UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

Investigation of the viability of a solar water heating system when used as a replacement of an instant electrical water heating system

By

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DECLARATION

I **Edward Mwirigi Kinyua** declare that this research is my original work and has not been presented in any other university for examination.

Sign: ____________________ Date____________________

SUPERVISOR'S DECLARATION

We confirm that the above student carried out this research under our supervision as University supervisors.

Sign: ______________

Date_____________________

Prof. James A. Nyang'aya

Sign: ______________

Date_____________________

Dr. A. A. Aganda

ACKNOWLEDGEMENT

First and foremost I give glory to the almighty God for the grace He bestowed to me enabling my completion of this project.

Second, I wish to recognize the work of my supervisor's who dedicated their time and effort in guiding me towards a successful completion of this work. The selflessness of these scholars cannot be quantified and for that I express my gratitude.

Third, I give gratitude to the management of Eton Hotel for providing me an opportunity to use the hotel for this study.

Lastly I wish to thank all my fellow students with whom we shared a lot academically and socially. They served as a beacon of hope and encouragement throughout the course.

DEDICATION

This research work is dedicated to my wife Preda Marura and my beloved daughters Elsie Njeri and Keyla Makio.

ABSTRACT

This study focused on investigating the viability of replacing an electric instant shower system at a hotel located in Thika with a passive solar water heating system. The study involved quantifying the average daily hot shower water consumption per room at the hotel in order to choose an appropriate size of solar water heater. To quantify the shower water, a flow meter was installed on the shower line just before the instant shower head in the hotel room. At the same time, an electricity meter was installed on the same shower to quantify the consumption of electricity for every shower session. A digital thermometer was then fixed at the shower head to monitor the temperature of the exiting water. Measurements from this set up were recorded for a period of 30 days from 1st February 2015 to 2nd March 2015.

The study found the average shower water consumption per room per day to be 47.17 liters and the average water temperature from the instant electric shower to be 39.8°C. Further, the average electricity consumption per shower was found to be 0.75kWh per room per day.

Thereafter, a solar water heating system was installed at the roof top of the hotel and connected to the hotel room. The instant shower unit was then isolated and the use of the solar water heater commenced. Digital thermometers were then used to measure the temperatures of the hot water from the solar water heater at

the roof tank storage and at the exit of the shower head at the following intervals 0900hrs, 1200hrs, 1500hrs and 1800hrs for a period of 30 days from 11th March 2015 to 9th April 2015. The average water temperatures from the Solar Water Heater (SWH) at the roof tank storage at 0900hrs, 1200hrs, 1500hrs and 1800hrs were 28.1°C, 44.1°C, 49.2°C and 32.6°C respectively. On the other hand, the average water temperatures from the SWH at the showerhead of the hotel room at 0900hrs, 1200hrs, 1500hrs and 1800hrs were 26.9°C, 42.2°C, 47.1°C and 31.2°C respectively. Supplemental heating would thus be required for the shower water at 0900hrs and 1800hrs. The average supplementary heating required at 0900hrs would have been 0.71kWh per room per day while at 1800hrs it would have been 0.47kWh per room per day.

The calculated payback period for the use of the SWH in heating shower water was 6.5years.

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ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DOE	Department of Energy of the United States of America
EC	Energy Charge
ERC	Energy Regulatory Commission
ERCL	Energy Regulation Levy
FA	Forex Adjustment
FC	Fixed Charge
FCC	Fuel Cost Charge
FPC	Flat Plate Collector
GHG	Green House Gases
IA	Inflation Adjustment
IFC	International Finance Corporation
Kshs	Kenya Shillings
kWh	Kilowatt Hour
PVC	Polyvinylchloride
REP	Rural Electrification Program
SRCC	Solar Rating & Certification Corporation
SREP	Scaling-up Renewable Energy
SSA	Sub-Saharan Africa
SWH	Solar Water Heater
US	United States of America
WARMA	Water Regulatory Management Authority
WBG	World Bank Group
VAT	Value Added Tax

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Solar water heaters (SWH) are becoming increasingly attractive in sustainable development. World over, efforts are continuously made to reduce their cost to make them more affordable [1]. The drive to increase uptake of SWH is derived from the need to reduce operating expenditure by hot water users and the abundance of solar radiation especially in Sub-Saharan African (SSA). In developed countries, the need to reduce Carbon emissions from conventional and commonly used sources of energy such as fossil fuels has been a major driver in the uptake of SWH.

Heating water contributes a large portion of the energy needs of hotels worldwide. For hotels in developing nations, heating water is often one of the most energy intensive processes and throughout the developing world; hotels struggle to meet their hot water needs. Families in SSA typically heat and boil water by burning firewood and charcoal. The high dependency on wood and charcoal by a large percentage of the population is a major cause of deforestation in Kenya [2]. In developed countries, hot water needs are met through use of electricity or fossil fuels such as furnace oil or propane. These fuels options are unsustainable due to their contribution to the buildup of greenhouse gases in the atmosphere.

One potential solution to this problem is the use of solar energy to heat water. SWHs are environmentally friendly technologies which can be a supplement to the rising energy demand and can offset dependency on conventional sources of energy. SWH technology is used in many parts of the world including the United States, China, India, and the Middle East. In Kenya, the Government has formulated policy and regulatory interventions to ensure increased use of SWH. Such interventions include the Energy (Solar Water Heating) Regulations of 2012 that make it mandatory for all premises within the jurisdiction of a local authority with hot water requirements exceeding 100litres per day to install and use SWH [3].

1.2 Problem Statement

In Kenya, electricity consumption has been on the rise. It is uncertain how the energy sector may grow to meet the large and increasing electricity demand in Kenya. Plans have been developed based on very high growth rates. The Updated Least Cost Power Development Plan (LCPDP) presumes a 14% annual growth rate in electricity supply between 2010 and 2030 (which is twice as high as the growth rate in the previous decade) [4].

It is thus apparent that with the projected electricity consumption and the limited generation source, Kenya will have to embrace energy efficiency measures while at the same time exploiting alternative sources such as solar. Substituting conventional fuel sources with solar energy would also help in reduction of Carbon emissions.

The hotel where this study was conducted has each of its 60 occupancies fitted with Lorenzetti instant shower heaters of 4.5kW rating. The instant heaters draw power from the national electricity grid. In a typical month, the hotel's electricity bill amounted to Kshs88,585.99 which would translate to Kshs1,063,031.91 in a year assuming uniform consumption. The desire to manage energy costs has resulted into the management of the hotel turning to energy management for a solution. In hotels (lodging buildings), water heating is the largest single end user of energy, making up to 32% of total energy use [5]. Fig. 1.1 indicates the commercial lodging energy end use in the United States (US).

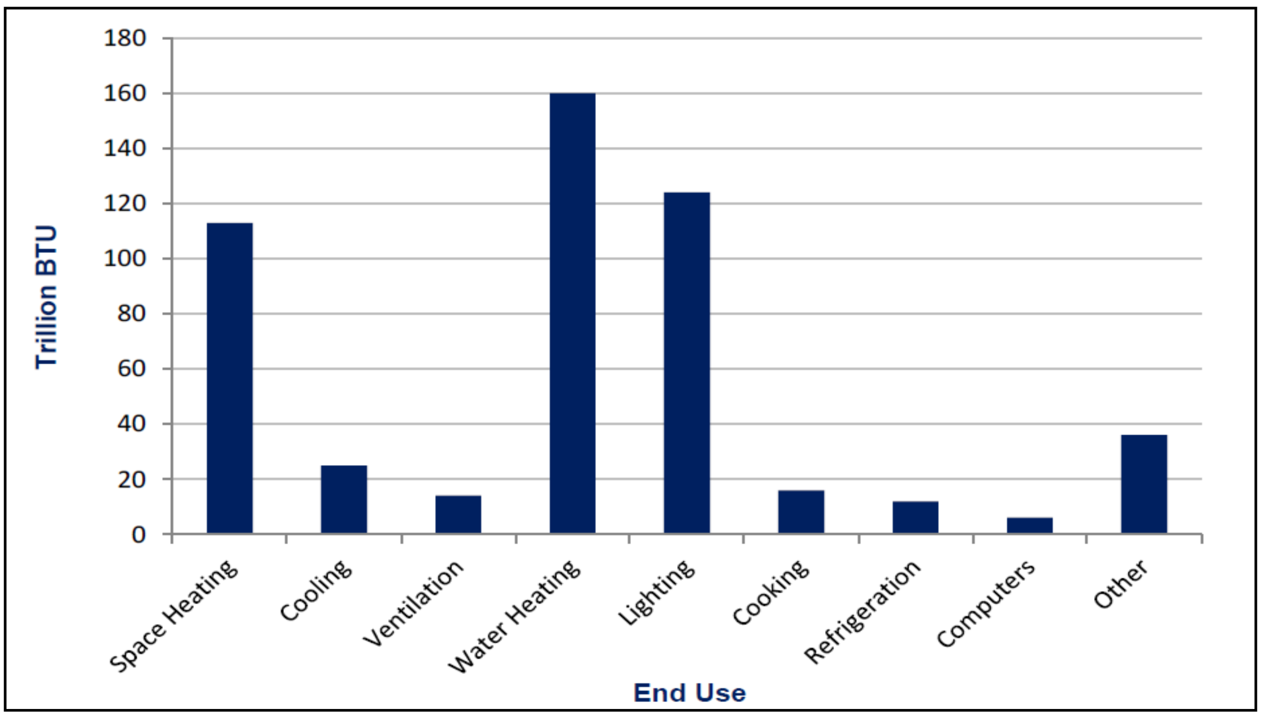

Fig. 1.1. The commercial lodging energy end use in the United States [5]

Fig. 1.1 indicates that the highest consumer of energy in commercial lodgings in the US is water heating, followed by lighting and space heating in that order. It therefore means that hotels aiming at reducing their energy bills through proper management of energy use should start with water heating costs. It is on that basis that this study was conceptualized whereby the viability of the use of solar energy to heat shower water in place of electric instant heaters was investigated. The hotel was located at Thika town whose monthly diffuse solar radiation is between 6-8.5MJ/m^2/day [6].

1.3 Objectives

The specific objectives of the study were:

i. To quantify the average daily hot water shower volume requirement for a standard hotel room;
ii. To determine the daily electric power consumption while using an instant electric shower in a standard hotel room;
iii. To install a thermo-siphon solar water heater at the hotel, connect it to a standard room and monitor its performance for a period of 30 days; and
iv. To calculate the payback period of the solar water heating system in (iii).

CHAPTER TWO

2.0 LITERATURE REVIEW

There is a current global need for clean and renewable energy sources. Fossil fuels are non-renewable and require finite resources, which are dwindling because of high cost and environmentally damaging retrieval techniques [7]. Solar water heating is one of the oldest and most effective forms of renewable energy. The use of solar energy contributes to lesser emission of Green House Gases (GHGs) which are associated with most conventional sources thus assuring sustainable development.

The first solar water heaters were bare metal tanks painted black containing water and tilted to face the sun [8]. The first commercial solar water heater was introduced by Clarence Kemp in the 1890's in California. For a $25 investment, people could save about $9 a year in coal costs [9]. The Clarence Kemp model lacked insulation of the storage tank and people had to wait for water to warm up in the morning after having lost heat during the night. In 1909, William J. Bailey solved this problem by separating the solar water heating system into a collector and an insulated hot water storage tank [10].

Installation of solar water heating has become the norm in countries with an abundance of solar radiation like the Mediterranean, Japan and Australia [11]. However, the most pervasive barriers to SWH use relate to the lack of established or accepted methods to address up-front costs, poor policies, lack of promotion and technology failures [12].

Nevertheless, solar water heaters for residential and commercial applications are one of the most cost-effective renewable energy technologies. As shown in Fig. 2.1, when a SWH is in use, savings in electricity costs can be used to offset the high capital costs of the SWH over a period of 6-8 years.

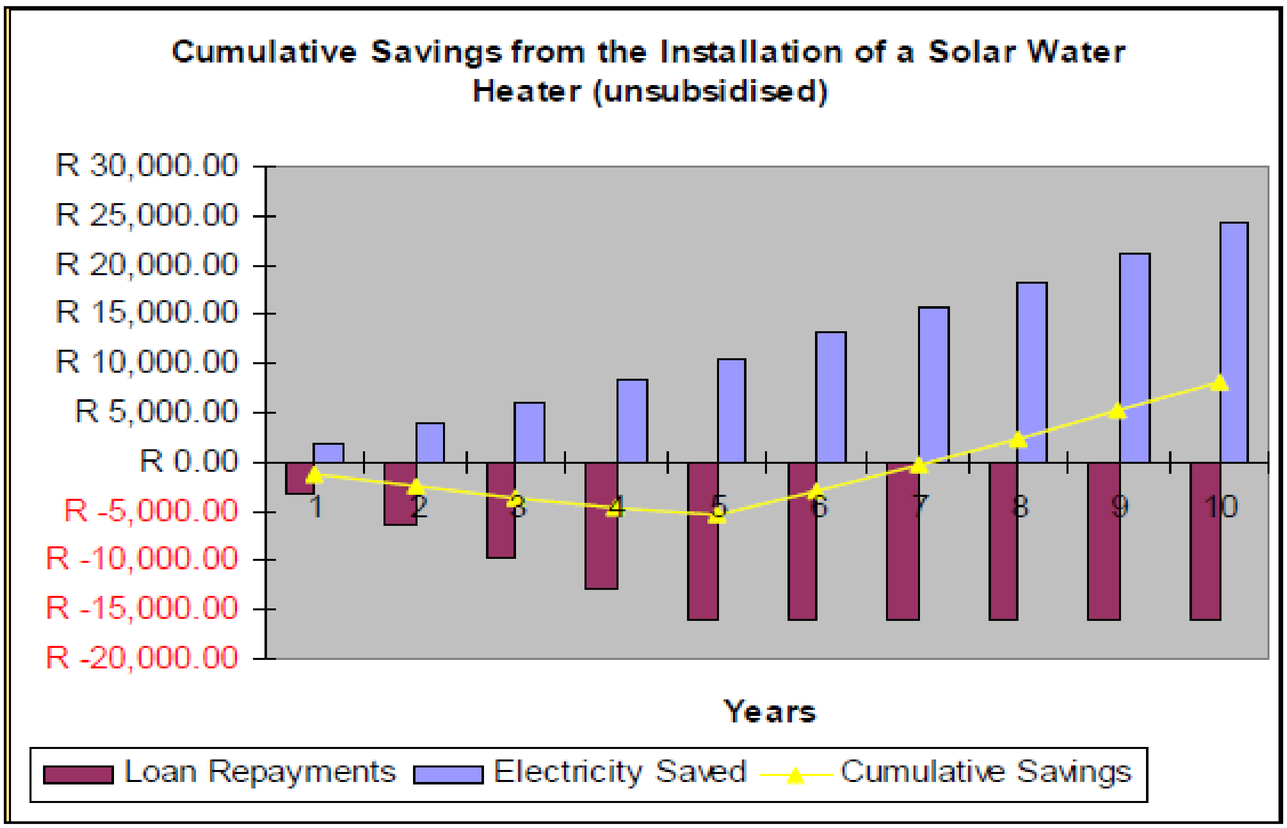

Fig. 2.1. Cumulative savings from the installation of a SWH [13]

2.1 COMPONENTS OF A SOLAR WATER HEATING SYSTEM

Solar water heating systems use solar panels called collectors fitted to the roof and an absorber surface that transfers the heat from the collectors to the working fluid. The heat transfer unit may include a pump to circulate the working fluid from the collectors to the storage tank, control and safety equipment. Many systems also have a back-up heater to ensure that the desired temperature of hot water needed is met even when there is insufficient sunshine. Solar water heaters perform 3 basic operations as shown in fig. 2.2, collection, transfer and storage.

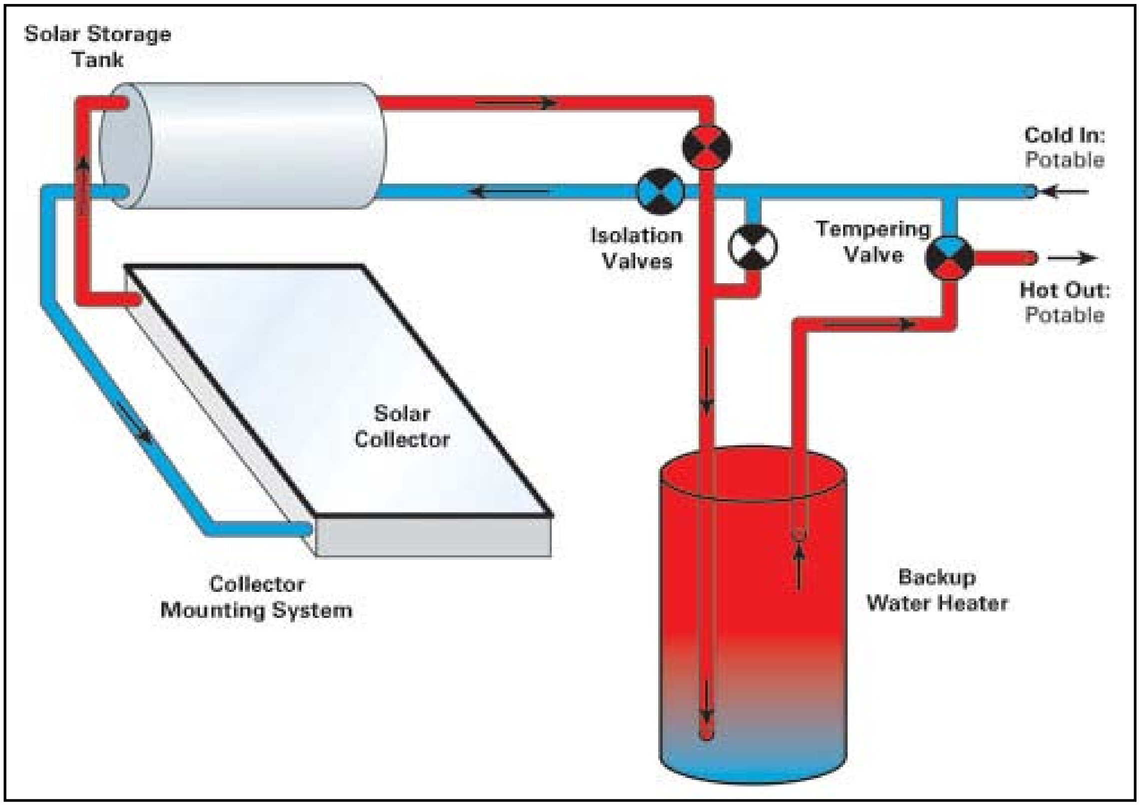

Fig. 2.2. Schematic of a SWH system [14]

i. **Collection**: Solar radiation is "captured" by a solar collector;

ii. **Transfer**: Circulating fluids transfer this energy to a storage tank; circulation can be natural (thermo-siphon systems) or forced (uses a pump); and

iii. **Storage**: Hot water is stored until it is needed at a later time.

2.2TYPES OF SOLAR WATER HEATING SYSTEMS

2.2.1 PASSIVE SOLAR WATER HEATING SYSTEMS

A passive solar water heating system requires no moving parts and no external energy source except the sun itself. As such, these systems do not use a pump to circulate water from the solar collector to the water storage tank. Passive solar water heating systems work on thermo-siphon principal. The thermo-siphon refers to a method of passive heat exchange based on natural convection, which circulates liquid without the necessity of a mechanical pump. An example of a passive solar water heater system is illustrated in fig. 2.3.

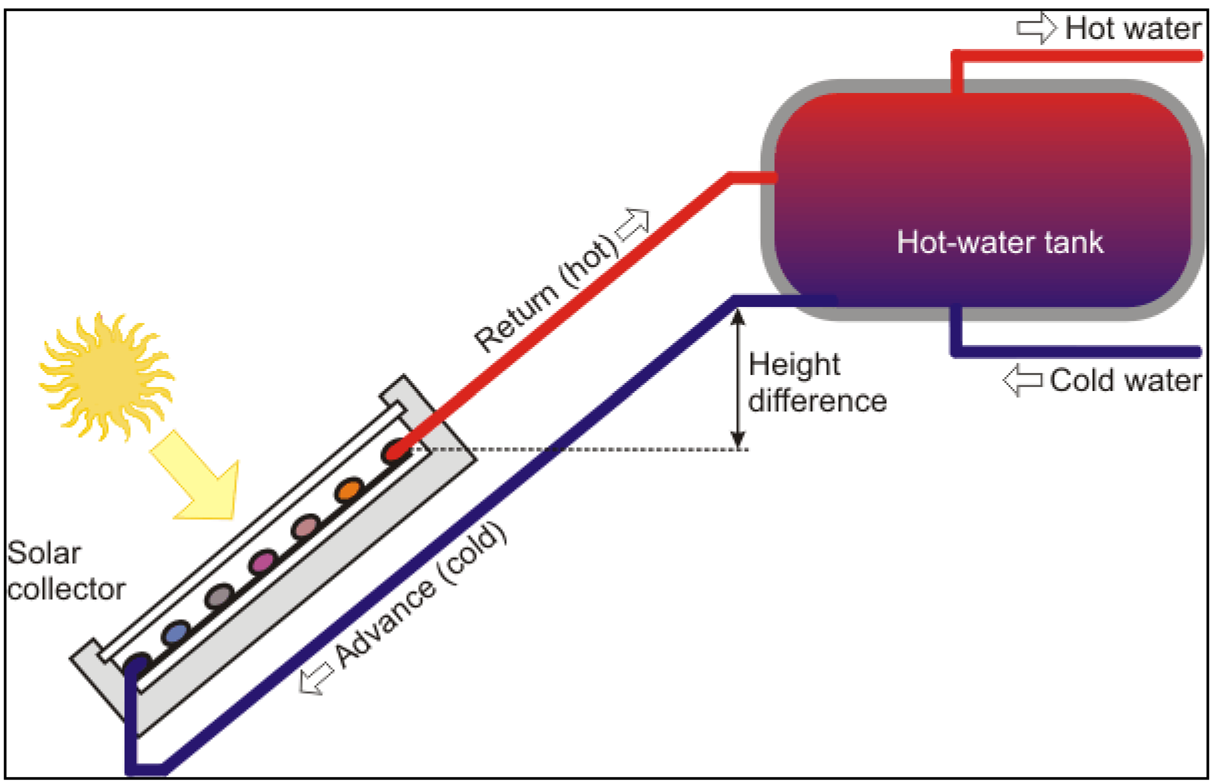

Fig.2.3. A passive solar water heater system [15]

2.2.2 ACTIVE SOLAR WATER HEATING SYSTEMS

Active solar water heaters are more efficient than passive solar water heaters. However, active systems require more equipment such as sensors, pumps and controllers.

Because active systems do not require a roof-mounted tank they have less visual impact, particularly when the solar collectors are mounted flush with the roof. However, active systems are usually more expensive to purchase and require more maintenance than passive systems. Active systems generally use more energy than passive systems because extra energy is required for pumping. However, if renewable energy is used to power the pump and a high level of insulation is used for the pipes and tank, active systems can reduce greenhouse gas emissions as much as passive systems [16]. Fig. 2.4 shows an active SWH.

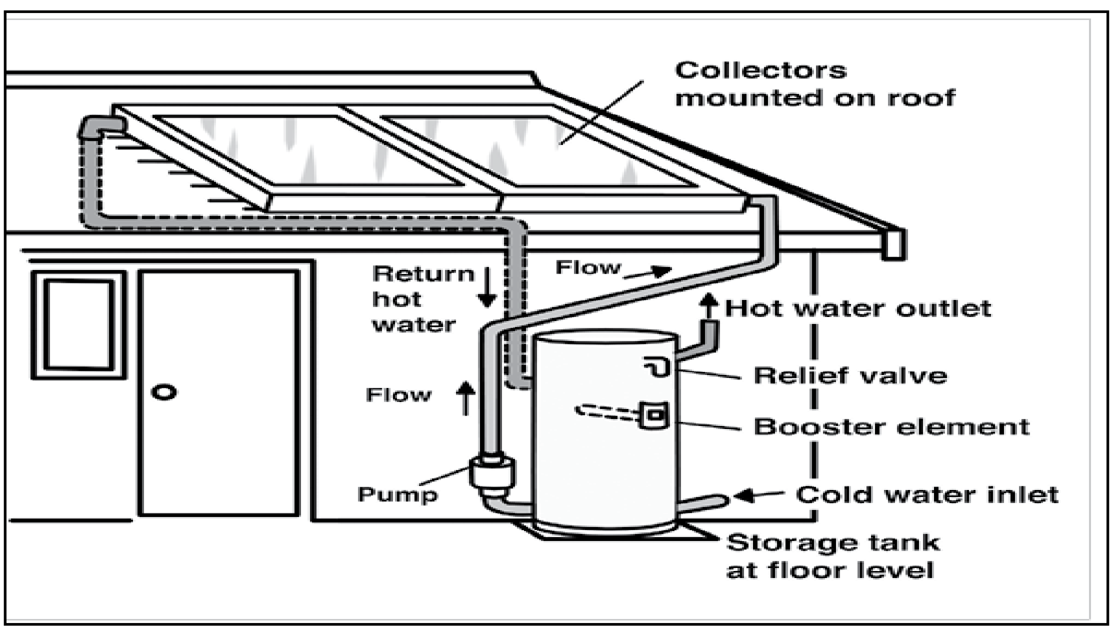

Fig. 2.4. An active SWH [16]

2.3 WATER CONSUMPTION PER OCCUPANCY IN HOTELS

Baseline information on water consumption in hotels was available from several sources. For instance, the Energy (Solar Water Heating) Regulations of 2012 in Kenya put the average hot water consumption in hotels at 40 litres per bed occupancy [3]. The Werden and Spielvogel study found an average of 14 gallons or 52litres/room/day in a range of hotels averaging 55 rooms. The smallest hotel contained 20 rooms and the consumption was 22 gallons or 83litres/room/day), while the largest contained 113 rooms and the consumption was 6 gallons or 23 litres/room/day) [5]. The American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) standard hot water daily usage values, based on the same study, are as follows: 20 gallons or 75litres/room for motels of 20 or less rooms, 14 gallons or 52litres/room for motels with 20 to 60 rooms, and 10 gallons or 37litres/room for motels with more than 60 rooms [5]. In addition, Enver Doruk Ozdemir in a study conducted in Guateng Province of South Africa in 2012 found that the average per capital consumption of water per day was 46litres [17].

2.4 HOT WATER DRAW PROFILES

A hot water draw profile is the percentage of the total daily hot water flow that occurs as a function of time of day [5]. A study conducted by Ndonye & Sarr in 2008 found that the highest hot water draw offs occurred at 1900hrs while the second highest occurred at 0700hrs [18]. In addition, high water draw off was noted between 0800hrs and 0900hrs and also at 2300hrs. The study also indicated that no water draw off was recorded between 0100hrs and 0300hrs. This is illustrated in fig. 2.5.

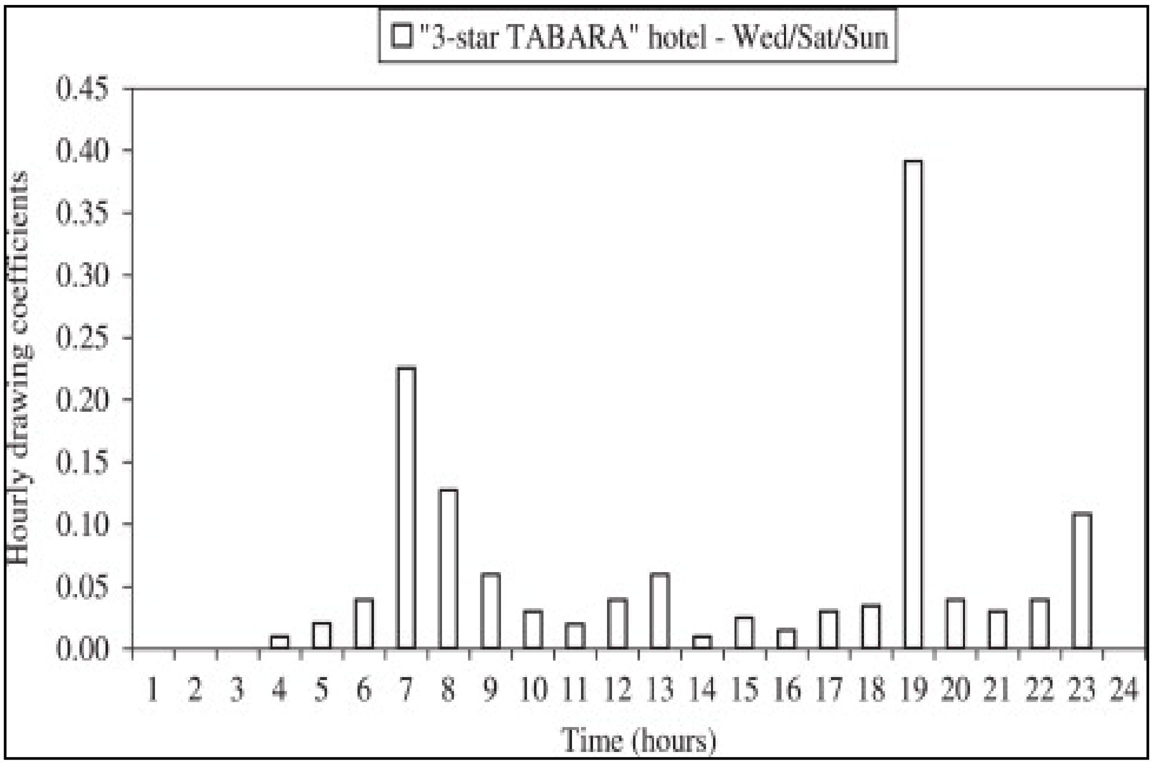

Fig.2.5. Hot water draw profiles for a hotel in South Africa [18]

Results on hot water draw profiles from other studies were provided by Fairey P. & Parker D. in 2004 indicating high draw offs between 0700hrs and 1100hrs. Further, the study indicated high draw offs between 1800hrs and 2100hrs. The peak draw off was at 0800hrs whereas the lowest draw off was between 0300hrs and 0400hrs. This is illustrated in fig. 2.6.

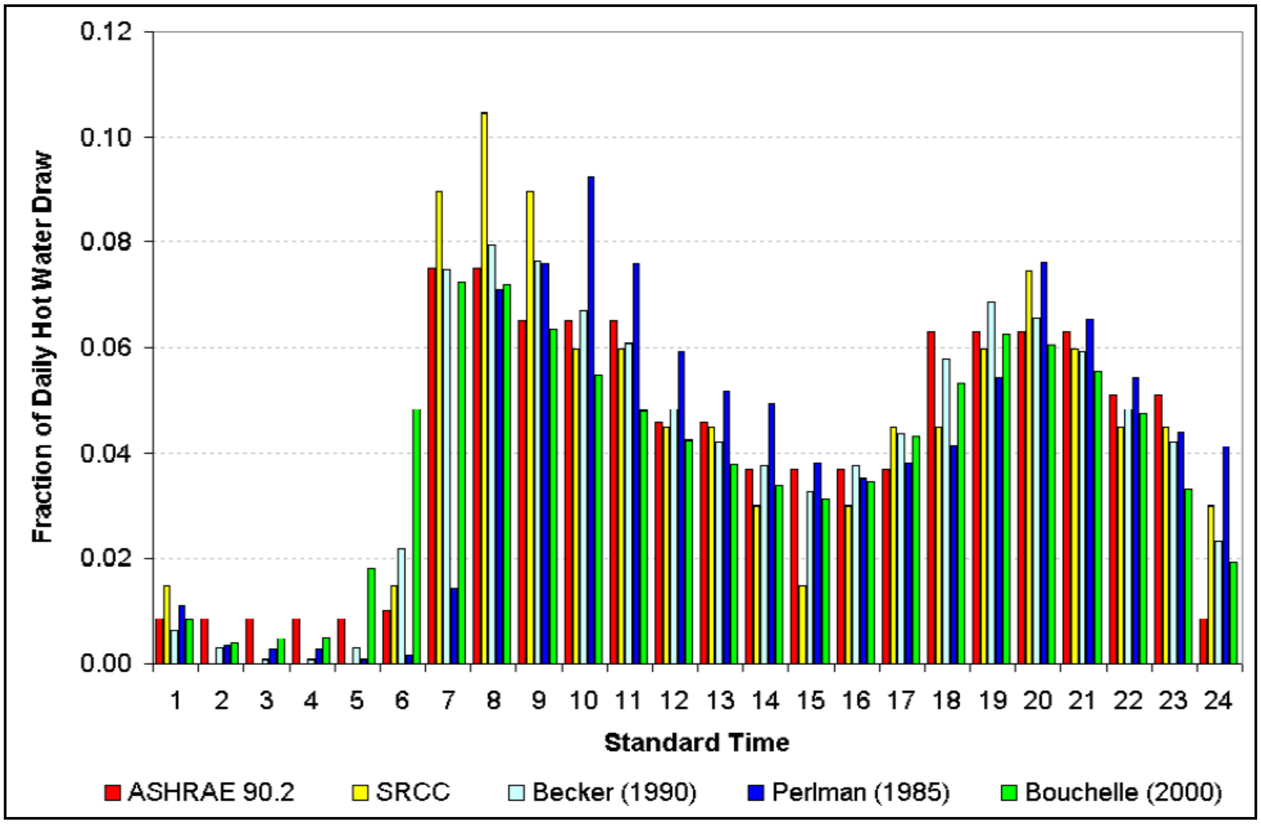

Fig.2.6. Results of water draw profiles for different studies [19]

2.5 USE OF INSTANT ELECTRIC HEATERS IN HOTELS

Instant electric heaters are sometimes referred to as tank less water heaters since they eliminate the need for a hot water storage tank as has been the conventional method of heating shower water. Tank less water heaters save energy not by heating water more efficiently than conventional storage water heaters but by reducing or eliminating standby losses associated with storing hot water in a tank [20].

2.6 PERFORMANCE OF SOLAR WATER HEATERS IN HOTELS

Shahidul Islam Khan in his study in 2011 found the output water temperature from solar water heaters to be 20 -30ºC higher than the room temperature during day time [21]. The study was performed for the entire year with water temperatures being monitored in the mornings and evenings. The results are presented in fig. 2.7 and 2.8.

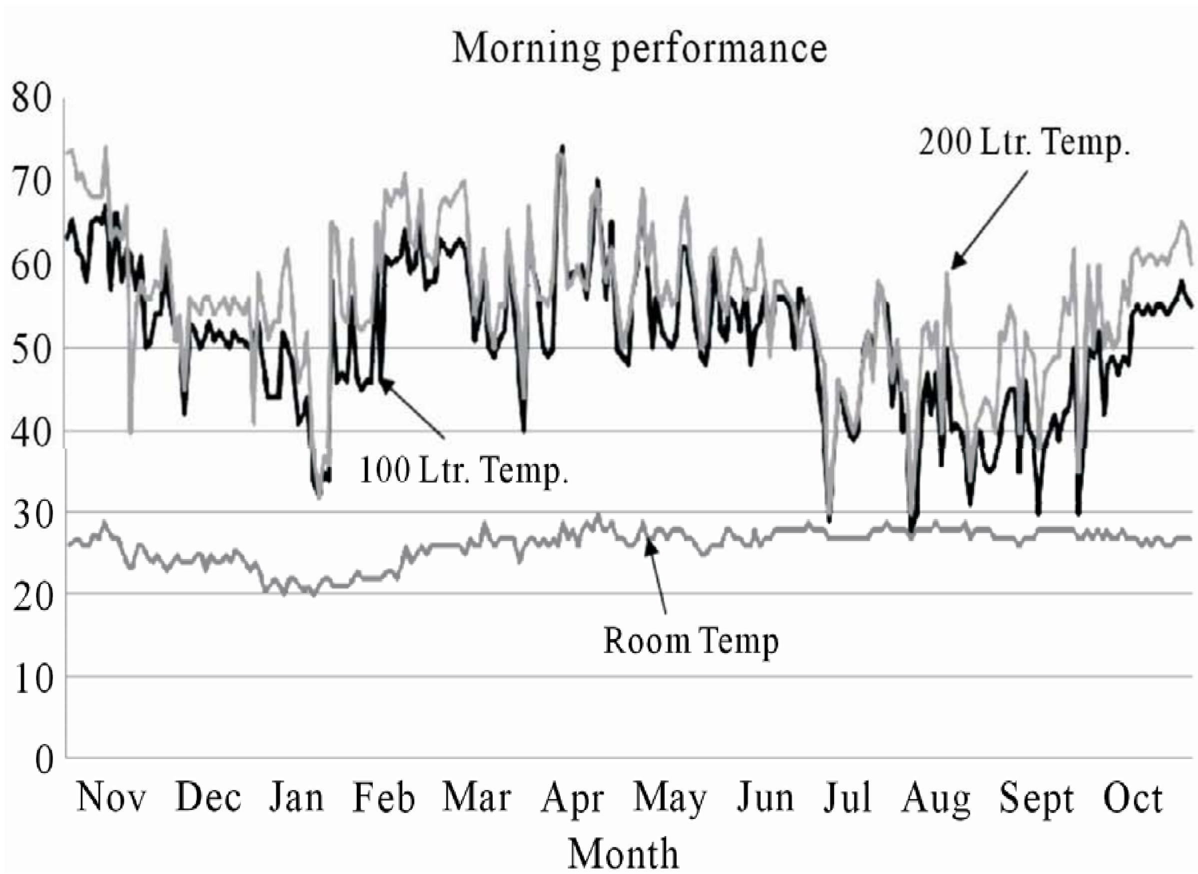

Fig. 2.7. Water temperatures while using a SWH in the mornings [21]

Fig. 2.7 indicates that the lowest recorded water temperature in the mornings for the 200litres tank storage was in the month of August and was about 29ºC. The highest recorded temperature was experienced in December and was about 75ºC.

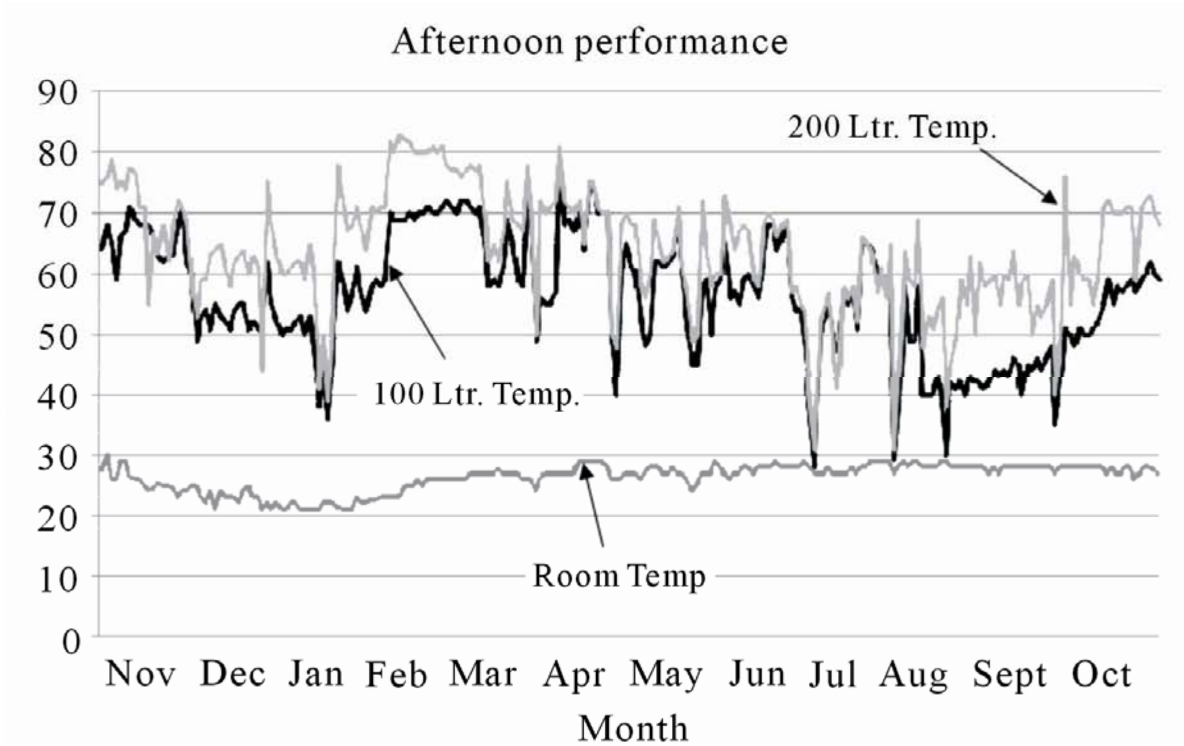

Fig.2.8. Water temperatures while using a SWH in the afternoons [21]

Fig. 2.8 indicates that the lowest recorded water temperatures in the afternoons for the 200litres tank storage was in the month of July and was about 29ºC. The highest recorded temperature was in February and was about 82ºC.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Measurement of volume flow, water temperature and power consumption while using an instant electric shower

The initial part of the study involved the determination of the daily volume of shower water in a standard room in the hotel. This was determined by use of a Kent rotary piston type flow meter that was installed on the shower line just before the head. At the same time, the temperature of the water exiting the shower head was measured by use of a Ringder digital thermometer.

Further, in order to determine the level of electrical energy consumption per each shower session, a Honey type meter model EMS12 was connected to the electrical unit of the instant shower. The electrical meter reader was fixed to the wall of the shower room by use of strong adhesive tape. Fig 3.1 shows the set up of the instant shower parameter monitoring instruments.

Fig.3.1. Layout of the study instruments at the hotel room

Fig. 3.1 shows an electric meter connected to the power cables delivering electrical energy to the heater in the shower head. Further, the figure shows a water meter connected to the shower line for purposes of measuring the volume flow of water into the shower head. Fig. 3.1 also shows the connections of the temperature probe to the shower head to monitor temperature of the hot water generated.

The study then transitioned into the next phase which involved the installation of a SWH system and connecting it to the shower in one room at the hotel. Based on the recorded average daily shower water volume consumption, a 200litre tank capacity ProSolar brand thermo-siphon SWH was chosen. An additional Ringder digital thermometer was then fixed to the SWH system to monitor the temperature of the hot water in the storage tank of the SWH. The set up of the SWH at the hotel is illustrated in fig. 3.2 and 3.3.

In the set up, cold water flowed by gravity from an elevated 500litre storage tank to the water pipes connected to the flat plate solar collector. As heat transfer occurred in the collector, the hot water flowed out of the SWH tank as a result of nature convection. Fig. 3.4 indicates the position of the cold water inlet, the hot water outlet and the hot water temperature measurement thermometer.

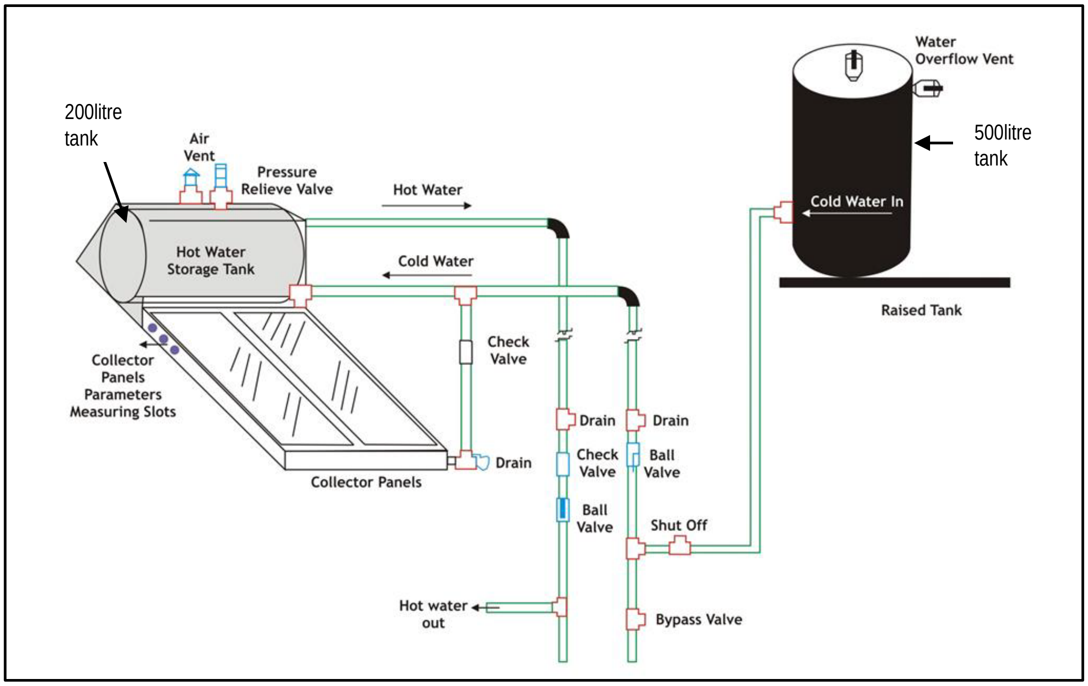

Fig.3.2. Schematic of the SWH system similar to the one installed at the hotel [15]

Fig.3.3. Flat plate collector SWH at the hotel

The performance characteristics of the SWH are outlined in table 3.1

Table 3.1: Performance characteristics of solar water heater with a flat plate collector model FPC1200A [22]

COLLECTOR THERMAL PERFORMANCE RATING							
Kilowatt-hours (thermal) Per Panel Per Day				Thousands of Btu Per Panel Per Day			
Climate -> Category (Ti-Ta)	High Radiation (6.3 kWh/m².day)	Medium Radiation (4.7 kWh/m².day)	Low Radiation (3.1 kWh/m².day)	Climate -> Category (Ti-Ta)	High Radiation (2000 Btu/ft².day)	Medium Radiation (1500 Btu/ft².day)	Low Radiation (1000 Btu/ft².day)
A (-5 °C)	8.4	6.4	4.4	A (-9 °F)	28.7	21.8	14.9
B (5 °C)	7.5	5.5	3.5	B (9 °F)	25.7	18.7	11.8
C (20 °C)	6.1	4.2	2.2	C (36 °F)	21.0	14.2	7.5
D (50 °C)	3.6	1.8	0.3	D (90 °F)	12.2	6.1	1.0
E (80 °C)	1.4	0.1	0.0	E (144 °F)	4.6	0.5	0.0
A- Pool Heating (Warm Climate) B- Pool Heating (Cool Climate) C- Water Heating (Warm Climate) D- Space & Water Heating (Cool Climate) E- Commercial Hot Water & Cooling							

COLLECTOR SPECIFICATIONS					
Gross Area:	2.000 m²	21.53 ft²	Dry Weight:	35 kg	77 lb
Net Aperture Area:	1.850 m²	19.91 ft²	Fluid Capacity:	1.8 liter	0.5 gal
Absorber Area:	1.853 m²	19.94 ft²	Test Pressure:	900 kPa	131 psi

The left half of table 3.1 gives performance in metric units, and the right in US units. The flat Plate Collector used in the study fits category C; water heating in a warm climate where Tinlet - Tambient = +20°C. As per table 3.1, the collector is capable of providing energy equivalent to 6.1kWh or 21.96MJ in heating water during periods of high radiation, 4.2kWh or 15.12MJ during medium radiation periods and 2.2kWh or 7.92MJ during low radiation periods [22].

3.2 Data Collection Procedure

Monitoring of the temperature of the water from the instant shower and the electricity consumption by the instant shower was carried out for a period of 30 days from 1st February 2015 to 2nd March 2015. The temperature of the hot water from the SWH was taken and recorded at 2 points; the roof tank storage and at the shower head in the hotel room. At the time of monitoring the temperatures of the water from the SWH, care was taken to ensure that the instant shower system had been switched off.

Temperatures recordings at the 2 points were taken 4 times per day i.e. 0900hrs, 1200hrs, 1500hrs and 1800hrs. Table 3.2 shows sample recordings of the temperatures of water at the roof tank storage of the SWH system while table 3.3 illustrates sample recordings of the temperature of water at the shower head. The temperatures were taken sequentially beginning with the roof top tank storage followed by the shower head at the hotel room. For the shower head, shower water would be put on and then monitored until the thermometer readings stabilized.

Table 3.2. Sample recordings of the temperature of water in ºC at the roof top storage of the SWH.

Day	@0900hrs	@1200hrs	@1500hrs	@1800hrs
11-Mar-15	25.6	38.6	47.3	38.5
12-Mar-15	26.2	41.2	50.3	34.5
13-Mar-15	30.1	40.1	53.5	28.5
14-Mar-15	27.0	49.0	54.5	28.0
15-Mar-15	30.1	51.4	55.0	42.6
16-Mar-15	28.2	48.7	55.5	42.5
17-Mar-15	31.7	50.5	56.6	49.5
18-Mar-15	32.8	37.2	52.1	32.7

Table 3.3. Sample recordings of the temperature of water in ºC at the shower head.

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
11-Mar-15	24.3	36.7	44.9	36.6
12-Mar-15	25.0	39.3	47.9	32.9
13-Mar-15	28.7	38.3	51.0	27.2

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
14-Mar-15	25.7	46.6	51.9	26.7
15-Mar-15	29.2	49.9	53.4	41.3
16-Mar-15	27.0	46.7	53.2	40.8
17-Mar-15	30.1	48.0	53.8	47.1
18-Mar-15	31.1	35.3	49.4	31.0

3.3 Data Analysis

The collected data was organized and analyzed by use of a Microsoft Excel spreadsheet. The data was then presented in bar and line graphs.

3.4 Data Verification

Data verification was done by proof reading the final data sheet against the original recordings. This method was time consuming but quite accurate.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 RESULTS

4.1.1 Shower water consumption:

The average shower water consumption in a standard hotel room for the period 1st February 2015 to 2nd March 2015 was 47.17litres per day. The detailed results of the shower water consumption measurements in this period are presented in fig. 4.1 and table 4.1.

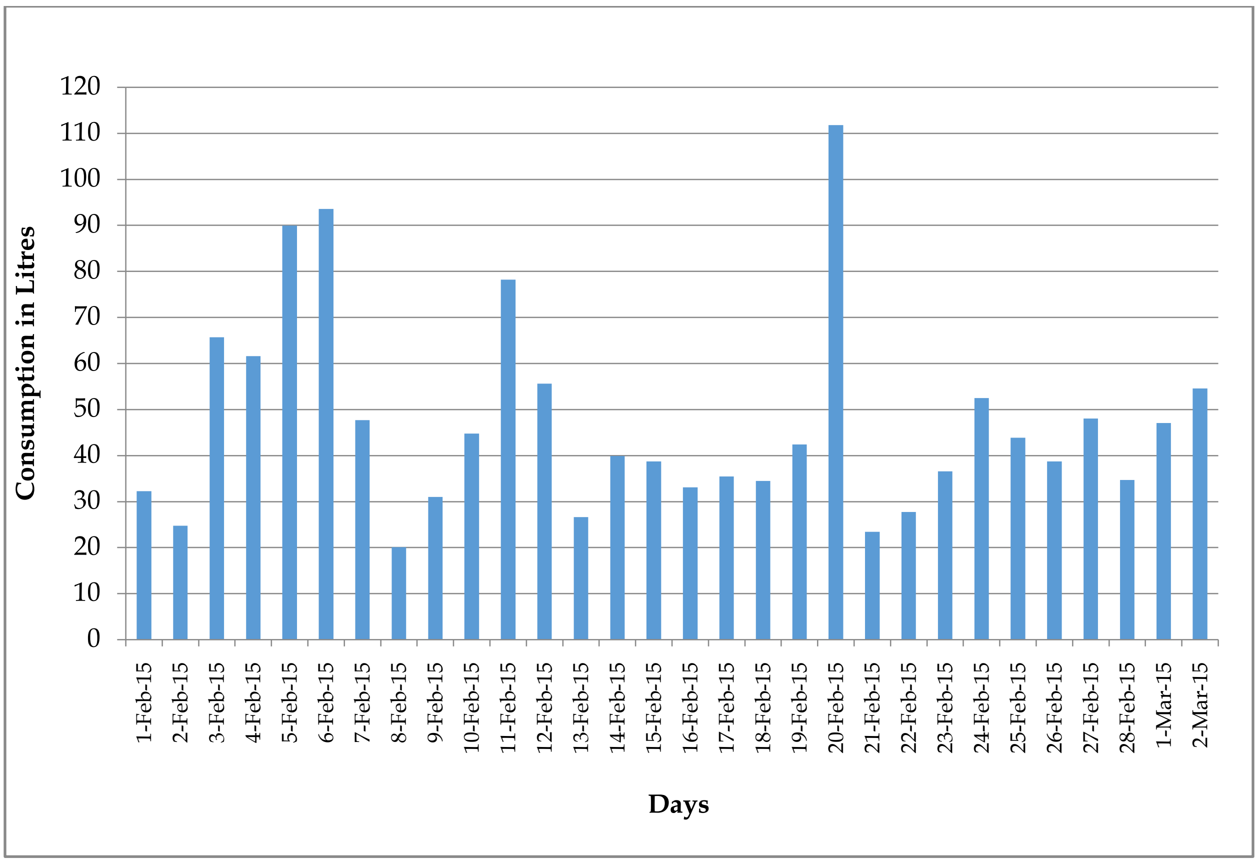

Fig.4.1. Shower water consumption in a standard hotel room

The result of the daily average shower water consumption per room is comparable to the Werden and Spielvogel study that found an average of 14 gallons or 52litres/room/day in a range of hotels averaging 55 rooms [5].

Table 4.1: Shower water volume flow recordings at the hotel room

Date	Consumption in Litres
1-Feb-15	32.25
2-Feb-15	24.75
3-Feb-15	65.70
4-Feb-15	61.60
5-Feb-15	89.95
6-Feb-15	93.60
7-Feb-15	47.70
8-Feb-15	20.10
9-Feb-15	31.00
10-Feb-15	44.80
11-Feb-15	78.25
12-Feb-15	55.60
13-Feb-15	26.65
14-Feb-15	39.90
15-Feb-15	38.70
16-Feb-15	33.10
17-Feb-15	35.45
18-Feb-15	34.45
19-Feb-15	42.40
20-Feb-15	111.80
21-Feb-15	23.45
22-Feb-15	27.75
23-Feb-15	36.60
24-Feb-15	52.50
25-Feb-15	43.90
26-Feb-15	38.70
27-Feb-15	48.05
28-Feb-15	34.70
1-Mar-15	47.05
2-Mar-15	54.55
Average	**47.17**

From the data, it is noted that the highest shower water consumption was recorded at 111.80litres on 20th February 2015 while the least consumption was recorded at 20.10litres on 8th February 2015. The variations in shower water consumption can be explained in four ways:

a) Client behavior: The different occupants of the room could have had variant shower lengths leading to variations in water consumption;
b) Volume flow settings: Some clients may have had their shower water valves opened more leading to high water flow rates and eventual higher consumption;
c) Number of shower sessions: Some occupants could have had more than the traditional 2 showers i.e. morning and evening showers; and

In regard to solar water heating, a SWH with a 200litres roof top storage tank was chosen. The 200litre capacity was chosen based on the findings of the study by Shahidul Islam Khan in 2011 which found that the temperature retaining capacity of a 200litre storage tank SWH was better when compared to a 100litre storage tank SWH [21]. Based on the resultant shower water consumption of 47.17litres per room per day, the SWH with a 200litre storage tank would serve about 4 rooms at the hotel.

4.1.2 Shower water temperature while using the instant electric shower:

The average temperature of the water from the instant electric shower was 39.8°C per day. The results of the water temperature measurement from the instant electric shower are presented in fig. 4.2 and table 4.2.

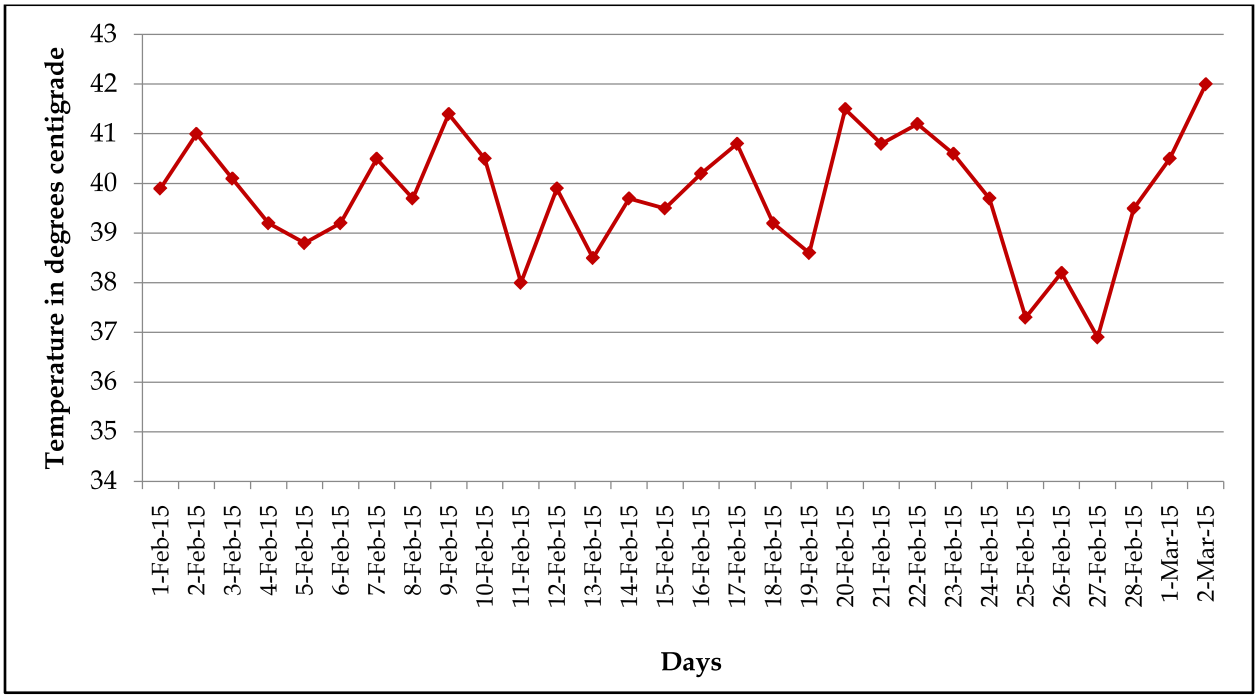

Fig.4.2. Water temperature from the instant electric shower at the hotel room

The findings indicate that the highest recorded temperature of water from the instant electric shower was 42.0°C on 2nd March 2015 while the lowest temperature was 36.9°C and was recorded on 27th February 2015.

Table 4.2: Water temperature recordings from the instant electric shower at the hotel room

Days	Temperature in °C
1-Feb-15	39.9
2-Feb-15	41.0

Days	Temperature in ºC
3-Feb-15	40.1
4-Feb-15	39.2
5-Feb-15	38.8
6-Feb-15	39.2
7-Feb-15	40.5
8-Feb-15	39.7
9-Feb-15	41.4
10-Feb-15	40.5
11-Feb-15	38.0
12-Feb-15	39.9
13-Feb-15	38.5
14-Feb-15	39.7
15-Feb-15	39.5
16-Feb-15	40.2
17-Feb-15	40.8
18-Feb-15	39.2
19-Feb-15	38.6
20-Feb-15	41.5
21-Feb-15	40.8
22-Feb-15	41.2
23-Feb-15	40.6
24-Feb-15	39.7
25-Feb-15	37.3
26-Feb-15	38.2
27-Feb-15	36.9
28-Feb-15	39.5
1-Mar-15	40.5
2-Mar-15	42.0
Average	**39.8**

4.1.3 Instant Shower electricity consumption:

The study found that the average electricity consumption by the 4.5kW rated Lorenzetti instant electric shower was 0.75kWh per room per day. Assuming uniform electricity consumption by the instant electric showers installed in each of the 60 rooms, the hotel would have consumed 45kWh of electricity per day. This translates to 1,350kWh per month. For a typical month, the contribution of the electricity bill as a result of the instant showers was 36% with the other power consumption utilities being refrigeration, water pumping, space cooling and lighting. The results of electricity consumption by the instant electric shower are presented in fig. 4.3 and table 4.3.

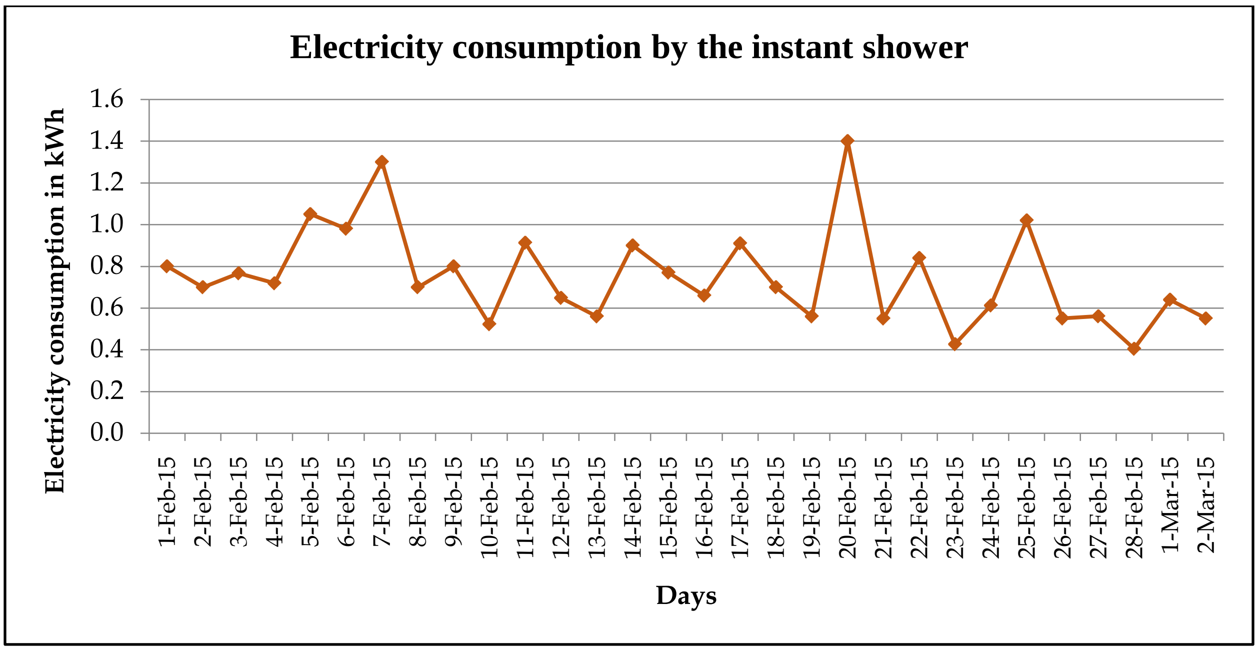

Fig.4.3. Electricity consumption by the instant shower

Fig 4.3 indicates that the highest electricity consumption by the instant electric shower was 1.40kWh and was recorded on 20th February 2015, the same date when the volume of shower water consumed was highest. It therefore means that the higher the volume of water heated by the instant electric shower, the more power was consumed.

Table 4.3 Recordings of electricity consumption by the instant shower

Days	Electricity consumption in kWh
1-Feb-15	0.80
2-Feb-15	0.70
3-Feb-15	0.77
4-Feb-15	0.72
5-Feb-15	1.05
6-Feb-15	0.98
7-Feb-15	1.30
8-Feb-15	0.70
9-Feb-15	0.80
10-Feb-15	0.52
11-Feb-15	0.91
12-Feb-15	0.65
13-Feb-15	0.56
14-Feb-15	0.90
15-Feb-15	0.77
16-Feb-15	0.66
17-Feb-15	0.91
18-Feb-15	0.70
19-Feb-15	0.56
20-Feb-15	1.40
21-Feb-15	0.55
22-Feb-15	0.84
23-Feb-15	0.43
24-Feb-15	0.61
25-Feb-15	1.02
26-Feb-15	0.55
27-Feb-15	0.56
28-Feb-15	0.40
1-Mar-15	0.64
2-Mar-15	0.55
Average	**0.75**

Based on the average electricity consumption and the prevailing electricity tariff, the instant electric showers at the hotel incurred about 344,184.62Kshs/year as illustrated in table 4.4.

Table 4.4. Sample electricity bill for the hotel when using instant electric showers

Component	Kshs
Fixed Charge (FC)[3]	150.00
Energy Charge (EC) - 13.5Kshs/kWh [3]	221,737.50
Fuel Cost Charge (FCC) - 251 cents/kWh [3]	41,226.75
Forex Adjustment (FA) - 106 cents per kWh [3]	17,410.50
Inflation Adjustment (IA) - 23 cents per kWh [3]	3,777.75
Warma Levy (WL) - 5 cents per kWh [3]	821.25
ERC levy (ERCL) - 3 cents per kWh [3]	492.75
Rural Electrification Program Levy (REP)* - 5% [3]	11,094.38
Sub-Total	296,710.88
*Value Added Tax (VAT) -16%[3]	47,473.74
Electricity bill payable	**344,184.62**

REP Levy = 5 % X (FC + EC) (4.1)

*VAT = 16 % X (FC+EC+FCC+FA+IA+WL+ERCL+REP) (4.2)

4.1.4 Temperature of the hot water at the roof top tank storage of the SWH

The highest water temperature at the roof top tank storage of the SWH was 56.6°C and was recorded on 17th March at 1500hrs. The lowest water temperature was 19.0°C and was recorded on 29th March 2015 at 0900hrs.

Results of the water temperature measurement at the roof top tank storage of the SWH are presented in fig. 4.4 and table 4.

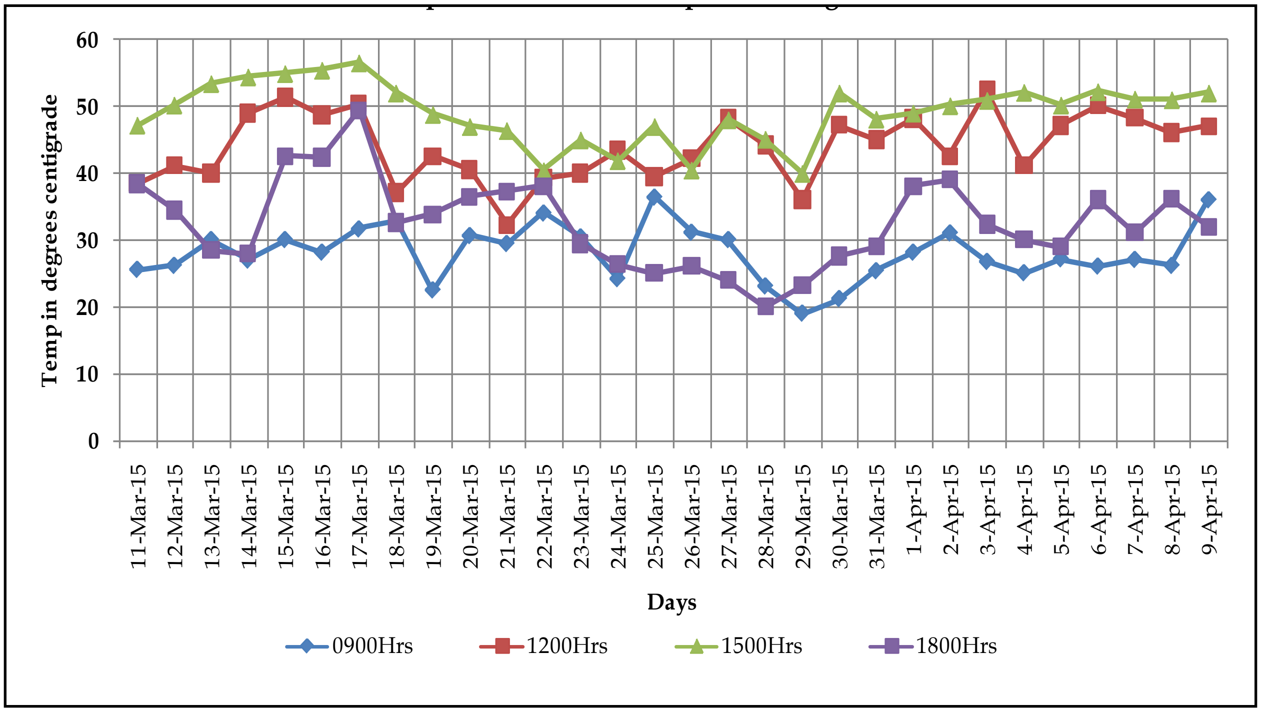

Fig.4.4. Temperature of water at the roof top tank storage of the SWH

Table 4.5. Temperature of the water at the roof top tank storage of the SWH

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
11-Mar-15	25.6	38.6	47.3	38.5
12-Mar-15	26.2	41.2	50.3	34.5
13-Mar-15	30.1	40.1	53.5	28.5
14-Mar-15	27.0	49.0	54.5	28.0
15-Mar-15	30.1	51.4	55.0	42.6
16-Mar-15	28.2	48.7	55.5	42.5
17-Mar-15	31.7	50.5	56.6	49.5
18-Mar-15	32.8	37.2	52.1	32.7
19-Mar-15	22.5	42.6	48.9	33.9
20-Mar-15	30.7	40.6	47.1	36.6
21-Mar-15	29.5	32.4	46.5	37.4
22-Mar-15	34.1	39.4	40.5	38.1
23-Mar-15	30.5	40.1	45.1	29.5
24-Mar-15	24.2	43.5	42.0	26.5
25-Mar-15	36.5	39.6	47.1	25.1
26-Mar-15	31.2	42.3	40.6	26.2
27-Mar-15	30.1	48.3	48.1	24.1
28-Mar-15	23.1	44.3	45.2	20.1
29-Mar-15	19.0	36.2	40.1	23.2

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
30-Mar-15	21.2	47.3	52.1	27.6
31-Mar-15	25.4	45.1	48.2	29.1
1-Apr-15	28.2	48.2	49.1	38.2
2-Apr-15	31.1	42.6	50.2	39.1
3-Apr-15	26.8	52.5	51.0	32.4
4-Apr-15	25.1	41.2	52.2	30.2
5-Apr-15	27.2	47.2	50.3	29.1
6-Apr-15	26.1	50.2	52.3	36.1
7-Apr-15	27.1	48.3	51.2	31.2
8-Apr-15	26.2	46.1	51.1	36.2
9-Apr-15	36.1	47.1	52.1	32.1
Average	**28.1**	**44.1**	**49.2**	**32.6**

4.1.5 Temperature of the water from the SWH at the shower head of the room

The highest water temperature from the SWH at the shower head of the hotel room was 53.8ºC and was recorded at 1500hrs on 17th March 2015. The lowest water temperature was recorded at 18.1ºC and was recorded at 0900hrs on 29th March 2015. The results indicate that a drop in the water temperature occurred as it traversed from the roof top tank storage to the shower head of the room. The temperature drop is attributable to heat losses as the water travelled down the Polyvinylchloride (PVC) pipes. The results of the water temperature measurement at the shower head when the SWH was in use are presented in fig. 4.5 and table 4.6.

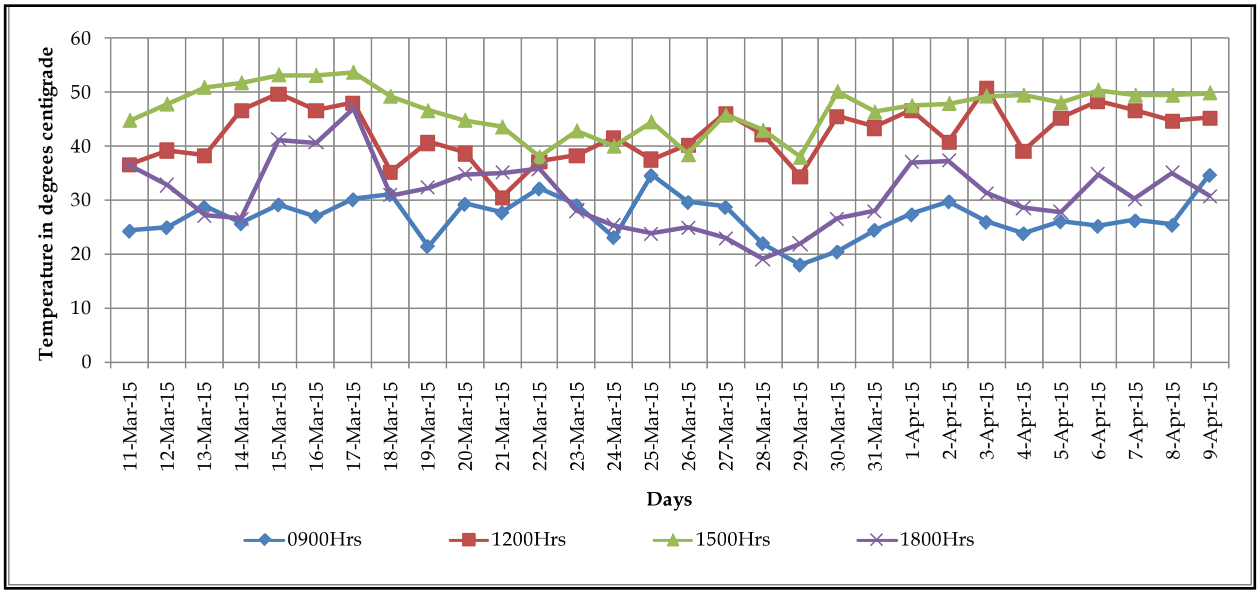

Fig.4.5. Temperature of the water at the shower head while using the SWH

Table 4.6. Temperature of the water at the shower head while using the SWH

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
11-Mar-15	24.3	36.7	44.9	36.6
12-Mar-15	25.0	39.3	47.9	32.9
13-Mar-15	28.7	38.3	51.0	27.2
14-Mar-15	25.7	46.6	51.9	26.7
15-Mar-15	29.2	49.9	53.4	41.3
16-Mar-15	27.0	46.7	53.2	40.8
17-Mar-15	30.1	48.0	53.8	47.1
18-Mar-15	31.1	35.3	49.4	31.0
19-Mar-15	21.5	40.7	46.7	32.4
20-Mar-15	29.3	38.7	44.9	34.9
21-Mar-15	27.7	30.5	43.7	35.2
22-Mar-15	32.2	37.2	38.2	35.9
23-Mar-15	29.1	38.2	43.0	28.1
24-Mar-15	23.1	41.6	40.2	25.3
25-Mar-15	34.6	37.5	44.7	23.8
26-Mar-15	29.6	40.2	38.6	24.9
27-Mar-15	28.7	46.1	45.9	23.0
28-Mar-15	22.0	42.2	43.1	19.2
29-Mar-15	18.1	34.4	38.1	22.0
30-Mar-15	20.5	45.6	50.3	26.6
31-Mar-15	24.5	43.5	46.5	28.1

Days	@0900hrs	@1200hrs	@1500hrs	@1800hrs
1-Apr-15	27.4	46.8	47.6	37.1
2-Apr-15	29.8	40.8	48.0	37.4
3-Apr-15	26.0	50.9	49.4	31.4
4-Apr-15	23.8	39.1	49.6	28.7
5-Apr-15	26.1	45.2	48.2	27.9
6-Apr-15	25.2	48.5	50.5	34.9
7-Apr-15	26.2	46.8	49.6	30.2
8-Apr-15	25.4	44.7	49.6	35.1
9-Apr-15	34.7	45.2	50.0	30.8
Average	**26.9**	**42.2**	**47.1**	**31.2**

4.1.6 Combined temperature profiles of the water at the roof top tank storage and at the shower head while using SWH

The temperature drop between the roof tank storage of the SWH and the shower head of the hotel room is illustrated in fig. 4.6 and table 4.7.

Table 4.7. Average temperature drop at the shower head compared to the roof top tank storage of the SWH.

Location	0900hrs	1200hrs	1500hrs	1800hrs
Roof top storage	**28.1**	**44.1**	**49.2**	**32.6**
Shower Head	**26.9**	**42.2**	**47.1**	**31.2**
Temperature difference in ºC	**1.2**	**1.9**	**2.1**	**1.4**

The highest average recorded temperature drop between the roof top tank storage and the shower head was 2.1ºC and occurred at 1500hrs while the lowest drop was 1.2ºC and was recorded at 0900hrs.

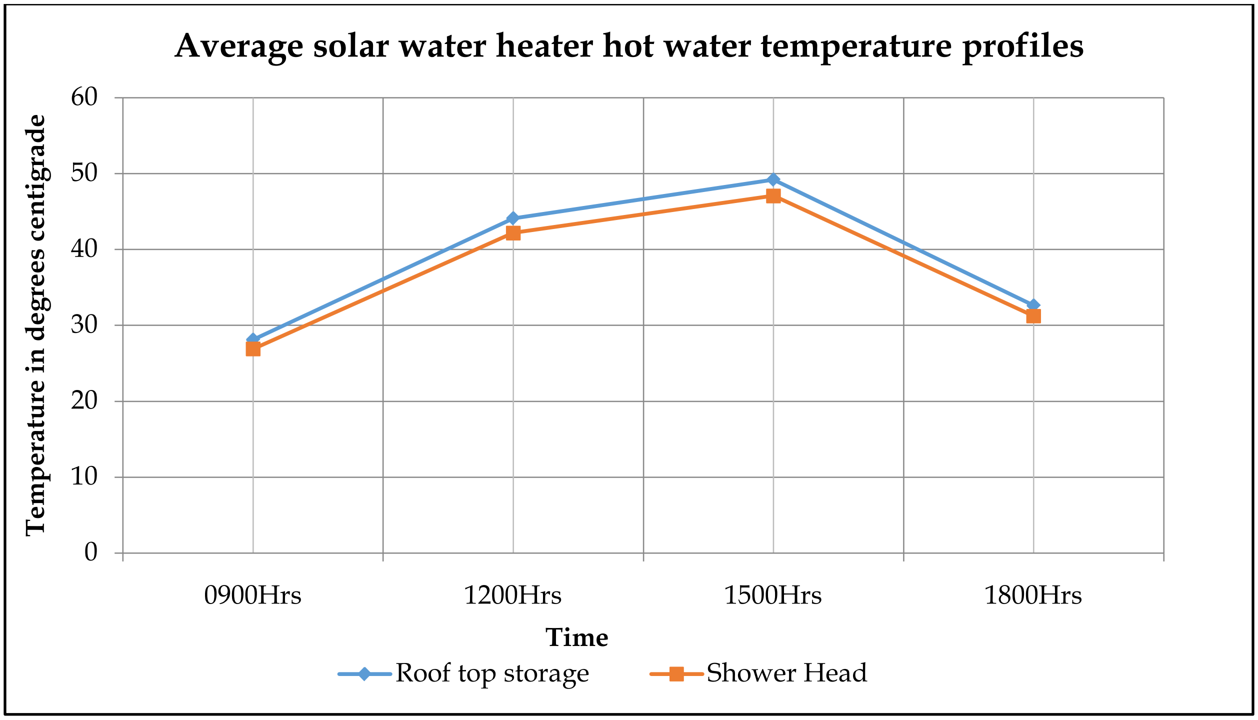

Fig.4.6. Combined graph of the water temperature at the roof tank storage and the shower head in room 101 when the SWH was in use

4.2 DISCUSSIONS

As illustrated in table 4.4, the calculated electricity bill for the hotel while using instant electric shower heaters would have been Kshs.344,184.62 assuming uniform consumption by the 60 rooms at the hotel. Further, the results of water temperature measurements at the shower head of the hotel room while the SWH was in use indicate an average temperature of 26.9°C at 0900hrs and 31.2°C at 1800hrs. If shower water was to be drawn at these times, supplementary heating would be required and the electricity consumed due to such heating is calculated as follows:

1. Assuming that hot showers were taken at 0900hrs, the extra electricity required to heat the water would have been calculated as:

   $m*c*(T_R - T_A)$ (4.3)

   Which becomes 47.17 X 1000 X 4.2J/g.K X (39.8-26.9) = 2.56MegaJoules (MJ)

   1kWh = 3.6MJ

   Converting the energy used in extra heating = 2.56/3.6 =**0.71kWh** per room per day

   Where:

   i) m is the average shower water volume consumption per person per day which was 47.17

   ii) c is the heat capacity of water which is 4.2J/g.K

   iii) T_R is the average shower water temperature while using an instant electric shower which was 39.8ºC

   iv) T_A is the average water temperature at 0900hrs at the shower head while using a SWH which was 26.9ºC

2. Assuming that hot showers were taken at 1800hrs, the extra electricity required to heat the water would be:

   i. 47.17 X 1000 X 4.2J/g.K X (39.8-31.2) = 1.70MegaJoules (MJ)

   ii. 1kWh = 3.6MJ

iii. Converting the energy utilized in additional heating into kWh = 1.70/3.6 =**0.47kWh** per room per day

Due to the high supplementary heating required especially at 0900hrs which almost equals the consumption of 0.75kWh by the instant electric showers, it would be beneficial to explore alternatives SWH technologies such as the evacuated tube collector system. Evacuated tubes work efficiently at low radiation levels with high absorber temperatures and can provide higher output temperatures than flat plate collectors and they can be used in applications where the demand temperature is 50–95 °C or in colder climates [23].

The calculated average water temperature at the showerhead of the hotel room when the SWH was in use from 0900hrs to 1800hrs was 36.8°C. Taking into consideration the extra heating required, the payback period for the SWH project can be calculated as follows:

Extra electrical energy required in heating the water = 47.17 X 4.2 X 1000 X (39.8-36.8) = 0.59MJ

Converting the energy into kWh = 0.59/3.6 = 0.16kWh per room per day or 59.82kWh per room per year

For the 60 rooms at the hotel this translates to 3,589.17kWh per year. The electricity bill payable for this level of consumption is illustrated in table 4.8.

Table 4.8. Bill payable for the extra electrical energy required to supplement the SWH in heating shower water

Component	Kshs
Fixed Charge[3]	150.00
Energy Charge - 13.5Kshs/kWh[3]	48,453.80
Fuel Cost Charge (FCC) - 251 cents/kWh[3]	9,008.82
Forex Adjustment - 106 cents per kWh[3]	3,804.52
Inflation Adjustment - 23 cents per kWh[3]	825.51
Warma Levy - 5 cents per kWh[3]	179.46
ERC levy - 3 cents per kWh[3]	107.68
Rural Electrification Program Levy (REP) - 5%[3]	11,094.38
Sub-Total	73,624.15
VAT -16%[3]	11,779.86
Bill payable due to extra heating requirement when the SWH is in use	**85,404.01**

The payback period = ((15*112,500)/ (344,184.62-85,404.01)) = **6.5years**

Where:

i. 15 is the number of SWH required for the hotel bearing in mind that each SWH has 200litre tank storage and that the consumption per hotel room is 47.17litres per day and that the hotel has 60 rooms.

ii. 112,500 was the cost of purchase and installation of 1 SWH

iii. 344,184.62 is the electricity bill when using the instant electric showers for all the rooms at the hotel.

Due to the high cost of SWHs, programs such as Scaling-up Renewable Energy in Low Income Countries (SREP) have been developed. Kenya is one of the six pilot countries selected to benefit from the SREP [24]. In Kenya, the SREP is jointly managed by the African Development Bank (AfDB), the World Bank Group (WBG) and the International Finance Corporation (IFC).

SREP targets installation of 50,000 SWHs in Kenya at a total cost of USD60,000 of where USD10,000 will be contributed by SREP and the balance by Multi Lateral Development Banks (MDBs), Development Partners and the Private Sector [24]. SREP estimates that energy demand side management by using domestic solar water heaters can reduce the energy demand in Kenya by up to 820GWh per year from the grid [24]. Converting this level of electricity consumption into a bill, amounts to KShs16.5 billion which is the approximate amount either in whole or part that the country would save by embracing use of SWH.

CHAPTER FIVE

5.0 CONCLUSSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The objectives of this study were to determine the volume of shower water consumed per room at a typical hotel. Thereafter purchase and install a suitable SWH system and investigate its viability when used as a replacement to the instant electric shower system. In investigating the viability of the SWH system, the study aimed at comparing the water temperatures achieved by the SWH system at the shower head with the water temperatures attained while using an instant electric shower system. Further, while using the SWH as an alternative to the instant shower, the study sought to establish the savings in form of electric energy consumption and thereafter calculate the payback period for the SWH. The following conclusions can be drawn:

1. The shower water consumption at the hotel was found to be **47.17litres per room per day**.
2. The daily electric consumption by the instant shower was found to be **0.75kWh per room per day**.
3. The average shower water temperature from the instant electric shower was **39.8ºC**.

4. The highest recorded water temperature at the roof top tank storage of the SWH was **56.6ºC** while the lowest recorded water temperature was **19.0ºC**.
5. The highest recorded water temperature from the SWH at the shower head of the hotel room was **53.8ºC** while the lowest recorded temperature was **18.1ºC**.
6. The average temperature drop from the roof tank storage of the SWH to the shower head of the hotel room was **1.7ºC**.
7. The calculated payback period for the SWH project was **6.5years**.

5.2 RECOMMENDATIONS

To further enrich the findings of this study, it is recommended that:

1. Further studies be conducted on the viability of the replacement of an instant electric shower system in a hotel by use of a more efficient SWH system such as the evacuated tubes type;
2. Additional studies be conducted to investigate the performance of different SWHs in similar environments;
3. Collection of solar data for Kenya be undertaken to make it easy to estimate the performance of SWH in other places in the republic.

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