Red Feather- Team B12

Preliminary Proposal

Randall Holgate

Noah Kincheloe

Jessie Russell

Brittney Rogers

Wesley Garcia

2020

Project Sponsor: Red Feather Development Group

Faculty Advisor: Dr. David Trevas

Sponsor Mentor: Chuck Vallance

Instructor: Dr. David Trevas

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

TABLE OF CONTENTS

[Use your word processor to delete the following Table of Contents and insert a new TOC. Include front matter (except for the cover page), body of the report, and all appendices. The Table should include four levels of headings, e.g., down to 2.2.1.3, as illustrated below. Front matter should be in Roman numerals.]

Contents

1 BACKGROUND

1.1 Introduction

On the Navajo Nation and Hopi Reservation they have been primarily using wood and coal stoves as the main heat source. This creates problems due to the lack of coal, which makes an inconsistent heat source. Another problem is that coal and wood stoves create a poor air quality which can increase the amount of asthma cases. Since it can hurt the lungs of the families living there, it can make it worse if COVID is caught. Another type of heat that is used is propane or natural gas, which can be expensive for long term use. Red Feather Development group has been installing solar furnaces on several homes however those only heat the homes during the day when the sun is shing.

1.2 Project Description

Previous capstone groups have designed solar furnaces that are reliant on the sun to produce heat for daytime use, however this left the problem on how the house would be warmed at night. In order to solve some of these problems Red Feather Development group would like a design for a thermal storage device that can provide heat for the home at night. The device is meant to use solar energy in order to capture extra heat and store it in a medium to then release it at night. The materials for the device should be locally available materials. They should be within the price range set by the Red Feather group and their customers.

2 REQUIREMENTS (Randall/Wesley)

2.1 Customer Requirements (CRs)

Table 1: Customer Needs

Question/prompt	**Customer statement**	**Interpretation/Need**
What is the main problem?	"A solution is still required to keep the home comfortable throughout the night."	Device should provide consistent heat source to keep houses warm at night, storing heat during the day and releasing at night.
What is the scope of the project?	"Current solar furnace is Arctica solar. Run by solar panel that runs the thermostat inside and monitors the temperature. System without electricity. Runs thermostat, fan, takes care of all electrical needs."	Device should store heat during the day and release it at night.
Where do you primarily work on homes in the reservation?	"Predominantly doing Hopi and western side of Navajo, includes major Navajo areas. Tuba City, Cameron, Leupp, Bird Springs. Currently, temperature drops into 40 degrees in the evening, 100 degrees all the way down into the 40's and 30's. June and July is 100-60. Gets colder as progress into fall. In the summer it is 100-50 degrees. In the fall it is 100-40 degrees. In the winter, goes down to 20's."	Device should be suited to functioning in Western Agency Council and Hopi Mesa regions.

How warm does the device need to keep the house?	"The design of thermal storage devices to be used in conjunction with thermal furnace solutions to keep indoor temperatures at or above 50+ deg F are the product deliverables."	Device should maintain comfortable indoor temperature throughout night.
What is the budget?	"Comfortable with $1200/$1500 per unit." [Although this is likely in tandem with Arctica Solar Air Furnace, for $500/unit]	Device should be within purchasing capabilities of Red Feather and the relevant clients.
Are there any readily available resources?	"Could ask Arctic solar if they would consider donating one [of the solar furnaces] to us to look at. Resources available would be donations." [Needs to be easily understood by donators]	Design should be straightforward.
What are our limits to size and dimension?	"If you start drilling holes in the roof, though, you could cause enormous problems. Exterior wall mounted systems work. Even in those systems, avoid a roof-mounted system. Any attempt to mount something on the roof will present a problem."	Device geometry should fit a variety of housing situations (no roof cave-ins).
What are the limits to the available materials?	"Device should be constructed with locally available materials"	Materials should be readily available in the region.
Will the device be reliable?	The device needs to consistently work for people in homes without maintenance.	Design a reliable design.
Will the device remain intact if dropped or damaged?	The device needs to withstand normal, everyday conditions, including different applications of force and different ranges of weather.	Create a durable and robust design.

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

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

2.2 Engineering Requirements (ERs)

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

$$Q = mc_p\Delta T \quad (1)$$

In which Q is the Heat Energy in BTUs, m is the mass of the medium fluid, in pounds, is the specific heat in BTU/°F/lb, and is the change in temperature, in Fahrenheit. If is negative, heat is lost, and if is positive, heat is gained. The target ER is 7,000 BTU/h.

Other engineering requirements include that the budget be within $1,500, which is the target ER, for the device alone. This comes from a desire for the device to be affordable and reliable for the Navajo and Hopi reservations. To create a straightforward design which is not too complex, the team required the device to have a limited amount of parts. For this purpose, the fewer the parts required indicates a better mechanical design. Due to the need for a device that adapts and functions on a variety of styles of homes, the team requires the device to meet certain device dimensions and weight, so that it is not unavailable to certain types of homes. The target ER is for the device to be within 100 ft^2 and less than 500 lbs.

Because resources are difficult to deliver to the customers' locations, and to address the customer need of using readily available materials, the team uses time as a metric for how justifiable it would be to use different resources for our device. Specifically, how long does it take for a particular material to be delivered to the location? Later the team will also look at how often a resource is needed for the device, thus determining how often this delivery time will occur as a barrier to the customer. The target ER is 2 hours maximum delivery time.

Another important engineering requirement is for the device to be durable and robust, withstanding forces that may commonly occur, as well as experiencing different weather conditions. This is tested by applying different amounts of force, such as dropping the device and being hit by another object. For weather conditions, volume of water on the device measures the amount of rain or snow it can withstand. Ideally, the design creates a protective barrier of some sort to keep water and snow out and away from the thermal storage components. The target ER for force withstood is 1,600 lb-f.

Table 2: Engineering Requirements

Engineering Requirement	Derived from this Customer Need	Method of measurement	Unit of Measurement	Target ER
Device outputs a consistent amount of heat to the house at night. Device maintains	Device should maintain comfortable indoor temperature throughout night	Thermometer or Temperature Sensor for temperature of air	Fahrenheit	60F

consistent house air temperature (60deg F)				
Device works in environments with outside temperatures ranging from 20 degrees to 60 degrees Fahrenheit.	Device should provide consistent heat source to keep houses warm at night, functioning within standard season range of Navajo Nation and Hopi Reservation temperatures.	Thermometer or Temperature sensor	Fahrenheit	20-60F
Device stores heat in an effective method.	Device should provide consistent heat source to keep houses warm at night AND device should store heat during the day and release it at night.	Heat equation, using mass, material qualities such as the specific heat of the medium fluid, and a measured change in temperature	BTU/h	7,000 BTU/h
Device budget is within $1,500	Device should be within purchasing capabilities of Red Feather and the relevant clients.	Pricing	Dollars	<$1,500
Device has limited number of major components	Design should be straightforward.	Counting	Unitless	<8
Device able to install onto a variety of homes.	Device geometry should fit a variety of housing situations (no roof cave-ins)	Device dimensions and weight	Feet, Lbs.	100ft^2 <500 lbs.
Materials should have minimal delivery (transit) time	Materials should be readily available in the region	Transit time of materials	Hours, Days	2 hours
Device should work without interruption or maintenance.	Design a reliable design.	Amount of time device works without stopping	Hours, Days	300 days
Device should be able to withstand common displays of force without breaking as well as weather conditions.	Create a durable and robust design.	Amount of force device can withstand.	Lbf	1600 lbf

2.3 House of Quality (HoQ)

The House of Quality presented all the customer needs and weighed them alongside corresponding engineering requirements to find which engineering requirements weigh most heavily in the concept selection stage. A figure of the House of Quality can be seen below in **Figure 1**. The results were that the most weighted engineering requirement is the heat transfer rate of the device with an Absolute Technical Importance (ATI) of 186, and a Relative Technical Importance (RTI) of 0.1862. The second most weighted engineering requirement was the device cost, with an ATI of 148 and an RTI of 0.1481. Following these, the next most weighted engineering requirements were, in order, the outdoor temperature range, indoor air temperature, cycles without failure, number of parts, dimensions and weight, force withstood, and finally, max material delivery time as the least weighted engineering requirement.

House of Quality (HoQ)												
Customer Needs	**Customer Weights**	**Engineering Requirement**	indoor air temp. (°F)	heat transfer rate (BTU/h)	Device cost ($)	Number of parts (unitless)	Dimensions (ft^2)	Weight (lb)	Max material delivery time (hrs)	Outdoor temp. range (°F)	Force withstood (lbf)	Cycles without failure (Days)
1. Consistent heat source at night	5		3	9	3		1	1		3		9
2. Store heat during day	5		3	9	3		1	1		9		1
3. Maintain comfortable indoor temperature throughout night	5		9	9	3		1	1		3		1
4. Device should be within purchasing capabilities of Red Feather and the relevant clients	5		0	0	9	6	3	3	3		1	1
5. Design should be straightforward.	3		0	0	3	9	1	1			1	1
6. Functions within standard season range of Navajo Nation and Hopi Reservation temperatures.	4		3	6	3					9	3	
7. Device geometry should fit a variety of housing situations	4		0	0	1	6	9	9			1	
8. The device should be efficent as possible.	3		6	9	3	1	1	1		3		6
9. The device should be durable	4		0	0	3	1	1	1			9	6
10. Materials should be readily available in the region	2		0	0	6	1			9			
Absolute Technical Importance (ATI)			105.00	186	148	90	76	76	33	120	60	105
Relative Technical Importance (RTI)			0.10511	0.1862	0.1481	0.09	0.08	0.08	0.03	0.1201	0.06	0.11
Target ER values			60	7,000	1200	<8	100	<500	2	20-60	1600	300
Tolerances of Ers			(+-) 10		(+) 200							

Figure 1: The Device's House of Quality (HOQ)

3 Functional Decomposition

As a functional decomposition, the team created a black box model to show a basic concept of what the device should be doing. Furthermore, the team created a Functional Model to show the broken-down components at each step of the process in our system.

3.1 Black Box Model

The Black Box Model shows sunlight and water as physical inputs. Sunlight comes in naturally to the solar panel without a physical interaction. Water remains available in a closed loop system where the water is recycled after first being heated to transfer heat to the air and then cooled down and recycled. There is a signal input in the form of temperature data from the Arduino. The function of our system is to store thermal energy throughout the day to dispense during the night. The physical output of the system is heat in the form of warm air to be provided to the home. The signal output is temperature data from the Arduino. The Black Box Model can be seen below in **Figure 2**.

Black Box Model

Figure 2: Black Box Model

3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis (Jessie Russell)

The system has two solar panels. The one at the top of the functional model converts thermal energy from the sunlight to electricity which is stored to be able to constantly monitor temperature of the water being stored, the water after being heated, and it also monitors the temperature of the air going into the house and the temperature inside the house. This electricity also powers the pump(s) and fan. The solar panel on the bottom heats the water with thermal energy. The middle of the functional model shows how the water is stored, pumped to a heat exchanger, and is then heated and pumped into another heat exchanger. This heat exchanger takes the heat transfer from the hot water to heat air and cool down the water. This hot air is then blown into the house. The remaining cold water from this process is pumped back into the storage tank. The functional model can be seen below in ***Figure 3***.

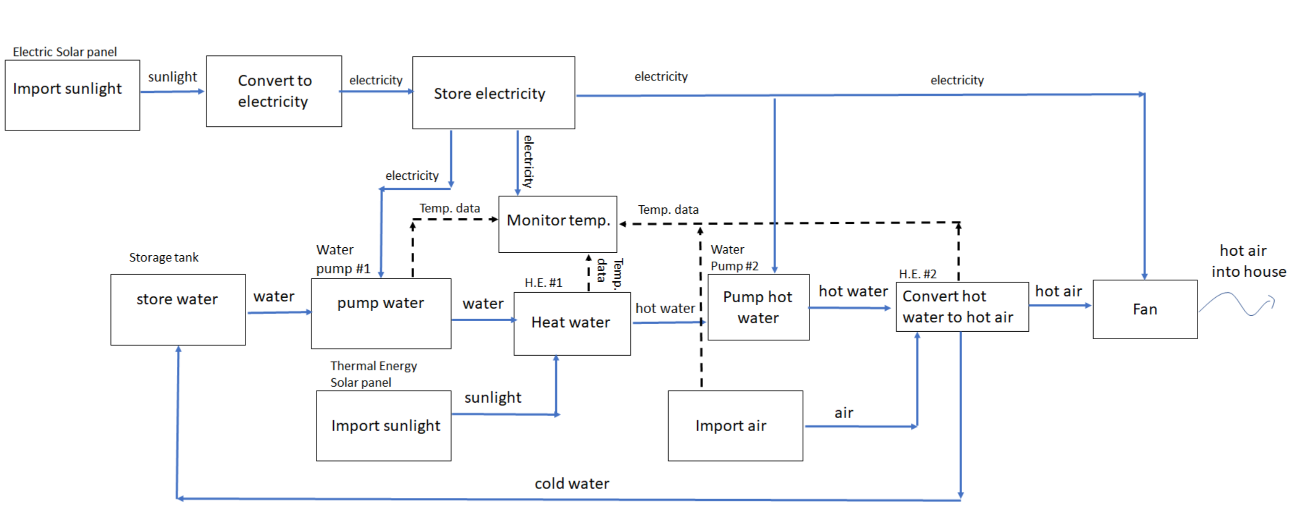


Figure 3: Preliminary Functional Model

4 DESIGN SPACE RESEARCH

4.1 Literature Review

In order to create a successful design capable of fulfilling the given criteria, it was first necessary for the team to do background research on a variety of topics related to the project. Their findings are detailed below.

4.1.1 Team Member 1 (Wesley Garcia)

4.1.1.1 Aqueous Lithium–Iodine Solar Flow Battery for the Simultaneous Conversion and Storage of Solar Energy [1]

In this paper a team investigated the positive implications of developing a new kind of lithium battery for storing solar energy. This battery is referred to as an aqueous lithium-iodine solar flow battery. From preliminary testing the team found that the device was able to save approximately 20 percent more energy than a standard lithium battery. Along with this being an interesting evolution of the standard lithium iodine batter it also is stated to have the potential to be a design bases for other systems like it.

4.1.1.2 Improved hydrometallurgical extraction of valuable metals from spent lithium-ion batteries via a closed-loop process [2]

This study examined the development of a closed loop process of harvesting the useful metals from lithium batteries that have reached the end of their usefulness. This understanding can be useful in the ways that it improves are devices ability to be less wasteful. The process itself includes several sub processes that first reduces the components into its metal components. Then the lithium is extracted followed by the other metals that compose the device. During this process the authors showed that an extraction yield of up around 95% can be accomplished.

4.1.1.3 A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island [3]

This journal explored the possibility of creating an almost entirely self-sustaining home on an island. For such a system a deep cycle battery was used. Through this section of the journal the authors discuss all the specifications going into the device. Though it has impressive capabilities such a battery would be much too expensive for small scale budgeted ventures. However, the paper outlines many of the calculations one might make when considering a similar kind of battery used for solar storage.

4.1.1.4 Solar-rechargeable battery based on photoelectrochemical water oxidation: Solar water battery [4]

In this article the authors took the time to propose a new kind of solar energy storage device. The authors refer to this new device as a “solar water battery”. This is due to the attributes that the device stores the energy produced by solar device and stores it by using it to cause a reaction that causes the water in the device to oxidize. This process is meant to allow for the energy to be both converted and stored in a useful form. Though a deviation from the well-established hydrogen-based batteries of similar type these batteries would require less processes to occur and possibly retain energy more easily than its counterpart.

3.1.1.5 Highly Efficient Perovskite Solar Cell Photocharging of Lithium Ion Battery Using DC–DC Booster [5]

In this article the author is discussing the uses of using solar cells to charge Lithium batteries. The processes the author is encouraging the use of is a DC-DC voltage booster. This booster being an optimal way to charge a lithium battery with a solar cell. Along with this the article discusses the high efficiencies in storage and energy use based around using this converter in order to charge the battery. It also states that this approach would be viable for devices ranging from cars to basic sensors.

3.1.2 Team Member 2 (Randall Holgate)

3.1.2.1 Thermal Performance escalation of cross flow heat exchanger using in line elliptical tubes [6]

This team analyzed heat transfer and friction characteristics of in-line elliptical tubes are studied experimentally and numerically to increase the thermal performance. The elliptical tubes with an aspect ratio of 0.35 and 0.50 and with circular tubes of the aspect ratio of 1 are selected for Reynolds number ranging from 5000 to 21000. The results indicate that the elliptical tube showed higher heat transfer rate with a reduction in the friction factor for the range of Reynolds number values. The performance of the elliptical tube is often due to the aerodynamic cross-sectional profile of the tubes which promotes better heat transfer and with a reduction in the frontal area of the tubes. The study is performed for the two different pitch to major axis ratios of 1.25 and 1.5. The results show that at a pitch ratio of 1.25 and an aspect ratio of 0.50 increases heat transfer rate, while a pitch ratio of 1.50 and an aspect ratio of 0.35 showed better thermo-hydraulic efficiency relative to 0.50.

3.1.2.2 Shell and tube Heat Exchanger [7]

A shell and tube heat exchanger work between two fluids that are in tubes, which then are in thermal contact to transfer heat. An image of this is shown in **Figure** 4**: Shell and Tube Heat ExchangerFigure** 4.

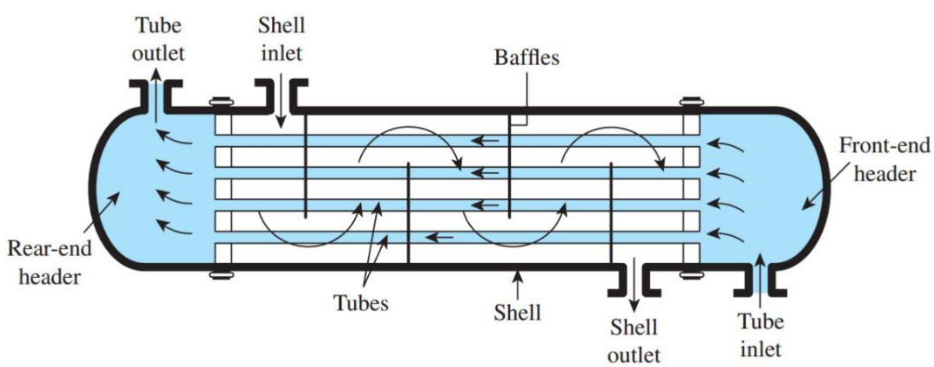


Figure *4***: Shell and Tube Heat Exchanger** *[7]*

As seen in the schematic the tubes will be either hot or cold fluid and the heat will pass between the two and they will stay in the separate tubes so that the fluids won't mix. There are two inlets and two outlets shown in the schematic. This is so the fluids will never mix, because they enter and exit at different places. The baffles shown are barriers which can cause turbulence in the flow. The three main types of shell and tube heat exchanger are the u-tube heat exchanger, the fixed tube sheet exchanger and the floating head exchanger [7].

3.1.2.3 Functionality of a Plate Heat Exchanger [8]

In a plate heat exchanger, the plates are gasketed and set up so that the two mediums that go into the heat exchanger do not mix with each other. The plates are designed so that they create turbulence in the medium fluids as they flow through the plates to create a heat transfer coefficient. Greater turbulence creates greater heat transfer. Temperature difference creates heat for the colder medium. The plates can be designed differently in shape to offer different functionality. A schematic of a plate heat exchanger can be seen below in **Figure 5** [8].

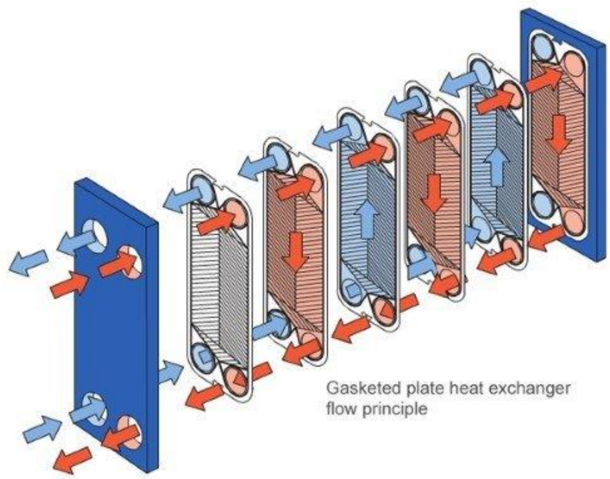


Figure 5: Gasketed plate heat exchanger *[8]*

3.1.2.4 Modeling and Simulation of a Solar Thermal System for Domestic Space Heating Using Radiators Low Temperature [9]

The major point of this article was to compare the effectiveness of a radiators ability to heat a home when set at a lower temperature and powered by solar panels. This article found that when compared to a normal radiator system found in a home, this system accomplished the goal of keeping a warm home juts as well as the traditional system. Along with this they found that the actual effort of using the separate system integrated easily with a hot water radiator. This shows that using a hot water radiator backed by a thermal storage tank and solar panels can be just as effective as a standard system.

3.1.2.5 Design Features and Benefits of a Spiral Heat Exchanger [9]

Spiral heat exchangers consistent of two long metal plates, rolled together around a central axis to create concentric spiral flow paths for the two fluids. Their shape and exact dimensions can be optimized for specific heat transfer fluids and applications. There are certain advantages to this design: first, spiral heat exchangers are highly efficient. Next, they are often self-cleaning, as the shape of the passages induce shear that removes deposits. Finally, they are relatively small and accessible, making maintenance and installation easier [9].

3.1.3 Team Member 3 (Noah Kincheloe)

This literature review was done with the purpose of reviewing the major findings of previous Red Feather projects, which have all been focused on some form of heat generation on the Navajo Nation. To do this, previous team's reports were reviewed, as well as a variety of relevant sources included within in order to gain an idea of what ground previous teams had covered.

3.1.3.1 Red Feather 2019 Final Report [10]

The first item examined, therefore, was the 2019 Red Feather Team's final report. While this contained a wealth of useful information, this literature review focused on concept selection, and which designs were and were not determined to be viable by the 2019 team. From this, there were several key takeaways. First, the 2019 team decided that solar furnaces were not feasible, due to their budget constraints. This was quite important because it helped narrow the range of available heat sources. Another important detail of this section is the information that the team concluded that Phase Change Materials, or PCMs, were too costly to be a viable thermal storage medium. The final key takeaway from this report was that in the end, the team decided to abandon the creation of a thermal storage and heating device; instead, they determined that the most cost-effective solution to the problem was to update and improve the insulation in the affected homes, while still using combustion-powered furnaces for heat [10].

3.1.3.2: Navajo Nation EPA Air Quality Control Program Indoor Air Quality [11]

Once the prior Red Feather team's conclusions had been established, the logical next step was to examine the combustion furnace that would be used in tandem with their improved insulation. The source for this information was "NNEPA Air Quality Control Program Indoor Air Quality," a presentation created by the Navajo Nation EPA, which described the air quality issues currently found in many Navajo homes using outdated, home-made, or otherwise inefficient combustion furnaces. The presentation detailed the extent of these issues, in addition to ways to address these contamination problems. It also described the stove change-out project, an ongoing initiative by the NNEPA to replace unsafe home furnaces with safer, more efficient models. This is useful because it properly highlights the problem at hand, in addition to providing some idea of the solutions other organizations are implementing [11].

3.1.3.3 Navajo Nation EPA Implementing a Tribal Indoor Air Quality Program [12]

Following up on this research, it was decided to further investigate the exact specifications of the updated furnace, detailed in the presentation "NNEPA Implementing a Tribal Indoor Air Quality Program". Since it was the primary heat source of the 2019 Red Feather team, researching this allowed for useful insight into the minimum amount of heat required for the home. Additionally, it encouraged the team to consider an additional potential heat source, as the furnace could be used to create the thermal energy stored in the battery. The presentation detailed a variety of heat transfer and dimensional specifications (included in the Benchmarking section), which will be incredibly useful when it comes to creating a design capable of heating as many houses as possible [12].

3.1.3.4 Active Solar Heating [13]

The next article examined in this literature review was one of those used to determine the financial unviability of solar furnaces by the Red Feather 2019 team. It is "Active Solar Heating," an article created by the US Department of Energy. There is a great deal of useful information contained within, but the most relevant section relates to cost. It states that active solar furnace systems are "most cost-effective in cold climates with good solar resources when they are displacing the more expensive heating fuels, such as electricity, propane, and oil" [13]. While this system will exist in a cold location with good solar resources, it would not be replacing a more expensive heating fuel- instead, coal and wood are extremely cheap, contributing to their widespread use [10]. Since the existing heating method was more cost-effective, the 2019 Team's decision to keep the solar furnace is logical.

3.1.3.5 Red Feather Spring 2020 Concept Generation and Selection [14]

The final item examined as part of this literature review is the Spring 2020 Red Feather capstone group's Concept Generation and Selection presentation. Though this team has not yet completed their project, the work they are doing is quite similar to that detailed in this preliminary report, and as such it was useful to examine their selected design for comparison purposes. This revealed that the Spring 2020 team's preliminary design (as created during their concept selection phase) involved heating water in a self-designed solar thermal panel, made from plastic tubing with corrugated metal fins. Their design also included a thermal storage device, some concepts for which shared similarities with those created by this team. It also detailed combinations of these, and the final top designs [14]. This was useful as it demonstrated where other teams were in their design process when creating concepts, and it also provided clear indication of how viable it would be to integrate this team's design with that of the prior Red Feather capstone group.

3.1.4 Team Member 4 (Brittney Rogers)

3.1.4.1 A Review on Thermal Energy Storage Unit for Solar Thermal Power Plant Application [15]

The first article looked at was "A Review on Thermal Energy Storage Unit for Solar Thermal Power Plant Application," which discussed how the downside of solar energy production would be counteracted. This specific application of a solar thermal heat storage system uses a phase change material in order to be able to store and use thermal energy all day, but it also discusses non phase change materials. It discusses the use for a power plant in order to store the thermal energy. This design talked about how batteries would be used to store electrical energy [15]. Figure 6 shows all the selections that go into having a heat storage system.

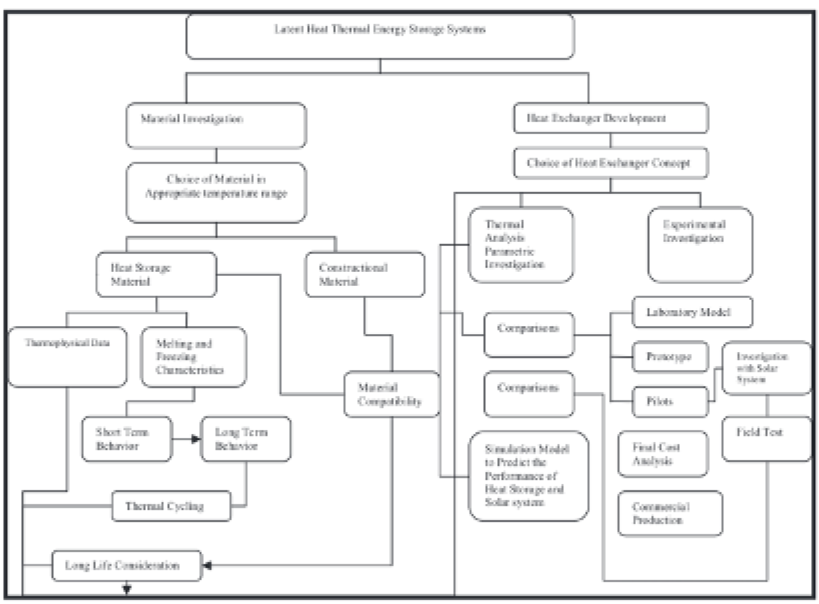


Figure 6: Choices for thermal heat storage *[15]*

This article mainly discusses how a system is designed in order to have a consistent energy storage system, which shows the growing use of this type of system.

3.1.4.2 Review of Solar Heating Furnace Development [16]

Then the article, "Review of Solar Heating Furnace Development" was looked at because it discussed current systems like the team's project being used. However, this design is for industry use so the system, reaches a much higher temperature then necessary for a residential design. This system utilizes concave mirrors in order to concentrate the solar rays. Then the focal point is then heated to a high temperature in order to heat the air for solar towers step. This type of system has been tested in a few places in Europe, they are very large systems but are effective at heating the air or thermal storage systems. The article discusses how solar heating furnace technology has existed for many years; however, the technology still needs to be perfected to be used on a widespread basis. This article mostly focused on commercial large systems, but it is still helpful to see how other solar furnaces and thermal storage systems are used [16].

3.1.4.3 Seasonal Solar Thermal Energy Storage [17]

The next article is, "Seasonal Solar Thermal Energy Storage" discusses the use of solar energy to be thermally stored for heating or cooling. It discusses the first uses of solar water heater in 1891. It states that it is believed that thermal storage will be preferred over batteries because of the large loads it could support and that it is generally a cheaper solution. One of the systems discussed is pictured in **Figure** 7, it's a solar system that heats a water tank and when the water has enough heat, then it releases excess through the sand-bed usually under the garage floor through radiation [17].

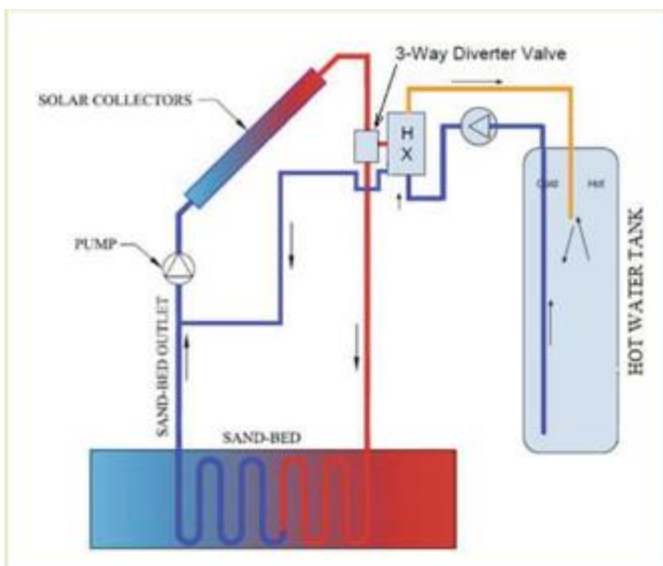


Figure *7*: **Sand-Bed Thermal Heat Storage** *[17]*

This is a good example because it heats the home in many ways. The next example is one that is commonly used already in **Figure** 8.

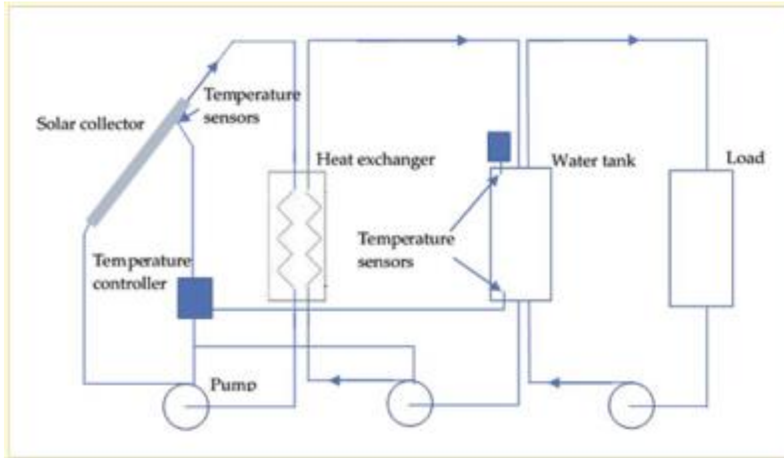


Figure 8: Commonly Used Water Thermal Storage System *[17]*

Figure 8 shows a system that uses a solar thermal collector to heat the water in the tank to supply enough heat for the load [17]. It utilizes heat exchangers and pumps in order to do this which is like the team's design.

3.1.4.4 Everything You Wanted to Know About Solar Water Heating Systems [18]

The article "Everything You Wanted to Know About Solar Water Heating Systems" was looked at next since it talks about a lot of specifics when designing a solar water heating system. This discusses a system design that uses solar power to heat the water, which is then pumped in order to be used in the home. It discusses how the size of the tank is chosen based on the household needs and the collector are needs to be at least 20 sq feet for two people. It states that a tank storage of 50 to 60 gallons will be sufficient for 1-3 people. However, this talks more about a system providing hot water the team is choosing a similar design to heat the hot water which will need an additional step of releasing hot air. This is another good example of a system that represents the heating method [18].

3.1.4.5 Solar Thermal & Solar Thermal Storage Tanks [19]

The next article is, "Solar Thermal & Solar Thermal Storage Tanks" which discusses all the uses and benefits to solar thermal storage. It discusses three different useful space heating designs. The first design talked about is radiant floor systems. The benefit to this type of domestic heating is that the tank only needs to reach 95 degrees Fahrenheit which means that less solar generation is necessary. However, this design requires the floors to be ripped out which increases installation costs greatly. The next design discussed is forced air systems. This needs a water to air heat exchanged and then some form of fan to release the air. This tank size generally needs to be 120 degrees Fahrenheit. The last design is using a hydronic baseboard. This usually generates 225 Btu per foot when the water is 120 degrees Fahrenheit [19]. This article was helpful, because it discusses uses that this company sells in order to produce heat with their water tanks. It talks about a closed system like the team's design.

3.1.5 Team Member 5 (Jessie Russell)

3.1.5.1 Use of a Closed Feed Air Heater to Dry Wood [20]

To find an alternative to highly polluting heaters, Ahmed Khouya researched a water and air heating solution. This solution involved a concentrated photovoltaic thermal system (CPV/T), which powers a water-air heating pump, and it also has a constant temperature monitoring system to turn the pump off when desired temperatures are reached. The CPV/T system's mirror size is 100 m^2 with a concentration factor of 100. Water is heated from a water storage tank to go through a heat exchanger to transmit heat from the hot water to the air. Air comes out of a heater with some lost energy in evaporation, so the system recovers some of the lost heat. The heated air heats refrigerant through an evaporator and into a compressor to improve the coefficient of performance in a following compressor. The final step involves a second water-air heat exchanger which transmits heat onto wood to dry it. The schematic for this system can be found in **Appendix A.**

3.1.5.2 Proposed Dish-Stirling Solar Concentrator and Thermal Energy System [21]

A team proposed an alternative solar thermal energy system using a Dish-Stirling unit with water-to-water to supply energy to a building in the engineering department in Palermo, Italy. The results showed that the system provided 97% of the building's annual thermal loads and 64% of the electrical energy needed. The Dish-Stirling unit collects thermal energy, having an output power of 30 kWe, and is used with a Borehole Thermal Energy Storage (BTES) system. Water is held in a buffer tank, where cold and hot water are circulated. Water goes through two heat pumps, heating from 8-20℃ and then to 45° before going through a heat exchanger, then through a backup heater, and then into the building. Leftover heat is circulated back through the heat exchanger and into the closed system. The schematic for this system can be seen in **Appendix B**.

3.1.5.3 Analyzing Different Types of Solar Water Heating Systems and Costly Savings [22]

Four-person households in Phoenix, Arizona are expected to save 80% in energy using a SunEarth® solar system. There are direct and indirect circulation types for this water heater solar system with actively cycled or passively cycled water, both with a collector to capture solar energy from sunlight. The active systems pump water through the system while the inactive, or passive, systems move water through natural convection, from collector to storage tank as the collector heats up. Direct systems force water through the system pipes to heat up through the collector and then into a storage tank or into the house. This makes direct systems less practical for cold climates where the water may freeze. The indirect system cycles a non-freezing heat transfer fluid, usually a mix of this fluid and water, through the collector to heat up before passing through a heat exchanger to transfer the heat from the fluid to water. A schematic of this can be seen below in **Figure 9**.

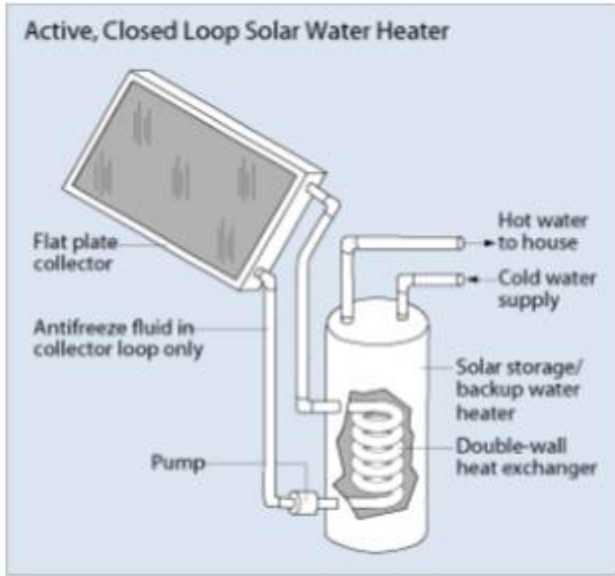


Figure 9: Indirect System with Active Circulation *[22]*

3.1.5.4 Use of a Closed Loop Thermosyphon in Thermal Storage [23]

Thermosyphons make systems more cost effective, because they eliminate the need for a water pump as temperature change causes buoyancy that will circulate the fluid. Such a system has a storage volume for the heat transfer fluid, a heat exchanger or heating component, and a flow restrictive component, which is a thermosyphon in this case. Heat in warmer fluid, with the assistance of gravity, causes pressure to push the fluid through the heating part until enough energy from the heat has accumulated to stop the flow. A schematic of a thermosyphon can be seen below in **Figure 10.**

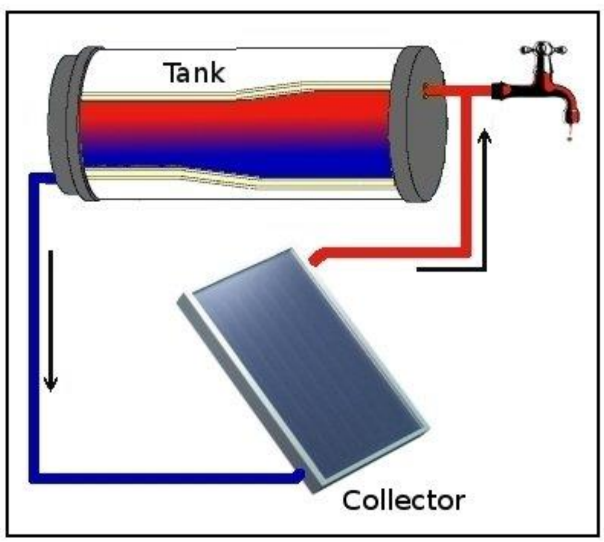


Figure 10: Thermosyphon and Solar Collector System *[24]*

3.1.5.5 "Experimental Study on a Forced-Circulation Loop Thermosiphon Solar Water Heating System [25]"

Tao Zhang analyzed wickless gravity loop thermosiphons (LTs), which proved to be a useful component for long-distance heat transfer in solar water heaters. Instead of using gravity, there is forced circulated with a pump to push fluid through the system. This is less cost-effective but has better thermal performance.

4.2 State of the Art – Benchmarking

To assess the viability of the design, it will be useful to compare it to existing technology intended to fulfill the same purpose. To this end, the team examined a variety of competing, system-level designs intended to fulfill the same purpose as the one being created by the team, as well as a set of competing subsystem-level designs.

4.2.1 System Level State of the Art – Benchmarking

Three different system-level designs were examined for the purpose of benchmarking. They were chosen based on relevance- all designs are either current or proposed solutions to heating homes on the Navajo Nation and Hopi Reservation. They include the current, outdated wood stoves, more modern hybrid stoves, and the solar air heater currently being used by the Red Feather Development Group.

4.2.1.1 Current Heating Device: Wood Stove

This benchmark reflects the current, most-common form of heating in the given area. While the exact model of stoves varies, in general many of those in use on the Navajo Nation are inefficient, with poor ventilation and sealing of the stove exhaust. In many cases, stoves designed for use with wood are used with coal instead, further contributing to inefficiency. Furthermore, the poor ventilation and exhaust problems can have significant consequences for the indoor air quality of the home, with carcinogenic particulate leading to increased breathing problems and other health issues. This is a particular issue with home-made stoves, such as the example shown below (**Figure *11***). For these reasons, these stoves have been targeted as part of the Navajo Stove Change-Out project, which is intended to provide higher quality heating devices as detailed below [11]. In general, this design is highly inefficient and rather dangerous. While the exact heat output of these varies, health effects remain the primary concern, so creating a healthier heating method will be a key goal of the team.

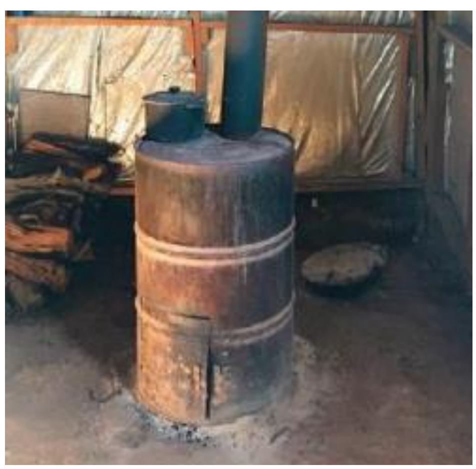


Figure 11: Home-made Barrel Stove from Lupton, AZ

4.2.1.2 Updated Stove: Wood/Coal Hybrid from Change Out Project

This benchmark is intended to reflect more modern, health and environment-conscious forms of the stoves detailed above. While still combustion driven, these stoves are designed to provide a healthy and cheap way for members of the Navajo Nation to heat their homes, and are being installed as part of an indoor air quality program created by the Navajo Nation Environmental Protection Agency (NNEPA) in order to counter the health and environmental effects caused by the deficient stoves described above. These are hybrid, and as such are specially designed to use coal or wood to heat buildings up to 1000 sq ft in size. When burning wood, they have a minimum output of 15,000 BTU/hr, and a maximum of roughly 27,000 BTU/hr. Conversely, when burning coal, they are capable of outputting roughly 7,000 BTU/hr at minimum, and 10,000 BTU/hr at maximum [12]. It also weighs roughly 280 lbs, with an adjustable height of 28" – 34" and a footprint of 17" x 24". They also come in a variety of colors, with design intended to fit a "Navajo Aesthetic" [11]. In general, this device will likely provide a valuable standard for the team's design to meet, due to its high heat output in a relatively compact package. Of note is the minimum heat output value, which will provide the team with a useful basis for the necessary minimum heat output by their device.

Figure 12: Change-Out Project Stove [12]

4.2.1.3 Arctica Solar Air Heater: Current Daytime Heater for Navajo Communities

Currently, the Red Feather Development Group has implemented many installations of the company Arctica Solar's solar air heater which provides significant heating during the day. The heater uses a solar heating panel made of solar-absorptive materials on the side of the house. It generates its own electricity to circulate the hot air into the house, and it has a thermostat [26]. It weighs 50 lbs., is 74.013" total in height, and 38.279" in width. It heats 150 ft^2 rooms, heating incoming air to be 75°F higher than as it comes in [27]. The Red Feather Development Group reported the homes being heated to 80°F. This solar air heater can be seen below in **Figure 13.**

Figure 13: Arctica Solar Assembled 1500 Series Solar Air Heater

4.2.2 Subsystem Level State of the Art Benchmarking

4.2.2.1 Subsystem #1: Heat Exchangers

4.2.2.1.1 Existing Design #1: 12x24 Water to Air Crossflow Heat Exchanger [28]

This heat exchanger is made of 1" copper ports. It provides 115,200 BTUs, has a fin area of 12"x24". The tubing is ¼" copper. The heat exchanger is hooked up to a boiler or a chilled water source to provide water as the second medium fluid to heat the air.

4.2.2.1.2 Existing Design #2: Shell and Tube Heat Exchanger [29].

This type of heat exchanger is are small and compact. They are easily built and effective heat exchangers. The three main types of shell and tube heat exchanger are the u-tube heat exchanger, the fixed tube sheet exchanger and the floating head exchanger. The floating head exchanger is the most expensive type, but it has the best efficiency and maintenance. The u-tube exchanger is good for when there are high temperature differences, because it allows for room to expand and contract, however the curves are hard to clean. The fixed tube sheet exchanger is the easiest to build and the cheapest, but the temperature difference has to be small, due to no expansion room.

4.2.2.1.3 Existing Design #3: Cast Iron Radiator, 18 Sections, 19"H, 4 Tubes [29]

These kinds of radiators tend to be fairly reliable and capable of spreading heat throughout a room. For our design, a system similar to this could be useful in taking the warmth from our water and heating up space. Being a comfortable 19 by 31 inches the device is large enough to heat a decent sized area while not being too cumbersome. It also provides a simple system for heating that doesn't require many complexities.

4.2.2.2 Subsystem #2: Water Tanks

4.2.2.2.1 Existing Design #1: 40 Gallon Tamco® Vertical Natural PE Tank with 8" Lid & 3/4" Fitting - 19" Dia. x 41" High [29]

The first design I explored is an actual water heater tank. This design is useful to include as it is reasonably priced and something that most people are familiar with. ITs also useful to understand the components that make up the tank along with the purposeful insulation that uses a foam type substance of ¾ inches thick. Along with this a tank of this make is already intended to be attached to a full system leading to a design that may be more easily integrated into our system. With all of this in mind the device itself is not designed for the purpose of being a thermal storage device. This means it would have the tradeoff of being a need to rework the tank to better fit the design goals.

4.2.2.2.2 Existing Design #2: Hydroflex Flexible Thermal Storage Tank – T100 [30]

Unlike the tank above this water storage tank is specifically designed to store hot water for later use. It uses a similar insulation method with an inner and outer shell-based design that includes a foam-based insulation between the shells. The tank itself does appear to be less structurally stable being stated as being able to be compressed more easily. It is also stated to be able to hold 100 gallons which is a useful amount given the scope of what our team is trying to accomplish.

4.2.2.2.3 Existing Design #3: DN Tanks [31]

The DN Tanks largest advantage is that they have been produced by the same company for over 30 years. This suggests a large amount of reliability and trust that can be placed in their tanks design. Like the example above these tanks have been made specifically for the task of storing thermal energy in the form of water. Made pf concert these designs are highly durable and lily able to work in most areas. Unfortunately, their design mostly benefits large scale thermal storage situations and may not be viable for individual homes.

4.2.2.3 Subsystem #3: Solar PV systems

4.2.2.3.1 Existing Design #1: SunPower

The first solar PV system that was looked at was the Sunpower solar panel. The solar panel has a good efficiency compared to competitors at 22.8% [32]. Compared to the other two manufactures this is the highest panel efficiency. This panel has a temperature coefficient of –0.29, which compared to LG it rates higher, but it rates lower compared to Panasonic [32]. For the materials warranty it is 25 years which is the same as the other two manufacturers [32]. However, this is much longer from the industry standard of 10 years.

4.2.2.3.2 Existing Design #2: LG

The next solar PV system design looked at was from the manufacturer LG monocrystalline solar cells design. This design had a panel efficiency of 22%, which is slightly smaller than the Sunpower system [32]. However, this efficiency is much greater than that of Panasonic. Then for the panel's temperature coefficient it is –0.30 which is the worst for the three solar panel manufacturers [32]. For the materials warranty it was the same as the other two designs at 25 years which is greater than the industry standard of 10 years [32].

4.2.2.3.3 Existing Design #3: Panasonic

The last solar PV design to be analyzed is the system from Panasonic. The design is made with monocrystalline solar cells, which is utilized by the best competitors. This system scored the worst out of the three for panel efficiently at 20.3% efficiency [32]. However, this panel has the best temperature coefficient out of the competitors at –0.26, which is greatly better than the other two systems [32]. It has the same materials warranty of 25 years as the other two designs [32].

5 CONCEPT GENERATION

5.1 Full System Concepts

5.1.1 Full System Design #1: Sand Box

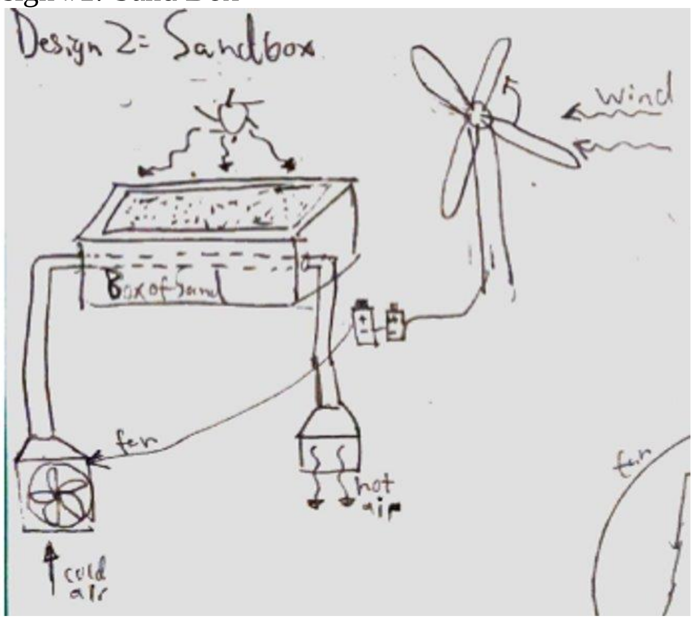


Figure 15: Sand Box

The main focus of this design was to explore the viability of using sand. The design used sand in order to store all of the thermal energy given off by the sun during the day. This design used a small number of parts and mostly relied on sand and a simple heat exchanger to convert the hot water to hot air. Though the design was simple it still scored fairly low. The low success rate of sand as a thermal medium along with using more challenging parts like a wind turbine led to the device scoring low overall.

5.1.2 Full System Design #2: Lifted Tank

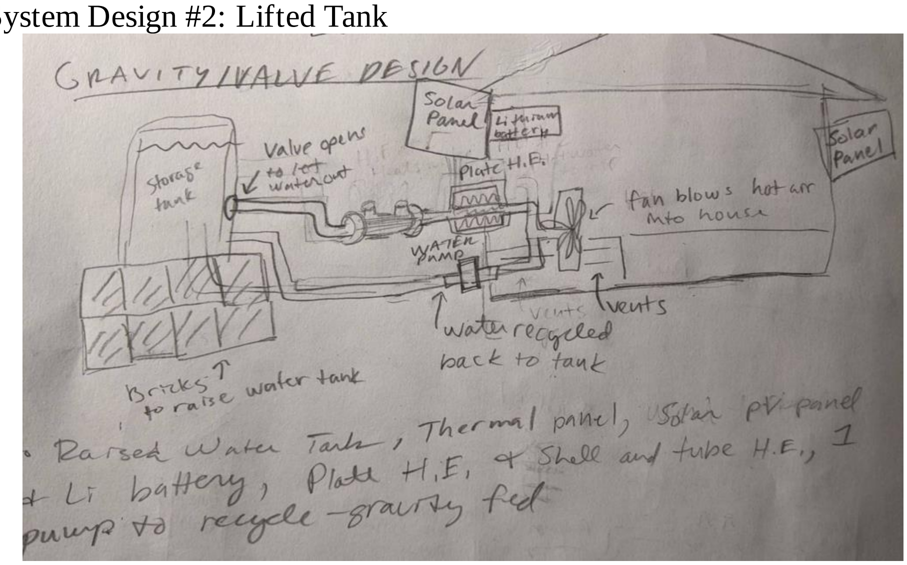


Figure 17: Lifted Tank

This was one of the more complex designs with several pumps, heat exchangers, and multiple forms of energy production. Though its complexity made it less practical it did allow it to do a thorough job of heating the home. Along with this by being buried it was able to reduce heat loss to its environment allowing it to be more efficient with the heat it collected.

5.1.3 Full System Design #3: Resistive Network

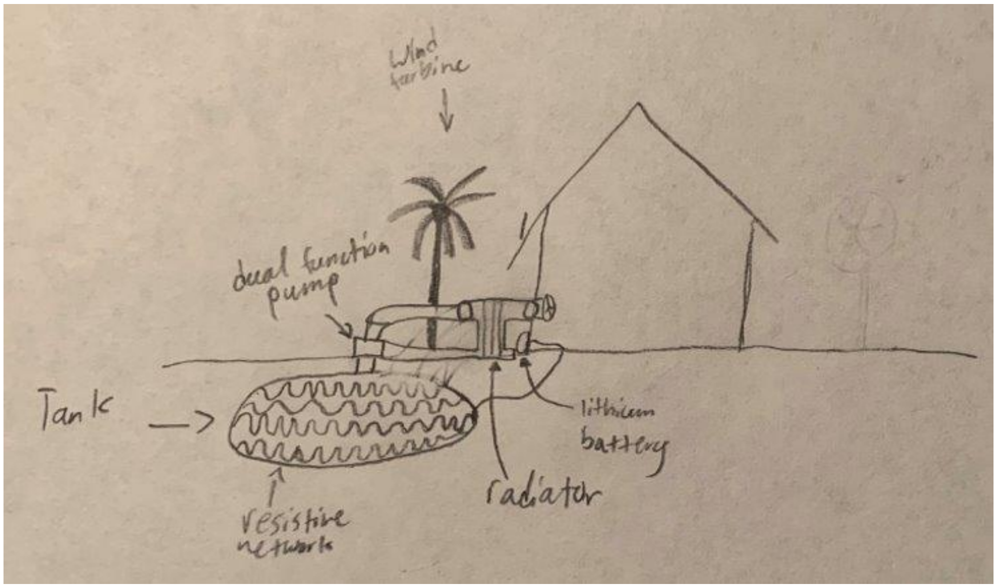


Figure 18: Resistive Network

This design was fairly creative but required elements that made it less realistic to actually implement. Mostly this is due to the fact that it is entirely independent of solar heat. The whole system uses a resistive network in order to heat the liquid that would be used for heating the homes. Due to this it required several forms of energy creation including a lithium battery and a wind turbine. Overall the device performed within the higher range of design concepts. This is due to the way it balanced simplicity and some more unrealistic elements.

5.2 Subsystem Concepts

When generating concepts for these designs, a variety of subsystems were considered. Variations in these subsystems was used to create diverse concept ideas via a morphological matrix. The most critical of these subsystems were heat generation, thermal storage, and electricity generation. These are shown in the section of the morph matrix below (**Table *3*: Morphological Matrix**Table 3).

Table 3: Morphological Matrix

Sub-function	1	2	3	4	5
Thermal Storage	Phase Change Material	Single water tank	Rocks	Buried water tank	Raised water tank
Heat generation	Thermal panel	Resistive network	Direct solar radiation	propane	Heating tubes

Electricity Generation/Storage	Solar PV Panel + Li Battery	Wind turbine + Li battery	Stirling engine	Propane generator	Grid Power

5.2.1 Subsystem #1: Thermal Storage
This subfunction refers to the portion of the design intended to absorb and store heat. The variants take a variety of forms, as detailed below.

5.2.1.1 Design #1: Phase Change Material
This thermal storage medium would take the form of some material that changes phase as it heats up, going from a solid to a liquid (changing phase). The advantages of this variant are its ability to store heat, as well as be stored as a solid when not heated. The main disadvantage relates to cost and availability, making it less ideal for rural, low-cost application.

5.2.1.2 Design #2: Single Water Tank
This concept variant involves using a single tank filled with water to store heat. The main advantages are simplicity, as well as the high specific heat of water, which allows it to store a great deal of thermal energy. The main disadvantage of this design is weight and the potential for heat loss through the surface of the tank.

5.2.1.3 Design #3: Rocks
This subsystem variant would use solid rocks, heated either via the sun or by warm air moving through them. The primary advantage of this design is cost and availability; rocks could be dug up on-site in most cases. The main disadvantage is the low thermal conductivity of rock, as well as high mass and weight, making it difficult to implement in a single-home use.

5.2.1.4 Design #4: Buried Water Tank
This subsystem variant is similar to #2, with the additional specification that the tank is to be buried underground. The primary advantage to this would be the thermal insulation provided by the ground, which should significantly reduce heat loss. The disadvantage of this variant is the required amount of labor to dig a sufficiently large hole, and the accompanying cost of that labor.

5.2.1.5 Design #5: Raised Water Tank
This is another variant on the water tank design. Unlike the buried water tank, it would involve a tank perched on some form of elevated platform. The advantage of this design is that it reduces the need for a pump; once the water is pumped into the tank, it can be returned via gravity. The disadvantage is its relative size, in addition to the additional cost of structural materials and insulation for an elevated tank.

5.2.2 Subsystem #2: Heat Generation
This subfunction refers to the method in which the device generates the heat stored in its thermal storage medium. These variations are useful in order to consider which systems the device may have to interface with. Said systems are detailed below.

5.2.2.1 Design #1: Thermal Panel
This functional variant is a solar-thermal water heating panel, which uses energy from the sun to heat water passing through. The primary advantage of this system is that it is proven and has a relatively developed market with a great deal of variation. It is also environmentally friendly and efficient. The main disadvantage of this system is its size, and the relatively high cost of the panels.

5.2.2.2 Design #2: Resistive Network

This subfunction would use a network of resistors, installed within or adjacent to the thermal storage medium, to create the heat. The primary advantage of this system would be its relatively robust and low-cost design; most water heater systems use similar devices. The drawback of such a system is its reliance on electricity for heating, and the associated issues with providing consistent, large amounts of power on the Navajo Nation and Hopi Reservation.

5.2.2.3 Design #3: Thermal Radiation (rocks)

This subfunction would involve the use of direct sunlight to heat the thermal medium, with the thermal medium itself being heated within its container by the sun. The main advantage of this design is its extremely low cost and accompanying robust nature. The disadvantage is that it is an inefficient method of heating and may be insufficient for the purposes of the device.

5.2.2.4 Design #4: Propane Heater

This subfunction variant would use a simple propane heater to warm the thermal storage medium. The main advantage of this design would be relatively low cost, and very high heat output. The main disadvantages are the need for regular resupply, the potential for the system to fail, and the health and safety concerns associated with the use of natural gas.

5.2.2.5 Design #5: Heating Tubes

This variant also uses solar radiation to heat the thermal storage medium, with the medium circulating through heated glass tubes in the sun. The advantage of this design is that it is relatively efficient, and cheaper than similar devices. The main disadvantage is the potential for it to be fragile, in addition to potentially taking up a lot of space.

5.2.3 Subsystem #3: Electricity Generation

This subfunction refers to the device's method of electricity generation. It is important that the device has power throughout the night in order to maintain heat output, and that power will be generated with one of the following subfunction variations.

5.2.3.1 Design #1: Solar PV Panel and Li+ Battery

This design would use a solar photovoltaic panel and lithium ion battery to generate and store electricity. The primary advantage of this is that it is a proven technology, with relatively low maintenance costs. The disadvantage is its size, and the initial cost of the panel and battery setup.

5.2.3.2 Design #2: Wind Turbine and Li+ Battery

This design would use a wind turbine and lithium ion battery to generate and store electricity. The main advantage is its relative low cost, with technology that is proven and has been used for some time. The disadvantage for wind turbines is that they require frequent maintenance and take up a great deal of space.

5.2.3.3 Design #3: Stirling Engine

This subfunction variant, the Stirling Engine, uses a temperature differential to generate electricity. The main advantage of this would be that, in theory, it does not require a battery to store electricity, due to the ever-present temperature differential. The disadvantages are high cost, low reliability, and general fragility of this design.

5.2.3.4 Design #4: Propane Generator

This variant, a propane generator, would use propane to generate electricity that would be stored in a battery. It would best be used in tandem with a propane heater for the thermal storage medium. The advantages of propane are its relatively low cost, and high efficiency. The disadvantages include size, weight, the need for frequent resupply, and the loud noise created by the generator.

5.2.3.5 Design #5: Grid Power

This subfunction variant requires a direct connection to some sort of electrical grid. It has the advantage of being the cheapest variant by far, and the simplest. The disadvantage of this design is that it makes the design inoperable in certain locations, and as such would significantly limit the versatility of the device when it comes to home type and location.

6 DESIGNS SELECTED – First Semester

6.1 Technical Selection Criteria

Table 4: Decision Matrix

Decision Matrix											
	105	186	148	90	76	76	33	120	60	105	999
	11%	19%	15%	9%	8%	8%	3%	12%	6%	11%	100%
Designs	indoor air temp. (°F)	heat transfer rate (BTU)	Device cost ($)	Number of parts (unitless)	Dimensions (ft^3)	Weight (lb)	Max material delivery time (hrs)	Outdoor temp. range (°F)	Force withstood (lbf)	Cycles without failure (unitless)	Score
Randall 1	4	4	2	2	3	2	3	4	3	4	3.20
Randall 2	3	2	3	4	3	3	3	4	3	4	3.13
Randall 3	3	3	1	1	1	2	2	4	3	3	2.38
Noah 1	4	3	3	2	3	3	3	3	3	4	3.12
Noah 2	1	1	4	4	2	2	4	2	4	3	2.48
Noah 3	3	3	1	2	4	4	1	4	1	2	2.59
Brittney 1	1	1	4	4	2	2	3	2	4	3	2.44
Brittney 2	4	3	3	2	3	3	3	3	3	3	3.02
Brittney 3	3	2	3	3	3	2	2	3	3	3	2.70
Jessie 1	3	2	3	3	3	3	3	3	3	2	2.71
Jessie 2	4	4	2	3	2	2	3	3	3	3	2.99
Jessie 3	4	4	2	2	2	2	2	4	3	2	2.88
Wesley 1	3	3	3	3	3	3	3	4	3	3	3.12
Wesley 2	2	3	4	4	3	3	3	3	3	4	3.24
Wesley 3	1	3	4	3	2	2	3	3	4	2	2.74

In this decision matrix our designs were split into ten subfunctions. Each device was compared relative to each other and their ability to perform well in each of the ten categories. The students with the top two best preforming designs were Randall Holgate and Wesley Garcia. Randall's design scored a 3.20 and Wesley's scored 3.24 on their overall designs. The reasons for this situation is that Wesley and Randall's designs had almost inverse scores of each other. This means where one design fell short the other did well and vice versa.

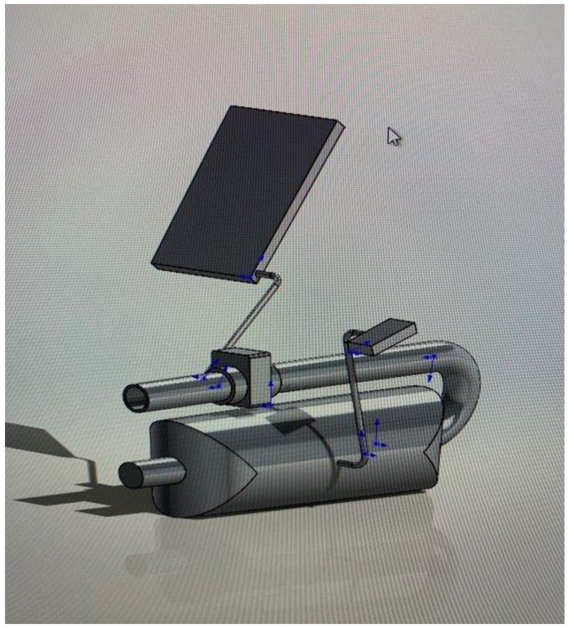


Figure 19: Top Ranking Design

As it can be seen in the figure above this design is simplistic and compact. It requires less space and fewer parts. This simplicity is what gave it a significant edge over the other designs. Along with this it uses a single pump, and heat transfer mechanism allowing it to be low cost as well. The major downside to this design is that it doesn't perform as well as other designs in terms of heating the home.

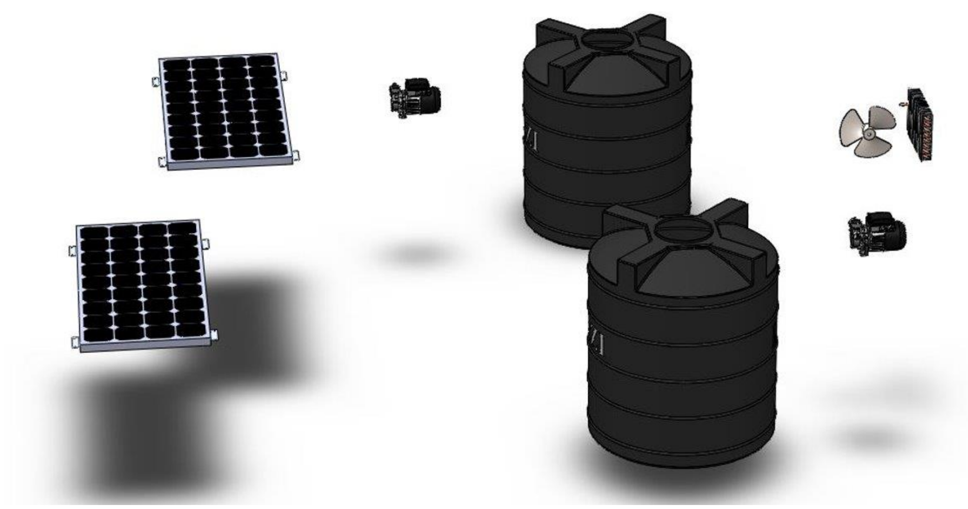


Figure 20: Second Highest Ranking Design

This design has an entirely different problem. The greatest downside to this device is its considerable amount size, cost, and part total. However, despite this draw back, it preformed high in all the tasks that required providing quality and reliable warmth to the home.

6.2 Rationale for Design Selection

Due to how different yet successful these designs were in the Decision Matrix; it was decided that more information and designing needed to be done. This would be carried out in order to create a design that

could best fit the overall design criteria of this project. So, for this stage of the design not one but two designs have been selected. The first being Randall's first design highlighted in the Decision Matrix above and the second being Wesley's second design.
[33]

7 REFERENCES

[1] W. D. M. D. R. B. Z. H. X. R. a. Y. W. Mingzhe Yu, "Aqueous Lithium–Iodine Solar Flow Battery for the Simultaneous Conversion and Storage of Solar Energy," *ACS Publications,* pp. 8332-8335, 2015.

[2] Y. H. J. L. L. Q. Y. Y. X. G. W. X. Yuanpeng Fua, " Improved hydrometallurgical extraction of valuable metals from spent lithium-ion batteries via a closed-loop process," *Journal of Alloys and Compounds,* vol. 847, pp. 1-11, 2020.

[3] H. Y. L. L. Tao Ma, " A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island Journal: Applied Energy," *Applied Energy,* vol. 121, pp. 149-158, 2014.

[4] M. O. Y. P. Gonu Kim, "Solar-rechargeable battery based on photoelectrochemical water oxidation: Solar water battery," *Scientific Report ,* pp. 1-9, 2016.

[5] K. C. R. K. S. S. A. G. V. R. P. R. N. Q. Q. Ashim Gurung, "Highly Efficient Perovskite Solar Cell Photocharging of Lithium Ion Battery Using DC–DC Booster Journal: Advanced Energy Materials," *Advanced Energy Materials,* pp. 1-8, 2017.

[6] C. K. Mangrulkar, A. S. Dhoble, K. P. Pant, N. Kumar, A. Gupta and S. Chamoli, "Thermal performance escalation of cross flow heat exchanger using in-line elliptical tubes," *Experimental Heat Transfer,* 2019.

[7] C. Cavallo, "All About Shell and Tube Heat Exchangers - What You Need to Know," Thomas Publishing Co., 2020. [Online]. Available: https://www.thomasnet.com/articles/process-equipment/shell-and-tube-heat-exchangers/. [Accessed 18 10 2020].

[8] Alfa Laval, "How does a plate heat exchanger work," [Online]. Available: https://www.alfalaval.my/products/heat-transfer/plate-heat-exchangers/gasketed-plate-and-frame-heat-exchangers/heat-exchanger/how-plate-heat-exchanger-work/. [Accessed 18 October 2020].

[9] A. C. I. Zeghib, "Modeling and Simulation of a Solar Thermal System for Domestic Space Heating Using Radiators Low Temperature," *International Journal of Renewable Energy Research,* vol. 5, pp. 1-11, 2015.

[10] Gooch Thermal Systems, "Spiral Heat Exchangers," Gooch Thermal Systems, Inc., 2020. [Online]. Available: http://www.goochthermal.com/spiral-heat-exchanger/design. [Accessed 18 10 2020].

[11] J. Macauley, J. Shaw, E. Beraud and W. Legrand, "Red Feather Thermal Energy for Homes," NAU, Flagstaff, 2019.

[12] M. King, "Navajo Nation EPA Air Quality Control Program Indoor Air Quality," NNEPA, Fort Defiance, 2016.

[13] T. Denetdeel and M. King, "NNEPA Implementing a Tribal Indoor Air Quality Program," NNEPA, Fort Defiance, 2016.

[14] "Active Solar Heating," US DoE, 2019. [Online]. Available: https://www.energy.gov/energysaver/home-heating-systems/active-solar-heating. [Accessed 18 10 2020].

[15] N. Fisher, L. Hernandez and T. Scott, "Concept Generation & Selection," NAU, Flagstaff, 2020.

[16] A. K. a. S. Shukla, "A Review on Thermal Energy Storage Unit for Solar Thermal Power Plant Application," *Energy Procedia,* vol. 74, pp. 462-469, 2015.

[17] R. V. a. N. M. R. Varia, "Review of Solar Heating Furnace Development," *International Journal of Advance Engineering and Research Development,* vol. 5, pp. 987-991, 2018.

[18] G. Hailu, "Seasonal Solar Thermal Energy Storage," in *Thermal Energy Battery with Nano-enhanced PCM*, IntechOpen, 2018.

[19] P. Terlip, "Everything You Wanted to Know About Solar Water Heating Systems," *Energy Saver,* vol. 1, 2014.

[20] Hydroflex Systems, Inc, "Solar Thermal & Solar Thermal Storage Tanks," Hydroflex Systems, Inc. Water Storage Tanks, [Online]. Available: http://www.hydroflexsystems.com/index.php?page=tanks.

[21] A. Khouya, "Performance assessment of a heat pump and a concentrated photovoltaic thermal system during the wood drying process," *Applied Thermal Engineering,* vol. 180, 2020.

[22] S. Guariano, A. Buscemi, G. Ciulla, M. Bonomolo and V. Lo Brano, "Adish-stirlingsolarconcentratorcoupledtoaseasonalthermalenergy storagesysteminthesouthernmediterraneanbasin:Acogenerativelayout hypothesis," *Energy Conversion and Management,* vol. 222, 2020.

[23] E. T. d. Fresart, "Design, Simulation, and Analysis of Domestic Solar Water Heating Systems," Arizona State University, Phoenix, 2012.

[24] K. S. Benne, "TRANSIENT PERFORMANCE OF CLOSED LOOP THERMOSYPHONS," UNIVERSITY OF MISSOURI–ROLLA, Rolla, 2007.

[25] Wikipedia, "Thermosiphon," 6 June 2020. [Online]. Available: https://en.wikipedia.org/wiki/Thermosiphon#:~:text=Thermosiphon%20(or%20thermosyphon)%20is%20a,necessity%20of%20a%20mechanical%20pump.. [Accessed 18 October 2020].

[26] T. Zhang, "Experimental Study on a Forced-Circulation Loop Thermosiphon Solar Water Heating System," *Hindawi International Journal of Photoenergy,* vol. 2018, 2018.

[27] Arctica Solar, "See the Product," 2020. [Online]. Available: http://www.arcticasolar.com/#product. [Accessed 17 October 2020].

[28] Arctica Solar, "1500 Series Data Sheet," 2019. [Online]. Available: http://www.arcticasolar.com/product/1500_series_datasheet_v2.pdf. [Accessed 17 October 2020].

[29] Badger Insulated Pipe, "12X24 WATER TO AIR HEAT EXCHANGER~~1" COPPER PORTS W/ EZ INSTALL FRONT FLANGE," 2020. [Online]. Available: https://badger-pipe.com/products/12x24-water-to-air-heat-exchanger-with-1-copper-ports?variant=29106665873&currency=USD&utm_source=google&utm_medium=cpc&utm_campaign=google+shopping. [Accessed 18 October 2020].

[30] "AFSupply," AFSupply, [Online]. Available: https://www.afsupply.com/cast-iron-radiator-18-sections-19-h-4-tubes.html?gclid=CjwKCAjwz6_8BRBkEiwA3p02VWrXxcuIxVWDomyzb6VBgohSNu4I-pMwIL6U4XcarRRqLT1zX_-jhhoCNdsQAvD_BwE. [Accessed 18 October 2020].

[31] "United States Plastic Corp," UPS, [Online]. Available: https://www.usplastic.com/catalog/item.aspx?itemid=121250 . [Accessed 18 October 2020].

[32] "HouseNeeds," HouseNeedsd, [Online]. Available: https://www.houseneeds.com/heating/indirect-storage-hot-water-tanks/hydroflex-thermal-storage-tanks-solar-wood-100-gallons-t100. [Accessed 18 october 2020].

[33] "Thermal Energy Storage," DN Tanks, [Online]. Available: https://www.dntanks.com/what-we-do/thermal-energy-storage/. [Accessed 18 October 2020].

[34] S. Matasci, "Best Solar Panels in 2020 [Complete List]," Solar News, 28 9 2020. [Online]. Available: https://news.energysage.com/best-solar-panels-complete-ranking/. [Accessed 18 10 2020].

[35] W. D. M. D. R. B. Z. H. X. R. a. Y. W. Mingzhe Yu, "Journal of the American Chemical Society," *Aqueous Lithium–Iodine Solar Flow Battery for the Simultaneous Conversion and Storage of Solar Energy,* pp. 8332-8335, 2015.

[36] W. D. M. D. R. B. Z. H. X. R. a. Y. W. Mingzhe Yu, "Journal of the American Chemical Society," *Aqueous Lithium–Iodine Solar Flow Battery for the Simultaneous Conversion and Storage of Solar Energy,* p. 4, 2015.

[37] Y. J. L. Y. X. W. YuanpengFua, "Journal of Alloys and Compounds," *Improved hydrometallurgical extraction of valuable metals from spent lithium-ion batteries via a closed-loop process,* pp. 1-11, 2020.

[38] H. Y. TaoMa, "Applied Energy," *A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island,* vol. 121, pp. 149-158, 2014.

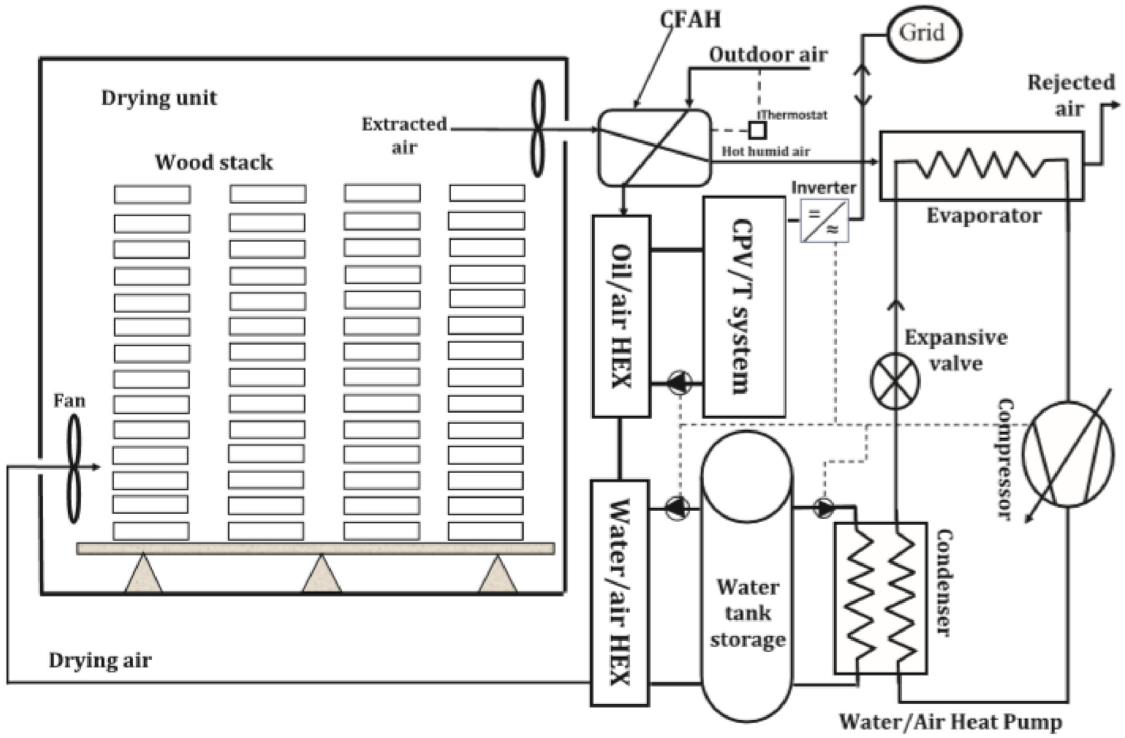
[39] M. O. Y. P. Gonu Kim, "Scientific Report," *Solar-rechargeable battery based on photoelectrochemical water oxidation: Solar water battery,* pp. 1-9, 2016.

[40] K. C. R. K. S. S. A. G. V. R. P. R. N. Q. Q. Ashim Gurung, "Advanced Energy Materials," *Highly Efficient Perovskite Solar Cell Photocharging of Lithium Ion Battery Using DC–DC Booster,* pp. 1-8, 2017.

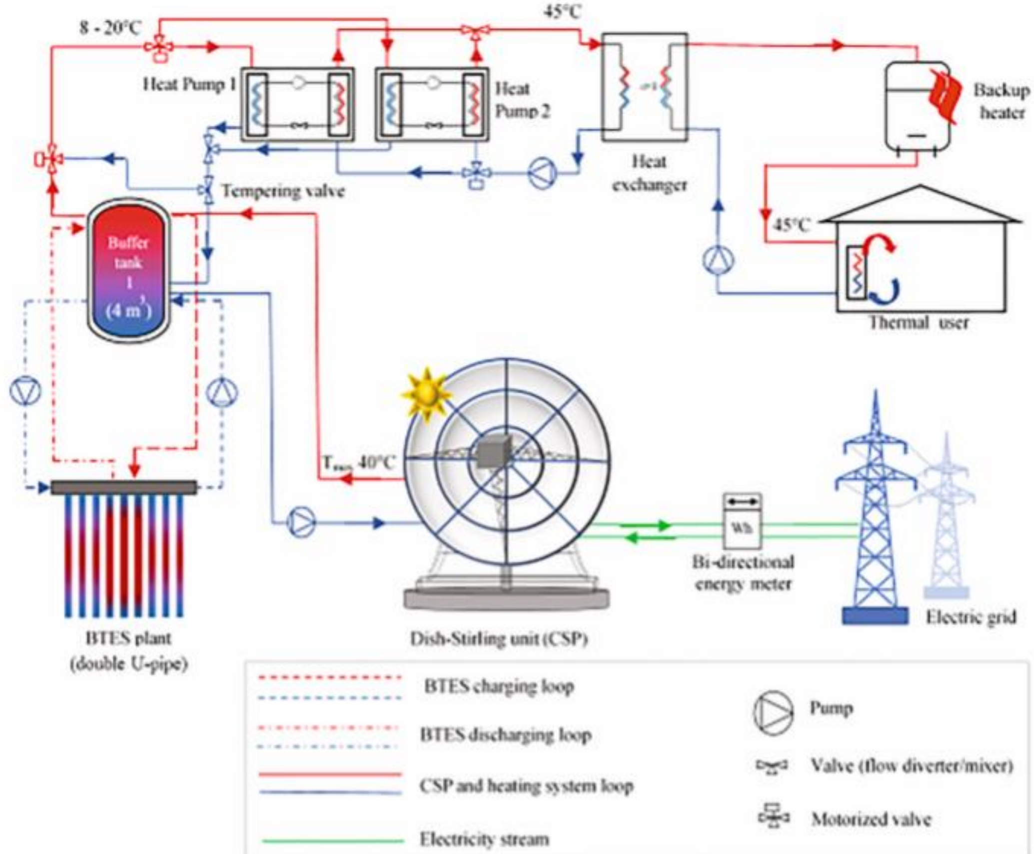
[41] "Energy.Gov," Energy.Gov, [Online]. Available: https://www.energy.gov/energysaver/home-heating-systems/heat-distribution-systems. [Accessed 18 October 2020].

8 APPENDICES

8.1 Appendix A: Closed Feed Air Heater to Dry Wood System Schematic



8.2 Appendix B: Dish-Stirling Solar Concentrator and Thermal Energy System Schematic



8.3 *Appendix C: Decision Matrix*

Decision Matrix

Designs	heat transfer rate (BTU)	Device cost ($)	Outdoor temp. range (°F)	indoor air temp. (°F)	Number of parts (unitless)	Cycles without failure (unitless)	Dimensions (ft^3)	Weight (lb)	Force withstood (lbf)	Max material delivery time (hrs)	Score
	186	148	120	105	90	105	76	76	60	33	999
	19%	15%	12%	11%	9%	11%	8%	8%	6%	3%	100%
Randall 1	4	2	4	4	2	4	3	2	3	3	3.20
Randall 2	2	3	4	3	4	4	3	3	3	3	3.13
Randall 3	3	1	4	3	1	3	1	2	3	2	2.38
Noah 1	3	3	3	4	2	4	3	3	3	3	3.12
Noah 2	1	4	2	1	4	3	2	2	4	4	2.48
Noah 3	3	1	4	3	2	2	4	4	1	1	2.59
Brittney 1	1	4	2	1	4	3	2	2	4	3	2.44
Brittney 2	3	3	3	4	2	3	3	3	3	3	3.02
Brittney 3	2	3	3	3	3	3	3	2	3	2	2.70
Jessie 1	2	3	3	3	3	2	3	3	3	3	2.71
Jessie 2	4	2	3	4	3	3	2	2	3	3	2.99
Jessie 3	4	2	4	4	2	2	2	2	3	2	2.88
Wesley 1	3	3	4	3	3	3	3	3	3	3	3.12
Wesley 2	3	4	3	2	4	4	3	3	3	3	3.24
Wesley 3	3	4	3	1	3	2	2	2	4	3	2.74