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Solar Water at Trinity

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The main objective for this project is to design a solar water heating system that is affordable for low-income families in San Antonio, Texas. Commercially available solar water heaters have a high up front cost and a lengthy payback period of 12 years or longer. This acts as a disincentive for low-income and other families to switch from electric or gas to solar water heaters. The design also aims to meet SRCC OG-300 certifications, receive federal tax credits and qualify for CPS Energy rebates which is included in the payback period calculation. This design will easily integrate with existing electric water heater to act as a pre heater and reduce the user's energy bills. The payback period of the system is calculated to be 25 months with an initial cost of $2,977, assuming the system receives certification and including the installation cost of $1,000.

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Executive Summary

Consumers have numerous solar water heaters from which to choose. While these designs reduce the amount of money spent on power bills due to decreased energy use, there is a high initial cost associated with switching to a solar water heater, which could have payback period (the amount of time before cumulative energy savings equal initial cost) of 12 years or longer. As a result, a large population in San Antonio is reluctant to use a solar water heater continues to use conventional (gas or electric) water heaters. Switching the source of water heating energy from gas or electric to solar will reduce energy expenses. Introduction of low-initial-cost solar water heaters will encourage more of the population to switch to the more environmentally friendly solar water heating. San Antonio, which naturally has a reliable source of solar energy year round, is a favorable area to implement wide spread use of solar water heaters. The main objective for this project is to design a solar water heating system that is affordable to low-income families in San Antonio, Texas.

The solar water heater must meet design constraints in order to be considered successful. The most important constraint is that the water heater must have no greater than a two year payback period. This means that after two years all costs attributed to the switch from electric to solar will be offset by the savings on the power bill due to using less power from switching. In addition, the design of the solar water heater must meet all of the Solar Rating and Certification Corporation (SRCC) standards and regulations. This would ensure that the design is safe to the user, an acceptable product in the market, and qualified for the CPS Energy Rebate.

The design chosen to meet the project goals is a batch collector system. The collector was built and tested in order to measure the performance. Initial tests consisted of a prototype to test the effect of more or fewer layers of glass. Outdoor testing consisted of exposing the collector to the operating environment by placing it at the optimal angle to the sun on the roof of a four story building. By measuring the temperature of the water throughout testing, the performance could be quantified. The payback period was calculated to be 25 months by analyzing the system function and comparing it to conventional heater function.

The full system design will consist of two large tanks which can hold up to 40 gallons of water, in each tank, enclosed in a wooden frame with a glass cover. The design includes two tempering valves to control the temperature of the water delivered to the conventional backup water heater and the water delivered to the household. The final cost of this design is $3,000. A

list of materials needed in order to create this design has been created as well as a list of vendors that can supply the material.

Since the expected cost of the design is greater than the budget ($1,200) a scaled down version of the actual design will be built, consisting of one collector and the attachments (thermostatic mixing valves and pipes) separately.

1. Introduction

The two systems that are currently in place in households to heat water are gas and electric water heaters. These two methods have been relied upon for many centuries and people do not yet see the motivation to switch to solar energy to heat water. One problem with gas and electric water heaters is that overtime they are both more expensive than using solar. In addition, the carbon footprint for electric and gas are both greater than the carbon footprint for solar. In 2005, Sunbelt Solar determined the amount of savings in carbon emissions that solar water heaters produced that year versus the electric heaters saved 29 million tons of carbon which equates to 70 million barrels of oil being saved that year. Seventy million barrels of oil in one year equates to taking 4.36 million cars off the road for a year which would have a significant impact on the environment.

Current solar water heating systems are expensive, costing between $6,000 and $8,000 according to the Executive Director of Solar San Antonio, Lanny Sinkin. Based on the price of electric power in San Antonio, it was calculated that if the cost of purchasing and installing a solar water heater were less than $3,200, this cost could be paid off in approximately 2 years from the electrical energy savings. In order to ensure hot water will be provided to the consumer at all hours and time of the year, the solar water heater will be a preheater to the existing electric water heater. The solar water heater will do the hard work of heating the water before it enters into the electric heater. If the water temperature is at the set temperature when it enters the electric heater than the electric heater will not turn on, and therefore save the consumer money. However, this design alteration to the water heater will not be noticed by the consumer since the electric heater to heat the water before it enters the house when the solar water heater fails to do so.

Because gas-powered water heaters are cost-competitive with solar water heaters, the economic incentive for replacing a gas water heater is not as great as replacing an electric heater.

Gas heaters, are ineligible for the CPS rebates which are important to determining the payback period of the project. The CPS rebate gives households 60 cents for every kWh of electric water heating that is replaced by solar. An estimation for the amount received by this rebate was calculated into the payback period of 2 years. Therefore, it is essential that the final design of the water heater will receive the CPS rebate. While switching from an electric heater to a gas heater may save a little money to the consumer, it would not reduce carbon emissions and in the long run it will still be more expensive than a solar water heater.

The objective of the SWAT team is to design, build, test, and evaluate a solar hot water system that can be sold to the consumer at low cost and that is manufactured in San Antonio using locally available materials to the greatest extent feasible. The following are the design objectives:

- The water heater should heat 80-120 gallons of water daily to a temperature of 120°F. This volume of water is the average water use for a family of four, and 120°F is the standard temperature that water is heated to using an electric water heater for residential water heaters. Since the intent is to be used as a preheater to an electric heater, than the solar heater will need to heat the water to at least 120°F before it enters the electric system.
- The design must be able to be used in all types of weather conditions. During the winter months, it is important that the water heater will not freeze and that it will still provide hot water to the electric system. During the summer months, it is important that the water is not sent to the household at an extreme temperature.
- The solar water heater and associated system component must be capable of being installed with minimal to no risk to the installer and the household.
- The water must be potable and, therefore, the materials and the water must not be contaminated with pathogens, toxins and waterborne diseases.
- The system must have a payback period of two years or less. In order to have a two year payback period, the system needs to cost less than $3,200 including the cost of installation, which is estimated to be $1,000. The project budget as provided by Trinity University Engineering Science Department is $1,200. Therefore, only a prototype of the final design will be built and tested.

- The final design will meet Solar Rating and Certification Corporation (SRCC) standards in order to be eligible for the CPS rebates which will reduce the payback period.

A wide variety of existing solar water heater designs were investigated before determining the final design of the solar water heater created by the group. Some solar water heater designs use a pump to move water through the system and others rely on a thermosyphon effect. However, the design implemented by the group relies on the pressure of the supply water to keep the design simple and to reduce costs. Another decision made regarding the design of the system, is whether an open loop or closed loop system will be designed. The open loop system consists of heating the water directly instead of using a heat exchanger, and the closed loop system, will pass a thermal fluid through the collector and then through a heat exchanger to heat water. The open loop system was decided to be most cost efficient and require the least amount of maintenance in years to come. There are three common types of solar collectors used in current designs on the market: a batch collector, a flat plate collector, and evacuated tubes. The batch collector is the simplest design but has been proven to provide hot water to the user. The group decided that a batch collector would be the most cost efficient design while still meeting all of the design objectives.

2. Design

This system design consists of two collectors installed on a roof with downstream subsystems that provide the hot water to a household. The collector is designed as a preheater to the current electric water heating system, a subsystem, in the household, therefore, when hot water is required, the hot water from the electric heating tank is removed and the tank is refilled with the water heated by the sun in the collector. A diagram of this system is shown as Fig. 2.1, below, where the blue arrows indicate cold water, red arrows indicate hot water, and purple arrows indicate blended water. In order to receive the maximum amount of sunlight, the collector is mounted on the roof of the house and angled at 40° to the horizontal and is directed towards the south. Other subsystems are added downstream to the collector in order to protect the existing water heater, to prevent burning the user, and to pipe hot water from the collector to the house.

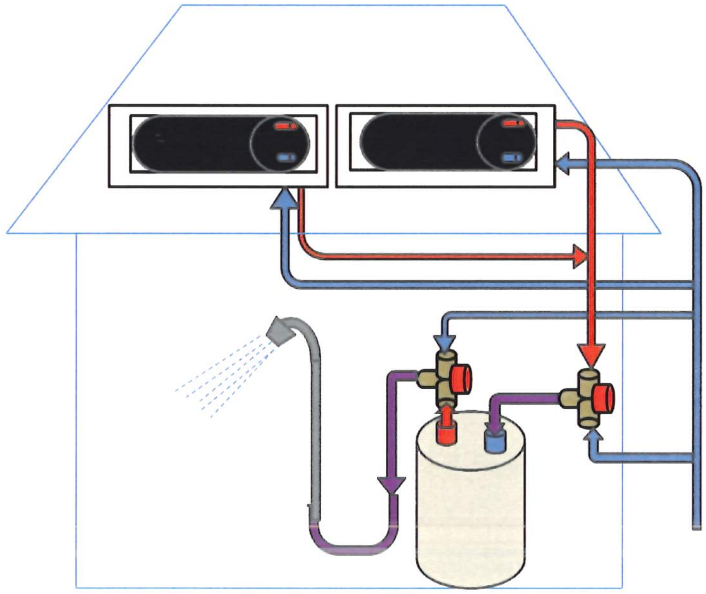


Figure 2.1. Solar Water Heating System Design.

2.1 Collector Design

The collector design consists of a tank, a frame, and piping, as shown in Fig. 2.2, below. The tank is enclosed in the frame, filled with water, and exposed to the sun. The hot water will remain at the top of the tank and will be removed when the household uses hot water. The pipes are used to deliver cold water to the collector and remove the hot water from the collector. Two collectors are positioned at equal levels on a roof to provide twice the amount of hot water to the household. Budget constraints for the collector prototype only allowed for the construction of one of the collectors.

Figure 2.2. Collector Design to be installed on the roof.

2.1.1 Tank:

The collector tank used in the prototype is a large black painted repurposed 40 gallon electric water heater. This water heater was stripped of its casing, insulation, and electrical components so that the inner steel tank could be painted and used to heat water. The heating elements were removed from the tank and the existing holes were plugged using Galvanized Iron Plugs. The tank is painted flat black in order to maximize radiation absorption. The main reasons for using this type of tank in this design are these tanks are made for withstanding hot and hard water and have most of the necessary parts already installed that were used in this design. The pressure release valve is required to meet the SRCC standards, and the cold and hot water ports are used by the system. An electric water heater was donated to this project to be used in the prototype; however, the repurposing of this tank requires more maintenance and labor. It is recommended that if this design is to be replicated for mass production, to purchase the steel tanks before they are manufactured into electric water heaters.

2.1.2 Collector Frame:

The frame reduces convective and radiative losses from the water tank, and protects the tank from weather. The frame is a recycled wooden box of dimensions 60 x 40 x 36 inches which contains the water tank. Two holes for ¾ inch piping are cut on the bottom side of the frame to allow the cold and hot water pipes to pass through the frame and be transferred to the house through the roof. Deck stain is used to weatherproof the frame.

Tempered glass with a thickness of ¼" is used on the top side of the frame to allow solar radiation to strike the tank, while providing protection. The tempered glass is stronger both physically and thermally than a standard sheet of glass because it undergoes a toughening process when being manufactured. This type of glass was used not only because it is stronger, but also because it is safer when broken and will not cause jagged pieces of glass. A single layer of glass confers optimal heat gain opportunities without incurring significant heat losses. A cost benefit analysis which considered the cost, weight, and efficiency due to the additional layer of glass, concluded that one layer of glass is sufficient.

Insulation is attached on the inside walls of the frame to reduce the amount of heat loss through the wood. The fiberglass insulation used in the collector prototype 9-1/4" thick and has an R-value of 30. This allows for the assumption that convective losses through the other sides of the frame are negligible using insulation. Fiberglass insulation is four times less expensive than polycyanurate insulation boards, another insulation option considered to reduce the size of the collector, when requiring R-values greater than 6. The budget constraint on this scaled collector prototype as well as the final collector design prohibits a more expensive option for insulation.

2.1.3 Piping:

The design uses a combination of copper piping and ThermaPEX tubing which are suitable for potable water and which can withstand high temperatures. Both flexible and rigid copper pipes are used to connect the tank to the ThermaPEX tubing. Directly attached to the tank at both the inlet and outlet is a flexible copper water heater supply line. The entirety of this pipe remains inside the frame and is not exposed to outside conditions. Soldered to this flexible copper is a rigid Type M copper pipe. Copper pipe is used as opposed to galvanized steel because the minerals in San Antonio water react with the zinc used to coat the inside of galvanized steel pipes. Eventually the pipes would become blocked (Keidel 2011). The pipe exits the bottom of the box, as shown in Fig. 2.2, so that the least amount of pipe is exposed to the weather, thereby reducing the chance of freezing within the pipe. The large volume of water in the tank prevents water within the collector from freezing in San Antonio. This was proved using a model described later in this report. Using a brass coupling, the rigid copper pipe is connected to the ½" ThermaPEX oxygen barrier PEX tubing. PEX tubing is flexible plastic tubing that is made specifically for transporting potable water. ThermaPEX is made specifically for hot water (up to 200°F) and is much cheaper than copper, however, it is for indoor use because it is not UV resistant. This tubing is used to transport the hot water to the existing electric water heater.

2.2 Subsystem Designs:

Two subsystems are incorporated into the entire solar water heating system design downstream of the collector: the electric water heater and two thermostatic mixing valves. The ThermaPEX tubing will be connected to the plumbing in the house that connects to the existing water heater. A thermostatic mixing valve is connected to the inlet of the electric water heater to ensure that water enters the electric water heater at a temperature within the heater's specifications (typically a maximum of 180°F). As a safety redundancy, a second thermostatic mixing valve is placed at the outlet of the electric heater to limit the water temperature supplied to the user. How these systems work and their implementation into the solar water heating system design is discussed below.

2.2.1 Electric Water Heater:

The homeowner's existing electric water heater will be used as a back-up water heater to ensure that a supply of hot water can be maintained under all weather conditions. The heater is a tall metal drum usually positioned in the basement or first floor in a household.

2.2.2 Heating Element:

The upper and lower heating elements are typically a copper or steel coiled rod at the center and bottom of the tank. They are electrically heated and controlled by the user with the thermostats on the outside of the tank. Each element has its own thermostat. The thermostat controls the water temperature within the range of 120 °F and 180 °F, however most manufacturers recommend that the water be set between 120 °F and 140 °F to prevent scalding. This risk will be eliminated in the Solar Water Heating system due to the planned installation of two thermostatic mixing valves mentioned in the following subsystem design. If the water flowing into the electric water heater has a higher temperature than the value set by the user, then the elements will not turn on and will idle until the water cools down. This is why the solar collector will help the user save electricity and, therefore, money.

2.2.3 Water Pipes:

The cold water provided to the house enters the drum through the inlet pipe at the top of the heater and is dipped down to the bottom of the heater with a "dip tube". As the temperature of the water increases due to the heating elements, the hotter water rises to the top of the heater. When hot water is needed by the user, the outlet at the top takes the hotter water that remains at the top of the tank. This same concept is applied to the collector, but the sun is heating the water rather than the heating elements.

2.2.4 Anode Rod:

A solid pipe, also known as the anode rod, is an aluminum or magnesium pipe that prevents the tank from deteriorating. The electrolytic process that occurs when the steel tank is filled with water deteriorates the steel. It is, therefore, necessary to include a better electrolytic conductor such as aluminum or magnesium in the system to allow the process to occur on the rod rather than the tank. This anode rod comes installed in the tank and is also implemented in the tank used in the prototype, which is an additional benefit of using a repurposed water heater.

2.3 Thermostatic Mixing Valves:

A thermostatic mixing valve (TMV) is used to blend hot and cold water to prevent scalding and system malfunction. Figs 2.3 and 2.4 show the image of a thermostatic mixing valve and its working. The change in temperature of the hot and cold water alternately expands and contracts the thermostat element, most commonly a wax thermostat. This thermostat causes the slide valves on the inlets to regulate how much of each inlet is necessary to reach the desired outlet mixed water temperature. In the solar water heating system design, two TMVs are used, one upstream and one downstream of the electric water heater. The upstream TMV mixes the hot water from the collector with the cold water supplied to the house in order to assure that the water entering the electric water heater will be less than 180 °F. Water above this temperature could cause damage to the electric water heater and the electrical components. The second TMV will blend the hot water from the existing water heater with cold water to a temperature decided by the homeowners (usually around 120 °F) to be supplied to the household [1].

Figure 2.3. Picture of a thermostatic mixing valve [2]

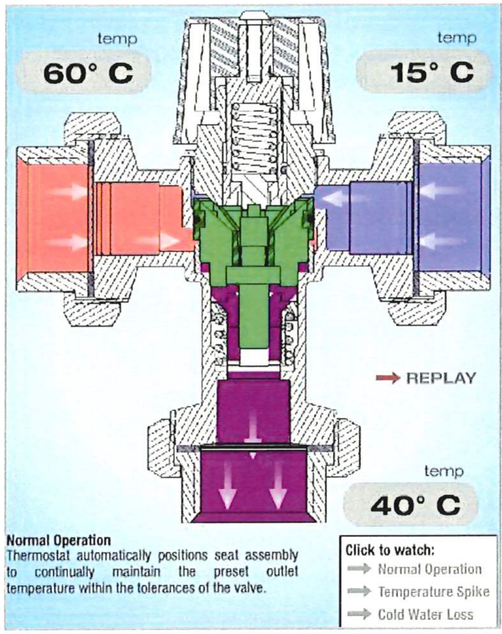


Figure 2.4. Working of a thermostatic mixing valve [3]

2.4 Computer Design Description:

Modeling the solar water heater is necessary to predict the heater performance under various weather conditions and to analyze the effects of design parameters (e.g. the level of insulation or transmissivity of the glass cover). A computer model developed in Engineering Equation Solver (EES) allows the design to be altered virtually which minimizes the use of construction time and budgeted funds.

2.4.1 Model Theory:

The model is based on the thermal network shown in Fig. 2.5. In order to create the model, the temperature of the inside layer of the frame (the insulation and the lowest pane of glass) were assumed to be at uniform temperature, the tank and water were assumed to be one object with a uniform temperature distribution.

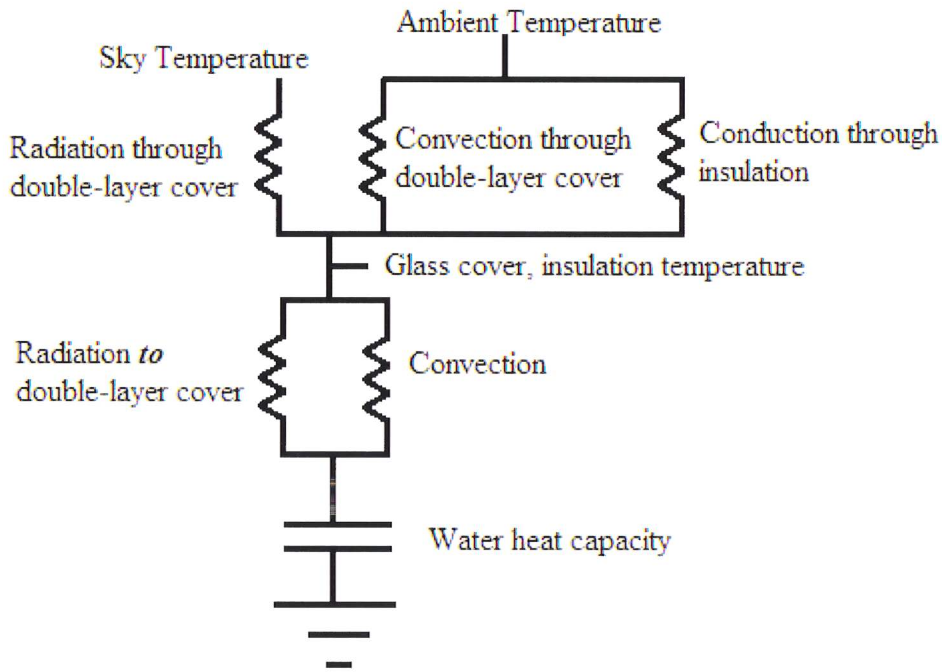


Figure 2.5. Solar water heater thermal network.

The uniform inner-frame temperature assumption is valid because the inside of the frame will be approximately the temperature of the air within the frame. Assuming that the weight of the water is much greater than the weight of the tank is valid because 40 gallons of water weighs 334 lbs and the tank weighs 60 lbs (15 % of the total). The temperature across the surface exposed to the sun is assumed to be uniform. The tank radiates to the insulation from the half of the tank not directly in the sun and the insulation is assumed to be highly reflective. Based on these assumptions—uniform inner-frame temperature, water and tank as a single unit, and uniform water-tank temperature—the model for the frame and for the cover is two concentric cylinders (Fig. 2.6) and an enclosed rectangular cavity at an angle (Fig. 2.7), respectively.

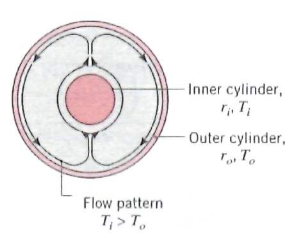


Fig. 2.6. Convection between enclosed concentric cylinders [5]

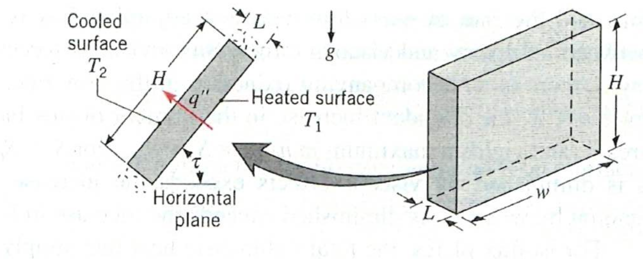


Fig. 2.7. Convection within an enclosed rectangular cavity heated on one side [5]

The other components of the thermal network are modeled as free and forced convection and gray body radiation.

2.4.2 Convection Between Enclosed Concentric Cylinders:

Bergman et al. presents empirical correlations for free convection in the space between two concentric cylinders, one of which is heated. In the EES model, the cylinder in the center, which represents the tank and water, is the heated cylinder. Equation 2.1 calculates the heat transfer between the two cylinders with the effective thermal conductivity (k_{eff}) calculated in Eq. 2.2 and the critical length (L_c) calculated in Eq. 2.3. Pr is the Prandtl number and Ra_c is the critical Raleigh number. Dimension and temperature parameter locations are shown in Fig. 2.2.

$$q = \frac{2\pi L k_{eff}(T_i - T_o)}{\ln\left(\frac{r_o}{r_i}\right)} \qquad (2.1)$$

$$k_{eff} = 0.386\left(\frac{Pr}{0.861+\mathrm{Pr}}\right)^{\frac{1}{4}} Ra_c^{\frac{1}{4}} \qquad (2.2)$$

$$L_c = \frac{2\left[\ln\left(\frac{r_o}{r_i}\right)\right]^{\frac{4}{3}}}{\left(r_i^{-\frac{3}{5}} + r_o^{-\frac{3}{5}}\right)^{\frac{5}{3}}} \qquad (2.3)$$

2.4.3 Convection Through an Enclosed Rectangular Cavity:

The convection shown in Fig. 2.3 is often used in the modeling of solar water heaters (Bergman, 588). Empirical correlations presented by Bergman et al. are used to calculate the heat flux through the two sides—the two glass layers—of the rectangular cavity. For angles less than the critical angle, calculated from Table 2.1, the Nusselt number is calculated using Eq. 2.4. The dimensions and temperatures are explained in Fig. 2.3. The terms in Eq. 2.4 with asterisks are set equal to 0 if the term is negative.

Table 2.1. Critical angle for various H/L ratios (Bergman, Table 9.4).

(H/L)	1	3	6	12	>12
τ*	25°	53°	60°	67°	70°

$$\overline{Nu_L} = 1 + 1.44\left[1 - \frac{1708}{Ra_L\cos(\tau)}\right]^{*}\left[1 - 1708\frac{\sin(1.8\tau)^{1.6}}{Ra_L\cos(\tau)}\right] + \left[\left(\frac{(Ra_L*\cos(\tau))}{5830}\right)^{\frac{1}{3}} - 1\right]^{*} \quad (2.4)$$

Because the length of the glass covers (H) is more than 12 times the distance between the glass (L), only the correlation in Eq. 2.4 is needed. The rectangular cavity correlation evaluated at various angles is plotted in Fig. 2.8 and this figure shows that the optimal glass spacing in order to minimize heat loss is at 0.5 inches.

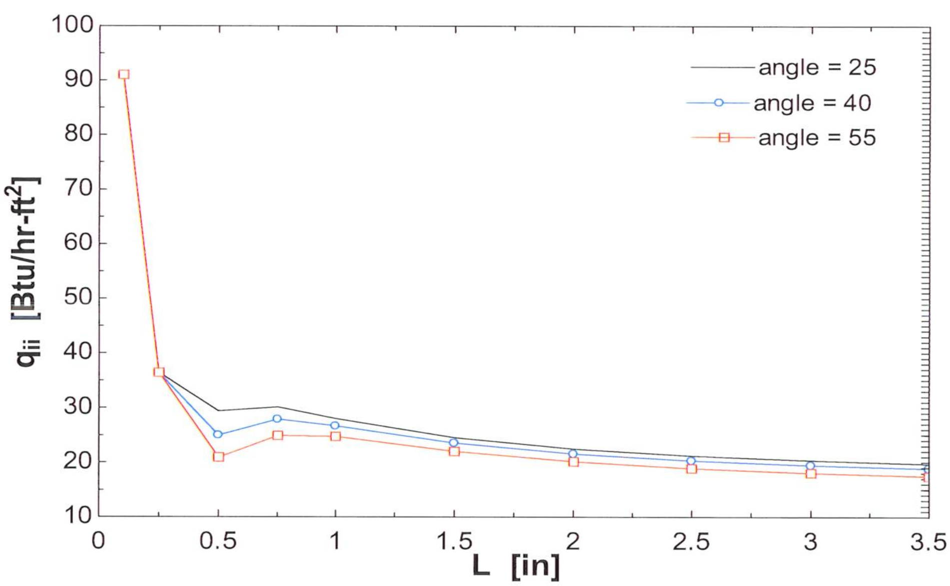


Figure 2.8. Flux through the rectangular cavity evaluated for the solar water heater with τ equal to 25°, 40°, and 55°.

3. Methods

Several tests were performed in order to analyze the design of the solar collector. The methods of the various tests are described below.

3. 1 Glass Layer Testing:

A small scale collector was built in order to run tests on single and double layers of glasses. The decision regarding whether to use single or double layers of glasses for the collector was based off these test results.

3.1.1 Experimentation:

Heating and cooling tests were performed in order to determine the optimum layer of glasses for the collector design. The test apparatus was a geometrically scaled down model of the collector prototype. The test apparatus contained a cylindrical water bucket that could hold 1 liter of water while the collector will have a cylindrical tank of 40 gallons. This was done to save resources in the light of limited project budget. Internal water and air along with external air temperatures were measured in order to determine whether single or double layers of glasses are better at gaining heat and preventing heat loss. These tests were performed indoors under controlled conditions using heat lamps to simulate the sun's insolation. A sketch of the setup is shown in Fig.3.1. The five arrows show the placement of thermocouple. The rectangular object in the center represents the water bucket that was filled with water and thermocouples were placed inside it. This was then covered with lid and remained in this state throughout all tests. The heat lamp (not shown in Fig. 3.1) was placed directly over the water bucket. To prevent thermocouples from absorbing direct radiation from the heat lamp, radiation shields were made for the ones measuring air temperatures. The other thermocouples were already shielded from direct radiation from the heat lamp. The arrows show the placement of thermocouples for measuring air and water temperatures. The heat lamp was placed overhead the water bucket shown in the center.

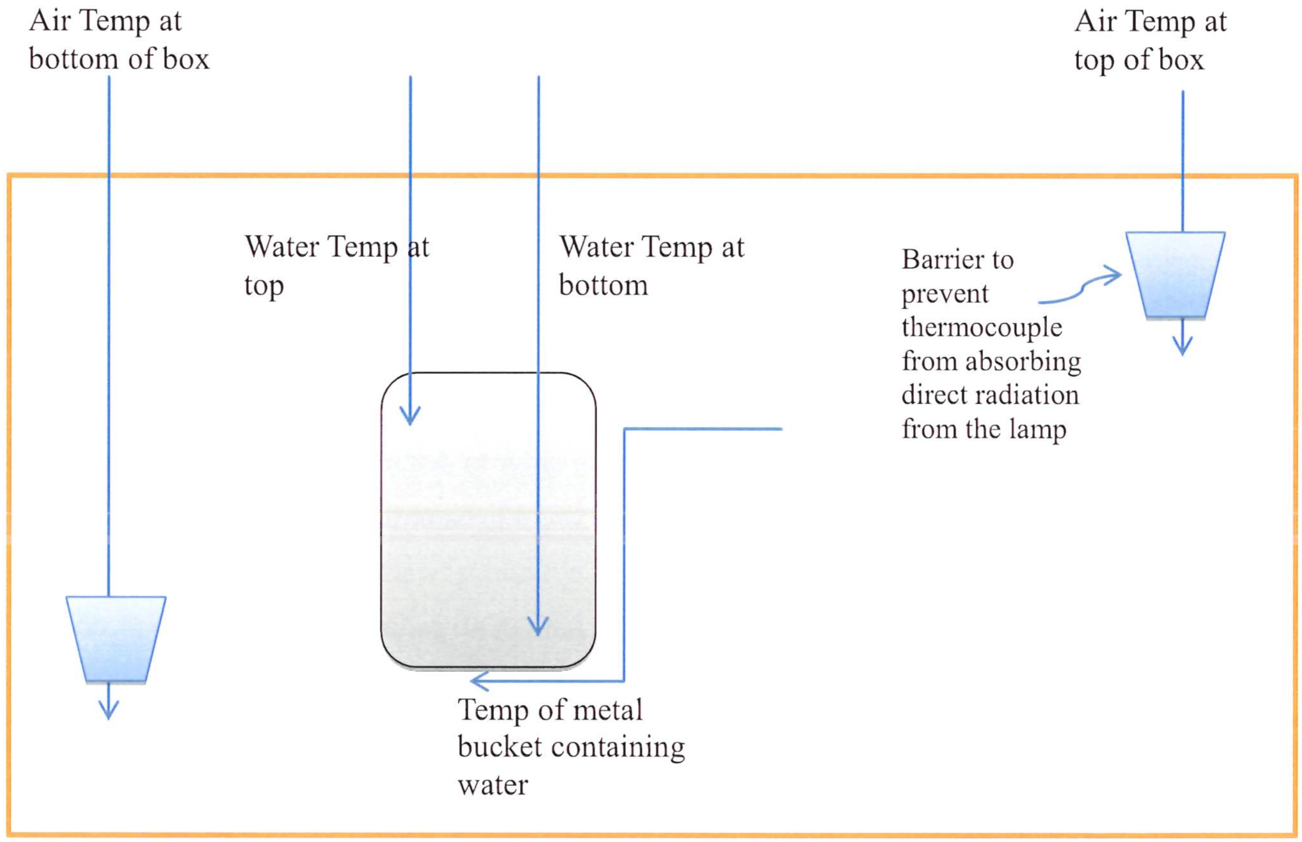


Figure 3.1: A sketch of the test setup, placement of water bucket and temperature measurements using five thermocouples

3.1.2 Preliminary Tests:

Preliminary tests using a scaled down test apparatus had to be performed because existing literature does not provide specific data for heat gain and loss for containers enclosed using tempered, regular glass or combinations of both. The experimentation involved testing single and double layers of glasses while keeping other variables such as coating, insulation type and thickness constant. A total of eight trials were performed, the test matrix for which is shown in Table 3.1 The "daytime" (i.e. heating) and "night time" (i.e. cooling) conditions were simulated by setting the heat lamps to ON or OFF respectively.

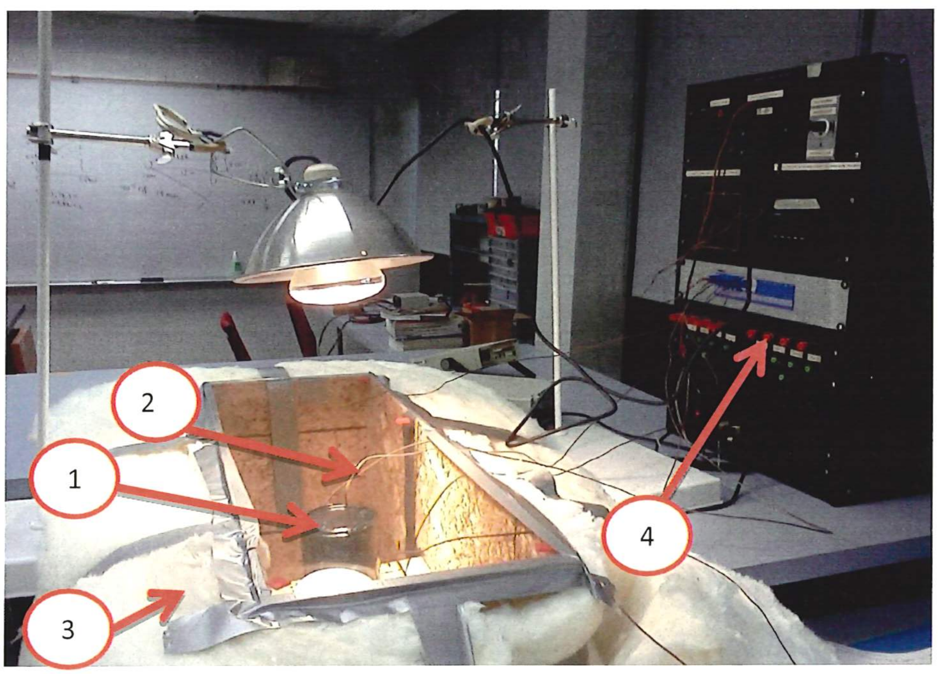
Table 3.1. Test Matrix to determine if single or double layer of glasses provides optimum heating and cooling results.

	Heating	Cooling	Heating	Cooling
	Natural Convection		Forced Convection	
Tempered Glass 1 Layer				
(Tempered + Regular) 2 Layers				

Heating and cooling tests were run for approximately 60 and 120 minutes respectively. Cooling tests were run for longer because it required more time to cool the water to its initial temperature once it had been heated.

3.1.3 Experimental Apparatus:

Figure 3.2 shows experimental setup for measuring temperatures during and heating cooling tests using single or double layers of glasses.



1: Cylindrical Water Bucket 2: Thermocouples 3: Fiberglass Insulation 4: DAQ

Figure 3.2. Experimental Setup to measure internal air, water and external air temperature during heating and cooling of miniature prototype.

The test apparatus consists of an outer wooden box measuring 12 inches wide, 36 inches long and 40 inches deep as shown in Fig. 3.2. The inner sides of the box are covered with fiberglass insulation on all sides. The lateral and bottom insulations are 9 inches thick. Due to space constraints, lateral insulation is put on the outside of the box while the bottom insulation is put inside the box. This detail is presumed to not affect the final temperature measurements because in both cases, it achieves the same result of preventing heat losses. The depth of the test apparatus and thickness of bottom insulation are identical to that in the collector prototype. The same depth ensures that the results from this preliminary testing can be applied to predict the behavior in the geometrically scalable collector prototype. Inside the wooden box, there is a cylindrical metal water bucket painted matt black just as the 40 gallon tank in the collector prototype. The water bucket has an internal volume and holds about 1 liter. Based on this volume and specific heat capacity of water along with the power rating of heat lamps, it was estimated that the water temperature would reach about 120° F from its initial temperature within 14 minutes. The measured time to achieve this result was 60 minutes.

3.1.4 Experimental Procedure:

The water bucket was filled with water to the brim. Two thermocouples were inserted inside the water bucket such that one of them measured lower and the other measured upper water temperatures. Another two thermocouples were placed inside the wooden box such that they measured lower and upper air temperatures. The fifth thermocouple simply measured external ambient air temperature. The heat lamp was turned ON and the temperature measurements were begun simultaneously using LabVIEW. The position of the water bucket and heat lamp was unchanged for all experiments.

After 60 minutes, the heat lamp was switched OFF and temperature measurements for cooling tests begun. After approximately 120 minutes, a table fan under a low speed setting (about 2 m/s) was used for forced convection tests. The same speed setting was used throughout all forced convection tests to maintain uniformity. Heating and cooling tests were repeated under forced convection conditions.

For double layer testing, the top layer of tempered glass was removed and regular glass was placed. A wooden frame of about 1 inch thick was placed between the regular glass and the tempered glass. In both tests, tempered glass instead of regular glass was placed on the top because the collector design requires tempered glass for protection against inclement weather conditions such as hail and minor accidents. The same tests performed with a single glass layer were repeated for double layers.

3.2 Testing of the collector prototype:

A collector prototype was built to test for the functionality of a 40 gallon collector. The temperature of water was measured over time to quantify the heat gain and heat loss, and to evaluate the proposed design. The prototype also helped determine the mechanical performance of the collector using qualitative evaluations. The durability and longevity of collector was tested by exposing it to different weather conditions like sunlight, and rain.

3.2.1 Experimentation:

The final design of the solar water heating system specifies two 40 gallon solar collectors placed in parallel. Because the two collectors will operate independently, performance testing of a single collector prototype is sufficient. In addition, only a single prototype collector was affordable for the project's budget. A single 40 gallon collector was prototyped and tested as part of the actual experimentation process. One of the goals of the testing was to see if water temperature of greater than 120°F could be reached in 40 gallon tank during the day. If a single collector reached the desired temperature of water, then 40 gallons of hot water could be easily obtained from one collector. Two of these collectors in parallel would output 80 gallons of hot water. In addition to testing the heating up of water during the day, another goal of the prototype testing was to assess the ability of the collector to retain heat at night. Temperatures at three locations in the water tank, as well as air temperatures at two locations within the collector frame were measured during a 48 hour period. Tests were performed on the roof of Mars Mclean Science building and the ambient weather conditions (wind speed, air temperature, and solar insolation) were recorded at multiple times during the 48 hour testing period. It is important to note that during the testing, the water stayed still inside the tank. In the actual design, the water will flow through the collector.

3.2.2 Prototype Design and Experimental Setup:

The collector prototype consisted of a 40 gallon tank, a wooden frame, and tempered glass cover for the frame. The tank was painted black (emissivity of approximately 0.8-0.9), lay horizontally, and filled with water. It was kept inside a wooden box frame with the fiber glass insulation that was 9-1/4 inches thick. The tempered glass cover of ¼" thickness was placed on top of the tank and the frame to entrap a large amount of heat using greenhouse effect, and also protect the tank from rain. The dimensions of the frame were 80 in X 40 in X 36 in, and it was made out of wood recycled into OSB sheathing of wood. The collector was positioned at an angle of 40 degrees to the roof, and facing in the south direction. Figure 3.3 shows the picture of the collector prototype, and setup for testing. The testing was conducted on the roof of Mars McLean Science (MMS) building.

Figure 3.3 Experimental setup of the collector prototype.

For testing purposes, the thermocouple wires were connected to take measurements of the temperature of water inside the tank, and of air inside as well as outside the box. The T-type thermocouples enable measurements of air and water temperature to be taken by using a handheld thermometer. Six thermocouples were attached to the prototype; five of them are shown in Fig. 3.4. The sixth thermocouple that measured the temperature of air outside the box is not shown in this figure. As shown in figure, the thermocouples T1 and T2 were placed hanging inside the box, T1 being to the east and T2 towards the west. This was done to find temperature distribution of the box as the sun goes up and then down. The temperature at different places inside the box is expected to be different, and T1 and T2 help measure the estimated horizontal temperature distribution of the box. Both thermocouples were placed inside a duct tape cone which was used to shield the thermocouples from the sun as best as possible. The thermocouples T3, T4 and T5 were placed inside the tank filled with water to measure the vertical temperature distribution inside the horizontal tank. The measurement of water at three different points helped study the temperature distribution in the water. Additionally, a thermocouple was placed in shade behind the box to measure the ambient air temperature. To keep track of the test and weather conditions, a weather station device was used. This weather station monitors all the conditions (solar insolation, temperature, humidity, etc.) on the MMS rooftop, and could be used to take weather data from the display. Temperatures recorded over time using several thermocouples provided some information necessary to determine the performance of the 40 gallon batch heater prototype.

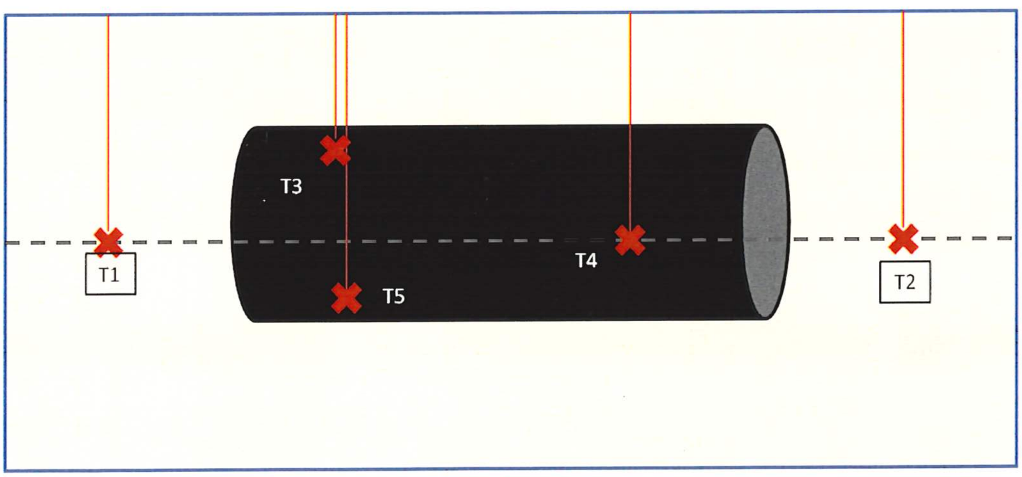


Figure 3.4 Vertical Plane Diagram of Thermocouples of the Collector Prototype.

3.2.3 Experimental Procedure:

The data was recorded for two types of tests—heating and cooling of the collector over time. The data was collected continuously for two days, and at discrete time intervals. The data was collected for two days in order test the multiple day-night heating and cooling cycles, and to be able to gauge how the heat loss at night and the heat gain during the day affects the water temperature from one day to another. The tests were conducted on the MMS roof and the temperature of each thermocouple was measured over discrete time intervals by members of the design group. The test matrix for this test included the test conditions, the date and time of the test, wind speed and direction, outside temperature and humidity, solar insolation, the temperature of water and the box, the ambient temperature outside the box. A brief check was performed to note down any other conditions like rain, or fogging on the glass. The "daytime" (i.e. heating) and "nighttime" (cooling) tests were performed by conducting tests in the presence and absence of sunlight. The readings were taken at an interval of one hour during the daytime. The night time readings were taken at an interval of approximately 8 hours.

4. Results

Results from miniature prototype test, 40 gallon test, anti-freezing test, , and full system test are described and analyzed below.

4.1 Prototype Results:

The results from the small prototype test enabled decisions to be made about the materials used for the 40 gallon prototype.

4.1.1 Heating Test Results:

The data from the heating tests were linearized using the formula shown in Eq. 4.1. Data linearization is based on the equation for heat transfer due to convection shown in Eq. 4.2. The solution to Eq. 4.2 is Eq. 4.3.

$$T_{linearized} = \ln\left(\frac{\theta}{\theta_i}\right) = \ln\left(\frac{T_\infty - T}{T_\infty - T_i}\right) \tag{4.1}$$

$$mC_p\left(\frac{dT}{dt}\right) = hA(T_\infty - T) \tag{4.2}$$

$$\frac{T_\infty - T}{T_\infty - T_i} = e^{\frac{-hA}{(mC_p)}t} \tag{4.3}$$

The slope of the linearized temperature plotted against time is a quantity useful to find the relationship between convection coefficients in the cooling and heating tests because area (A), mass (m), and specific heat (C_p) are held constant. The only variable is the convective heat transfer coefficient (h)—slope is independent of time (t). The results of the linearization are plotted in Fig. 4.1.

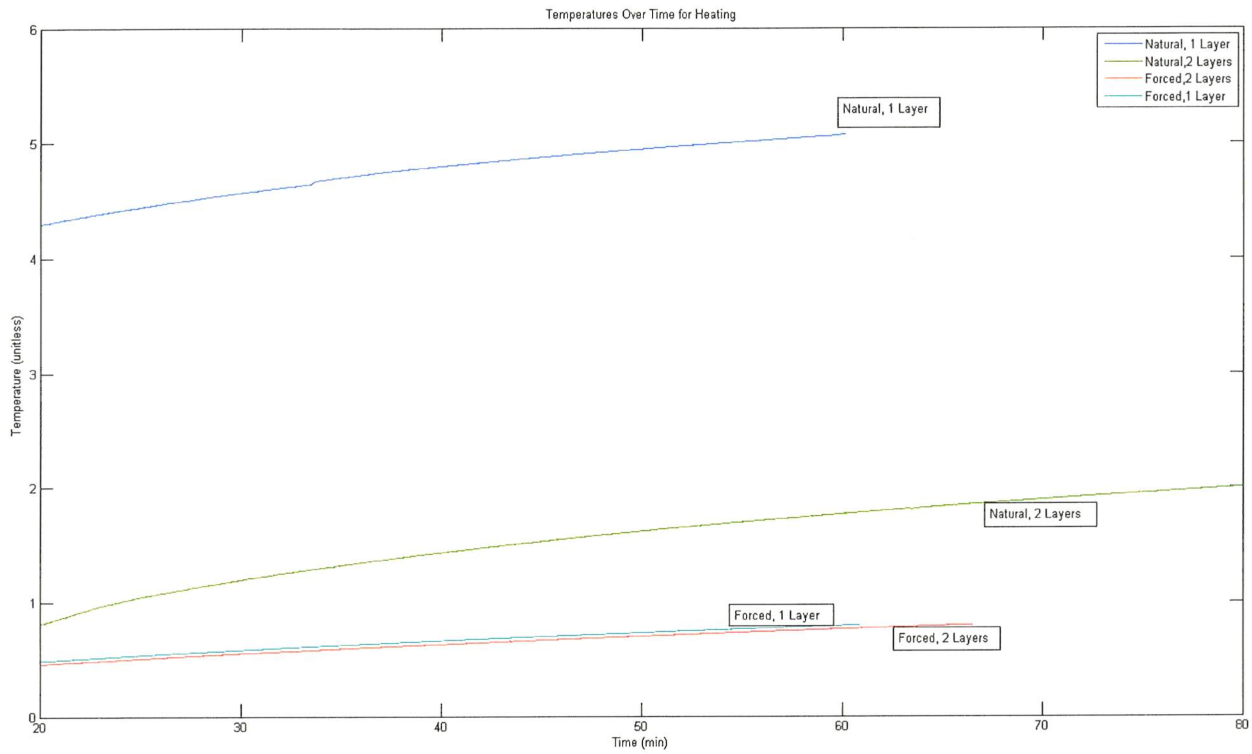


Figure 4.3. Linearized plots for average temperatures during heating tests for single and double layers under natural and forced convections.

Table 4.1 shows the slope analysis of the linearized temperatures from the heating tests.

Table 4.4: Results from heating tests for single and double layer of glasses under natural and forced convection conditions

Heating							
Natural,1 Layer		Natural, 2 Layers		Forced, 2 Layers		Forced, 1 Layer	
(min)	Unitless	(min)	Unitless	(min)	Unitless	(min)	Unitless
22.53	4.376	33.98	1.297	24.67	0.5014	25	0.5344
56.75	5.032	63.57	1.812	52.7	0.7177	52.94	0.7506
Slope‡:	0.01917		0.017405		0.007717		0.007738

‡Equal to $hA/(\rho VC_p)$

4.1.2 Cooling Test Results:

Using the same method of analysis as in §4.1.1 Fig. 4.2 shows the linearized performance of the miniature prototype in cooling.

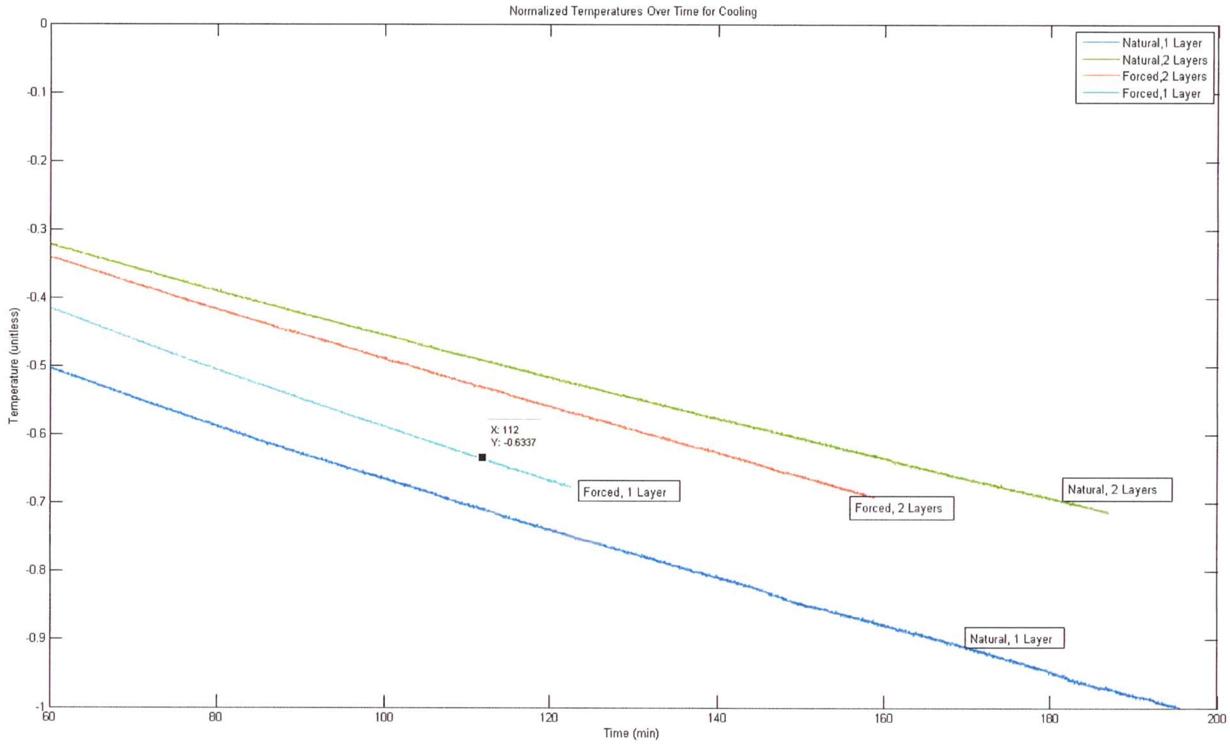


Figure 4.4. Linearized plots for average temperatures during cooling tests for single and double layers under natural and forced convections.

Table 4.2 shows the slope analysis results for the cooling test.

Table 4.5. Results from cooling tests for single and double layer of glasses under natural and forced convection conditions.

Cooling							
Natural,1 Layer		Natural, 2 Layers		Forced, 2 Layers		Forced, 1 Layer	
t (min)	θ (Unitless)	t (min)	θ (Unitless)	t (min)	θ (Unitless)	t (min)	θ (Unitless)
62.95	-0.5162	74	-0.3691	68.77	-0.3749	62.63	-0.4266
186.8	-0.9676	171.4	-0.6682	146.6	-0.6487	112	-0.6337
Slope‡:	-0.00364		-0.00307		-0.00352		-0.00419

‡Equal to $hA/(\rho VC_p)$

4.1.3 Comparison of Heating and Cooling Tests:

The slopes obtained from linearized plots were compared for heating and cooling tests. The difference in slopes indicated whether single or double layers of glasses gained or lost heat quicker under natural and forced convection conditions. This also indicated which one was better for a given condition. Table 4.3 lists below by how much percentage single or double layers are better during heating or cooling.

Table 4.6: Comparison of results from heating and cooling tests to determine single or double layer of glasses provides most desired results during natural and forced convection conditions

During Cooling		**During Heating**	
% that 2 layers are better		% that 1 layer is better	
Natural Convection	Forced Convection	Natural Convection	Forced Convection
15.75	16.14	10.14	0.28

It can be seen that two layers of glasses are better during cooling since it does not lose heat as much quickly. However, this difference is negligible for natural and forced convection. This indicates that additional convection losses due to a higher air velocity over the surface of top glass layer are minimal. This result is in contrast to the initial expectation that two layers of glasses will reduce additional heat losses due to convection as air velocity continues to increase. This result proves however, that two layers of glasses have about 16% lower heat loss than a single layer of glass. This is a desirable feature since lower heat loss during night will keep the water relatively warm inside the tank overnight for consumption in the morning.

During heating, single layer of glass gains heat about 10% more heat than double layer during natural convection. This heat gain is almost negligible under forced convection. From these two results, it can be inferred that single layer of glass gains more heat but also loses more heat under natural convection conditions. Similarly, the single layer of glass loses more heat but not gain as much during forced convection.

If cost and weight of the final batch water heater design were not important considerations, the logical choice would be double layers of glasses. The tempered glass layer for the 40 gallon prototype costs about $127 and weighs about 50 lbs. Similarly, the regular glass layer costs about $60 and weighs about 35 lbs. Considering the high cost and weight due to the additional layer of glass, a single layer of glass confers good heat gain opportunities without incurring significant heat losses. Furthermore, the heat loss could be minimized by using additional insulation and an air tight wooden box. In this preliminary testing, the top layer of tempered glass was not sealed with the wooden box. This could have introduced some convection losses that could be avoided in the final prototype. From these results and a cost benefit analysis, it was determined that a single layer of glass would be the optimum choice for glazing in the final batch water heater design.

4.2 40 Gallon Test Results:

The purpose of building a collector prototype was to test its functionality. Evaluating the effectiveness of our collector in capturing solar energy during the day and minimizing thermal losses overnight is a main concern for this design. Two quantitative tests were performed; water temperature and thermal losses, and one qualitative test, mechanical integrity was conducted by the use of the 40 gallon prototype. The water temperatures were measured in order to determine if it reached 120°F and if so, for how long and at what time of the day. Similarly, thermal losses were measure in order to quantify heat losses overnight. In addition, the mechanical integrity of the collector design was assessed throughout the duration of the quantitative testing.

4.2.1 Water Temperature Results:

As mentioned in § 3.2.3 five thermocouples were used to record the temperature in the water and in the box over a period of two days. The results from these recording are displayed in the figure below, where the bold line represents the desired water temperature of 120°F.

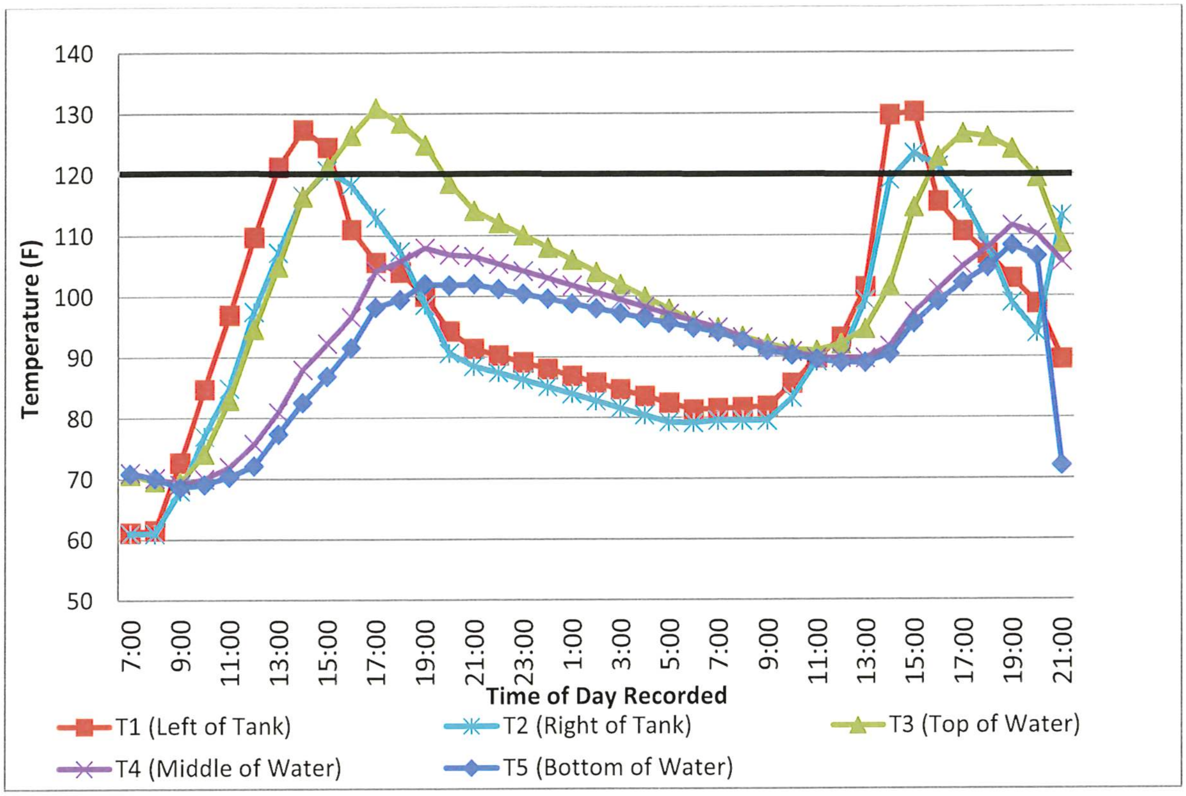


Figure 4.3. Outdoor testing raw data.

While the trends of all the thermocouples are important, the most important results come from the water temperature of the top of the tank, the water temperature of the middle of the tank, and an average of these water temperatures. This is because the water that is used by the household will be drawn from the top of the tank and therefore, it is most accurate to represent an average of the top and middle water temperature as a conservative estimate of the temperature of the water being drawn to the house. The following graph represents the data which was found most important when determining the effectiveness of the solar water heater.

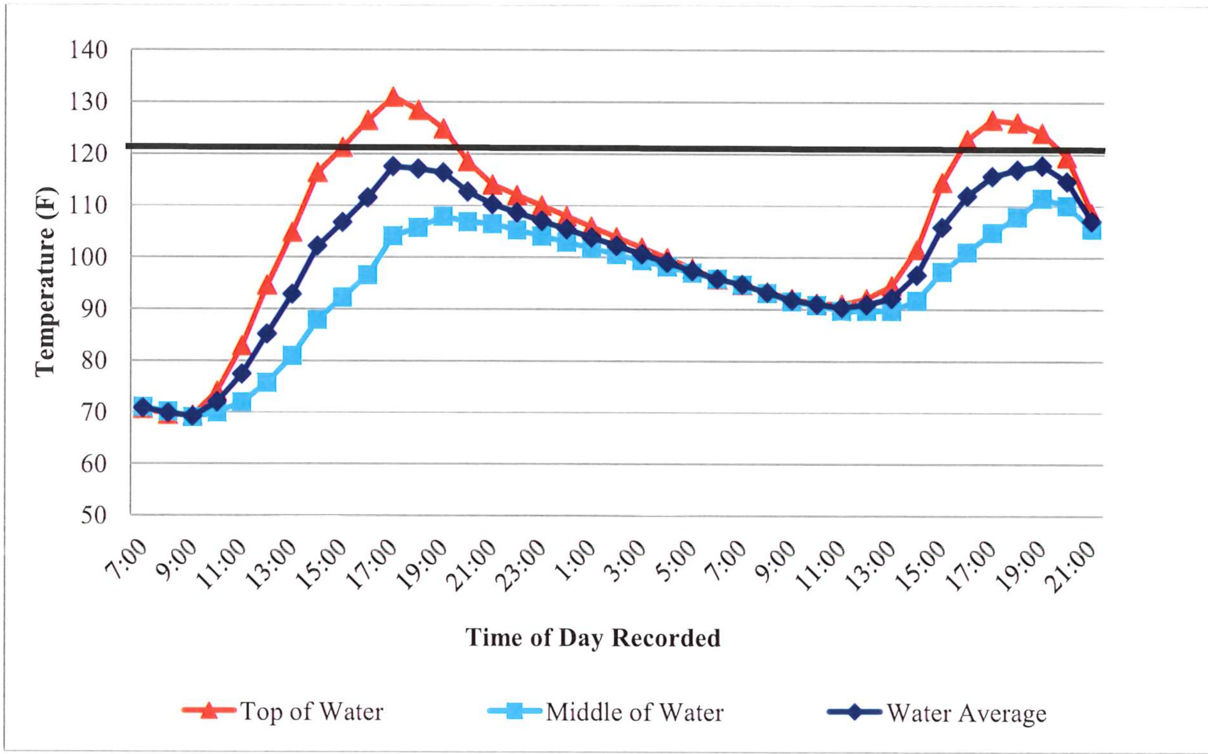


Figure 4.4. Water temperatures measured at the top and middle of the tank and an average of those temperatures as recorded over two days.

The weather conditions for both days of testing are important when analyzing the data. The average ambient temperature for day one is 75°F and the average ambient temperature for day 2 is 74°F. The solar insolation, which is a measure of solar radiation energy received on a given surface area in a given time, was recorded each hour during the testing and calculated for each day. The solar insolation for day one 6,372 (W/m^2) and for day two 4,738(W/m^2). This indicates that day two was cloudier than day one which is the effect of the maximum temperature of day one greater than the maximum temperature of day two.

There are a few trends which can be seen from this graph. The start of the water temperature is about 70°F which is the same temperature as incoming tap water from SAWS. The first day it takes longer to heat the water to the desired temperature than the second because it is starting at a lower temperature. However, for both days the top of the water stays above 120 degrees for about 5 hours between the hours 3 and 7 pm. From research it was determined that 20% of hot water usage for a family is during these hours of 3 to 7pm. This information is important when determining the convenience of the pre solar water heater to the household.

Another trend observed is the overnight heat loss measured. It is observed that while the temperature does decrease during the evening, it never gets below 90°F. This is important because in the morning the water will still be hot, but the electric heater will need to be turned on if a family wants to use it at 120°F.

4.2.2 Thermal Losses:

The thermal losses overnight are more closely measured in order to determine ways in which the design can be improved. The heat losses for the top, middle and bottom water temperatures overnight are displayed in Fig 4.5. As predicted the top of the water loses the most heat during the night, because it is closest to the transparent glass which has no radiative barrier to keep the heat enclosed during the evening.

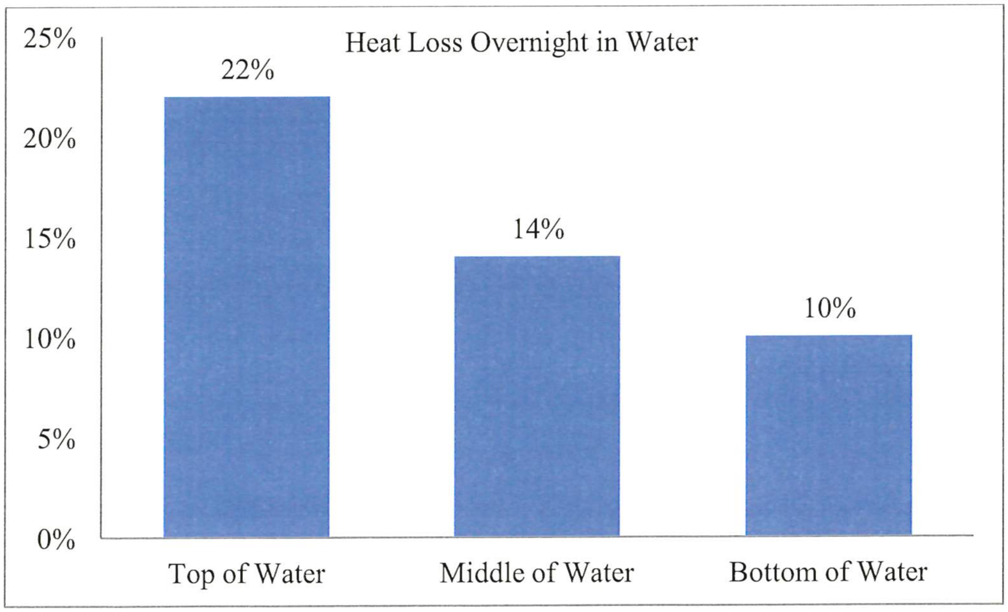


Figure 4.5. Percentage of heat loss measured at the top, middle and bottom of the water.

Once the heat loss with no barrier was observed, two nights of additional testing were conducted where a radiative barrier was placed on top of the glass during the night hour. The results from these tests are displayed in Fig. 4.6.

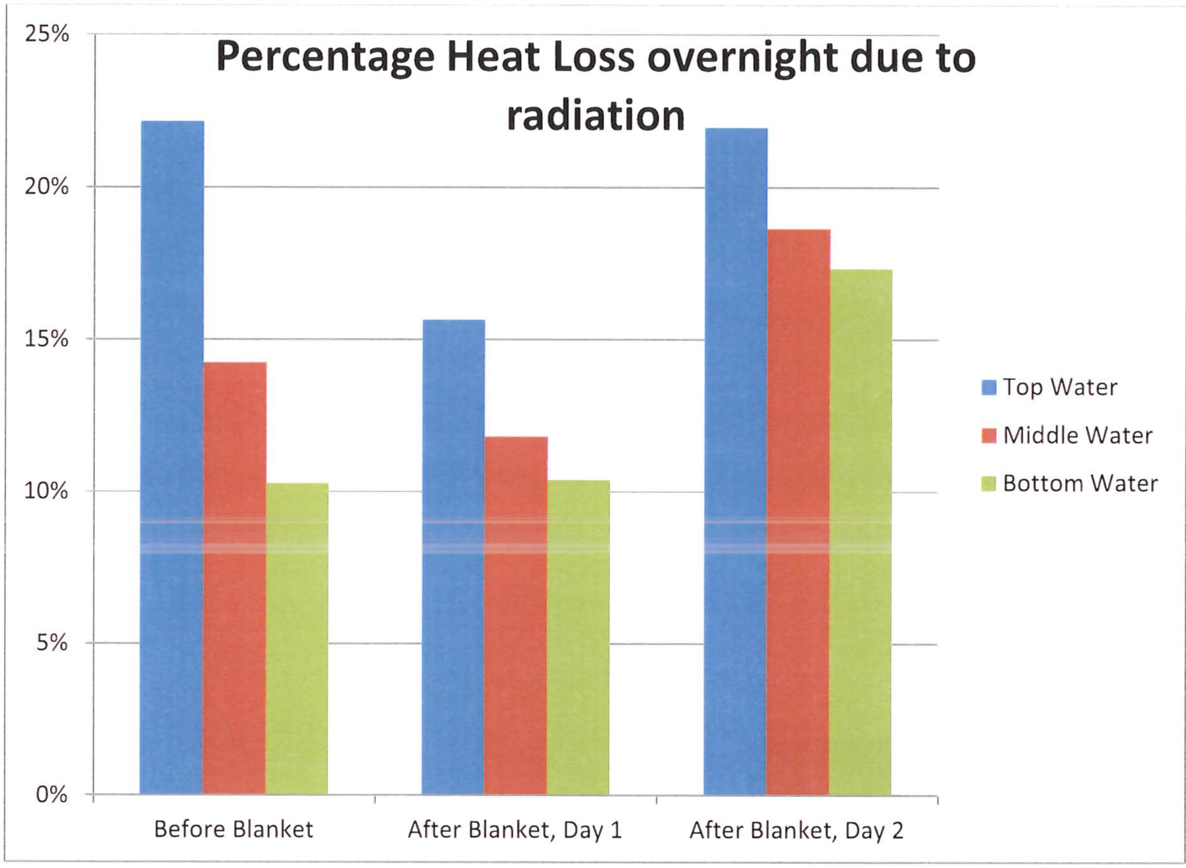


Figure 4.6. Comparison of overnight heat loss with and without the radiative barrier.

4.2.3 Mechanical Integrity:

The lesson was learned is that sturdier material for building the frame should have been considered instead of the wood that which is currently being used. After 30 days of being outside, it was noticed there was some warping at the base of the frame. Ideally, the collector would be re-designed using a sturdier material for the frame. The most ideal material to use would be pressure treated CD exterior plywood because it is the cheapest cost for the most durable material and will not add significant weight to the overall batch collector. The analysis of the considered materials will be discussed in § 5.4.1. In addition to the warping of the wood, the design of the attachment of the glass would need to be improved. The simple L brackets were ideal for testing; however, this would not be the ideal design of the consumer usage as it makes it very difficult to access the tank if any problems were to arise. All other materials, after being placed in the sun on the roof for 30 days, are desirable in the final design of the batch collector.

4.3 Resistance to Freezing

One of the important factors when evaluating the design is to test is whether it will freeze in extreme weather conditions or not. This is also important for the SRCC certification. The anti-freeze verification was done by using the extreme weather conditions in the EES model. In the design, there are two main components to be considered for freezing of water--the collector (batch heater) and the pipes that connect the collector to the attic of the house.

For the collector, the large volume of hot water prevents freezing. For the pipe, the analysis was performed using an EES model where very extreme weather conditions were used (Sky temperature of 14 F, or -10 C; Wind speed of 50mph). This weather is the most extreme weather that San Antonio has seen in 80 years. The hypothesis is that, if the water in pipes does not freeze under these conditions, then it will most likely not freeze in normal San Antonio weather. The model was designed based on water inside a pipe 1 m long with high density polyethylene insulation of 0.1m thickness around it. Figure 4.7 shows that over a period of 12-14 hours, the water temperature in the pipe never reached below 36 F, which is higher than the freezing point of water. Since the water did not reach the freezing point in extreme weather conditions, it is not likely to freeze in San Antonio cold weather either.

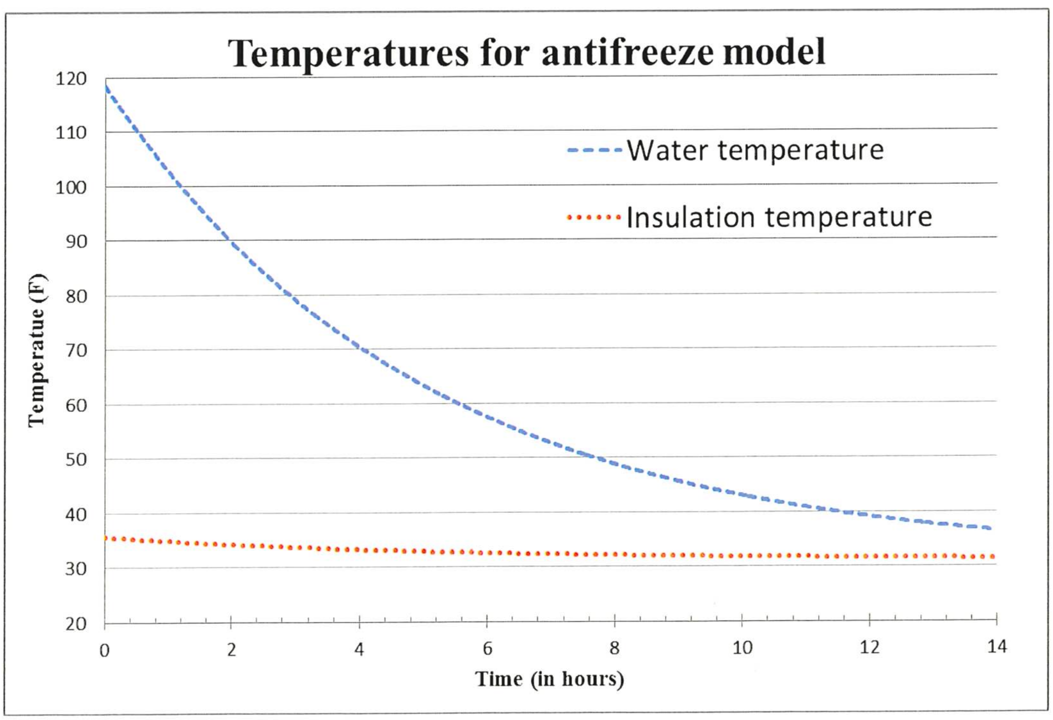


Figure 4.7. Extreme weather simulation of exposed pipe.

The claim that water inside the pipe won't freeze is strengthened by two facts. First, the pipes are never directly exposed to this weather, they are connected from the solar collector box to the house attic, hence very little exposure to cold. Second point to be noted is that the water is used mostly in the morning or in the late evening. This means that water would be never be stationary for 14 hours, making it less likely to freeze.

5. Conclusions and Recommendations

During the course of the project, SWAT team was able to design, build and test a batch water heater that acts as a preheater and saves consumers about $261 per year. It costs about $3000 including installation and pays itself in about 25 months given the rebates from local utility - CPS Energy and tax credits from the federal government. The collector does not heat up 80 gallons of inlet water up to at a temperature of 120°F at all times of the day but the end user continues to get hot water at all times of the day irrespectively since this design acts as a preheater. One of the goals of a preheater is to reduce heating load for the backup electric water heater and the SWAT design meets this goal very effectively. The next few paragraphs will evaluate whether or not the design meets its stated constraints and objectives. This is an important step in assessing success during the design of every product.

5.1 Hot Water Supply and Affordability

Two of the project constraints were: providing 80 gallons of potable hot water and making the design affordable for low-income households of San Antonio. After testing and analysis, it was realized that both constraints had to be evaluated together because of its interdependence. In order to evaluate if the project meets the affordability criteria the team needed to determine the amount of annual savings for a household using the batch water heater. The annual savings depended on the heating load offset by using the SWAT preheater.

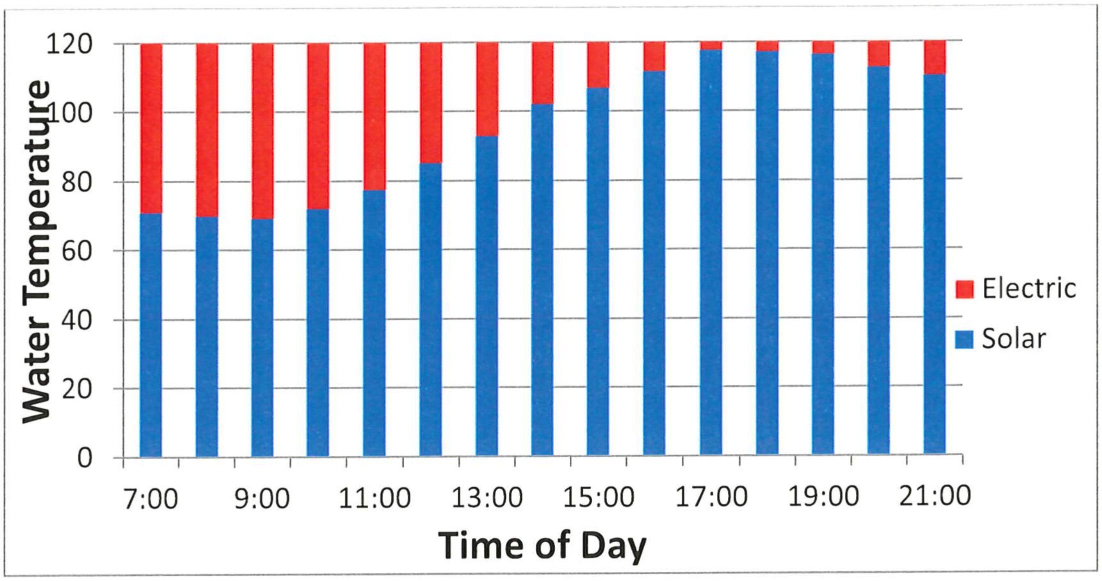


Figure 5.1: The sharing of hot water load by solar preheater (blue) and the backup electric water heater (red)

In Fig. 5.1, the blue bars represent the average water temperature inside the collector at different times of the day and the red shows the additional temperature increase required in order to reach the desired temperature of 120°F. Typically, mornings (7-10 am) and evenings (6-10 pm) account for about 30% and 20% domestic hot water consumption. The collector provided hot water at 90°F and 120°F during the morning and evening respectively on the test day. This test data was normalized for the given insolation on the test day. Based on average monthly solar insolation in San Antonio, the team was able to extrapolate test day results for savings each month. The sum total of these savings was used to calculate annual savings, the details of these calculations are shown in Appendix C. Using the water temperature data during testing of the collector and domestic hot water usage profile, the team calculated an estimated annual savings of $261.85.

Initially, the cost constraint was set as $3200, based on subsidies from the utility and tax incentives from the federal government. The initial cost was based on an estimated annual savings. After calculating annual savings based on test results, the cost constraint was revised to $2,977. The actual cost of the system prototype is about $3,000 including $1,000 for installation. It can be seen that the design costs $23 more than the revised cost constraint. This is within 1% of the constraint and the revised payback period for the design is about 25 months instead of 24.

5.2 Meeting SRCC Certification

The rebate from CPS Energy that offsets the cost to the end-user is dependent on the design meeting SRCC standards and obtaining a certification/rating. Therefore, it is essential that the design meets all conditions set forward by SRCC. SRCC conducts an elaborate set of tests before providing a performance rating. Figure 5.2 shows some of the major tests that will be performed. The checkmarks show these tests have been performed by the team and half-check shows it is in the process. The remaining two have not been tested but were considered during the design.

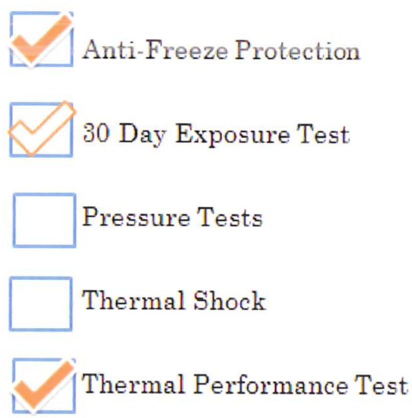


Figure 5.2: Major Tests Performed by Solar Rating and Certification Corporation (SRCC) in order to provide a rating.

The team is confident that the design will successfully pass the testing for anti-freeze conditions because the theoretical model has assured us anti-freeze protection as shown in § 4.3 above. Similarly, the SRCC exposes the collector to the sun for 30 days and assesses any structural damage. So far, the collector prototype has been exposed to the sun for more than 30 days and there have not any been major damages expect for warping of the frame which is addressed in the final design. Furthermore, SRCC conducts pressure tests on the collector. These tests have not been performed but the tank is fitted with a pressure release valve to protect against building high pressures inside the tank. SRCC also conducts thermal shock experiments on the collector. To satisfy this requirement, tempered glass was used which provides better protection against sudden changes in temperature. SRCC also performs thermal tests that the solar collector design was designed to withstand and a rating for this design based on the results.

Although this design is not currently SRCC certified, the design is on track to become certified with more time and finances.

5.3 Use of local and recycled materials for design

One goal of the project was to use recycled materials to keep the design as green as possible. When researching using recycled materials, as opposed to new, a few problems arose such as cost, availability, and durability.

Two items that were purchased recycled or used for the prototype are the tank and the wooden frame. The frame was recycled plywood that even though was less expensive ended up warping rather quickly, and therefore, the tradeoff of recycled wood is not desirable in the final design. The tank was donated to the group by Solar San Antonio and required some restoration labor in order to get to a useable tank. Normally, tanks have a life span of approximately 25 years, and usually replaced because of rusting on the inside. If a tank is used in the design that is recycled, it is likely that the tank will rust more quickly and contaminate the water.

For the collector prototype the minimum of each component was purchased, and therefore, finding recycled materials was not difficult. If this was to be manufactured in bulk, however, then the availability of the items would become an issue.

5.4 Recommendations

After the design was evaluated, there were many aspects of the final product that could be improved upon in order to create a more durable and successful design for the consumer.

5.4.1 Design Improvements

Using the radiative barrier saved an extra 0.25 kWh in the collector compared to not using it. With close start temperatures (42.6 °C and 41.97 °C for with and without the barrier respectively) and assumption that both nights are comparable it was calculated that the barrier yielded a savings of 2.4 cents per day. With the CPS subsidy, the savings is about $54 a year. Because the cost of the radiative barrier and a high torque motor exceeds $54, the system upgrade does not make fiscal sense. The radiative barrier, thus, is not recommended for implementation.

The wood choice of pressure treated CD exterior plywood would add $28.97 per sheet of plywood used. In the prototype 5 sheets of plywood were used, and therefore it is expected to increase the cost of the design by $109.85. This new type of plywood, however, is treated to withstand all weather conditions. Other types of wood did have higher ratings; however, the CD exterior plywood is sufficient material for the extent of the project for the price tradeoff.

In addition, it was previously mentioned that the glass would need to be attached using a different technique. The design would best be improved by creating a cutout on the backside of the wood which would allow access to the tank by the consumer instead of through the pane of glass. This would allow for the glass to be permanently attached to the wooden frame without the needing to open it in case of maintenance. The glass would be sealed by using a c-channel design, where the width of the glass is fit exactly to the C-channel width that is connected to the wooden frame.

5.4.2. Reduce Collector Size

The collector is over-sized currently and this was done intentionally to allow room for testing and modifications, if necessary during the prototyping process. This over sizing contributed to bulkiness and extra weight to the collector. Therefore, the team recommends that the collector size be reduced by at least 12 inches in length. This will reduce the final length of the collector frame to 68 inches. Since the tank is 40 inches long, it will leave about 14 inches on both sides for insulation and plumbing. It is understood that there will be less space for insulation so, a thinner layer of insulation should be considered. Most of the heat loss at night occurs due to radiation through the glass and therefore, marginal effect due to a thinner layer of insulation should be minimal. If there are opportunities for dimension reduction along breadth and width, these should be considered as long as there is sufficient space for plumbing and insulation.

5.4.3 Product Appeal to Consumers and Installers

For this product to be successful, it has to appeal to consumers and installers. It has been determined from previous studies that the biggest obstacle to adoption of solar water heaters is public perception of solar power as expensive and unreliable. A considerable effort needs to be spent either directly or indirectly through other organizations, such as Solar San Antonio, to educate the potential customers about reliability and financial appeal of this solar water heater.

Emphasis should be placed on the fact that this is a preheater and end-users will continue to get hot water in all seasons while savings hundreds of dollars every year. For greater acceptance, aesthetics of this design needs to be improved to blend in with the roof structure. If there are ways to mount it on the ground, these should be considered as alternatives to mounting it on the roof, if preferred by end-users.

5.5 Conclusion

Before this design can be used by consumers, system integration tests between the designed preheater and the electric water heater will be necessary. It involves simply connecting the outlet of the preheater to the inlet of the electric water heater. In essence, the project started out as a vision and has been now transformed into a product that allows the user to receive 80 gallons of hot water at a desirable temperature, irrespective of weather conditions while saving about $261 annually. Therefore, this design is appealing to low-income households as well as everyone else.

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Appendix-A: Drawings and Assembly

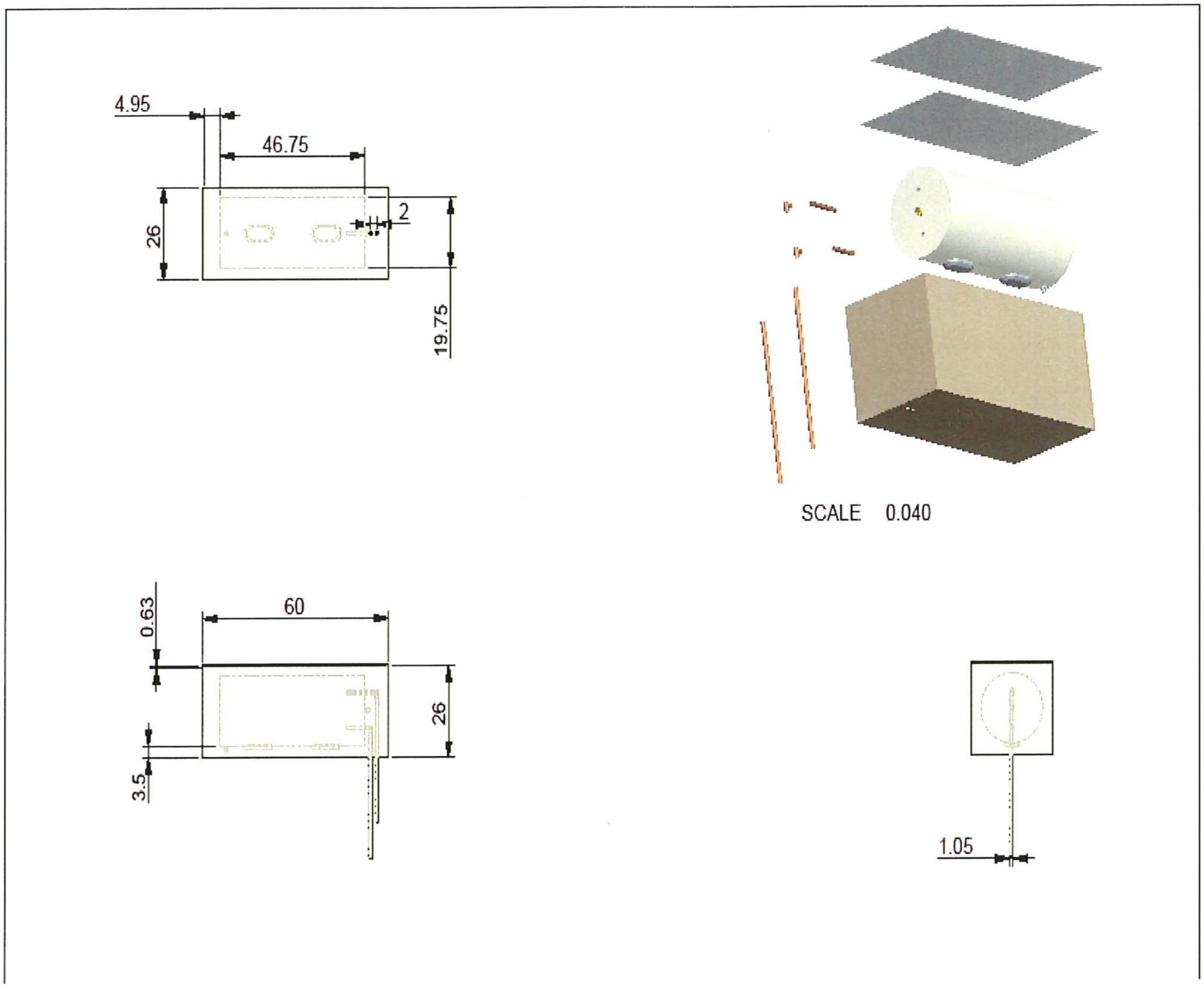

Figure A-1: Drawing showing all the parts of batch collector

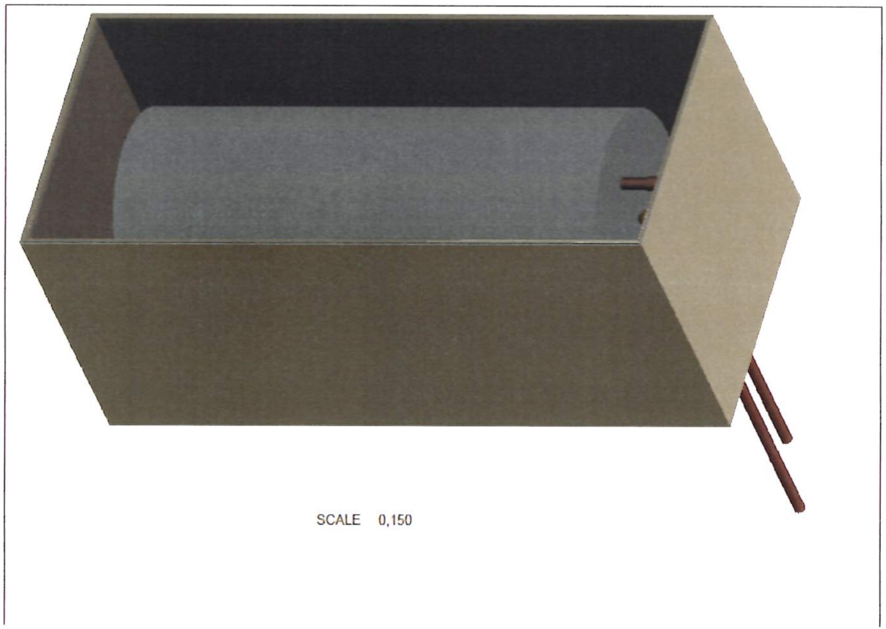

Figure A-2: Drawing showing collector for the batch heater

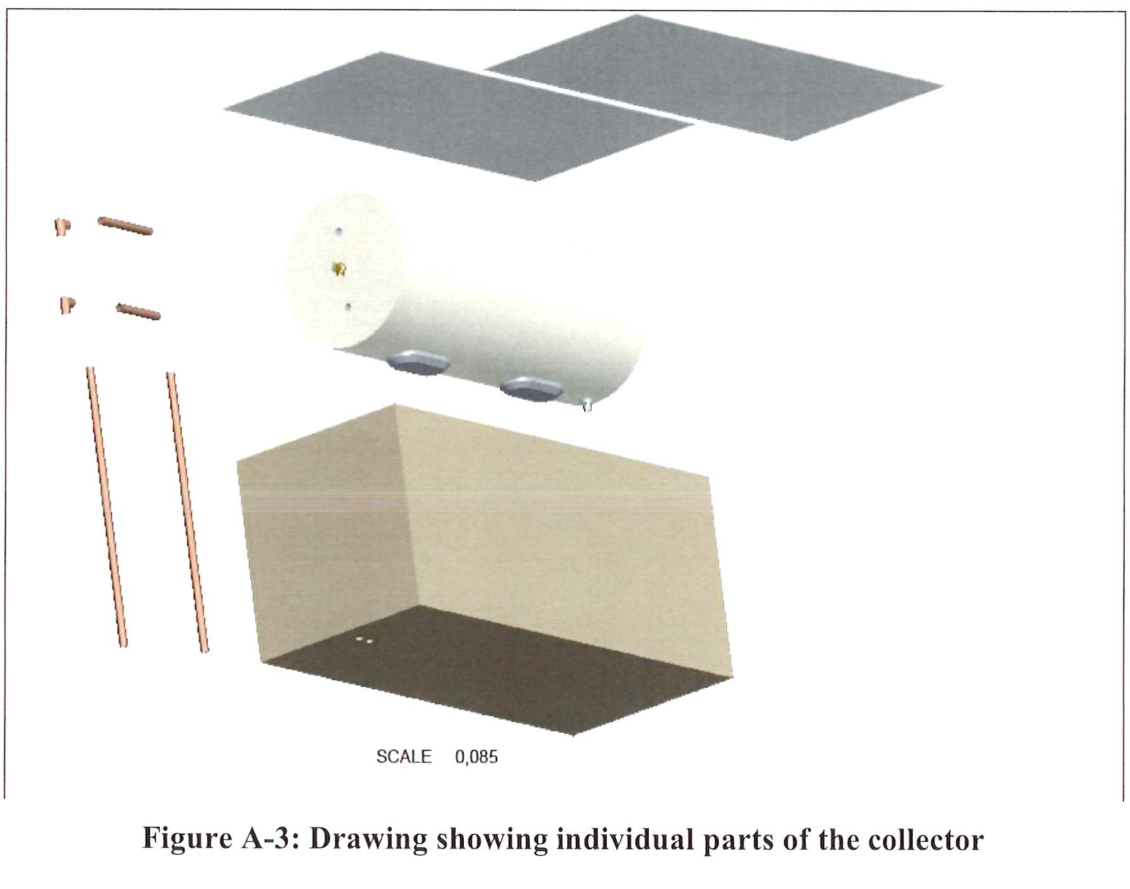

Figure A-3: Drawing showing individual parts of the collector

Appendix-B: Bill of Materials

B-1 Details of Constituent Parts

1. **Johns Manville 300"L x 15"W x 9-1/4"D R-30 Fiberglass Insulation Roll**
    a. Manufacturer: Johns Mansville
    b. Source: Lowes
    c. Model #: B390
    d. Description: Good for insulating enclosures. Will be used in the collector to assure energy efficiency.
2. **7/16 x 4 x 8 OSB Sheathing**
    a. Manufacturer: Georgia Pacific
    b. Source: Lowe'a
    c. Model #: LBR12212
    d. Description: OSB Sheathing used for the structure of the collector frame. Needs to withstand rotting and cracking while remaining cheap.
3. **Speciality High Heat 1 qt. BBQ Black Paint**
    a. Manufacturer: Rust-Oleum
    b. Source: Home Depot
    c. Model #: 7778502
    d. Description: Use Rust-Oleum Specialty High Heat 1 qt. Oil Base BBQ Black Paint on grills, wood-burning stoves, radiators, engines and other metal items. This tough, protective enamel features an oil base and is formulated to effectively retains its color and finish when subjected to temperatures of up to 1,200 degrees Fahrenheit. This is used on the tank in the collector.
4. **Premium Semi-Transparent Deck, Fence and Siding Weatherproofing Wood Stain**
    a. Manufacturer: Behr
    b. Source: Home Depot
    c. Model #: 2508801
    d. Description: The Behr Premium Semi-Transparent Acrylic Deck, Fence and Siding Weatherproofing Wood Stain is formulated for easy application with a brush, roller or sprayer. The formula provides complete weather protection for decks, fences and siding. It resists mildew growth. This was died black and used to weatherproof the frame.
5. **Professional Aerosol Primer**
    a. Manufacturer: Rust-Oleum
    b. Source: Home Depot
    c. Model #: 7569838
    d. Description: The Rust-Oleum Aerosol Primer can be used on metal, wood, concrete and masonry. The oil-based formula dries in as little as 15 minutes to and can cover an area of up to 20 sq. ft. The primer resists corrosion and weather, making it durable and suitable for indoor or outdoor use. This primer was used on the tank prior to painting it with the High Heat flat black paint.
6. **Flat-Head Philips 1-1/4" Metal Screws**
    a. Manufacturer:
    b. Source: Trinity Shop
    c. Model #:

   d. Description: These screws were used for connecting the frame, the glass and cradle to the frame, and the angled supports.

7. **Repurposed Electric Water Heater - Tank**
   a. Manufacturer:
   b. Source: Solar San Antonio
   c. Model #:
   d. Description: The heater was stripped of the casing, insulation, and all electrical components so that the tank is all that was left.
8. **Low Iron Tempered Glass**
   a. Manufacturer: Alamo Glass
   b. Source: Alamo Glass
   c. Model #:
   d. Description: One layer of 1/4" thick glass is installed as the top of the collector.
9. **Copper Pipe (3/4" x 10ft) Type M Red Copper Pipe**
   a. Manufacturer: Cambridge Lee
   b. Source: Home Depot
   c. Model #: 308752
   d. Description: Will be used for inlet and outlet pipes to the batch collector. The pipes will be used minimally in order to save money.
10. **¾ in. FIP x ¾ in. FIP x 18 in. Copper Water Heater Supply Line**
    a. Manufacturer: Homewerks Worldwide
    b. Source: Home Depot
    c. Model #: 7211-18-34FIP-S
    d. Description: The Homewerks Worldwide Copper Water Heater Supply Line connects a water heater to piping with 3/4 in. solder and female-threaded fittings. This 18 in. supply line is corrugated to offer flexibility. Two of these were used to connect the tank in the frame to the piping for the household.
11. **Armacell Tubolit 3/4 in. x 6 ft. Polyethylene Pipe Wrap Insulation**
    a. Manufacturer: Armacell Tubolit
    b. Source: Home Depot
    c. Model #: OEP07838
    d. Description: The Armacell Tubolit 3/4 in. x 6 ft. Polyethylene Pipe Wrap Insulation helps save energy by protecting copper and iron pipes from freezing. This insulation is mold resistant and fire rated helping ensure a safe and long-lasting use. (Home Depot)
12. **Honeywell R-AM-101C-US-1 Thermostatic Mixing Valve**
    a. Manufacturer: Honeywell
    b. Source: Sears
    c. Model #: R-AM-101C-US-1
    d. Description: A Honeywell mixing valve allows the setting of a water heater to a higher temperature to reduce the threat of bacteria growth, yet the mixing action helps prevent scalding. Plus, increase available hot water supply by mixing hot water with cold. (Sears)
13. **Watts 3/4 in. Brass MPT x FPT Temperature and Pressure Safety Relief Valve**
    a. Manufacturer: Watts
    b. Source: Home Depot

c. Model #: LL100XL
d. Description: Ideal for use with hot water heaters, the Watts 3/4 in. Brass MPT x FPT Temperature and Pressure Safety Relief Valve offers pressure relief at 150 psi and temperature relief at 210 degrees Fahrenheit. The valve features a self-closing design.

14. SharkBite 3/4 in. Brass PTC Ball Valve
a. Manufacturer: SharkBite
b. Source: Home Depot
c. Model #: 22185-0000
d. Description: The SharkBite 3/4 in. Brass PTC Ball Valve helps you make quick connections to copper, PEX or CPVC piping with its featured push-fit connection design. (Home Depot)

15. ¾" x 10 ft. Rubber Foam Tape
a. Manufacturer: Thermwell Products
b. Source: Home Depot
c. Model #: 202262324
d. Description: This self-sticking tape can be used as a gasket, for insulating, for cushioning and for creating a tight seal around air conditions, windows and appliances. It is weatherproof and features memory foam construction for a tight seal. This product was used as an insulating gasket between the glass and the frame.

16. 1-1/4 in. x 10 ft. PVC Schedule 40 DWV Pipe
a. Manufacturer: Charlotte
b. Source: Home Depot
c. Model #: PVC 07100 0600
d. Description: The PVC is used to provide stability and protection of the pipes and pipe insulation.

17. Galvanized Steel Heavy Angle connector
a. Manufacturer: Simpson Strong
b. Source: Home Depot
c. Model #: ML26Z
d. Description: The ML angle provides a 90 degree connection for medium to heavy duty applications. The angle connectors were used to attach the glass to the frame.

18. 6 in. x 6 in. Rubber Packing Sheets
a. Manufacturer: DANCO
b. Source: Home Depot
c. Model #: 59849A
d. Description: Cut custom packing or gaskets with the DANCO 6 in. x 6 in. Rubber Packing Sheets. These rubber sheets measure 1/6 in. thick and 6 in. square. These rubber packing sheets were used as a gasket between the glass and the angle connectors.

19. 1-1/4 in. Galvanized Iron Plug
a. Manufacturer: LDR Industries
b. Source: Home Depot
c. Model #: 311 P-114

d. Description: Featuring a threaded design, the 1-1/4 in. Galvanized iron Plug is suitable for use in steel piping applications and withstands up to 150 psi of pressure. These were used to plug the holes in the repurposed tank where the electrical heating elements were.

20. Steel Element Screw-In Wrench

a. Manufacturer: Whirpool
b. Source: Lowes
c. Model #: 26376
d. Description: This was used to remove the heating elements from the repurposed electric water heater.

21. ThermaPEX ¾" Pipe

a. Manufacturer: PEX Supply
b. Source: PEXsupply.com
c. Model #: T050-300
d. Description: This pipe is used to connect the collector to the electric water heater. It is a flexible PEX tube with an oxygen barrier for radiant heat.

22. Zero Lead Brass ¾" PEX Crimp x 3/4" Copper Tubing Adapter

a. Manufacturer: PEX Supply
b. Source: PEXsupply.com
c. Model #: 46645
d. Description: Used to connect the copper pipe to the ThermaPEX tubing.

B-2 Material Costs

Table B-1 Summary of description, quantity, cost per item, total cost, model cost and availability of required materials in stores.

Material Item Description	Vendor	Budgeted Amount	Actual Amount
Coating for Tank (Matt Black Paint)	Home Depot	$25.97	$25.97
Stain for wood	Home Depot	$36.98	$36.98
Insulation	Lowes	$49.92	$49.92
Georgia-Pacific 7/16 x 4 x 8 OSB Sheathing (5)	Lowes	$39.85	$39.85
Glass-For prototype test	Alamo Glass	$52.50	$52.50
Whirlpool Steel Element Screw-In Wrench	Home Depot	$7.27	$7.27
sponges scrubbing	Wal-Mart	$2.42	$2.42
paper towel	Wal-Mart	$3.54	$3.54
Rust-Oleum Professional 15 oz. Aerosol Primer	Home Depot	$11.16	$11.16
Linzer 3 in. Flat Poly/Bristle Stain Brush	Home Depot	$6.97	$6.97
protective glass	Home Depot	$2.48	$2.48
3" flat cut all paint brush	Home Depot	$7.47	$7.47
duct tape	Home Depot	$2.97	$2.97
googone	Home Depot	$7.48	$7.48
Temp/Press relief valve	Home Depot	$29.94	$29.94
2 X 4 Wood (21.05 ft)	Trinity Shop	$12.81	$0.00
100 1-1/4" screws	Trinity Shop	$6.94	$0.00
Tank	Solar San Antonio	$300.00	$0.00
Large Tempered Sheet of Glass	Alamo Glass	$173.32	$173.32
Thermostatic Mixing Valve (1)	Honeywell	$79.97	$79.97
Copper Water Heater Supply Line (2) 24" long	Home Depot	$27.94	$27.94
Copper Pipe	Home Depot	$23.37	$23.37
Copper Pipe Caps	Home Depot	$3.92	$3.92
Rubber Foam Tape	Home Depot	$15.94	$15.94
ThermaPEX 1/2" white Tubing 100ft	Pex Supply	$32.55	$32.55
1/2" PEX to Copper Adapter (2)	Pex Supply	$2.40	$2.40
Brass PTC valve (2)	Home Depot	$18.84	$18.84
PVC Pipe	Home Depot	$13.95	$13.95
PVC Caps	Home Depot	$9.66	$9.66
Pipe Insulation	Home Depot	$4.72	$4.72
Galvanized Angle Connector	Home Depot	$40.48	$40.48
Rubber Packing Sheets	Home Depot	$13.71	$13.71
Pipe Caps	Home Depot	$19.74	$19.74
Galvanized Iron Plug (2)	Home Depot	$6.16	$6.16

Appendix-C: Savings Calculation

C-1: Calculation of Cost Using Solar Pre Heater

Time	Percent of Water Used at Time	Gallons of Water	T (F)- average temp of top and middle	T water(C)	Delta T	Kg of Water	Energy required of Electric Heater (kJ)	Cost of Hr
7:00	0.09	7.2	70.88	21.6	27.29	27.25	3123.78	0.07
8:00	0.11	8.8	69.89	21.05	27.84	33.31	3894.91	0.09
9:00	0.09	7.2	69.26	20.7	28.19	27.25	3226.81	0.07
10:00	0.06	4.8	72.05	22.25	26.64	18.17	2032.92	0.05
11:00	0.06	4.8	77.45	25.25	23.64	18.17	1803.98	0.04
12:00	0.05	4	85.19	29.55	19.34	15.14	1229.86	0.03
13:00	0.05	4	92.93	33.85	15.04	15.14	956.40	0.02
14:00	0.03	2.4	102.2	39	9.89	9.08	377.33	0.01
15:00	0.01	0.8	106.79	41.55	7.34	3.03	93.34	0.00
16:00	0.03	2.4	111.56	44.2	4.69	9.08	178.91	0.00
17:00	0.05	4	117.59	47.55	1.34	15.14	85.15	0.00
18:00	0.05	4	117.14	47.3	1.59	15.14	101.05	0.00
19:00	0.06	4.8	116.42	46.9	1.99	18.17	151.78	0.00
20:00	0.07	5.6	112.73	44.85	4.04	21.20	359.59	0.01
21:00	0.06	4.8	110.3	43.5	5.39	18.17	411.25	0.01
other (10)	0.13	10.4	100	37.78	11.11	39.37	1837.19	0.04
								0.809

C-2: Calculation of Cost Using No Solar Pre Heater

Time	Percent of Water Used at Time	Gallons of Water	T (F)	T water (C)	Delta T	Kg of Water	Energy required of Electric Heater (kJ)	cost of hour
7:00	0.09	7.2	70	21.11	27.78	27.25	3179.75	0.07
8:00	0.11	8.8	70	21.11	27.78	33.31	3886.36	0.09
9:00	0.09	7.2	70	21.11	27.78	27.25	3179.75	0.07
10:00	0.06	4.8	70	21.11	27.78	18.17	2119.83	0.05
11:00	0.06	4.8	70	21.11	27.78	18.17	2119.83	0.05
12:00	0.05	4	70	21.11	27.78	15.14	1766.53	0.04
13:00	0.05	4	70	21.11	27.78	15.14	1766.53	0.04
14:00	0.03	2.4	70	21.11	27.78	9.08	1059.92	0.02
15:00	0.01	0.8	70	21.11	27.78	3.03	353.31	0.01
16:00	0.03	2.4	70	21.11	27.78	9.08	1059.92	0.02
17:00	0.05	4	70	21.11	27.78	15.14	1766.53	0.04
18:00	0.05	4	70	21.11	27.78	15.14	1766.53	0.04
19:00	0.06	4.8	70	21.11	27.78	18.17	2119.83	0.05
20:00	0.07	5.6	70	21.11	27.78	21.20	2473.14	0.05
21:00	0.06	4.8	70	21.11	27.78	18.17	2119.83	0.05
other (10)	0.13	10.4	70	21.11	27.78	39.37	4592.97	0.10
								1.70

C-3: Calculation of Savings Based on Solar Insolation Per Month

Month	Solar Insolation (kW/m^2) [6]	Savings Per Day	# days	Savings Per Month
Jan	2.57	$ 0.38	31	$ 11.82
Feb	3.7	$ 0.55	28	$ 15.37
Mar	4.43	$ 0.66	31	$ 20.37
Apr	5.54	$ 0.82	30	$ 24.65
May	5.94	$ 0.88	31	$ 27.31
June	6.62	$ 0.98	30	$ 29.46
July	6.49	$ 0.96	31	$ 29.84
Aug	6.28	$ 0.93	31	$ 28.88
Sep	5.7	$ 0.85	30	$ 25.37
Oct	4.67	$ 0.69	31	$ 21.47
Nov	3.43	$ 0.51	30	$ 15.26
Dec	2.62	$ 0.39	31	$ 12.05
Cost to keep hot water idle	4.8325		total saving	$ 261.85
0.55				