heating the electronic components can cause them to short or not work	1	Run system in cold, 20 F temperatures for a long period of time	1	8	Make sure the Arudino and electronic components are properly insualted
#11 Thermocouples	Thermal Fatigue	Thermocouple breaks, cannot read temperatures properly	7	Temperature changes cause expansion and contraction of metal, weakening the thermocouple	3	Run system nonstop for 7 days	2	42	Switch out thermocouples on a routine maintenance basis
	Hydrogen Damage	Thermocouple breaks, cannot read temperatures properly	7	Oxygen gets into sealed thermocouple, reacting with the metal	3	Run system nonstop for 7 days	2	42	Switch out thermocouples on a routine maintenance basis