FEASIBILITY STUDY ON SUBSTITUTING ELECTRIC WATER HEATERS WITH SOLAR WATER HEATERS IN GHANA; A CASE STUDY OF OFFICIAL RESIDENTIAL FACILITY OF GOLDFIELDS GHANA LIMITED, TARKWA MINE

By

YIRFA, Norbert Napari

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science degree in Renewable Energy Technologies at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana under the supervision of the undersigned.

All works consulted have been duly acknowledged in the references.

YIRFA, Norbert Napari	…………………………	……………………
(PG 6310411)	Signature	Date

Certified by

Prof F. K. Forson		
(Supervisor)	…………………………	……………………
(Dept. of Mech. Eng, KNUST)	Signature	Date
Dr S. M. Sackey		
(Head of Department)	……………………………	………………………
(Dept. of Mech. Eng, KNUST)	Signature	Date

ABSTRACT

Solar water heating is one of the cost-effective technologies in heating hot water for domestic (residential) use. In this thesis, with the aid of T-sol software, a solar water heater was sized and installed for domestic use at Apinto ridge, a residential area located at Goldfields Ghana Limited, Tarkwa Mine. Currently, it cost Goldfields Ghana Limited about GH¢ 0.27/kWh (about US$ 0.14 kWh) of electricity used because the company falls under the tariff customer group of SLT-HV for Mines [1]. At Goldfields Ghana Ltd, a typical residential facility has two 2- kW electric heaters installed, one with 70-litre storage tank for the kitchen and the other with 80-litre storage tank for the bath house. The average hot water consumption is estimated to be about 80 litres per day. With the 600 housing units of the company, it costs Goldfields Ghana limited GH¢ 324.00 per day for electricity (1.2 MWh) used in heating water only for domestic purposes (for cooking, bathing, washing dishes etc).

Prior to the design of the proposed solar water heating system, two field visits were embarked upon to ascertain among others the thermal performance of the field installations of two distinct collectors; a flat plate and an evacuated tube collector. It was observed that the type of collector did not really matter in Ghana, once the proper sizing and installation were carried out. This was no different from the simulation results of performance analysis carried out using the T-sol software. Following from these, an evacuated tube water heater was installed for one household, since that unit design is what is readily available in the Ghanaian market. The performance of the installed solar water heater was monitored for a period of six months trial (38 Weeks). Data of temperatures compiled for 6am and 6pm for six months has shown that the project is viable considering the cloudy nature of the weather and also the frequent rainfalls there.

The total cost of the installation for a household of three persons was GH¢ 1400.00 and the average hot water temperatures were measured to be between 34°C and 59°C throughout the 38 weeks of the motoring of the installed system

Per the economic analysis carried out, the associated electricity bill currently for a month for the electric waters installed in the 600 housing units stands at GH¢ 9396.00. The amount spent on electricity bill on water heating in only a month can purchase seven 100-litre evacuated tube solar water heaters.

This project can be considered to be feasible and cost effective based on the thermal performance and economic analysis of the installed water heater.

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ACRONYMS

SWHs: Solar Water Heater/Heating Systems

ETC: Evacuated tube collectors

FPC: Flat Plate Collectors

EWH: Electric Water Heater/Heating Systems

GFGL: Goldfields Ghana Limited

DHW: Daily Hot Water

PURC: Public Utilities Regulatory Commission.

NOMENCLATURE

			Units
1.	A_C	Collector area	m^2
2	S	Absorber incident solar irradiance	W/m^2
3	T_{abs}	Temperature of absorber	^oC
4	T_{amb}	Ambient Temperature	^oC
5	T_i	Inlet Temperature	^oC
6	T_o	Outlet Temperature	^oC
7	$\dot{m}$	Supply water flow rate	Kg/s
8	F_R	Collector heat removal factor	dimensionless
9	τ	Transmittance of glass cover	dimensionless
10	L_w	Hot water Load	W
11	α	Absorptance of the absorber	dimensionless
11	U_L	Overall heat loss coefficient	W/m^2K

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Above all I say to God be the glory!

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

Reliable energy is arguably one of the major challenges the world faces today, touching all aspects of our lives. For those living in extreme poverty (Sub- Saharan Africa), lack of access to modern energy services dramatically affects health and limits opportunities (investors). The vulnerability of the poor is worsened with recent challenges from climate change, increasing population and volatile energy prices. There is the need to meet the most basic energy needs of the poor especially heat for cooking and mechanical power. Also improved household energy technologies for the poor can prevent the almost 2 million deaths a year attributable to indoor air pollution from solid fuel use [2]. Heating water dominates the energy needs of households worldwide. For households in developing nations, heating water is often the most energy intensive process and therefore the most expensive or time-intensive house chores. In communities throughout the developing world, poor households struggle to meet their hot water needs. Some households rely on biomass to heat water. In many countries, demand for wood fuel is one of the principal contributors to deforestation. Others rely on electricity or liquid fuels such as propane to heat their water. These fuels options are unsustainable as they are costly to households and contribute to the buildup of greenhouse gases in the atmosphere. Many communities face limited or intermittent access to fuel and or electricity, limiting their ability to access hot water for hygienic and domestic use [3]. One potential solution to this problem is the use of solar energy to heat water. Solar water heaters are environmentally friendly technologies which can be a supplement to the rising energy demand and can offset dependency on biomass and other sources of fuel for water heating if adopted on a large scale.

Solar water heating technology is used in many parts of the world including the U.S., China, India, and the Middle East. Most hotels and well to do residential facilities (Goldfields Ghana, Tarkwa Mine's residential facilities) in Ghana use electric water heaters to meet their hot water needs. Usage of these electric water heaters increases pressure on the already overburdened national Grid. The solar energy potential in Ghana is not put to adequate use. Solar radiation and sunshine duration data have been collected by the Ghana Meteorological Services Agency (MSA) for over 50 years. The daily irradiation data has a probable error of 15%. Currently, the Mechanical Engineering Department at Kwame Nkrumah University of Science and Technology (KNUST) is measuring hourly global and diffuse irradiance using standard instruments that have a probable error of 5%. The average duration of sunshine varies from a minimum of 5.3 hours per day at Kumasi, which is in the cloudy semi-deciduous forest region, to 7.7 hours per day at Wa, which is in the dry savannah region. The monthly average solar irradiation in different parts of the country ranges between 4.4 and 5.6 $kWh/m^2/day$ [4].

This project seeks to assess the possibility of substituting electrical water heaters used in Ghana with solar water heaters and the associated cost benefits of using solar water heaters.

1.2 Benefits of Solar Water Heating

Three broad benefits namely socio-economic benefit, energy savings benefit and environmental benefits are discussed in this section.

1. Socio-economics

Domestic hot water is a basic house hold requirement. The use of solar water heaters (SWHs) can contribute to the socio-economics of our Ghanaian economy immensely in the following ways:

- Reduction in expenditure of households on energy, as a result of savings can be are made.
- Increase in job creation, since there will be the need to manufacture, sell, install and maintain SWHs.
- Reduction in the use of charcoal, coal, wood or kerosene stoves etc to reduce air pollution, thereby improving on the health of the community.

2. Energy savings

The use of SWHs will help reduce domestic demand of power from the national grid. This will as a result decrease the peak power demands (in the mornings and evenings) during which times water heaters are often used. Importation of crude oil or fuel will be reduced, since the demand for LPG, kerosene, etc. to heat water will be minimised as a result of the use of SWHs.

3. Environmental Benefits

Burning of fossil fuels produces greenhouse gases which are harmful to the atmosphere and also causes global warning.

The use of SWHs will impact positively on the environment and green house gas emission will be reduced as a result of a reduction in the use of electricity where applicable, or charcoal, or wood as fuel.

1.3 Problem Statement

In Ghana, electricity consumption has been growing at 10 to 15 percent per annum for the last two decades [5]. It is projected that the average demand growth over the next decade will be about six percent per year. The projected electricity growth has profound economic, financial, social and environmental implications for the country [5]. Developing Countries aspiring for higher living standards can only be satisfied through sustained development of their electric power markets as part of their basic infrastructure. Electricity demand will grow much faster than overall economic growth (4-5 percent per year) or than population growth (which is less than two percent a year) because continuing urbanisation will allow newly urbanised segments of the population to expand their electricity consumption [5]. Installed power capacity of the country increased from about 1,860 Megawatt (MW) in early 2010 to 2,185.5 MW, i.e. about 17.5% growth by December 2010. [4]

In 2011, it was projected under Strategic National Energy Plan (SNEP) that the total electricity generation required for the country would be 13,300-14,488 GWh with a corresponding maximum peak (including suppressed demand) between 1,787-2,207 MW. However, this is not attainable considering the limited installed grid power capacity in the country and also lack of significant potential import. The available demand capacity and the expected generation in 2011 was estimated at 1,865 MW and 14,051.5 GWh, respectively [4].

The use of solar water heaters in place of electric water heaters will go a long way to decrease the demand on the already scarce electricity. Also the power used by the electrical water heaters(EWHs) can be channeled for use in other projects such as rural electrification.

Many households could reduce their fuel costs by eliminating or reducing their need for wood, gas or electricity to heat water. Substituting traditional fuel sources with solar energy would reduce carbon emissions. For instance Shangri-La Hotel in Ghana which is a 100 bed-capacity hotel with kitchen and laundry has installed a micro chip controlled solar water heating system that grants 100 % hot water supply throughout the year even during cloudy and rainy days. The system guarantees a 7,500 litre-water capacity with hot water temperatures of 85°C. The substitution of the 100 kW conventional electric water heaters allows the hotel to cut down its electricity bills by 40-45 % a year [6]. This success story points to the fact that solar water heaters are the best option to heating water in Ghana than any other means.

For instance in the case of the residential facilities at Goldfields Ghana, Tarkwa Mine, the use of solar water heaters in place of the electric water heaters currently in use will go a long to reduce their electricity bills.

In Ghana, it costs about GH¢ 0.27/kWh (about US$ 0.14kWh) of electricity for Goldfields Ghana Limited which falls under the tariff customer group of SLT-HV Mines [1]. At Goldfields Ghana Ltd, a typical residential facility has two, 2- kW electric heaters installed, one with 70-litre storage tank for the kitchen and the other with 80-litre storage tank for the bath house. The average hot water consumption at Tarkwa Goldfields residential facilities is estimated (from data collected from the 600 housing units) to be about 80 litres per day. This required hot water is (water) heated from ambient temperature of about 24 ^{o}C to about 40 ^{o}C over a period of one hour daily.

From unit cost of electricity, with the 600 housing units of the company, it would costs Goldfields Ghana limited GH¢ 324.00 per day for electricity (1.2 MWh) used in heating water only for domestic purposes (for cooking, bathing, washing dishes etc).

It is indeed during peak times of the day (mornings and evenings) when power demand on the national grid is highest that EWHs are used in GFGL residential facilities. If this daily energy demand of 1.2 MWh for water heating is catered for by SWHs, then the pressure on the national grid during peak times could be minimised.

The sub-Saharan African region where Ghana falls under is endowed with a lot of solar resources and unfortunately not much of it has been utlised very well. One opportunity to make good use of these resources is by replacing currently installed EWHs with SWHs.

1.4 Objectives

The main objective of this thesis is to conduct a feasibility study on substituting electric water heaters with solar water heaters in Ghana with Goldfields Ghana, Tarkwa mine's official residential facility as a case study.

The specific objectives are as follows:

i. To undertake a survey to obtain the average hot water needs of household assigned for this project.

ii. Size and select a solar water heating system suitable for the hot water needs of the household

iii. Install one water heater and monitor its performance

iv. Do a cost benefit analysis on the solar water heater selected and its economic implications.

1.5 Methodology

The methods that will be employed to execute this project will be as follows.

1. Review of literature on works that have been carried out, the areas of interest include;
    i. Existing and working solar water heating systems in Ghana.
    ii. the energy situation in the country
    iii. Relationship between the sun's radiation and heat generation. Sources of information will include; KNUST library, UMAT library, internet etc.

2. Conduct load assessment on household assigned to get daily hot water needs. Goldfields Ghana, Tarkwa Mine will be the catchment area for the assessment with the help of Electricity Company of Ghana on current tariffs and billing system.
3. Select and size an appropriate solar water heating system to suit the hot water needs of the household. This will be done using T-sol software.
4. Based on sizing, a SWH will be installed and its performance monitored over a period of six months.
5. Do a comparative cost analysis on the benefits of using solar water heaters over electric water, using current utility tariff (electricity bill) from Public Utilities Regulatory Commission (PURC).

1.6 Thesis Organisation

The thesis is in five chapters. Chapter 1 introduces the thesis topic; these include the background of the project, benefits of water SWHs, problem statement, objective of project and methods to achieve the desired objectives.

Chapter two reviews existing literature on SWHs. In the literature review, the various components of SWHs and their functions are reviewed. Relationship between the sun's radiation and heat generation are also reviewed.

Chapter three discusses the sampling of hot requirements of a selected house type at GFGL residential facility. The Sizing and selection process of the SWH installed are also discussed in chapter three. This topic is a continuation of the work done by Kaunda in 2005 and Amoabeng in 2012. They both ended at the sizing stage and used software simulation to obtain their results. This project goes a step further to install one SWH and compare the actual results with computer aided simulations. These are discussed in chapter four.

Chapter four discusses the test set-up and results obtained from the SWH installed.

In chapter five of the thesis, the conclusions and recommendations resulting from the study are presented.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Solar thermal and other technologies are renewable because they have the sun as source of energy. It is believed that the sun will continue to shine brightly for another 5 billion years with its life expectancy being approximately 10 billion years [7]. The sun is believed to be a ball formed of very hot gases, of which 98% are hydrogen and helium. The diameter is 1.39 million km. That is 109 times larger than the earth diameter. [7]

Inside the sun nuclear fusions takes place constantly, in which hydrogen atoms merges into helium and a part of the mass is converted into energy. This energy leads to very high temperature up to 15 - 20 million Kelvin in the center. On the surface, the temperature is approximately 5770 K [7]. The energy radiated by the sun in all directions is about 8,000 to 10,000 times the current energy needs on earth [7]. This implies that the energy from sun is being underutilised and also should be enough to meet all our energy needs on earth. The radiations from the sun can be grouped into three components; direct, diffused and reflected radiations, as shown in figure 2.1

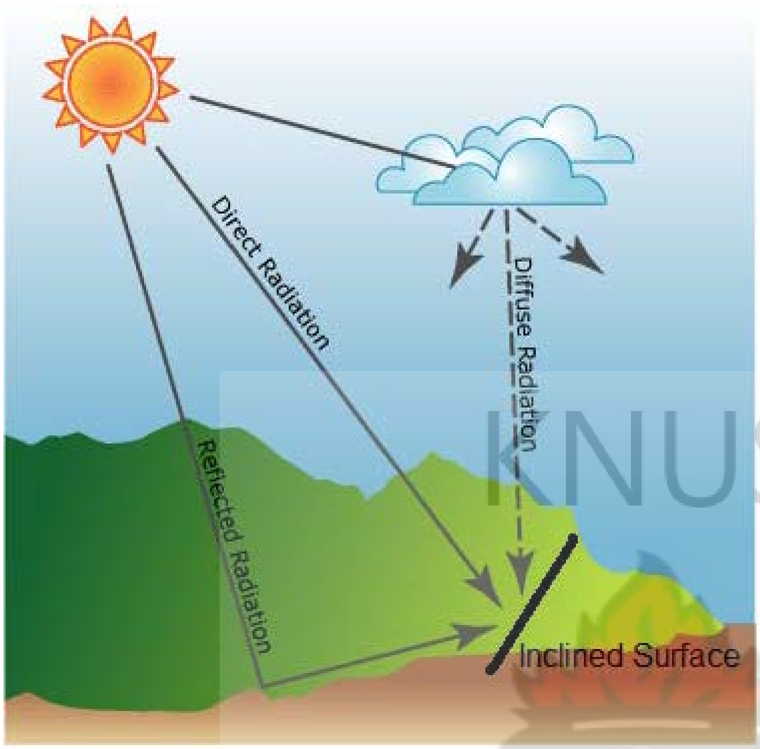

Figure 2.1 Components of radiations. Source [7] Yao and Ramde.

Direct solar radiations are radiations received from the sun directly without been scattered by the Atmosphere. As the name implies diffuse solar radiations are radiations that are received from the sun after their route has been changed by the atmosphere through scattering. Diffuse radiation is often referred to as sky radiation. Reflected solar radiations are radiations received after they are reflected from the ground and from the environment. This radiation is zero for a horizontal surface.

Solar water heater uses energy from the sun to heat water. A solar water heater works basically by absorbing radiation from the sun and converting it to heat energy to heat water for domestic or commercial use. A solar water heater comprises three main parts: the collector, the storage tank, and the heat transfer fluid. The various components will be briefly discussed.

2.2 Solar collector

A solar collector is used for heating up a heat distribution medium (e.g. water) by absorbing solar radiations from the sun. The solar radiation passes through a glass and then hit the absorber and is absorbed by the absorber. There is a subsequent transfer of energy from the absorber to distribution medium. The distribution medium flows through the absorber and transports the heat energy from the collector to storage. Solar collectors can be grouped into unglazed, glazed and evacuated tube collectors [8]. Figure 2.2 shows a typical structure of the collector.

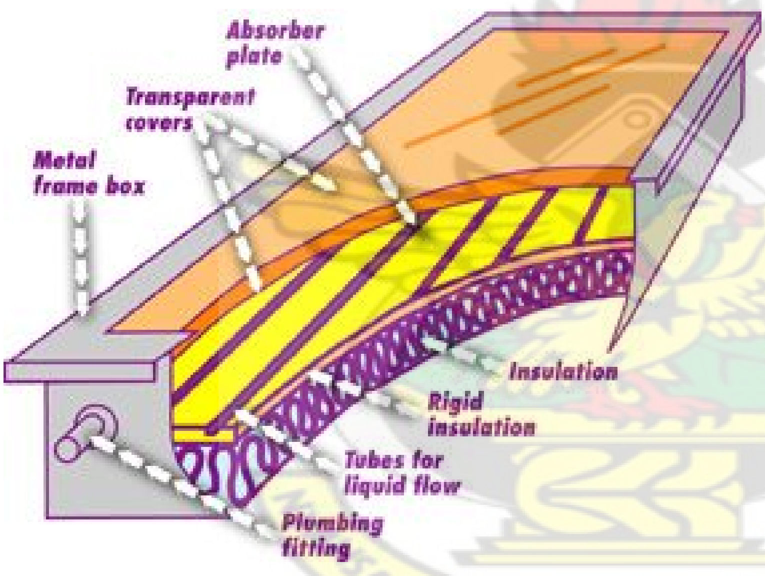

Figure 2.2 Structure of a solar collector, source [8] http://hydroponics.com.au/free-articles/issue-59-renewable-energy/

2.2.1 Unglazed collectors: These solar collectors consist of absorbers without the glass covering. They are not normally insulated; but best suited for low temperature applications. Because they are not insulated, a large portion of the heat absorbed is lost, particularly when it is windy and not warm outside .Unglazed collectors are used for heating outdoor swimming pools, pre-heating water for car washes, and heating water used in fish farming operations. They are relatively cheap, rugged, and lightweight. Unglazed collectors perform poorly during cold and windy days, because they are not thermally insulated [9]. Figure 2.3 shows an example of an unglazed collector.

2.2.2 Glazed collectors: These are collectors which operate based on the greenhouse effect principle. The energy emitted by the sun is in the form of radiation whose wavelength corresponds to the visible light. The material (glass or plastics) used in glazed collectors is transparent to this range of wavelength. . Glazed collectors are opaque to radiations and retain most of the infrared radiant energy which the absorber absorbs during its heating process. As a result the heat released by the absorber remains confined within the collector. Glazed collectors are designed to operate at much higher temperatures and cost much more per square foot than unglazed collectors. Glazed collectors are used in water heating, building heating as well as indoor swimming pool heating. [10] An example of a glazed collector is shown in figure 2.4 below.

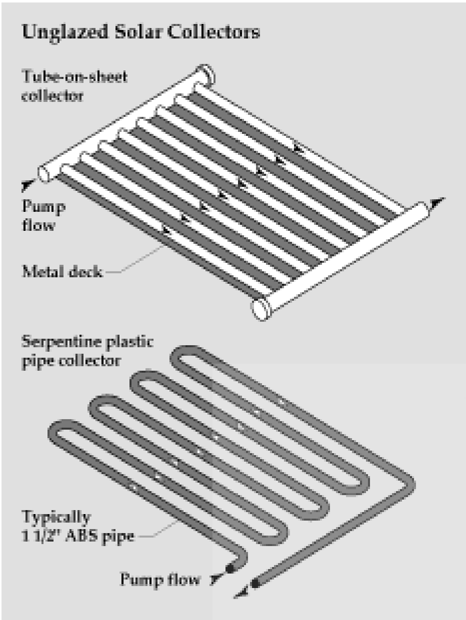

Figure 2.3 Unglazed solar collectors. Source: [9] http://www.house-energy.com/Solar/Collector-Type-Use.htm

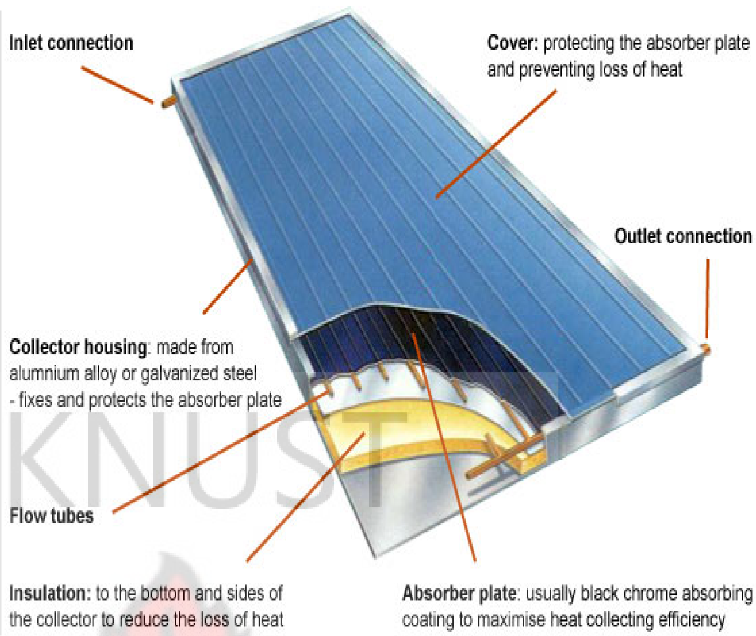

Figure 2.4 Glazed solar collector. Source [9] http://www.house-energy.com/Solar/Collector-Type-Use.htm guidance/

2.2.3 Evacuated tube collectors: The evacuated tube collector is the most efficient and expensive among the three types of solar collectors. Evacuated tube collectors are made from transparent glass tubes consisting of a glass outer tube and an inner tube or absorber. The inner tube or absorber is covered with a selective coating that absorbs solar energy but does not allow heat loss. The air is withdrawn (evacuated) from the space between the tubes to form a vacuum, which eliminates conductive and convective heat losses. The absorber of the evacuated tube collector contains a working fluid in it which receives the heat absorber. The hot working fluid then flows to heat water for domestic and other uses. Applications of vacuum collectors are similar to the glazed collectors which include water heating, building heating as well as indoor swimming pool heating [10]. Figure 2.5 gives an illustration of how the evacuated tube collectors operate.

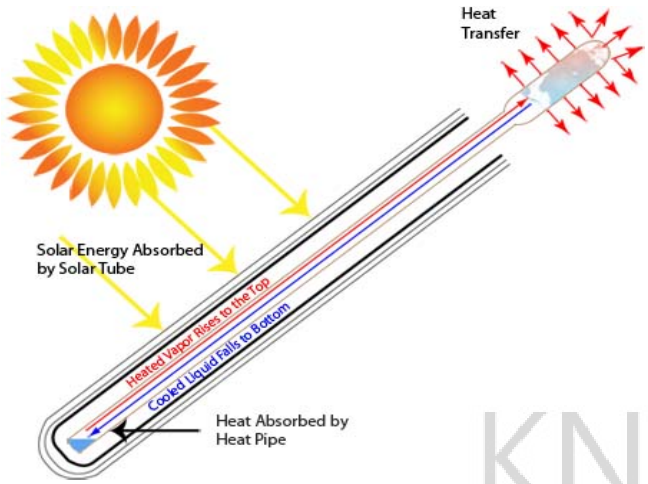

Figure 2.5 Evacuated tube collectors. Source [10]; http://www.solarpanelsplus.com/evacuated-tube-collectors/

Under steady-state conditions, the useful energy (heat) delivered by a flat-plate solar collector is expressed as;

$$\dot{Q}_U = A_c I - A_c K_i \left(T_{abs} - T_{amb}\right) = \dot{m} C_p \left(T_o - T_i\right) \qquad 2.1$$

Where $\dot{Q}_U$ is the useful energy absorbed in W, I is the absorbed incident solar irradiance in W/m^2, A_c is the collector area in m^2 , T_{abs} and T_{amb} are absorber temperature and ambient temperature, respectively in ^oC. K_l is the overall heat loss coefficient in W/m^2.K, T_o and T_i is outlet and inlet temperature of fluid (water) in ^oC, C_p is the specific heat capacity of fluid in kJ/KgK.[11]

Solar collectors mainly consists four components; an absorber, insulation to reduce thermal losses, Transparent material and a piping system for working fluid.

- ❖ The absorber

An absorber converts radiations from sun into heat energy. A good absorber must have a high thermal conductivity, adequate mechanical properties and good resistance to corrosion. They are often made up of copper, steel or thermoplastic.

❖ Working fluid piping

Piping enhances flow of the fluid through the collector. The length of the pipe determines the amount of heat loss. The longer the pipe the more heat is lost and vice versa.

❖ Transparent material (Glazing material)

It is generally made up of toughened glass (or plastic), very resistant to thermal losses, non-degradable. It performs three functions:

1. Transmission of the maximum of solar energy to the absorber;
2. Prevention of convective and radiative thermal losses from the absorber;
3. It prevents the absorber from direct exposure to bad weather.

❖ insulation

Insulation materials are used to prevent heat losses in pipes, the storage tank etc. Materials used for insulation must have the following properties:

I. Low thermal conductivity
II. Be stable at high temperatures (up to 200 °C);
III. Not emit gases at temperatures up to 200 °C;
IV. Must be anti-corrosive.

2.3 Storage tank

Storage tank for hot water must be able to store energy for long period in order to ensure supply of hot water during low or no solar radiation time. Therefore, the storage tank needs a large volume, a stable temperature and a good insulation. Inflow of the cold water should be situated at the bottom of the tank and outflow of the hot water at the top of the tank. These prevent the cold water from mixing with the hot. As a result of density difference the hot water will remain at the top since it is less dense and vice versa.

2.4 Solar fraction

Solar fraction is defined as the ratio of the amount of input energy contributed by a solar energy system to the total input energy required for a specific application [12]. The performance of a SWH system may be defined by its solar fraction or the fraction of a building's water heating energy demand met by the SWH system. A system with a 60 % solar fraction reduces the water heating demand (and also the water heating energy costs) by 60 % [13].

2.5 Previous work done on solar water heaters at KNUST

Most recent works carried out at the mechanical engineering department KNUST are those of Kaunda in 2005 and Amoabeng in 2012.

Kaunda in 2005 dealt with a computer aided design of a solar water heater system based on heat load, weather conditions and economic scenarios of a typical location, college of engineering guest house of Kwame Nkrumah University of Science and Technology. He employed math lab software to design and perform the system's thermal and economic performance.

TRNSYS software was also employed in Kaunda's work to stimulate dynamic performance of the designed system. The economics aspect of the work looked good, since total capital investment of system stood at 6733 US$ with a simple payback period of seven years.

Amoabeng with the aid of T*SOL® software assessed the prospects of installing solar water heating system for the KNUST hospital. The assessment was based on the thermal performance and economics of two distinct collector configurations; flat plate and evacuated tube collectors. With the economics aspects of the project, the total cost of investment after sizing stood at US$ 2700 with a project life span of 20 years and a simple payback period of 6 years.

2.6 Field visits

Two field visits were embarked upon to get acquainted to solar water heaters and also ascertain if the solar water heaters are able to meet their hot water needs throughout the year. The two places visited include; Anita hotel in Kumasi and Bui power authority at their project site in Bui.

At Anita hotel, ten 300 -litre flat plate water heaters are installed to supply hot water to the various rooms for their guests, the kitchen as well as the laundry. These heaters have been installed since the inception of the hotel in 2007, and they constantly get hot water supply through the year. Each 300-litre water heater comes with a 2.5 kW auxiliary electric heater. Figure 2.6 shown below are some installed flat collectors at Anita hotel. Average hot water Temperatures produced varies from 33^{o}C to 55^{o}C.

Figure 2.6 Flate plate collector water heaters installed at Anita Hotel in Kumasi,Ghana

At the project site of the Bui power Authority, fifty, 150-litre evacuated tube water heaters are installed for use at their residential facilities on site. Each water heater has a 2.0 kW auxiliary electric heater. These were installed to cut down total electricity demand, since they currently run on diesel generators.

Some of the staff in these residential facilities confirmed that the solar water heaters were able to meet their hot water needs. Figure 2.7 shows an evacuated tube collector installed at Bui power authority. The average hot water temperatures produced varies from 36^{o}C to 60^{o}C.

Figure 2.7 an installed evacuated tube solar water heater at Bui, Ghana

Based on the findings from the field visits, it can be deduced that the type of collector doesn't really matter. Once the correct sizing and installation are carried out.

CHAPTER THREE: SIZING OF PROPSED WATER SOLAR HEATING SYSTEM

3.1 INTRODUCTION

A questionnaire was administered to the people living in the designated house at GFGL residential apartment. The aim of the interview was to establish quantitatively the following information:

- The number of people in each household
- What they use the hot water for
- Desired temperature of hot water
- Daily amount of hot water required.

The project household is made up of four people, but only three out of the four persons in the household use hot water at temperatures of about 40 ^{o}C for bathing only. Daily amount of hot water required is 30 litres per person, making it a total of about 90 litres. To get the desired hot water temperature, water was heated and thermometer used to measure the temperature after each member felt the degree of hotness with their hand. The confirmed state of water requirement was established by measuring with a thermometer. Appendix B in this report contains sample questionnaire and completed ones by members of household.

3.2 Overview of T*SOL® Software

T*SOL® is a programme for the design and simulation of solar thermal systems including hot water preparation, space heating and swimming pool heating. The programme allows the planner to investigate the influence of individual system components on the operating behaviour of a solar thermal system. Simulation results can be evaluated in graphical or tabular format. Main features of the software are given below:

- Simulation of solar thermal systems supporting domestic hot water and space heating over any period of time up to one year
- Design of the system to reach specific targets
- Influence of partial shading by the horizon and other objects (buildings, trees etc)
- Graphic and tabular entry of shade values
- Design Assistant with automatic system optimisation
- Comprehensive component database
- Working on different of systems at the same time within a project is possible, making it easy to compare systems
- Domestic hot water consumption profiles included in the calculations
- Investigation of energy use, pollutant emissions and costs
- Calculation of standard evaluation values for solar thermal systems such as system efficiency, solar fraction etc
- Detailed presentation of results in reports and graphics
- Economic efficiency. [14].

3.3 SIZING AND SIMULATION OF SWH USING T*SOL®

In this thesis, simulation and analysis were done for a flat plate collector and an evacuated tube collector using the T*SOL® software. The performance of two different manufacturers (Wagner and Solahart) were also analysed. The sizing and simulation was done based on the weather data and information gathered from the household. This was necessary because the best performing, efficient and cost effective collectors were required.

The following parameters were required for the design using T*SOL® software;

i. Average daily hot water consumption
ii. Desired temperature of hot water
iii. Power rating of auxiliary heater.
iv. Supply water flow rate

Appendix A gives a systematic approach to the sizing of the water heater using T*SOL® software. The average daily hot water consumption (90l for three people) and the desired temperature of hot water (40 ^oC) were derived from the questionnaire administered (as shown in appendix B). The mass flow rate (0.032Kg/s) of the supply was also determined by measuring the time taken to fill a one litre container. In sizing the auxiliary electric heater, the total heat load required, L_w is given by; $L_w = \dot{m}C_p(T_f - T_i)$, where $\dot{m}$ is the mass flow rate of supply water, C_p is the specific heat capacity of the water, T_f and T_i are desired hot water temperature and supply water temperature respectively.

L_w= 0.032x4186 (40-25) Kg/sxJ/KgKxK

=2009.29W, ≈2kW

Tables 3.1 to 3.3 and figures 3.1 to 3.4 show the monthly thermal performance for both the evacuated tube and flat plate collectors. The aim of this simulation using T*SOL® software was to ascertain which collector would yield the best performance given the load and weather conditions in Tarkwa. This simulation was also to confirm if the make of the collector had an influence on performance, since the field visits of two existing installation pointed to the fact that the type of collector did not matter, once the correct sizing and installation were carried out. The information obtained from these graphs and tables include; electricity savings, CO_2 emissions avoided, solar fraction, efficiency of SWH. The results obtained as shown in figures 3.1 to 3.4 and tables 3.1 to 3.2 in graphical and tabular forms respectively were obtained after simulation using T*SOL® software and 2011 ground weather data from AngloGold Ashanti's weather station.

From figures 3.1, 3.2 and table 3.1, the total annual electricity savings stood at 1,649 and 2,462 kWh for the evacuated tube and flat plate collectors, respectively. During the year, the annual electricity projected to be used by the auxiliary heater stood at 360 and 0kWh for the evacuated tube and flat plate collectors, respectively. This implied that with a solarhart water heater, a plate collector will best serve the purpose of this project.

From figure 3.3-3.4 and table 3.2, the annual electricity savings stood at 2,957 and 2,880kWh for the evacuated tube and flat plate collectors respectively. The annual electricity projected to be used by the auxiliary heater stood at 3.4 and 25.6 kWh. Thereby making the evacuated tube collector with Wagner as the manufacturer the best for this project.

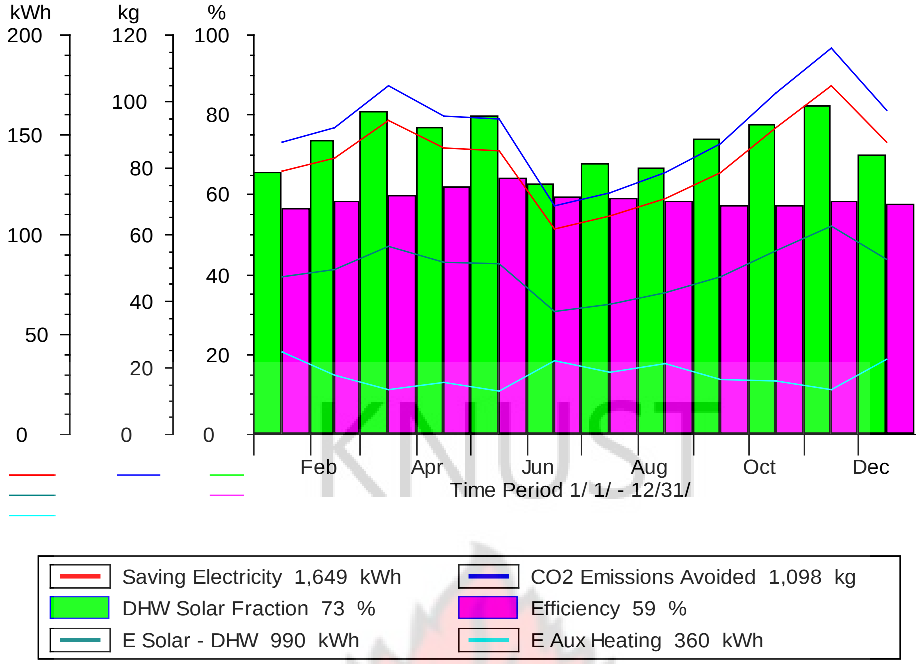

Figure 3.1 Average monthly thermal performance solahart ETC

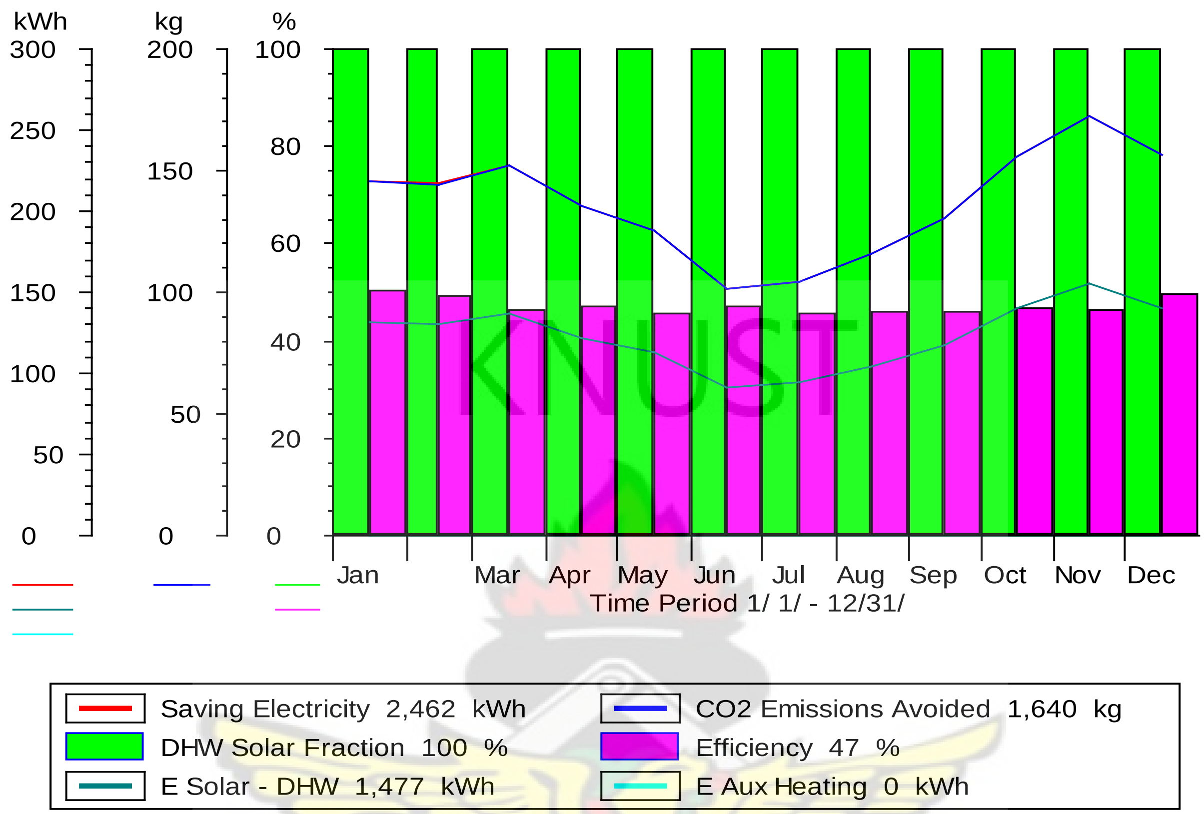

FIGURE 3.2 Average monthly thermal performance of a solahart FPC

Table 3.1 Comparison of performance of Solahart ETC and FPC

MONTH	Saving Electricity		CO2 Emissions Avoided		DHW Solar Fraction		Efficiency		E Solar - DHW		E Aux Heating	
	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC
	1,649 [kWh]	2,462 [kWh]	1,098 [kg]	1,640 [kg]	73 [%]	100 [%]	59 [%]	47 [%]	990 [kWh]	1,477 [kWh]	360 [kWh]	0 [kWh]
JAN	132	219	88	146	65	100	57	50	79	131	42	0
FEB	138	217	92	145	74	100	58	49	83	130	30	0
MAR	157	228	105	152	81	100	60	47	94	137	22	0
APR	144	203	96	135	77	100	62	47	86	122	26	0
MAY	142	188	95	125	80	100	64	46	85	113	22	0
JUN	103	152	69	101	63	100	59	47	62	91	37	0
JUL	109	157	73	104	68	100	59	46	66	94	31	0
AUG	118	174	79	116	67	100	58	46	71	104	35	0
SEP	131	196	87	131	74	100	57	46	79	118	28	0
OCT	154	234	102	156	78	100	57	47	92	140	27	0
NOV	174	259	116	173	82	100	58	46	105	156	23	0
DEC	146	235	97	156	70	100	57	50	88	141	38	0

Table 3.2 Comparison of performance of Wagner ETC and FPC

MONTH	Saving Electricity		CO_2 Emissions Avoided		DHW Solar Fraction		Efficiency		E Solar - DHW		E Aux Heating	
	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC
	2,957 [kWh]	2,880 [kWh]	1,938 [kg]	1,918 [kg]	100 [%]	99 [%]	4.4 [%]	12.8 [%]	1,746 [kWh]	1,728 [kWh]	3.40 [kWh]	25.6 [kWh]
JAN	263	256	175	171	100	98	5	14	158	154	0	4
FEB	240	244	160	162	100	100	4	13	144	146	0	0
MAR	252	257	168	171	100	100	4	12	151	154	0	0
APR	243	239	162	159	100	98	4	13	146	143	0	3
MAY	231	230	154	153	99	99	4	13	139	138	1	2
JUN	220	205	147	136	100	96	5	15	132	123	1	6
JUL	222	212	148	141	100	98	5	14	133	127	0	3
AUG	234	225	156	150	100	97	5	14	141	135	0	4
SEP	229	227	153	151	100	100	4	12	138	136	0	1
OCT	248	250	165	166	100	99	4	12	149	150	0	1
NOV	258	262	172	174	99	99	4	11	155	157	1	2
DEC	269	274	179	182	99	100	4	13	161	164	1	0

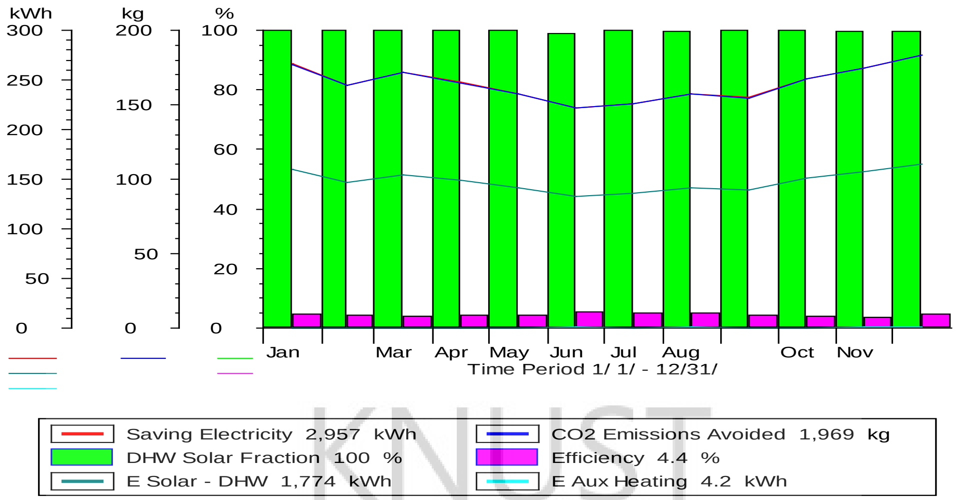

Figure 3.3 Average monthly thermal performance of a Wagner ETC

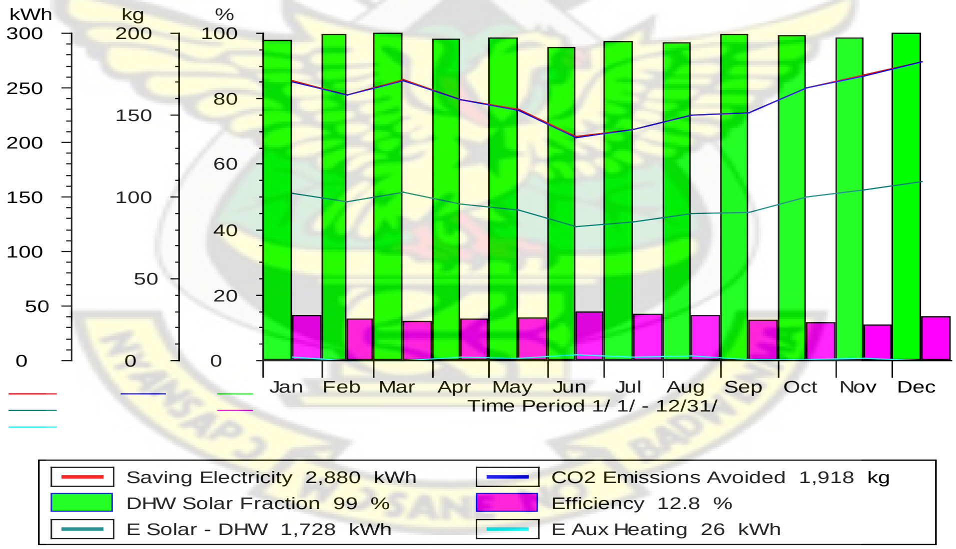

Figure 3.4 Average monthly thermal performance of a Wagner FPC

The weather data used in the thermal performance analysis with the aid of T*SOL® software is given in Table 3.3.

Table 3.3 Monthly Global Radiation and Temperature data for Tarkwa

MONTH	GLOBAL RADIATION/W/m^2	TEMPERATURE/°C
JANUARY	114	26
FEBRUARY	159	26
MARCH	152	26
APRIL	185	27
MAY	125	26
JUNE	135	26
JULY	85	24
AUGUST	120	24
SEPTEMBER	134	26
OCTOBER	89	25
NOVEMBER	158	35
DECEMBER	128	34

From the simulation results obtained in Tables 3.1 and 3.2, it can be concluded that either a flat plate or evacuated tube collector can be used for used for this project. The brand or make does not really matter, once the proper sizing and installation are carried out. This also confirms what was observed at the field visits, two different collectors installed at different locations, Bui and Kumasi. These SWHs installed at Bui power authority and Anita Hotel in Kumasi are able to meet hot water needs of their users throughout the year.

The evacuated tube collector was selected for the project and that was also readily available in the Ghanaian market. A solar-7 evacuated tube water heater was purchased and installed. The installation process will be discussed in chapter four.

CHAPTER FOUR: TEST SETUP, RESULTS AND DISCUSSION

Before installation, risk assessments were conducted around the proposed site for the installation. This became necessary to ensure that there were no accidents that lead to injuries before, during and after installation. The details of the assessment carried are presented in appendix C.

There was an existing electric water heater before this project, hence plumbing and electrical wiring installations were already in place. The only challenge was whether to assembly the solar water heater on the ground before mounting it on the roof or doing both assembling and mounting on the roof. In the end the SWH was assembled and mounted on the roof simultaneously, since lifting a completely assembled one turned out to be difficult.

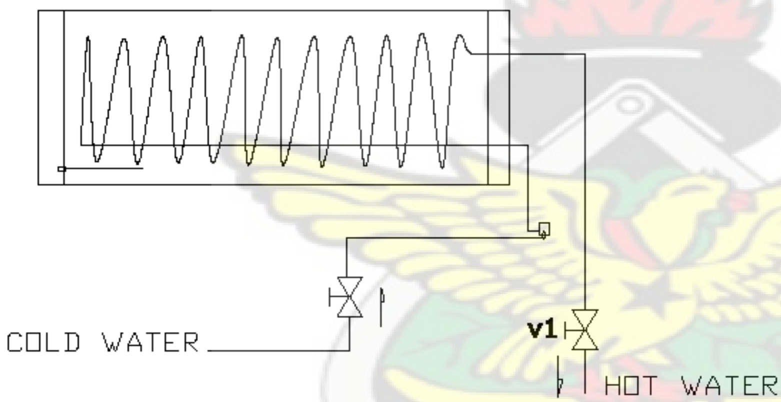

Figure 4.1 Water circuit Diagram

The task was to integrate the SWH to the existing plumbing that had being done for the electric heater. The water circuit diagram in figure 4.1 above shows how the integration was done. The cold line was connected to the inlet of the SWH and hot line that leads to the bath house was connected to the outlet of the SWH.

4.1 Water heater installation

The installation was done with the assistance from a team from the camp workshop of GFGL. The team comprised; carpenters, electricians, and plumbers.

The carpenters assisted in securing the frame (stand) for the SWH. Since the installation had to be one on the roof of the building, it was prudent to get on board a carpenter to bring his expertise to bear. Figure 4.2 (a&b) shows how the frame of the SWH was carpenters securing the frame on the roof. For firm gripping of the frame, the frames had to be reverted to wood which had to be secured to the ridges on the roof before other components were mounted on it.

a

Figure 4.2 b Carpenters securing the frame

The plumbing work was to integrate the inlet and outlet pipes to the existing piping system. Figure 4.3 (a&b) shows how plumbing works done and evacuated tubes being installed

a

Figure 4.3b Plumbers installing evacuated tubes and pipes

The evacuated tubes ten in number had to be installed one after the other. The tubes were installed after the frame and the hot water storage tank was installed.

The auxiliary electric heater required electric power from the mains; this was connected to the power source for the electric water installed in the building. Since the SWH was replacing the electric water. Other components that required electric power include the solenoid valve and the control unit to regulate water flow and for display of parameters (water level and temperature) respectively. Figure 4.4(a&b) shows the auxiliary heater and control unit being installed.

a

Figure 4.4b Installation of auxiliary heater and control unit

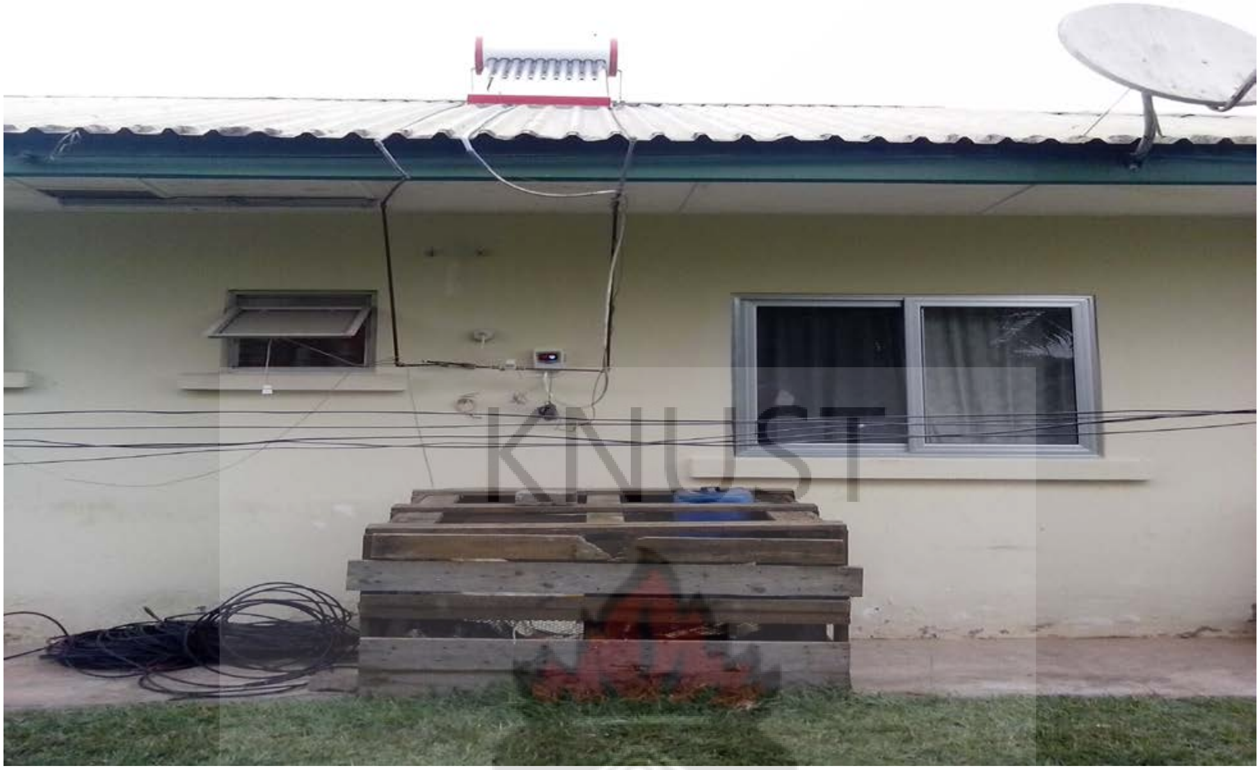

Figure 4.5 Picture of final installed SHW

Figure 4.5 shows the installed SWH ready for testing. There was a successful commissioning after installation to check for leakages and other defects. The monitoring of performance of the solar water heater was done by taking the temperatures of hot water at 06:00GMT and 18:00GMT daily. Table 4.1 gives a detailed cost of the installed SWH.

Table 4.1 Detailed cost Breakdown of the unit installed.

Item number	Component	Quantity	Unit cost/GH¢	Amount GH¢
1	100-litre Solar water heater(evacuated tube collector)	1	1100	1100.00
2	1/2in Copper pipes (8m in length)	16	5	80.00
3.	2/3in Couplings set	1	15	15.00
4	Thread tape	5	1	5.00
5	T&T	1	50	50.00
6	Labour	1	150	150.00
7	**Equipment cost plus Overheads**			1400.00

4.2 RESULTS AND DISCUSSION

Hot water temperatures at 6 am and 6 pm were collected over a period of six months (38 weeks) on daily basis to monitor the performance of the installed SWH.

Figure 4.8 shows weekly average temperatures of hot water at 6am and 6pm, with hot water temperatures varying from 37^{o}C to 59^{o}C. During peak times (mornings and evenings) when most households make use of hot water; residents of Goldfield Ghana residential facility are no exception. Also it is at these peak times that the most households in Ghana use a lot of electricity and this puts undue stress on the national grid. Besides, during the day when the sun is up the sky, there will be hot water running through the system.

The periods between 6pm and 6am are very critical to the success of this project because it is at these periods that the hot water is on high demand and also there is no sunshine.

Hot water temperature were obtained at 6am and 6pm from the control unit of the SWH, the control units displays the hot water temperature, water level and also the source energy for heating the water. Data was collected with the help of a member the household, who recorded the hot water temperatures at the periods specified above.

Figure 4.6 Control unit displaying hot water temperature at 6pm

Figure 4.7 Control unit displaying hot water temperature at 6am

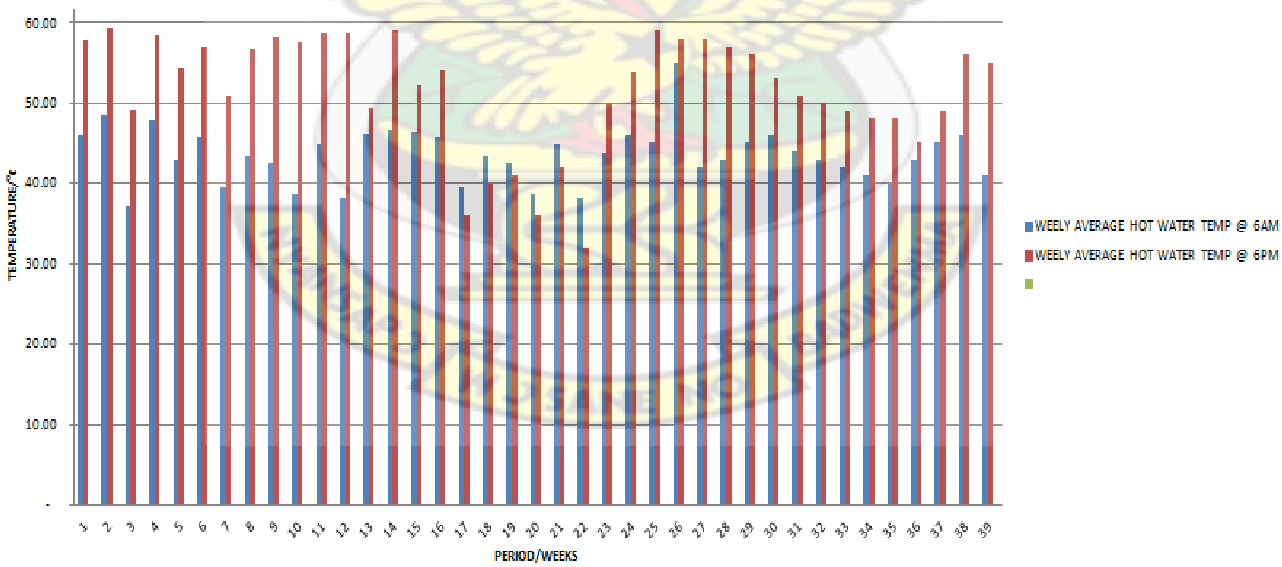

Figure 4.8 Average weekly hot water temperatures at 6am and 6pm

From figure 4.8, the temperature of hot water varied from 37°C to 59°C. In most cases during rainy periods, the household were able to get hot water. In Tarkwa where Goldfields Ghana is situated, the weather is usually cloudy with frequent rainfalls. The ambient temperature varies from 24°C to 34°C with rainfall varying 10mm to 153mm [15]. Even with such climatic conditions, the SWH was able to heat water to the desired temperatures. That notwithstanding, from data gathered, as shown in figure 4.8, 10 days out the 152 days had hot water temperature to be 34^0C.

4.3 Economic Analysis

As a result of the United nations Secretary-General initiative on sustainable energy for all, cost of renewable energy equipment is gradually declining [2]. The Ghanaian market is no exception, prices of renewable energy equipment is relatively declining with the passing into law the renewable energy bill into law [5]. The economic analysis in this thesis, seeks to achieve two things;

i) If the cost of electricity used in heating hot water will be enough to pay for the cost of the solar water heaters.

ii) The payback period and the net present value.

It cost GFGL GH¢324 to heat water using electric water heaters per day for their 600 households. This implies that it will cost them GH¢9720 in a month to heat water using electricity. The cost of installing a 100-litre solar water heater is GH¢1400, which implies that the monthly cost of electricity will be enough to install 7 solar water heaters. To be able to install solar water heaters in all the 600 household, it will be required to invest seven and a half years of the cost of electricity consumed to pay for the solar water heaters. Since the life of the water heater is between 20-30years

.It will be worth an investment since after eight years of using cost of electricity consumed to purchase and install the water heaters, there will be no extra cost except for maintenance which will not be as high as the electricity bill.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the foregoing, the following conclusions can be drawn from the study;

i. A survey was successfully carried out to establish the average daily hot water requirement of Goldfields Ghana Limited which was estimated to be 80 litres per day for a household of three.

ii. Based on (i) above a 100-litre solar water heater with 2 kW auxiliary electric heater was sized and successfully installed for use for one housing unit with a household of three persons.

iii. The installed water heating system was tested for six month (38 weeks) and the hot water average temperatures at 6am and 6pm were monitored corresponding to the periods of intense usage of the design. The average hot water temperature varied from $34^{o}C$ to $59^{o}C$.

iv. The cost benefits analysis carried out revealed that the payback period for the water heating system would be 8 years with a life span of 20-30 years.

6.2 Recommendation

The recommendations from this study are that;

i. Future buildings should include renewable energy systems (e.g. solar water heating system) in their architectural designs. This will make installation of such systems much easier and cost effective.

ii. Further studies should focus on how often the auxiliary heaters when there is no sunshine

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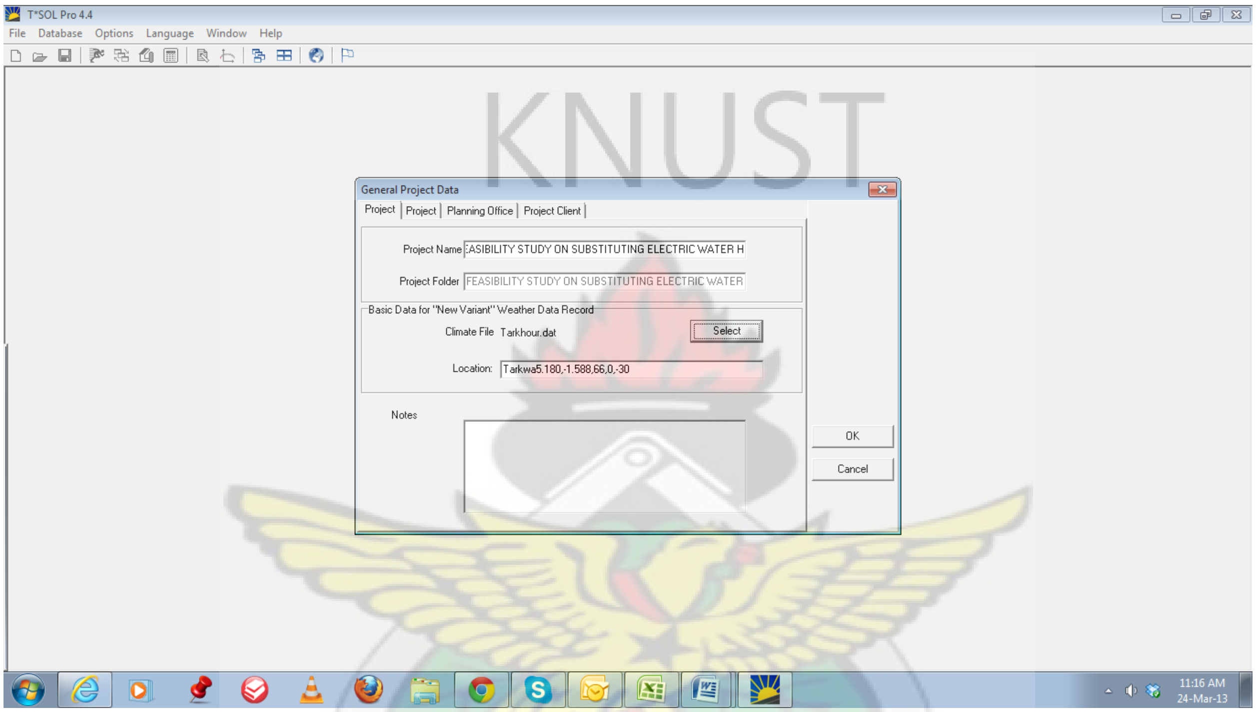
LIST OF APPENDICES

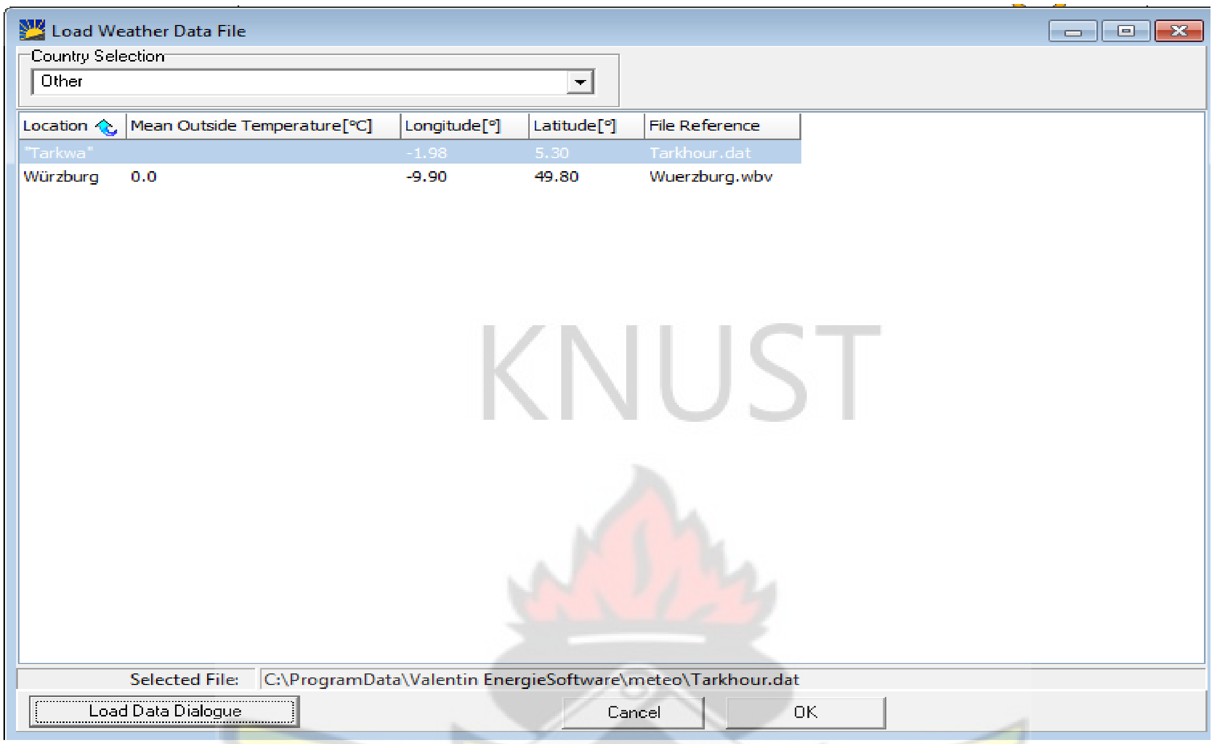
APPENDIX A

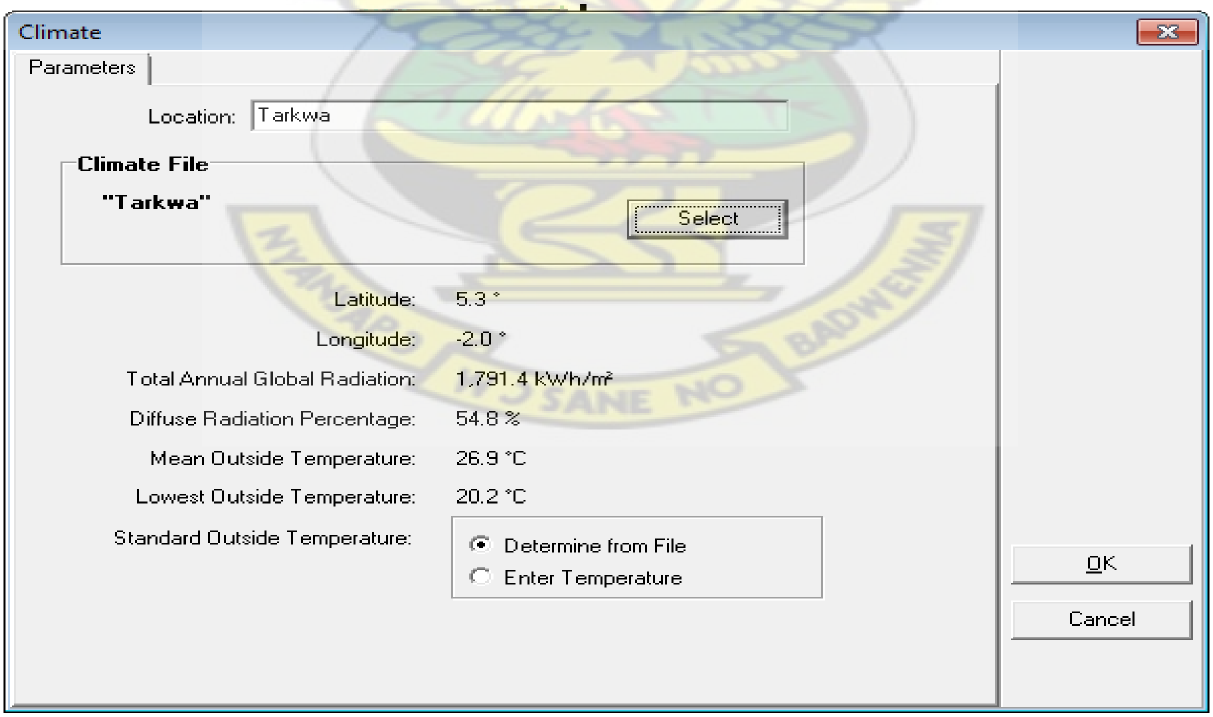
T*SOL Solar Thermal System Software Programme

Labeling Project

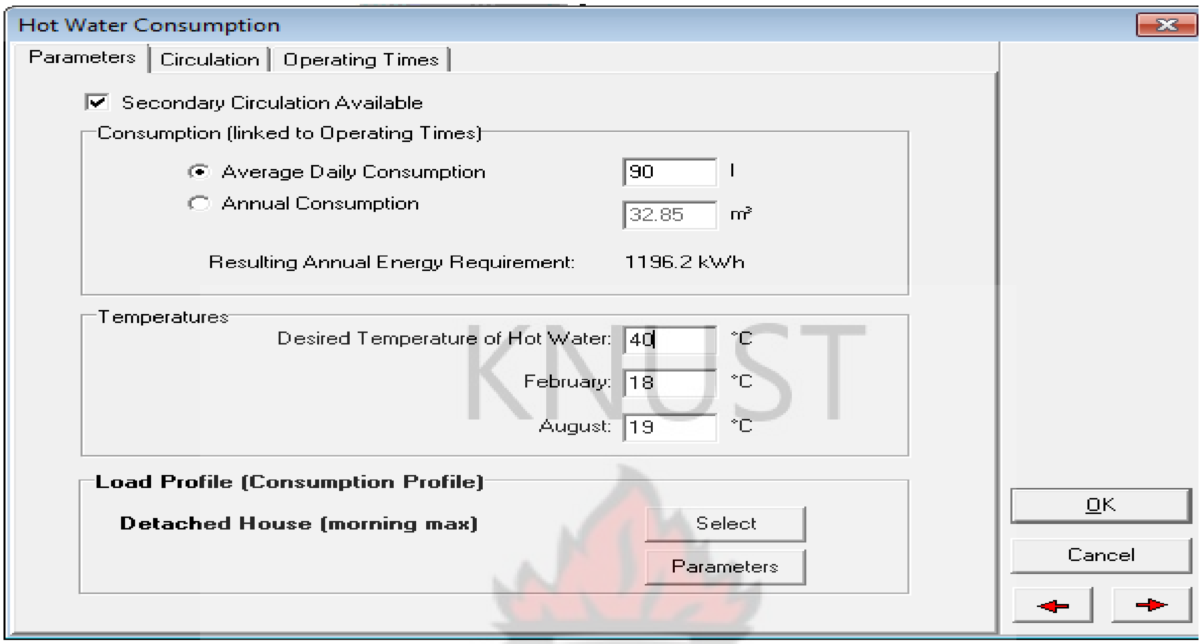


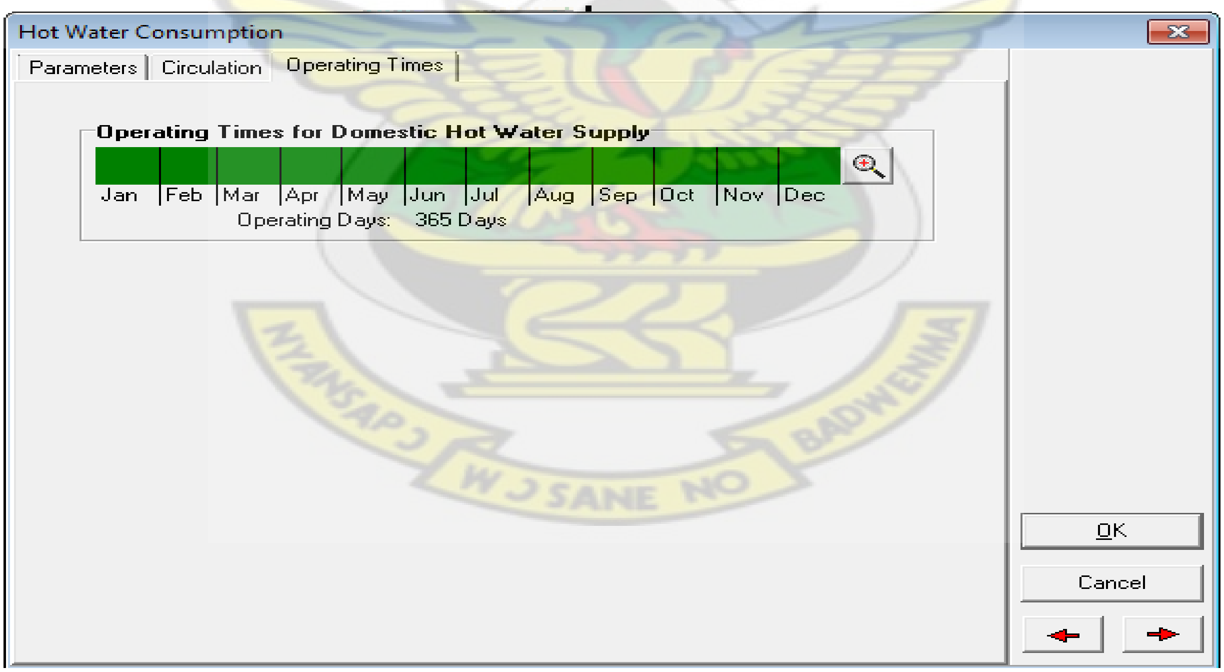
Loading of tarkwa weather data

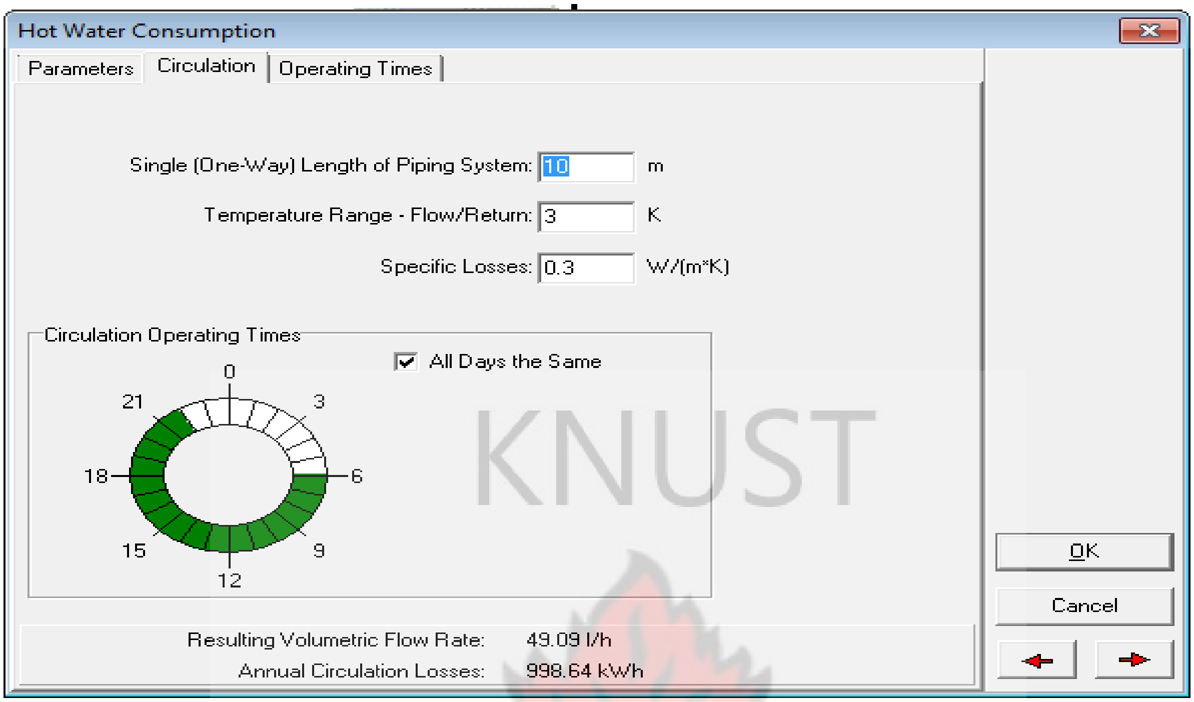




Hot Water load calculation






Hot Water Consumption
Parameters
Circulation
Operating Times
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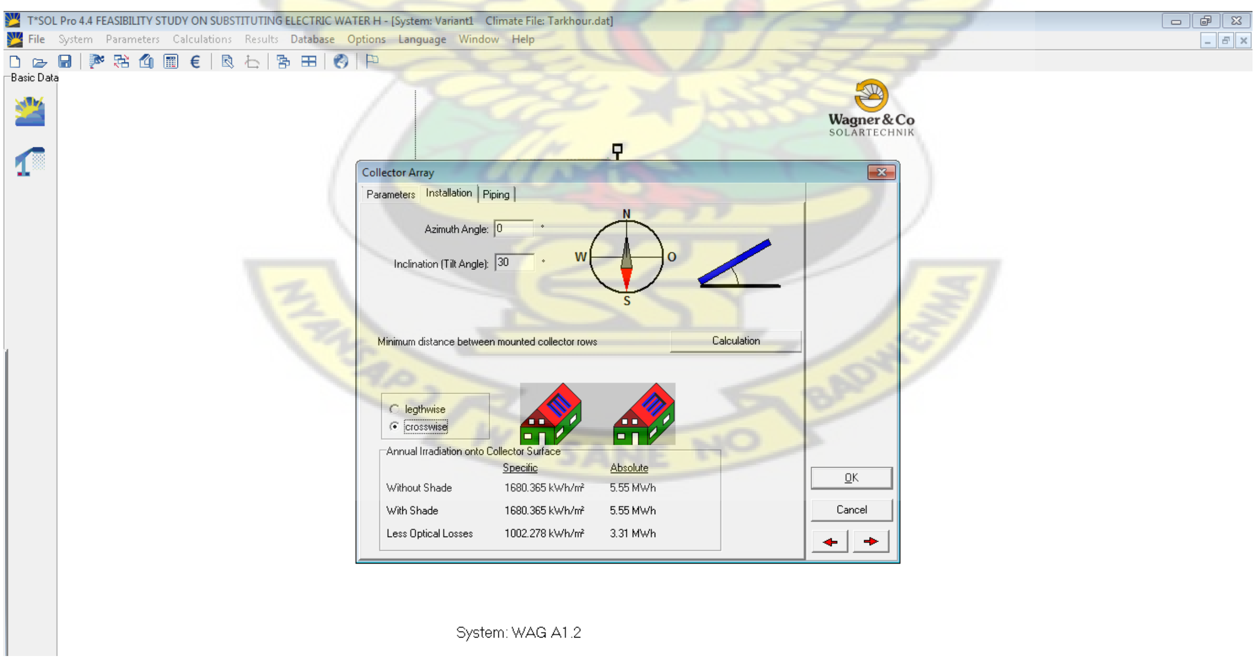
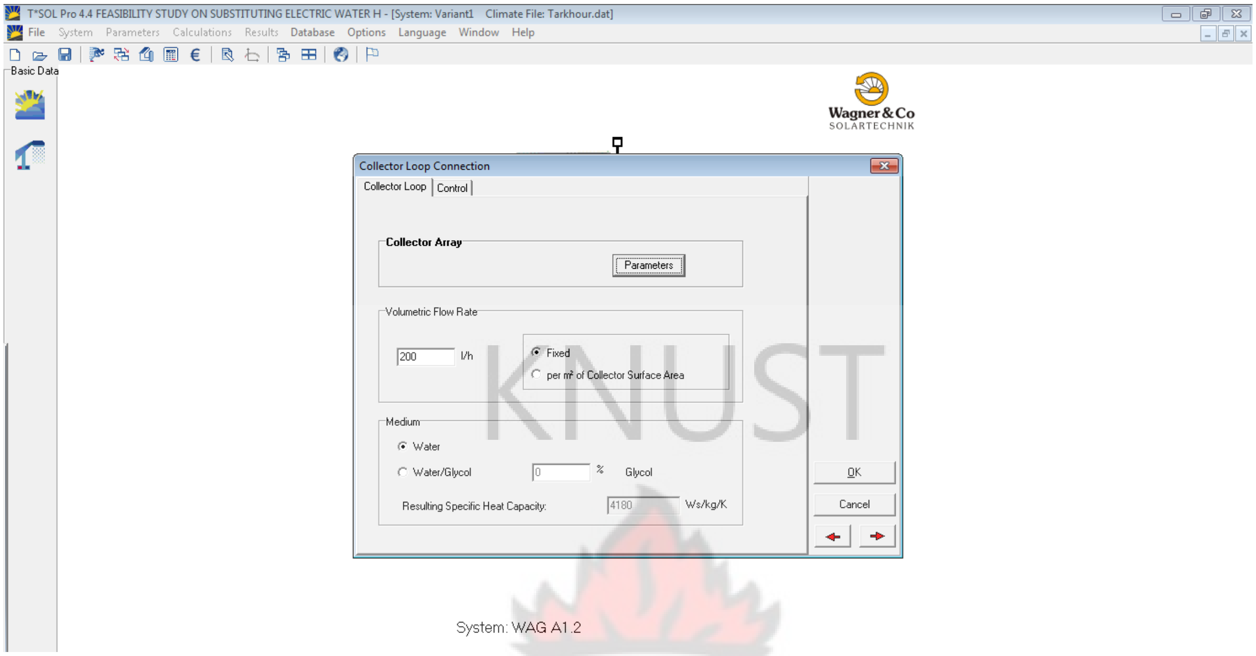
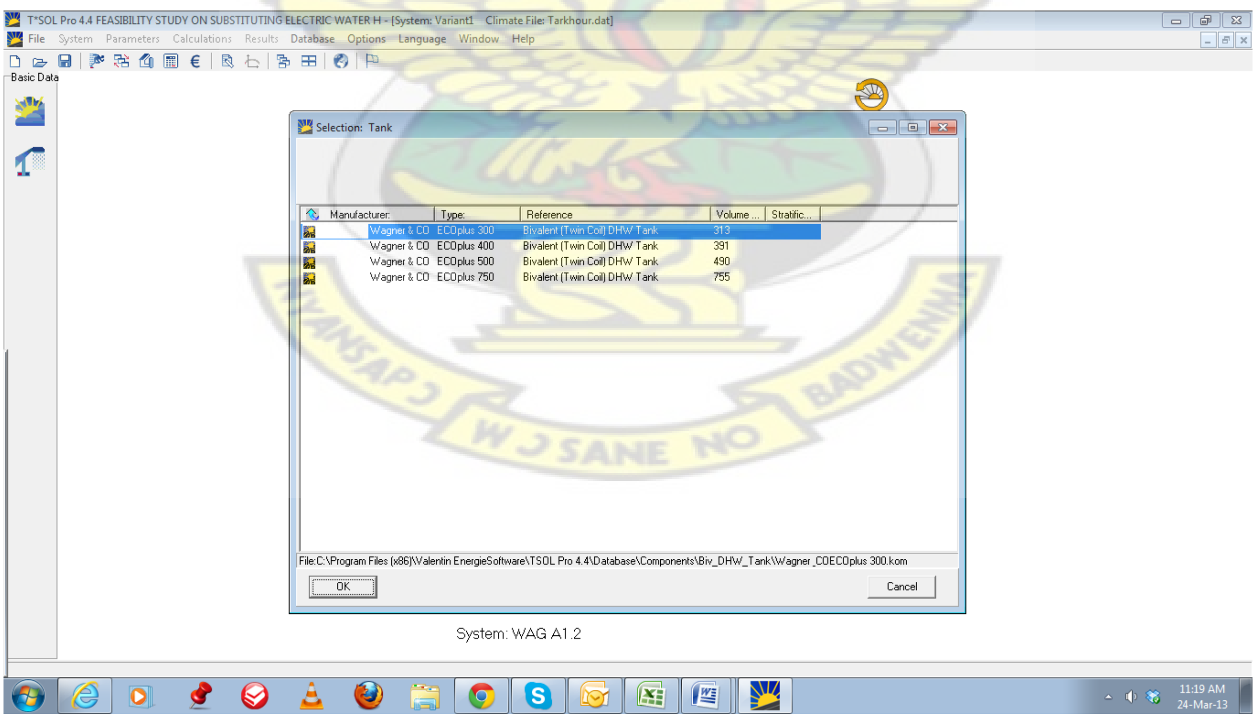
Temperature Range - Flow/Return: 3 K
Specific Losses: 0.3 W/(m*K)
Circulation Operating Times
All Days the Same
0
3
6
9
12
15
18
21
OK
Cancel
Resulting Volumetric Flow Rate: 49.09 l/h
Annual Circulation Losses: 998.64 kWh


T*SOL Pro 4.4 FEASIBILITY STUDY ON SUBSTITUTING ELECTRIC WATER H - [System: Variant1 Climate File: Tarkhour.dat]
File System Parameters Calculations Results Database Options Language Window Help
Basic Data
Wagner & Co
SOLARTECHNIK
Collector Array
Parameters
Installation
Piping
Azimuth Angle: 0 °
Inclination (Tilt Angle): 30 °
N
W
O
S
Minimum distance between mounted collector rows
Calculation
legthwise
crosswise
Annual Irradiation onto Collector Surface
Specific
Absolute
Without Shade 1680.365 kWh/m² 5.55 MWh
With Shade 1680.365 kWh/m² 5.55 MWh
Less Optical Losses 1002.278 kWh/m² 3.31 MWh
OK
Cancel
System: WAG A1.2

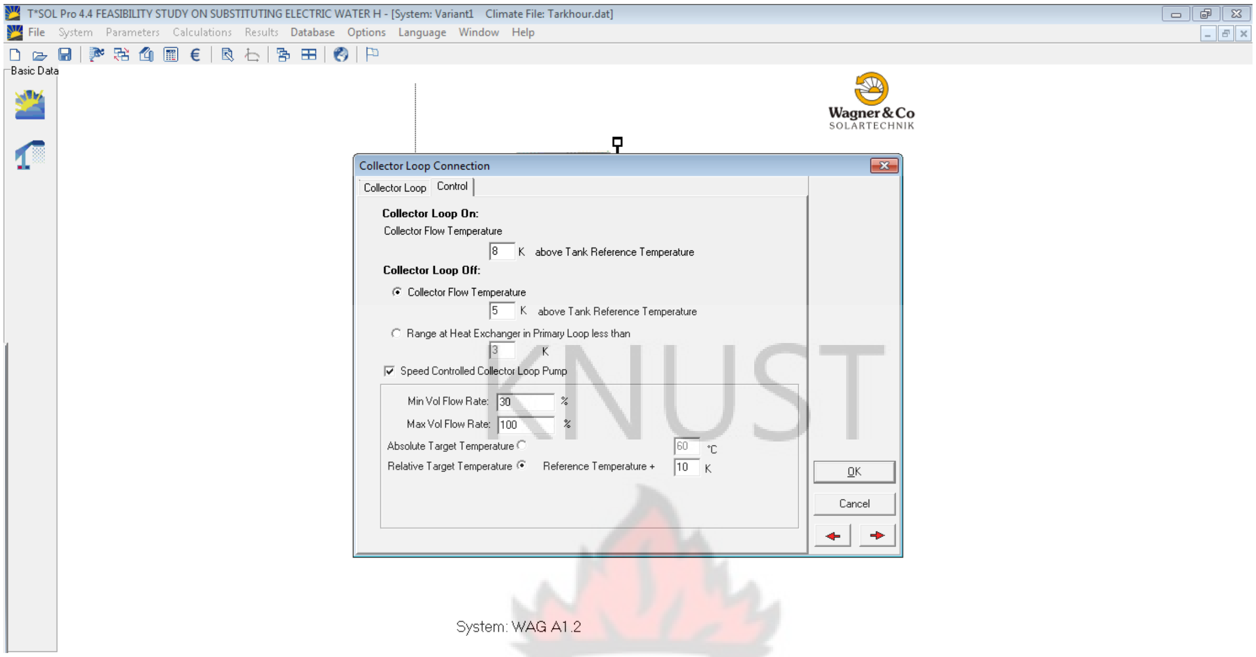
Collector Specification

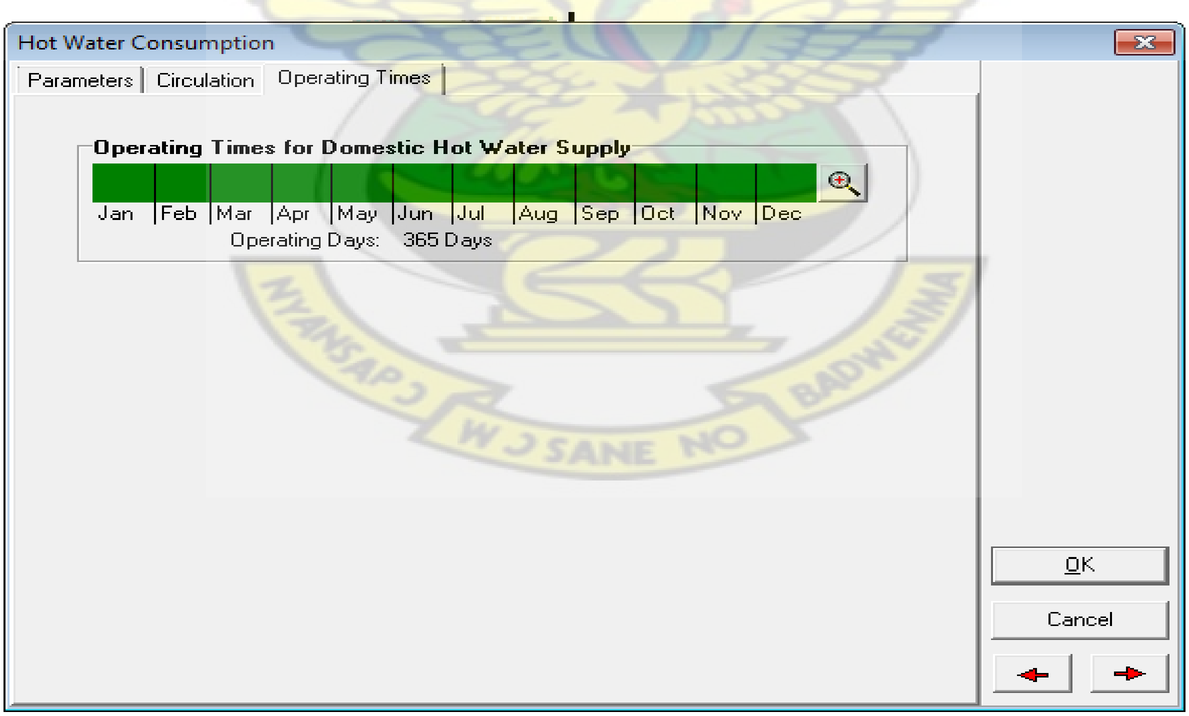


Selecting water heater



Collector loop specification





APPENDIX B

Sample Questionnaire

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MSC RENEWABLE ENERGY TECHNOLOGY

QUESTIONAIRE ON HOT WATER LOAD ASSESMENT AT APINTO RIDGE,GOLDFIELDS GHANA LIMITED TARKWA MINE

PLEASE KINDLY COMPLETE THE QUESTIONS BELOW

1	SEX	M ☐	F ☐			
2	AGE	0-12yr ☐	13-24yr ☐	25-36yr ☐	37-48yr ☐	above 48yr ☐
3	DO YOU USE HOT WATER	YES	NO	please circle answer		
4	IF YES, GIVE PURPOSE OF HOT WATER	LAUNDRY ☐	BATHING ☐	WASHING DISHES ☐	COOKING ☐	
5	DAILY AMOUNT OF HOT WATER USED	1-3gal ☐	4-6gal ☐	7-9gal ☐	10-12gal ☐	
6	DESIRED HOT WATER TEMPERATURE/oC	0-40 ☐	41-50 ☐	51-60 ☐	61-70 ☐	

Questionnaire completed by member of household

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MSC RENEWABLE ENERGY TECHNOLOGY

QUESTIONAIRE ON HOT WATER LOAD ASSESMENT AT APINTO RIDGE,GOLDFIELDS GHANA LIMITED TARKWA MINE

PLEASE KINDLY COMPLETE THE QUESTIONS BELOW

1	SEX	M ✓	F			
2	AGE	0-12yr	13-24yr	25-36yr	37-48yr	above 48yr ✓
3	DO YOU USE HOT WATER	YES	(NO)	please circle answer		
4	IF YES, GIVE PURPOSE OF HOT WATER	LAUNDRY	BATHING	WASHING DISHES	COOKING	
5	DAILY AMOUNT OF HOT WATER USED	1-3gal	4-6gal	7-9gal	10-12gal	
6	DESIRED HOT WATER TEMPERATURE/oC	0-40	41-50	51-60	61-70	

Questionnaire completed by member of household

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MSC RENEWABLE ENERGY TECHNOLOGY

QUESTIONAIRE ON HOT WATER LOAD ASSESMENT AT APINTO RIDGE,GOLDFIELDS GHANA LIMITED TARKWA MINE

PLEASE KINDLY COMPLETE THE QUESTIONS BELOW

1	SEX	M [ ]	F [✓]			
2	AGE	0-12yr [ ]	13-24yr [ ]	25-36yr [✓]	37-48yr [ ]	above 48yr [ ]
3	DO YOU USE HOT WATER	(YES)	NO	please circle answer		
4	IF YES, GIVE PURPOSE OF HOT WATER	LAUNDRY [ ]	BATHING [✓]	WASHING DISHES [ ]	COOKING [ ]	
5	DAILY AMOUNT OF HOT WATER USED	1-3gal [ ]	4-6gal [✓]	7-9gal [ ]	10-12gal [ ]	
6	DESIRED HOT WATER TEMPERATURE/oC	0-40 [✓]	41-50 [ ]	51-60 [ ]	61-70 [ ]	

Questionnaire completed by member of household

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MSC RENEWABLE ENERGY TECHNOLOGY

QUESTIONAIRE ON HOT WATER LOAD ASSESMENT AT APINTO RIDGE,GOLDFIELDS GHANA LIMITED TARKWA MINE

PLEASE KINDLY COMPLETE THE QUESTIONS BELOW

1	SEX	M	F			
2	AGE	0-12yr	13-24yr	25-36yr	37-48yr	above 48yr
3	DO YOU USE HOT WATER	YES	NO	please circle answer		
4	IF YES, GIVE PURPOSE OF HOT WATER	LAUNDRY	BATHING	WASHING DISHES	COOKING	
5	DAILY AMOUNT OF HOT WATER USED	1-3gal	4-6gal	7-9gal	10-12gal	
6	DESIRED HOT WATER TEMPERATURE/oC	0-40	41-50	51-60	61-70	

Questionnaire completed by member of household

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MSC RENEWABLE ENERGY TECHNOLOGY

QUESTIONAIRE ON HOT WATER LOAD ASSESMENT AT APINTO RIDGE,GOLDFIELDS GHANA LIMITED TARKWA MINE

PLEASE KINDLY COMPLETE THE QUESTIONS BELOW

1	SEX	M	F ✓			
2	AGE	0-12yr	13-24yr	25-36yr	37-48yr	above 48yr ✓
3	DO YOU USE HOT WATER	(YES)	NO	please circle answer		
4	IF YES, GIVE PURPOSE OF HOT WATER	LAUNDRY	BATHING ✓	WASHING DISHES	COOKING	
5	DAILY AMOUNT OF HOT WATER USED	1-3gal	4-6gal ✓	7-9gal	10-12gal	
6	DESIRED HOT WATER TEMPERATURE/oC	0-40 ✓	41-50	51-60	61-70	

APPENDIX C

RISK ASSESMENT CARRIED OUT BEFORE INSTALLATION;

The following were identified as high risk issues;

1. Getting electrocuted
2. Potential of team members falling from the high roof
3. Potential of team members falling from ladder whiles climbing
4. Tools and equipment falling from roof
5. Components of water heater falling from and getting damaged
6. Causing damage to the roof of the building, which lead to leakages

After identifying these high risk issues, a countermeasure was made follows;

1. Switch of power supply to electric heater before uninstalling it
2. Wear proper personal protective equipment for protection.
3. Walking on wooden ridges to prevent damaging roofing sheets.
4. Secure ladder firmly and also ensuring that one person uses it at a time..