TRINITY UNIVERSITY

SWAT

Solar Water at Trinity

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Abstract:

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. Our batch water heater is designed with an initial cost of $2400 and a payback period of approximately 2 years. An installation cost of $1000 is included in the initial cost. 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. Our design will easily integrate with existing electric water heater to act as a preheater and reduce the user's energy bills.

Executive Summary

Many different designs and types of solar water heaters are available in the market for household consumers today. While these designs eventually reduce the amount of money spent on power bills due to the decrease in energy used, there is a high up front cost associated with switching from an electric water heater to a solar water heater, which results in a payback period of 12 years or longer. As a result, a large population in San Antonio is unable to afford a solar water heater, and they continue 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.

After many months of market research, cost analysis, efficiency analysis and brainstorming a final design was decided upon. The team compared the three traditional types of water heaters: batch collector, flat plate collector, and evacuated tubes. Other design considerations included whether the system should be an open or closed system and whether it should be active or passive. All of these decisions were weighed using a decision table and the results lead to a closed, passive design either using a flat plate or a batch collector. Since some questions still remained, a cost analysis and an efficiency analysis were then conducted.

The costs analysis clearly showed that a batch collector would be cheaper than any type of flat plate system by 85.2% for the most basic design of each. Calculations done using Engineering Equation Solver, EES, indicated that only for the most basic flat plate and batch collector designs there is little difference in the efficiency of the model. Based on the results of these analyses, the SWAT team determined that a solar water heater that uses a batch collector would be the most appropriate design to meet our constraints and goals.

The batch 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 front in order to absorb heat. The design also includes a tempering valve which can control the temperature of the water delivered to the household. The final cost of this design is expected to be around $1,359. 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, containing only one of the 40 gallon water tanks. After building the design is completed, tested will be conducted in order to determine the efficiency of the system. The information gathered from the tests will enable for any appropriate changes to the design to be made before marketing it to households in San Antonio.

1. Introduction

Current solar water heating systems are expensive, costing between $6,000 and $8,000 according to Lanny Sinkins from Solar San Antonio when asked in August of 2011. Based off of the cost of electric power in kWh for San Antonio, it was calculated that a cheap solar water heater design ($3,200 or less) could be paid off in approximately 2 years by saving received. Gas-powered water heaters are cost competitive with solar water heaters and are popular among low income families. Gas heaters, however, are ineligible for the CPS rebate that are important to our 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. It is therefore essential that our design will receive the CPS rebate.

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 from locally available materials to the greatest extent feasible. The most important measurable criterion for our design is that the water heater should heat 80-120 gallons of water daily for a family of four at a temperature as high 120°C. In addition, the design must be able to hold enough water to be used during the winter season and maintain the water temperature during extreme heat periods. Another design constraint is that the end product 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. Lastly, the system must have a payback period of 2 years or less which was calculated to be less than $3,200 for final cost including the cost of installation, which we estimate to be $1,000. However, 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.

There were many decisions to be made regarding the implementation of the system. The first is whether the design would use a pump to move the thermal fluid (active system), or rely on the thermosyphon effect (passive system) in which the flow of the thermal fluid is caused by the variation in the fluid density as a function of temperature. The second decision is whether an open loop hot water system will be designed which consists of heating the water directly instead of using a heat exchanger, or a closed loop system, which will pass a thermal fluid through the collector and a heat exchanger filled with water. The final decision is the type of solar collector which would be implemented in the design. One common type used is a batch collector, which consists of solar water heaters in which the storage tank is the collector. Another design is the flat plate collector which consists of a large hollow box with pipes running through the box to a storage tank. Another design which is commonly used consists of concentric tubes with the innermost tube having a thermal fluid and the outermost tube containing the inner tube and a vacuum in the volume between the tubes. After initial research was done, an open loop, passive system was decided upon since it would be the least expensive design. However the group needed more information to decide between a batch collector and a flat plate collector. Cost and efficiency analyses were conducted and batch collector was determined as the final design.

2. Design Overview

The collector design consists of a frame, a collector, and piping. Other subsystems are added downstream to the collector in order to protect the existing water heater and to pipe hot water from the collector to the house. The collector is mounted on the roof of the house and angled such that it receives the maximum amount of sunlight.

2.1 Collector

The collector, essentially a large black tank, is a repurposed 40 gallon General Electric water heater. The water heater consists of a steel tank, a pressure release valve, a drain valve, hot and cold water outlets, temperature controls, and two heating elements. The heating elements and temperature controls will not be used in the collector. Despite not being used, the heating elements and temperature controls will remain in the tank unless the components can be easily removed. The pressure release valve is required by the SRCC, and the cold and hot water ports are used by the system. The reasons for choosing a water heater for the tank are that it can be purchased locally and is less expensive than a steel tank customized to be corrosion resistant and contain high temperature water. The tank is painted flat black (as opposed to the more reflective gloss black) in order to maximize radiation absorption.

2.2 Collector Frame

The frame reduces convective losses and radiative losses from the water tank, and protects the tank from weather. The tank is put inside a pine box of dimensions 60 x 26 x 26 inches. Two holes for ¾ inch piping are cut on the bottom side of the frame to allow the cold water pipe and the hot water pipe to enter the house through the roof. Deck stain is used to weatherproof the frame.

Two plates of 1/8 inch glass are used on the top side of the box to allow solar radiation to strike the tank. Two plates are used as opposed to one plate because the extra layer of glass reduces convective and radiative losses while still maintaining low cost. Convective losses through the other sides of the box are reduced using insulation.

2.3 Piping

The design uses copper piping so that the collector pipes do not melt in the high temperatures. Two 90 degree, ¾ inch copper pipe fittings are used to connect the tank to the house plumbing. The pipe fittings connect about four feet of ¾ inch 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 so that the least amount of pipe is exposed to ambient temperatures. By exposing very little of the pipe to ambient temperatures, the chance of freezing is greatly reduced. The large volume of water in the tank prevents water within the collector from freezing in San Antonio.

3. Subsystem Designs

Two subsystems are incorporated into the entire Solar Water Heating system downstream to the collector, which was discussed in the previous section. The copper pipes leaving the collector will be connected to the plumbing in the house that connects to the existing water heater. A thermostatic mixing valve will be placed between the collector and the water heater so that water enters the existing water heater at a suitable temperature as well as after the electric heater so that the water provided to the household does not scald the user. How these systems work and their implementation into the Solar Water Heating system is discussed below.

3.1 Back-up Electric Heating System

The back-up water heater that will be used in this system will be the homeowner's existing electric water heater. The heater is a tall metal drum usually positioned in the basement or first floor in a household. A schematic of this system with the elements listed below is shown in Fig. C-3.

3.1.1 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.

3.1.2 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 element, the hotter water rises to the top of the heater. Once the temperature of the hot water reaches the desired temperature of the water, a temperature selected by the user, the water exits the heater through a pipe at the top of the water heater and is distributed to the household.

3.1.3 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.

3.1.4 Drain Valve

The drain valve is a valve near the bottom of the tank and is used to remove all of the water from the tank when necessary (i.e. maintenance, repairs, etc.)

3.1.5 Insulation

There is insulation inside the walls of the tank that prevents heat loss from the system and the water.

3.1.6 Temperature and Pressure Relief Valve/Discharge Tube

The TPR valve is a safety valve that releases water from the tank to relieve pressure and temperature if either gets too high. The water exits through the discharge tube that is long to prevent splashing of hot water.

3.2 Thermostatic Mixing Valves

A thermostatic mixing valve (TMV) is used to blend hot and cold water to prevent scalding and system malfunction. Figs. C-1 and C-2 (in Appendix C) show the image of a thermostatic mixing valve and it’s working. In the Solar Water Heating system, two TMVs will be used before and after the backup water heater. The first TMV will mix the hot water from the collector with the cold water to assure that the water being provided to the existing water heater will be less than 180 °F. Water above this temperature could cause damage to the electric heater and prevent the back-up system from working if the collector does not supply enough hot water for the household. 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].

3.2.1 Inlets/Outlet

The TMV has two inlets, hot and cold water, and one outlet for the mixed water.

3.2.2 Temperature Dial

A numbered dial on the top of the TMV is rotated to the desired temperature of the mixed water. The outlet water temperature can range from 70 °F to 145 °F depending on the brand and the type of mixing valve used. This dial controls the limits of the thermostat/slide valve mentioned in the following subsection.

3.2.3 Thermostat/Slide Valves

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.

4. Conclusions and Future Work

SWAT team will pay heed to feedback received during design presentation from Board of Advisors members to improve on the design, if needed. After finalizing all specifications for the design, the team will begin ordering parts to build and test the prototype. SWAT team will evaluate various vendors for essential parts required and select local manufacturers whenever possible. The possibility of purchasing recycled materials, if applicable will be considered if their quality and supply is reliable. The additional cost to treat recycled materials to ensure water quality and potability will also be taken into account before making purchasing orders. Ordering of the parts will begin early next semester. The prototype will be scaled down and involve only one collector with a 40 gallon tank although the real design would involve two collector system, with a 40 gallon tank each. This is because the design budget for prototyping and testing is only $1200 while the total system cost is constrained to be less than $3200. A total of $1200 will be sufficient to build and test one collector prototype and test results could be scaled up to evaluate the performance of a two collector system.

The work on building the prototype will begin as soon as parts arrive early next semester. SWAT team anticipates working on the prototype no later than the end of January. During the testing phase, special attention shall be paid to heat loss from batch collector as a function of insulation thickness. Considerations will also be given to volume of water heated to a set temperature and the difference in inlet and outlet water temperatures as a function of insolation. Test results from different months and times of the day will be used to assess the reliability in supply of hot water to an average household of four members in San Antonio. Since next semester will coincide with the onset of winter, the team will be mindful of the fact that insolation will be lower and angle of the Sun's rays striking the collector surface will be higher. The biggest challenge for SWAT team will be to ensure supply of reliable hot water in winter months especially during the mornings. This is because batch water heaters are notorious for failing to prevent heat loss from the tank during the night despite good insulation. SWAT team has intelligently used double layer of glass to minimize heat loss when there is no Sun. The team aims to setup tests to record water temperatures at night and use the results to make design changes, if necessary to ensure a reliable hot water supply.

If test results prove that the prototype can supply reliable hot water in winter months, it will be logical to assume that it will easily meet hot water needs in the summer. Besides the supply of hot water, the team will also test the possibility of freezing of tubes in the collector. Using the same analogy described previously, if the tubes can withstand winter temperatures without freezing, it would be logical to assume that the tubes will not freeze during the summer. Depending on test results on heat loss from tank and potential freezing of tubes, parameters such as thickness of insulation or choice of insulating materials might be altered. Similarly, depending on test results from water heated and their temperatures, parameters such as orientation and surface area of collectors, glazing on collector surface or selection of collector tube material might be altered.

References

[1] Watts Water Technologies. *Thermostatic Mixing Valves* [Internet]. Available: http://www.watts.com/pages/learnAbout/temperingValves.asp?catId=64

[2] Sears (2011, March 18). *Honeywell R-AM-101C-US-1 Thermostatic Mixing Valve* [Internet]. Available:http://www.sears.com/shc/s/p_10153_12605_SPM3227716501P?sid=IDx20101019x00001a&ci_src=14110944&ci_sku=SPM3227716501

[3] Wikipedia user (2010, August 12). *Mixing Valve Operation* [Internet]. Available:http://upload.wikimedia.org/wikipedia/commons/1/19/Mixing_valve_operation.JPG

[4] Keidel Plumbing, Cabinetry, Lighting, Appliances. *Galvanized Steel Pipe*. http://www.keidel.com/mech/pvf/pipe-galvanized.htm

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Appendix-A: Drawings and Assembly

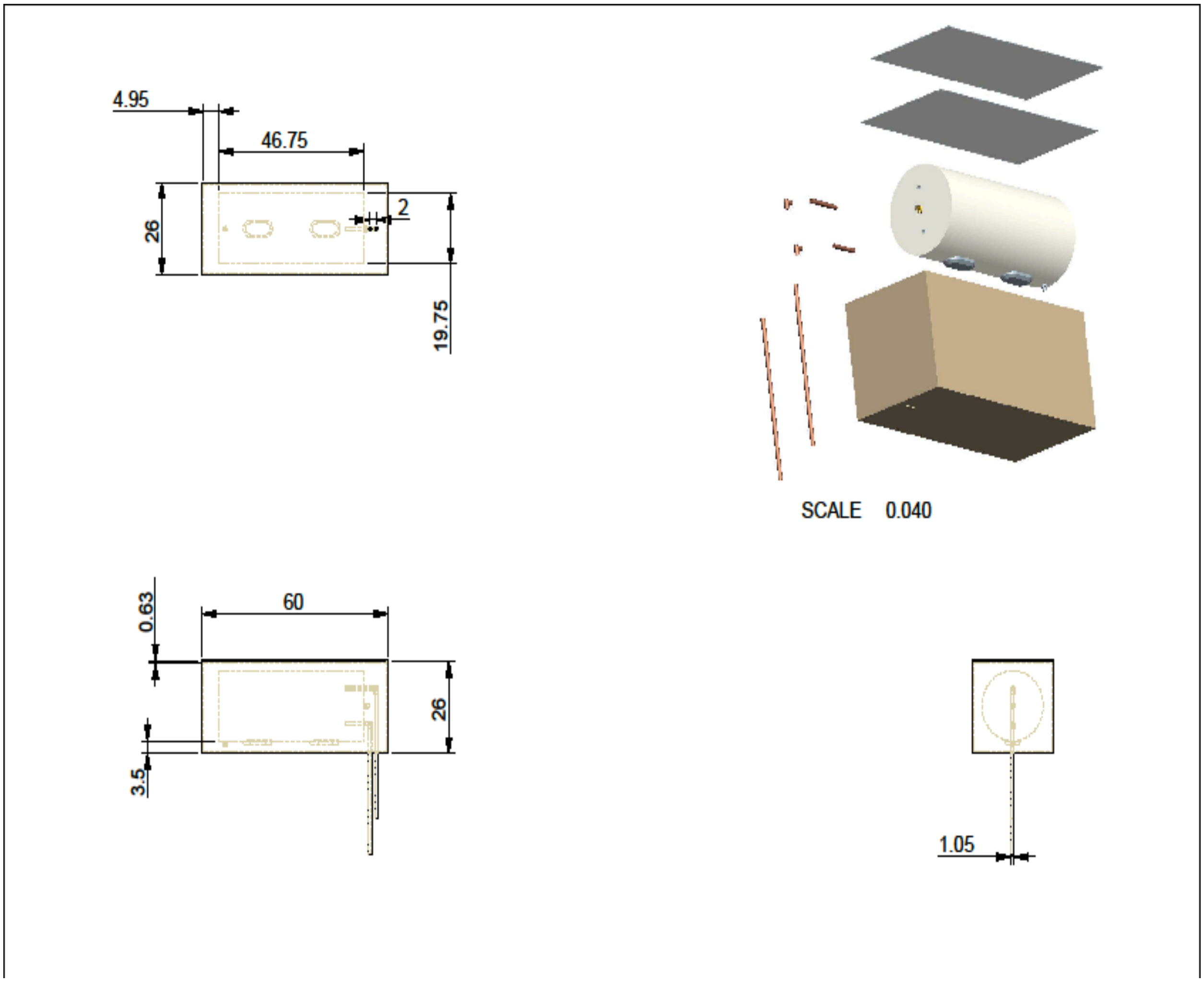

Figure A-1: Drawing showing all the parts of batch collector

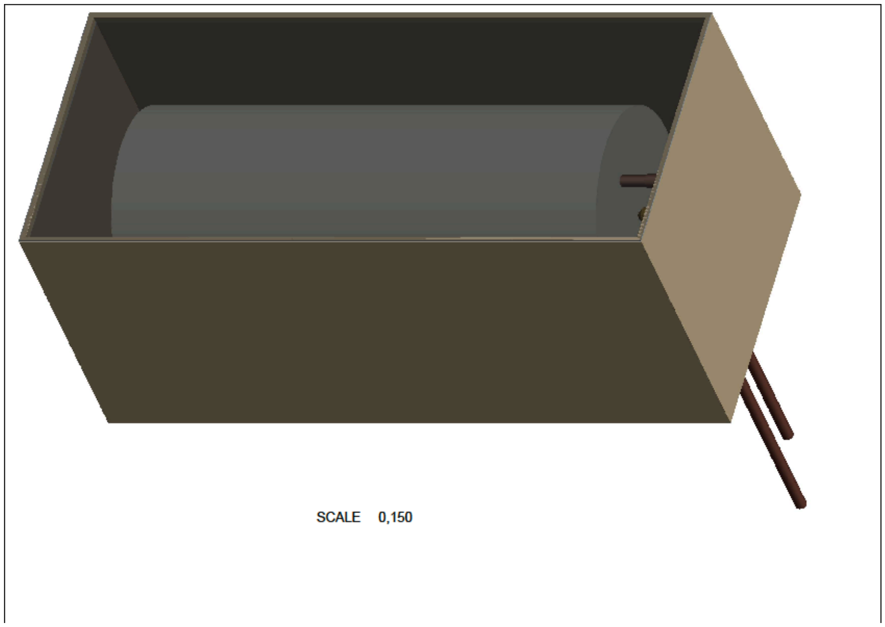

Figure A-2: Drawing showing collector for the batch heater

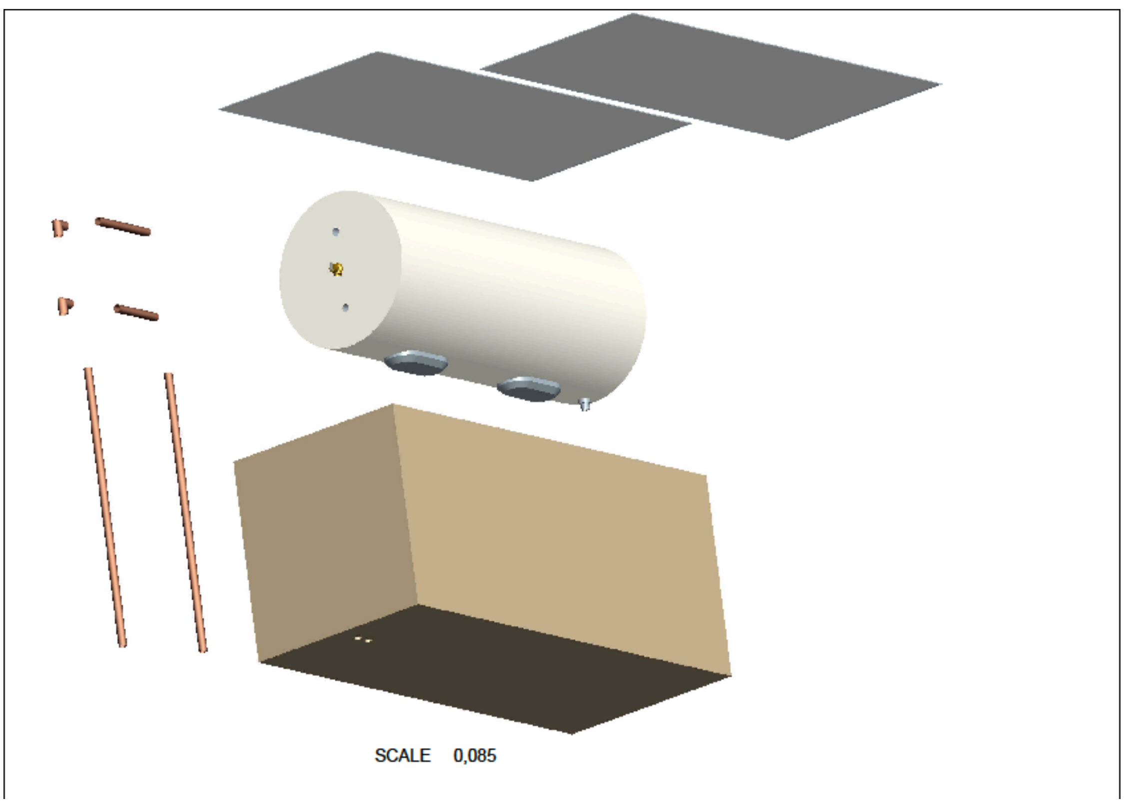

Figure A-3: Drawing showing individual parts of the collector

Appendix-B: Bill of Materials

B-1 Details of Constituent Parts

1. **Thermwell Products 3/4 in. x 17 ft. Closed-Cell Weatherseal Tape**
    a. Manufacturer: Thermwell Products Co.
    b. Source: Home Depot
    c. Model #: V449H
    d. Description: Thermwell Products Co. Inc. 3/4 in. x 17 ft. Closed-Cell Weatherseal Tape. This vinyl foam tape fits 1 average door or window, is waterproof and weather resistant, features moderate compression for filling irregular gaps and is self-sticking for easy installation. Intended to be used in the collector. (Home Depot)

2. **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.

3. **"REFECTIX" SPIRAL DUCT**
    a. Manufacturer: Reflectix
    b. Source: Ace Hardware Superstore
    c. Model #: 4293155
    d. Description: "REFECTIX" SPIRAL DUCT INSULATION12" x 25'. Fiber free. Reflects 97% of radian energy. Non-toxic and non- carcinogenic. Reduces heating and cooling costs. Environmentally safe. Lightweight and clean. Not affected by moisture or humidity. Resists growth of fungi, mold and mildew. (Ace Hardware Superstore)

4. **7/16 x 4 x 8 OSB Sheathing**
    a. Manufacturer:
    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.

5. **Low Iron Glass**
    a. Manufacturer: Glass Cages
    b. Source: Glasscages.com
    c. Model #:
    d. Description: Two layers of 1/8" thick glass are to be installed as the front case of the collector.

6. **GE 40 Gal. Medium 6 Year 4500 Watt Double Element 240 Volts Electric Water Heater**
    a. Manufacturer: GE
    b. Source: Home Depot
    c. Model #: GE40M06AAG
    d. Description: Use this electric water heater as the tank in the batch collector. The heating elements will be removed and the tank will be painted black in order increase the amount of sunlight absorbed.

7. **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.

8. **NIBCO 3/4 in. Copper Pressure Tee**
    a. Manufacturer: Nibco
    b. Source: Home Depot
    c. Model #: C611
    d. Description: Use the NIBCO 3/4 in. Copper Pressure Tee to provide a branch water-supply line from a main line. The durable copper tee is de-zincification resistant. (Home Depot)

9. **NIBCO 3/4 in. x 3/4 in. Copper 90-Degree Cup x Cup Pressure Elbow**
    a. Manufacturer: Nibco
    b. Source: Home Depot
    c. Model #: C607
    d. Description: The NIBCO 3/4 in. x 3/4 in. Copper 90-Degree Cup x Cup Pressure Elbow is made from dezincification-resistant copper and features a maximum working pressure of 582 psi. This solder-joint pressure fitting relies on force or pressure to maintain flow and is designed for use above ground as water supply piping. (Home Depot)

10. **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 your copper and iron pipes from freezing. This insulation is mold resistant and fire rated helping ensure a safe and long-lasting use. (Home Depot)

11. Watts Water Technologies Watts Water Technologies P-34-100R Coil PEX Tubing

a. Manufacturer: Watts Water Technologies
b. Source: Sears
c. Model #: P-34-100R
d. Description: Coil PEX Tubing. Flexible, corrosion-resistant, no electrolysis, and freeze damage-resistant. PEX pipe can be connected to galvanized, copper, and CPVC systems. PEX pipe meets or exceeds ASTM F-876 and F-877 standards. PEX pipe is easy-to-install and will handle all normal temperatures and pressures common in residential systems and commercial potable water systems. (Sears)

12. TEC Invision 10.5oz Latex Sanded Smoke Gray Caulking

a. Manufacturer: TEC Invision
b. Source: Lowes
c. Model #: 36010
d. Description: The caulk will be used to fill any gaps in either the collector or the tank, mostly around the corners.

13. Standard Caulk Gun

a. Manufacturer: Standard – Lowes
b. Source: Lowes
c. Model #: 53485
d. Description: Need a caulk gun in order to use caulk

14. 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)

15. 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. (Home Depot)

16. SharkBite 3/4 in. Lead Free Check Valve

a. Manufacturer: SharkBite
b. Source: Home Depot
c. Model #: U2016-0000LFA
d. Description: The SharkBite Check Valve is a general purpose, spring loaded check valve that can be installed in seconds on copper, CTS CPVC and PEX. The SharkBite check valve can be installed horizontally or vertically and prevents the reverse flow of water through the water supply line. (Home Depot)

17. 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)

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.

Materials	Qty	$/item	Total Cost	Store	Model Number
Foam Insulating Tape	6	$3.57	$21.42	Home Depot	V449H
Fiberglass Insulation Roll	4	$15.87	$63.48	Lowes	B390
Reflective Insulation Wrap	8	$11.47	$91.76	Ace Hardware	4293155
OSB Sheathing (7/16"x4'x8')	14	$6.49	$90.86	Lowes	LBR12212
Low Iron Glass (1/8")	4	$15.00	$60.00	Glasscages.com	---
Water Heater Tank (40)	2	$227	$454.00	Home Depot	GE40M06AAG
Copper Pipes (10')	4	$20.44	$81.76	Home Depot	308752
Copper T Joints (3/4")	6	$2.71	$16.26	Home Depot	C611
Copper Elbows (3/4")	10	$1.40	$14.00	Home Depot	C607
Pipe Insulation (3/4"x6')	6	$1.18	$7.08	Home Depot	OEP07838
Pex pipe (3/4"x200')	1	$84.95	$84.95	Sears	P-34-100R
Caulking	4	$6.74	$26.96	Lowes	36010
Caulking Gun	1	$1.97	$1.97	Lowes	53485
Mixing Valve	2	$79.99	$159.98	Sears	R-AM-101C-US-1

Temp/Press Relief Valve	2	$14.97	$29.94	Home Depot	LL100XL
Brass Check Valve	4	$19.69	$78.76	Home Depot	U2016-0000LFA
PTC Brass Ball Valve	4	$18.84	$75.36	Home Depot	22185-0000
			$1,358.54		

Appendix-C: Wiring and connections

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Figure C-1: Picture of a thermostatic mixing valve [2]

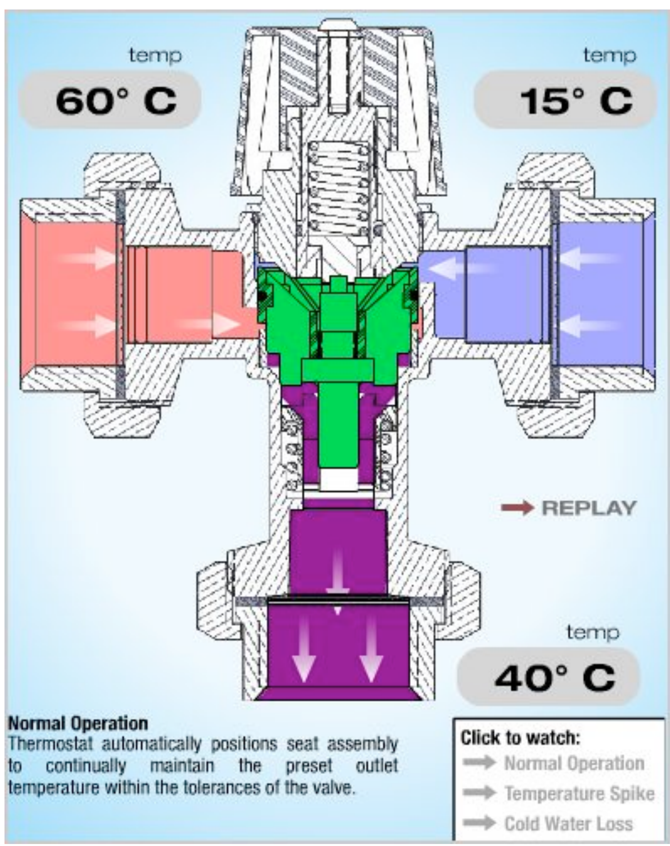

Figure C-2: Working of a thermostatic mixing valve [3]

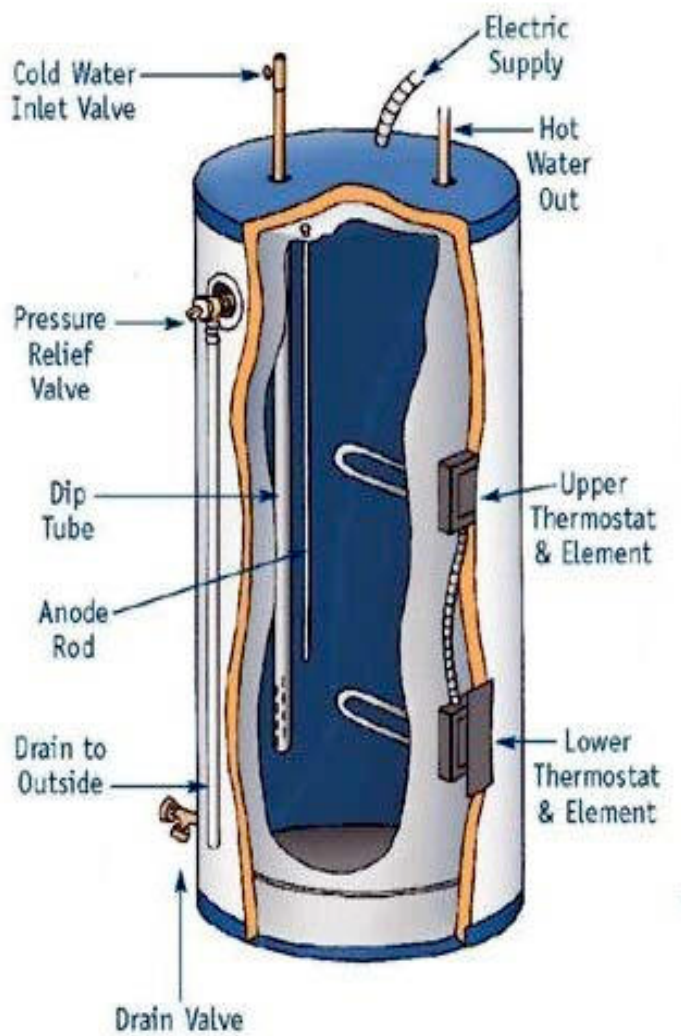

Figure C-3: An example drawing showing the connections for water heater

(Source: http://www.buildmyowncabin.com/electrical/wiring-diagrams-water-heater.html)