COST EFFECTIVE SOLAR WATER HEATER

By:

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Institute of Environmental Sciences and Technology

School of Civil and Environmental Engineering

National University of Sciences and Technology

2010-2014

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Maham Asif (2010-NUST-BE-ENV-17)

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This is to certify that the thesis titled

COST EFFECTIVE SOLAR WATER HEATER

Submitted by

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Nafey bin Afan (2010-NUST-BE-ENV-24)

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has been accepted towards the partial fulfillment of the requirements for

BACHELORS OF SCIENCE

IN

ENVIEONMENTAL ENGINEERING

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Approval Sheet

Certified that the contents and form of thesis titled "Cost Effective Solar Water Heater" submitted by Hassan Riaz Gondal, Maham Asif, Nafey bin Afan and Sarmad Hussain has been found satisfactory for the requirement of the degree.

Supervisor: ___________________________

Head of Department: ___________________

Associate Dean: ___________

Dedication

We dedicate this endeavor to Almighty Allah

Our beloved families

&

Friends

Who were there with us whenever needed, encouraged and raised us when we were down and helped us making this immense task a success

Acknowledgement

First and foremost, we would like to express our sincere gratitude to Dr. Ishtiaq Qazi (Associate Dean IESE), Dr. Sher Jamal Khan (HOD Environmental Engineering IESE) and Dr. Muhammad Fahim Khokhar (Supervisor) for their inspiration, motivation, enthusiasm, support, and immense knowledge.

Besides we are greatly thankful to NUST administration and the IESE department who offered their guidance and expertise and without whom this would not have been possible.

Accomplishing the task of writing the thesis so appreciably is only due to the unrelenting support and critical comments of our supervisor Dr. Muhammad Fahim Khokhar. We could not have imagined having a better advisor and mentor for our final year project.

Most of all we are thankful to Almighty Allah, who gave us the will, determination and strength to accomplish this task in this manner.

Never to forget we offer our gratitude to our beloved parents and friends whose unconditional love and support guided us throughout, ultimately making this task a successful reality.

Sincerely,

Hassan Riaz Gondal

Maham Asif

Nafey bin Afan

Sarmad Hussain

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Abstract

Extreme weather events and Climate change has directly affected Pakistan's economy and the lives of its people. Climate change, global warming and extreme weather events (torrential rains, floods, hurricanes, and drought) are linked to increase in greenhouse gas emissions caused by anthropogenic activities worldwide. Burning of fossil fuels including coal, natural gas, and oil for electricity and heat is the largest single source of global greenhouse gas emissions. Pakistan is currently experiencing a severe energy crisis -with a shortfall of natural gas of approximately 2 BCF per day and an average electricity shortfall of 3000-6000 MW. In addition to recent- droughts and consequent floods of 2010, 2011, 2012 and~~nad~~ 2014- has left Pakistan in a very vulnerable position by threatening its national security.

In this study, efforts are made to manufacture a cost effective solar water heater, -a partial solution/contribution to current energy crises. The main emphasis was to meet the needs of- both domestic and more importantly, the industrial sectors. Finally, cost effective and a simple solar water heater (SWH) was designed by making use of readily available and relatively inexpensive materials like copper, iron and convex lenses.

The prototype SWH was prepared- after preliminary studies and experimentation on the lab scale model. Both solar water heaters were tested against their efficiency to work in all types of environmental conditions and to reach maximum high temperature. A number of experiments were done and- the time taken by the SWH to heat the water for a temperature range of approximately 40ºC to 90ºC was calculated. In a clear sunny day our prototype SWH took approximately 20 to 90 minutes to reach at 100 C during noon

Formatted: Font: (Default) Times New Roman, 12 pt, No underline, Font color: Auto, Complex Script Font: Times New Roman, 12 pt, Pattern: Clear and evening times-, respectively. The capital cost of our prototype SWH was about 40 to 50 percent less as comparedd to commercially available SWH in Pakistani markets. Furthermore, the cost and benefit analysis indicated that by introducing such cost-effective SWH can contribute significantly in order to avoid/lower the current energy crises in Pakistan..

1. Introduction:

1.1. Climate Change:

Climate change is affecting almost all important sectors including health, agriculture, biodiversity and energy etc. and consequent extreme weather events have gained considerable scientific attention recently due to their potentially catastrophic impacts. Pakistan is also affected by such extreme events e.g. floods of year 2010, 2011 and frequent heat waves (Rasul *et al*., 2011).

According to recent reports from German watch Global Climate Risk Index (GW, 2012), Pakistan is among the top ten countries most affected by extreme weather events from 1991 to 2010.

Climate change indicators (temperature rise, sea level rise and extremes in the hydrological cycle) are linked to increase in greenhouse gas (GHG) emissions as a result of anthropogenic activities (fossil fuel combustions). The evidence of climate change from observations of the atmospheric composition has grown significantly during recent years. According to recent report from the United Nations' Intergovernmental Panel on Climate Change (IPCC, 2013) estimates a global warming of 0.85±0.2 °C (combined land and ocean surface temperature data) over the period 1880 to 2012 with forecast of most likely increased heat waves in large parts of Europe, Asia and Australia (Hartmann et al., 2013). This increase in temperature has given rise to changes in climate and weather all over the world resulting in:

- 5 – 15% drop in yield of crops
- 3 -10% increase in rainfall during heavy rain events (over some regions)
- Increased flooding risks
- Decreased stream flow in river basins
- More frequent and intense wildfires (NRC, 2011).

Weather patterns in Pakistan are becoming increasingly erratic (Cooke, 2013). During the time period of 1999 till 2002, there was a dramatic decrease in the flow of River Indus and its tributaries and consequentially, Pakistan suffered from severe droughts. Then in 2010 till 2012, extensive flooding occurred due to abnormally intense monsoon rains causing the River Indus to overflow its banks. Both these anomalies in the local climate displaced millions of people and took the lives of thousands. Alone during 2010, the estimated flood losses were around 5% of the GDP while the adaptation cost was US $ 5.75 billion and these costs are likely to increase further if proper actions are not taken by the Government of Pakistan (Khan, 2011).

1.2. Energy Crisis in Pakistan:

The energy crisis that is presently facing Pakistan is not a new predicament. ~~Owing to negligence in timely reaction to growing demands,~~ Pakistan faced a serious shortfall of electricity during the 1980's and 1990's, Owing to negligence in timely reaction to growing demands ~~as well~~ (Asif, 2011). In 1994, the Government of Pakistan formed a new organization by the name of the Private Power Infrastructure Board (PPIB) to address the crisis at hand. The PPIB was aimed at facilitating the private sectors participation in power generation.

Pakistan is currently experiencing a severe energy crisis. During year 2013 Pakistan faced a shortfall of natural gas of approximately 2 BCF per day and an average electricity shortfall of 3000-6000 MW. In addition to natural gas outages, urban areas face electricity blackouts of 10-12 hours and rural areas have no electricity for 16-18 hours a day. The number of people living without electricity in Pakistan has increased from 65

Million people ~~million people~~ in 2000 to 71.1 million people in 2008 (Asif, 2011). Pakistan needs to resolve these energy crises on a priority basis, essentially by exploiting renewable energy resources. The pie chart shown in figure 1 depicts the amount of energy supplied by various renewable and non-renewable sources in Pakistan.

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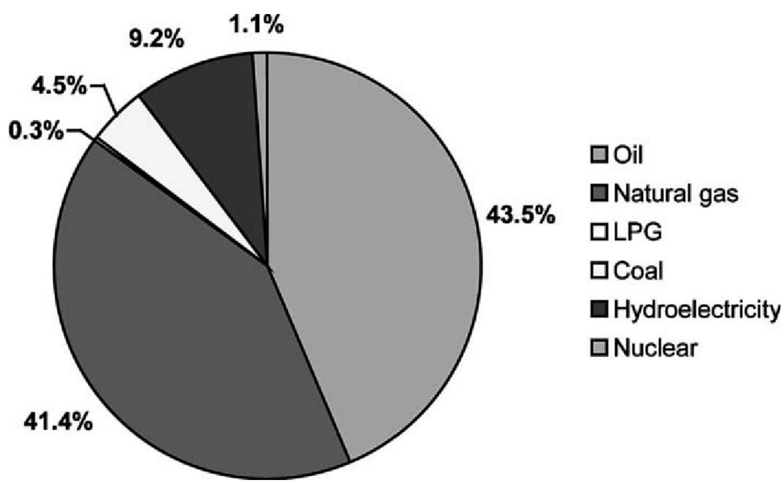

Figure 1.1: Primary energy supplies by source. (Source: Pakistan Energy Yearbook 2001)

Figure 1.1: Primary energy supplies by source. (Source: Pakistan Energy Yearbook 2001)

Development of Pakistan's renewable energy resources is rapidly becoming crucial to meet its industrial needs and to sustain its economic development. Furthermore, Pakistan's coal, oil and natural gas reserves are running out leaving our economy to rely on imported fuel. The situation has gradually worsened overtime forcing people in both urban and rural areas to use wood as fuel for cooking and heating water etc. Consequently, it is not only exhausting natural resources of Pakistan but also deteriorating the environment of Pakistan. Now, it is not just our forest reserves that need to be saved and protected but our economy as well.

A study Qudrat-Ullah and Karakul (2007), has indicated a recent increasing trend in oil- and gas-based power generation while a decreasing trend in the hydro-based power generation in Pakistan. It also mentioned that as a result the environment is exposed to the additional 167 million tons of CO_2 in addition to other air pollutants such as SO_2 and NO_2 etc. A temporal increase is observed in the thermal power generation data of Pakistan. For instance, the thermal power generation was increased during year 2008 to 2011 with maximum during the year 2010. Among thermal power generation, the use of coal and furnace oil was larger as compared to use of gas as fuel.

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Table 1.1: Share of Coal, Oil and Gas consumption by power sector of Pakistan with total Hydro and Thermal power generation (Khattak *et al.*, 2014)

Year	**Power Generation in Pakistan by Using Fuels**			**Power Generation in Pakistan by Sector**		**Annual SO_2 Column Densities over Pakistan (DU)**
	Oil (GWh)	**Gas (GWh)**	**Coal (000 metric tonnes)**	**Hydro (GWh)**	**Thermal (GWh)**	
2008	39.18	33.7	162.2	28667	57602	0.172
2009	42.27	31.8	112.5	27763	56614	0.161
2010	46.07	28.7	125.5	28492	60746	0.335
2011	43.09	27.2	96.5	32259	58316	0.298
r^2	0.68	0.77	0.18	0.24	0.79	1
Slope	0.026	-0.026	-0.013	0.021	0.44	1

A temporal increase is observed in the thermal power generation data of Pakistan presented in the Table 2. A recent study (Khattak et al., 2014a) described the observed temporal increase in SO_2 columns during the time period of 2004-2011 is mainly contributed by trans-boundary SO_2 pollution caused by both regional volcanic eruptions (Khattak et al., 2014b) and anthropogenic activities, and use of furnace oil and coal for

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thermal power generation in Pakistan to meet the industrial needs (especially, onward from year 2008) and to overcome the power outages.

The Water and Power Development Authority (WAPDA) is dubbed as the foremost and the largest shareholder in power sector of Pakistan as it contributes 11,343 MW (56.6%) of the total electrical capacity. The ~~second most significant contribution is made by the~~ group of Independent Power Producers second most significant contribution, that has~~ve~~ a total installed capacity of 6,391 MW making up around 31.9% of the total capacity (Asif, 2011). Others include 0.1% of the total capacity is fulfilled through imported electricity from Iran.

The Government of Pakistan has been unsuccessful in providing fail-safe measures to counter the energy shortfall, for instance, the development of hydropower and the construction of new dams. The planned growth of hydropower has been plagued~~marred~~ over the last three decades ~~primarily~~ due to the politicization ~~and the consequent shelving~~ of the~~e~~ Kalabagh dam issue (Asif, 2011). During this time period, the only project that was carried out was the run-off-river Ghazi Barotha project of 1450 MW commissioned in 2003.

During the year 2008, the idea of rental power plants was introduced by the Government of Pakistan. Out of the 2800 MW rental power that was sanctioned by the Government of Pakistan, only 800 MW could be included in the. Even after paying Rs. 21.8 billion to the Rental Power by the current government, none of these power plants functioned at ~~their~~ full capacity and ~~produced~~ only 1200 MW of electricity was produced in total (Akhtar, 2012).

1.3. National Needs of the Project:

In Pakistan, as on a global scale, water, food and energy create a nexus of interdependence whose balance is thrown off by a globally changing climate (Sayed, 2011). The power consumption of Pakistan has risen almost 80% but Pakistan has failed to match this energy requirement primarily due to partially implemented reforms and poor investment in the energy sector by the Government of Pakistan (Khan, 2011) and private sector. A Gallup poll conducted in July 2009 concluded that 53% of the total population was devoid of electricity for more than eight hours a day but since then this shortage has increased by 42% nationwide.

According to Government of Pakistan, the current power shortages has cost Pakistan's economy approximately 2% of its GDP (Economist, 2011). Furthermore, it has been predicted that by 2025 and 2030, Pakistan's domestic oil and gas reserves will be exhausted. A cost of $ 10 billion was previously estimated to counter the energy crises for short-term while at least double this cost is crucial for long-term planning and solution (Iqbal, 2010). About 30% of Pakistan's energy supplies are already being imported and this figure is expected to rise to almost 75% by 2025 if the current situation continues (Javaid, 2011).

The energy crises can be overcome by switching to renewable energy. A more diverse energy mix can help stabilize Pakistan and its economy. Instead of depending on fossil fuels (oil, gas and coal), a more focused approach can be taken to exploit hydro power potential in the North and solar energy in Punjab and central Pakistan. Wind energy is also a viable option for various areas of Sindh and Balochistan. The Government of Pakistan has taken on a number of renewable energy projects in recent years which will help to counter the current scenario of energy shortages. On individual level, a fairly recent trend has been set (especially in urban areas) where people have installed solar panels and solar water heaters on their rooftops. This trend is also becoming apparent on an institutional level; as there are a number of high rise buildings throughout Pakistan which have solar panels installed as a crucial part of their design and working.

The concept behind the butterfly effect states that the smallest and most unnoticeable change can revolutionize the world. Like a butterfly flapping its wings in Brazil may cause a tornado in Texas, in the same manner one Pakistani adopting renewable energy may help to address power- crisies in country.

A partial solution to this energy crisis is the introduction of effective and economically feasible solar water heaters. Especially, there is need to design SWH which do not require special plumbing and can benefit both industrial and domestic sectors: a direct heating system, with a relatively lower capital cost, easier installation and twenty four hour water heating ability.

Most of the research in solar water heaters has been concentrated on collector types and storage tanks. The payback period of solar water heaters currently used in Pakistan is between 18-24 months “when compared with the fuel costs of the natural gas” (Farooqui, 2014).

This project focuses on the production of a system which uses and retains heat from solar energy to heat copper rods in a heat trapping apparatus and particularly for all weather conditions. The proposed system is temperature-based: the system efficiency is dependent upon the rate of change of temperature which varies with the weather conditions. The focal point of the prototype being developed is to provide the public with a cost-effective SWH to cater the needs of a single household-.

1.4. Research Objectives:

The concept of the study is aimed at moving towards renewable energy for a greener and cleaner future. The research objectives of the study are:

- To improvise the design of the conventional solar water heater.
- To introduce a cost-effective solar water heater**.**
- To create a prototype which can be further developed for small scale industries.
- To contribute in efforts to counter the energy crisis of Pakistan.

2. Literature Review:

2.1. Renewable Energy in Pakistan:

Pakistan's hot climate and changing patterns of snowmelt and precipitation exacerbate existing social and economic pressures on natural resources (Sayed, 2011). To promote the idea and use of renewable energy, the Government of Pakistan created a number of departments including the National Institute of Silicon Technology (NIST); Appropriate Technology Development Corporation (ATDC); Pakistan Council of Appropriate Technologies (PCAT); and Pakistan Council of Renewable Energy Technologies (PCRET). Another effort in this area was made in 2002 by the formulation of the Alternate Energy Development Board (AEDB). As of mid-2009, AEDB had accomplished the following goals:

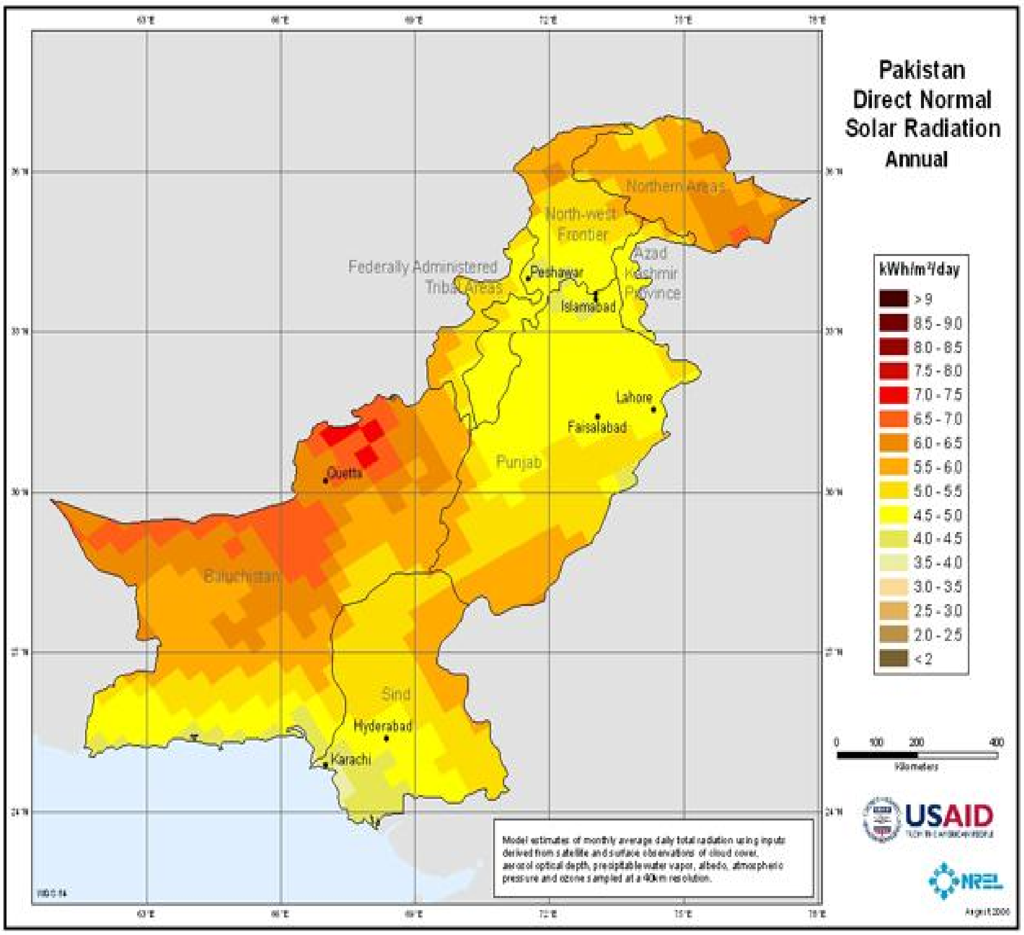
- In Jhimpir, a wind farm with a capacity of 6 MW was installed.
- Two 10kW capacity wind turbines were installed in Kallar Kahar.
- In Sindh and Balochistan, approximately 100 micro wind turbines of 500 W each were installed to provide electricity to villages.
- Also, 80 W solar home systems were installed in about a thousand houses (Asif, 2011).

Energy from biomass based, non-commercial sources accounts for nearly 35% Pakistan's total energy consumption (Asif, 2011).

2.2. Solar Energy in Pakistan:

Nearly all areas of Pakistan witness roughly 300 sunny days on average each year. Pakistan is an ideal contender for the exploitation of solar energy due to its topography, climatic conditions and its geographical location (Asif, 2011).

Figure 2.1: Solar insolation map of Pakistan (Source: www.pres.org.pk).



The potential of Pakistan's solar energy is approximately equal to 2.9 TW (Bhutto *et al.*, 2012). Pakistan witnesses around 1500 to 3000 hours of sunlight each year with a mean global irradiation of 200 – 250 W/m^2 on a horizontal surface. Balochistan alone has an average daily global insolation of approximately 19 – 20 MJ/m^2 per day which roughly equals to 1.93 – 2.03 MWh/m^2 per annum with eight to eight and a half sunshine hours in a day (Mirza *et al.*, 2003). Pakistan's daily solar energy potential, as a whole, has been presented by the Energy Information Administration as 5.3 kWh/m^2 which amounts to 1.93 MWh/m^2 per year.

The Government of Pakistan set up eighteen photovoltaic stations with an installed capacity of roughly 440 kW for village electrification in the 1980's. However, these systems failed to perform per their requirement due to lack of technical knowledge and maintenance. The current use of solar energy and technology in Pakistan involves a number of equipment and processes including the following:

- To power emergency telephones on highways,
- To power standalone telephone exchanges in rural areas,
- To power refrigerators in hospitals for the storage of vaccines and medicines,
- ~~Cathod~~ cathode ~~ic~~ protection, etc.

For the provision of drinking water, around twenty solar water pumps have also been installed by the Public Health Department.

Recently, the Punjab Government signed a Memorandum of Understanding with AEG, a German company for collaboration in the solar energy division. According to this

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MoU, in Punjab, solar projects of installed capacities of approximately 50 MW to 100 MW and 300MW were to be set up in 2013 and 2014 respectively (The Nation, 2012). Muhammad Shahbaz Sharif, the Chief Minister of Punjab claimed that for the benefit industrial sector, solar energy projects of 20 MW each will be set up whereas in Cholistan, projects of 50 to 100 MW will be launched.

Table 2.1: Average monthly irradiation values for Pakistan, (kWh/m²day)

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Month	Karachi	Quetta	Multan	Lahore	Islamabad	Peshawar
January	131.8	113.7	105.1	90.4	87.0	90.4
February	131.3	128.9	117.6	111.2	109.6	115.2
March	173.9	162.8	155.0	151.6	133.5	149.8
April	185.0	201.7	187.5	180.0	183.3	179.2
May	198.1	235.9	203.2	198.9	209.3	214.4
June	187.5	238.3	190.0	196.7	194.2	220.8
July	150.7	214.4	186.0	162.8	181.7	199.8
August	144.7	207.5	184.3	167.9	176.5	180.0
September	250.8	192.5	168.3	165.0	162.5	160.0
October	162.8	169.6	143.8	137.8	135.2	137.8
November	130.8	127.5	116.7	103.3	96.7	135.8
December	121.4	105.9	95.6	87.8	69.8	90.4

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Table 1, adopted from (Asif, 2010)

A 1.8 MW solar power plant is being installed at the Parliament house building in Islamabad (Saeed, 2014). The following table gives the average monthly solar irradiation values for various cities of Pakistan.

The introduction of solar dryers has proven to be very successful in agricultural areas like the hybrid solar dryer for apricots, dates and other fruits, which was developed and designed by PCRET (Bhutto *et al.*, 2012). Even though the technology of solar water heaters is relatively mature, Pakistan has been unable to fully benefit from it due to its high capital cost.

2.3. Solar Water Heaters:

The use of solar water heaters is encouraged to produce domestic hot water, because they can substantially reduce primary energy consumption compared with conventional water heaters (Hernandez and Kenny, 2012). Solar water heaters can be classified by their thermal performance and their characterization is based mostly on the conductivity of the working fluid as well as the transmittance, absorption and conduction abilities of solar energy (Jaisankar *et al.*, 2011).

Studies conducted in China state that solar collectors should get up to a minimum of four hours of sunlight. As further investigated by *Li and Liao* ,(2014) even roof-installed collectors may be shaded by higher adjacent buildings. Hegazy, (2011) investigated heating efficiency with respect to various tilt angles, the effect of dust accumulation on the glass cover of solar collector. The results of this study showed that the fractional reduction in glass transmittance is dependent upon the amount of dust deposited in concurrence with the tilt angle of the plate, the exposure period and site climatic conditions (Hegazy, 2001). Earlier, Soulayman, (1991) also investigated the effect of dust deposition on solar collectors with respect to several tilt angles ranging from 0º to 90º. It concluded that the most amount of dust is accumulated at -0º angle and the least amount at a 90º angle.

The recyclic double-pass sheet-and-tube solar water heater with internal fins was theoretically investigated by (Ho and Chen, 2008) whereas a flat-plate solar air heater's thermal performance was optimized by (Varun, 2010) -using a genetic algorithm

Taheri *et al., (2013)* studied the enhancement of heat transfer in the pebble bed which was used as the absorber segment of a composite solar water heating system using a numerical simulation method and the EES (Engineering Equation Solver) software. The composite solar water heater's potential for energy saving was assessed using a thermal network analysis model.

A number of experiments and studies have also been carried out to assess the heat losses from storage tank and to minimize them. Colle et al., (2001) carried out experiments with various thicknesses of different materials used to provide proper insulation to reduce heat losses. Naphon , (2006) carried out a very comprehensive review on the application of various active techniques including the electric field, vibration, and acoustic; and passive techniques including special surface geometries, twisted tapes, curved tubes, helically and spirally coiled tubes to enhance heat transfer . Tthe comparison revealed that without the help of any external energy, the passive techniques have better heat enhancement (Jaisankar *et al.,* 2011). Also the use of a suitable aero profile design can reduce heat loss due to convection from the glass cover. This design prevents the air movement over the glass surface (Jaisankar *et al.,* 2011).

2.4. Cost and Billing Data Collection:

The billing data collected from NUST H-12 Campus for the month of January 2014 is presented in the Table 2.2.:

Table 2.2: Monthly Natural Gas Bill for January 2014 of NUST main campus (PKR)

	Number of geysers	Natural gas bill (without kitchen)
Hostels	162	PKRRs. 2, 254, 330/-
Other buildings	69	PKRRs. 686, 580/-

Capital costs of instant, electric and gas geysers were also gathered with the help of various surveys. The data collected is as shown:

Table 2.3: Capital cost of geysers (PKR).

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Geyser Type	Capacity	Capital Cost of Geyser
Instant Gas Geyser	8 L	PKRRs. 8000/- to PKRRs. 9000/-
	12 L	PKRRs. 12000/- to PKR Rs. 13000/-

	14 L	PKR~~Rs.~~ 13500/- to PKR~~Rs.~~ 15000/-
Gas Geyser	35 gal	PKR~~Rs.~~ 13500/- to PKR ~~Rs.~~ 14600/-
	55 gal	PKR~~Rs.~~ 15000/- to PKR~~Rs.~~ 16000/-
Electric Geyser	8 gal	PKR~~Rs.~~7500/- to PKR~~Rs.~~ 8500/-
	10 gal	PKR~~Rs.~~ 10500/- to PKR~~Rs.~~ 11500/-
	12 gal	PKR~~Rs.~~ 13000/- to PKR~~Rs.~~ 14000/-

~~**Table 2.3: Capital cost of geysers.**~~

The operational cost of a gas geyser for domestic consumers using more than 300 m^3 per month is around PKR~~Rs.~~ 530.69 per MMBTU (Million Metric British Thermal Unit).

The cost of electricity for the number of units used per month is given below:

Table 2.4: Tariff per unit of gas used (PKR)~~.~~

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Number of Units Used per month	Tariff per unit
Up to 50	Rs. 2

1 – 100	Rs. 5.79
101 – 200	Rs. 8.11
Above 700	Rs. 18

Table 2.4: Tariff per unit of gas used.

The operational cost of an electric geyser can be calculated as shown:

Table 2.5: Operational cost of electric geyser (PKR).

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Power supplied	9 kW
Power consumed	6.7 kW
Voltage Supplied	220 V
Hot water consumption	3 hours/day
Tariff per units used	Rs. 8.11/unit
Cost of monthly usage	6.7 kW x 3 hrs/day x 30 days x Rs. 8.11/unit = Rs.PKR 4890.33

Table 2.5: Operational cost of electric geyser.

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3. Materials & Method:

3.1. Old Model:

The original lab scale model used in the study was a wooden box with dimensions 2 ft x 4 ft. It was covered from the top by glass and lined with Styrofoam -sheet on all sides. The base was covered with aluminum foil over as layer of thermo pole sheetsprayed with black pain. The length of the 80 ft of 2 mm diameter coiled copper pipe having diameter of 2 mm was 80 feetfixed inside the model with the help of plastic hooks. This model basically acts as a flat plate collector with water running through the copper pipe shaped as a spiral. Both the copper pipe and aluminum foil covering were spray – painted black to maximize absorbance of solar energy.

The aim of the model was to make use of simple insulation materials and methods; to improve the heat retaining qualities of the model to make it more effective and efficient. The glass retains maximum heat inside the box and allows minimum heat to escape. The wooden box coupled with the lining of thermo poleStyrofoam sheet acts as an insulation material; it keeps the heat from escaping and traps it inside box. Aluminum foil was also placed on the thermo poleStyrofoam layer on the base to reflect light back the incident photons on to the copper piping, as shown in the Figure 3.1.

Copper being a good conductor of heat, effectively transfers the heat energy to the water running through the pipe. Since black colored surfaces are capable of absorbing more heat, the aluminum foil and the copper pipe were painted black using simple spray paint which further enhanced the heat retaining potential of the model. During the process, it was observed that the time taken for the water to reach a certain temperature depends on the heat available, i.e. the solar insulation at that specific time, ~~and~~ place and weather conditions at that instant.

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Fig~~ure 3.1:~~Figure 3.1: Old Model on the roof top of IESE building~~.~~

The prototype was designed to overcome the drawbacks of this model which primarily consist of leakages, heat loss to surroundings and water flow rate.

3.2. Prototype model:

The prototype SWH was designed to make a more compact and ~~elaborate solar~~efficient solar water heater on the basis of avoiding shortcomings ~~inferred~~ experienced -in the case of old model- ~~from the model~~ as described ~~earlier~~in the previous section.

The prototype is a 2 ft x 2 ft square iron casing, 3 inches deep~~high~~, with a stainless steel bottom, inside a wooden box of the same size. The addition of plastic wool between

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~~Figure 3.2: New prototype on the roof of IESE.~~

~~the~~ iron~~iron~~ casing and the wooden cover ~~reinforces the~~acting as insulation ~~of the water heater~~ and thus preventing heat from leaving the box.

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Figure 3.2: New prototype on the roof of IESE

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On the lines of the previous model, 40 ft of 2 mm diameter coiled copper pipe is fixed in the water heater with the help of plastic hooks. The temperature of the water running in the copper pipe rises due to the heat~~ed~~ conducted by copper pipe and the heat present in the solar water heater apparatus. The copper pipe does not touch the stainless steel sheet~~,~~ and was~~it is~~ fixed 0.25 cm above ~~it~~the surface. To further concentrate heat onto the copper pipe, simple convex lenses ~~are~~ were mounted on rotatable iron rods. There are a total of four rods 4 inches apart; placed at 3.8 cm above the copper pipe. Seventeen convex lenses are attached to each rod, roughly 0.5 cm apart with a focal length of 3.8 cm. Each convex lens is 2 cm in diameter and is removable; the lenses have been introduced in the prototype to concentrate the sunlight directly onto the copper pipes, thus reducing the time taken for the water to heat. The rods are inserted into the water heater in such a manner that the lenses neither come into contact with the copper pipe nor the glass cover, as shown in Figure 3.2.

~~On the top is a~~A 5 mm thick glass cover ~~, similar in kind to the one described in the earlier apparatus,~~ was purposed to store heat inside the apparatus. The outlet of the solar water heater is controlled by a temperature valve which only allows water to flow out when it has reached the preset temperature (~~–~~controlled by a thermostat, as shown in Figure 3.3). Near the outlet, before the copper pipe leaves the water heater, a removable thermocouple is attached to the copper pipe with the help of a T-joint welded onto it. The thermocouple is attached to the temperature valve and the temperature controller; from the temperature controller we can set the desired temperature and then water will only discharge from the solar water heater when the thermocouple detects that temperature. For example, if the temperature is set at 60º C, water will start to flow from the outlet when the temperature of the water in the T-joint has crossed 60ºC. The temperature controlled valve runs on electricity supply of 250 V.

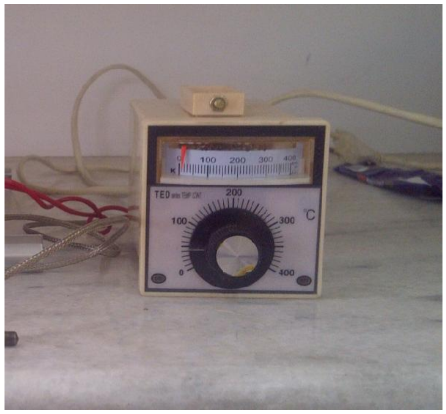

Figure 3.3: Temperature Controller setup used in prototype model

The thermal conductivities and capacities of various materials used in the prototype are given in the following table:

Table 3.1: Thermal properties of various materials (Source: www.engineeringtoolbox.com)

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Material	Thermal Conductivity (W/m.K)	Thermal Capacity (kJ/kg.K)
Glass	1.05	0.2
Wood	0.13	2.0
Copper	401	0.09
Stainless steel	16	0.53
Glass wool	0.04	0.67

Iron	80	0.11

~~**Table 3.1: Thermal properties of various materials (Source: www.engineeringtoolbox.com)**~~

3.3. Design Modifications and Materials:

A comparison of the design features and the materials used in the old model and the prototype is shown in the table below:

Table 3.2: Feature comparison between Old Model and Prototype

Design Feature/Material	Old Model	Prototype
Top cover	5 mm glass	5 mm glass
Copper pipe	2 mm, 70 – 80 ft	2 mm, 35 -40 ft
Convex lens	-	2 cm, 65 – 70
Size	2 ft x 4 ft	2 ft x 2 ft
Outer cover material	Wood	Wood
Inner material	Aluminum foil	2 ft x 2 ft iron casing, stainless steel sheet
Insulation material	~~Thermo pole~~Styrofoam sheet	Glass wool
Valve	~~Temperature valve~~-	Temperature valve

~~**Table 3.2: Comparison of Old Model and Prototype.**~~

3.4. Cost Effectiveness of Prototype:

The prototype has been designed using the simplest, inexpensive and widely available objects like wood, iron, steel, glass etc. All the materials used in the designing and

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Formatted: Outline numbered + Level: 1 + Numbering Style: 1, 2, 3, … + Start at: 1 + Alignment: Left + Aligned at: 0" + Indent at: 0.25" manufacturing of this solar water heater were finalized on the basis of their thermal properties and economic feasibility.

The outer wooden casing remained the same in both models but the length of the prototype was reduced to make it compact and transportable. In place of pieces of ~~thermo pole~~Styrofoam sheet which provide a very crude form of insulation, glass wool was used to improve the heat retaining quality of the prototype. The cost of glass wool can be considered negligible when compared to the total cost of the solar water heater. The iron casing and stainless steel sheet replaced the aluminum foil in the prototype for the same reason. The cost-effectiveness of the prototype has been mainly based on reducing the time required for the water to heat to a certain temperature and the cost and energy saved in heating the water as compared to conventional means.

The cost-effectiveness of the model is not only reflected by its low capital cost but also by the time and energy saved in heating the water ~~-~~ to desired temperatures~~using the solar water heater~~.

3.5. Experimentation Phase:

Preliminary experiments that were run on the old model led towards a better and more compact solar water heater. A comprehensive study was then carried out on the performance of the prototype.

The solar water heater was faced towards the south and placed at an angle of 30º from the horizontal since this angle is the optimum angle for maximum solar insolation. It was placed on the roof~~-~~top of Institute of Environmental Sciences and Engineering (IESE-SCEE) at the National University of Sciences and Technology (NUST), Islamabad. The inlet of the solar water heater was connected to the direct water supply of IESE and the discharged water was collected in a small bucket.

The experiments were carried out three times a day, at sunrise, noon and sunset for a range of temperatures from 40ºC till 90ºC. The time taken for the water to reach the desired temperature was recorded and for each temperature the experiment was carried out three times. The values were then averaged and the result of each time (sunrise, noon, sunset) was recorded in the form of a graph of temperature against time.

Before the experiment was conducted, the solar water heater was flushed with tap water to bring its temperature down to the ambient temperature so as to measure the maximum time required to heat the water to a certain temperature and minimize any human errors. Also, the glass cover was cleaned before each experiment so as to minimize the effect of scattering of solar energy due to accumulation of dust ~~accumulation~~particles.

The experimentation phase was carried out in two parts, yielding two sets of values for the same range of temperatures as mentioned above. The first set of experiments was performed without any change in the original prototype whereas for the second set of experiments, the iron casing, stainless steel sheet and the copper pipe of the prototype were painted black using spray paint. The method of experimentation was kept the same (as described earlier) for both sets of experiments so as to determine the effect of the black paint on the time taken for the discharge water to reach the specified temperature.

Figure 3.4: Prototype after black spray paint.

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4. Results & Discussion:

4.1. Daily Results with Original Equipment:

4.1.1. 16th May 2014:

The daily ambient maximum temperature was 34º C whereas the minimum recorded temperature was 19º C.

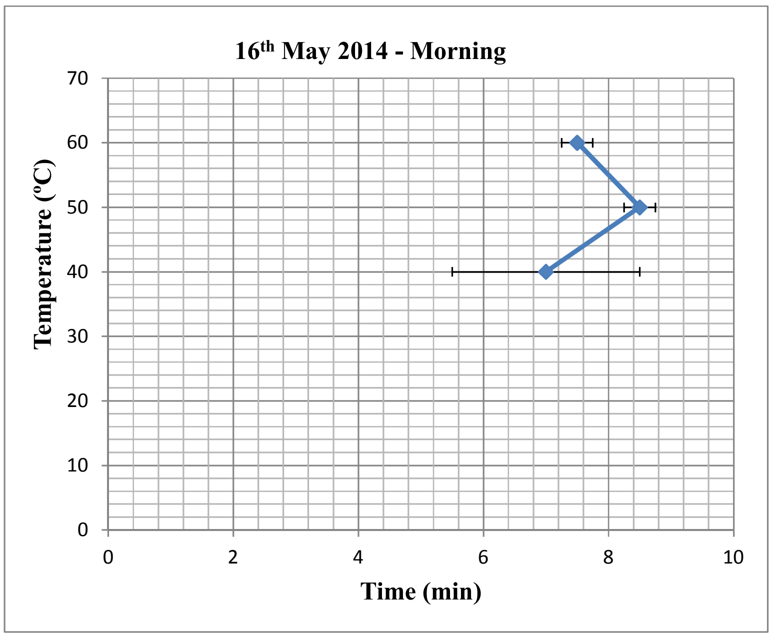

Figure 4.1: 16th May Readings

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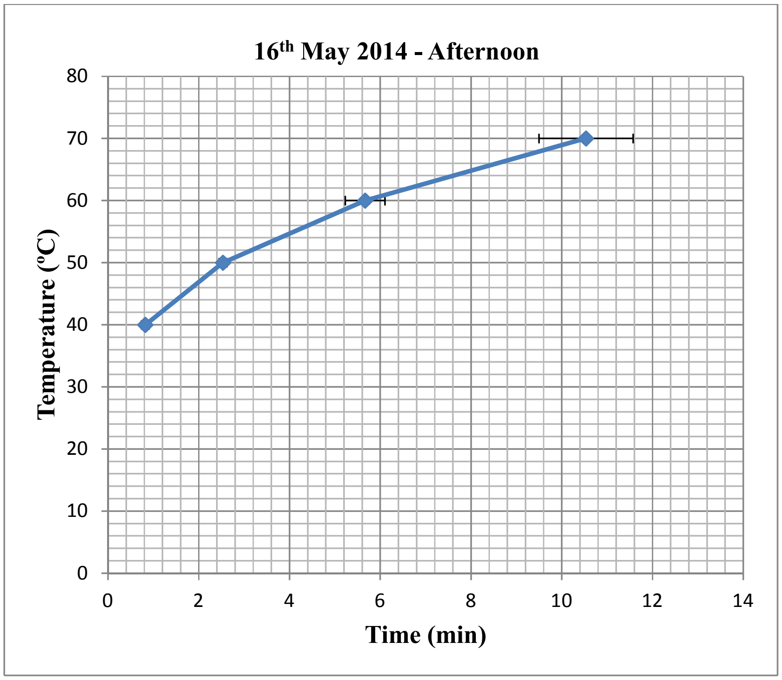

Figure 4.2: 16th May Readings

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As it is apparent from the graphs above (Figures 4.1 and 4.2), due to a high ambient temperature of 34ºC and relatively low wind speed (about 7 km/h), the water heats up to 40ºC in less than a minute, and ~~reaches~~ reached to ~~to~~ a temperature of 70º C within ten minutes during the peak sunlight hours. During the morning, however, it took seven to nine minutes for the discharge water to reach temperatures of 40º C, 50 ºC and 60 ºC, respectively. The disparity in the morning and afternoon time periods occurs due to the fact that the sun rises in the morning, thus, there is not much heat in the surroundings till the sun reaches its apex.

4.1.2. 17th –May 2014:

The daily ambient maximum temperature was 29ºC whereas the minimum recorded temperature was 21ºC.

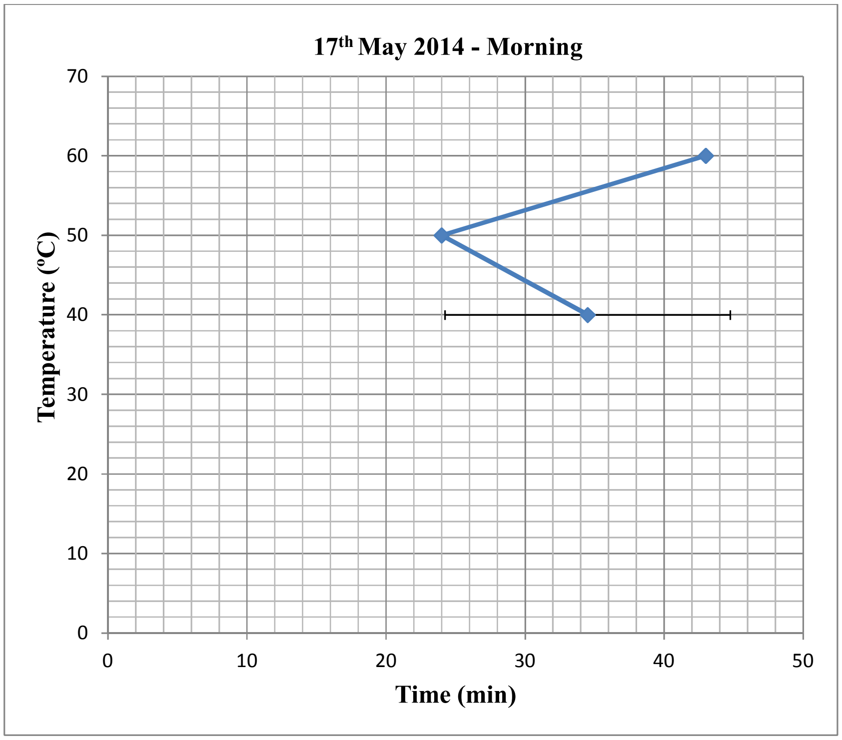

Figure 4.3: 17th May Readings

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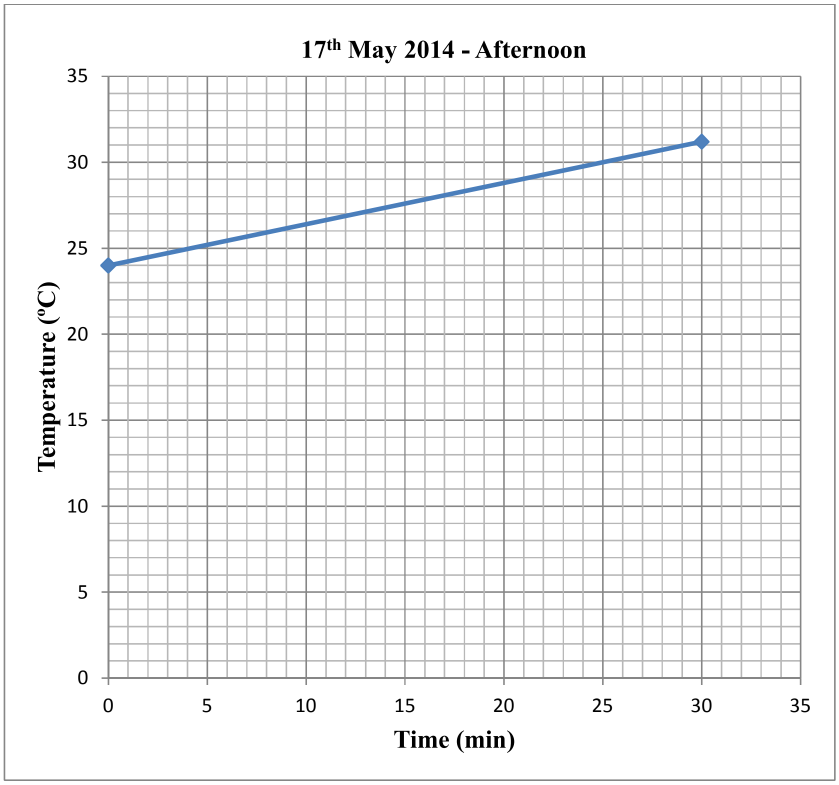

Figure 4.4: 17th May Readings

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During the morning and evening, the water took an average of half an hour to warm up to a mere 40º C. The reason behind this is that the ambient air temperature of 17th May (29ºC) was lower than that of 16th May (34ºC) thus, resulting in a longer time period. A relatively higher wind speed and cloud cover on 17th May accounted for the longer time period.

4.1.3. 18th May 2014:

The daily ambient maximum temperature was 26ºC whereas the minimum recorded temperature was 19ºC.

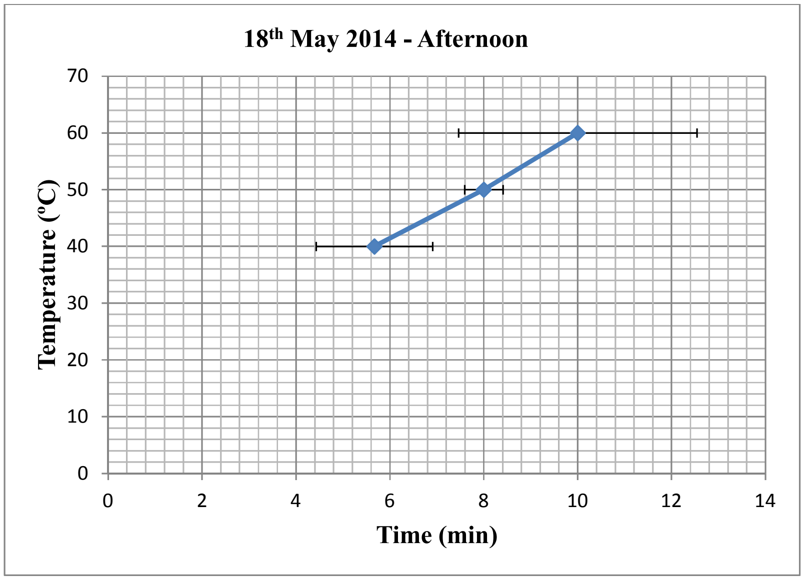

Figure 4.5: 18th May Readings

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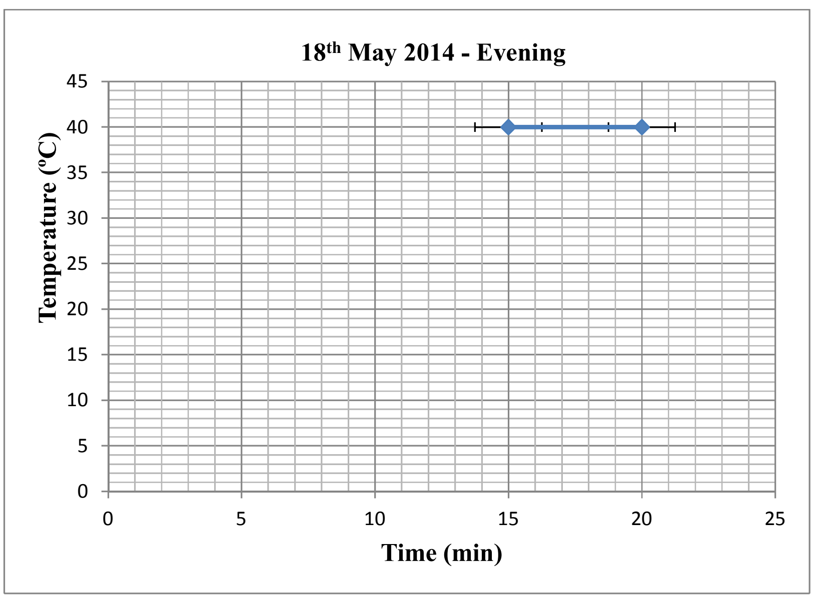

Figure 4.6: 18th May Readings

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An even lower temperature (26ºC) than 17th May (29ºC) and moderate wind speed (up to 10km/h) accounted for the further increase in time taken for the water to heat. The afternoon readings are better suited to the purpose of the solar water heater as compared to the evening readings. This is because the sun is at its peak during the afternoon while in the evening the heat begins to decline, resulting in an increase in the time taken for the water to heat; in this case fifteen to twenty minutes.

4.1.4. 19th May 2014:

The daily ambient maximum temperature was 32ºC whereas the minimum recorded temperature was 19ºC.

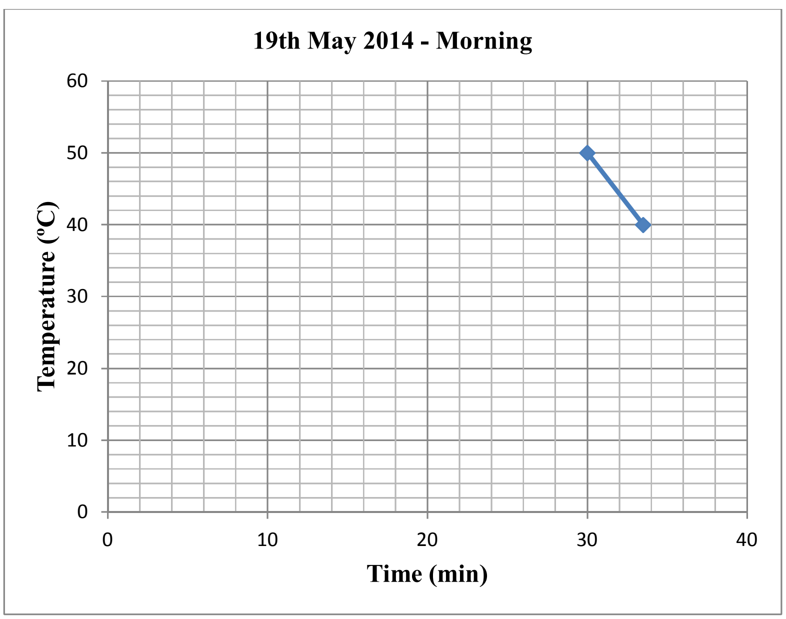

Figure 4.7: 19th May Readings

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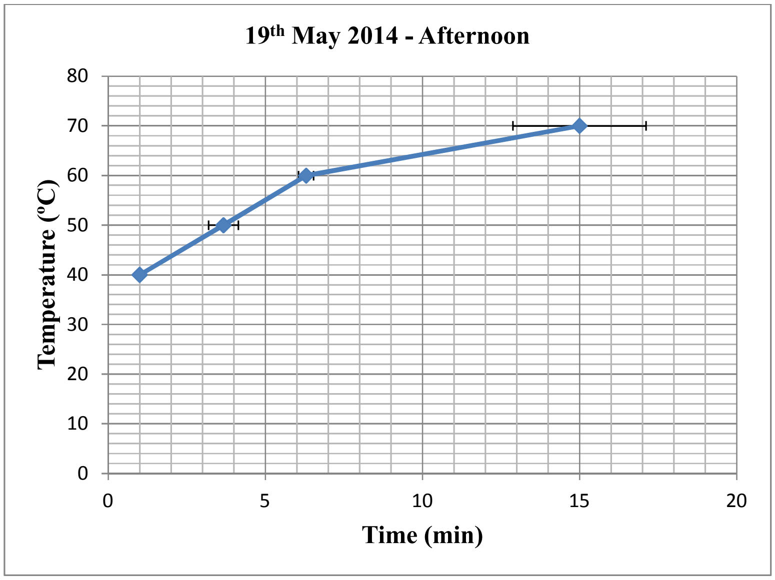

Figure 4.8: 19th May Readings

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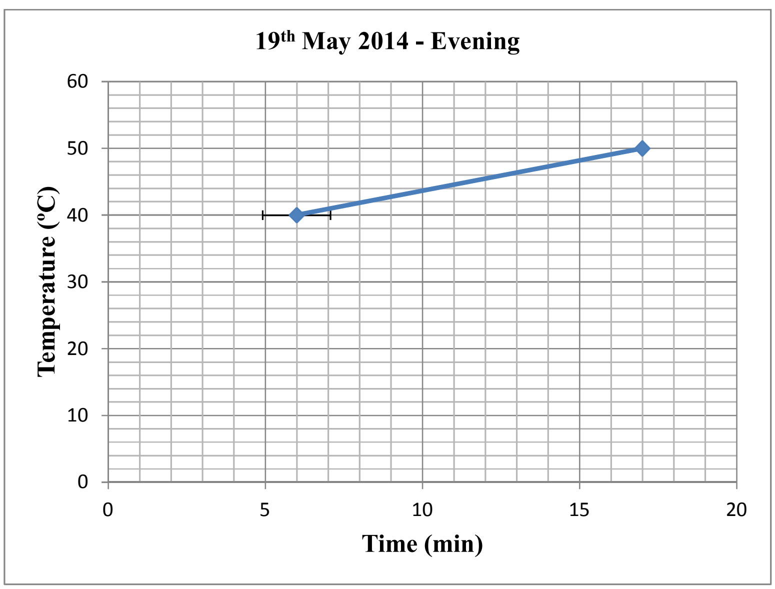

Figure 4.9: 19th May Readings

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Two readings were taken in the morning, for 30ºC and 50ºC and heated water was discharged after thirty-four and forty minutes respectively. As the sun rises, the heat in the surroundings progressively increases, thus, the time taken for the water to heat progressively decreases. Hence, as shown in the readings, it only ~~takes~~ took ~~the water~~ around six to seven minutes to heat the water from 30ºC to 50ºC. Since, 19th May was a relatively hot day with low wind speed (approximately 8 km/h) the same trend can be seen in the afternoon readings where the discharge water reached a temperature of 70ºC in fifteen minutes. The evening trend is also similar to the morning trend but as the sun starts to set, the heat intensity starts decreasing thus the time period increases. In this case, the increase in the time period is almost negligible and therefore can be ignored.

4.1.5. 20th May 2014:

The daily ambient maximum temperature was 34ºC whereas the minimum recorded temperature was 21ºC.

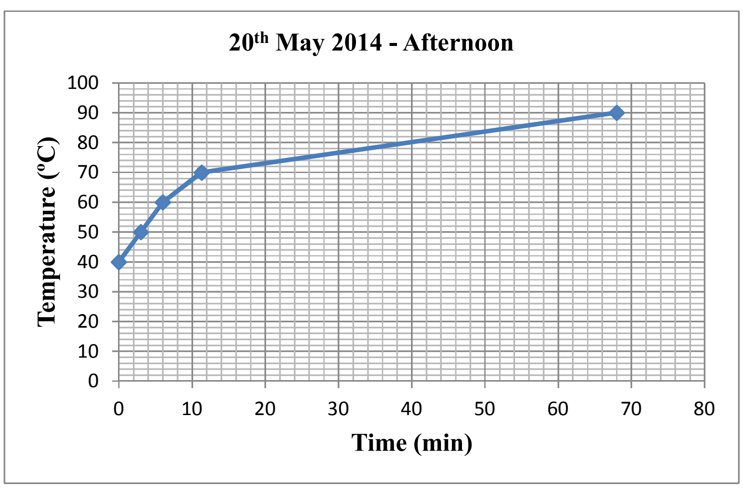

Figure 4.10: 20th May Readings

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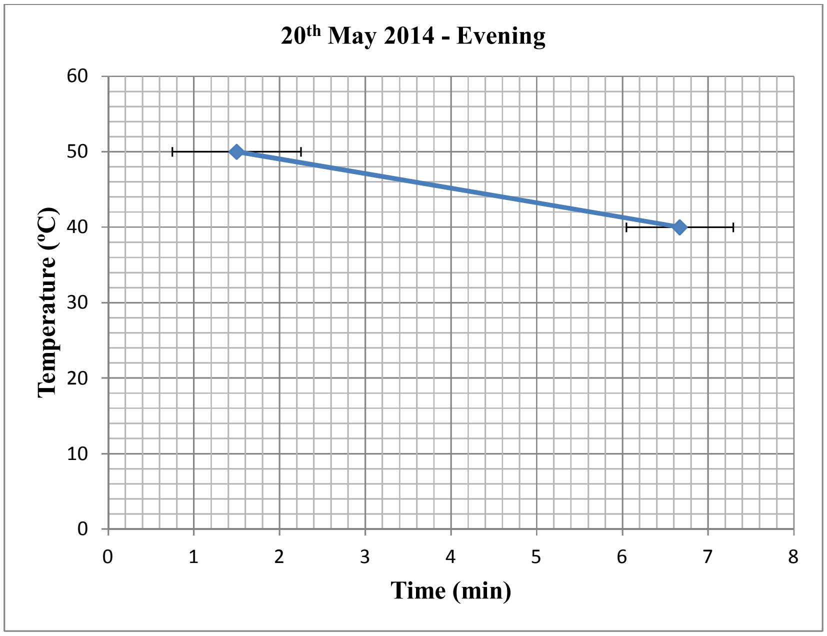

Figure 4.11: 20th May Readings

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The temperature of the discharge water crossed 90º C on 20th May during the afternoon readings. Even with an ambient temperature of 34º C, it took an average of sixty-eight minutes for the water to reach 90ºC. Other than this, the solar water heater was able to achieve temperatures up to 70 ºC within eleven minutes during the afternoon readings. The evening readings were taken for two temperatures, 40ºC and 50ºC, but as it is apparent in the graph above, there are some abnormalities which will be discussed in the next section.

4.2. Tabulated Summary of May 2014:

Given below are all the readings taken during the time period of 16th – 20th May 2014, while testing the prototype in its original condition:

Table 4.1: Summary of R~~r~~eadings T~~t~~aken with O~~o~~riginal P~~p~~rototype

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Date	**Time of Day**	**Ambient Temperature (ºC)**	**Temperature Reached (ºC)**	**Time Taken (min)**
16th May	Morning	34 – 19	40	7
			50	8.5
			60	7.5
	Afternoon		40	0.82
			50	2.5
			60	5.7
			70	10.5
17th May	Morning	29 – 21	40	34.5
			50	24
			60	43
	Afternoon		31.2	30
18th May	Afternoon	26 – 19	40	5.7
			50	8
			60	10
	Evening		40	17.5
19th May	Morning	32 – 19	40	33.5
			50	30
	Afternoon		40	1

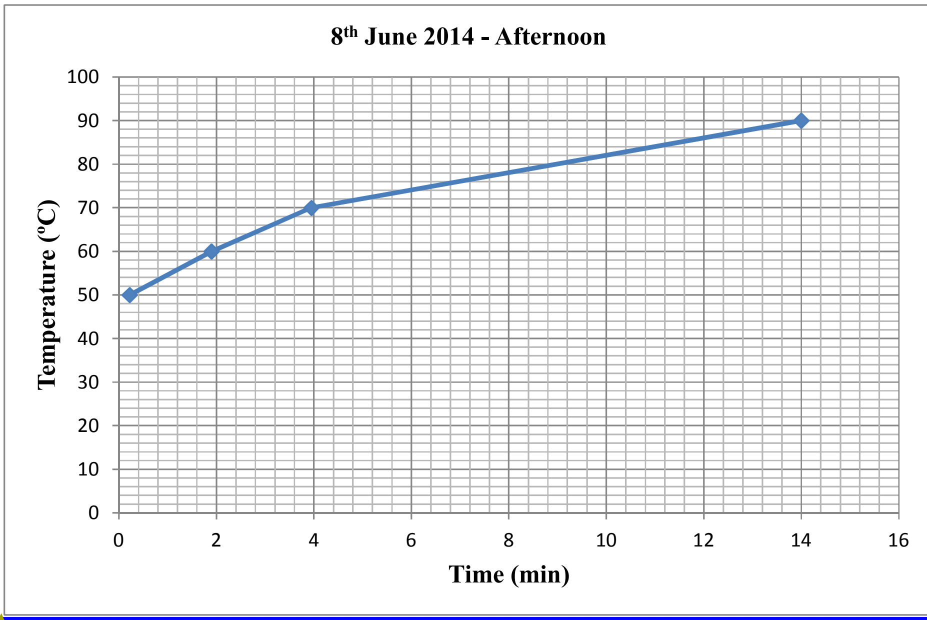
			50	3.7
			60	6.3
			70	15
	Evening		40	6
			50	17
20th May	Afternoon	34 – 21	40	0
			50	3
			60	6
			70	11.3
			90	68
	Evening		40	6.7
			50	1.5

~~**Table 4.1: Summary of readings taken with original prototype**~~

4.3. Daily Results with Black Paint:

4.3.1. 8th June 2014:

The daily ambient maximum temperature was 41ºC whereas the minimum recorded temperature was 26ºC.



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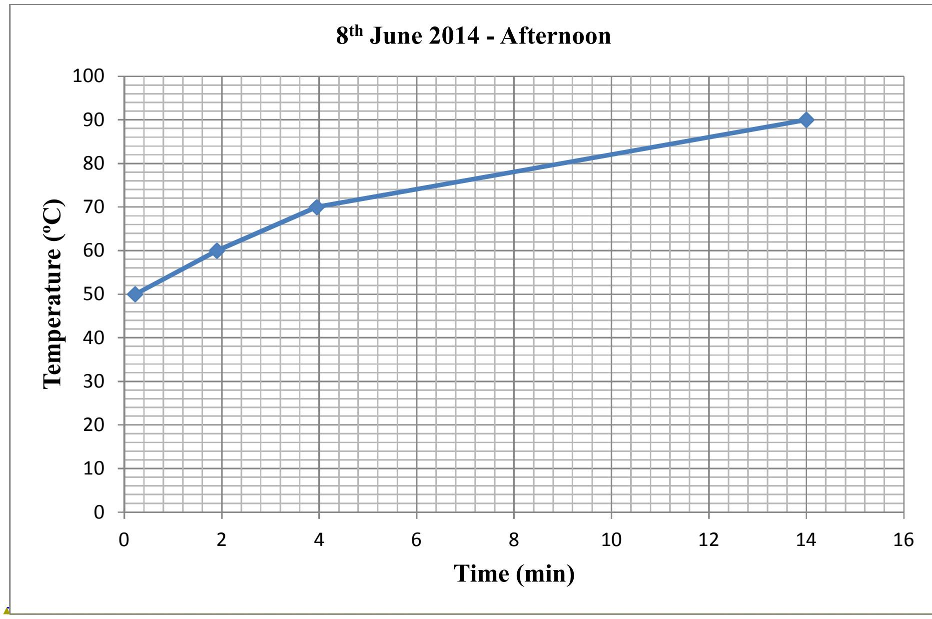

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Figure 4.12: 8th June Readings

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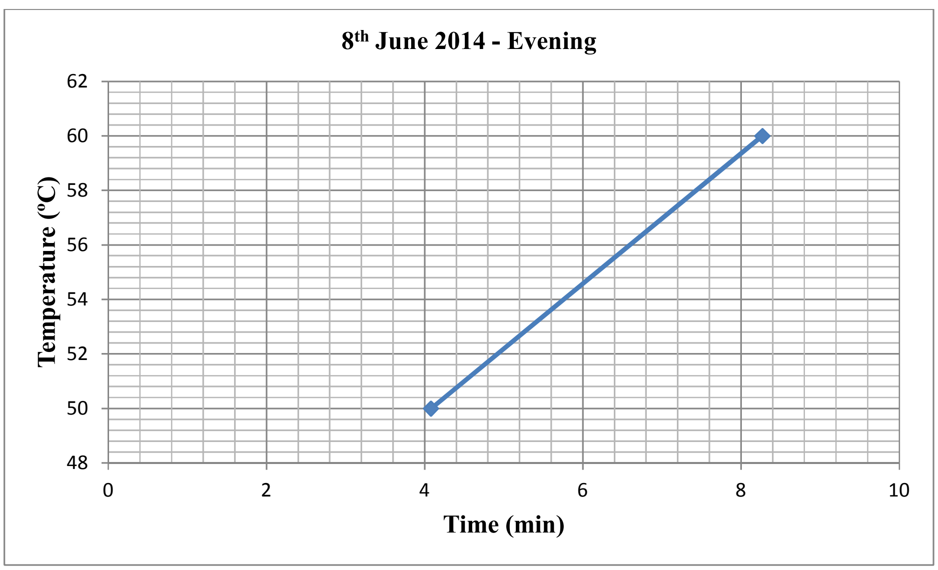

Figure 4.13: 8th June Readings

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As it is apparent from the graphs, the temperature of the discharge water crossed 60ºC in less than two minutes during the afternoon and in ~~a little over~~ eight minutes during the evening. By painting the equipment black, a temperature of 90ºC ~~can be~~was achieved within fourteen minutes even with the wind speed of around 15 km/h.

4.3.2. 9th June 2014:

The daily ambient maximum temperature was 41ºC whereas the minimum recorded temperature was 27ºC.

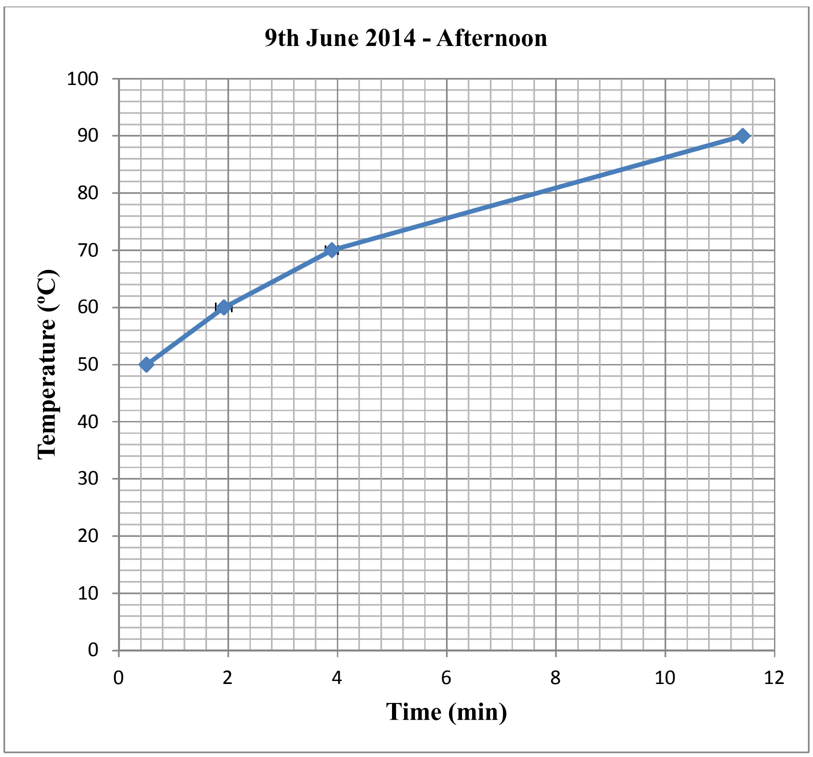

Figure 4.14: 9th June Readings

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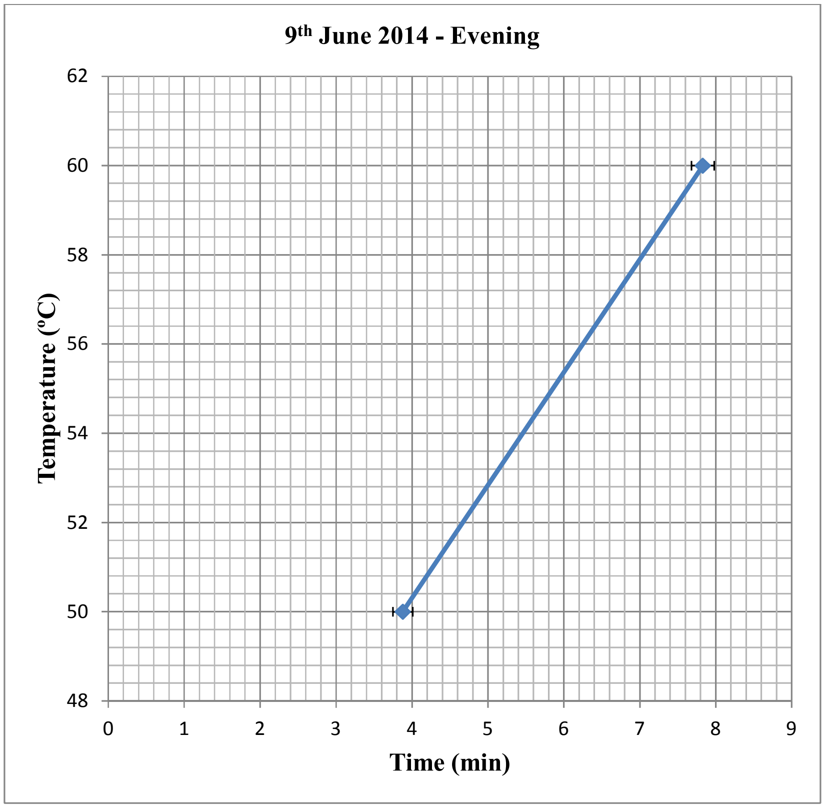

Figure 4.15: 9th June Readings

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The trend of the afternoon and evening graphs of 9th June is similar to those of 8th June.

4.3.3. 10th June 2014:

The daily ambient maximum temperature was 42ºC whereas the minimum recorded temperature was 26ºC.

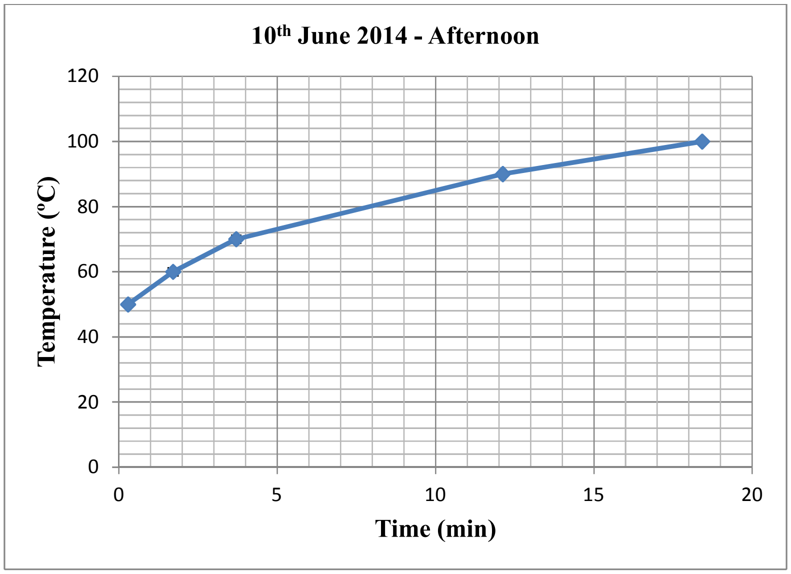

Figure 4.16: 10th June Readings

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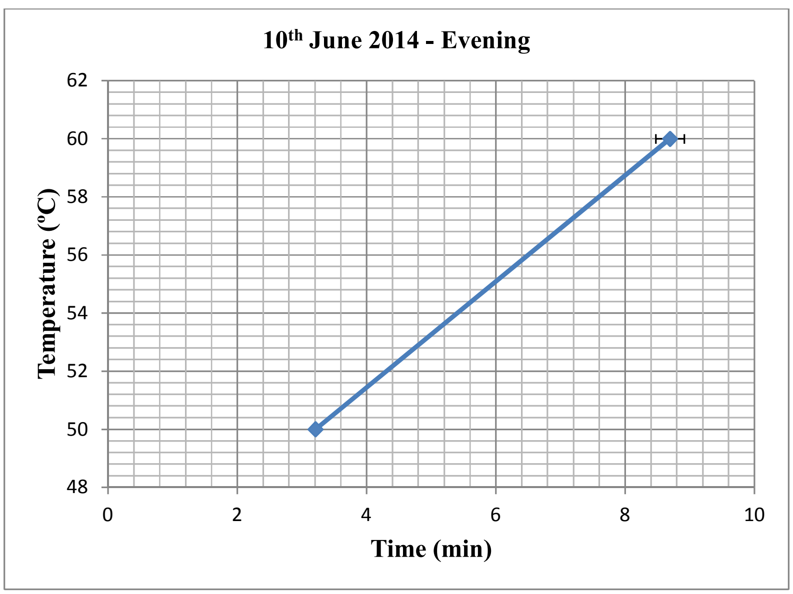

Figure 4.17: 10th June Readings

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The temperature of the discharge water almost instantaneously rises to 40ºC, even after flushing the solar water heater. The obvious reason for this instantaneous increase may be the high ambient temperature of 41ºC but comparing this to the earlier results of 17th May afternoon, it can be deduced that the black paint has increased the efficiency of the prototype.

4.4. Tabulated Summary of June 2014:

Given below are all the readings taken during the time period of 8 ~~16~~th – 10~~20~~th June~~May~~ 2014, while testing the prototype in its altered condition ~~original condition~~:

Table 4.2: Summary of R~~r~~eadings T~~t~~aken with B~~b~~lack P~~p~~aint

Date	Time of Day	Ambient Temperature (ºC)	Temperature Reached (ºC)	Time Taken (min)
8th June	Afternoon	41 – 26	50	0.2
			60	1.9
			70	4
			90	14
	Evening		50	4.1
			60	8.3
9th June	Afternoon	41 – 27	50	0.5
			60	1.9
			70	3.9
			90	11.4

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	Evening		50	3.9
			60	7.8
10th June	Afternoon	42 – 26	50	0.3
			60	1.7
			70	3.7
			90	12.1
			100	18.4
	Evening		50	3.2
			60	8.7

~~**Table 4.2: Summary of readings taken with black paint**~~

4.5.Average Results & Discussion:

The table below shows the average time taken for the prototype to heat the water to the specified temperature, with and without the black spray paint. The difference in percentage is also included in the table.

Table 4.3: Average Heating Ttime at Preset Temperature

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Temperature (°C)	Time Without Black Paint (min)	Time With Black Paint (min)	Difference (%)
40	12.5	-	-
50	10.9	2.03	81.4
60	13.08	5.05	61.4
70	12.27	3.87	68.5

90	68	12.5	81.6
100	-	18.4	-

~~**Table 4.3: Average time**~~

These averages have been calculated using the values obtained through experimentation (also mentioned in the previous ~~two~~ sections). The percentage difference between the time taken with black paint and without it ranges from 68 to 81%. This implies that the application of black paint reduces the time taken for the water to heat to a certain temperature by 68 to 81%. From the table above it is also apparent that the original condition of the prototype fails to reach even a temperature of 90ºC in less than an hour while the black paint allows the solar water heater to heat the water up to 100ºC within twenty minutes.

The anomaly seen in 20th May 2014 can be attributed to two reasons. The equipment is flushed with water before each experiment to cool the solar water heater to the ambient temperature. Thus, there is little to no residual heat left in the equipment. Furthermore, as the sun sets, its heat intensity decreases, increasing the time taken by the water to heat. This is why the water took more time to heat up to 40ºC.

The water took a mere three minutes to heat to 50ºC since the solar water heater was already heated till 40ºC. Thus, less heat is required to raise the temperature by 10 more degrees and consequently less time is taken by the water to reach 50ºC. The second reason can be due to human ~~errataerrata some temporary fault in the reading or a human~~ error during experimentation. The same reasons can be applied to the morning readings of 17th May.

5. Conclusion & Recommendations:

5.1. Conclusion:

This study can be concluded with the following remarks:

- The time taken for the water to heat up to a certain temperature depends on the daily ambient temperature and the weather conditions.
- The volume of water heated is also proportional to the daily ambient temperature. As higher ~~the~~ ambient temperature results in lesser time required for heating, and consequentially a larger volume of hot water can be generated in a smaller time period.
- The solar water heater can reach temperatures of up to 90ºC in its original condition as shown in the results.
- The application of black spray paint allows for better heat absorbance resulting in the reduction of time required for the water to heat.
- The solar water heater with improved design was able to cross temperatures of 100ºC within twenty minutes after the application of black paint. From this we can conclude that the prototype can be employed in the industrial sector as well.

5.2. Recommendations:

Some of the recommendations for future reference and use of this study are mentioned below:

- The electrically operated temperature valve can be attached to a small photovoltaic cell, so that electricity is not required by the solar water heater to work effectively.
- Further studies should be conducted to optimize the volume of the heated water. One such study to increase the capacity of the solar water heater can be to observe the effect of increasing the number of coils of the copper pipe.
- The shape of the glass cover can be changed from flat and square to parabolic.
- Fresnel lens can be used instead of simple convex lens.
- N-BK 7 plano-convex lenses (v coated, high power) can be used.
- An economical replacement of the wooden casing of the solar water heater.

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