Ultra Low Cost Solar Water Heater

By
Saleh Alsadiq, Matt Beckham, Austin Chott,
Thomas Griffin, Chris Heine
Team 13

Final Report

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design I – Fall 2013

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Contents

1 Summary of Deliverables from EPA Proposal

1.1 Evaluation of low-cost components for solar water heaters.

The main specification evaluated in this section while determining possible solutions was absorption per area per dollar. Designs that did not show promise of optimal absorption per area per cost were discarded. Analysis considers the high price of a commercial solar water heater sold in the US and reduces the cost by using parts found from local hardware stores that are significantly cheaper. Research shows that there is the possibility of scavenging the system's parts which in a do it yourself setting can significantly reduce the cost of the system.

Multiple concepts were considered for this project. Collector, circulation systems, and integration are the main aspects in the solar heater. Several options for both systems are briefly described in this section.

1.2 Construction and evaluation of a low-cost solar water design prototype.

Based on the engineering and cost analysis, it is apparent that the parabolic collector with two options in circulation and had the best absorption per area per dollar ratio. A parabolic solar collector uses one stationary parabolic reflector focused on a cylindrical absorber with a secondary storage tank. Through the geometry of the parabolic curve the solar rays bounce off the reflectors any number of times always being directed to the absorber.

We started our building by constructing three parabolic cut pieces of plywood. The three pieces were supported using plywood and angled at 45 degree using 2"x4" boards. Mylar reflective sheeting was used to cover the parabolic plywood and inform the parabolic shape. One inch diameter circular holes in top and bottom of the collector were added to allow multiple pipes options. An easily scavenged secondary storage tank was used in this design.

The most competitive alternative to the parabolic design was the flat plate collector. To perform comparison between the two designs, the team built a flat plate collector using the same circulation systems as the parabolic collector.

The team built a 5’x2’ flat plate collector using plywood as the back and 2"x4" boards for the sides. As for the top, both plastic and glass covers were considered for this design. Inside the box, there are ten ¾ inch PVC pipes glued next to each other using T connectors. The box is angled at 45 degree using 2"x4" boards.

1.3 Financial analysis of ultra-low-cost solar water heaters

The main application of the design is a do-it-yourself solar water heater, which the return is greater than the cost to build in less than two years. As a result the team analyzed a cost scenario with all parts purchased and also analyzed the cost based on what parts are reasonably scavenged, and what parts can be scavenged with considerable effort.

The main aspects of the financial analysis were absorption, area and cost. The energy absorbed by the collector in one hour was converted to equivalent thermal or electrical energy to calculate the savings in gas or electric. Payback time is defined from savings per household annually

2 DATA AND FINDINGS

2.1 Theoretical Analysis

This section presents the results of the theoretical analysis conducted on the basis of absorption per area per dollar. Several variations of the key components were modified and analyzed in order to identify which components had a significant effect on the absorption per area per dollar analysis.

2.1.1 Bread box design

The bread box design was only analyzed with two different coverings, plastic and glass. While glass is much more transparent and therefore allows much more radiation to get to the black painted pipes, plastic is much cheaper. Our analysis showed that the glass covering was much more economical in terms of absorption per area per dollar with almost double the plastic covering. Table 1 shows the final theoretical analysis numbers.

Table 1: Bread box analysis

Bread Box SWH	Absorption	Area	Cost Of collector	Cost of Integration	Total Cost	Ab/A/$
Glass Covering	628.67	1.672254	209.735	272.76	482.495	0.779
Plastic Covering	320.49	1.672254	132.605	272.76	405.365	0.473

2.1.2 Parabolic trough design

The main component compared in the analysis of the parabolic trough design was the material used in the collection pipe. Each material had significantly different costs as well as different thermal conductivities. PVC pipe is the cheapest material and also has the lowest thermal conductivity. Galvanized pipe is more conductive but more expensive. A black painted galvanized pipe had the best absorption per area per dollar for both an active and a passive circulation system. Table 2 shows the final theoretical analysis for a parabolic collector with an active circulation system, and Table 3 shows the same analysis for a passive circulation system.

Table 2: Parabolic collector with active circulation system analysis

Parabolic Collector w/active circulation	Absorption	Area	Cost Of collector	Cost of Integration	Total Cost	Ab/A/$
PVC col. pipe	691.833832	0.92903	$ 230.13	$ 312.76	$ 542.89	1.372
Unpainted Gal col. Pipe	514.065812	0.92903	$ 238.13	$ 312.76	$ 550.89	1.004
Gal col. Pipe	737.039587	0.92903	$ 239.13	$ 312.76	$ 551.89	1.438

Table 3: Parabolic collector with passive circulation system analysis

Parabolic Collector w/passive circulation	Absorption	Area	Cost Of collector	Cost of Integration	Total Cost	Ab/A/$
PVC col. pipe	691.833832	0.92903	$ 230.13	$ 272.76	$ 502.89	1.481
Unpainted Gal col. Pipe	514.065812	0.92903	$ 238.13	$ 272.76	$ 510.89	1.083
Gal col. Pipe	737.039587	0.92903	$ 239.13	$ 272.76	$ 511.89	1.550

2.1.3 Flat plate design

The flat plate design was analyzed like the bread box design with both plastic and glass coverings. However, in this case the results were much closer. The analysis also compared using PVC pipe and galvanized pipe. Because the galvanized pipe was much more expensive the absorption per area per dollar for the PVC was much higher. Like the parabolic trough design analysis was conducted for both an active circulation system shown in Table 4, and a passive circulation shown in Table 5. The passive circulation system with a glass cover has the highest absorption per area per dollar at 1.10.

Table 4: Flat plate collector with active circulation system analysis

Flat Plate Collector w/active circulation	Absorption	Area	Cost Of collector	Cost of Integration	Total Cost	Ab/A/$
PVC pipe w/glass cover	394.763326	0.92903	$ 109.91	$ 312.76	$ 422.67	1.005
PVC pipe w/plastic cover	371.077527	0.92903	$ 91.53	$ 312.76	$ 404.29	0.988
Gal pipe w/glass cover	438.819019	0.92903	$ 197.19	$ 312.76	$ 509.95	0.926

Table 5: Flat plate collector with passive circulation system analysis

Flat Plate Collector w/passive circulation	Absorption	Area	Cost Of collector	Cost of Integration	Total Cost	Ab/A/$
PVC pipe w/glass cover	394.763326	0.92903	$ 109.91	$ 272.76	$ 382.67	1.110
PVC pipe w/plastic cover	371.077527	0.92903	$ 91.53	$ 272.76	$ 364.29	1.096
Gal pipe w/glass cover	438.819019	0.92903	$ 197.19	$ 272.76	$ 469.95	1.005

2.1.4 Theoretical analysis conclusions

The analysis conducted was used to determine which designs were built and tested. The top three designs were all parabolic collectors. Table 6 shows the top three designs in order.

Table 6: Top three SWH designs

Top Three Designs	Absorption	Area	Total Cost	Ab/A/$
Passive Parabolic w/black painted galvanized collection pipe	737.0395872	0.92903	$ 511.89	1.550
Passive Parabolic w/black painted PVC collection pipe	691.833832	0.92903	$ 502.89	1.481
Active Parabolic w/black painted galvanized collection pipe	737.0395872	0.92903	$ 551.89	1.438

2.1 Building

This section will outline what was actually built for testing. All decisions for building were based on heat transfer analysis and what was thought would work best. Each component of building is broken down below.

2.1.1 Collectors

Two collector designs were built for testing. The first being a parabolic collector and the second being a flat plate collector. From previous analysis, it was determined that the parabolic design was ideal when the absorption per area per dollar parameter was considered. After continuing analysis and market research it was determined that a flat plate collector could also be a viable option. This was due to a close comparison to the parabolic collector, and it was also noticed that the majority of the solar water heater designs on the market are of the flat plate variety. It was decided that the results would be more comparable if there was more than one collector for testing. The parabolic collector can be seen below in Figure 1 while the flat plate collector can be seen in Figure 2.

Figure 1: Parabolic Collector Design

All of the parts used for building both of these systems can be found at your local hardware store. The parabolic collector has a few more components to it but it mainly includes wood, a galvanized/copper pipe, and a reflective material. The flat plate just consists of wood, pvc piping, and a glass covering. This list of such simple materials allows for the cost of the collectors to be very low.

Figure 2: Flat plate collector design

2.1.2 Tracking

One downside of the parabolic collector is that it must track the sun throughout the day in order to work efficiently. It is important to note that there was no actual tracking system built and all tracking was done manually for the sake of testing. However, a cheap and simple way to get the parabolic collector to track is presented below. The proposed tracking system consists of four separate components including a worm gear, a gear, a high torque revolving motor, and a solar tracking sensor. There are two ways that a parabolic collector can track the sun. The first way is to swivel the entire collector around the horizontal axis and the second way to swivel the parabolic portion of the collector around the center pipe. The design that was built swivels around the horizontal axis but the proposed tracking system can work for either. The tracking system works by using a solar tracking sensor that is hooked up to a rotating motor. A schematic of how this light sensor works can be seen in Figure 3.

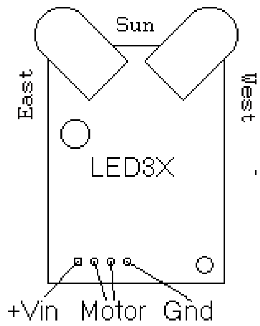
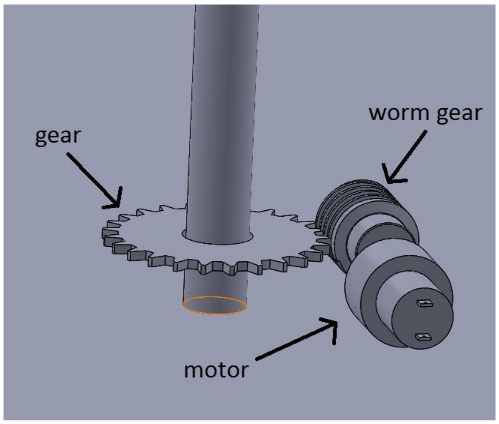


Figure 3: LED3X Solar Tracker Diagram

This solar tracking device works by putting the direct sunlight in-between the two bulbs seen at the top of the diagram. A motor is wired to the sensor so that the collection system can be moved so that the sun can hit the middle of the bulbs. The proposed way to swivel the collector that was built can be seen below in Figures 4 and 5.



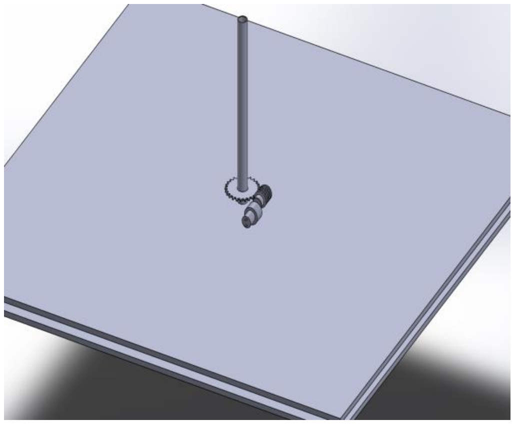


Figure 4: Horizontal Axis Close Up **Figure 5:** Isometric View

Because the top piece of plywood is sitting on a lazy susan, the motor can rotate the attached worm gear which in turn rotates the fixed gear that sits on a fixed pipe. The worm gear will work itself back and forth so that the sun can align with the connected sensor. To swivel the parabola around the heating pipe, it takes the same concept with different placement of parts. Figure 6 and 7 below shows the exact placement of the tracking system parts.

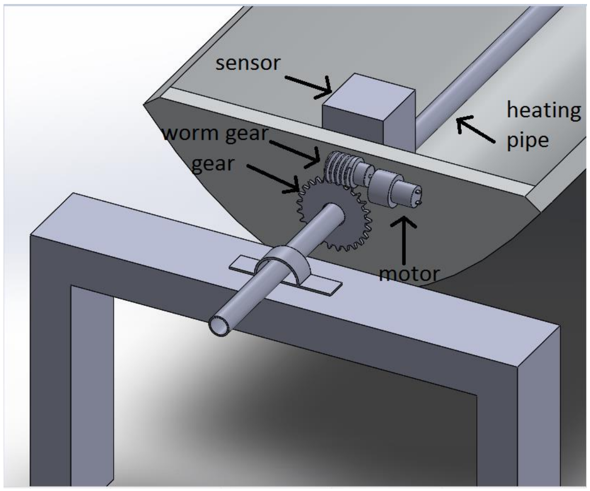


Figure 6: Pipe As Axis Close Up

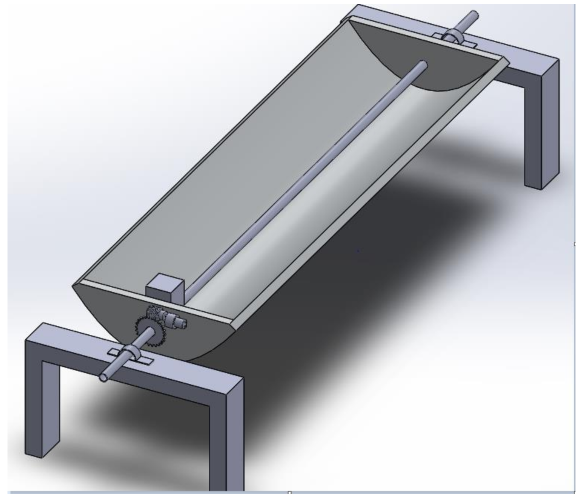


Figure 7: Isometric View

The motor is wired to the sun tracking sensor and rotates the worm gear. This worm gear then moves along the gear that is fixed to the heating pipe which causes the whole parabolic trough to swivel. The worm gear allows the motor to stop working once the collector has stopped in the correct position. More information about the solar tracking sensor can be found at http://www.redrok.com/led3xassm.htm.

2.1.3 Tank integration

The final component to making a full solar water heater system is to integrate the existing tank to the storage tank to the collector. In this testing case, the connection that would normally be made from the existing tank from the storage tank is just a valve that can be opened or closed at the top of the tank. This is where the "hot water" would come out and into the existing tank. To integrate the storage tank to the existing tank would just take a certain amount of pvc piping and valves to ensure safe travel of the hot water.

To integrate the storage tank with the collector, a series of tubing/hose, pvc piping, and galvanized piping was used. The hoses can be switched to piping for the flat plate design but to track with the parabolic design they needed to be flexible hoses. The way the piping was designed allowed for quick and easy swapping of the collectors. Figure 8 below shows the entire layout and how the piping was used to connect the storage tank to the collector.

Figure 8: Tank to collector integration

2.2 Testing Results

This section presents the results of the actual data collected on the basis of absorption per area per dollar. Several variations of the key components were modified and analyzed in order to identify which components had a significant effect on the absorption per area per dollar analysis. Comparisons between different systems can also be found below.

2.3.1. Actual results per collector

Many of the results obtained during testing were close matches to the theoretical values. Major differences were seen in the passive flat plate system due to the slow flow rate caused by head loss in the pipes.

Table 7: Parabolic collector with active circulation results

Parabolic Collector w/active circulation	Absorption	Area	Total Cost	Ab/A/$
Gal col. Pipe	320.20	0.92903	$ 570.01	0.605
Gal col. Pipe w/ Turbulence	641.09	0.92903	$ 570.01	1.211
Copper col. Pipe	396.22	0.92903	$ 559.39	0.762

Table 8: Parabolic collector with passive circulation results

Parabolic Collector w/passive circulation	Absorption	Area	Total Cost	Ab/A/$
Gal col. Pipe	713.19	0.92903	$ 545.33	1.408

Table 9: Flat plate collector with active circulation results

Flat Plate Collector w/active circulation	Absorption	Area	Total Cost	Ab/A/$
PVC pipe w/glass cover	316.98	0.92903	$ 428.43	0.796
PVC pipe w/plastic cover	316.98	0.92903	$ 405.96	0.840

Table 10: Flat plate collector with passive circulation results

Flat Plate Collector w/passive circulation	Absorption	Area	Total Cost	Ab/A/$
PVC pipe w/glass cover	5.45	0.92903	$ 351.40	0.017

Based on the absorption per area per dollar of the collectors above the parabolic collector fitted with black galvanized pipe and a passive circulation system was the optimal design. The cost of the pump off set the absorption in the parabolic collector with induced turbulence enough to make passive circulation a better option.

2.3.2. Collector comparisons

All percent differences for the collectors are in reference to the performance of the better collector categorized by the lowest value for Payback Time, i.e. 28.79% in Table 11 shows the flat plate collector is roughly 28% less expensive and 72.13% shows that it will pay off in 72% less time.

Table 11: Parabolic vs. Flat plate with active circulation

Parabolic vs. Flate plate with active circulation				
Collector	Initial Collector Cost (USD)	Heat Absorbed (W)	Savings (USD/Year)	Payback Time (Years)
Parabolic	570.01	320.02	103.89	5.49
Flat plate	405.96	316.98	102.9	3.96
% Difference	**28.79**	**0.01**	**0.01**	**72.13**

Table 12: Parabolic vs. Flat plate with passive circulation

Parabolic vs. Flat plate with passive circulation				
Collector	Initial Collector Cost (USD)	Heat Absorbed (W)	Savings (USD/Year)	Payback Time (Years)
Parabolic	545.33	713.19	231.53	2.36
Flat plate	351.40	5.45	1.77	198.63
% Difference	**64.44**	**99.24**	**99.24**	**84.17**

From Table 12? the flat plate collector proved to the better collector design with passive circulation. The significant reduction in cost and minimal sacrifice in heat absorption allowed a payback period of about 4 years.

2.3.3. <u>Flat Plate Collector Results</u>

The following section compares the flat plate collectors through both active vs. passive circulation and glass vs. plastic cover.

Table 13: Flat plate active vs. passive circulation

Flat plate active vs. passive circulation				
Circulation Type	Initial Collector Cost (USD)	Heat Absorbed (W)	Savings (USD/Year)	Payback Time (Years)
Passive	351.40	5.45	1.77	198.63
Active	405.96	316.98	102.90	3.96

Table 14: Flat plate glass vs. plastic covering

Flat plate active vs. passive circulation				
Cover Type	Initial Collector Cost (USD)	Heat Absorbed (W)	Savings (USD/Year)	Payback Time (Years)
Glass	428.43	316.97	102.9	4.16
Plastic	405.96	316.98	102.90	3.96

The optimal flat plate design, by means of payback period, was the plastic system. The glass and plastic coverings both absorbed the same amount of heat into the water but initial cost for the plastic covering was lower than glass allowing the reduced payback time.

The figures below show the data collected for the individual parabolic collectors. The slope lines were used to calculate values for the change in temperature of the tank providing the energy absorbed.

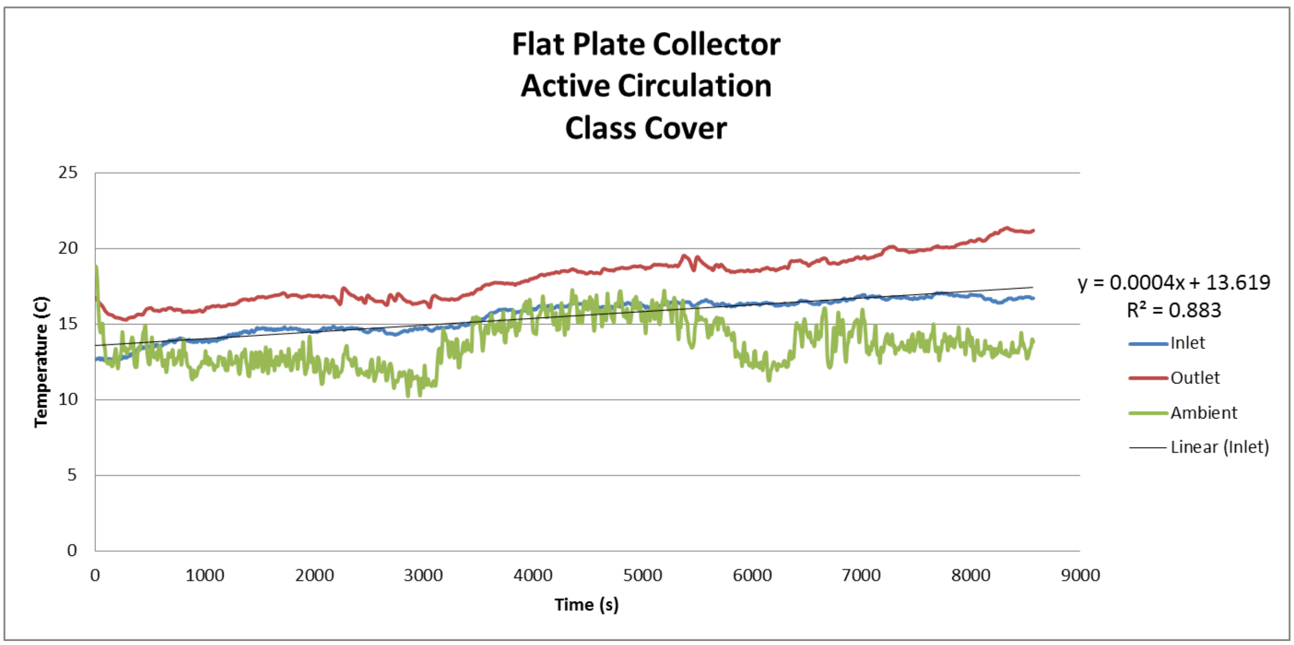


Figure 9: Glass flat plate collector testing results

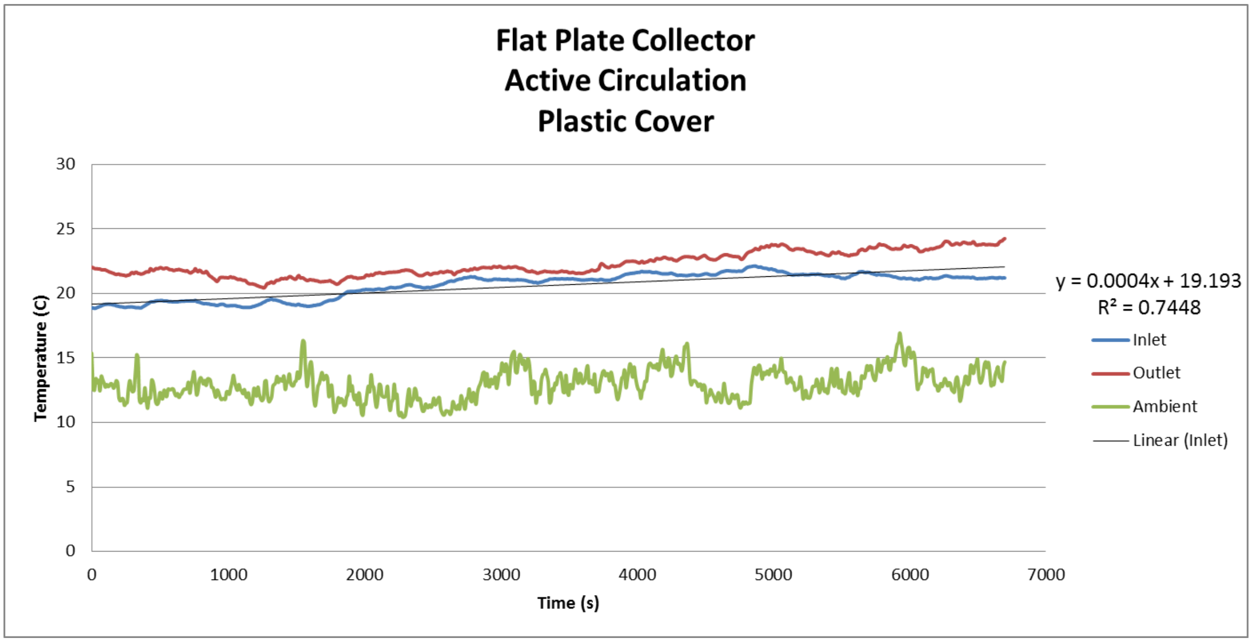


Figure 10: Plastic flat plate collector testing results

2.3.4. Parabolic Collector Results

The parabolic collector concentrates the most sun light onto the pipe and provided the best results. The passive system was the overall best, costing less than the others and absorbing the most energy. From Table 15 below the turbulence induced galvanized pipe almost doubled the amount of solar energy absorbed by the pipe. The restriction in flow caused by the metal insert used to create turbulent flow caused too much head loss to be practical with a passive system.

Table 15: Parabolic collector comparison

Parabolic active vs. passive circulation					
Circulation Type	Pipe Material	Initial Collector Cost (USD)	Heat Absorbed (W)	Savings (USD/Year)	Payback Time (Years)
Active	Black Galvanized	570.01	320.02	103.89	5.49
Active	Black Galvanized w/ Turbulence	570.01	641.09	208.12	2.74
Active	Black Copper	559.39	396.22	128.63	4.35
Passive	Black Galvanized	545.33	713.19	231.53	2.36

The figures below show the data collected for the individual parabolic collectors. The slope lines were used to calculate values for the change in temperature of the tank providing the energy absorbed.

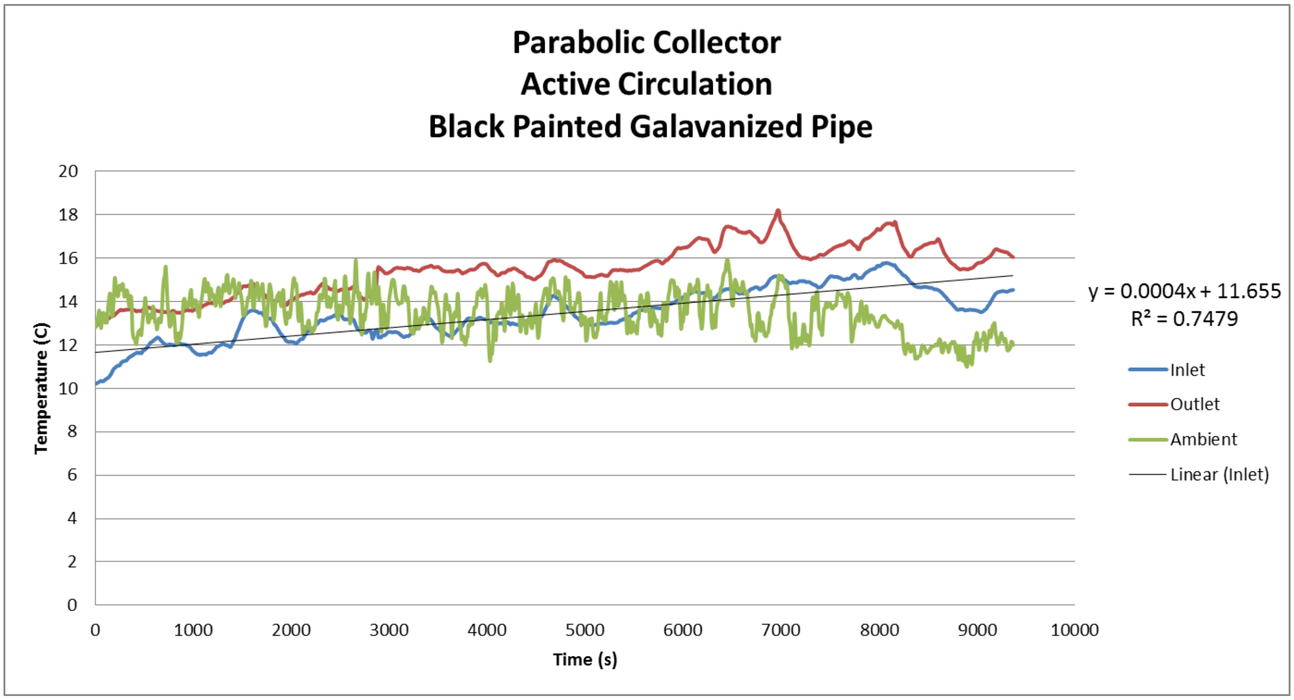


Figure 11: Galvanized active parabolic collector testing results

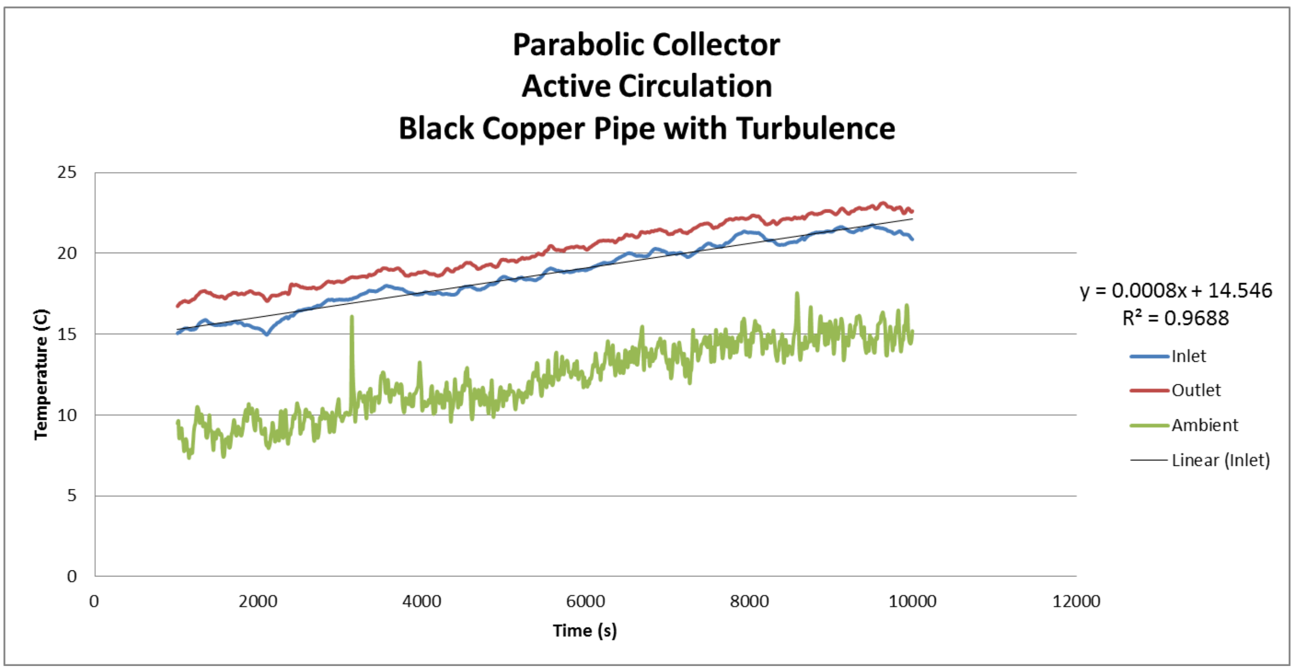


Figure 12: Galvanized active parabolic collector with turbulence testing results

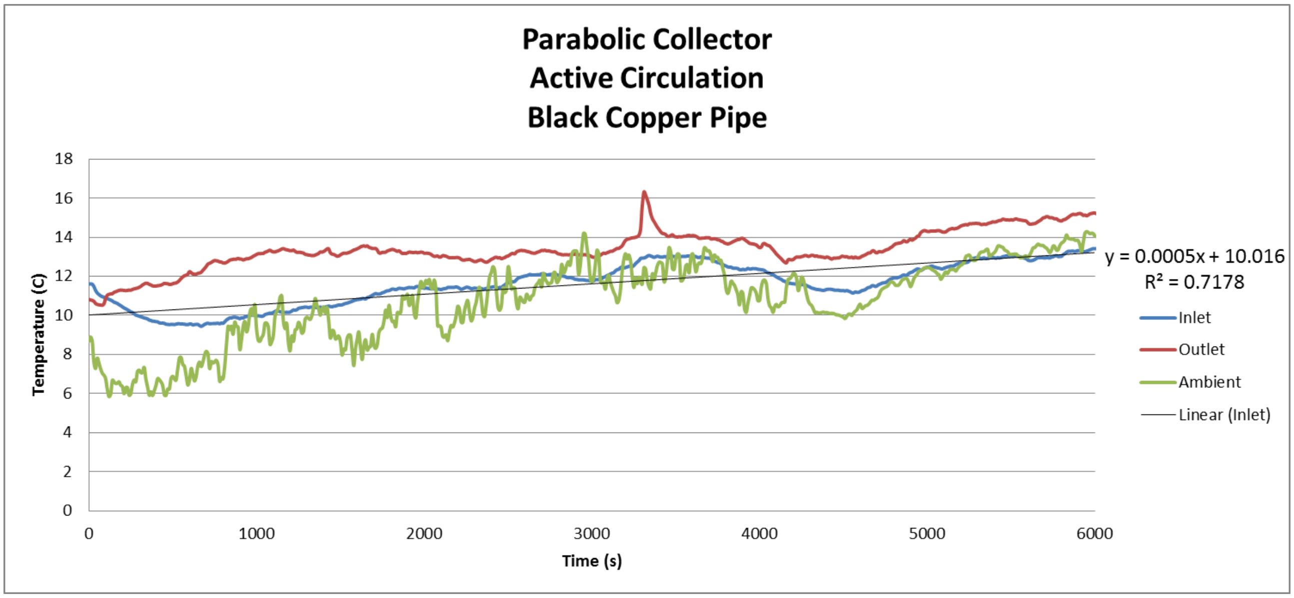


Figure 13: Copper active parabolic collector testing results

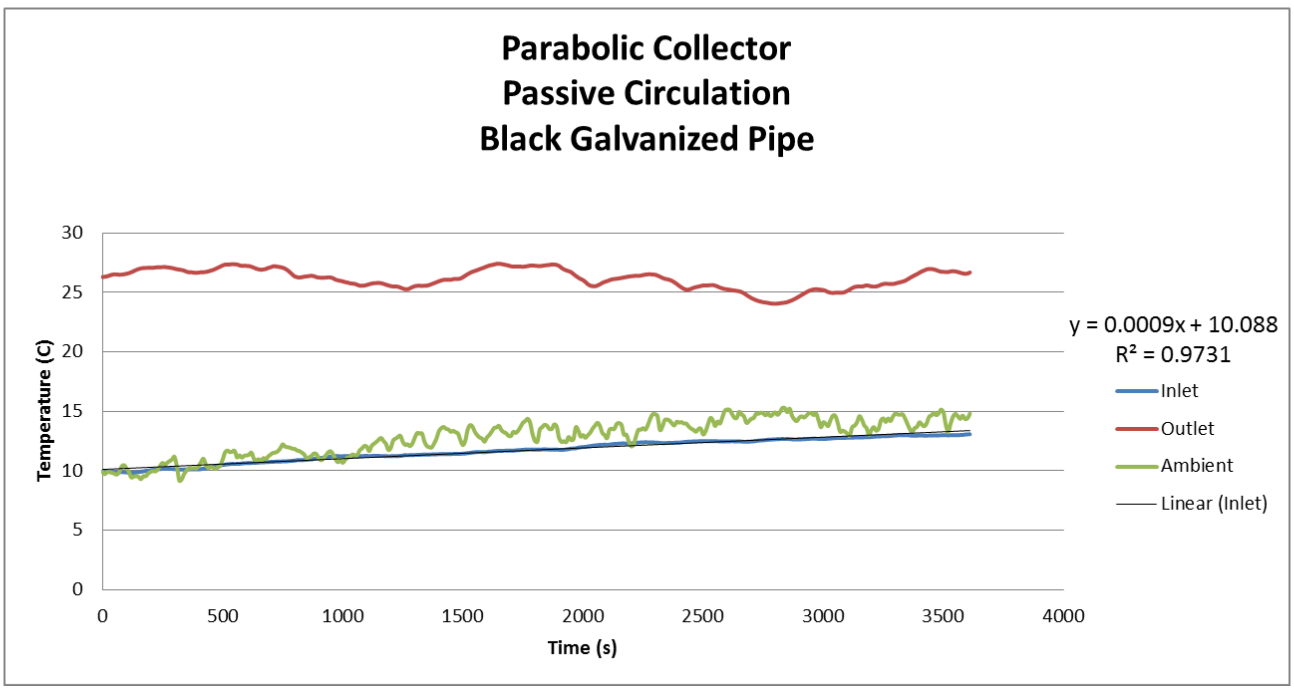


Figure 14: Galvanized passive parabolic collector testing results

3 Discussion, Conclusions, Recommendations

3.1 Analysis

The two designs chosen were the parabolic collector using the black galvanized pipe and the flat plate collector using the plastic insulation. Through analysis and testing it was apparent that the parabolic collector using a passive circulation system is most applicable in a residential setting whereas the flat plate collector using a active system is most applicable is a commercial setting. The reasoning behind this, is that the parabolic collector using black galvanized pipe and a passive circulation system proved to have the highest absorption per area per cost in a residential setting but not in a commercial setting where a secondary storage tank is not needed. In this commercial setting the flat plate collector proved to be the best because of its significant difference amount in cost when compared to the parabolic collector. An organized break down of the costs and absorption per are per cost can be seen in Table 16.

Table 16: Payback period for each collector

Collector Type	Circulation Type	Pipe Material	Return Res. (Years) kWh	Return Comm. (Years) kWh
Parabolic	Active	Black Galvanized	5.486738464	N/A
Parabolic	Passive	Black Galvanized	2.355375763	1.19
Parabolic	Passive	Black Galvanized	4.239676373	2.14
Parabolic	Active	Black Galvanized w Turbulence	2.738876427	1.33
Parabolic	Active	Black Copper	4.348986057	2.47
Flat Plate	Passive	Glass	198.6302007	N/A
Flat Plate	Active	Glass	4.163544433	1.28
Flat Plate	Active	Plastic	3.945177737	0.95
Best return residential				
Best return commercial				

According to an adjusted analysis for scavenged material (Table 17), if a residential user were to integrate a parabolic collector into their water heating system the payback period dramatically decreases from 2.36 years with un-scavenged parts to 1.133 with scavenged parts. The same goes for a commercial setting. The flat plate collector's payback period with un-scavenged parts was 3.95 versus 1.28 years with scavenged parts.

Table 17: Payback period for scavenged parts

Collector Type	Circulation Type	Pipe Material	Return Res. (Years) kWh	Return Comm. (Years) kWh
Parabolic	Active	Black Galvanized	2.763246278	N/A
Parabolic	Passive	Black Galvanized	1.133308357	1.19
Parabolic	Passive	Black Galvanized	2.039955043	2.14
Parabolic	Active	Black Galvanized w Turbulence	1.37936046	1.33
Parabolic	Active	Black Copper	2.018963852	2.47
Flat Plate	Passive	Glass	37.52155015	N/A
Flat Plate	Active	Glass	1.282211919	1.28
Flat Plate	Active	Plastic	1.282211919	0.95
Best return residential				
Best return commercial				

The difference is solar resources around the United States could positively or negatively affect the payback period depending upon how cold and how many sunny days per year that area has. Areas like Michigan would have a longer payback period because of the decrease in sunny days per year compared to Arizona. Obviously, in order to minimize the payback period this solar water heater would make the most sense to be installed in a place with a high number of sunny days per year. The reduction in sunlight correlates to a colder climate and a colder climate will play a role in reducing the collector's performance in transferring heat from the collector to the storage tank which will decrease the overall heat gained by collector, in turn increasing the payback period.

The payback period for any solar collector could be reduced if the hot water being produced by the collector was mainly used during the daytime, when the hot water is being produced by the collector. This is possible because the need for secondary storage would be eliminated ultimately increasing the absorption per area per cost and decreasing the payback period.

Based on the data found by the business team, males that are between the ages of 50 and 59, that have an income of around $50,000-$100,000, are capable of maintaining the collector, and that have enough space in their household are the target applicants for this solar water heater. Refer to Table 18-19 and Figure 15 for a visual representation of target applicants.

Table 18: Comparing age to level of interest in the DIY option for the solar water heater.

Age and DIY Interest	Interested		Uninterested		Neutral	
	% of Total	% of Group	% of Total	% of Group	% of Total	% of Group
20 - 29	14%	80%	3%	20%	0%	0%
30 - 39	7%	50%	7%	50%	0%	0%
40 - 49	10%	50%	7%	33%	3%	17%
50 - 59	21%	60%	10%	30%	3%	10%
60 - 69	3%	50%	3%	50%	0%	0%
70 - 79	7%	100%	0%	0%	0%	0%

Table 19: Comparing household income to level of interest for DIY SWH

Household Income and DIY Interest	Interested		Uninterested		Neutral	
	% of Total	% of Group	% of Total	% of Group	% of Total	% of Group
50,000-100,000	38%	73%	10%	20%	3%	7%
over 100,000	24%	50%	21%	43%	3%	7%

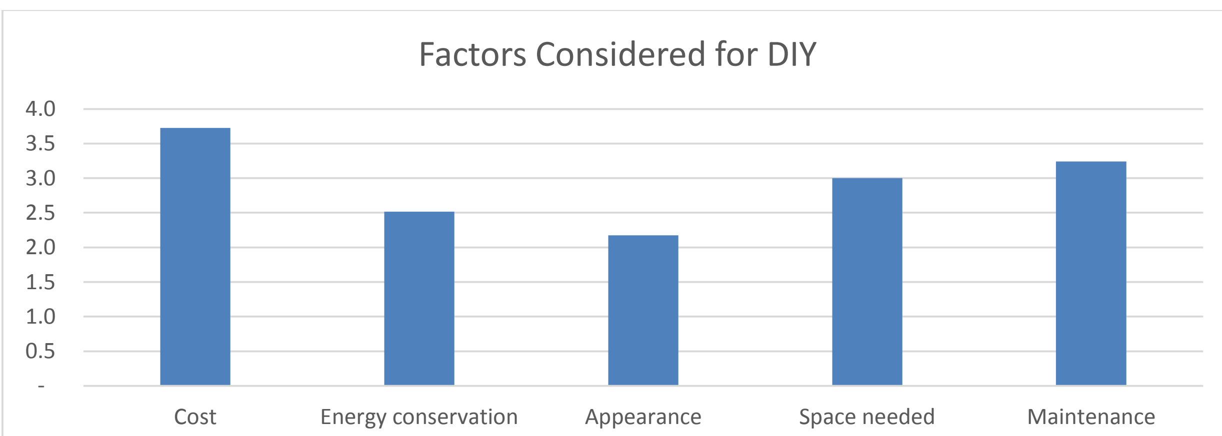


Figure 15: Important factors when investing in a solar water heater.

For residences using an electric water heater, integrating the solar water heater makes sense. This is because of the efficiency associated with each water heater. The electric water heat is so much more in-efficient than the gas water heater that if a user were to integrate the solar collector into an existing electric water heating system then the user would save $231.53 annually, versus just $24.67 annually with gas water heater. The same is true for commercial applications. With an electric water heating system, the annual saving would be $102.90 and $10.96 with a gas water heating system.

The type of industrial users that would benefit from integrating a flat plat collector to their existing system will be the industries that will be able to make use of hot water throughout the day, when the hot water is actually being produced by the collector.

3.2 Design

Through building and testing design improvements were identified. The biggest issue identified was the durability of the frame components on the collectors. Both the parabolic collector and the flat plate collector were framed out of wood. In a climate such as flagstaff, the longevity of these wooden frames may be less than the payback period. As a result, the device would take longer to pay off. Two changes can be made to eliminate this problem. First, the frame components could be manufactured from metal. A metal frame would be lighter, smaller, and would resist weathering. However, a metal frame may cost more. The second, low cost, solution to the durability of the wood components is to use a wood treatment to protect the wood.

Several components of the solar water heaters were relatively difficult to obtain. The pump and several components of the tracking system must be ordered from distributers that may not be readily available in every location. Also, the water heater used as the secondary storage tank is bulky and heavy, and must be transported or delivered to the consumer's home. It also includes all the components required to heat water on its own, which increases the cost. In order to reduce the cost, an insulated storage tank without those extraneous components could be produced. This would reduce the cost as well as the bulk of the tank.

A do-it-yourself builder requires skills including plumbing and building skills. They will need to also have the skills and knowledge to run pluming from the system outside to their existing water heater. As an alternative to the plumbing, they may choose to hire a professional plumber to integrate the system into their existing water supply. The most important aspect of building the parabolic collector is the precision in which the trough is built. In order for the collector to be effective, the trough must be very accurate in reflecting light onto the collection pipe. This may become an issue in a do-it-yourself setting depending on the skill level of the user. If the system is manufactured and sold as a kit this is not an issue.

3.3 Testing

Several issues which may enhance performance include head loss in pipes, insulation of pipes and tank, and air in the system. Each of these issues arose during testing of the various collectors.

Head loss became an issue when attempting to thermosyphon the water through the system. The original garden hoses used had a reduced diameter from the rest of the pipe and were also of a different material which caused the thermosyphon to move very slowly. The results of this very slow flow can be seen in Table 13 by the small absorption into the tank from the flat plate collector.

Insulating the piping from the collector to the tank proves beneficial per the amount of heat that will be saved based on the length of the piping. All test were ran without insulation for comparable results.

In order to produce optimal flow from the collector the system must be fully pressurized with water. Air pockets can develop from leaks in the system as well as improper bleeding of the collector. When air pockets form they prevent the movement of the water from the collector in the tank in a thermosyphon system.

3.3.1 Conclusion to Results

Based on the results of the testing the optimal system was the parabolic collector equipped with a black painted galvanized pipe utilizing a thermosyphon system for circulation. There are several way this system can be improved to produce even more return. Adding insulation to the piping will reduce the heat loss of the water in transit to the tank. Optimization of the tracking system and solar angle per location can also improve this design.

The flat plate collector with a plastic covering and active circulation was the second best system. This design, based on the results, may show improved performance through the use of galvanized pipe. The cost of the collector will increase however the galvanized pipe absorbs a greater amount of heat than the black PVC piping. Pipe insulation would improve the efficiency of the flat plate collector. One last improvement that can be made to the flat plate collector is the sealant of the plastic above the collecting surface. Basic silicon gel was used in sealing the design above, however more industrial caulking may provide a better seal and allow less heat the leak out.