Salt River Project Team

Final Report

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EXECUTIVE SUMMARY

There are around twenty thousand homes off the grid on the Navajo Reservation. These off-grid homes are forced to rely on other heating sources such as coal, propane, and wood. These heating methods are unsafe and are a potential health hazard as these methods release toxic smoke. Salt River Project (SRP) gave our team the task to utilize renewable resources to combat the issue of toxic smoke. The objective of the project was to find out whether a solar thermal air heater could be paired with phase change material (PCM) to provide clean and efficient heating over the course of any night during the year and to create a non-invasive system to implement it. The PCM goes through a phase change process that heats up and melts it stores energy; when the temperature drops it releases that energy to warm up the ambient temperature. The goal was to get the solar air heater to operate during the day to distribute warm air throughout the home and at night, the PCM would release excess stored energy to keep the home warm. Over a couple of months, the team did extensive background research on solar heating systems, solar power, PCM, insulation, coils, batteries, and Green Rhino material. After an extraneous design selection process, the team chose to build a solar air heater thermal box. The design featured a solar air heater that was attached to a heavily insulated box containing the PCM. Throughout the day the box was to charge a battery via solar panels to run the fans. These fans were made to circulate the cold air from the house, though the solar panel and re-distribute warm air back into the house. At night, the energy stored in the PCM would be released to keep the home warm.

The solar air heater box was tested on a 535 sq. ft. apartment. The results showed that the air heater heated the same side of the room up to 98 degrees Fahrenheit and the rest of the room to above 73 degrees Fahrenheit. Overnight the PCM was able to hold the inside temperature to about 66 degrees until 12:30 am, and it fully solidified, while the outside dropped to 28 degrees. Even though it was not able to hold the temperature above 73 degrees, the box is large enough to utilize more PCM to fit the user's need of holding more heat. The box works best on homes that are moderately insulated. A simulation was also run through the EnergyPlus+ software to test the efficiency of the PCM over winter nights. The test was done on a modern Hogan with no insulation. It was found that the best application of the PCM would be to use it as insulation. The results showed that it was able to hold the inside temperature above 60 degrees Fahrenheit while the outside temperature fell to -4 degrees Fahrenheit. Even though the PCM worked as insulation it would cost over 4500$ for the material alone which would not be feasible for the Navajo Nation.

ACKNOWLEDGEMENTS

The NAU Salt River Project capstone team has much gratitude to SRP, SolarthermiX, and Green Rhino Building Systems. Without their support, the project would not have been possible. Our team was grateful to have the opportunity to help the Navajo Nation and the Navajo people that live off the grid. Special thanks to SolarThermiX for providing the PCM for the project and Green Rhino Building Systems for manufacturing our thermal container at a low cost. Thanks to fellow teammate and team leader, Taylor McCormack for allowing testing and manufacturing of our prototype at his apartment. Our team gives thanks to our sponsor and sponsor's mentor, Kyle Yamamato for guiding the team on our project. Special thanks to Dr. Sarah Oman for being our instructor for the Mechanical and Electrical Engineering team of this project. This project could not be possible without the NAU CEFNS Design4Practice Program (D4P).

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1 BACKGROUND

For this project, our team was tasked with designing a heater that would utilize both solar heating and phase change material (PCM) for the Navajo Nation. Currently, many homes on the Navajo Nation are off the grid and in order to heat their homes, residents are using unsafe systems such as burning coal, wood, or propane. Salt River Project (SRP) approached us with this project to provide a safe and clean means to heat Navajo homes, even during the cold winter months.

1.1 Introduction

Salt River Project is a community-based nonprofit utility that has been serving central Arizona since 1903. They are the oldest multipurpose federal reclamation project in the United States and currently are the largest provider for both electricity and water in the greater Phoenix metropolitan area.

Salt River Project has partial ownership of the Navajo Generating Station located near Page, Arizona and have developed strong relations with the Navajo Nation [1]. During several months out of the year, northern Arizona can reach below freezing temperatures. Due to homes that are off the grid, conventional means of heating are impractical, so residents must rely on other alternatives for heating such as burning coal, wood, or propane. Over 20,000 homes on the nation utilize these heating sources which are both a fire hazard and bad for health. The goal of this project is to reduce or eliminate these fuels burning methods by using renewable resources.

The SRP capstone team was approached with the idea of pairing both solar heaters and PCM to efficiently heat these homes during the harsh winter months. The final product should be able to heat a home during the day while storing the excess heat into the PCM, which will be used later in the evening and throughout the night. Through research, the team will be accumulating data on weather patterns, home constructions, and energy consumption on the reservation. From this data, SRP wanted us to achieve an understanding of how much PCM needed to be paired with a solar heater to effectively heat these homes. For this project, a company named SolarThermiX, based out of Tempe AZ, provided a solar heater and PCM to be used during the project.

1.2 Project Description

The following is the original project description provided by the sponsor:

> "The project will examine the effectiveness of pairing phase change material (PCM) with solar air heaters to heat homes on the Navajo Nation. At the end of the capstone we hope to understand the best configuration of PCM and a solar air heater needed to sufficiently heat a home. The project scope includes research of Navajo climate and home construction, modeling home energy consumption for heating, estimating the required quantity of PCM to pair with the solar air heater, designing how the PCM and solar air heater would be configured, building a small-scale prototype, testing the design, and evaluating the performance."

1.3 Original System

For this project the team had the challenge of dealing with two different types of systems. The two systems that the team was given are a solar air heater and phase change material. The team was not given the task to redesign either one of these systems, but to combine the two to work together as a single system itself. The idea of the new system is to use the solar air heater to heat the home and the phase change material during the day and once the sun goes down the system would utilize the phase change material and use that heat source to heat the home during the night time.

1.3.1 Original System Structure

The original system that the team had designed connects two different types of systems, the solar air heater and phase change material. These two products would be connected to a concrete box that would house the phase change material and it will contain the warm air that will be used. Also housed in the box would be electronics such as an Arduino, a 12-volt battery, and transistors. These would all be in an area within the box. All these components would be working in conjunction to heat the home to best of its abilities. The original system is shown below in Figure 1.

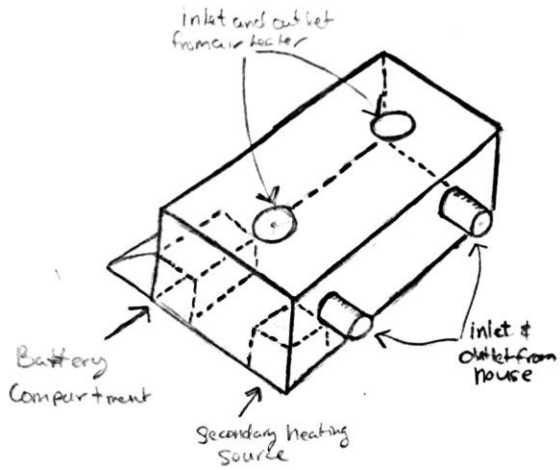


Figure 1: Original solar air heater design

1.3.2 Original System Operation

The operation of the original system that the team had designed is to warm up the house during the day and during the night. The main system of this would be the solar air heater. This system would be able to heat the house during the day and it would be able to heat the phase change material as well during the day. Once the sun went down and the solar air heater would not be able to be used, the phase change material is what would be used to heat the home at night. Fans would turn on within the box and that's what would create a flow of warm air and that is what would be flowing into the house at night.

1.3.3 Original System Performance

The performance of the solar air heater is simple. According to the SolarThermiX website, the solar air heater itself is able to heat 1000 Sq. Ft. and can output as much as 7000 BTU's/Hr [1]. This solar air heater should be more than enough to heat a home that is less than 1000 Sq. Ft. The solar air heater is a large heat source and it can be used to heat up the PCM. The PCM is able to melt and store energy at 73 degrees Fahrenheit [2]. According to Insolcorp, the PCM is able to store up to 100 BTU's per Sq. Ft. [2]. The original design that was created can hold up to 10 sheets of PCM. Combining all the sheets of PCM should be able to produce enough heat to heat the house during the night.

1.3.4 Original System Deficiencies

The deficiencies that the system has would be the solar air heater and the PCM functioning by themselves. The solar air heater deficiency would be that it would only be able to work during the day. Once the sun would go down the solar air heater would have no power to heat the air that would be flowing through it. As for the phase change material, it would need heating source in order to reach 73 degrees Fahrenheit so that it can store the energy. Without the heating source, the phase change material would not store any energy and it would be useless. The original design that the team created would address these deficiencies and it would create a better heating source during the day and night.

2 REQUIREMENTS

The following requirements were created from the project description provided by SRP. Research was conducted on modern Navajo Hogans, houses build from wood and mud, to complete the customer requirements (CRs). The customer requirements are assigned an objective that must be met and from which engineering requirements (ERs) can be constructed. Engineering requirements are assigned with a target and tolerance values. The House of Quality (HoQ) is shown in Table 5 and is also included in Appendix A.

2.1 Customer Requirements (CRs)

The following CRs are defined by SRP, the sponsor of the project. The solar air heater is to be designed for Navajo families that live off the grid. The list of CRs are weighted based on the significance of the requirements to the final design. The weight of the CRs are out of a total of 50.

As a team, the CRs were developed by the using the project description provided by the sponsor. The sponsor specified a low-cost and easy to use system for the project. For a low-cost design, the team decided to use a simple design to minimize the maintenance. Safety was a top concern because the solar air heater is near the home, so the team made safety a 9 out of 50. Other requirements that received the same score as safety include ease of use, simplicity of design, and low cost. Efficiency was also a top concern as the project aims to replace wood and coal as sources of fuel. The size was rated a 5 out of 50 so that the box would not be hard to move and implement. Aesthetic was given a low rating of 4 because the design does not depend on the aesthetics of the design.

Table 1: Customer Requirements

Customer Requirements	Weight (Total = 100)	Rationale
Ease of Use	14	Ensures that the solar air heater can be operated and maintained by the average consumer.
Simplicity of Design	14	The simplicity of the design would reduce costs for prototyping and testing.
Low Cost	14	By having a low cost, this ensures that Navajo families can heat their home safely and can be accessible to everyone.
Safety	14	This ensures that the PCM would not put the contents of the home at risk for fires or damages.
Feasibility	14	This ensures that the operation of the solar heater can be operated by all ages.
Efficiency	14	Shows how much energy the solar air heater can produce and how much energy can be converted to heat the home.
Size	8	The size of the SolarThermiX STX 7000 is 4x8x2 ft. and must be able to be place outside the home.
Aesthetics	8	The overall design must fits client's needs and blend within the desert landscape.

2.2 Engineering Requirements (ERs)

The following ERs in Table 2 were the measurable parameters of the listed CRs. Each ER had a target value along with a tolerance value that each requirement was expected to meet in the final design. A rationale of the ERs was also provided.

Table 2: Engineering Requirements

Engineering Requirements	Target	Tolerance	Rationale
Size	4x8x2 ft.	±4 in.	To maximize the dimensions of the SolarThermiX STX 7000 solar air heater.
Cost	$2,500	N/A	The allowance given by SRP. The cost of design, prototyping, and testing should not exceed $2,500.
Weight (PCM)	50 lbs.	± 10 lbs.	To be able to safely lift the PCM off the SolarThermiX heater and bring inside the home.
Heat Absorption	73° to 80° Fahrenheit	± 3° Fahrenheit	PCM must be able to heat up the home within this temperature range.
Ease of Assembly/Installation	≤2 hours	N/A	Assembly of the solar air heater and placement of the PCM should not exceed 2 hours.
Lifespan	10 years	+ 1 year	The solar air heater and PCM must have a lifespan of 10 years as specified by SolarThermiX.
Heat Storage	8 hours	± 2 hours	PCM must be able to heat up the home for at least 8 hours.
Flow of Energy	7.9 MJ/hr.	N/A	The flow of energy specified by SolarThermiX STX 7000.
Maintenance	$300	N/A	The cost of repair of the solar air heater or replacement of the PCM should not exceed $300.

2.3 Testing Procedures (TPs)

To ensure that the engineering requirements were met, testing procedures were developed to test each parameter. Each TPs were numbered in correspondence to the number in the House of Quality (Appendix A). TPs were required to ensure that each ER is within the tolerance values shown in Table2.

2.3.1 Testing Size (1)

The team specified that box would be 48x96x24 in. The actual dimensions of the box are 48x94.5x28 in. All of which was within the specifications set in the engineering requirements.

Length: 94.5 inches

Figure 2: Length Measurement of the Box

Width: 48 inches

Figure 3: Width Measurement of the Box

Height: 28 inches

Figure 4:Height Measurement of the Box

2.3.2 Cost (2)

The amount allocated to our project was $2,500. The amount spent was $2,473.16. Further details can be found in the budget section of our report section 6.3.

2.3.3 Weight of PCM (3)

The sheets of PCM were weighed on a scale and each sheet was found to weigh about 6.4 pounds. It met the weight requirements of being under 10 lbs.

Figure 5: Weight of PCM

2.3.4 Testing Heat Storage (4)

Our box was able to heat the home up to about 73-74 degrees Fahrenheit. We had thermometers posted at 9 inches, 14 feet, and 23 feet from the box in the 566 sq. ft. apartment room. We do not have a video for the progression since the thermometers were measured from 1 PM to 6 AM.

The first thermometer was 9 inches from the duct transporting hot air into the house, it reached almost 100 degrees Fahrenheit.

Figure 6: Temperature Reading from 9 Inches Away from Heat Source

The second thermometer was placed 14 feet from the duct into the house and reached about 74 degrees Fahrenheit.

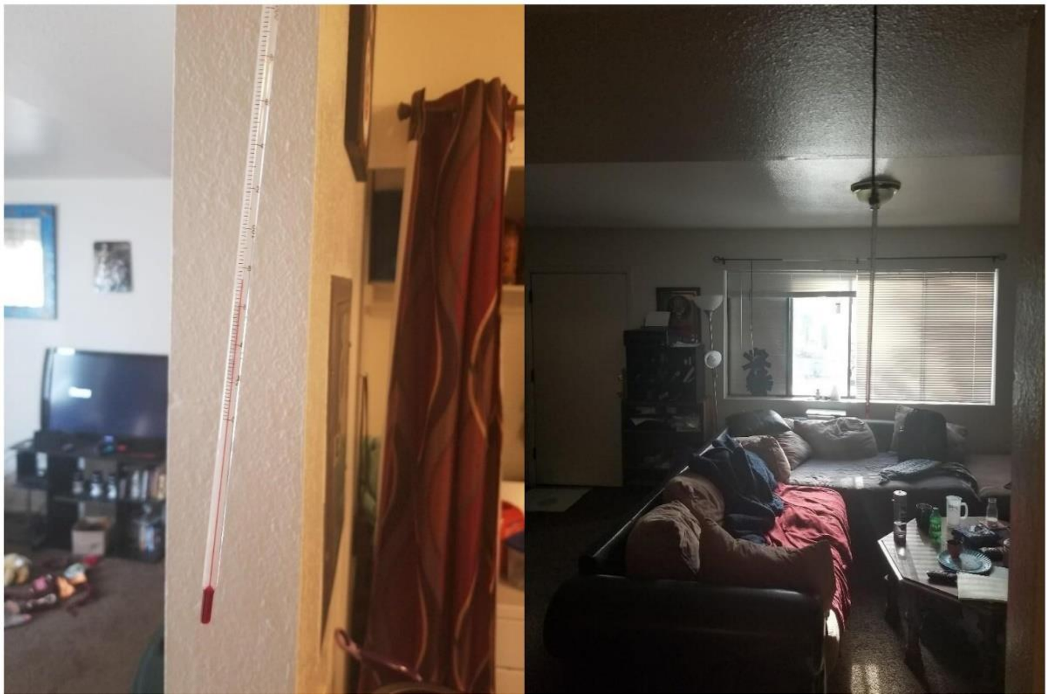


Figure 7: Temperature Reading from 14 Feet Away from Heat Source and Distance Shown

The third thermometer reached about 74 degrees Fahrenheit and was located 23 feet from the duct into the house.

Figure 8: Temperature Reading from 23 Feet Away From Heat Source and Distance Shown

2.3.5 Testing Ease of Assembly (5)

The only parts that should need assembly are the connection of the ducting from the solar air box to the house. The box should come fully assembled. The attaching of the ducts can be connected through a window with insulation put over it, or 2 small 6 in. and 4 in. holes can be cut into the home to attach the box, overall it should not take more than 2 hours. To install on the window for testing took about 40 minutes.

2.3.6 Lifespan (6)

The box that was made is made of Styrofoam and a concrete stucco mixture. We visited a home in Phoenix, AZ that was made from the material and has been standing for over 15 years with little wear to the home. The solar air heater by SolarthermiX is made out of metal and it is very sturdy. The ROTC building on the NAU campus has several air heaters attached to it and have no signs of wearing to them [2]. We do not have an accurate estimate for how long they will last.

Figure 9: SolarThermiX Solar Air Heater on ROTC Building [2]

2.3.7 Testing Heat Storage (7)

During the day the solar air box can keep the house above 70 degrees Fahrenheit. The PCM was able to last by itself from 6 PM when the solar air heater on top was shut off till about 12:40 AM and kept the apartment about 66 degrees Fahrenheit until then. It lasted about 6 hours to keep it at 66 degrees Fahrenheit. Even though it was not able to hold the temperature above 73 degrees Fahrenheit during that time the solar air box has plenty of room to add more PCM to fit the users need. Videos of our box can be found in the gallery section of our website. Further details for the heating can be found in the results section of the report.

2.3.8 Flow of Energy (8)

This was for the Solarthermix solar air heater that we used for our box. It is a pre-existing system and that was the specifications given to us by the team from SolarthermiX [2].

2.3.9 Maintenance (9)

The maintenance needed on the box would be to buy concrete mixture and patch any weathering that may occur. The fans my need to be replaced after several years but are inexpensive and are approximately 11 dollars each. The PCM may wear down if moved into the home constantly without care and cost 24 dollars per sheet, but the box is designed to be able to hold the PCM with no need to remove it from the box. The battery may need replacing after several years and has a price of 150 dollars. The user should not have to spend more than 300 dollars in the 10 years to maintain the box.

2.4 Design Links (DLs)

2.4.1 Size (1)

For the size the whole system had to be created to size with the solar air heater and also it would be big enough to house the phase change material. The solar air heater is 4x8x2 ft and each phase change material sheet would have to hung within the box. In order to maximize the use of the solar air heater and also contain the heat created by the phase change material the box would have to be the specified size so it could contain the phase change material and it would have to house the solar air heater as well.

2.4.2 Cost (2)

The team was able to meet the engineering requirement of keeping the whole project under $2,500. Each part was purchased and utilized within the project. After all the products were purchased and the final cost was evaluated it was found that the team was able to keep the cost under the $2,500 and the team was left with an amount left.

2.4.3 Weight (3)

Each piece of phase change material was calculated to be about 6.4 pounds per sheet. The team had wanted the total weight of the phase change material to be 50 pounds or under that weight. After calculating the total weight, the full 10 sheets of phase change material would be a total of 64 pounds. This didn’t necessarily meet our engineering requirement of 50 pounds. In order to fix this the team would have to reduce the amount of phase change material needed for the project.

2.4.4 Heat (4)

Each sheet of PCM is able to melt and store heat at about 73 degrees Fahrenheit. Our engineering requirement was to heat the home up to 73 degrees. Taking this into account the PCM was able to melt and liquify and hold heat, this would be used in conjunction with the solar air heater and the whole system was able to produce a temperature of 98 degrees Fahrenheit.

2.4.5 Ease of Assembly (5)

The whole process of putting together the project itself doesn't take too long because the box requires the minimal of parts. Each section of the project is very simple in it's design and it doesn't take the team no longer than 2 hours to create the whole system.

2.4.6 Lifespan (6)

The rated lifespan of the solar air heater on top is ten years, knowing this the team had tried to get certain parts that could match that same lifespan. Every part within the concrete box would be stored safely away from the outside environment and should be able last ten years being ran safely inside. All the components on this project will be able to last 10 years if not more.

2.4.7 Heat Storage (7)

For heat storage the team created an insulated section within the box. The insulation was used in order to keep the heat from escaping and that it would maintain the heat inside for a long period of time. The PCM can store heat and being inside the insulated section it should be able to maintain a constant heat.

2.4.8 Flow of Energy (8)

To get the flow of energy in our system, the team added fans on either side of the box. These fans that are added will aide in pushing air through the whole system and it will maximize the efficiency of our whole system.

2.4.9 Maintenance (9)

Each component that is within the box that would possibly need maintenance is inexpensive. The electrical components within the box are small electronic devices that cost several dollars to replace. For the concrete box, the user can buy concrete mix to patch any spots as needed.

2.5 House of Quality (HoQ)

The following section contains the House of Quality (HoQ) that was developed by the CRs and ERs. The CRs were assigned a weight and were then transformed to ERs. The ERs were then assigned to target and tolerance values. All of these values were recorded and displayed in the HoQ. The HoQ helped the team to decide what aspects of the design were required to concentrate on in order to complete all the requirements. The HoQ are represented in Appendix A. According to the HoQ, heat absorption, heat storage, maintenance, and the weight of the solar heater are the four factors that the team must focused on.

3 EXISTING DESIGNS

There are a few current variations of existing designs that utilize solar air heaters to heat a home. The research began with investigating different solar air heaters and types of PCM. After the team understood how the materials functioned, the scope was then narrowed down to system levels, subsystem levels, and functional decomposition.

3.1 Design Research

The research started with the materials that were provided and donated by SRP. The team investigated the design and layout of the SolarThermiX STX 7000 Solar Air Heater. The team was also able to get into contact with SolarThermiX. It was also provided with information that was related to the details and design that was measured up to one ton of carbon mitigated per year using their heater. [1] This simple design has a solar panel 4 ft by 8-ft unit onto the exterior wall of a house at 90 degrees that used a six-inch hole in diameter at the bottom of the unit. This solar air heater applied the concept of absorption to warm up the air pushed by the fan. The AC transformer that passes through the enclosure heated up the air, then directed the air back into the house through another 6-inch diameter hole back into the house. According to the company, this unit had to be 1,000 square and required to heat up to 70 degrees through an output of 7,000 BTU's per hour [2]. The estimated price was $1,500 per unit. Another important material for the project was phase change material.

The next material researched was InfiniteR PCM, also donated to the team by SRP. The company that manufactured this PCM was Insolcorp. According to the company's website, InfiniteR PCM is described as, "ice inside a cooler, slowly melting or thawing to maintain a target temperature using the process of phase change [3]". This material combined with the solar air heater was meant to provide a comfortable and safe environment while reducing emissions and increasing energy efficiency. The PCM was made out of clay, salt water, and a gelling agent. The PCM changed phase at 73 degrees Fahrenheit. The size dimension for this PCM was a mat variation that measured 2 ft. by 4 ft. of the exact model number, 23C M100. The PCM price was estimated at $3 per square foot.

Other researched PCM products by companies had multiple different applications and temperatures. PCM materials were designed for a range of temperatures from subzero weather to high temperature weather. The subzero eutectic degree ranges from 32 degrees Fahrenheit to -173 degrees so this particular material held a specific heat capacity anywhere between 0.992 to 0.566 BTU's per pound Fahrenheit. Whereas, the Hydrated Salt material had a temperature range from 45 degrees Fahrenheit to 243 degrees Fahrenheit and held a specific heat range between 0.203 to 0.405 BTU's per pound Fahrenheit. "When the material freezes, it releases large amounts of energy in the form of latent heat of fusion, or energy of crystallization, PCM can be used in a number of ways, such as thermal energy storage whereby heat and coolness can be stored for a period of time." [4] This eutectic tended to be a solution of salt in water for temperatures below freezing without crystallization.

The other solar air heater the team researched was SolarSheat 1000GS PV-DC. The cost of the system was $1,349. The SolarSheat system includes an air collector, a 20 watt PV panel, thermostat, fan, collars, filter, sensors, gaskets and snap lock duct. According to the company website, "The SolarSheat 1000GS is a self-powered solar air collector that can deliver space heating for up to 400 square feet [5]". To install the system in the house, a six-inch grill was attached to the intake to the interior of the house. On a clear sunny day, this system put 9,900 BTU's per day, and the fan was a solar electric PV panel which generated 14.5 watts. The CO_2 reduction was estimated at 18 tonnes per year. This huge panel was 12 ft by 9 ft with a total weight to of 68 lbs. This system was made of aluminum, tempered glass, and PV panel and could heat up a house to 90 degree Fahrenheit.

3.2 System Level

As stated in prior sections the team is required to heat up a Hogan on the Navajo reservation. The products we will be using are solar air heaters and PCM. The team's task will be combing these two products in order to heat the Hogan during the day as well as at night. However, after researching, the team could not find any products that incorporate both concepts. Each heating system that used solar air heaters only incorporated solar air heaters itself. This section will be describing three different types of solar air heaters that are currently being used. These air heaters are the back pass, tube type, and screen type air heaters. Each one of these heaters have the same principles when it comes to heating the air coming through it but each one incorporates different types of materials and components to do so.

3.2.1 Existing Design #1: Tube Type Solar Air Heater

The tube type solar air heater is a solar air heater that incorporates aluminum tubes that will be able to heat the air that will be flowing through it. Many people, however, have been known to use aluminum cans rather than actual aluminum tubing. It's the same concept as other solar air heaters the air will come in flow through the aluminum cans/tubes, these should be able to produce heat as it comes out from the top. The cans/tubes can be oriented in certain ways in order to have the airflow continue longer in order to generate more heat within the air. [5] To better understand how this process works refer to Figure 10.

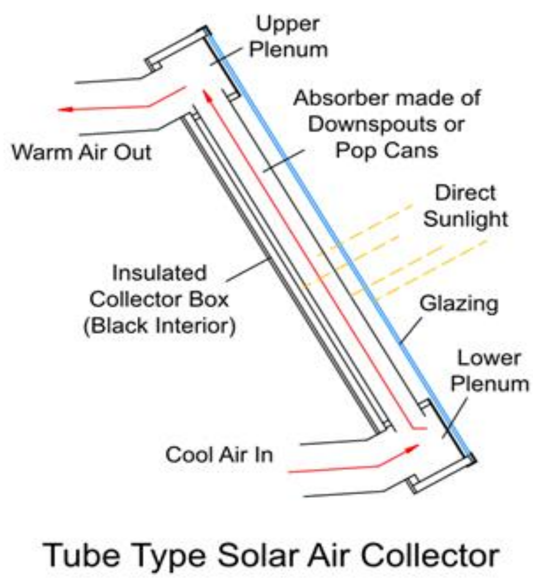


Figure 10: Tube Type Solar Air Heater

3.2.2 Existing Design #2: Screen Type Solar Air Heater

The screen type solar air heaters have the same concept as the back pass solar air heaters, however, the don't incorporate an aluminum sheet that will absorb the heat. The screen type uses a screen that absorbs the heat and that is what generates hot air. The cold air comes in from the bottom of the heater and as the cold air flows through the box the screen absorbs the sunlight and produces heat and it converts the cold air into hot air and that is blown out through the top of the box. This design is another cheap version of solar air heater due to the materials that are being used within the system. To understand the concept better refer to Figure 11 for a visual representation. This design will meet the requirements of heating the

Hogan and the PCM material that will be used at night [5].

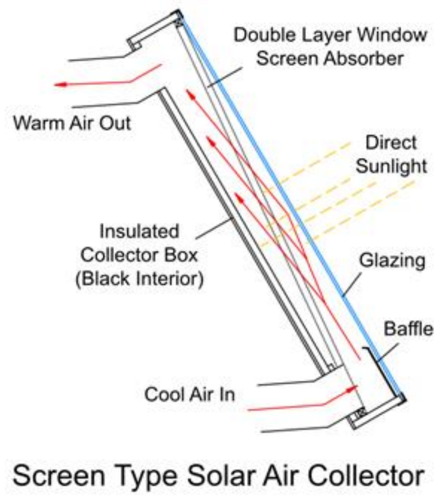


Figure 11: Screen Type Solar Air Collector

3.2.3 Existing Design #3: Back Pass Solar Air Heater

The Back Pass Solar air heater is a pretty basic concept when it comes to heating air. The main concept is heating the cold air coming in using a solar heat absorber. Cold air comes in from the bottom of the heater and as the air flows through the device, it is slowly being heated by the solar heat absorber within the box. This heat that has been produced is then pushed out from the top producing heat for a fully understand how this air heater works please refer to Figure 12. home. This design is the most basic when it comes to solar air heaters, in order to reduce cost and make the product easy to operate the team may look into using this solar air heater technology. This current design relates to our project requirements because it will be heating the Hogan during day and the PCM [5].

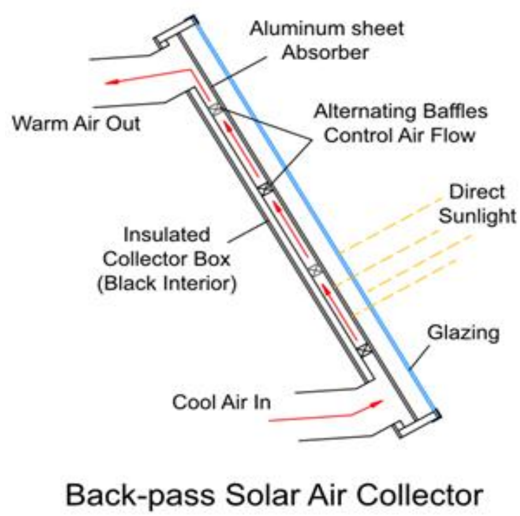


Figure 12: Back-pass Solar Air Collector

3.3 Subsystem Level

3.3.1 Functional Decomposition

The functional decomposition of the solar air heater is demonstrated by the black box model and functional model that shows how the solar air heater functions. The black box model displays the inputs as the solar heat, electrical, and on/off signals and the output as the heat leaving the solar box and the heat moving into the home. The system is controlled by a thermostat which automatically turns on the heater when it is a certain time of day. The output of the box is the warm air that it produces and pumps into the house or Hogan by means of fan.

3.3.2 Black Box Model

The Black Box model in Figure 13 is a visual of the inputs and outputs of the solar air heater. The inputs of the solar air heater box capture solar energy heat which then comes out of the system by the dial of the thermostat.

The Black Box is an integral encapsulate of this project since it maps out the inputs and outputs of the solar air heater. The inputs of the solar air heater black box include solar light, on/off heating, and elect Human. The designated output includes heat output, mechanical heat output, and the heat output of the on/off switch. The solar heat output can only be experienced when the thermostat is dialed. The purpose of the solar heater box is to absorb the solar heat.

The solar heater box is mechanically modeled to allow air to enter from one corner and exit from another. The box is painted black to increase its absorbance and retention of solar heat. Maximum efficiency can be achieved by insulating the box to prevent heat from escaping through the process of conduction. The solar heater box is also covered by tempered glass which is a material that is resilient to heat and very strong which ultimately secures the box.

Figure 13: Black Box Model of the Solar Air Heater

3.3.3 Functional Model and Work Flow Diagram

The functional model of the solar air heating system is shown Figure 14. It is a comprehensive depiction of the mechanical and electrical steps that would occur in the process of heating the home using solar energy. The system works in several stages. The system begins when the solar air heater panels captures the light, which then is converted into heat. The air that cycles throughout the house is vacuumed by an air filter and goes into the solar box to be heated. The pre-installed fans in the solar air heater then pushes the warm air into the house.

Figure 14 will be pivotal for this project since it partitions the entire system into segments making it easier to understand the entire system. The objectives are to be achieved at every stage is clearly outlined. The diagram can also be used as the basis for the formulation of recommendations that can better the efficiency and usability of the system. The recommendations can be targeted to improve the functionality of an aspect of the system. The model also makes it easier to pinpoint design flaws in the system.

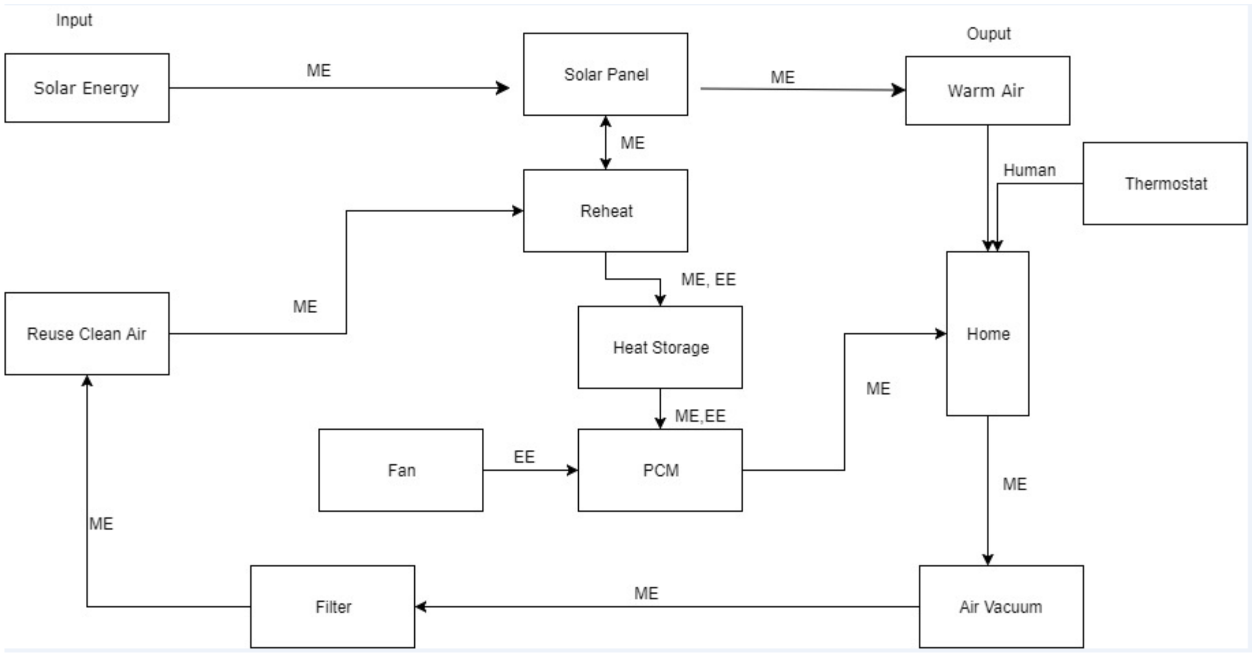


Figure 14: Functional Model of the Solar Air Heating System

Figure 15 is a workflow diagram that captured the work process in the design. The diagram addressed factors that impacted the design and production processes of the solar air heater. Such processes included funding and market players. The figure also captures flow of work in the development of the solar air heater, the role of SRP team, and how a client preferred heat storage for nighttime use. Materials to be procured, such as SolarThermiX were also included. Holistically, the diagram represented the implementation phase of the project. Figure 14 represented the vital design for the project, since it elucidates fundamentals points of consideration that implements the phase of the project. The diagram presents team members with a holistic understanding of the role of suppliers, clients, and the SRP team in the implementation of the design and establishment of a satisfactory solar air heater system that served the needs of the target group.

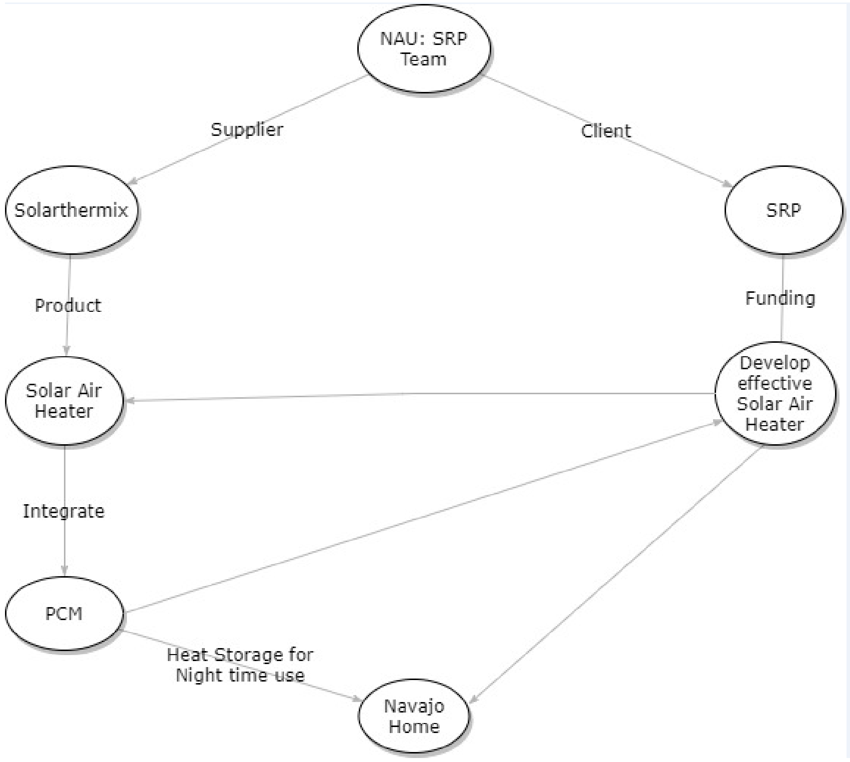


Figure 15: Workflow Diagram

3.3.4 Subsystem Level

Each subsystem details the different means of harnessing the most heat between the cold air intake to the hot air exhaust. The main components that were different in each existing type of thermal panel were the dark material used in order to capture/absorb the sunlight.

3.3.4.1 Subsystem #1: Back of Panel Material Type

The main difference in all three of the existing designs is the type of material that is used in order to capture the heat from the sun and contain it in the solar thermal air heater. This is important to the project because the type of material depends on the thermal heating of the air as it passes through the heater. Another reason that this subsystem is important is that each different material has a varying level of longevity, and since the system is supposed to last for 10 years in good conditions, the material chosen in the final design will be optimized.

3.3.4.1.1 Existing Design #1: Aluminum Tubing

This first design implements aluminum tubing either in the form of proper aluminum tubing or aluminum cans with a black painted coating. This design is effective in terms of keeping heat, but in terms of longevity, which is the tightest constraint, the aluminum can design most likely uses a low end of black paint and thus would peel and prove ineffective in a few mere years. In terms of producing a sufficient heat flow, the design would also fail this requirement because of the peeling paint [5].

3.3.4.1.2 Existing Design #2: Black Background and Absorbing Mirror

This design reflects the incoming light from the sun into a mirror and then reflects it and builds up heat and captures the remaining heat into a black background of the panel. This idea can be good assuming the absorbing mirror reflects some of the light. The only drawback to this design is the potential that the plastic that insulates the device can fade due to the UV lights that it soaks in almost every day. In terms of the heating, this device can produce much heat and should be able to meet the requirements stated in the engineering requirements [5].

3.3.4.1.3 Existing Design #3: Alternating Baffle Design

This design intakes the cold air and then uses baffles in order to wind the air around so that it slows down the flow of the air and gives the air a chance to heat up more evenly and fully. The advantage in this design is that the baffle design provides a more efficient route for air to take so that it can provide much hotter air at top of the design. In terms of longevity, the fact that the baffles are metal and thus they can last much longer due to lack of paint. The black absorbing back of the device would be the only concern depending on the coating of the back in terms of longevity [5].

3.3.4.2 Subsystem #2: Insulating Cover for Device

The type of insulating clear cover for the thermal heating air unit depends on how much heat can be contained within the unit. This system is important because the material depends on how much heat can be kept within the unit and pumped into the home. In terms of longevity, if the system contains too much heat then it can melt any plastic pieces within the unit or the fan that pushes the hot air into the home [5].

3.3.4.2.1 Existing Design #1: Double Walled Plastic Cover

The doubled walled plastic cover uses UV-resistant plastics with a small pocket of air in between the two sheets of plastic. Because it is UV-resistant, the plastic can last for many years without any noticeable fading. By testing with different types of plastics, SolarThermiX decided that this type of material is best suited to work with their type of solar thermal air unit. In terms of thermal resistance, this material has a relatively high resistance and thus provides good insulation for when there is cold air outside in the winter [5].

3.3.4.2.2 Existing Design #2: Triple Walled Plastic Cover

This cover implements the same concept as the double walled plastic cover except it has yet another wall of air insulation. This at times provides excess heat during the summer and has the potential to produce

extremely hot air and can melt this plastic cover. In terms of longevity, this cover will not be able to keep the air hot for 10 years of service. For heat, this cover will perform above the maximum in terms of heat for the air, but if the cover is deformed then it will fail to retain the heat in the unit. This information was provided by Michael Daly, co-owner of SolarThermiX [5].

3.3.4.2.3 Existing Design #3: Lexan Glazing

Lexan is a type of clear polycarbonate sheet that is used solely to act at a weather shield for the unit. Due to its thickness, this material does not have very high thermal resistance compared to the other coverings. This material does have a 10-year guarantee against yellowing and breakage, so this handles the engineering requirement to last for 10 years. In terms of heat storage, this material will handle slightly worse than the other materials, but for the guaranteed indestructibility, this material seems to be a great choice to implement into a heating unit [5].

3.3.4.3 Subsystem #3: Phase Change Material

Because there is a multitude of types of PCM, the three practical phase change materials that are used are oil and polystyrene, solid-solid, and a salt hydrate-based material. This subsystem is implemental in determining which material would tend to fare the best in the considered temperature conditions on the Navajo Nation. Because SRP required that the team implement PCM in tandem with the solar thermal air heater, the choice of phase change material will be crucial in heating the Navajo homes

3.3.4.3.1 Existing Design #1: Oil and Polystyrene

This phase change material takes polystyrene and mixes it with plant-based oils to dissolve it. This is good in the sense of environmental helping because it reduces plastic waste. Because there are concerns for household fires, this material would not be best in order to implement because both plastic and oil are extremely flammable. This material does have good thermal heat properties and it can be relatively cheap to produce, but because of the major concern of safety of residents, this phase change material type is not the best option [6].

3.3.4.3.2 Existing Design #2: Solid-Solid

This phase change material has a range from 77 to 356 degrees Fahrenheit. This would prove slightly ineffective with this type of PCM and thus would not suit the temperature parameters of a hogan. The heat of this PCM, because it stays as solid material, is also inefficient because it does not undergo liquid to solid heat emission during the night. Due to the two subjects discussed prior, this PCM is ineffective for the location and application that it needs to be used for, this PCM should not be used in the team's design [7].

3.3.4.3.3 Existing Design #3: InfiniteR Salt Hydrate

This phase change material implements clay, water, and salt crystals so that it can melt at around 73 degrees Fahrenheit. This would be perfect for a Hogan on the Navajo Nation because the solar thermal air heater can heat the air inside of the house by about 70 degrees. When it is snowing, the hot air will be sufficiently able to melt this material. Because of the natural and nonflammable ingredients in this type of PCM, there are no safety hazards for the residents. The thermal resistance for this material is very high when compared to housing insulation, so at night when the PCM freezes from liquid to solid during the night, this will provide heat for a fair amount of time. Considering all of the requirements, InfiniteR fits most of the requirements the best and thus should be used in the final design [8].

4 DESIGNS CONSIDERED

4.1 Design #1: Vertically Heated Box with Removable PCM

In Figure 16, there was a vertically positioned box that used a solar thermal air heater in order to heat the PCM which was stored inside of a box. The insulation was meant to keep the heat inside. It was made of Green Rhino brand Styrofoam building material which had very good thermal resistance. In order to prevent the material from degrading, it was covered in special coating in order to ensure strength. During the day, the PCM was to heat up and melt, and during the night, the material would be removed and put in the house. A pro of this design was that it contained heat easily so there was minimal loss. On the other hand, the con of the design was that it was difficult in having to transfer the PCM at night and in the morning.

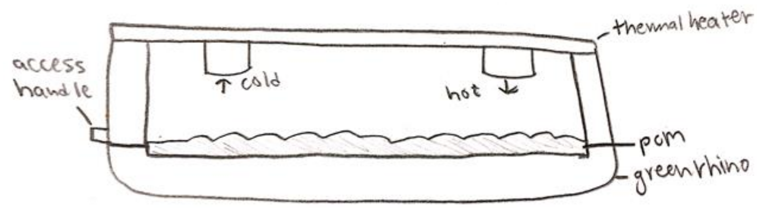


Figure 16: Vertically Heated Box with Removable PCM

4.2 Design #2: Wall Integrated PCM with Roof Mounted Heating Unit

In Figure 17, it utilized a roof mounted solar thermal air heater. Using a small solar PV panel, it provided power to a fan in order to push hot air into the home during the cold winter days. During this time, excess heat sept into the walls and melt the PCM. During the night, the PCM would release heat back into the house and provide substantial warmth. An identified pro of the system was that it could provide heat to the residents both during the day and the night, while it was disadvantageous in that it was not able to provide significant heat throughout the night as well as intruding into the prior structure of the house.

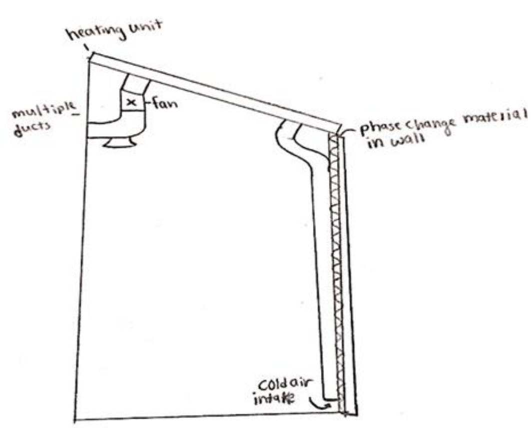


Figure 17: Wall Integrated PCM with Roof Mounted Heating Unit

4.3 Design #3: Door-Replacing Heat Box with Fan

Figure 18 uses a rolling system in order to roll the box to and from the doorway of the home. During the day, the heater would heat the PCM, which was permanently held in the box. The slider prevented heat from escaping while the PCM got heated during the day and removes when transferring heat from the box to the home. At night, the design would be rolled in front of the home's door, and a thermal exchange generator would provide the power to run a fan to circulate the hot air into the home. This design is useful for the night because it provides much heat and provide good circulation into the house, but it was not useful in the sense that it blocked the resident's door thus posing an emergency hazard.

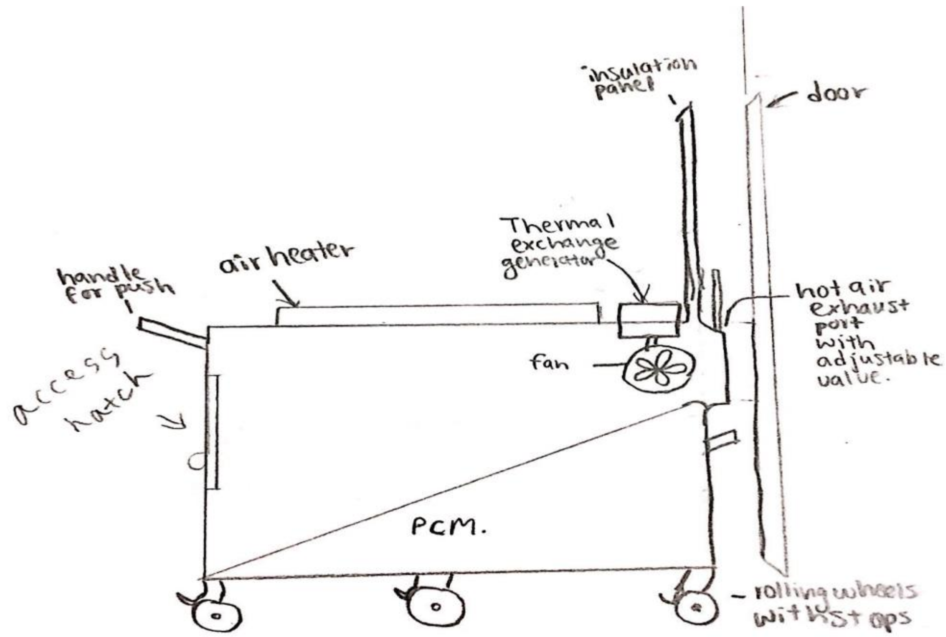


Figure 18: Door-Replacing Heat Box with Fan

4.4 Design #4: Wall-Mounted Constant Heating Device

Figure 19 used a wall-mounted solar thermal air heater installed facing south to output maximum heat during the winter. After the hot air reached the top of the panel, the solar powered fan pushed the air out into an enclosed box that stored phase change material. After the hot air passed through the PCM, the duct then emitted warm air into the home. This allowed constant heating because at night the resident would remove the PCM and lay it out in order to exude heat into the room, which proved to be a pro. A con of this design was installing the heating unit and mounting it onto the wall because it took extra time and effort.

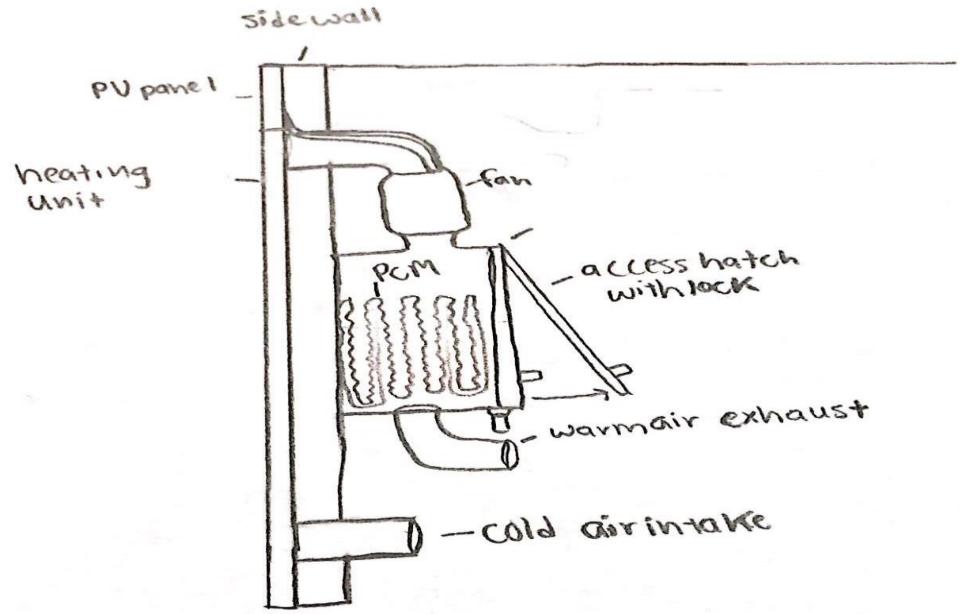


Figure 19: Wall-Mounted Constant Heating Device

4.5 Design #5: Switch-based Ducted Heating Storage

The main objective of this design (Figure 20) was to use the PCM as a thermal battery during the day. It was held inside of the house. A pro to this concept was that that excellent heat emitted from the house to minimize heat loss. There is a wall-mounted solar thermal air heater and a solar PV panel which powers the fan. During the day, the fan will send the hot air into the phase change material box, while temperature sensors will close off the heat when the PCM produces a desired temperature. This switch will change the direction of the heat flow from the heating unit to the PCM bank into the house during the night, whereas the only identified con was that there was no fan to pump heat into the house at night and there needed to be ductwork in the house provided that there was space.

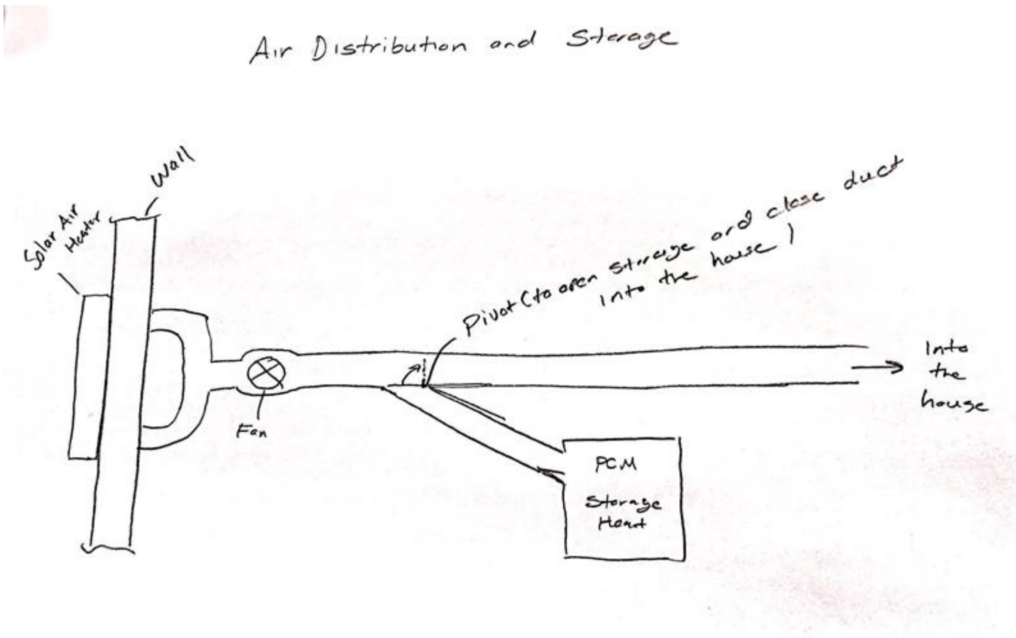


Figure 20: Switch-based Ducted Heating Storage

4.6 Design #6: Air Heater with Weight Driven Fan

This design (Figure 21) implements a home-heater on wheels that connects to the solar air heater which is also on wheels. Having the home-heater on wheels allows a user to move it wherever it can be best utilized. Having the solar air heater on wheels allowed a user to move it for best access to sunlight. The home-heater had a mechanical weight powered fan that could either be set every day by user winding or an electrical powered device powered by the solar panels in the solar air heater. After set, the weight powered fan would act like a cuckoo clock; dissipating stored energy in the form of a raised weight, over time.

The phase change material would be in the sidewall of the home-heater and would have a top access hatch for easy access to the PCM. The home-heater would have a hot air intake to take in hot air from the solar air heater and air vent to vent hot air from the home-heater pushed out by the fan. An advantage of this design was that both the solar air heater and home-heater were easily movable for access, while a disadvantage to this design was that the weight powered fan had inadequate stored energy to last an entire night.

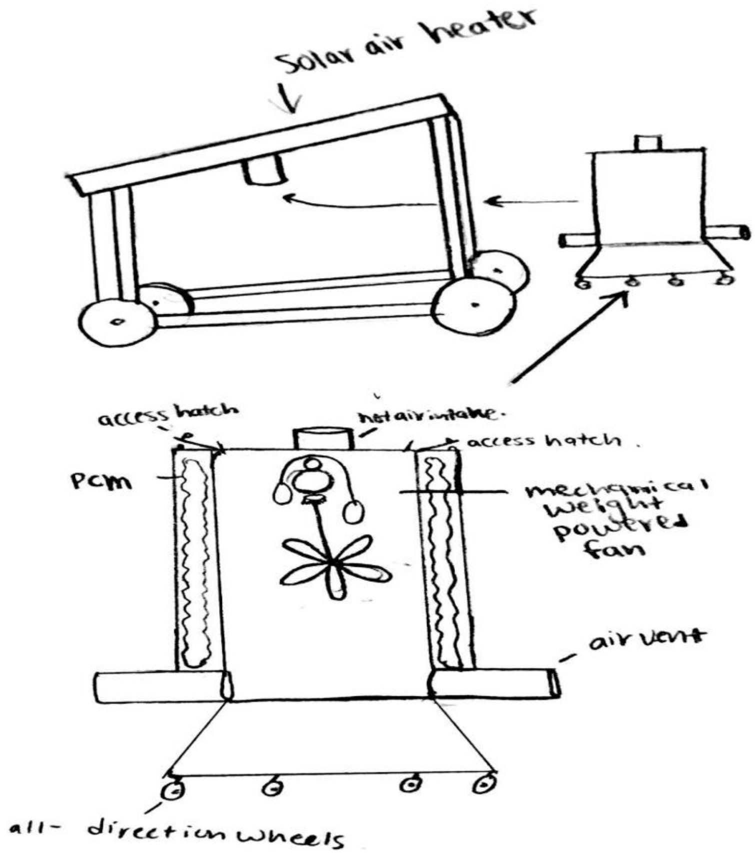


Figure 21: Air Heater with Weight Driven Fan

4.7 Design #7: Wall-Mounted Air Heater with Trapezoidal Heater

The main component of this design (Figure 22) is a movable home-heater that utilizes a wall mounted solar air heater. The ability for the home-heater to be able to move allowed a user to place it anywhere convenient for adequate heating at night. A mesh opening allowed warm air moving from the solar air heater through the duct to enter the home-heater and warm the PCM. This duct was made flexible for easy access to the PCM and allowed easy placement of the home-heater in the home. The cons to this design included possible inadequate circulation of warm air throughout the house without a fan, no control of the system for use at night and the need to drill into the home for hot and cold air ducts. The pros to this design were the easy access for the user.

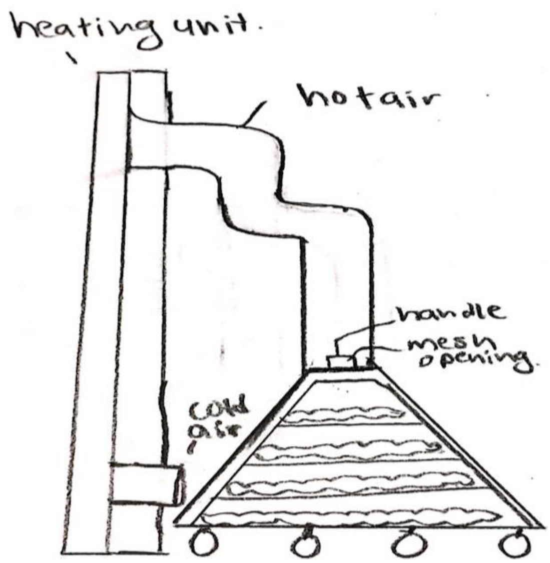


Figure 22: Wall-Mounted Air Heater with Moveable Trapezoidal Heater

4.8 Design #8: Roof Mounted Air Heater

This design (Figure 23) utilized a ventilation system at the top of the door to push warm air from a basin of PCM into the house. A small fan was controlled by an Arduino which moved warm air from the PCM basin to the house through a system of ductwork. The Arduino triggered the fan either at a specific time or when the darkness of night triggered a sensor. The solar panels in the solar air heater powered a battery that was be used to power the Arduino and fan during the night. This basin could either be mounted on top of the house or to the side of the house. The pros to this design were that it could not require drilling into the house walls for placement of a duct system and the fan and Arduino was powered via a battery, so the system can be controlled at night to effectively heat the home. A con to this design was that a battery had to be used as one of the constraints to the project required it to last about 10 years.

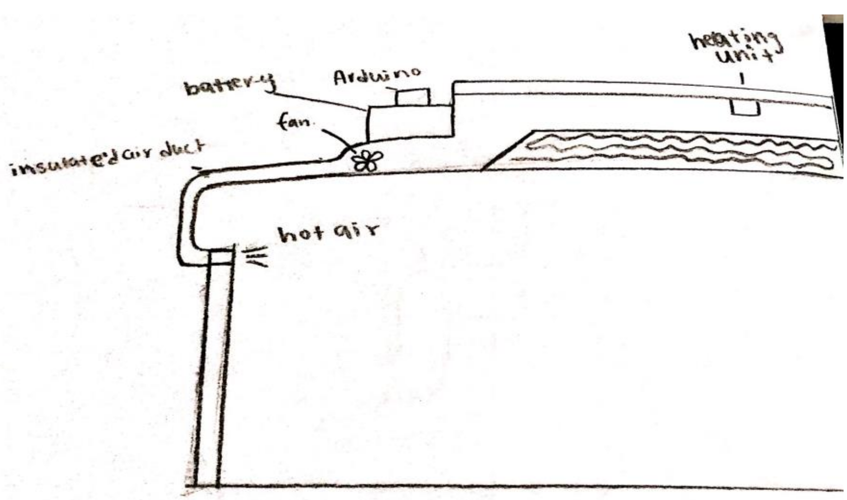


Figure 23: Roof Mounted Air Heater

4.9 Design #9: Beehive PCM Slat/ Movable Solar Heater

This design (Figure 24) uses a solar air heater on wheels and a central box with slats of PCM as the design's main feature. The design worked by pushing warm air from the solar air heater into a box with a mesh support and PCM slats. For use, the PCM slats could be pulled out and placed in the home as needed to emit warm air in the house. The pro to this design was that the solar air heater was movable for placement in high sunlight and the PCM would have high access to the warm air emitted from the solar air heater. The only disadvantage to this design were that there was no way to move the warm air from the PCM throughout the home and a user would have to move PCM slats into the home every night for use.

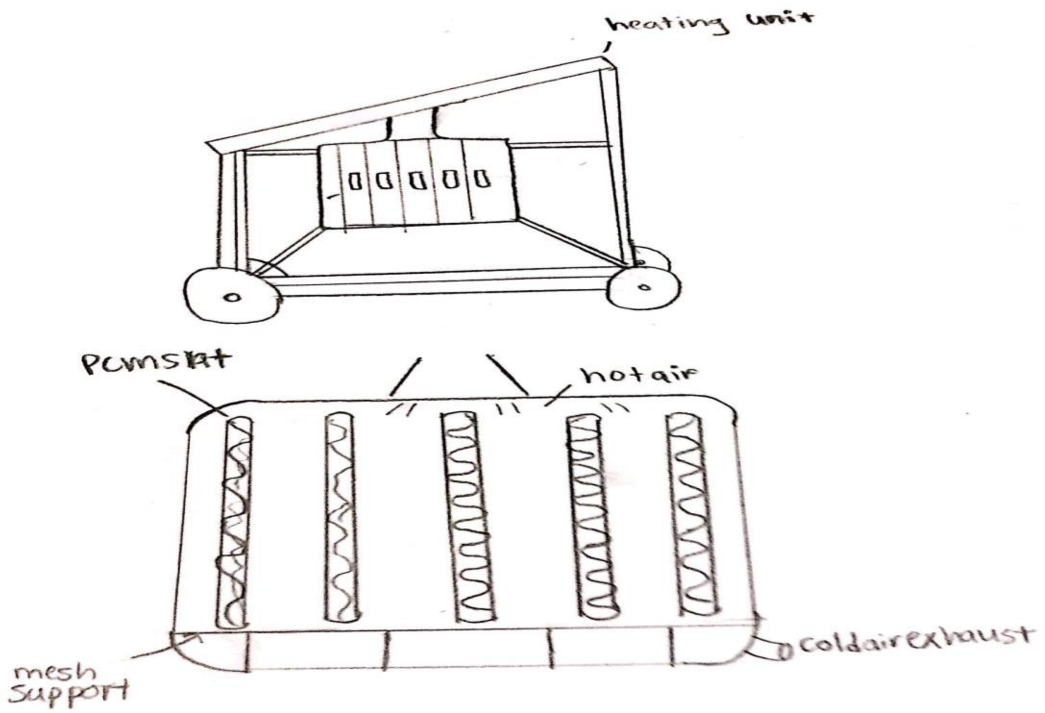


Figure 24: Beehive PCM Slat/ Movable Solar Heater

4.10 Design #10: Mobile Cylinder Heater with Automatic System

This design (Figure 25) implements the use of a portable home-heater and solar heater. This portable home-heater utilizes a rechargeable battery to power a low-power LCD display to exhibit battery level and heat capacity, a fan to circulate heat throughout the home and an Arduino to control the systems. The solar heater station would be movable for best placement in available sunlight and would be used during the day to heat the PCM in the home-heater and the solar panel would recharge the battery. Possible con to this device was that it required few components that might not last 10 years including the battery and display. Possible pro to this device was that it was easily moveable for placement in the home or in the case of the solar heater easily movable for placement in direct sunlight and it was fully automated for easy use.

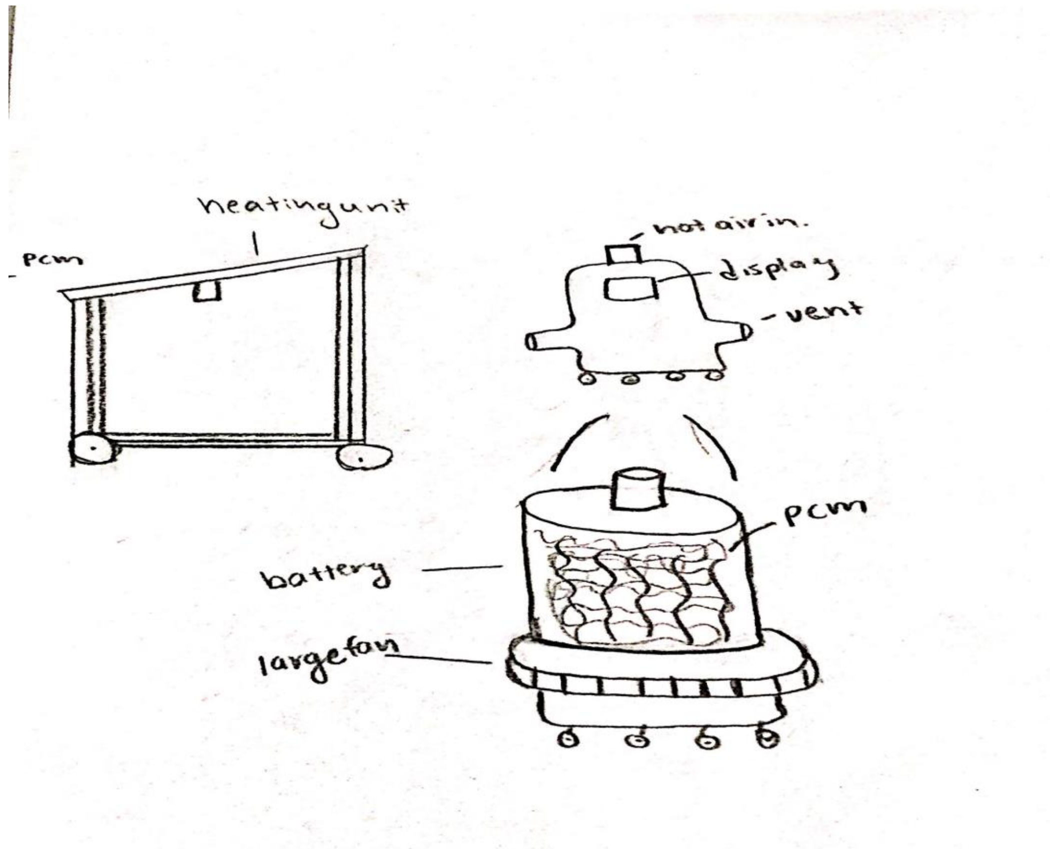


Figure 25: Mobile Cylinder Heater with Automatic System

4.11 Design #11: Vertically Heated Box with Control System and PCM

In this design (Figure 26 and Figure 27), a vertically positioned box that uses a solar thermal air heater in order to heat the PCM stored inside of a box is utilized. The insulation was meant to keep the heat inside is made of Green Rhino brand Styrofoam building material which has very good thermal resistance. In order for the material to not degrade, they were covered in special coating in order to ensure strength. During the day, the solar air heater circulated heat through the home while the PCM stored excess heat. At night this PCM would dissipate heat over time and after a set period of time a coil heating system turned on heating both the PCM and house once again, this cycle kept repeating throughout the night. A pro of this design was that it contained heat easily so there would be minimized loss. Another pro of this design was that it would work regardless of what home/structure needed to be heated. A con for the design included the inclusion of so many working parts.

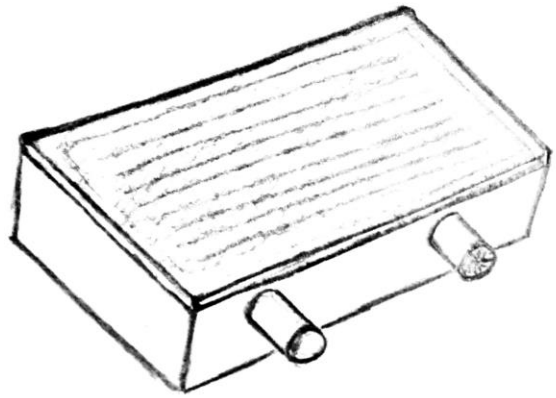


Figure 26: Vertically Heated Box with Control System and PCM (Outside View)

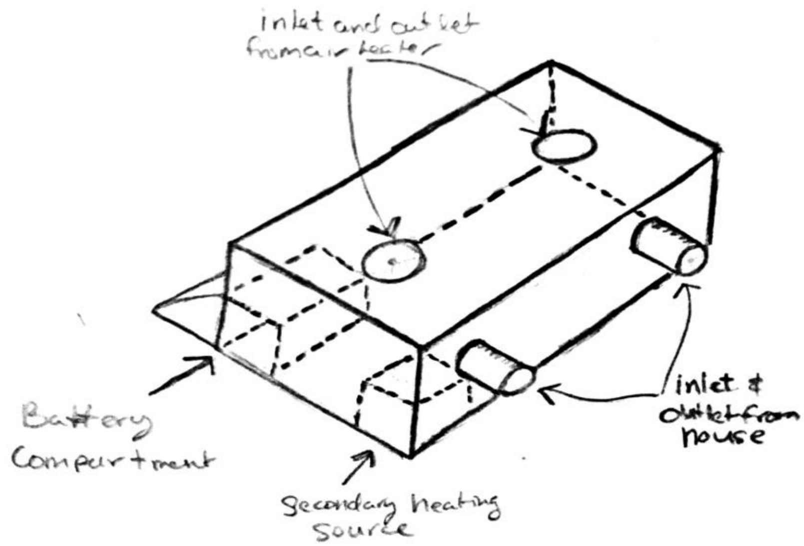


Figure 27: Vertically Heated Box with Control System and PCM (Inside View)

5 DESIGN SELECTED – First Semester

This chapter contains the information of planning in the first stages of a design, by outlining the tasks and how long the objective took to get the project done on time while meeting the needs of the customer. The budget was part of the planning phase, as to how much the materials costed for the project. The stage process was used to discover the product, project planning, product definition, conceptual design, product development and supporting the product. The generation of deliverables for tasks and a schedule that aided in keeping the project on Schedule. Prototyping the project was in the means of proof of function, product, process and the production of the prototype. The use software to get the image of the product, and the assembly of the prototype. Also, the generation of a chart that rated which prototype scored the highest by rating. In addition, the record of the project as it progressed from the planning phase to the final phase of the product being distributed to the client and users.

5.1 Rationale for Design Selection

A Pugh chart works by using a list of criteria with weights to determine the best concept out of a group and was usually performed before a decision matrix to narrow down the total number of ideas. When a concept worked well for one specific criteria a + was recorded for that concept in the corresponding row and column, when it performed poorly with a given criterion a - was recorded and when the criteria was not affected a 0 was recorded. The weights multiply through these scores and the outcome was summed for the given concept. Design 11 performed better than all other designs on aesthetics and efficiency.

From the results of the Pugh chart Design 11: Vertically Heated Box with Heat Circulation, Control System and Secondary Heat Source had the highest score of +16. Design 4: Wall-Mounted Constant Heating Device was very close with a score of +15

The results of the decision matrix coincided with the results of our Pugh chart. It was evident that Design 11: Vertically Heated Box with Heat Circulation, Control System and Secondary Heat Source was the best choice for the given criteria based on its score of 7.6. Several others were close including the Design 4: Wall-Mounted Constant Heating Device with a score of 6.68. Design 11 had a better overall score on all criteria and outweighed Design 4 in the following parameters: Heat Coverage and Size. To ensure accurate results, the same designs were run through a Pugh chart. This chart provided very similar results, Design 11 scored the highest with Design 4 scoring just below. With this information the team was confident with the final design selection.

The following were the team's Decision Matrix and Pugh Chart choices:

1. Vertically Heated Box with Removable PCM
2. Wall Integrated PCM with Roof Mounted Heating Unit
3. Door-Replacing Heat Box with Fan
4. Wall-Mounted Constant Heating Device
5. Switch-based Ducted Heating Storage
6. Separate Air Heater and Moveable Cylinder Heater with Weight-Driven Fan
7. Separate Wall-Mounted Air Heater with Duct-Work and Movable Trapezoidal Heater
8. Roof Mounted Air Heater with Arduino-Controlled Fan and Door-Top Mounted Duct-Work
9. Beehive-like PCM slat and Movable Solar Air Heater
10. Movable Cylinder Home-Heater with Automatic System/LCD battery display and Solar Heater

Station

11. Vertically Heated Box with Heat Circulation, Control System and Secondary Heat Source

Table 3: Pugh Chart

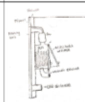
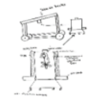
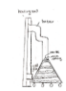
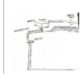
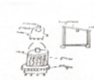
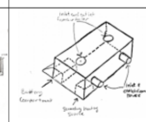
Concept	Datum	Concept #1	Concept #2	Concept #3	Concept #4	Concept #5	Concept #6	Concept #7	Concept #8	Concept #9	Concept #10	Concept #11
Sketch	Solar ThermiX STX 7000											
Criteria/ weight												
Ease of use/4	0	0	+	-	+	+	-	-	+	--	-	+
Simple design/ 4	0	++	-	0	+	-	-	-	-	0	0	+
Low cost/5	0	+	-	0	0	-	-	0	-	+	--	-
Size/2	0	0	0	-	+	0	0	0	+	-	+	-
Aesthe-tics/2	0	0	+	+	+	+	0	+	+	0	+	+++
Efficient /3	0	0	+	0	+	-	+	+	0	+	+	+++
+	0	13	9	2	15	6	3	5	8	8	7	23
-	0	0	9	7	0	12	13	8	9	10	14	7
Net Score	0	+13	0	-5	+15	-6	-10	-3	-1	-2	-7	+16

Table 4: Decision Matrix of Possible Designs

Designs	Weight	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8	Design 9	Design 10	Design 11
Longevity	.2	8	6	4	9	8	3	7	5	7	5	7
Size	.08	8	3	4	3	3	8	5	7	5	9	9
Usability	.1	4	5	8	8	8	4	7	7	7	9	8
Complexity	.3	7	4	3	9	4	2	5	5	6	4	7
Cost	.1	6	3	5	7	4	7	7	7	7	4	6
Heat Coverage	.22	1	1	8	2	8	6	1	2	2	9	9
Totals	1	5.56	3.66	5.08	6.68	6	4.26	4.92	4.9	5.44	6.2	7.6

5.2 Design Description

The team's final design chosen was the Solar Air Heater thermal storage box shown in Figure 26 and 27. The team's goal was to have the Solar Air Heater function during the day and maintain a steady flow of heat throughout the night, thanks in part to a solar panel charging a 12V battery during the day. The team used the original Solar Air Heater which is 8 ft. by 4 ft. The Solar Air Heater on the design was placed on top of the thermal storage box that would slide on top of it. The thermal air storage was manufactured out of Green Rhino foam. Since the Green Rhino foam had a low thermal conductivity and so could insulate the warm air entirely throughout the day while the PCM was absorbing and storing heat. The team also implemented a coil in our design which heated up during the night to prolong the storage of heat into the PCM. The final design was tested in a computer simulation in EnergyPlus+ software to test the efficiency of our product and adjust for peak performance. After, the team presented and displayed results and conclusion with SRP at a conference in Tempe.

After the design selection process, a CAD model of the final design was created as shown below in Figure 26 and Figure 27.

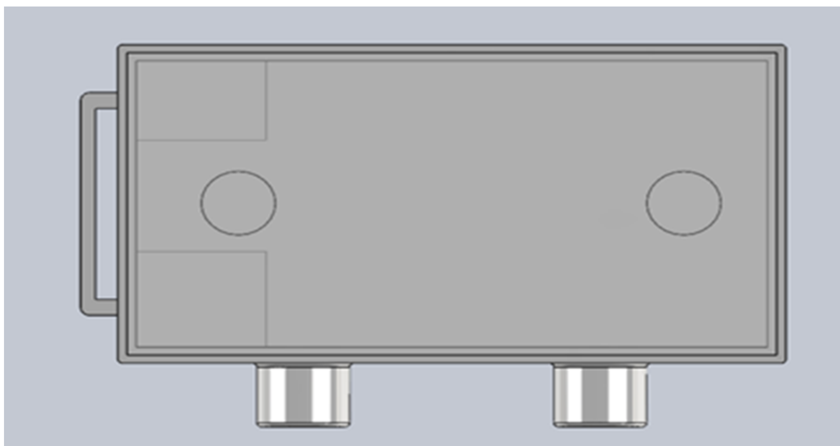


Figure 28: Vertically Heated Box with Control System and PCM CAD Model (Outside View)

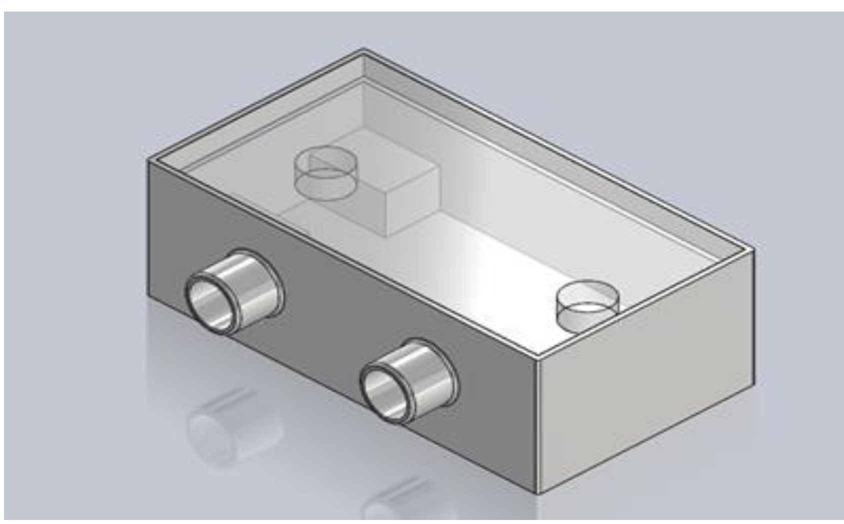


Figure 29: Vertically Heated Box with Control System and PCM CAD Model (Inside View)

The dimensions of the final design were 8 ft. x 4 ft. x 2ft box that stores the heat by the PCM, shown in Figure 26 and 27. The PCM was hang by a length of 1.125 ft. apart sitting in the box by a length of 8 ft. This collected the heat generated by the Solar Air Heater which produced the heat during the day. The heat stored was expected to last from sundown of the previous day into the next day if possible. If the heat carried on to the next day, then it was considered successful after 3 trials if the box needed to be scaled down.

6 PROPOSED DESIGN – First Semester

6.1 Implementation

The implementation of the project was to complete every task that every member had done in the technical analysis as well as to purchase the materials needed for this project. The source of our funding was SRP, which we were given the amount of $2500. The expected budget was $2,286.00 for the materials that the team needed. The material that was selected for the Design 11 was a Green Rhino Foam that was meant to insulate the heat into the thermal box where the PCM will be stored. The Green Rhino foam was purchased from Green Rhino Building Systems company that had affiliation with SolarThermiX. The thermal box was also manufactured by the Green Rhino Building Systems, which was beneficial to the team. Because the solar thermal air heater was already being provided by SolarThermiX, there was no need to manufacture it. The amount of building at most was to wire the Arduino and solar panel once they are implemented into the box.

This section will be describing the deliverables that the team were given to complete for both the fall and the spring semesters. Each one of these deliverables had tasks that were needed in order to complete the assignment/deliverable that was given. These tasks were split up to each team member, this was to ensure that each team member contributed to each of the assignments. The schedule was shown as a table, in chronological order from when the first assignment was due to the last assignment.

6.2 First Semester Schedule Tasks

This is the first semester assignments that the team accomplished. Each assignment had tasks that were needed for the assignments. The schedule is shown in Table 5.

Table 5: First Semester Schedule Tasks

Date	Deliverable	Task
10/5/17	**Preliminary Presentation**	· The Team gathered background information on the company and project given · Developed consumer, design, and engineering requirements for the project
10/20/17	**Preliminary Report**	· Each team member was given a section to complete within the report · Design considerations were created · Previous designs of systems and subsystems were evaluated to aide in creating designs
10/20/17	**Individual Analysis**	· Components of the design were split up to different team members · Each team member was required to evaluate and come up with solutions to their component of the project.
10/29/17	**Prototype**	· Supplies were gathered · Building the prototype · Presenting the prototype during the staff meeting
11/8/17	**Final Proposal Presentation**	· Final design created · The presentation was created and implemented a detailed description of the design and the tasks needed to complete the project
11/10/17	**Final Proposal Report**	· The final design was inserted in the previous report · Budget and requirements were updated to accommodate the new design · New sections were spilt up to the team to complete

6.3 Second Semester Schedule Tasks

This is second semester assignments that the team accomplished. Each assignment had tasks that were needed for the assignments. After talking with Green Rhino they are willing to create our box, so the only manufacturing we have is creating the model of our Hogan. This schedule is shown in Table 6.

Table 6: Second Semester Schedule Tasks

Date	Deliverable	Task
2/7/18	**Parts Received**	· Parts that were ordered will be received. · Inventory of the parts will be made.
2/12/18	**Start Construction of Product**	· Each team member will begin construction on their part of the product.
02/26/18	**Individual analysis**	· After finalizing the design, new analyses should be made for each component that is different from prior design considerations. · Each team member must complete an analysis of their component.
03/5/17	**Hardware Review**	· Each component of the product is evaluated. · A component is assigned for a team member to review.
3/7/18	**Electrical Components are Implemented**	· Electrical components are added to the final design. · Code will be created to control each component.
03/12/18	**Midpoint Report/Presentation**	· The design and the process of the produce should be reported and presented. · Each team member should produce a report of their progress for their part of the project. · These reports will be combined to complete a midpoint report.
04/9/18	**Final Product and Testing**	· The construction of the product should be completed. · Testing of the product will be done. · A professional report will be made of the testing and the results of the product.
04/16/18	**Poster/Manual**	· The final product should be summarized and put into poster. · Each team member will produce a part of the manual that corresponds to the component they created.
4/20/18	**Final Presentation at SRP**	· The team will travel to Tempe to present our final product to SRP.
04/23/18	**UGRADS**	· Each team member will have a part of the presentation to created and practice.
04/30/18	**Final Report and CAD package**	· Each team member will have a section they will need to complete for the final report. · CAD drawings will be made and finalized to be turned in with the final report.

6.4 Budget

The budget was estimated to be $2,312 for the purchase of materials needed for the project, but after buying materials and assembly the budget was adjusted. Table 7 is a budget, listing with the corresponding materials that were bought but also had additional materials that were not on the last budget. The budget also lists what was purchased and what was donated. SolarThermiX donated one sheet of PCM for the project and everything else was bought. The team purchased an additional 9 of the 2 ft by 4 ft. sheets for a total of 10 sheets of PCM. The team had $26.36 left out of the budget after all materials were purchased and accounted for.

Table 7: Bill of Materials

Item	Cost	Quantity Needed	Size Of Materials	Function	Part Number/Company Producing	Website	Purchased or Donated?
Solar Air Heater	$1,500	1	4 ft. x 8 ft.	Heating Air	STX7000/SolarThermix	SolarThermix.com	Purchased
PCM(Phase Change Material)	$24.00	9	4 in. x 2 ft. x 4 ft. x 8 lbs.	Controlling the temperature	Infinite R/InsolCorp.	SolarThermix.com	Purchased 9 /Donated 1
Travel	$50	N/A	153 miles	Travelling to Competition	N/A	N/A	
Battery	$150.00	1	12 volts./55Ah	Used for powering the coil	UB1250/Universal Battery	Amazon.com	Purchased
Coil	$11.72	2	3 x 7 x 3 inches	Heating PCM	5300622034/Garp	Walmart.com	Returned
Arduino Uno	$19.22	1	9.8 x 6.6 x 2.4 inches	Controller for electrical use	A000073/Arduino	Amazon.com	Purchased
Fan	$19.99	2	120 by 120 by 38 mm	Moving air in from the coil area	PMD1212PMB1-A/Sunon	Amazon.com	Purchased 2/ 2 w/ heater
Thermasheath Rmax	$34.00	2	2 in. by 4 in. by 8 ft	Made into a wall for separation air flow	#416989/Thermasheath	HomeDepot.com	Purchased
Green Rhino Box	$300.00	1	4 ft. x 8 ft.	Durable for nature, contains air from escape	Green Rhino	GreenRhino.com	Purchased
Speedi-Collar Open/Close	$10.30	2	5 in.	Change air flow direction	#1000677624/Speedi-Collar	HomeDepot.com	Purchased
Insulated Flexible Duct	$26.75	1	5 in. x 25 ft.	Channels air flow	#1000683500/Master Flow	HomeDepot.com	Purchased
Master Flow Wye	$11.25	1	4 in. x 4in. x 4in. Wye	Channeling air flow	#232940/Master Flow	HomeDepot.com	Purchased
Solar Panel	$90.00	2	100W at 12 volt system	Used for recharging the battery	GS-Star-100W/GrapeSolar	HomeDepot.com	Donated
Rebar	$4.20	2	3/8 in. x 20 ft.	Rack for PCM	REB/3/615G40/20	HomeDepot.com	Purchased
Total	$2,473.64	Not including tax					
Total Budget Left	$26.36						

7 IMPLEMENTATION – Second Semester

7.1 Manufacturing

After receiving all of the parts that were needed for the project the team set ready to start manufacturing the prototype. The team will be doing the manufacturing the final product at Taylor McCormack's apartment in Flagstaff, AZ. The first step in manufacturing was to create an inlet and outlet holes on the box itself. The 4 ft. by 8 ft. box was made from Green Rhino construction foam with a concrete mixture covering the outside, it was very hard but the team was able cut into it with a diamond tip blade. The next process of manufacturing was cutting the ThermaSheath insulation material and create a box within the Green Rhino box of this material. The team used Great Stuff Gap filler to make the insulation box air tight inside of the Green Rhino box. To cut the material the team used a cutting utensil to cut the insulation, the team members doing the cutting ensured that they wore the correct protective to ensure that they don't inhale any Styrofoam. After installing the ThermaSheath insulation the team was able to cut the inlets in the material, these cuts were held rebar that will be holding the PCM. Ten, four foot pieces of rebar that were used to hold the PCM were installed. In order for each bar to fit within the box the team spaced each bar four inches apart to make sure each bar would fit and also there would be enough space for the PCM to be placed on them. Since the inlet and outlet holes were cut into the box the team attached the fans on the box. This task utilized screws that drilled the fans to the box. The team also built the photo resistor and fan circuits then attached them in the box to the battery pack. The only parts of the project that really needed to be manufactured for the team by an outside source were the green rhino box and the solar air heater, however, other than that the team was able to assemble and alter the components that were needed for the project.

7.2 Design Changes

Several design changes were made in order to keep our system within the ERs. Changes include removing the coil heating system, adding a thermal box, moving the intake and outtake holes of the box. In addition to the previous changes, due to the fact that the team could not afford to build a model Hogan for testing, a new testing site was used for testing. Figure 29 displays the final CAD model.

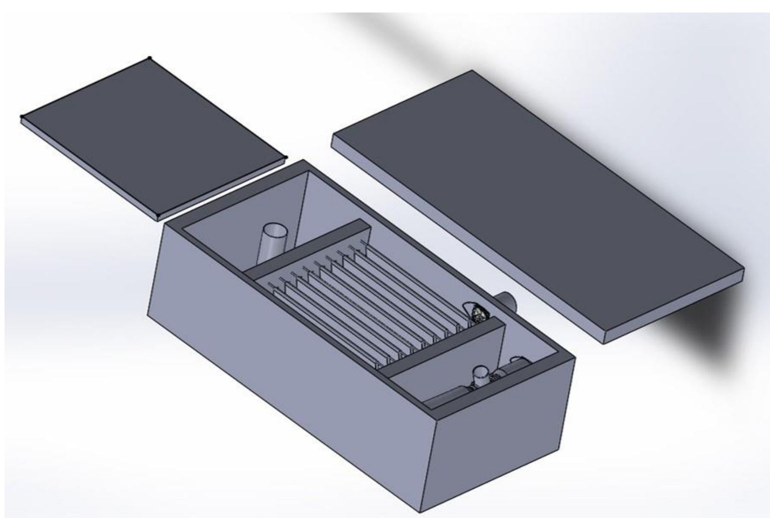


Figure 30: Final CAD Model

7.2.1 Coil Heating System

From the individual analysis, it was discovered that it would take a significant amount of power to keep the fans and coil heating system running for eight hours. Equation 1 was used to determine the amount of time the system would run with various amount of current in a 12 V battery.

Equation 1: $T = \frac{Ah}{i}$

Where T is time in hours, Ah is ampere per hour in Ah, and i is current in amps.

To determine the amount of current that the system used, the current (A) of all the components since the system was in series. Two fans of the system were rated at 1.6 A and the other two fans were rated at 1.8 A. An estimate of the coil heating system was estimated to be at 3 A. The results showed that an 80Ah 12V battery would be sufficient to heat the overall circuit for eight hours.

Using Equation 1, the amount of time that the battery would provide would be 5.61 hours.

$$T = \frac{55}{1.6 + 1.6 + 1.8 + 1.8 + 3} = 5.61\ hours$$

In the team's ERs, the team specified a low-cost design, and the battery required to power the system would be very expensive. It was determined if the coil circuit would be taken out, a 55Ah 12V battery would be needed. This battery was meeting the budget of the team and the amount of time the system required to run. From these results, the team decided not to include the coil heating system.

7.2.2 Thermal Box

A thermal box to hold the PCM was included to ensure that the heat from the solar air heater would be retained during the day. The box would be made out of foam insulation. One wall of the box would be splitting the input hole of the box from the output hole, which would separate the cold air from the warm air flowing into and out of the thermal box. By having the thermal box, the PCM would be heated up with only warm air. The team decided to add this component to better realize the main concept for this project which was the modeling of PCM material with a solar air heater.

Figure 31: Partially Completed Thermal Box

7.2.3 PCM Rack

A rack that would hold the PCM was added to the box to have easier access to the user and to allow heat to flow through the material easier. This would ensure that the PCM would be properly stored.

Figure 32: PCM Compartment

7.2.4 Schematic Design

The original design of the schematic was designed with an Arduino and a transistor that would control the fans via a photoresistor that would determine whether it was light or dark outside. The original schematic that was designed for the project is shown below in Figure 33.

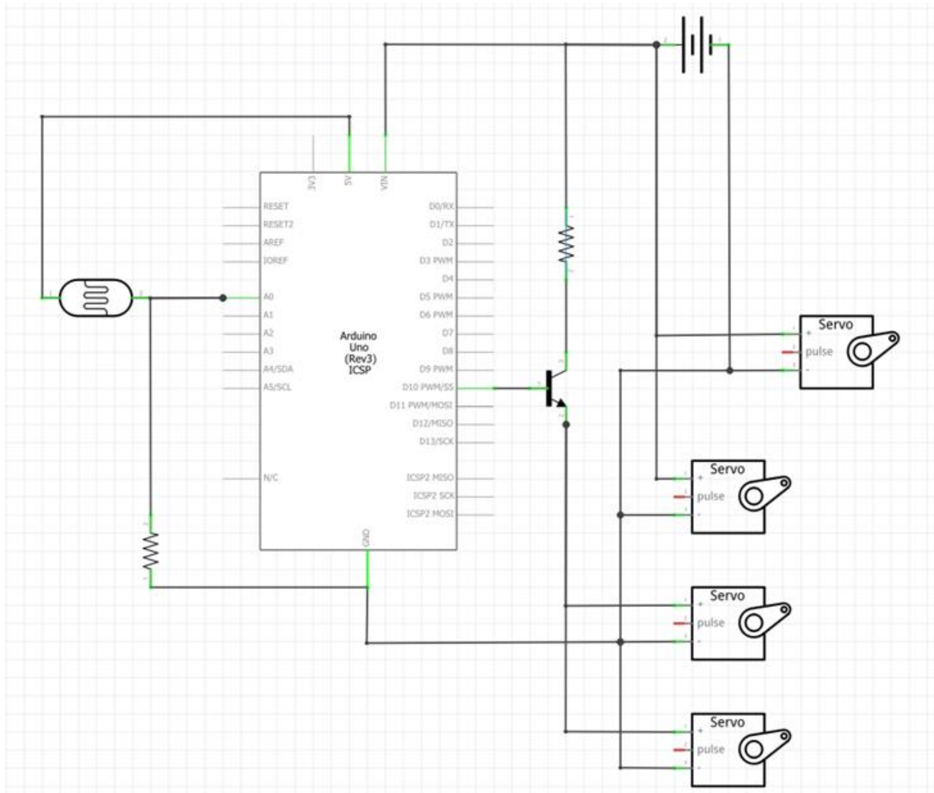


Figure 33: Original Schematic

However, after physically testing the schematic and running it with all the components it was found that the battery was putting out too power for the Arduino itself. This would cause the Arduino to break and it would not allow the photoresistor or the transistor work. After brainstorming the situation the team had decided it would be best that the fans should just be turned on and off manually through the transistor. Two fans would be constantly running, however, two other fans would be turned on and off with a transistor. The gate of the transistor would be connected either to ground or power in order to turn the fans on or off. The new schematic that the team implemented for the physical testing is shown below in Figure 34.

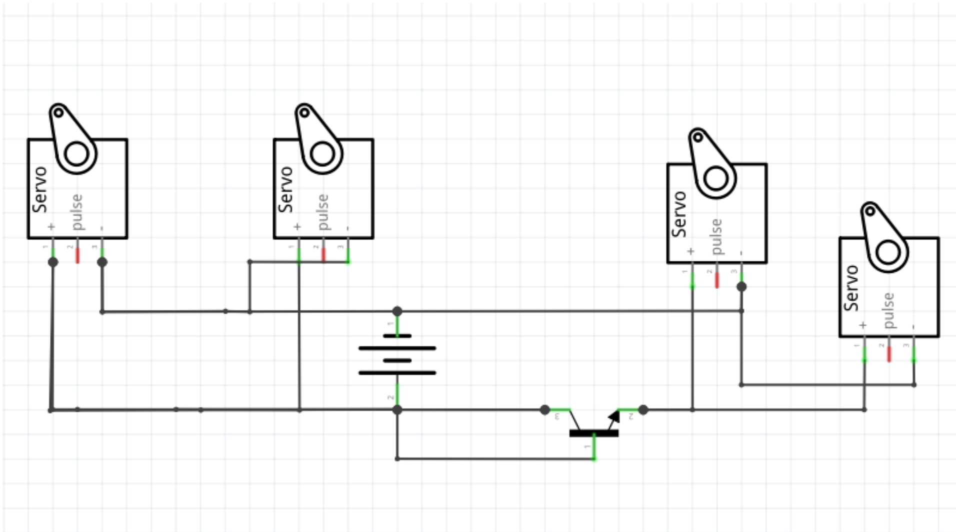


Figure 34: Final Schematic Design

7.2.5 Intake Hole

The placement of the input hole was moved closer to the top of the box. This would help the flow of warm air, as warm air rises. The warm air would be easier to distribute to the PCM in the thermal box and to the Hogan.

7.2.6 Testing Environment

Due to the team not having enough funds to build the Hogan for testing, the new testing site was set to be a 535.5 sq. ft. apartment room. To attach the solar air heater for testing the team cut out insulation and put holes into it to run the duct work through the window of the room. Even though the room had more insulation than a Hogan it was a good source to use to ensure that the box was working as intended. The team tested the depth of how much the thermal box to determine if it will sink into the ground by doing geotechnical engineering of the box. It was determined to be absolutely zero.

7.2.7 Testing via Modeling Software (EnergyPlus+)

As time progressed in the project it became evident that building a Hogan for testing the project would be infeasible. Thus, it became even more imperative that a software-based model be created for the project. Energy+ software was prescribed for the team to use for this purpose. It required the use of two GUI programs to run a simulation: IDFeditor and EP-Launch. In IDFeditor a user was required to enter all relevant information about a building being modeled such as: wall and roof dimensions, heating and cooling information, building use and location and scheduling for the simulation. EP-Launch runs the simulation based on the idf file created by the user and weather file of the location being modeled.

7.2.8 Testing with LabVIEW Software

Testing with the LabVIEW software would evaluate the overall quality of the thermal box. That the thermocouples were attached at different locations within the thermal box to evaluate the overall performance of the box over time. Also, evaluating if there was a possibility of losing heat to the ground through heat transfer. The ground became a negative possibility of placing it on the ground. This technique helped where there was need of placing the thermal box on a metal frame.

8 TESTING

The testing of the Solar Air Heater thermal battery was done by using our team leader, Taylor McCormack apartment where it was manufactured and built. This testing was done by by reading the thermometers that were placed 19 feet, 14 feet and 23 feet away from the duct into Taylor's apartment. More testing was done by using the EnergyPlus+ software which used to model the testing phase of the project. The team will discuss about the results finding about our experiment on the project of what is to be determined to be effective of placing the PCM into the thermal box or around the walls of the modern home or a traditional hogan.

8.1 Testing of Solar Air Heater Box

According to our Engineering Requirements in section 2 heat storage is one of our most important requirements as such we went about proving the overall quality of our heat storage. The solar air heater was tested on a 535.5 sq. ft. apartment room shown in Figure 35. The box started at approximately 1 pm and ran until 12:30 am. During the testing, the thermometers were set up at 9 inches, 14 feet, and 23 feet from the duct into the house from the heater. Temperatures were recorded and displayed in Figure 36 below.

Figure 35: Final Product Setup

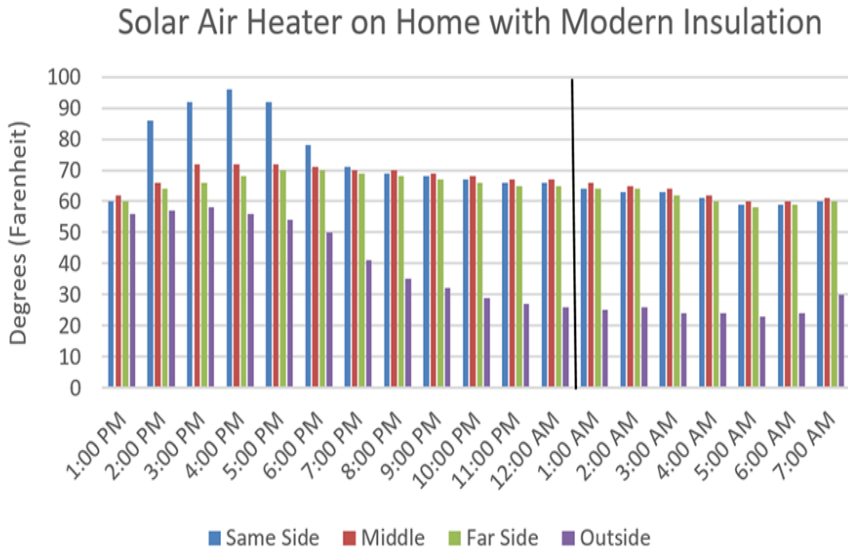


Figure 36: Solar Air Heater Results

From the results of our solar air heater it can be seen that from 9 inches away the temperature, that it almost reached 100 degrees Fahrenheit. From 14 and 23 feet away the room reached about 74 degrees Fahrenheit. The PCM itself lasted until around 12:30 am and was able to hold the inside temperature around 66 degrees Fahrenheit until it fully solidified.

8.2 Testing of EnergyPlus+ Software

One of our most important customer requirements was to have high efficiency. The EnergyPlus+ software was used to test the efficiency of the PCM inside a modern Hogan of 560 sq. ft. shown in Figure 37. The Hogan is made of red cedar wood covered in a dirt coating. The solar air heater box could not be modeled into the EnergyPlus+ program due to problems with setting up the airflow nodal system. The main objective for this was to test the efficiency of the PCM so a couple tests were done in EnergyPlus+ to test that. The software used the Four Corners International Airport weather files to set the temperature, since this was the most readily available weather file that match the temperature profile found on the Navajo Reservation. The average low temperature during the winter months was 32 degrees Fahrenheit and the lowest was -4 degrees Fahrenheit. The results shown in Figure 38, shows the data for the coldest night when the temperature dropped to -4 degrees. It was found through the software that the best application of PCM which would be use as insulation. The first test ran a simulation of the Hogan with no insulation to set a basis for showing the PCM efficiency. The second test shows the results for the Hogan with PCM insulation.

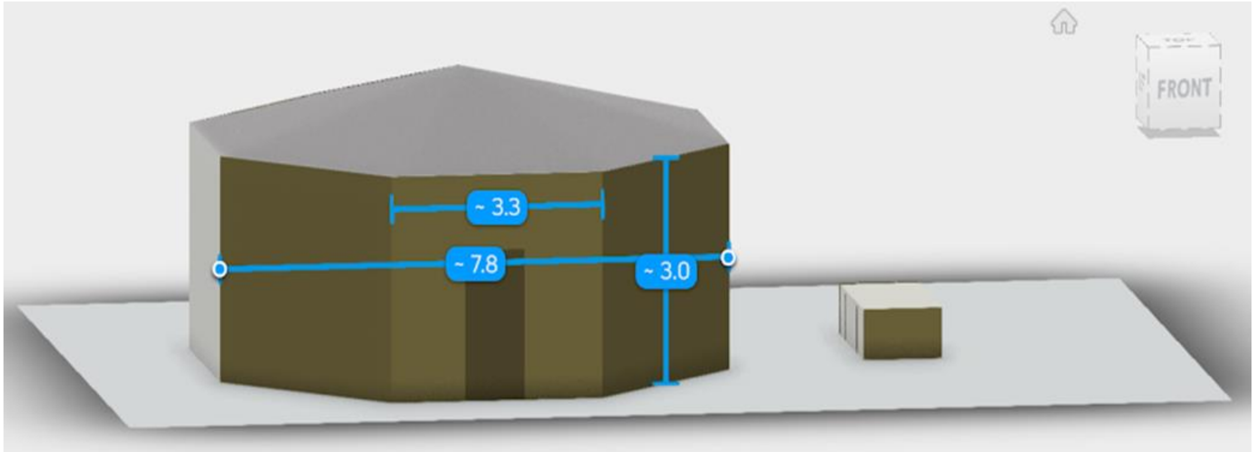


Figure 37: EnergyPlus+ Modeled Hogan

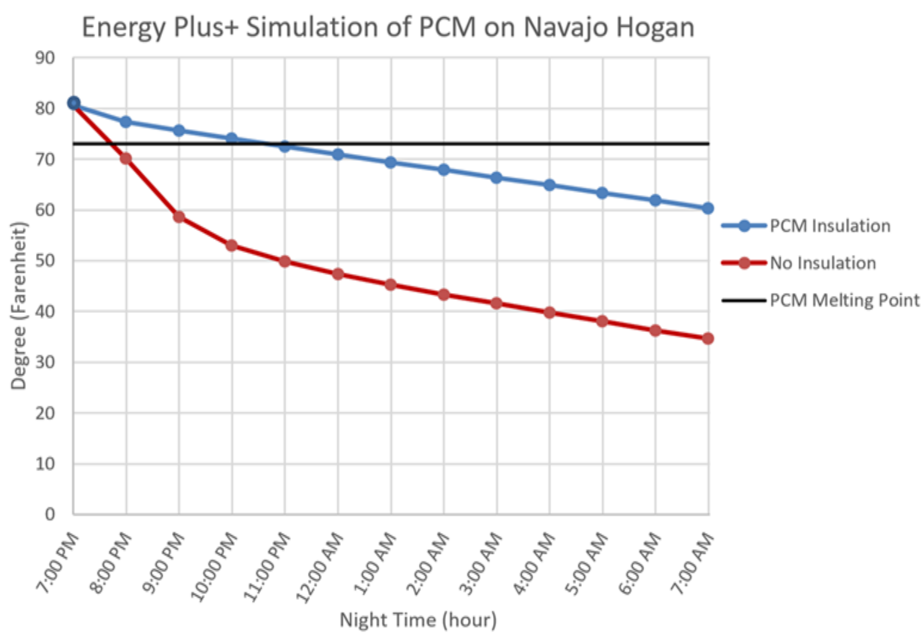


Figure 38: EnergyPlus+ Results

From the results it can be seen that the PCM was very successful in insulating the Hogan during the coldest night for the weather file. Without the PCM the temperature inside the Hogan dropped to about 32 degrees Fahrenheit. The test with the PCM insulation showed that the PCM was able to hold the temperature above 60 degrees Fahrenheit. This was very good since the temperature during that night dropped to -4 degrees.

9 CONCLUSIONS

To conclude, the Solar Air Heater operates as intended, but is only efficient enough to work on a home that is moderately insulated, based on the results we recovered using the solar air heater test as shown in Figure 34 and the simulations were done by using the EnergyPlus+ software. Even with the temperature not being held at 73 degrees Fahrenheit, the user could add more PCM for more heat retention. From the EnergyPlus+ simulation, we have determined that to make the best use of the PCM with no insulation in a house, it would need to be place around the home instead of placing them in the box. When modeling a 566 Sq. Ft. Hogan in EnergyPlus+ software, the user would need 177 sheets of 2 Ft. by 4 Ft. PCM at $24 a piece to keep the Hogan sufficiently warm at 73 degrees Fahrenheit. With 177 sheets multiplied by $24 dollars a piece it would equal out to $4,248 total not including a $1500 solar air heater to heat during the day. In terms of feasibility with money, it would not be as practical, but in feasibility of most ages being able to operate this machine it is very likely with a simple operation and maintenance manual.

9.1 Contributors to Project Success

Contributors to the success of this project include SRP for the inspiration behind the heating up homes that are off the grid on the Navajo Reservation. They also provided environmentally friendly solutions, and a donation of $2500 for the project. Our client SRP has given NAU a project contrary to project of ASU and UA, working on cooling in the valley of Phoenix and Tucson; of warming off grid homes.

Another key contributor to the project's success is SolarThermiX for the use of their Solar Air Heater systems, PCM, detailed plans, and more. SolarThermiX has given us their Solar Air Heater and additional PCM to be used into the project. Also SolarThermiX has provided how the Solar Air Heater should be used but we have met the SRP requirements of making the heating last by using PCM.

The last contributor to this project success that needs to be mentioned is the Green Rhino with the industrial foam box covered in ⅜ in. concrete mixture that is fire retardant providing a safe but durable place for components. Without SolarThermiX the team would not have known the existence of its material used in this project, created by Green Rhino.

The Sponsors of this project were great contributors to the success of this project. However, our mentor was also a big contributor to our project. Kyle Yamamoto was able to meet with the team every two weeks in order to ensure that the team was on the right path during this project. Kyle had a good knowledge of what our client was looking for and was able to answer every question that the team had about the project itself.

Another contributor of our success would be our class instructor, Dr. Sarah Oman. Without her guidance throughout the two semester's the team wouldn't have been as successful with the project. Sarah was able to offer her help when it came to proofreading documents and aiding in what would be best for the team when it came to the design or documents that were needed for the project. Everyone that contributed to our project was great help and the team is very grateful and appreciative for the time they have given us.

Lastly, each team member that has been working on this project has each contributed to the success of this project. The project itself was very large and it wouldn't have been easy for a small team to complete. Each team member had specific jobs when it came to completing the project, whether that job was small or large, every assignment completed by a team member has been taken into account and everything that has been done has been a team effort.

9.2 Opportunities/areas for improvement

If the group was to redo this project, a smaller project would become more practical. In the redesign, the schematic would change for the electrical components to work with a voltage regulator. This would decrease the chances of blowing up the Arduino's due to too much voltage running through this component, while also being able to add in a photoresistor that would measure the light for the automatic turn on and off of the Solar Air Heater.

To improve the overall design and performance of the solar air heater box we would implement the coil heating method when buying a high voltage battery to sufficiently supply enough current to heat the coil. For another design improvement we would consider sealing the thermal box to prevent the warm air from escaping. Also, we would try to maximize the Solar Air Heater output temperature to that which is specified as the max temperature that was measured to be 122 degrees Fahrenheit instead of only 98 degrees Fahrenheit. An important design improvement would be taking insulated duct throughout the home to get a more even temperature throughout the home instead just stopping at the window.

The most practical improvement would to purchase more PCM material for our thermal box to improve the overall quality of our thermal battery. However, the redesign phase would require the Solar Air Heater to be placed perpendicular to the sun's light as suggested by SolarThermiX, the supplier of our heater.

In the future, the next redesign phase is to remember that the Solar Air Heater should be placed perpendicular to the sun and thus create a system that tracks sunlight and ensures the panel is in the correct location. This would be done by using the photoresistor as well as a GPS to track the sun's movement in the sky and move the solar air heater accordingly.

More improvements would include preventing heat loss through the walls of the Hogan or a modern home depending on the square footage of a home. If a system was to be designed by the square footage of the overall home then the thermal battery should still be effective. In Mechanical Engineering terms, the house would need a HVAC (Heating, Ventilation and Air Conditioning) of moving the warm air uniformly throughout the house by a means of placing a network of ducting into the home or a Hogan. If the system was designed with maximum efficiency in mind the efficiency should be similar in any environment and the difference of a size of the house should not make a difference.

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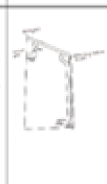
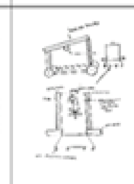
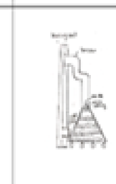
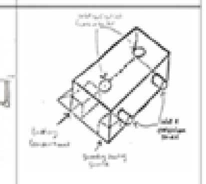
11 APPENDICES

11.1 Appendix A: House of Quality (HoQ)

			Technical Requirements							
	Customer Needs	Customer Weights	Size	Cost	Weight	Heat Absorption	Ease of Assembly	Lifespan	Flow of Energy	Maintenance
1	Ease of Use	9	9	1	9	3	3	3	3	3
2	Simplicity of Design	9	9	3	1	3	9	9	3	9
3	Low Cost	9	3	9	1	9	9	3	9	9
4	Safety	9	9	3	9	9	9	9	9	9
5	Efficiency to replace current Heating	9	9	9	9	9	3	3	9	3
6	Manageable Size	3	9	9	9	3	9	3	9	9
7	Aesthetically Pleasing	3	1	1	1	1	1	1	1	1
	Technical Requirement Units		Cubic Feet	Dollars	Pounds	kiloJoules	Minutes	Years	Joules per Feet per Second	Dollars
	Technical Requirement Targets		96	2000	<100	2000	20	>10	20	200
	Absolute Technical Importance		381	255	291	309	327	255	327	327
	Relative Technical Importance		1	5	4	3	2	5	2	2

11.2 Appendix B: Pugh Chart for First Semester Design

Concept	Datum	Concept #1	Concept #2	Concept #3	Concept #4	Concept #5	Concept #6	Concept #7	Concept #8	Concept #9	Concept #10	Concept #11
Sketch	Solar ThermiX STX 7000											
Criteria/ weight												
Ease of use/4	0	0	+	-	+	+	-	-	+	--	-	+
Simple design/ 4	0	++	-	0	+	-	-	-	-	0	0	+
Low cost/5	0	+	-	0	0	-	-	0	-	+	--	-
Size/2	0	0	0	-	+	0	0	0	+	-	+	-
Aesthe-tics/2	0	0	+	+	+	+	0	+	+	0	+	+++
Efficient /3	0	0	+	0	+	-	+	+	0	+	+	+++
+	0	13	9	2	15	6	3	5	8	8	7	23
-	0	0	9	7	0	12	13	8	9	10	14	7
Net Score	0	+13	0	-5	+15	-6	-10	-3	-1	-2	-7	+16

11.3 Appendix C: Updated Budget for Second Semester

Item	Cost	Quantity Needed	Size Of Materials	Function	Part Number/Company Producing	Website	Purchased or Donated?
Solar Air Heater	$1,500	1	4 ft. x 8 ft.	Heating Air	STX7000/SolarThermix	SolarThermix.com	Purchased
PCM(Phase Change Material)	$24.00	9	4 in. x 2 ft. x 4 ft. x 8 lbs.	Controlling the temperature	Infinite R/InsolCorp.	SolarThermix.com	Purchased 9 /Donated 1
Travel	$50	N/A	153 miles	Travelling to Competition	N/A	N/A	
Battery	$150.00	1	12 volts./55Ah	Used for powering the coil	UB1250/Universal Battery	Amazon.com	Purchased
Coil	$11.72	2	3 x 7 x 3 inches	Heating PCM	5300622034/Garp	Walmart.com	Returned
Arduino Uno	$19.22	1	9.8 x 6.6 x 2.4 inches	Controller for electrical use	A000073/Arduino	Amazon.com	Purchased
Fan	$19.99	2	120 by 120 by 38 mm	Moving air in from the coil area	PMD1212PMB1-A/Sunon	Amazon.com	Purchased 2/ 2 w/ heater
Thermasheath Rmax	$34.00	2	2 in. by 4 in. by 8 ft	Made into a wall for separation air flow	#416989/Thermasheath	HomeDepot.com	Purchased
Green Rhino Box	$300.00	1	4 ft. x 8 ft.	Durable for nature, contains air from escape	Green Rhino	GreenRhino.com	Purchased
Speedi-Collar Open/Close	$10.30	2	5 in.	Change air flow direction	#1000677624/Speedi-Collar	HomeDepot.com	Purchased
Insulated Flexible Duct	$26.75	1	5 in. x 25 ft.	Channels air flow	#1000683500/Master Flow	HomeDepot.com	Purchased
Master Flow Wye	$11.25	1	4 in. x 4in. x 4in. Wye	Channeling air flow	#232940/Master Flow	HomeDepot.com	Purchased
Solar Panel	$90.00	2	100W at 12 volt system	Used for recharging the battery	GS-Star-100W/GrapeSolar	HomeDepot.com	Donated
Rebar	$4.20	2	3/8 in. x 20 ft.	Rack for PCM	REB/3/615G40/20	HomeDepot.com	Purchased
Total	$2,473.64	Not including tax					
Total Budget Left	$26.36						

11.4 Appendix D: Schedule of Manufacturing Implementation

Dates	Parts of manufacturing accomplished
February 18th, 2018	Inlet and outlet holes on Green Rhino box cut
February 21st, 2018	Built photoresistor and fan circuits separately
February 25th, 2018	Cut Thermasheath and made into thermal box
February 28th,2018	Combined fan and photoresistor circuit
March 4th, 2018	Sealed gaps in thermal box
March 7th, 2018	Tested the fans and photoresistor circuits with battery on box
March 11th, 2018	Cut rebar then added to the thermal box for PCM rack