

2008

Experimental Test and Cost Analysis of Residential Solar Water Heaters

Sai Mahesh Dharanikota
Cleveland State University

Follow this and additional works at: <https://engagedscholarship.csuohio.edu/etdarchive>

 Part of the [Mechanical Engineering Commons](#)

How does access to this work benefit you? Let us know!

Recommended Citation

Dharanikota, Sai Mahesh, "Experimental Test and Cost Analysis of Residential Solar Water Heaters" (2008). *ETD Archive*. 425.
<https://engagedscholarship.csuohio.edu/etdarchive/425>

This Thesis is brought to you for free and open access by EngagedScholarship@CSU. It has been accepted for inclusion in ETD Archive by an authorized administrator of EngagedScholarship@CSU. For more information, please contact library.es@csuohio.edu.

**EXPERIMENTAL TEST AND COST ANALYSIS OF
RESIDENTIAL SOLAR WATER HEATERS**

SAI MAHESH DHARANIKOTA

Bachelor of Mechanical Engineering

OSMANIA University

May 2006

Submitted in partial fulfillment of requirements for the degree

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

at the

CLEVELAND STATE UNIVERSITY

December 2008

This thesis has been approved
for the Department of **MECHANICAL ENGINEERING**
and the College of Graduate Studies by

Thesis Committee Chairperson, Dr. Asuquo Ebiana

Department/Date

Dr. Rama Gorla

Department/Date

Dr. Majid Rashidi

Department/Date

ACKNOWLEDGEMENT

My first and foremost words of appreciation go to my esteemed academic advisor, Dr. Asuquo Ebiana. I have continuously benefited from his outstanding expertise and enormous source of knowledge in both theoretical and practical matters for the past two and half years. I am truly privileged to be blessed with such a rare opportunity, to observe and hopefully learn his unique approach to analyzing problems, entertaining and structuring new ideas, developing viable solutions and putting them to practice. I would like to thank him for all his guidance in my study.

I would like to express my sincere gratitude to Mr. Ken Skoczen and Mr. Paul Gerg from HMI Industries, for their guidance throughout my thesis work and also thank them for taking time and patiently reviewing my thesis and giving valuable suggestions.

I also would like to thank my other thesis committee members, Dr. Rama Gorla and Dr. Majid Rashidi for reviewing my thesis, providing me with valuable suggestions and also for taking time to attend my thesis presentation.

I thank my department of Mechanical Engineering, Cleveland State University for giving me the opportunity to pursue my Master's in

Mechanical Engineering. I thank Dr. Paul.P.Lin ex-chairman of our department and also Dr. William Atherton chairman for their valuable suggestions. I also thank my friend Mr. Praveen Gidugu for his help during my program of study.

I would like to thank my parents and my sister for their support and encouragement in every phase of my life. I also would like to thank all my friends for their good wishes in pursuing my degree.

**EXPERIMENTAL TEST AND COST ANALYSIS OF
RESIDENTIAL SOLAR WATER HEATERS**
SAI MAHESH DHARANIKOTA

ABSTRACT

Non renewable energy sources have been diminishing in the recent times. Renewable energy is abundant in nature, but the use of it is very low. Lowering the energy consumption and using renewable energy, thereby decreasing the use of fossil fuels and nuclear energy would have a positive impact on our environment. The use of solar energy as an alternate resource is discussed in this research. The solar water heater is tested for its recovery rates, under normal solar radiation in static testing. The effect of solar radiation in increasing the temperature of water is studied and discussed. The solar water heater is then brought in series with an electric hot water tank, used in residential purposes. The energy consumption by the hot water tank is first calculated, by testing the recovery rates of the hot water tank. The hot water tank is then supplied with solar heated water and the recovery rates of the hot water tank are calculated. The energy consumption is calculated and the cost analysis is done in both the cases. The values of the energy consumed by the hot water tank with the use of electricity and solar heated water are compared. The DAQ system acts as an interface between the solar water heater and the hot water tank, which records and monitors the temperature data using thermocouples. The DC/AC adapter clamp and the multi meter, record the current usage by the hot water tank.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
NOMENCLATURE.....	xi
CHAPTER HEADING/SUBHEADING	
I. INTRODUCTION	1
1.1 Background	1
1.2 Literature Survey	4
1.3 Motivation and Objectives.....	5
II. OVERVIEW OF SOLAR COLLECTORS.....	7
2.1 Types of Solar Water heating systems	7
2.2 Glass Evacuated Tube Solar Water Heater.....	11
2.3 Factors Influencing the Performance of Solar Collectors.....	15
2.4 Theory	16
III. INSTRUMENTATION AND EXPERIMENTAL SETUP	19
3.1 Solar Collector Installation.....	19
3.2 Thermocouples	20
3.3 Fluke Hand Held Thermometer.....	21
3.4 DARWIN Data Acquisition System	23
3.5 Expansion Tank	26

3.6 Electric Hot Water Tank.....	27
3.7 Closed Loop Static Test.....	28
3.8 Hot Water Tank Recovery Rate Test	33
3.9 Open Loop Test of Hot Water Tank with Solar Heated Water....	39
IV. RESULTS AND CALCULATIONS	48
4.1 Introduction	48
4.2 Static Test Results	49
4.3 Recovery Rates and Energy Used by the Hot Water Tank	60
4.4 Recovery Rates and Cost Calculations of Hot Water Tank Test in Open Loop.....	72
V. CONCLUSIONS.	82
REFERENCES	86

LIST OF TABLES

		Page
Table 1.	Static Test Results of Solar Water Heater in a Closed Loop– Day 1	50
Table 2.	Static Test Results of Solar Water Heater in Closed Loop – Day 2	53
Table 3.	Second set of Static test results of Solar Water Heater in a Closed loop – Day 1	56
Table 4.	Second set of Static Test results of Solar Water Heater in a Closed Loop – Day 2	58
Table 5.	Recovery rate and energy calculations of Hot Water Tank.	61
Table 6.	Energy calculations and Cost analysis of the Hot Water Tank.	71
Table 7.	Open loop test results of Hot water tank in series with Solar water heater.	73
Table 8.	Energy Calculations and Cost Analysis of Open Loop Test.	80
Table 9.	Energy Savings of Hot Water with Electricity and Solar water heater.	84

LIST OF FIGURES

		Page
Figure 1.	Integral Collector Storage system	8
Figure 2.	Flat Plate Collector System	9
Figure 3.	Evacuated Tube Collectors	10
Figure 4.	Evacuated Tube Solar Collector	11
Figure 5.	Location of Inlet and Outlet	13
Figure 6.	Glass Evacuated Tubes	13
Figure 7.	Holes with Silicone Rubber Gaskets	20
Figure 8.	Thermocouples used in the experiment	21
Figure 9.	Fluke 52 II Thermometer	22
Figure 10.	Input Module of Darwin system	23
Figure 11.	DAQ Logger	25
Figure 12.	EXTROL Expansion Tank	26
Figure 13.	GE Electric Water Heater	27
Figure 14.	Location of Thermocouples	29
Figure 15.	Closed Loop Static Testing	30
Figure 16.	Temperature Measurements	32
Figure 17.	Probe Thermocouple on Hot Water Tank	34
Figure 18.	Recovery Rate Test of HWT	36
Figure 19.	Piping from Solar water heater to HWT	41
Figure 20.	Pressure reducer and Thermocouple T6	42
Figure 21.	Interface between Solar water heater and DAQ System	43

Figure 22.	Solar Water Heater connected in series with the Hot Water Tank	45
Figure 23.	Static Test Results of Solar Water Heater on Day 1.	51
Figure 24.	Static Test Results on Solar Water Heater in Closed Loop – Day 2	54
Figure 25.	Second set of Static test results of Solar Water heater in closed loop – Day 1	57
Figure 26.	Second set of Static Test results on Solar Water heater in a Closed Loop – Day 2	59
Figure 27.	Recovery Rate testing of Hot Water Tank	62
Figure 28.	Comparision between the water drained from the hot water tank to the electric current consumed in heating the water	72
Figure 29.	Recovery Rate testing of Hot water tank in Open Loop.	74
Figure 30.	Water Drained Vs Current usage for the Open loop test.	81

CHAPTER I

INTRODUCTION

1.1 Background.

The ability to do work is Energy. It is one of the most fundamental parts of the Universe. It is the property of the objects and systems, which is conserved by the nature. We depend on energy to help us accomplish our tasks as well as to maintain the standard of living. An act as simple as tossing up a coin to as complicated as lifting hundred of pounds requires energy. The modernization of society has brought about increased demands on energy sources and production. Societies with limited access to energy resources are significantly hindered from industrialization and economic growth.

Solar energy is one of the renewable sources of energy available, which can be used for varied purposes. A hot water tank uses electricity to heat up water there by converting electrical energy and supplying it as

thermal energy. The amount of electrical energy consumed by a hot water tank may vary, depending upon the capacity and specifications of it. The larger the tank is, the more electricity it consumes. Electricity is generated mainly using fossil fuels. This emits large amount of oxides into the air, which are toxic to human health and constitute serious health problem. Also it causes Global warming and carbon emissions. A suitable way to reduce these threats has to be found out and lowering the energy consumption and using renewable energy would accomplish several of these things. In this process, we look at the using Solar energy to supply the necessary thermal energy to water used in a hot water tank, thereby reducing the amount of electrical energy consumed by it contributing to the energy savings and cost savings as well.

The energy in sunlight is in the form of electromagnetic radiation in different wavelengths. Solar collectors extract energy out of this sunlight into a more usable or storable form. The water in the solar collector is allowed to expand using the solar energy and once it reaches a certain temperature, it was allowed to flow from the heater to the hot water tank, there by supplying pre heated water to the hot water tank. This would allow the electrical elements in the hot water tank to start late or never start, when water in it is drained out, thereby saving the electric current.

In this study, the experimental calculation of the recovery rates of static water in the solar water heater and when connected to the electric hot water tank are calculated. The static test is conducted with the water in

the solar water heater being stable in, where it does not flow within the system and the open loop test electric hot water tank to calculate the energy savings. These tests are conducted on a time domain for a certain interval of time to note the rate of change of the temperature in the solar tank.

Even though energy exists in different forms and different states, it cannot be created nor destroyed. It has to be converted from one form to another. Based on this, it is classified into two categories, Renewable and Non Renewable energy.

Non-Renewable Energy:

Non-renewable energy comes out from sources that cannot be replenished in a short time. They are fuels that are created under extreme conditions in earth crust. They cannot be used again, once they are used. These usually consist of Fossil fuels like Coal, Oil and Natural Gas, Radioactive minerals mainly Uranium and Thorium etc.

The advantages of these fuels are they are ready-made fuels available and are also relatively cheap. The main disadvantage with them is they cannot be used again and may become extinct in due course of time.

Renewable Energy:

Renewable energy is generated from natural resources such as sunlight, wind, water and geo thermal heat. These resources can be replenished and can be used number of times. Renewable energy technologies include solar power, Wind power, and Hydro electricity and bio fuels.

Wind power is the conversion of wind energy into useful forms of energy such as electricity, using wind turbines.

One of the easiest sources of renewable energy is Solar power. It is obtained from the sunlight and can be stored, used and converted into various forms. This is done by a Solar Collector. There are two types of systems in which this can be done.

1.2 Literature Survey.

The use of solar energy has been in use right from the Cave age, where early cave dwellers preferred caves that had openings facing south-east. This facilitated the morning sun to warm them up, without overheating during the warm months. The search for alternate fuel source and the usage of solar energy for the same was predominantly in use right from the Greek and Roman Age. In 1891 Clarence M. Kepm patented the world's first commercial Solar water heater, known as "Climax". It was a black painted water tank in an insulated box, with glass on one side, which acted as a reflecting media. In 1901, William J. Bailey designed a solar water heater consisting of a solar collector and a separate storage tank mounted above the collector, called "Day and Night Solar Water Heater" [2]. This was one of the first insulated solar water heaters in the flat plate collectors. The usage of solar collectors is largely in USA, was in Florida, which had a humid climate, which was started on a large scale during 1930's. There was a huge fall in these sales, once the World War II began. Also the

availability of raw materials at a lower price reduced the usage of solar water heaters. Currently the usage of Renewable energy comprises of about six percent in which Solar, both thermal and electric energy, comprises only one percent of the renewable energy share in USA [1].

1.3 Motivation and Objectives:

This experimental study focuses in setting up the solar collector heater equipment as a closed loop and Open loop systems. In the Closed loop system test, a Static test in a closed system measuring the ambient outdoor temperature effect on the solar water heater during different times of the day. The static test gives the rate at which the temperature of water rises within the solar water tank with the increase and decrease of the solar heat supplied to it.

Then the system is converted into an Open loop system by bringing in a hot water tank and running water through it. Draining every 5, 10, 15, 20, 25 and 30 gallons of water out of the hot water tank and filling it with the city water allowing the electrical elements in the tank to raise the temperature of the water the recovery rates of the electric hot water tank are calculated. The hot water tank is now brought in series with the solar water collector and the recovery rates of the electric hot water tank being supplied with solar heated water are calculated for every 5. 10, 15, 20, 25 and 30 gallons of water drained out of the hot water tank. The electric

power consumed by the hot water tank in both the cases is compared and the savings are calculated.

The Darwin data acquisition and recording system (DAQ) software has the ability to acquire information from a large number of points easily and economically. It uses a data acquisition engine and remote I/O modules which are completely separate from each other. It is supported by a personal computer, and a whole line up can be created starting with the data acquisition system for data logging, data monitoring and data recording. It measures the Temperature, DC voltage, Strain input, Pulse input, effective current, voltage and active power. This system is used in this experiment to continuously monitor and record the temperature values of the water in the solar water tank and hot water tank through J-type thermocouples connected to the DI/DO module. These values are stored in the computer. A digital thermometer is used to measure the temperature values manually by plugging in the thermocouples directly into it. This is to check any errors in measurement by the DAQ system, periodically.

A multi log 720 RMS unit is used to monitor the change in current and voltage. It is supported by a DCA/ACA clamp adapter, which is clamped around the electric circuit wires, which serves as the input module for the RMS unit. This monitors the change in the electric voltage and current and reports it back to the unit. This unit is used for the recovery testing of the electric hot water tank as well as the Open loop testing.

CHAPTER II

OVERVIEW OF SOLAR COLLECTORS

2.1 Types of Solar Water Heating Systems.

Integral Collector Storage:

Integral Collector Storage units are examples for Passive Solar Heating systems [3]. An integral collector storage system includes a tank system, a plurality of heat exchange tubes with at least some of the heat exchange tubes arranged within the tank system, a first glazing layer positioned over the tank system and a base plate positioned under the tank system [4]. In an ICS unit the hot water storage tank is the solar absorber. The tank is mounted in an insulated box with glazing on one side and is painted black or coated with a selective surface. The sun passes through the insulated box there by heating the black tank, there by warming the water inside it.

There are three types of ICS systems, Tank type ICS Collector, Tube type ICS Collector and Thermosiphon type ICS Collector. These ICS collectors are simple since they use no pumps or controllers and water

always flows through the collectors [5]. They work great in climates that never experience freezing conditions. That is because the surface area exposed to the atmosphere is large.

These systems do not lose heat quickly and often tend to provide 100 percent of the daily domestic hot water in hot and sunny conditions.

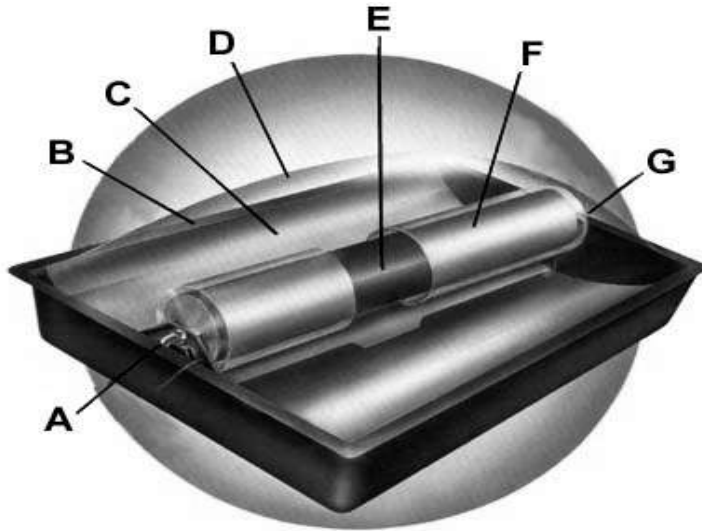


Figure 1: Integral Collector Storage system

[Courtesy: www.servamaticssolarparts.com]

A – Cold water inlet, B- Bottom enclosure, C- Reflective mirror, D- Outer glazing, E- Stainless steel collector, F- Inner glazing, G- Hot water outlet

Flat Plate Collectors:

Flat-plate collectors are the most common solar collectors for use in solar water-heating systems in homes and in solar space heating. A flat-plate collector consists basically of an insulated metal box with a glass or plastic cover (the glazing) and a dark-colored absorber plate [6]. They are rectangular shallow boxes made with a strong frame, a glazing fastened to

the front of the collector and a solid back. The main element of a flat-plate collector is the absorber plate which lies beneath the glazing. It covers the full aperture area of the collector and absorbs the maximum possible amount of solar irradiance, conducts this heat into the working fluid at a minimum temperature difference, and loses a minimum amount of heat back to the surroundings [7] i.e., solar radiation is absorbed by the absorber plate and transferred to a fluid that circulates through the collector in tubes.

These collectors can absorb both direct and diffused radiation. These do not require the orientation towards sun as the whole area is exposed to the atmosphere. The disadvantage of these collectors is the possibility of freezing in collector tubes in cold climates and can hold comparatively less amount of water in them [8].

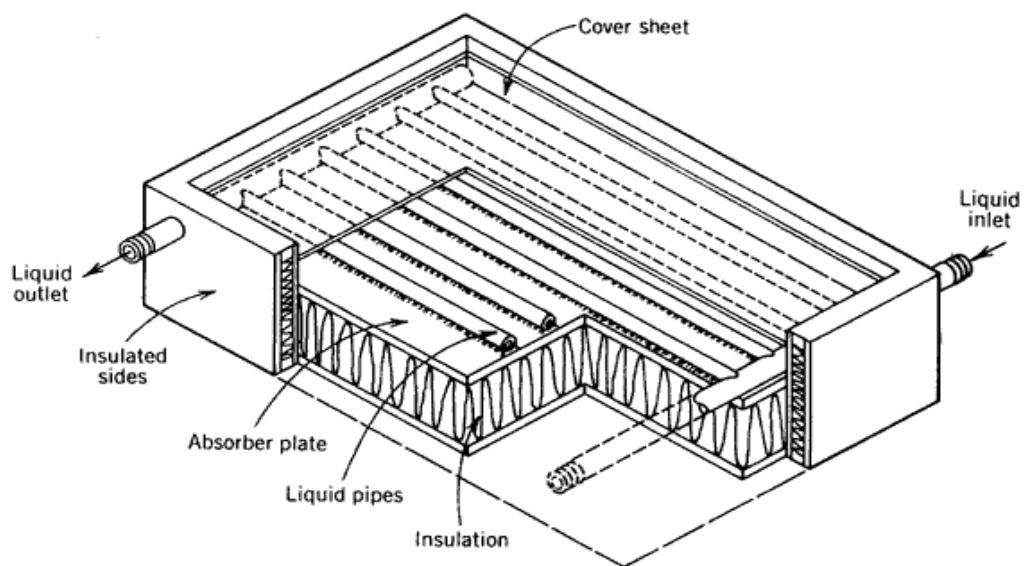


Figure 2: Flat plate collectors system. [Courtesy: U.S dept of Energy]

Evacuated Tube Collectors:

Reheating water in the recirculation loop, rather than preheating cold water, requires a collector with a very low loss coefficient. This is currently available only with evacuated-tube solar collectors, as opposed to flat-plate solar collectors [9]. These evacuated tube collectors consist of a large tank for holding water, a series of evacuated tube collectors constructed with a number of glass tubes. Each of these tubes has an absorber plate within the tube. The main advantage of these evacuated tube collectors is the insulation they provide due to the absence of air in the tubes. This allows higher temperatures to be achieved at the absorber end.

The disadvantage of these evacuated tube collectors is that they can generate temperatures above the boiling point of water, which might be an area of concern. Also the tubes are constructed with glass, which are fragile and delicate. They do not shed snow accumulated on the tubes, as

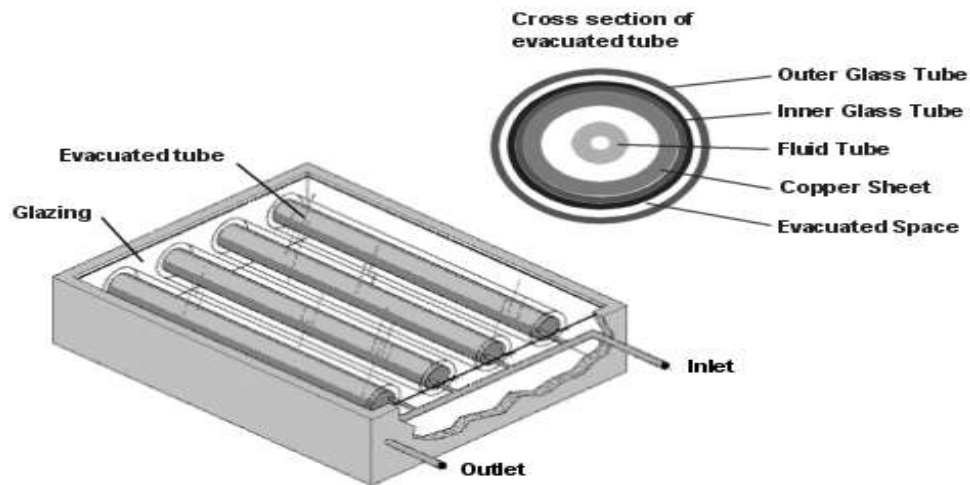


Figure 3: Evacuated tube collectors. Courtesy: [U.S dept of Energy]

they are very good insulators and little heat escapes from them, it sticks on the tubes for a long time.

2.2 Glass Evacuated Tube Solar Water Heater.

The glass evacuated tube solar water heaters comprise of 151.1 Liter (39.9 Gallon) stainless steel water tank, a series of fourteen vacuum tubes, an inlet and outlet for water and a pressure relief vent. The cylindrical stainless steel tank is machine made and is pressed on aluminum alloy (stainless steel) [10]. The inner layer of the water tank is made of SUS 304 type stainless steel plates, welded by argon arc. The SUS 304 type stainless steel has excellent tensile strength and resistance to corrosion [11].



Figure 4: Evacuated Tube Solar Collector.

Courtesy:[HMI Industries, Ohio]

The tank is surrounded by Urethane high density integral foaming with 55-millimeter super thickness insulation layer, to avoid extreme heat loss inside the tank due to the temperature difference between the solar water tank and ambient temperature.

Location of Inlet and Outlet:

The location of the inlet and outlet channels for the water should be carefully located; taking into account the heat losses that could take place within the system. The heat losses in a stored system could constitute the heat transfer losses of the thermal insulation and also the conductive losses by fluid circulation through connections and armatures [12]. Hence the inlet and the outlet are located at two different locations i.e., the inlet is located at the bottom of the tank and the outlet is located at the top of the tank. The main advantage of locating the outlet at the top is to avoid thermosiphoning of the system.

When water is heated, it gains kinetic energy from the heating source and gets excited. This water at an excited stage becomes less dense, expands and tends to rise upwards [13]. Thus in a system, hot water tends to rise upwards and cold water remains at the bottom. This process is known as thermosiphoning.

The same principle may be applied to the tank, where the water is heated by solar energy. Thus the water gains energy from the sun and tends to expand and rises upwards. The water at lower temperature settles down at the bottom of the tank. Hence it would be a convenient to have the water

inlet at the bottom of the tank, as the water, which enters the system, would be at a lower temperature. The outlet of the tank should be placed at the top in order to gain the maximum heat energy out of the system avoiding thermosiphoning of the system.



Figure 5: Location of Inlet and Outlet. Courtesy:[HMI Industries, Ohio]

Glass Evacuated Tubes:

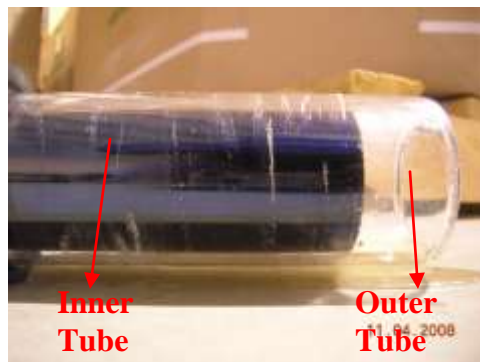


Figure 6: Glass Evacuated Tubes

Courtesy: [HMI Industries]

The process of capturing the solar energy and transferring it to heat up water in the tank is done by a series of borosilicate glass evacuated tubes

located at the bottom of the tank. There are a series of fourteen parallel tubes used in this case for the heating of water. These tubes are made up of annealed glass and have an absorber plate within the tube. Each tube consists of a glass outer tube and a glass inner tube (or absorber) covered with selective coating that efficiently absorbs the solar energy [14]. Air is drawn out of the space between these two tubes, which creates vacuum. This vacuum helps in achieving higher temperatures. These tubes adopt efficient AL-N/AL heat absorption coating as it has high absorptivity and low emission rate. The absorber plate used in this case is a stainless steel plate. This efficiently enhances the thermal efficiency of the solar energy water heater. These tubes are closed at one end (bottom end) and open at the other (top end).

The rubber gaskets seal the tubes with the tank. The tubes are lubricated with silicone or glycerin. In this case silicone grease spray is used to lubricate the tubes. This lubrication enables better contact of the tubes inside the base plate of the tank. There are silicone rubber seal gaskets that guard around the tubes and ensure tight contact of the tubes with the tank. These rubber gaskets are mounted on the tubes once the lubrication is done and then they are fitted into the base plate of the solar tank.

Working Fluid:

The working fluid usually employed in these solar water heaters is either Water or Glycol. The most economical and convenient working fluid is water as it is available abundantly and is relatively cheaper than compared

to glycol. It is usually employed in single fluid systems where the working fluid is extracted out and is used for other purposes. Glycol on the other hand is expensive when compared to water. It is used in a two fluid media where the working fluid does not move out of the system and is used to heat another liquid. In this case, the glycol is heated up in the solar heater tank and is circulated within a heat exchanger. The other fluid is passed within the heat exchanger and exchanges heat with the glycol, which flows in separate tubes.

The thermal conductivity of glycol ($0.07325 \text{ Watts}\cdot\text{ft}/(\text{h}\cdot\text{ft}^2\cdot^\circ\text{F})$) is lower than that of Water ($0.19631 \text{ Watts}\cdot\text{ft}/(\text{h}\cdot\text{ft}^2\cdot^\circ\text{F})$). This makes water a better heat conducting fluid than glycol. But the boiling point of water (212°F) is lower than that of glycol (386°F), which means water would evaporate faster than glycol with a raise in the temperature. Hence to attain higher temperatures, use of glycol is preferred than water.

2.3 Factors influencing the performance of the solar collectors.

Latitude:

The amount of solar radiation at a particular place varies with the latitude. It would be higher at some places and lower at other. Given the latitude, where the solar collector is installed, the amount of solar radiation incident at that particular area could be calculated.

Solar Orientation:

Solar collector should be installed at a place which is free from any sort of shadow cast by the buildings, or any other significant structures on the property. This depends on the position of the sun from season to season. Also the solar collector should be facing south to receive maximum amount of solar radiation incident on a particular day.

Air Movement and Temperature:

Sometimes the temperature at a particular place may increase or decrease due to the temperature of air at that place. Cold air on a sunny day may decrease the temperature and vice versa. Also the movement of air in the surroundings of the solar collector varies the temperature effect on the solar collector.

Losses in the Pump:

The losses in the pump, (if used any) could be due to piping losses or flow losses. Heat could escape when the water flows within the pump and through various pipe fittings, armatures or connections.

2.4 Theory.

The theory part of the experiment is in the determination of the power usage of the hot water tank and to calculate the energy savings when the solar water heater is connected to the hot water tank. The different

electrical units involved in this theory measurement are Amperes (amps), Watts, Volts and Kilo Watt Hour

Amperes (A):

The rate at which the charge carriers flow within is Current (I). The standard unit is the Amperes (A). It represents one coulomb of charge carriers flowing every second past a given point [15].

$$\text{Voltage (V)} = \text{Current (I)} \times \text{Resistance (R)}$$

$$\text{Hence } I = V / R$$

Watts (W):

The rate at which electric power is transferred by an electric circuit is known as Electric power (P). The SI unit of Power is Watt (W).

$$P = V \times I$$

Voltage (V):

Voltage (V) is defined as the potential difference across a conductor when a current of one Ampere dissipates one watt of Power [16].

$$V = W / A$$

Kilowatt Hour (kWh):

Kilo watt hour is the SI unit of energy. It is 3.6 mega joules, which is the amount of energy transferred if work is done at the rate of one thousand Watts per one hour [17].

Power Usage Calculations:

To calculate the power used by the system, the important things needed are the Voltage and the Current conducted in Amperes.

The current flow in the system is given by the multi meter, which gives the amperes of current. This amperes when multiplied by the voltage gives the power in kilo watts.

$$\text{Voltage} \times \text{Current} = \text{Energy}$$

$$V \times A = W.$$

$$\frac{\text{Watts}}{1000} = \text{kilo Watts}$$

The energy used in this case in the units of Wattage. This Watts has to be divided over 1000 to convert into kilo Watts. This Energy has to be converted into kilo watt hours to calculate the energy savings. In order to convert the energy in kW to kWh, the energy in kW has to be multiplied by the time consumed over an hour [18].

$$\frac{\text{Energy (kW)} \times \text{Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

This energy in kWh, when multiplied by the Cost per unit (\$) per kilo watt hour gives the total energy cost by the system.

$$\text{Energy Consumed} \times \text{Cost per unit / kWh} = \text{Energy Cost}$$

$$\text{kWh} \times \$ / \text{kWh} = \text{Total Cost.}$$

These set of formulae have been used to calculate the power savings of the system.

CHAPTER III

INSTRUMENTATION AND EXPERIMENTAL SETUP

3.1 Solar Collector Installation.

The main components in the Solar water heater are the Stainless steel tank and the boro silicate glass evacuated tubes. The bottom of the tank has a series of fourteen holes into which the vacuum tubes fit. Firstly, the silicone rubber gaskets are inserted into the holes and then the vacuum tubes are mounted on a steel rail base plate. These tubes are lubricated with the Silicone spray and then fitted into the holes at the bottom of the tank. They are inserted by a slow twist motion, which avoids any breakage of the tubes since they are quite delicate. The tubes pass through the rubber gaskets, which are placed inside the holes. These gaskets hold on to the tubes, there by making a tight junction and sealing the hole.



Figure 7: Holes with Silicone Rubber Gaskets. Courtesy: [HMI Industries]

3.2 Thermocouples.

Thermocouples are used either as temperature sensors or as a means to convert the thermal potential difference into electrical potential difference. These are usually identified by letter designation assigned by Instrument society of America. The J- Type thermocouple has been used in this experiment as these thermocouples are suitable for use in vacuum, and in reducing conditions to 760°C [19].

The thermocouples have male and female ends, depending upon the necessity. One end of the thermocouple would be immersed into the water and the other end would be left out, to make a note of the readings. The end wires of the thermocouple immersed in water should be soldered together for exact values. The other end would have either a male end or would be left open without being soldered, depending on the type of measuring device used.



Figure 8: Thermocouples used in the experiment. Courtesy: [HMI Industries]

Some of the thermocouples used in this experiment also have a 5” inch probe attached to one of the ends. This is extremely useful in cases where we have the convenience of plumbing the thermocouple within the system. The 5” probe acts as a temperature sensor and reports the temperature to the output device.

Usually Hand held thermometers or Data Acquisition Systems are used to measure the temperature with these thermocouples.

3.3 FLUKE Hand Held Thermometer.

The FLUKE 52 II Thermometer is a battery operated hand held digital thermometer, used for thermocouple and thermistor temperature measurement. It is usually used in places where the use of thermocouples is most and can measure for J, K, T and E type thermocouples. The male

ends of the thermocouples are coupled with the female end points located at the top of the thermometer. Once the thermocouple is inserted into the device, a digital reading of the temperature is visible on the screen of the thermometer. The units of the temperature are interchangeable between degrees Centigrade, Farenheit and Kelvin. The FLUKE hand held thermometer offers an accuracy of +/- 0.002 degrees Centigrade and can measure temperatures within the range of -210 °C to 1200 °C for J-type thermocouples



Figure 9: Fluke 52 II Thermometer. Courtesy: [HMI industries]

The type of thermocouple used in the system is selected by pressing SETUP and selecting the Thermocouple type option and pressing ENTER. The type of thermocouple can be adjusted by pressing the Up and Down

arrow buttons on the thermometer. Once the thermocouple type is chosen (type J in this case), pressing ENTER would store it in the system. The type of temperature units required can be selected by pressing the °C° FK button.

3.4 DARWIN – Data Acquisition System.

The DARWIN Data Acquisition System (DAQ System), measures, monitors, records and saves the temperature, voltage and resistance values. The DAQ system contains a Universal input module, DI/DO module, a GP-IB module connected to a personal computer with the Data Acquisition Software loaded on it.



Figure 10 : Input module of the DARWIN system. Courtesy: [HMI Industries]

The DS 400 unit is the input module of the DARWIN system, where the different thermocouples are plugged into different channels on the

configuration. These thermocouples transfer the data into the input module, which is in turn connected to the output module, the DAQ system. There are about 40 different channels in the input interface, for taking the measurements.

The output module has the software installed on the computer. The DAQ software has the Launcher, which has four important software's in it.

- 1) Software Configurator.
- 2) Hardware Configurator.
- 3) Logger.
- 4) Historical Viewer.

The software configurator enables to make operation settings to the software like saving the logging data to a directory, making necessary system configurations and calibration.

The hardware configurator enables to make data settings of a directly PC connected DA100/DC100 systems and these settings can be saved to a PC for further settings.

The logger plays the important part in the DAQ system. This enables to display the measurement and calculated math data on the PC's monitor and save those data to its hard disk. The Logger can be started by:

- 1) Double click on the Wmain icon on the Desktop.
- 2) Click on the **LOGGER** icon (Second from Left) on the top menu bar that appears.

- 3) Click on the **RECORD** button that appears on the pop-up menu to start recording the data.

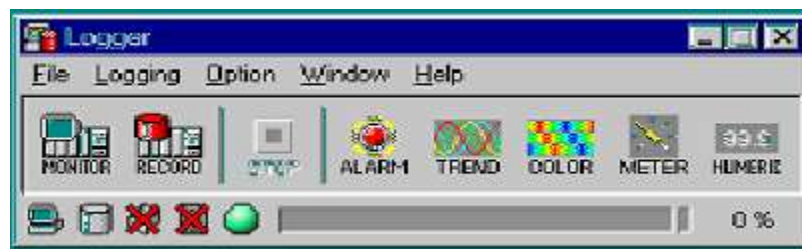


Figure 11: DAQ Logger. Courtesy: [HMI Industries]

- 4) Once the Record button turns Grey, click on the **NUMERIC** button to view the Temperature Values being recorded channel by channel.
- 5) To STOP recording, hit the **STOP** button on the Logger once. This will stop recording the values, but will continue to monitor the data without recording it.
- 6) To Stop monitoring the data or Close the Logger, hit the STOP button once again and close the Logger once the Monitor button

3.5 Expansion Tank.

The EXTROL expansion tank is a small tank which absorbs excess water pressure in any system. This excess pressure is caused when the water is subjected to high temperatures which cause the rise in the temperature there by expanding it [20]. The expansion tank removes the increased volume, there by preventing excess stress on the system.



Figure 12: EXTROL Expansion Tank. Courtesy: [HMI Industries]

The expansion tank has a rubber diaphragm filled with compressed air, which is equal and opposite to the water pressure. The open end of the tank is connected to the plumbing system, through which the water flows. As the water temperature rises, the water tends to expand. This expanded water pushes against the diaphragm and gently compresses the air. With the increase in the water temperature, the diaphragm flexes against the air cushion, located at the bottom of the tank, for the increased water expansion.

3.6 Electric Hot Water Tank.



Figure 13: GE Electric Water Heater. Courtesy: [HMI Industries]

The GE 50 Gallon Electric Water heater is a water heating device, which increases the temperature of water above its initial temperature. The capacity of the tank is 50 gallons and has two electric heating elements located at the bottom of the tank and the top of the tank. A thermostat located near the heating elements regulates the water temperature. The inlet and outlet to the water tank are located on the opposite sides on the top of the hot water tank. The inlet tube drops down into the tank, whereas the outlet tube starts collecting the water from the top of the tank, due to thermosiphoning. A temperature / pressure relief valve is located by the side of the inlet and outlet channels. This facilitates the removal of any excess heat or pressure in the system, thereby maintaining the stability in

the hot water tank. A drain valve is also located at the bottom of the tank, to completely drain out the water, out of the tank.

The temperature to which the water is heated mainly depends on the thermostat settings. Initially, the thermostat is preset to a particular temperature. Note that the temperature must be preset on both the thermostats located at the top and bottom of the tank. The water enters the hot water tank through the inlet, and starts filling the tank from the bottom. Once the water comes into contact with the electric heating elements at the bottom of the tank, the elements switch on, provided the temperature of the water is less than the preset temperature. The water at the bottom of the tanks starts getting heated immediately. As soon as the water reaches the heating elements on the top of the tank, they start to heat up the water to the required temperature. Once the preset temperature is reached, the water is no longer heated and the heating elements shut off.

3.7 Closed Loop Static Test.

The method of Static test, conducted on the Gomon Solar Water Heater is to study the functioning of the Solar Water heater and have an idea about how the temperature of water varies inside the tank. The static testing of the Solar Water heater gives the data related to the variations of temperature of water with the solar radiation incident on the solar water heater. It gives the rise and fall of temperature of water over a period of time. In the Static test, the water in the Solar Water tank does not move out

of the tank. The water is allowed to stay inside the tank and the tank is subjected to solar radiation, there by heating up the water over a period of time. The period of time is chose as per the convenience, and is 48 hours in this case. The water in this case, is not drained out of the tank for 48 hours and the changes in the temperature profile are noted. The graphs are plotted in the time – temperature domain, and the results are interpreted.

Location of Thermocouples:

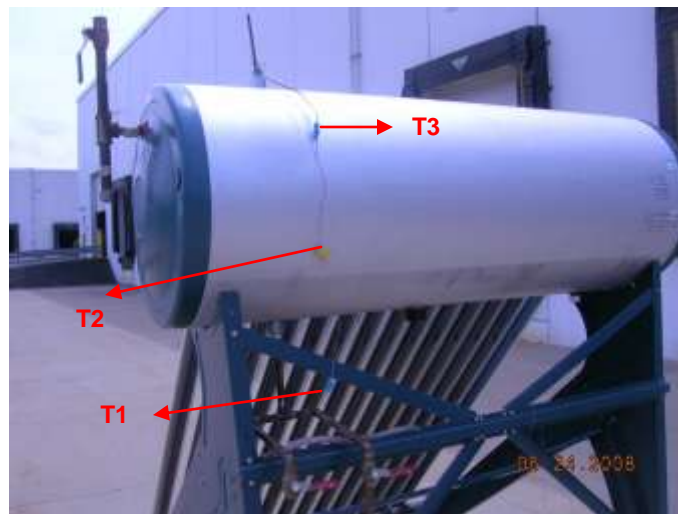


Figure 14: Location of Thermocouples. Courtesy: [HMI Industries]

Temperature in the tank is measured using thermocouples. These thermocouples located at three locations inside the tank to notice the variations of temperature within the Solar water heater. One end of the thermocouple is an open end, with its ends soldered together, while the other end has a male connector pin. The open ends are immersed in water and the tempearature reading is tanken with a hand held thermometer.

The three thermocouples located inside the Solar water heater are at different locations. The first one is placed inside the Glass evacuated tubes(T1), the other at the bottom of the solar water tank(T2) and the third one at the top of solar water tank(T3). This is to study the thermosiphoning effect of water inside the tank, where hot water rises to the top and cold water remains at the bottom. The thermocouples are glued to a plastic pipe at the top and bottom locations, and the pipe is dipped in water from the vent at the top of the tank. The other ends of the thermocouples, with the male connector plugs, hang outside the tank to facilitate for a reading. Apart from these three, another thermocouple is used to measure the ambient temperature (T4). This one is fixed to the grilled fencing around the Solar water heater.

Procedure:



Figure 15: Closed Loop Static Testing.

Courtesy: [HMI Industries]

The Boro Silicate Glass evacuated tubes and the water tank is assembled and the tank is made sure it is empty before the experiment. The thermocouples are installed in the system. The Solar water heater is placed in an open area, which is free from any shadows of buildings, structures, trees etc. The orientation of Solar water heater is towards South, to utilise maximum amount of solar radiation incident on the water heater. The city water hose is connected to the inlet of the Solar water heater. The outlet of the water heater is closed, to prevent the water from escaping outside. Hence the direction of the city water into the tank is uni directional.

The city water hose is opened up and the water is filled in the system at 8:00 AM. The criteria for filling up the system with cold water is that, the tank must be filled no later than 30 mins after sunrise or 30 mins after sunset. This stabilises the system as cold water enters into it. In case the tank is filled after the stipulated time, the glass evacuated tubes already get charged up with the incident solar radiation, and when the cold water hits them, there is a chance of the system getting damaged or even breaking up. The water supply is shut off once the tank is full and the hose is disconnected from the tank. The temperature readings are noted from the three thermocouples with the hand held thermometer for the initial water temperature at different locations of the tank. The ambient temperature (T4) is also noted. The water in the Solar water heater gets continuously heated by the solar radiation incident on the Evacuated glass tubes. The

temperature readings are taken for regularly in the intervals of 30 minutes for the T1, T2, T3 and T4 temperatures.

The Solar water heater is kept under observation for a period of 48 hours, noting down the temperature readings periodically. The incident solar radiation, transfers heat to the water, there by increasing its temperature.



Figure 16: Temperature Measurements. Courtesy: [HMI Industries]

The increase in temperature excites the water molecules. Since the water is in a closed system, where it cannot move beyond the water tank, the excited water molecules tend to move around within the tank. This builds up the pressure inside the system, as the pressure of a system is directly proportional to the temperature. Hence care has to be taken to periodically check the glass evacuated tubes and the sealings to be free from any water dripping down them, as the tank becomes a pressurised with the increase in temperature. Also there is a chance of the glass evacuated tubes to break, if the pressure is more inside the system. The glass

evacuated tubes have to be checked for any cracks that appear on them during this process.

After a period of 48 hours, the water inside the Solar water tank is completely drained out, by opening the drain valve. Once the system is drained out, it is filled back with City water at 8:00 AM, within the stipulated time in the criteria. The same procedure is carried out again, for a period of 48 hours, tabulating the readings for every 30 minutes. The temperature profiles are plotted and the rate at which the temperature of water increases inside the system is observed.

3.8 Hot Water Tank Recovery Rate Test.

The hot water tank runs with electric current. The water in the hot water tank gets heated up with the presence of electrical heating elements in the tank, which heat the water to a preset temperature, there by increasing its temperature to a desired level. The Hot water tank test, measures the rate at which the water is heated inside the electric hot water tank, connected to electric current. This also provides data on how much electric current has been utilized to heat the water for different levels of water discharge.

Equipment Setup:

The thermocouple located in this test is basically required to test the temperature inside the tank. The thermocouple used in this test is the probe type thermocouple, which has an elongated temperature probe located at one end and the other end may be either a male connector end

or a free end. The probe thermocouple (T5) is plumbed in through the exit of the hot water tank using a Tee connector. The probe of the thermocouple drops down the tee into the hot water tank, there by maintaining a contact with the water on the top of the hot water tank.



Figure 17: Probe thermocouple on Hot Water Tank.

Courtesy: [HMI Industries]

Since this test has to be done on a continuous basis and the temperature changes are quite fast, taking manual readings of the temperature may not be advisable. Hence the Darwin Data Acquisition System (DAQ System) is used to record the temperature change. The DAQ system is configured, and the channel zones on the input interface are cleared. The free ends of the two probe thermocouples are extended to meet the input interface of the DAQ system. The male connector plugs are removed and the positive and negative terminals of the thermocouples are plugged into the input channels accordingly. The positive wire (red) of the thermocouple T5 goes into the positive terminal of Channel 1 and the negative wire (black) of the

same goes into the negative terminal of Channel 1. The DAQ system is then started and is set onto monitor mode.

The DC/AC adapter clamp is used to note the electric charge by the hot water tank. The electric wiring, which leads to the power socket of the hot water tank, is drawn out and the adapter is clamped around the wiring. The adapter is set at 2000 Amperes. It is then connected to the multimeter and the units are set into millivolts (mV). The multimeter usually displays Zero on it, until it notices any change in the electric current passing through the adapter clamp. A stopwatch is also employed in this experiment to record the time interval.

Procedure:

The City water hose is connected to the inlet of the hot water tank. The inlet channel is opened and the 50 gallon hot water tank is filled with City water. The exit valve is also opened. The inlet channel is closed when the water drips out of the exit valve. Both the exit and inlet valves are closed when the tank is full. The thermostat settings of the hot water tank are set at a temperature of 120°F. The hot water tank is connected to the electric socket and the power is switched on. The electric heating elements switch on, and the water is heated electrically. The DC/AC adapter clamp connected to the multi meter notes the electric discharge and the stop watch is started when the multimeter shows any variations in the electric current charge being inducted by the hot water tank. The change in the reading of the multi meter is the indication of any electric charge being

used by the hot water tank. The multi meter shows the number of millivolts being used by the hot water tank during the observed time. The total duration in which the electric current is used by the hot water tank is counted by the stop watch.



Figure 18: Recover Rate Test of HWT. Courtesy: [HMI Industries]

Once the water in the hot water tank reaches the preset limit temperature, the electric heating elements in it switch off and stop heating the water. The hot water tank does not take in any further electric charge current once the heating elements are switched off. This change is notified by the multi meter, which drops down to zero, indicating the current is no longer being used by the hot water tank. The stop watch is then switched off, and the duration of the time is noted down. This gives the overall time taken by the

hot water tank, to heat the water coming at a lower temperature (city water temperature), to the preset temperature. The electric current used by the hot water tank is also given by the multi meter.

The recovery rates of the hot water tank are now calculated for different levels of water discharge, from the hot water tank. The measuring bucket used in this experiment is a 5 gallon bucket, which discharges 5 gallons of water when filled up to the level as indicated on the bucket. The exit valve of the hot water tank is opened and the water is allowed to drain out of the hot water tank. The measuring bucket is placed near the exit pipe, so that the water that flows out of the exit valve fills in the measuring bucket. The water is allowed to drain out of the hot water tank, until it fills in the measuring bucket to the desired level of 5 gallons. Once the water level inside the bucket reaches the 5 gallon mark, the exit valve is shut off. In the mean while, the inlet valve is opened up, and the city water enters into the hot water tank, which fills in the drained level of water from the hot water tank simultaneously. The city water is allowed to enter into the hot water tank, until it fills up the 5 gallons inside the tank. It is the pressure of the city water which enters the hot water tank that pushes the heated water out of the tank. Once 5 gallons of water is drained out of the hot water tank, the exit valve and the inlet valve are both closed. Now the tank is again filled up with 50 gallons of water, since the water which has been drained out of the hot water tank is replaced by the city water that enters into it. The temperature of the water entering the hot water tank is noted down. The

temperature of the water inside the hot water tank is disturbed and varies, as the water that enters into the tank is at a lower temperature when compared to the water inside the tank. Hence there is a drop in temperature inside the hot water tank, which falls below the preset temperature. This allows the electric heating elements inside the hot water tank to switch on, thereby heating the water to the desired temperature (120°F). The moment the electric heating elements switch on, the multi meter deflects and the change in the electric current is observed when the multi meter reading deflects from zero. The stop watch is started, when the deflection in the meter reading is shown up. This indicates, the water is being heated in the hot water tank. Once the water inside the hot water tank reaches the preset temperature, the electric heating elements switch off, and the multi meter drops back to zero. The temperature of the water inside the hot water tank is noted down, which is shown up on the DAQ system. The stop watch is switched off and the time duration is noted down. The amount of electric current used by the hot water tank is also noted down. This gives us the time in which the hot water tank raises the temperature of water entering at a lower temperature to a preset temperature, when a certain amount of water is drained out of it and the same is filled back. The electric current used by the hot water tank in this process is also indicated.

The same experiment is then repeated by draining out 10 gallons of water from the hot water tank, and the same is replaced by the city water

tank. The inlet and exit valves of the hot water tank are opened up, and the measuring bucket is placed near the exit valve pipe. Once the water from the hot water tank fills up the measuring bucket, until the indicated level of 5 gallons, the measuring bucket is drained out and immediately replaced. The water is allowed to fill up another 5 gallons into the measuring bucket. Once the water level reaches the 5 gallon mark for the second time, the exit and inlet valves are closed. The city water entering the hot water tank fills up the 10 gallons of water drained out of the hot water tank. Now the electric heating elements inside the tank switch on, as the water inside the tank is at a higher temperature than the water that entered the tank. The time taken by the hot water tank to heat the water to the preset temperature is calculated by observing the change in the multi meter readings and operating the stopwatch according to it.

Once the hot water tank reaches the pre set temperature, the same process is repeated for another 15 gallons, 20 gallons and 25 gallons of hot water discharge from the hot water tank, and the same being replaced by the city water.

3.9 Open Loop Test of Hot Water Tanks with Solar Heated Water.

The Solar water heater is connected in series with the Electric hot water tank. The solar heated water is supplied to the hot water tank instead of the city water and the recovery rates of the hot water tank are calculated. The hot water tank is connected to the electric power socket, and the electric

current charged by the hot water tank is also measured. This recovery rates of the hot water tank connected to the electric current are calculated when the solar water is supplied to it. The electric current charged by the hot water tank is also calculated for different levels of water discharge. The difference in the time and electric current charged by the hot water tank when connected to only electric current and solar water heater is noted down and an efficient system is designed.

Experimental Setup:

The solar water heater is plumbed in series with the hot water tank. The exit valve of the solar water heater is connected to the inlet valve of the hot water tank, replacing the city water hose. The water from the solar water heater runs through the piping that leads into the inlet of the hot water tank. The city water hose is hooked up to the inlet of the solar water heater. A pressure reducer is fixed in series with the city water hose, near the inlet of the solar water heater.

This pressure reducer helps in maintaining the water pressure, which enters the solar water heater. Since the water that enters the solar water heater directly from the city water hose, is at higher pressure, the usage of a pressure reducer helps in regulating the water pressure and maintaining it at a desired level.



Figure 19: Piping from Solar water heater to HWT. Courtesy: [HMI Industries]

A probe thermocouple (T6) is installed in series with the pressure reducer. This thermocouple records the initial temperature of water that enters the solar water heater from the city water hose. The other end of the thermocouple is plugged into the Channel 2 of the DAQ system, which records the temperature values of the inlet water.



Figure 20: Pressure reducer and Thermocouple T6. Courtesy: [HMI Industries]

The expansion tank is installed on the top of the solar water heater. This is employed, to reduce the pressure inside the solar water heater. This is connected to the upper end of a Tee junction near the exit valve; whereas the lower end of the Tee would lead to the hot water tank. Another probe thermocouple (T7) is placed in the piping, which leads to the inlet of the hot water tank. This records the temperature of water entering the hot water tank. The other end of the thermocouple is connected to the Channel 3 of the DAQ system.

Procedure:

The inlet valve of the solar water heater is opened, and the city water is allowed to enter the solar water heater. The pressure of the city water, entering the solar water heater is regulated by controlling the pressure reducer. The pressure reducer is set at a pressure of 10 psi (pounds per

square inch). Hence the water that enters the solar water heater fills in at a pressure of 10 psi. The solar water heater is completely filled up with water. The temperature of water entering the solar water heater is recorded on the Channel 2 of the DAQ system. The inlet valve is closed, once the tank is full. The solar water heater is subjected to solar radiation for a period of two days, in order to increase the temperature of the water. The temperature of the water inside the solar water heater is periodically monitored. The solar water heater is also checked for any cracks, due to the pressure developed inside the system. The exit valve of the solar water heater is closed during this period.



Figure 21: Interface between Solar Water Heater and DAQ System.

Courtesy: [HMI Industries]

The hot water tank is filled with city water for the first time and the water in it is allowed to heat to a temperature of 120°F. The recovery rates of the hot water tank, connected to the solar water heater are tested by draining out the water from the hot water tank and injecting the solar heated water into it and testing the time taken by the hot water tank to reheat the water to reach the preset temperature.

After two days of continuous exposure to solar radiation, the water in the solar water heater reached a temperature of 155.5°F. The exit valve of the solar water heater is opened and the inlet valve of the hot water tank is also opened. The measuring bucket is placed under the exit pipe of the hot water tank and the exit valve of the hot water tank is opened. The inlet valve of the solar water heater is opened and the city water is allowed to flow into the solar water heater. The pressure at which the city water fills in the solar water heater, pushes out the heated water out of the solar water heater. This water fills in the hot water tank and in return pushes out the water out of the hot water tank. The measuring bucket under the exit pipe of the hot water tank gets filled with the water coming out of the hot water tank. The water is allowed to flow out, until it fills in the measuring bucket to the required level of 5 gallons. Once the water reaches the 5 gallon level in the measuring bucket, the inlet to the solar water heater is closed and the tank is no longer filled with the city water. The exit of the hot water tank is also closed. The temperature of the water that flows in to the hot water tank is the temperature of the water inside the solar water heater. Hence when

the water enters into the hot water tank, the temperature of it would be 155°F.

The multi meter is checked for any deflections in its readings. This would indicate if any electric current is used by the hot water tank. The change in the multi meter readings is noted and the stopwatch is operated to note the duration of the electric current used by the hot water tank, if any.



Figure 22: Solar Water Heater connected in series with the Hot Water Tank. Courtesy: [HMI Industries]

The temperature in the hot water tank is noted down, as shown in the DAQ system. The system is left intact for a period of 30 minutes, to let the heating elements in the hot water tank to cool down, before the next test begins. If the heating elements in the hot water tank switch on to heat up

the water, the effect of the heat that comes out of the heating elements would continue to be around the coil for a period of 20 minutes. Hence the time lag chosen between each case of experiment is around 30 minutes.

The inlet to the solar water heater and the exit valve of the hot water tank are opened and the water from the city water hose is allowed to flow into the solar water heater. This pressure created inside the solar water heater, pushes the water out of the solar water heater tank into the hot water tank, there by pushing the water out of the hot water tank into the measuring bucket placed under the exit pipe of the hot water tank. Once the water level inside the measuring bucket reaches the 5 gallon mark, the bucket is drained and immediately replaced under the exit pipe for another 5 gallons. Hence a total of 10 gallons is drained out of the hot water tank and the solar water heater. These 10 gallons inside the hot water tank is replaced by the solar heated water from the solar hot water tank. The solar water heater is filled up with 10 gallons of city water to cover up the water level. The multi meter is checked for any deflection in the reading. This indicates the electric current used by the hot water tank. The current used by the hot water tank, the initial and final temperatures of water inside the hot water tank and the solar water heater is noted down. The stop watch is operated in case there is any deviation of the reading in the multi meter to note the time taken by the hot water tank to heat up the water.

The experiment is further continued by draining 15 gallons, 20 gallons, 25 gallons and 30 gallons of water out of the hot water tank, replacing the

same with solar heated water. The water level inside the solar water heater is maintained by constantly filling it up with city water.

CHAPTER IV

RESULTS AND CALCULATIONS

4.1 Introduction.

The results of the three tests done are dealt separately. The static test or the closed loop test, hot water tank test and the open loop test results are discussed in the order of the performance of the tests. The tabular results are taken and the graphical results of the same are plotted. The DAQ system recorded the various temperature values of the water inside the solar water heater, the hot water tank and the city water temperature. The raw data of the recorded values are taken and are condensed for the convenience of the calculations. The DAQ system recorded the temperature values for every minute. These recorded values are condensed for every 30 minutes to create sufficient data for reviewing. The graphs are plotted accordingly.

4.2 Static Test Results.

The solar water heater is filled with City water at 8 AM in the morning on the first day of the experiment. The temperature of the water when it entered the solar water heater was 63.5°F. The temperature measurements were taken with the hand held thermometer, by connecting the male ends of the thermocouples to the female connectors of the thermometer. The temperature readings were taken in the intervals of 30 minutes and the values were noted down. The results are listed below:

**Table 1: Static Test Results of Solar Water Heater in a Closed Loop–
Day 1.**

Time	T ₁ °F	T ₂ °F	T ₃ °F	T ₄ °F
8:00 AM	73.0	66.7	63.5	61.2
8:30 AM	64.6	69.6	64.2	66.0
9:00 AM	71.6	73.8	68.7	72.5
9:30 AM	72.5	76.3	70.7	71.6
10:00 AM	81.5	82.0	76.5	71.4
10:30 AM	87.4	86.4	81.7	74.5
11:00 AM	93.2	92.3	86.7	77.9
11:30 AM	101.7	98.1	93.7	77.4
12:00 PM	104.0	102.2	99.7	75.7
12:30 PM	110.8	108.0	106.0	75.4
1:00 PM	114.8	111.9	111.6	81.0
1:30 PM	120.0	115.9	117.1	81.0
2:00 PM	127.4	120.7	125.6	76.6
2:30 PM	128.5	122.0	130.5	76.8
3:00 PM	127.0	124.2	132.8	81.0
3:30 PM	128.3	127.9	137.3	78.8

T₁ = Temperature in the Tubes

T₂ = Temperature at the Bottom of the tank

T₃ = Temperature at the Top of the tank

T₄ = Outside Temperature

The thermocouples located at different locations of the solar water heater produced different temperature values. The thermocouple T_4 recorded the ambient temperature. This showed the temperature of the solar radiation incident on the solar water heater. The thermosiphon effect was seen in the tubes, where the difference in the temperature in the top and bottom of the tank was visible.

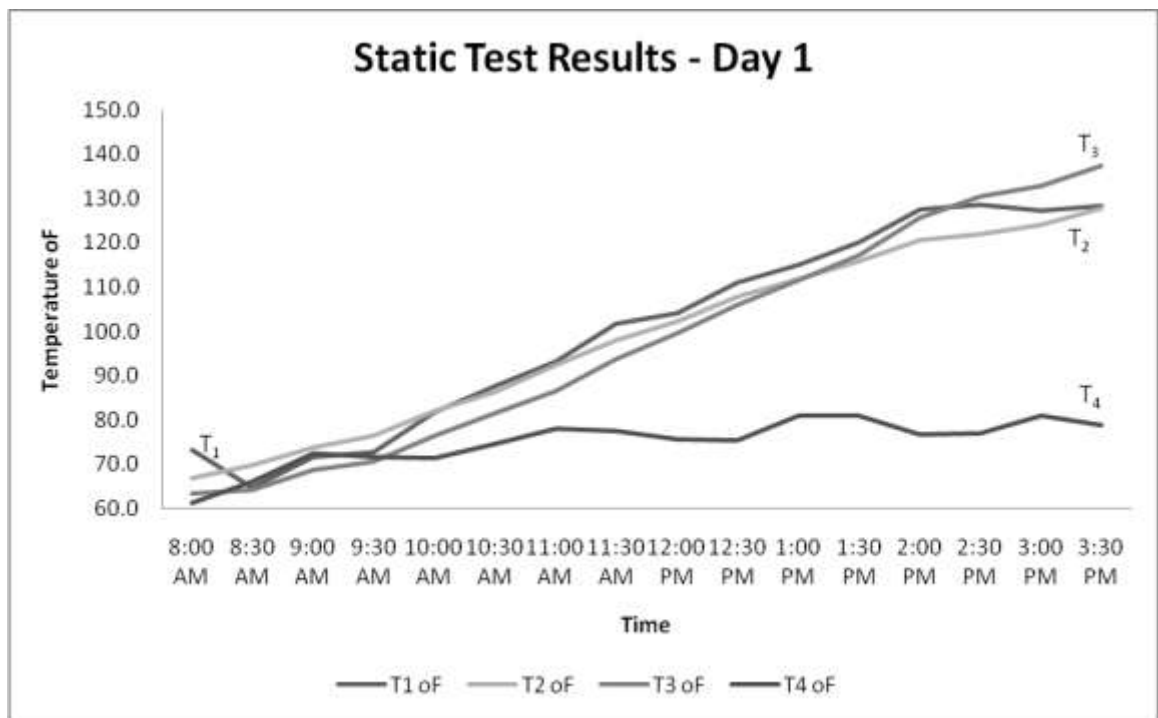


Figure 23 : Static Test Results of Solar Water Heater on Day 1.

The plots T_2 and T_3 show the difference in the temperatures in the tank. Even though the temperature of water in T_3 was lower than that of T_2 , the temperature went up gradually towards the end of the day, showing up the thermosiphon effect in the tank. The ambient temperature went up by

17.6°F during the calculated period of 7.30 hours. The temperature of water went up by 73.8°F as measured in the top of the tank. This shows that the solar radiation incident on the solar water heater was able to increase the temperature of water in the tank by 9.84°F for every hour when considered on a scale of uniform temperature rise. The temperature rise in the glass evacuated tubes was almost same as the temperature rise in the bottom of the tank. The only noticeable temperature difference was in the top of the tank which was 9.4°F at the end of the day when compared to the bottom of the tank. The tank was left out in the same condition all through the day, even though the values plotted were recorded until 3:30 PM.

The solar water heater was monitored the next day at 8.00 AM in the morning for the temperature difference. The results are tabulated as below:

Table 2: Static Test Results of Solar Water Heater in Closed Loop – Day 2

TIME	T ₁	T ₂	T ₃	T ₄
8:00 AM	71.2	125.8	129.2	71.2
8:30 AM	76.8	126.0	130.1	75.0
9:00 AM	92.5	126.5	135.5	76.3
9:30 AM	98.1	125.6	136.8	77.9
10:00 AM	108.1	129.2	142.0	81.9
10:30 AM	120.6	135.1	145.2	86.7
11:00 AM	126.5	137.3	152.1	79.7
11:15 AM	126.3	132.4	154.0	79.9
12:00 PM	126.0	134.6	157.3	80.6
12:30 PM	121.5	136.2	159.4	77.9
1:00PM	119.3	135.1	161.4	78.4
1:30 PM	117.5	127.2	161.2	80.6
2:00 PM	115.0	127.9	164.8	77.9
2:30 PM	105.3	131.0	167.0	73.4
3:00 PM	99.7	132.3	166.8	68.4

There was a steep drop in the temperature inside the Glass Evacuated tubes, which fell down by 57.1°F. This drop in temperature was due to a drizzle overnight which spanned for a period of 35 minutes. The drop in temperature was not observed in the tank, as it was pretty low when compared to the values on the previous day. The bottom of the tank observed a temperature drop of 2.3°F and the top of the tank observed a drop of 8.1°F. This drop in temperature is observed to be very minimum,

when compared to the drop in the tubes. This showed that, when the temperature of the water falls down, the impact of the drop is very minimal on the temperature of water inside the tank. The rise in temperature of water from the tubes to the tank was pretty fast; where as the fall in temperature is quite slow. The ambient temperature during the beginning of the day is 71.2°F and the highest point of temperature observed was 86.7°F at 10:30 AM. The day was pretty cloudy and the temperature remained quite low throughout. The rise in temperature at the top of the tank was by 37.62°F in a period of 7:00 hours. The temperature in the bottom of the tank remained quite constant during this period, where the raise in temperature was found to be 11.5°F.

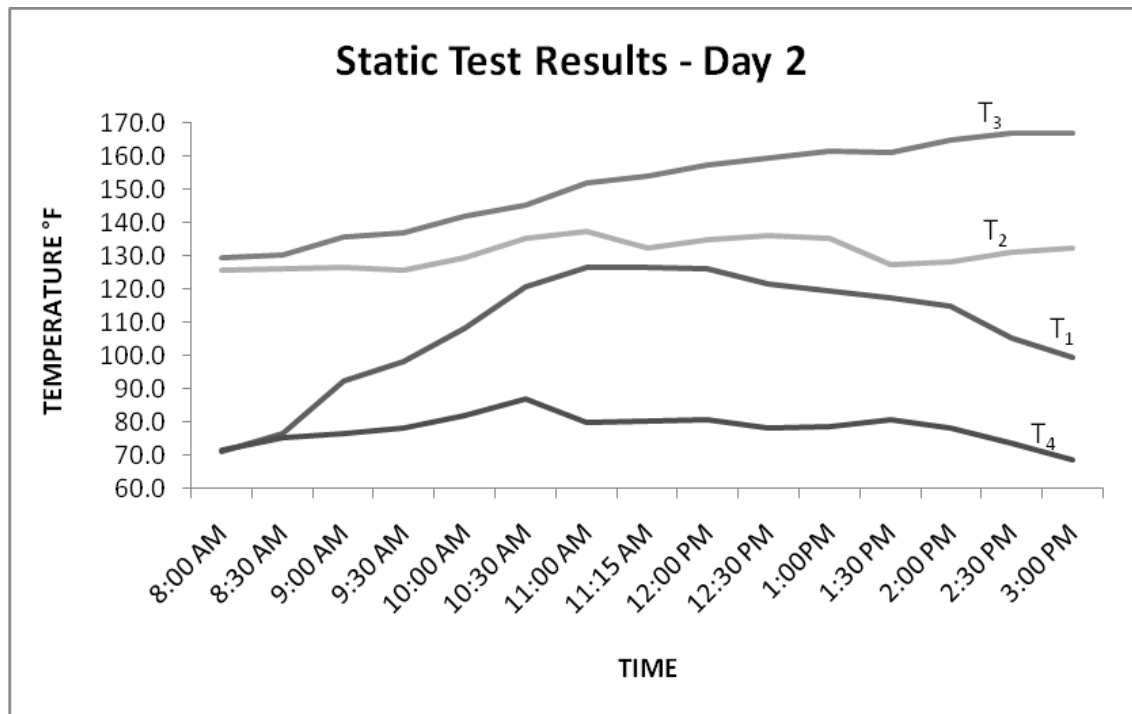


Figure 24: Static Test Results on Solar Water Heater in Closed Loop – Day 2

The thermosiphon effect was largely seen in the tank, where the difference in temperatures between T_2 and T_3 was seen to a large extent. The deviating plots of T_2 and T_3 imply the difference in temperatures in their respective locations.

The fall in temperatures during the final readings taken are due to rain that drizzled during the end of the day. The rain effect on the solar water heater is observed when the ambient temperature fell from 73.4°F to 68.4°F . The same is observed in the glass evacuated tubes, where the temperature dropped from 105.3°F to 99.7°F . This drizzle had a slight impact on the temperatures in the tank, where the temperature on the top of the tank dropped down by 0.2°F . The bottom of the tank went up by 1.3°F . This can be due to the flow of heat from the glass evacuated tubes into the tank.

The tank was drained out at the end of the day, and was refilled with city water at 8:00 AM for another set of results. The city water entered the solar water heater at a temperature of 64.7°F . The temperature measurements were taken at the three thermocouple locations inside the solar water heater for the water temperature at the top and bottom of the tanks and also in the glass evacuated tubes using a hand held thermometer. The ambient temperature was also recorded. The water was allowed to stay static inside the solar water heater for a period of 48 hours. The same test was repeated, to check the variations in temperature inside the solar water heater. The temperature was monitored for every 30 minutes, for 2 days.

Table 3: Second set of Static test results of Solar Water Heater in a Closed loop – Day 1:

Time	T ₁ °F	T ₂ °F	T ₃ °F	T ₄ °F
8:00 AM	72.4	64.7	62.5	63.2
8:30 AM	62.7	67.8	63.5	62.4
9:00 AM	72.6	72.6	66.9	74.5
9:30 AM	74.5	78.3	73.7	71.0
10:00 AM	83.5	83.5	79.0	72.4
10:30 AM	88.9	88.4	84.4	75.3
11:00 AM	94.2	91.3	87.7	76.9
11:30 AM	103.7	96.1	94.7	74.5
12:00 PM	105.0	104.2	101.7	71.5
12:30 PM	112.8	108.0	106.0	74.4
1:00 PM	114.8	110.9	109.6	80.7
1:30 PM	123.0	116.3	118.3	83.0
2:00 PM	128.4	123.3	127.6	72.6
2:30 PM	129.8	120.0	128.5	78.2
3:00 PM	125.0	127.2	134.6	81.1
3:30 PM	127.4	130.9	136.9	80.0

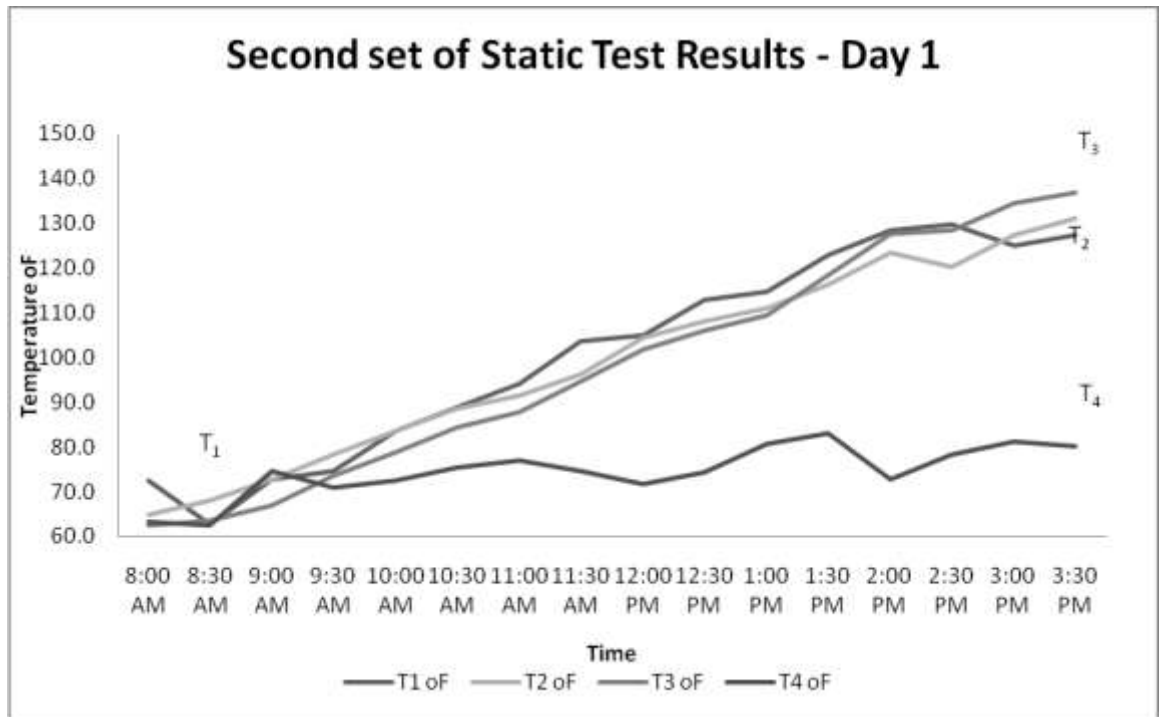


Figure 25: Second set of Static test results of Solar Water heater in closed loop – Day 1

Table 4: Second set of Static Test results of Solar Water heater in a Closed Loop – Day 2:

TIME	T ₁	T ₂	T ₃	T ₄
8:00 AM	107.4	122.8	125.0	70.9
8:30 AM	108.2	129.0	130.1	73.9
9:00 AM	110.6	123.5	130.5	79.3
9:30 AM	114.5	124.6	133.8	73.9
10:00 AM	119.9	130.2	136.0	82.3
10:30 AM	121.6	136.1	140.2	88.2
11:00 AM	122.5	134.3	145.1	79.7
11:15 AM	124.2	130.9	146.0	75.9
12:00 PM	125.2	136.0	150.3	80.6
12:30 PM	120.3	138.2	152.4	74.9
1:00PM	124.5	139.1	155.4	79.2
1:30 PM	128.7	138.9	159.2	80.0
2:00 PM	129.5	140.6	161.8	79.3
2:30 PM	132.1	143.7	165.1	80.2
3:00 PM	134.2	145.3	164.3	79.6

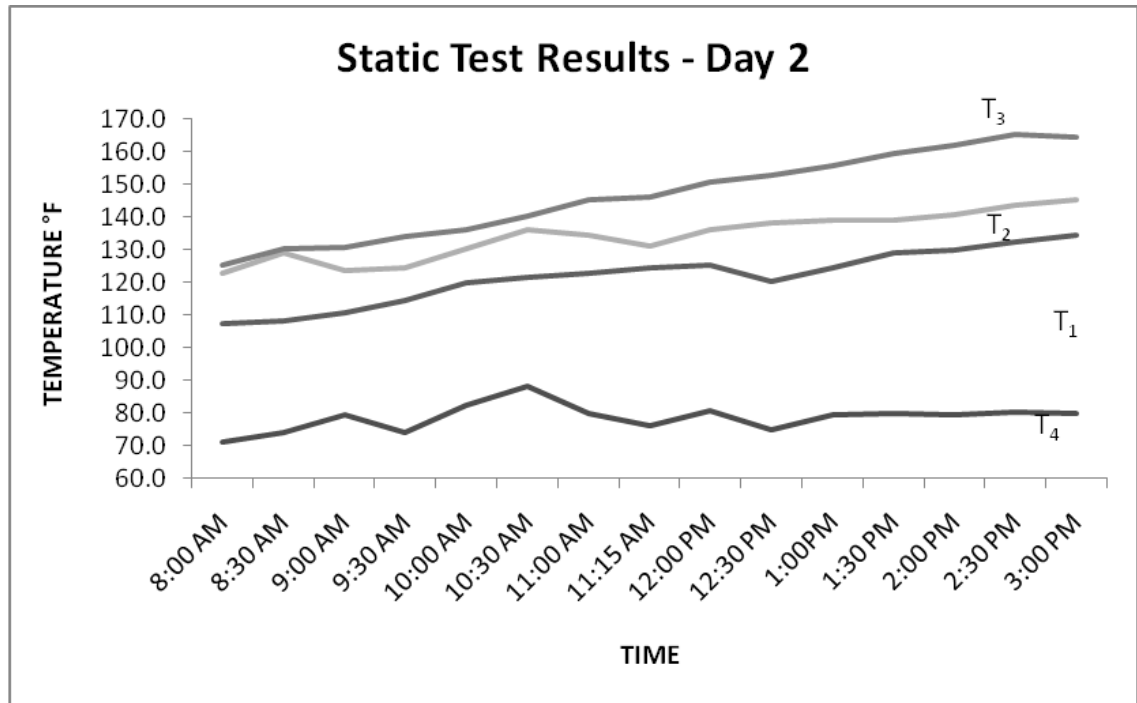


Figure 26: Second set of Static Test results on Solar Water heater in a Closed Loop – Day 2.

The temperature variations on the second set of the static test seemed to be the same way as the first set of results. The thermosiphon effect was clearly seen in the tank, on the two days, where the temperature of the water inside the tank was higher at the top of the tank when compared with the temperature of water at the bottom of the tank. The temperature of water inside the glass evacuated tubes was relatively low, when compared to the bottom of the tank. The significant change noted in the temperatures between the two set of results was the temperature in the glass evacuated tubes. The temperature in the tubes rose up to a maximum temperature of 134.2°F when compared to the temperature in the tubes in the first set of

results. This is due to the sunny conditions during the second time, when compared to the first test where a drizzle was observed.

Also the temperature in the bottom of the tank went up during the second day, when compared to the first set of results. The drop in the temperature values, when the tank was left intact overnight, was quite low. This shows that the heat loss by the tank is pretty slow due to proper insulation material around the tank.

4.3 Recovery Rates and Energy Used by the Hot Water Tank.

The recovery rates of the hot water tank are tested on the temperature – time domain. The basic criteria for calculating the recovery rates of the hot water tank, is to estimate the electrical energy used by the hot water tank, in heating the water to the preset temperature when the water is sent at a lower temperature. The electric energy used by the hot water tank is displayed by the multi meter, interfaced with the DC/AC adapter clamp. The temperature values of the water inside the hot water tank, is recorded by the DAQ system.

Table 5: Recovery rate and energy calculations of Hot Water Tank.

Multi meter reading (Amps)	Gallons drained from hot water tank	Hot water tank start temp(°F)	Source water temp (°F)	Heating element energized			Recovery time (min)	Energy Usage (Kwh)	Hot water tank Stop temp(°F)
				Start	Stop				
19.1	5	118.5	71.3	1:26 PM	1:39 PM	13	0.91	118.0	
19.0	10	118.9	71.3	1:45 PM	1:57 PM	12	0.83	118.0	
19.2	15	116.9	71.3	2:41 PM	3:00 PM	19	1.33	117.1	
18.9	20	110.3	71.3	3:18 PM	3:45 PM	27	1.87	116.1	
18.8	25	103.1	71.3	4:18 PM	4:56 PM	38	2.61	115.8	
19.1	30	102.1	71.3	8:54 AM	9:35 AM	41	2.87	115.8	

Recovery time by the hot water tank, is the time duration in which, the water in the hot water tank reaches the preset temperature, once the electric heating elements inside the hot water tank start heating it. This is recorded by the stop watch, monitoring the multi meter readings. The multi

meter reading is the current used in amperes over the given period of time. This is displayed on the multi meter, when the heating elements inside the hot water tank, start heating the water. Once the heating elements stop heating the water, the multi meter displays Zero reading. The difference of time between these two phases is termed as Recovery time by the hot water tank. The gallons of water drained out of the hot water tank is measured by the measuring bucket. The source water temperature is the temperature of water entering the hot water tank. This is the temperature of city water, that enters directly into the hot water tank. The start and stop times are calculated using the stopwatch.

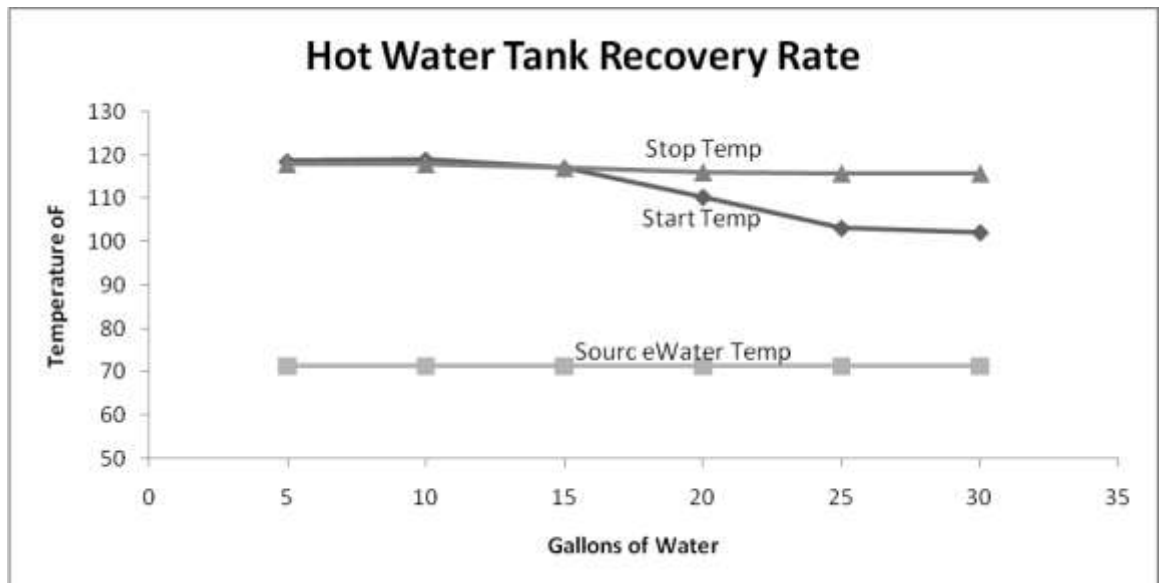


Figure 27: Recovery Rate testing of Hot Water Tank.

The tank was preset at the temperature of 120°F. 5 gallons of water at 120°F was drained from the hot water tank and was replaced with city water entering the tank at 71.3°F. The multi meter showed a deflection in

its reading to 19.1 Amps. This shows that electric current is being used by the hot water tank. The heating elements in the hot water tank, started to heat the water to bring it back to the preset temperature. The electric heating elements continued to heat the water for a time period of 13 minutes before they shut off. This time period was recorded by the stop watch. The ending temperature of water in the hot water tank is the temperature in the thermocouple T5. This reading is monitored on the DAQ system.

The Energy usage calculations for the 5 gallon water usage are :

Current I = 19.1 Amperes

Time Consumed T = 13 minutes.

Voltage used by the hot water tank V = 220 V

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 19.1$$

$$= 4202 \text{ W}$$

But $\text{W} / 1000 = \text{kW}$

$$4204 / 1000 = 4.202 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW) X Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.204 \times 13}{60} = 0.9104 \text{ kWh.}$$

The energy cost, as per residential rate schedule, is \$0.0774 per kWh or 7.74 Cents per kWh.

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 0.9104 \times 0.0774 = \$ 0.0704$$

Hence, to heat the 5 gallons of water for 13 minutes, the energy consumed by the hot water tank is 0.9104 kWh which amounts to a total of \$0.0704.

The time taken to heat up 10 gallons of city water entering into the hot water tank, when 10 gallons of water is drained out of it, is 12 minutes. This time duration is calculated in the similar way as first case of 5 gallons. The cost of the energy consumed to heat to the preset temperature is :

Current I = 19.0 Amperes

Time consumed T = 12 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 19.0$$

$$= 4180 \text{ W}$$

But $W / 1000 = kW$

$$4180 / 1000 = 4.180 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW) X Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.180 \times 12}{60} = 0.836 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 0.836 \times 0.0774 = \$ 0.0647$$

Hence, to heat the 10 gallons of water for 12 minutes, the energy consumed by the hot water tank is 0.836 kWh which amounts to a total of \$0.0647.

The time taken to heat up 15 gallons of city water entering into the hot water tank, when 15 gallons of water is drained out of it, is 19 minutes. The cost of the energy consumed to heat to the preset temperature is :

Current I = 19.2 Amperes

Time consumed T = 19 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 19.2$$

$$= 4224 \text{ W}$$

But $W / 1000 = kW$

$$4224 / 1000 = 4.224 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW)} \times \text{Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.224 \times 19}{60} = 1.3376 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

Cost for the energy used = Energy (kWh) x Rate per kWh

$$\text{Cost} = 1.3376 \times 0.0774 = \$ 0.1035$$

Hence, to heat the 15 gallons of water for 19 minutes, the energy consumed by the hot water tank is 1.3376 kWh which amounts to a total of \$0.1035.

The time taken to heat up 20 gallons of city water entering into the hot water tank, when 20 gallons of water is drained out of it, is 27 minutes. The cost of the energy consumed to heat to the preset temperature is :

Current I = 18.9 Amperes

Time consumed T = 27 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 18.9$$

$$= 4158 \text{ W}$$

But $\text{W} / 1000 = \text{kW}$

$$4158 / 1000 = 4.158 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW) X Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.158 \times 27}{60} = 1.8711 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 1.8711 \times 0.0774 = \$ 0.1448$$

Hence, to heat the 20 gallons of water for 27 minutes, the energy consumed by the hot water tank is 1.8711 kWh which amounts to a total of \$0.1448.

The time taken to heat up 25 gallons of city water entering into the hot water tank, when 25 gallons of water is drained out of it, is 38 minutes. The cost of the energy consumed to heat to the preset temperature is :

$$\text{Current } I = 18.8 \text{ Amperes}$$

$$\text{Time consumed } T = 38 \text{ minutes}$$

$$\text{Voltage} = 220 \text{ V}$$

$$\text{Energy Cost} = \$ 0.774 \text{ per kWh.}$$

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 18.8$$

$$= 4136 \text{ W}$$

$$\text{But } W / 1000 = \text{kW}$$

$$4136 / 1000 = 4.136 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW)} \times \text{Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.136 \times 38}{60} = 2.6194 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 2.6194 \times 0.0774 = \$ 0.2027$$

Hence, to heat the 25 gallons of water for 38 minutes, the energy consumed by the hot water tank is 2.6194 kWh which amounts to a total of \$0.2027.

The time taken to heat up 30 gallons of city water entering into the hot water tank, when 30 gallons of water is drained out of it, is 41 minutes. The cost of the energy consumed to heat to the preset temperature is :

Current I = 19.1 Amperes

Time consumed T = 41 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 19.1$$

$$= 4204 \text{ W}$$

But $W / 1000 = kW$

$$4204 / 1000 = 4.202 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW)} \times \text{Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.202 \times 41}{60} = 2.8713 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 2.8713 \times 0.0774 = \$ 0.2222$$

Hence, to heat the 30 gallons of water for 41 minutes, the energy consumed by the hot water tank is 2.8713 kWh which amounts to a total of \$0.2222.

Table 6: Energy calculations and Cost analysis of the hot water tank.

	Gallons Drained from the hot water tank	Current Used (Amps)	Energy consumed (kWh)	Cost of Energy Consumed (USD \$)
	5	19.1	0.9104	0.0704
	10	19	0.836	0.0647
	15	19.2	1.3376	0.1035
	20	18.9	1.8711	0.1448
	25	18.8	2.6194	0.2027
	30	19.1	2.8713	0.2222
Total	105	114.1	10.4458	0.8083

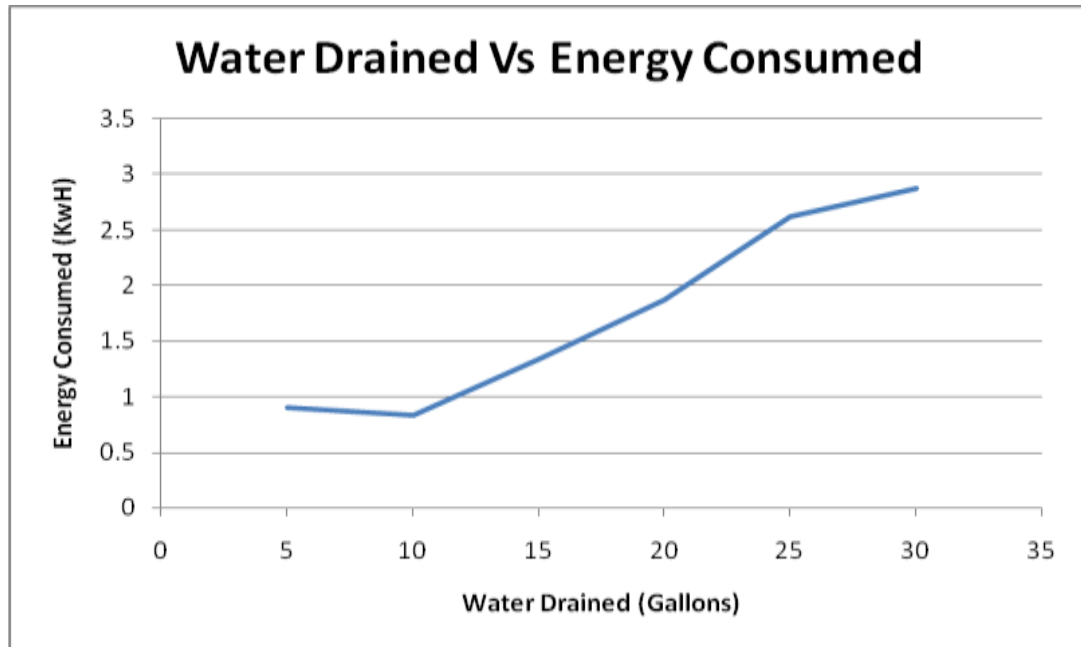


Figure 28: Comparison between the water drained from the hot water tank to the electric current consumed in heating the water.

4.4 Recovery Rates and Cost Calculations of Hot Water Tank Test in Open Loop.

The Solar Water heater is connected in series with the Hot water tank. The inlet to the hot water tank is replaced with the outlet of the solar water heater. The temperature of water in the solar water heater, when it was allowed to heat for 48 hours or two days is 155.5°F. The temperature of water inside the hot water tank is at the preset temperature.

Table 7: Open loop test results of Hot water tank in series with Solar water heater.

				Heating element energized			
Amps	Gallons drained from hot water tank	Hot water tank start temp	Source water temp	Start	Stop	Recovery time (min)	Energy Usage (KwH)
0	5	115.8	155.0			0	0
0	10	116.7	142.0			0	0
0	15	113.2	128.0			0	0
18.9	20	112.0	104.0	2:52 PM	3:04 PM	12	0.78
18.9	25	113.7	90.0	3:23 PM	3:40 PM	17	1.11
18.9	30	112.5	80.0	4:15 PM	4:35 PM	20	1.31

The temperature of water entering the hot water tank is 155°F. The recovery time of the hot water tank calculated in this case, is the time period during which the multi meter starts displaying the current charged by the hot water tank and when it comes back to Zero position. The inlet of the city water hose, is connected to the inlet of the solar water heater. The gallons of water drained out of the hot water tank is directly measured in the measuring bucket at the exit pipe.

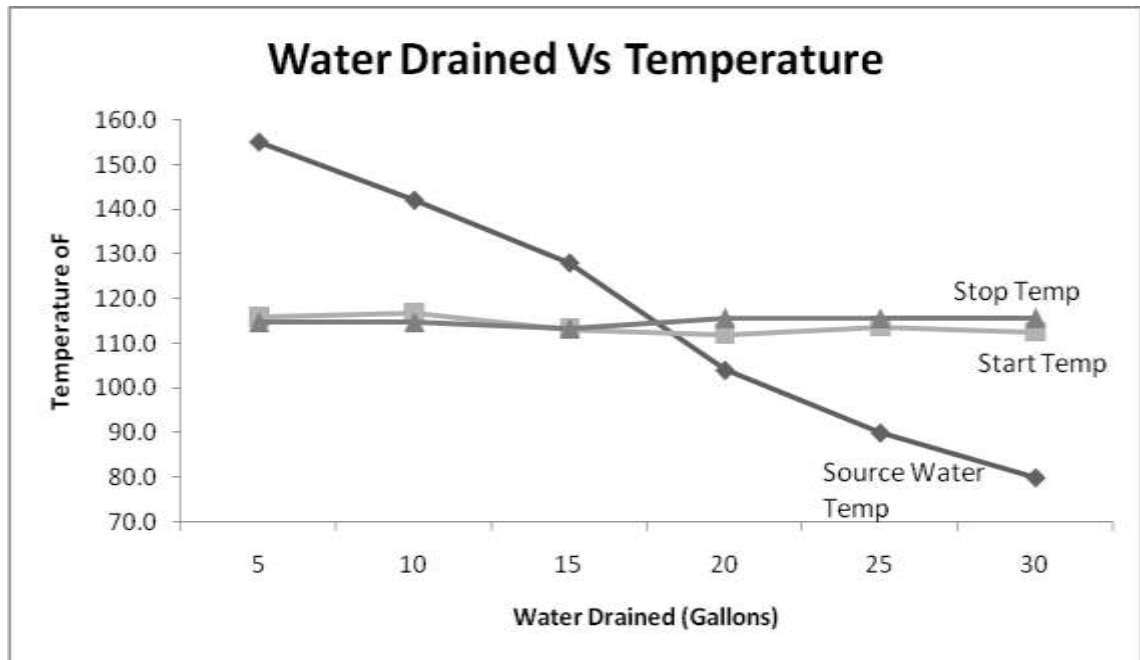


Figure 29: Recovery Rate testing of Hot water tank in Open Loop.

5 gallons of water is drained out of the hot water tank, and the same is replaced with pre heated water from the solar water heater. The multi meter is monitored for any change in the electrical reading, to check the energy consumption by the hot water tank. The stop watch is operated to note the time taken by the hot water tank to recover back to the preset temperature. The multi meter did not show any deflection in its Zero reading when 5 gallons of water was drained out. This indicates that the electric heating elements in the hot water tank did not switch on to heat the water. Hence there is zero usage of electricity by the hot water tank.

10 gallons of water is drained out of the hot water tank and the same is replaced with pre heated water from the solar water heater. The temperature of water entering the hot water tank is 142°F. The multi meter

is checked for any deflection in the Zero reading shown by it and the stopwatch is operated accordingly to note the time taken by the electric heating elements to heat the water in the hot water tank. This test also yielded Zero electric usage by the hot water tank, as the multi meter did not deflect from its Zero position. This shows that the electric heating elements in the hot water tank never switched on.

15 Gallons of water is drained out of the hot water tank and the same is replaced with the water from the solar water heater. The temperature of water entering the hot water tank is 128°F. The solar water heater is constantly filled with the city water, for the volume of water drained out of it, to the hot water tank. The multi meter is checked for any deflection from its Zero reading to check the electric current usage by the hot water tank. The multi meter did not deflect from its Zero reading, indicating that the electric heating elements in the hot water tank did not switch on. The time difference between each case is 30 minutes. The total amount of water drained out of the hot water tank until now is 30 gallons and the capacity of the hot water tank is 50 gallons. The same is replaced by the water from the solar water heater, which is filled with the 30 gallons of city water, entering at 71.3°F and the capacity of the solar water heater is 39.9 Gallons.

20 Gallons of water is drained out of the hot water tank and is filled with the solar heated water at 104°F. The multi meter yielded deflection from its Zero reading, indicating that the electric heating elements started heating

the water in the hot water tank. The hot water tank started using electricity to heat the water. The stop watch is started and the multi meter is monitored until it reaches Zero position. Once it reached the zero reading, the stop watch is stopped and the time difference is noted down.

The time taken to heat up 20 gallons of solar heated water entering into the hot water tank, when 20 gallons of water is drained out of it, is 12 minutes.

The cost of the energy consumed to heat to the preset temperature is :

Current I = 18.9 Amperes

Time consumed T = 12 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 18.9$$

$$= 4158 \text{ W}$$

$$\text{But } \text{W} / 1000 = \text{kW}$$

$$4158 / 1000 = 4.158 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW) X Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.158 \times 12}{60} = 0.8316 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 0.8316 \times 0.0774 = \$ 0.0643$$

Hence, to heat the 20 gallons of water for 12 minutes, the energy consumed by the hot water tank is 0.8316 kWh which amounts to a total of \$ 0.0643.

The time taken to heat up 25 gallons of solar heated water entering into the hot water tank, when 25 gallons of water is drained out of it, is 17 minutes.

The cost of the energy consumed to heat to the preset temperature is :

Current I = 18.9 Amperes

Time consumed T = 17 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 18.9$$

$$= 4158 \text{ W}$$

$$\text{But } W / 1000 = \text{kW}$$

$$4158 / 1000 = 4.158 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW) X Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.158 \times 17}{60} = 1.1781 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 1.1781 \times 0.0774 = \$ 0.0911$$

Hence, to heat the 25 gallons of water for 17 minutes, the energy consumed by the hot water tank is 1.1781 kWh which amounts to a total of \$0.0911.

The time taken to heat up 30 gallons of solar heated water entering into the hot water tank, when 30 gallons of water is drained out of it, is 20 minutes.

The cost of the energy consumed to heat to the preset temperature is :

Current I = 18.9 Amperes

Time consumed T = 20 minutes

Voltage = 220 V

Energy Cost = \$ 0.774 per kWh.

The Energy / Power Consumed by the hot water tank is :

$$P = V \times I$$

$$P = 220 \times 18.9$$

$$= 4158 \text{ W}$$

But $W / 1000 = kW$

$$4158 / 1000 = 4.158 \text{ kW}$$

The Energy consumed has to be converted into kilo watt hours (kWh), to calculate the energy cost by the system.

The energy in kWh is given by the formula :

$$\frac{\text{Energy (kW)} \times \text{Time Consumed}}{\text{One Hour}} = \text{Energy in kWh}$$

$$\frac{4.158 \times 20}{60} = 1.386 \text{ kWh.}$$

The total energy cost for the energy consumed over the period of time is calculated by:

$$\text{Cost for the energy used} = \text{Energy (kWh)} \times \text{Rate per kWh}$$

$$\text{Cost} = 1.386 \times 0.0774 = \$ 0.1072$$

Hence, to heat the 30 gallons of water for 20 minutes, the energy consumed by the hot water tank is 1.386 kWh which amounts to a total of \$0.1072.

Table 8: Energy Calculations and Cost Analysis of Open Loop Test.

	Gallons Drained from the hot water tank	Current Used (Amps)	Energy consumed (kWh)	Cost of Energy Consumed (USD \$)
	5	0	0	0
	10	0	0	0
	15	0	0	0
	20	18.9	0.8316	0.0643
	25	18.9	1.1781	0.0911
	30	18.9	1.386	0.1072
Total	105	56.7	3.3957	0.2626

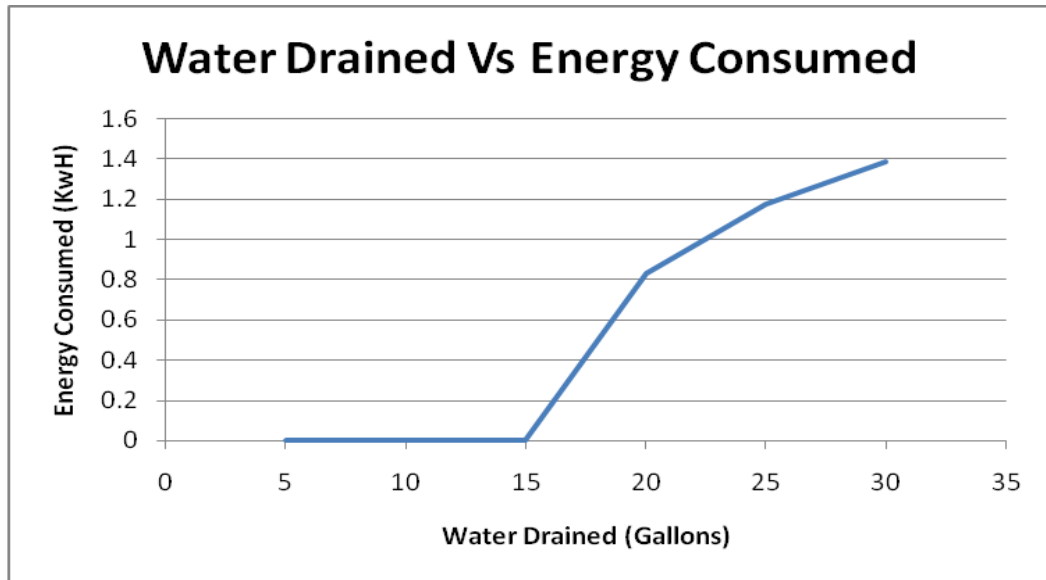


Figure 30: Water Drained Vs Current usage for the Open loop test.

CHAPTER V

CONCLUSIONS

An overview of solar collectors has been given in this thesis work. The Solar water heater has been tested for its recovery rate. The hot water tank used in the residential purposes has been tested for its recovery rate and the solar water heater has been used in series with the hot water tank, to calculate the energy savings by the hot water tank. The results of these tests are plotted and are discussed. The energy savings is calculated of the hot water tank with and without solar water heater are calculated.

The recovery rates of the solar water heater in the closed loop test, are pretty good.

- 1) The solar water heater could raise the temperature of the water entering at 63.5°F to a temperature of 137.3°F, there by increasing it by 73.8°F within a span of 7:30 hours.
- 2) The temperature loss of the solar water heater overnight, when the solar radiation incident is almost minimal, is also too low.

- 3) The effect of thermosiphoning was clearly seen in the tank of the solar water heater, where the temperature of the water was high at the top of the tank when compared to the bottom of the tank.
- 4) The temperature loss by the solar water heater is pretty low in the tank, when compared to the tubes, during any drizzle or rainfall.
- 5) The insulation of the tank is pretty good, as the temperature loss is pretty low in the tank.
- 6) The effect of temperature change due to rainfall / snow on the solar water heater, is first evident in the glass evacuated tubes, which drop the temperature very fast.

The open loop test of the solar water heater, connected in series with the hot water tank yielded good results.

- 1) The heating elements in the hot water tank did not switch on during the first three cases of 5, 10 and 15 gallons of water drain out of the hot water tank, when supplied with solar heated water.
- 2) The current charged during these three cases is Zero.
- 3) The heating elements switched on when 20, 25 and 30 gallons of water is drained out of the hot water tank for small duration of time.
- 4) The temperature of water entering the hot water tank is around 90°F during these three cases.
- 5) Solar water heater was able to maintain the temperature for long periods of time as the total volume of water drained out of the hot water tank is 105

gallons when compared to the capacity of the solar water heater, which is 39.9 gallons.

- 6) Solar water heater was able to regain the heat pretty fast.

Table 9: Energy Savings of Hot Water with Electricity and Solar water heater.

		With Electric Current		With Electric Current and Solar heated water	
	Gallons Drained from the hot water tank	Energy consumed (kWh)	Cost of Energy Consumed (USD \$)	Energy consumed (kWh)	Cost of Energy Consumed (USD \$)
	5	0.9104	0.0704	0	0
	10	0.836	0.0647	0	0
	15	1.3376	0.1035	0	0
	20	1.8711	0.1448	0.8316	0.0643
	25	2.6194	0.2027	1.1781	0.0911
	30	2.8713	0.2222	1.386	0.1072
Total	105	10.4458	0.8083	3.3957	0.2626

The total energy consumed by the hot water tank when run with electric current is 10.4458 kWh for heating 105 gallons of water to a temperature of 120°F. The cost of energy usage in this case is \$ 0.8083.

The total energy consumed by the hot water tank when connected to the solar water heater is 3.3957 kWh for heating 105 gallons of water to a temperature of 120°F. The cost of energy usage in this case is \$ 0.2626.

The difference in the energy consumption in both the cases is pretty high.

The energy saved when solar water heater is used in series with the hot water tank is about three times the electric energy used by the hot water when run by electricity only. The cost savings, when the solar water heater is used in series with the hot water tank is almost four times when compared to the cost of the hot water tank connected to electricity.

Considering the present situation, where the need for alternate energy resources is very high, given the fact that the non renewable energy resources are getting extinct at a rapid pace, and also causing global warming, the need for alternate energy sources is high. In these situations, saving the electric energy, with the use of a solar water heater, is very efficient. The electricity saved reflects on the cost savings too.

REFERENCES

1. Solar Water Heating – A comprehensive guide to solar water and space heating systems by BOB RAMLOW with BENJAMIN NUSZ.
2. www.votesolar.org
3. <http://solar.calfinder.com/library/solar-energy/water-heaters/collectors/integral-collector-storage>
4. Integral collector storage system with heat exchange apparatus, By Rhodes, Richard O. (San Francisco, CA); United States Patent 6722358.
5. [http://files.meetup.com/247150/A%20Solar%20Water%20Heater%20System%20\(Passive\).doc](http://files.meetup.com/247150/A%20Solar%20Water%20Heater%20System%20(Passive).doc).
6. Encyclopedia of Renewable Energy and Sustainable Living, By David Darling.
7. ASHRAE (1977), "Methods of Testing to Determine the thermal Performance of Solar Collectors," ASHRAE Standard 93-77, American Society for Heating, Refrigeration, and Air -Conditioning Engineering, New York.
8. G.D. Rai, Solar Energy Utilization, Textbook for Engineering Students,
9. A. Walker National Renewable Energy Laboratory, F. Mahjouri Thermo Technologies, R. Stiteler Mid-Atlantic Social Security Center, National Renewable Energy Laboratory conference paper June 2004.
10. <http://www.js-solar.com/sdp/157449/4/pd-1070364/308352.html> product catalog

11. F.Kojima et al. Electro magnetic non destructive evaluation, IOS press
2002
12. Solar Technologies for Buildings by Ursula Eicker
13. Citarella, Joe. "Thermosyphons - Better Approach to CPU Cooling?"
Overclockers. 5 August 2005.
14. Sustainable building design manual By Energy and Resources Institute,
Institut Catalá d'Energia, Asia Urb
15. Teach Yourself Electricity and Electronics By Stan Gibilisco Published by
McGraw-Hill Professional, 2006.
16. Rudolf F. Graf, "Volt", Dictionary of Electronics; Radio Shack, 1974-75. Fort
Worth, Texas. ISBN B000AMFOZY
17. "Half-high dots or spaces are used to express a derived unit formed from
two or more other units by multiplication." Barry N. Taylor. (2001 ed.) The
International System of Units. (Special publication 330). Gaithersburg, MD:
National Institute of Standards and Technology. 20.
18. Electrical and Magnetic Calculations: For the Use of Electrical Engineers
and Artisans, Teachers, Students, and All Others Interested in the Theory
and Application of Electricity and Magnetism By Albert Algernon Atkinson
Published by Van Nostrand, 1903
19. Building heat transfer, by Morris Grenfell Davies, Published by John Wiley
and Sons, 2004
20. Handbook of temperature measurement By Robin E Bentley, CSIRO
(Australia)