

Performance Analysis of Solar Assisted Domestic Hot Water System

by

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ABSTRACT

Testing was conducted for a solar assisted water heater and conventional all-electric water heater for the purpose of investigating the advantages of utilizing solar energy to heat up water. The testing conducted simulated a four person household living in the Phoenix, Arizona region. With sensors and a weather station, data was gathered and analyzed for the water heaters. Performance patterns were observed that correlated to ambient conditions and functionality of the solar assisted water heater. This helped better understand how the solar water heater functioned and how it may continue to function. The testing for the solar assisted water heater was replicated with the all-electric water heater. One to one analyzes was conducted for comparison. The efficiency and advantages were displayed by the solar assisted water heater having a 61% efficiency. Performance parameters were calculated for the solar assisted water heater and it showed how accurate certified standards are. The results showed 8% difference in performance, but differed in energy savings. This further displayed the effects of uncontrollable ambient conditions and the effects of different testing conditions.

DEDICATION

This thesis is dedicated to my parents Blanca and David, my brother Saul, and my sister Alyssa. I would not be who I am and where I am if it were not for your love and support.

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CHAPTER 1

INTRODUCTION

With the increase of pollution to the world's atmosphere and the continuous need of energy, comes a desire to minimize the impact on the environment without compromising daily needs. One of these needs come in the form of domestic hot water. Hot water within the residential sector accounts for about 3% of the nation's energy consumption (Rapp 13). Given that Arizona is one of the hottest states in the country, and even one of the hottest places in the world, it would only seem appropriate to use solar energy for domestic hot water. This is further validated with Figure 1, showing that Arizona as a whole receives more solar flux than any other state in the country. Leaving states like Alaska in the dust, most of Arizona on average receives more than 7.5 kW-hrs/m² a day.

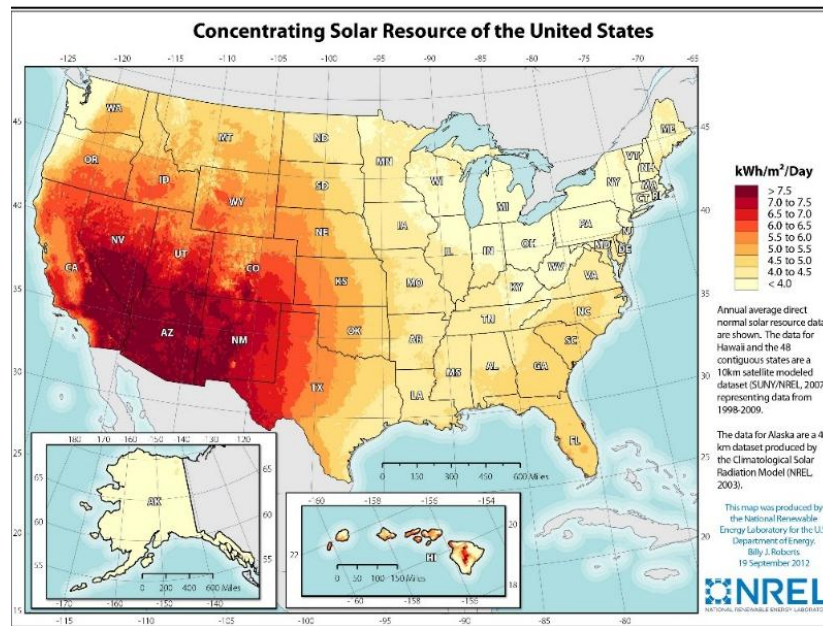


Figure 1. Concentrating solar resource of the United States (Roberts/NREL). This is a map of the United States showing the daily average concentration of solar flux and how it is disbursed throughout the country.

The idea of obtaining hot water from solar energy is not something new or innovative today. There are many systems that have been developed to extract solar energy into the water and replace electric and gas powered systems. With these solar systems raises the question of how useful it really is to use solar energy. Using this form of alternative energy requires technology that is newer or not as well developed, resulting in having an initial investment that economically discourages people from obtaining these systems. To help counteract the problem brought from initial cost investment, these solar systems are made to last long to give back on investment in the long run. One can only wonder how these systems will stand the test of time. In the Polytechnic campus of Arizona State University there is a facility that has been testing a domestic solar assisted water heater and a domestic all-electric water heater. These two water heaters has been continuously operating since April 2013. The objective of this research is to continue testing of the water heaters and observe its performance. This can be done by quantifying both the energy and costs of the water heaters. A typical household of four is used for what is considered to be the average household and the platform for setting the tests. With that in mind the objectives for this research are as followed:

- Quantify parameters of the water heaters pertaining to its functionality and uncontrollable ambient condition
- Observe performance and characteristics patterns produced though testing
- Analyze energy usage and costs and develop annual models representing the results
- Evaluate performance of the solar assisted system, validate and compare results with certified ratings

CHAPTER 2

BACKGROUND RESEARCH

2.1 Flat Plate Collectors

One main aspect of this research is that the testing will involve a flat plate collector. The flat plate collector was developed by Hottel and Woertz in the 1950's (Sayigh 106-107). The flat plate collector is amongst one of the simplest form of solar collectors, along with being one of the most economical. This makes it popular when it comes to solar energy collection. Typically this type of system is designed for operation in low temperature ranges (from ambient to 140°F) or medium temperature ranges (from ambient to 212°F) (Hough 65).

A flat plate collector consists of four different components. The first component is a plate which is used to absorb the incident solar radiation. Typically this part is black to reduce the amount of reflectivity. The Heat that is absorbed by this component will escape mostly through convection. The second component would be an insulated container. The purpose of the container is to minimize the amount of heat loss through conduction. The third component is a transparent plastic or a plate of glass, which may consist of more than one layer. This component is set on top and it allows radiation from the sun rays to enter, but aids in entrapping heat through convection or conduction. The last component of the solar collector is the tube or channels which circulate the liquid or gas that will be used to remove the heat entrapped in the flat plate collector (Sayigh 105-106). In the following page Figure 2 shows a diagram of what a typical solar collector looks like.

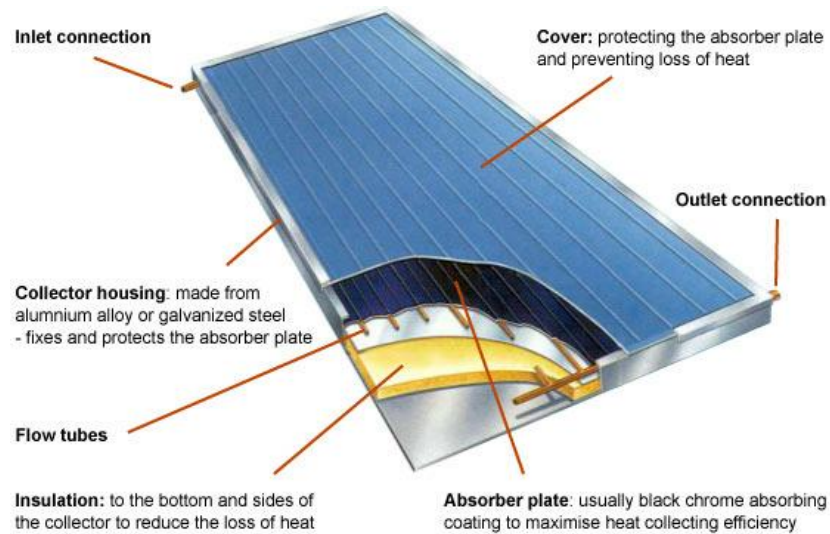


Figure 2. Diagram of flat plate collector (“Solar Hot Water Collectors”)

Solar collectors that heat water use two different types of methods for the water heating. The type of collectors use either direct or indirect water heating. When direct water heating is used, water flows through the solar collector. The advantage of this results in the water heating up much more efficiently. The issue comes with the weather and the geographical location. When the temperature get to cold, the water inside the collector may freeze, rendering it useless till the water heats up. This may also cause damage to the solar collector as well, if viewed from a logical stand point. Water expands when freezing, which would cause pressure. The second method involves using indirect heating towards the water. A heat transfer fluid (HTF) is circulated through the solar collector instead. The HTF has a lower freezing temperature than that of water. The HTF absorbs the heat from the sun rays and is then used to heat up the water. The disadvantage to using indirect water heating is that only a portion of the solar energy is transferred to the water.

2.2 Solar Rating and Certification Corporation

The SRCC is an organization that facilitated the national certification and rating of solar energy systems and equipment, which are often referred to as the Solar Rating and Certification Corporation (SRCC ratings). These performance ratings for each energy system have an overall rating based on a set geographical location and ambient conditions, but the ratings are also available for different geographical locations such as Phoenix, Arizona. For every certified solar system SRCC will present three performance ratings which are the Solar Energy Factor (SEF), Solar Fraction (SF), and Solar Energy Savings (Q_{SOLAR}).

The SEF is defined as the energy delivered by the system divided by the electrical or gas energy put into the system. The SEF is a unitless value that is used to determine the solar energy input into the system. The equation to solve the SEF of the system is as follows (“Solar Rating & Certification Corporation - Certification & Listing Directory”):

$$\text{SEF} = \frac{Q_{\text{DEL}}}{Q_{\text{AUX}} + Q_{\text{PAR}}} \quad (1)$$

Where:

Q_{DEL} Energy delivered to the hot water load (kJ/day)

Q_{AUX} Daily Amount of energy used by the auxiliary water heater or backup electric water heater with the solar system operating (kJ/day)

Q_{PAR} Parasitic energy, which is defined as daily amounts of AC electrical energy used to power pumps, controller, shutters, trackers (kJ/day)

The SEF is used to be converted into the equivalent SF. The SF is the rating that shows how the system compares to its conventional water heating system, whether it is electrical or gas powered. The closer the SF approaches 1, the more efficiently it is

compared to its conventional counterpart. SEF is a unitless value. The equation for solving the SF is as follows (“Solar Rating & Certification Corporation - Certification & Listing Directory”):

$$SF = 1 - \frac{EF}{SEF} \quad (2)$$

Where:

EF The Energy Factor (EF) is the ratio of the delivered energy to input energy for the reference electric auxiliary tank without solar contribution. Energy is lost to surrounding due to standby losses and conversion efficiency

The Q_{SOLAR} is defined as the total energy delivered to the hot water load by solar energy and excluding the energy delivered by the auxiliary and parasitic loads. The units for Q_{SOLAR} is in kJ/day. The equation for Q_{SOLAR} is defined as followed (“Solar Rating & Certification Corporation - Certification & Listing Directory”):

$$Q_{SOLAR} = Q_{DEL} * \left(\frac{1}{EF} - \frac{1}{SEF} \right) = SF * Q_{CONV} \quad (3)$$

Where:

Q_{CONV} Daily energy utilized by the auxiliary water heater or back up electric water heater of which does not utilize solar elements (kJ/day)

2.3 Energy Analysis

In this thesis there is energy analysis that is conducted. Working with a solar assisted water heater and an al electric water heater, there are three different forms of energy involved. The forms of energy come from energy in the water, energy from the electrical input, and solar energy. Energy into the water and energy from the electricity are main concern when it comes to calculations. The main concern with solar energy

comes from the energy savings. This can be obtained from the energy into the water and electrical energy. To obtain energy values from the water using flow rates, inlet and outlet water temperature, a slightly modified version of the simplified steady-flow thermal energy equation is used. The equation is shown as follows (Bergman, Incropera, Lavine, and Dewitt 17):

$$q = \dot{V} * \rho * c_p * (T_{out} - T_{in}) * \left(\frac{1m^3}{264.17gal} \right) * \left(\frac{1min}{60s} \right) * \left(\frac{5K}{9^{\circ}R} \right) \quad (4)$$

Where:

q The thermal energy delivered to water load, which is used for solving Q_{DEL} (kJ)

\dot{V} Volumetric flow rate (gal/min)

ρ Density which 1,000 kg/m³ is used for water (kg/m³)

c_p Specific heat which 4.186 kJ/kg-K is used for water (kJ/kg-K)

T_{out} Temperature at the outlet (°R)

T_{in} Temperature at the inlet (°R)

The energy produced by the electricity uses a much simpler equation. With the water heaters, there is varying current with a constant voltage source. To obtain energy the use of Ohm's law is required. To solve the energy the following equation was used ("Ohm's Law and Ohms Law Calculator."):

$$P = I * V \quad (5)$$

Where:

P Electrical energy [J]

I Amperage [A]

V Voltage [V]

CHAPTER 3

SYSTEM OVERVIEW

3.1 Facility Overview

The facility is located in Mesa, Arizona in the Arizona State University Polytechnic campus. In the facility there are a two domestic water heater types in testing and evaluation. The first is the conventional all-electric water heater that would normally be seen used in a typical household and the second is the solar assisted water heater. These two water heaters are each set up with flow meters, temperature sensors, and amperage meters. There is also a weather station installed on the rooftop of the facility. These sensors are all connected to a data acquisition system which records data continuously.

3.2 Electric Water Heater

The electric water heater in the facility is considered as the conventional storage water heater that is seen in a typical household. For that reason, this water heater acts as the baseline for comparison. It has an insulated storage tank that retains water and it uses electricity as its main source of energy to heat up the water. The all-electric system in the facility contains a 50 gallon water storage tank. It uses a two copper type immersion elements for its water heating. This system also includes an automated temperature control that works in a master/slave relationship where the bottom element only turns on if the top element is on. This system runs on a 240 voltage supply and can run on a maximum of 4,500 watts (“Residential Upright Energy Saver Electric Water Heater”).

There are a total of 4 sensors attached to the electric water heater system. It has a flow meter connected to an outlet pipe of water flow, temperature sensors inserted in the

inlet and outlet pipes of water flow, and it has amperage meter attach to voltage supply. Lastly there is a flow control valve at the outlet of the electric water heater with the functions of being open or closed. Figure 3 shows the all-electric water heater and Figure 4 displays a basic diagram of the electric water heater system with the sensors.



Figure 3. All-electric water heater. This water heater is located inside the facility.

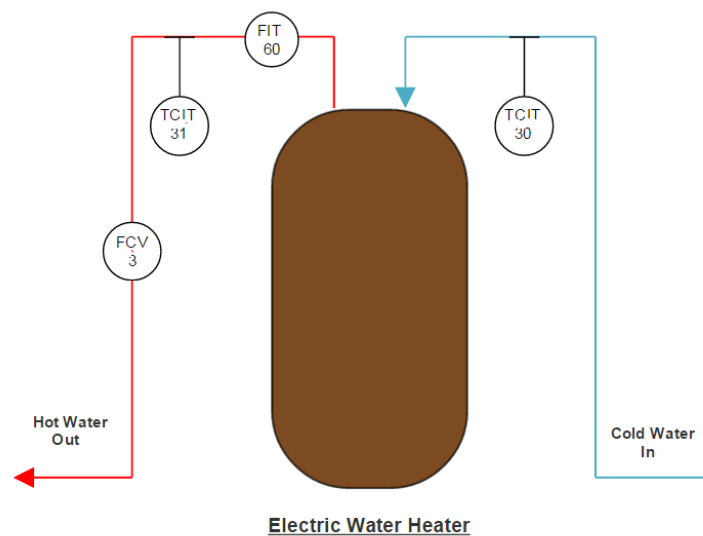


Figure 4. Diagram of all-electric water heater system.

3.3 Solar Assisted Water Heater

The solar assisted water heater has a glazed and insulated solar flat-plate collector installed on the rooftop with an 80 gallon water tank. The solar collector has the approximate area of 40.9 ft² which is exposed to the sun rays (“HESolar Heat Exchanger, Solar Tank, or Electric Storage Water Heater”). The solar collector is installed at a 30° angle and is set facing south. Figure 5 shows the solar collector that is mounted on the rooftop. This system uses energy absorbed from solar radiation to indirectly heat up the water and uses electricity to heat up the water when there is not enough solar energy to heat up the water. Specifically it circulates HTF through the solar collector when there is enough energy provided by the sun rays. The HTF is composed of 30% propylene glycol and 70% water, which prevents the HTF from freezing above 9°F. While the HTF is being circulated and extracting energy from the sun, it also provides energy to the water. This is provided by circulating the HTF through a wrap-around coil made from L type copper. The coil has a 5/8 inch diameter and is approximately 120 feet in length. The coil wraps around the lower part of the outside of the water tank and spans 24 inches of the tank. The HTF is circulated with a pump that requires a 120 Volt power source (“HESolar Heat Exchanger, Solar Tank, or Electric Storage Water Heater”).



Figure 5. The flat plate collector from solar assisted water heater (Thomas de Fresart)

The HTF is mainly used to preheat the water. When there is not enough heat provided to the water, an electric backup heater activates. This system includes an immersed copper element inside the water tank. This element heats up water when needed and has a 240 voltage energy supply that can run on a maximum of 4,500 Watts (“HESolar Heat Exchanger, Solar Tank, or Electric Storage Water Heater”).

The solar assisted water heater is equipped with a temperature differential controller that uses temperature sensors within the system to help regulate the temperature of the water. One temperature sensor is inserted at the rooftop to measure the temperature of the HTF, and the second one installed at the bottom of the water tank to measure the water temperature. The controller has three different modes which are on, auto, and off. When the system is set to on, the pump will be turned on and will continue circulating the HTF until this setting is changed. When the system is set to manual, it begins to work using the temperature sensors. It will automatically start the pump when the temperature of the HTF is 16°F greater than the water temperature. When the HTF is hotter than the water, but the temperature difference is less than 8°F, the pump will stop. When the temperature sensor at the bottom of the water tank reaches its maximum set temperature, which is set to 150°F, it will stop the pump as well. The HTF has a boiling point of 266°F. To prevent damage to the system, controller will stop the pump if the HTF reaches the boiling temperature. It will turn back on once the temperature of the HTF lowers to 261°F. The backup electrical heater is set to keep the temperature of the water at 125°F (“Steca TR0301 U Instruction EN”). The temperature differential controller is connected to a 120 voltage supply and in addition it provides energy to the

HTF pump. Figure 6 shows the solar assisted water heater tank, and on it the controller as well.



Figure 6. Solar assisted water heater tank and controller

There are a total of 8 sensors attached to the solar assisted water heater. It has one flow meter connected to the outlet pipe of water flow and one for the HTF at the inlet of the flat-plate collector. There are two temperature sensors inserted in the inlet and outlet pipes of water flow. There are also two temperature sensors at both the inlet and out of the solar collector. There is also one amperage meter attached to voltage supply of electric backup heater and one at the voltage supply of the temperature differential controller. Lastly there is a flow control valve at the outlet of the electric water heater that only works by being closed or fully open. A simple diagram of the solar assisted water heater is seen in Figure 7.

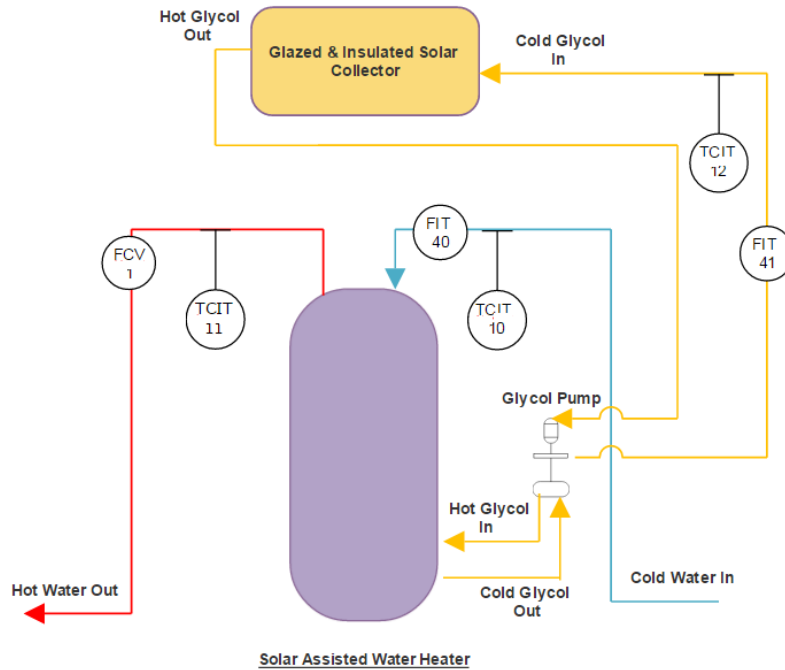


Figure 7. Diagram of all-electric water heater system.

3.4 Weather Station

A weather station is installed on the rooftop of the facility and is used to constantly provide meteorological data. The weather station has sensors that are used to obtain ambient temperature, relative humidity, wind speed, wind direction, and solar flux.

Figure 8 shows the weather station that is installed at the facility.



Figure 8. Weather station. This figure shows weather station installed on the facility.

3.5 Data Acquisition

The data acquisition used in the facility is a CR3000 Micrologger from Campbell® Scientific. The CR3000 has all of the sensors connected to and runs 24 hours a day. It is accessed through a computer that is installed inside the facility using a DB9 9 serial pin connector. This data acquisition requires CRBasic coding installed within the system to run. To implement this type of coding and monitor the data acquisition system a software called LoggerNet, version 3.4.1 is installed in the computer that is connected to the data acquisition. With the LoggerNet program it is possible to create graphical user interface (GUI) that allows constant monitoring and manual override activation of the flow control valves. The CR3000 is not required to be connected to the computer to be running, stores months of data, has a backup battery supply for emergencies, and outputs data as a Text Document that can be imported to Excel. The CR3000 at the facility is shown in Figure 9.

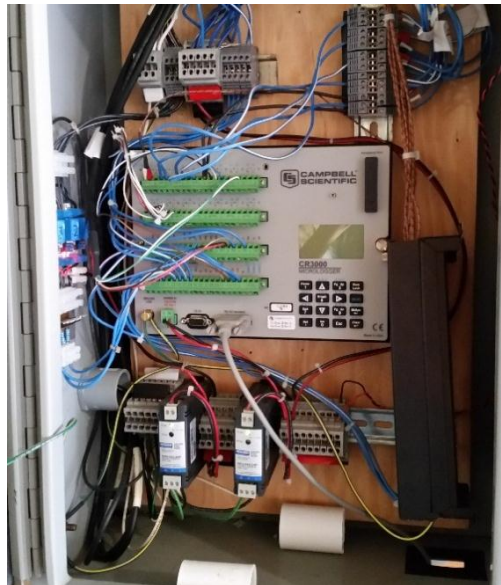


Figure 9. Data acquisition. This figure show the data acquisition installed in the facility.

CHAPTER 4

TESTING AND PROCEDURES

4.1 Water Draws

When programming the water draws for the water heaters it was desired to get the systems to reflect a typical household with a family of four. The SRCC rating conditions have 64.3 gallons for a typical household (“Solar Rating & Certification Corporation - Certification & Listing Directory”). According to the Florida Solar Energy Center, the average household of four uses approximately 63.1 gallons of hot water with strong seasonal variation. In the winter 45.2 gallons per day and in the summer 65.7 gallons per day (Parker, Fairey, Solar, & Lutz, 2015). For that reason, the water draws were planned to be set a minimum of 65 gallons, while being kept within a reasonable range. Since the solar assisted water heater stored 80 gallons of water, it was decided that drawing close to 80 gallons a day would be more appropriate for performance analysis. Essentially every day the solar assisted water heater would be emptied throughout the course of the day. The second thriving factor when setting up the testing was to set the water draws disbursed throughout the entire day. This would mean that there would be water draws during the day time and at night as well. The reason for getting the draw rates scattered through the day was to have further data on how the system performs depending on the time of day, though the main objective was still to evaluate the performance of the solar assisted system.

Between the years of 2014 and 2015, the water heaters were set up to have 4 water draws a day, being 12 AM, 6AM, 12PM, and 6PM. Each water heater had a flow rate close to 5 gallons per minute. This flow rate was reduced to have more control of

how much water would be drawn. There is a limited control on the water drains because the data acquisition's program is structured to have the capacity to turn on or off once at the start of every minute on the clock. A valve located on a pipe where the outlets of the water heaters are all connected to, was partially closed. This was done manually, and the valve was closed to have all the water heaters dump water at rates between 1.3 and 1.4 gallons per minute. Doing this allowed to have more control in the volume of water drawn with the data acquisition. For the systems to draw close to 80 gallons each, each would require to have the flow control valve opened for a grand total of 60 minutes. To make each water draw evenly, the system was set up to have 15 minutes of water draw for each of the scheduled draws. First the solar assisted water heater was set to dump water. When done, the proceeding water heater followed in order to reduce any static, false readings, and have better monitoring capabilities. Table 1 shows the draw schedule for the water heaters.

Table 1	
<i>Daily Water Draw Schedule with Four Water Draws</i>	
Time Start	Time Finish
12:00AM	12:15AM
6:00AM	6:15AM
12:00PM	12:15PM
6:00PM	6:15PM

On the second half of December 2015, the water draw schedule was modified. The water heaters were set to resemble those of SRCC test condition for the rating system. This meant that six water draws were set up starting from 9:30AM and recurring every hour. The approximate draw per day had to be as close to 64.3 gallons as possible,

and had to have the same amount drawn every hour. It was decided to set it up to run 8 minutes every hour, which would result in values closer to 70 gallons of water a day. Table 2 displays the water draw schedule that was implemented to better imitate the SRCC testing. These new results would be for future work and it would give the advantage of observing the impact of having different water draw schedules and seeing what changes in performance patterns occur. Tests have occurred for the months of December 2015 to February 2016, and test will continue to occur.

Table 2	
<i>Daily Schedule Implemented December 2015 With Six Water Draws</i>	
Time Start	Time Finish
9:30AM	9:38AM
10:30AM	10:38AM
11:30AM	11:38AM
12:30PM	12:38PM
1:30PM	1:38PM
2:30PM	2:38PM

4.2 Data Acquisition Programming and Functionality

A CRBasic code is installed into the data acquisition to run the tests and extract data. It was formatted to loop every minute, thus extracting data from the sensors on the minute mark. The code was structured to set up a table with headers per column upon initiation of running the code. After initial initiation the data acquisition extracts data from the sensors every minute in an organized way that matches the table format. Upon extraction of the data with the computer, it extracts the structured table and attaches the saved data in the data acquisition under the structured table. This is extracted onto a text file which can be imported onto excel. While extracting the data on the minute, the data

acquisition code is set up to check if the current time of day meets certain criteria. An example of this would be if the time happens to be 6:00 AM, the code would check the criteria set up and open the outlet valve for the solar assisted water heater. Throughout the testing, only very minor adjustment were made to code that may not be worth mentioning. Adjustments such as removing unnecessary spaces, changing variable name, or restructuring for logical consistency.

There is a GUI installed the computer for the data acquisition that provides live monitoring and allows manually override the outlet valves. A screenshot of the GUI set up is displayed in Figure 10. One disadvantage of running the data acquisition with data extraction on the minute mark is that there is a lag when monitoring the data live. This is because data is first extracted and then the data acquisition applies changes to the water heaters. The lag is minimized by having the computer set up to check the status of the data acquisition and sensors every second, as opposed to waiting for the next extraction of data at the end of the minute.

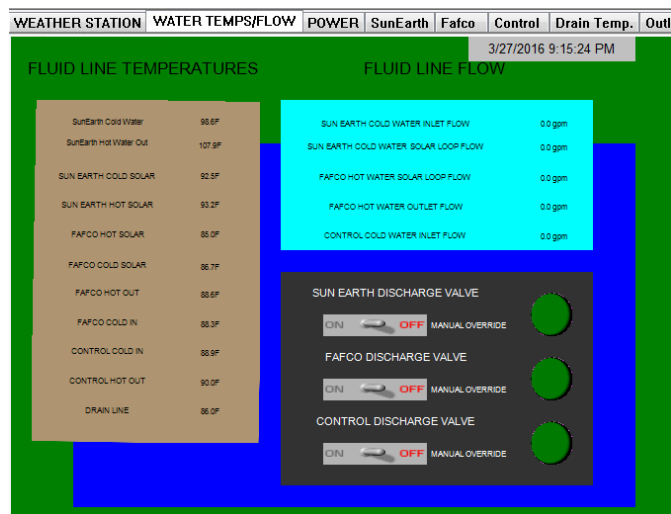


Figure 10. Graphical use interface (GUI) installed in computer. Figure shows GUI used to monitor and overwrite control valves with the data acquisition.

4.3 Data Extraction and Organization

An important aspect of obtaining performance results was the process used to convert the data obtained into information that could be easily interpreted. Figure 11 is a diagram that show the general process used to go from energy sources to the analysis. At this point in the process solar data and electric data have been extracted from the data acquisition and the next progress would be to organize all of the data.

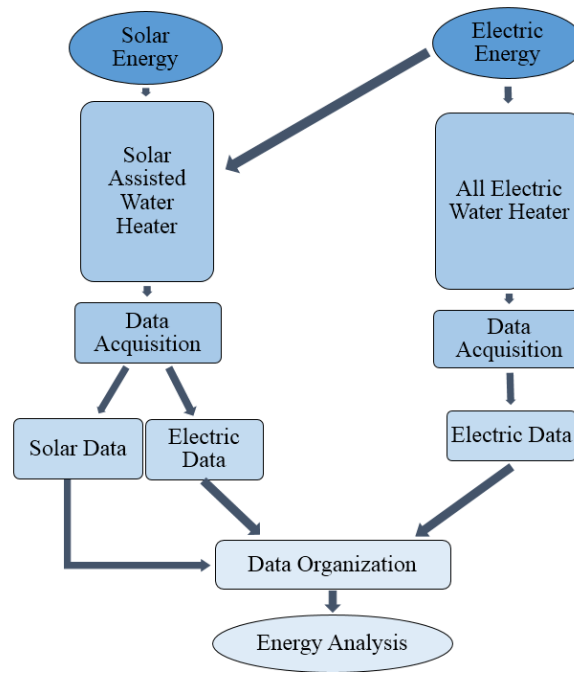


Figure 11. Diagram of process to go from energy to data analysis.

Every minute there are 21 relevant values gathered by the data acquisition. For every day there are a total of 1,440 times that the data acquisition records and adds new sets of data since the system runs 24 hours a day. The system within the facility is running majority of the year and this produces a large amount of data. Data is extracted as a Text Document from the data acquisition and is converted into information with the usage of a computer and Excel. This Text Document has to be imported and separated

into columns in Excel. Each month's worth of data is then imported individually to a new Excel file. The data within each Excel file is separated into days through the addition of tabs. For each day there are performance values obtained. Finally, a tab is created with a summary of the monthly performance data. At the initiation of the testing these processes were developed to organize the data.

Along with these processes and format, a few modules were used through Visual Basic (VBA) to work in conjunction with the processes. One issue within the data was that there would be false values extracted from the flow meters after the water heater flow control valves were closed. The reason for this is because the rotor within the flow meter would still be rotating after the flow stopped, as it lost momentum. The VBA module would take into account of the value, and if it was significantly lower, it would be removed. Another VBA module is used as a function to convert current values into energy values for the water heaters. There was also a VBA module that would automatically extract the data from each day and insert it into the summary tab.

This process has since been vastly improved to reduce the amount of time it took to organize the data and fit it into the same format. This was accomplished with the development of VBA modules and a GUI in Excel. The developed excel file is implemented after extracting the Text Document from the data acquisition and saving it onto the computer. The user then opens the developed Excel File. The GUI is set up so the user understands how the buttons work chronologically with number inserted one through four, representing each step. The first button is clicked, a screen appears that allows the user to select the saved Text document. The second button is clicked which organizes the data and only the valuable columns are extracted. With the third step, the

user fills in the required month and year for extraction and organization. Lastly the user clicks on the third button, which is number the fourth step, and an Excel File is created for the desired month with the same format as the original processes required. If more than one month is being organize the third and fourth step can be repeated, assuming the text document has the required data. There are also additional tabs that are included in the developed Excel File. These tabs allow the user to make modifications to the format without having to make any modifications to the VBA modules. The developed Excel File requires almost no labor to work with and no knowledge in VBA to run. Figure 12 shows a diagram that goes through this process, which would represent the data reduction block from Figure 11.

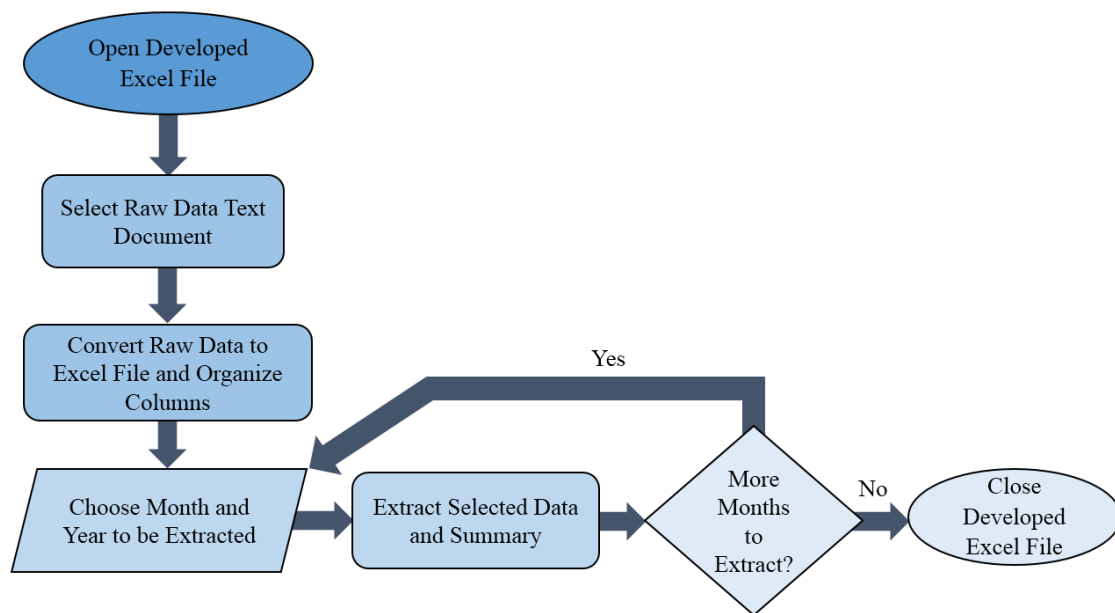


Figure 12. Block diagram showing process of Data Organization

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Lab Results

Data was collected with the four water draws a day for the months of March to December. For six water draws a day, so far data has been recorded for the months of December to February. Some months had more days' worth of data than other due to maintenance and repair that occurred throughout the testing. Test were conducted for every day possible to obtain results that would be seen in a household, regardless of the weather.

5.1.1 Results for Four Water Draws

The average daily water draw for the solar assisted system was 83 gallons per day, at an average temperature 115°F with a standard deviation 2.72°F. There are two main causes for the variability in the outlet temperature. First reason of the temperature variability is a result of the temperature not being evenly distributed in the water tank. Since the heat exchanger of HTF to water is at the bottom of the tank, the water temperature does not get distributed evenly from top to bottom. On top of that, if the water is not hot enough, the electric water heater will turn on and heat the water. This sometimes happens midway through the water draw, and the temperature is increased by one to two degrees Fahrenheit. The second reason is due to the combination of energy available from the sun and inlet temperature. The daily inlet temperature based on testing came out at 75°F with a standard deviation of 7.88°F. During the summer the inlet temperature is greater, data showing temperature around 85°F. While in the winter the temperatures come close to 65°F. This means less energy is required to heat up water in

the summer than it is during the winter, but at the same time more energy is available from the sun during the summer than the winter. The solar assisted water stay on the higher side of the temperature when it comes to the energy extracted from the rays and on the lower side when it comes to using the electrical backup heater. This is done to maximize the solar energy and minimize electrical energy and it is reflected on the temperature outlet. The electrical energy usage for the solar assisted water heater resulted at 3.10 kW-hrs per day, with a standard deviation 2.54 kW-hrs. The standard deviation is so large because there is so much difference in performance between summer and the winter. Most of the electrical energy comes from the electric water heater. During the summer it is rarely used and the electrical energy comes out less than 1.00 kW-hr per day, while in the colder months electrical energy is above 5.00kW-hrs per day.

The all-electric water heater had a slightly higher average annual water draw, averaging at 87.1 gallons per day with an average temperature of 112°F. The temperature has a standard deviation of 1.17°F. The variability in temperature is lower with the all-electric water heater because the temperature within the tank is more evenly distributed due to the two copper type immersion elements that heat the water. Also, the water is heated in a more consistent matter since only uses one energy source. The average water inlet temperature is lower than the solar assisted water heater coming up at 77°F. The main reason why there is a difference in inlet temperature has to do with the first minute of data obtained per water draw on each system. There is a delay on the water draw between the control flow valve for the solar assisted water heater opening up and the all-electric water heater opening up. This delay allows the majority of the water that has been standing still within the air conditioned facility to go through the solar assisted

water heater and not evenly distributed between both. The electrical energy usage for the all-electric water heater resulted at 7.59 kW-hrs per day, with a standard deviation 2.01 kW-hrs. The variation in energy is a result of the change in inlet temperature. The summary of the test data with the four water draw schedule is displayed in Table 6 which can be found in Appendix A.

From testing there was an effect in performance displayed due to change in total horizontal solar flux from day to day. When there was a decrease of total horizontal solar flux, the effect of this would carry over to the next day. In particular, the 12:00 PM and 6:00 AM water draws had the biggest impact. Figure 13 exemplifies the impact of total horizontal solar flux. The total horizontal solar flux was obtained directly from the data. The solar energy added to the water was solved by finding the difference in thermal energy found within the water and the electrical energy that is used from the backup electric water heater within the system. The assumption that all of the energy from the electric backup water heater goes into the water. For the 2nd of June it is seen that the solar flux is lower than the days they are surrounded by. Yet the 3rd of June, having a higher total solar flux, had less solar energy added to the water. The same thing happens on the 26th and 27th of June where the 27th has a lower result than that of the 26th. This is also displayed in the 15th where the total horizontal solar flux is noticeably lower. Since the 14th and the 16th have some of the highest solar flux in the month, the impact of the lower solar flux is mitigated and distributed with the 17th. This just comes to show that the performance for the particular day is influenced by the water draw times and by the previous day solar flux.

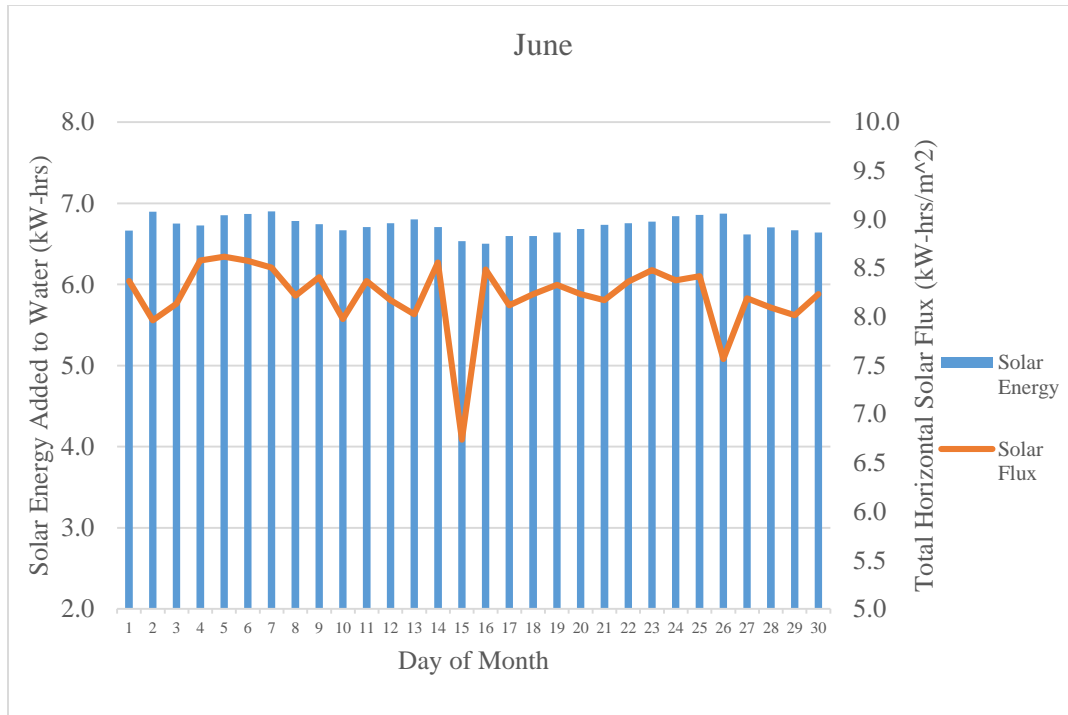


Figure 13. Bar graph of test results for June. This figure shows the amount of energy added to the water from solar radiation and the total horizontal solar flux for each day.

For each of the months, the energy that is obtained in the water from solar flux was calculated from the testing. The results were averaged out for its respective month and the standard deviation was added for its respective month. These results were then plotted and the outcome is shown in Figure 14. As expected, the summer months had the most consistency when it came to standard deviation. This was expected because this time of year the sun is exposed the most amount of time with the least amount of interruption. Toward the winter months there is a great increase in variety with results. This is mainly due to the increase of cloudy days. An example of this would be the results obtained from October. October 8 of 2014 was a mostly overcast day, where only 1.44 kW-hrs of energy was added into the water from the solar flux. In that same month on the 4th, one of the clearest days of the month, 6.72 kW-hrs of energy was added into

the water from the solar flux. These two days are confirmed to be conditions were confirmed by Weather Underground ("Historical Weather"). Figure 14 also shows that more solar energy was added to the water than in April and May than June and July. A big contributing factor to this is that during April and May the temperature of water going into the water heater was lower. This meant that more energy was required to heat at the appropriate temperature pushing the water heater performance closer to its limits.

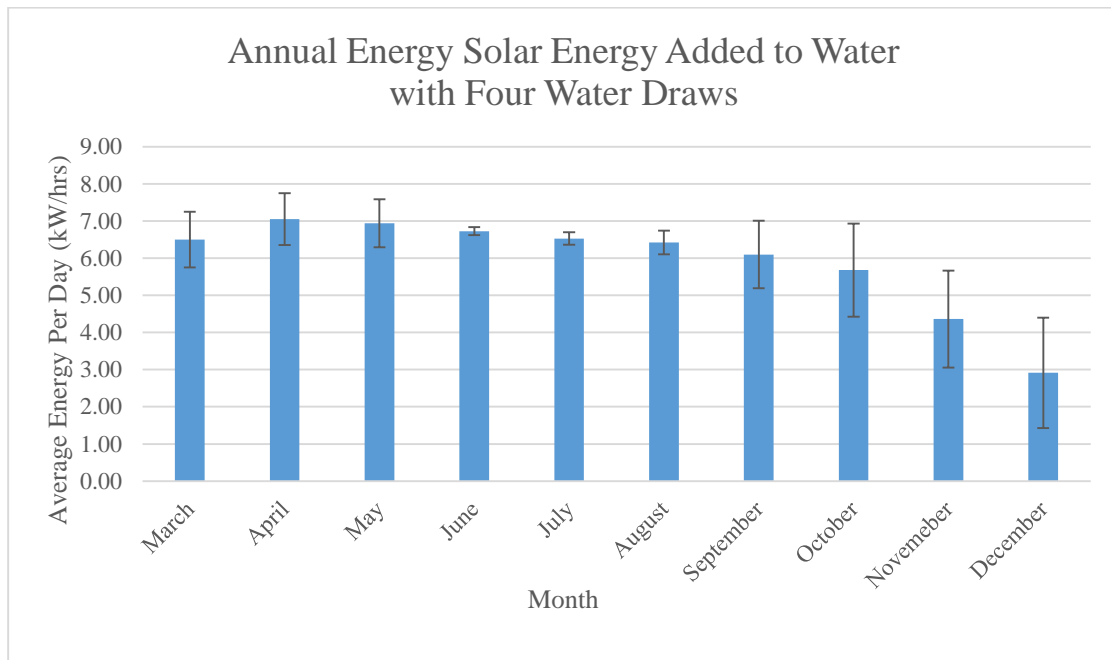


Figure 14. Bar graph of annual summary for solar energy added to water. Each bar represents an average day in that particular month.

5.1.2 Results for Six Water Draws

There has been data obtained with six water draws for the months of December of 2015 through February of 2016. For December of 2015, only the second half of the month actually had the six water draws per day, and the first half had the original four draws. For the first half of the month the total horizontal solar flux averaged at

2.9 kW-min/m², the second half was 2.7 kW-min/m². This equates to a 7% decrease

between the first and second half of the month. It was also observed that the average temperature for the second half of the month was approximately 4°F colder. The main advantage of using the data from the six water draws is that they could be normalized to be used with the data from the four water draw for comparison for both of the systems.

5.2 Solar Assisted and Electrical Comparison

With the data from the four water draws and data from the six water draws, a plot was developed that showed energy consumption of both water heater systems. The current data from the water heaters were converted into electrical energy using Equation 5 for both water heaters. For each water heater, the electrical energy was added up for each month and the results were divided by the number of gallons drawn for the respected month. For the month of January and February, the values had to be normalized because it was using different water draws. This was accomplished with the data from December, since both water draw schedules were conducted. It was assumed that the total horizontal solar flux had linear relation with the electrical energy usage for December. A constant multiplier was obtained using Equation 6 that was used to convert the values from January and February to match the four water draw schedule values. Equation 6 is as shown below:

$$K = \frac{\Phi_{S6}}{\Phi_{S4}} * \frac{X_4}{X_6} \quad (6)$$

Where:

K is constant multiplier (unitless)

Φ_{S6} is the average total horizontal solar heat flux for the 6 water draw schedule (kW-hrs/m²)

Φ_{S6} is the average total horizontal solar heat flux for the 4 water draw schedule
(kW-hrs/m²)

X_6 is the same parameter as the desired to be normalized, except December's
averaged value with the six water draw schedule

X_4 is the same parameter as the desired to be normalized, except December's
averaged value with the four water draw schedule

The multiplier constant was calculated to be approximately 1.01. The electrical energy obtained for both water heaters from January and February were each multiplied by the multiplier constant, and thus there was a value obtained from each month of the year. The results that were plotted are displayed by Figure 15.

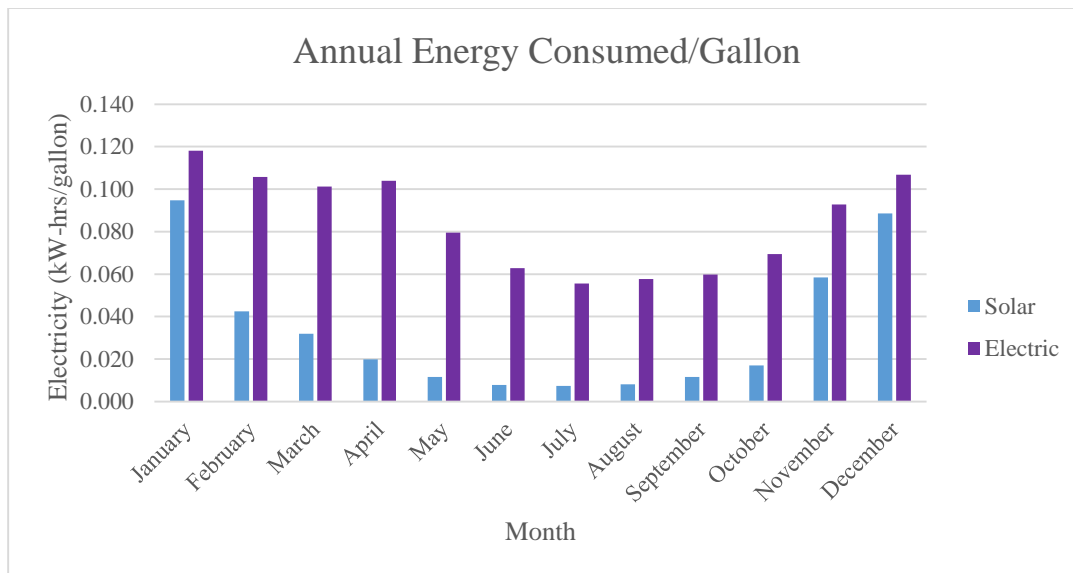


Figure 15. Bar graph of annual electricity consumption per gallon. This figure shows the results for the solar assisted water heater and the all-electric water heater.

As expected, the graph show a parabolic curve for both systems. The only exception would be for the electrical system in the month of April. The reason why the all-electric water heater value for April does not fit within the curve is because only one

day worth of data was obtained to represent this month. It was a result of lack of data and this does not imply that there is an anomaly occurring during this month. This plot also show that the solar assisted water heater works more efficiently during the summer and requires more energy during the winter. Using the solar assisted system would save 0.0152 kW-hrs per gallon on average, which would equal a savings of 1,200 kW-hrs a year if 64.3 gallons of hot water were used daily. With this being said, when compared to the all-electric water heater, the savings would be about 61% on electricity throughout the year.

Using the same data as the one for Figure 15, the cost for of electrical energy for each month was solved. Electricity rates were obtained through the Salt River Project website and are displayed in the table below ("SRP Basic Price Plan").

Table 3	
<i>Electricity Rates by Month</i>	
Duration	Cost (¢/kW-hrs)
Nov-April	7.92
May-June	11.02
July-August	11.68
Sept-Oct	11.02

The electrical energy consumption values for each water heater was converted into cost per gallon for each month. Each month was converted to a single price per month by making the assumption that each day 80 gallons of hot water were used and that each month consisted of 30 days. Figure 16 shows the bar graph that resulted from this information. From this graph it shows that the electric water heater cost stay fairly

consistent throughout the year. The graph also shows that the warmer months have the biggest cost savings throughout the whole year. Based on the results, it was calculated that the annual savings was \$142 for the entire year.

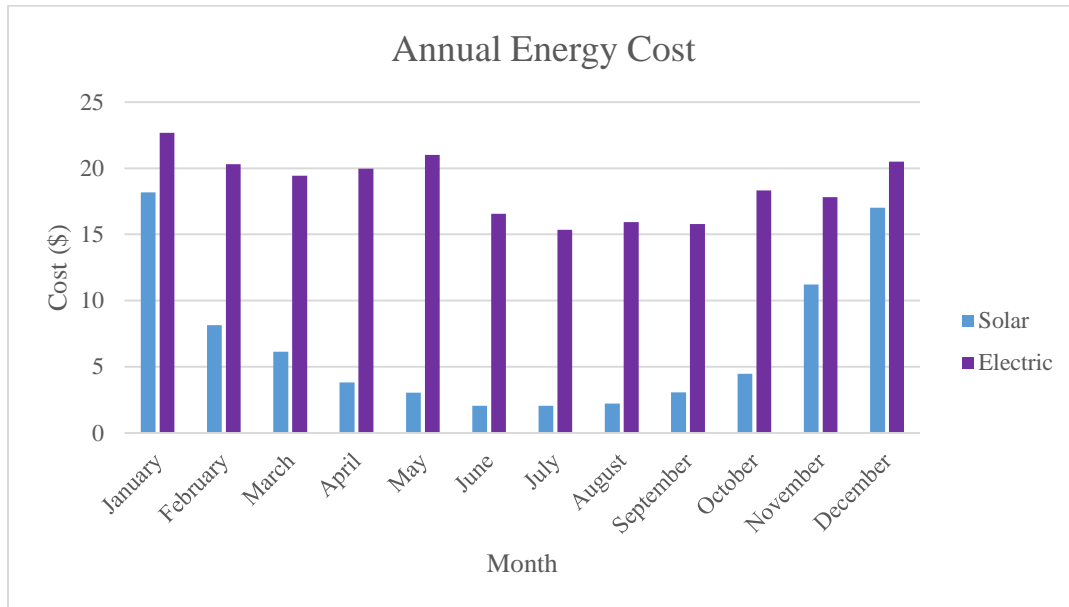


Figure 16. Bar graph of annual energy cost. This figure show the results for the solar assisted water heater and the all-electric water heater.

5.3 SRCC Ratings Comparison

One of the main purposes for this testing was to compare the performance of the solar assisted water heater. As explained in Chapter 2, SRCC has their set standards to provide performance ratings for solar energy systems and equipment. The results that were obtained through the testing were used to calculate performance parameters that SRCC uses. With these results, it is possible to have a one to one comparison with the SRCC results. If the results are similar, it would also have an implication that the testing with the four water draws was a valid form of testing.

Before any calculations, the SRCC ratings were obtained and the EF was reverse engineered with the use of Equations 1 to 3. The results from this are displayed in table 4 as followed:

Table 4			
<i>Performance Ratings For Solar Assisted System From SRCC</i>			
EF	SEF	SF	Q _{Solar} (kW-hrs)
0.87	5.1	0.83	2890

For each day of testing the Q_{DEL} was obtained using Equation 4, while Q_{AUX} and Q_{PAR} were obtained using Equation 5. For the months of January and February the six water draws schedule had been used. The values were normalize using Equation 6. The days were averaged out with other days in the same month, and each average value obtained represented an average day of that month. For each month, the SEF was obtained using Equation 1, and all 12 values of SEF were averaged out to represent the SEF of the solar assisted system. The same EF was used to have a consistent parameter value for comparison. With the EF of 0.87, the SF was obtained with Equation 2. The same process used for the SEF was used for the Q_{SOLAR}, except that Equation 3 was used and the end value had to be converted from a daily value to an annual value. The results were organized into a table with the SRCC results just under it and Table 5 was created.

Table 5				
<i>Performance Ratings From Testing and SRCC</i>				
Reference	Water Heater	SEF	SF	Q _{SOLAR} (kW-hrs)
ASU	Solar Hybrid	5.52	0.84	2261
SRCC	Solar Hybrid	5.10	0.83	2890

There two observations made from the results that came about from the testing. The first is that the SEF and the SF for the solar assisted system were very close to those of SRCC. This implied that the testing done to the systems was within line of appropriateness. Having the four water draws with two conducted at 12PM and 6AM would have a negative impact during the colder months. Yet the result show that the performance SEF from the testing is approximately 8% higher. This can be explained with the second observation which was seen by Q_{SOLAR} . As it shows in Table 5, the Q_{SOLAR} from SRCC is 2890 kW-hrs. This value is 629 kW-hrs higher than the results obtained from the test. A reason for this is because the inlet water temperature was a controlled value for the SRCC ratings. The inlet water value was lower, which caused the energy required to heat up the water to increase. This would aide help increase energy savings, but also reduce the SEF and SF. The inlet temperature for the testing in the facility is something that cannot be controlled, as it is supposed to play a role in simulating the typical household. These two differences help each other balance out for the SEF and the SF.

CHAPTER 6

CONCLUSION

The solar assisted water heater performed as it was expected to. The effects of having the four water draws were displayed in the performance values obtained from the solar assisted water heater. There was a greater amount of consistency of performance during the summer months, the variation increased as it approached winter. The all-electric water heater had much more consistency in performance, largely due to the weather impacts on the solar assisted water heater. When graphing both the solar assisted water heater and all-electric water heater annual energy usage, it was seen that the patterns followed the parabolic curve that it was predicted to. The efficiency of the solar assisted water heater was the greatest during the summer months. When compared to the all-electric water heater, the solar energy water heater showed an energy savings of 61% for the entire year. The costs were the most economical during the warmer months and an estimated savings of \$147 for the entire year was calculated.

The SRCC have performance ratings that match the results obtained from the test data. With their Solar Energy Factor being 5.10, and the test results showing an SEF of 5.52. This is an 8% difference between SRCC results and the test data. This not only helps confirm that the SRCC ratings are an appropriate source for getting performance information from solar energy systems and equipment, but it also helps validate that the testing was adequate for its purpose. Although the energy savings values differed from those of SRCC, this is widely due to the temperature of the water going in and not the solar assisted water heater itself. This research has resulted in a better understanding of the solar assisted system, and the performance advantages of it.

REFERENCES

- Bergman, Theodore L., Frank P. Incropera, Adrienne S. Lavine, and David P. Dewitt. *Fundamentals of Heat and Mass Transfer*. Hoboken, NJ: Wiley, 2011. Print.
- HESolar Heat Exchanger, Solar Tank, or Electric Storage Water Heater*. Fontana: SunEarth, 2008. *SunEarthInc.com*. SunEarth. Web. 31 Mar. 2016. <<http://sunearthinc.com/wp-content/uploads/SunEarthSolarTankBrochureAugust20102Pager.pdf>>. Spec. Sheet
- "Historical Weather." Weather History & Data Archive. The Weather Company, LLC. Web. 31 Mar. 2016. <<https://www.wunderground.com/history>>.
- Hough, Tom P. *Recent Developments in Solar Energy*. New York: Nova Science, 2007. Print.
- "Ohm's Law and Ohms Law Calculator." *DIY Audio Projects RSS*. DIY Audio Projects. Web. 01 Apr. 2016. <<http://diyaudioprojects.com/Technical/Ohms-Law>>.
- Parker, D. S., Fairey, P. W., Solar, F., & Lutz, J. D. (2015). *Estimating Daily Domestic Hot- Water Use in North American Homes*, 121.
- Rapp, Donald. *Solar Energy*. Englewood Cliffs, NJ: Prentice-Hall, 1981. Print.
- Residential Upright Energy Saver Electric Water Heater*. Bradford White Corporation. *Bradford White Water Heaters*. Bradford White Corporation, 2013. Web. 31 Mar. 2016. <http://www.bradfordwhite.com/sites/default/files/product_literature/201-B.pdf>. Spec Sheet
- Roberts/NREL, Billy J. "Concentrating Solar Resource of the United States." *Dynamic Maps, DIS Data, & Analysis Tool*. Web. 31 Mar. 2016. <http://www.nrel.gov/gis/images/eere_csp/national_concentrating_solar_2012-01.jpg>.
- Sayigh, A. A. M. *Solar Energy Engineering*. New York: Academic Pr., 1977. Print.
- "Solar Hot Water Collectors." *GreenSpec: Solar Power: Solar Panel Hot Water Collectors*. Greenspec. Web. 31 Mar. 2016. <<http://www.greenspec.co.uk/building-design/solar-collectors/>>.
- "Solar Rating & Certification Corporation - Certification & Listing Directory." *Solar Rating & Certification Corporation - Certification & Listing Directory*. Solar Rating & Certification Corporation. Web. 18 Dec. 2015. <http://www.solar-rating.org/certification_listing_directory/index.html>.

"SRP Basic Price Plan." Basic Price Plan for SRP Residential Electric Customers. Salt River Project. Web. 01 Apr. 2016.
<<http://www.srpnet.com/prices/home/basic.aspx>>.

Steca TR0301 U Instruction EN. SunEarth Inc. Web. 31 Mar. 2016.
<http://sunearthinc.com/wp-content/uploads/Steca_TR0301_U_instruction_EN.pdf>. User Manual

Thomas De Fresart, Edouard. *Design, Simulation, and Analysis of Domestic Solar Water Heating Systems in Phoenix, AZ*. Thesis. Arizona State University, 2012. Ann Arbor: ProQuest LLC, 2012. Print.

APPENDIX A
TEST RESULTS SUMMARY

Table 6

Summary of Data Gathered With Four Water Draws

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg	
											Avg	STDEV
Avg Environmental Temperature [°F]	67	70	81	91	94	90	86	76	59	53	73	14
Max Environmental Temperature [°F]	81	84	93	104	106	101	97	90	74	69	87	12.6
Min Environmental Temperature [°F]	52	54	66	74	82	78	76	64	47	40	60	14.5
Avg Room Temperature [°F]	67	67	72	76	76	76	75	77	69	63	71	4.9
Total Horizontal Solar Flux (kW-hrs/m ²)	6.2	7	7.6	8.2	7.1	6.4	5.5	4.6	3.6	2.9	5.5	1.7
Solar-Avg Outlet Water Temperature [°F]	113	113	114	119	120	119	117	114	113	113	115	2.7
Solar-Avg Inlet Water Temperature [°F]	70	71	78	84	86	85	83	80	70	63	75	7.9
Solar-Water Volume Draw [gal]	83	81	82	81	81	80	80	81	87	89	83	3.2
Solar-Avg Water Draw Rate [Gal/min]	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.5	1.4	0.05
Solar-Energy From Electricity [kW-hrs]	2.7	1.8	0.9	0.6	0.6	0.6	0.9	1.6	5.3	8.3	3.1	2.54
Solar-Energy Into Water [kW-hrs]	8.6	8.4	7.4	6.9	6.7	6.6	6.6	6.8	9.2	10.8	8.2	1.44
Solar-Auxiliary Energy (kW-hrs)	2.1	1.2	0.4	0.1	0.1	0.2	0.5	1.1	4.9	7.9	2.6	2.57
Solar-Energy Into Water From Solar (kW-hrs)	6.5	7.1	6.9	6.7	6.5	6.4	6.1	5.7	4.4	2.9	5.5	1.31
Electric-Avg Outlet Water Temperature [°F]	111	111	112	113	114	114	113	112	111	110	112	1.2
Electric-Avg Water Temperature [°F]	71	71	78	84	86	85	84	83	75	69	77	6.5
Electric-Water Volume Draw [gal]	85	86	84	83	82	82	83	85	93	94	87	4.4
Electric-Avg Water Draw Rate [Gal/min]	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.5	1.5	1.4	0.07
Electric-Energy From Electricity [kW-hrs]	8.9	9.3	7.1	5.5	4.9	5.1	5.5	6.4	8.8	10.4	7.6	2.01
Electric-Energy Into Water [kW-hrs]	8.3	8.5	7	6	5.7	5.7	5.9	6.2	8.3	9.6	7.4	1.43

APPENDIX B

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