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DEPARTMENT OF MECHANICAL AND MANUFACTURING

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VIRGINIA MUTHINI

BSC (MECHANICAL ENGINEERING), MOI UNIVERSITY, 2011

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TOPIC: **Assessment of Hotel Hot Water Systems and Viability of Solar Water Heating: Case Study of Sarova Hotel Nairobi**

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DECLARATION

Name of student: Virginia Muthini

Registration Number: F56/11978/2018

Faculty/School/Institute: Faculty of Engineering

Department: Department of Mechanical and manufacturing Engineering

Course Name: Master of Science in Energy Management

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Assessment of Hotel Hot Water Systems and Viability of Solar Water Heating: Case Study of Sarova Hotel Nairobi

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ABSTRACT

Hotel systems especially water heating consume significant amount of energy leading to high operational costs. High cost of electricity and fuel price volatility coupled with tighter environmental regulations on emissions have motivated hotels to invest in sustainable energy such as solar water heating (SWH). Studies have shown that the design and sizing of a SWH system is unique to every hotel depending on the hot water consumption patterns, climatic conditions and site location. This research focused on statistical analysis of recorded water-heating data in a case study hotel located in Kenya's capital city to determine average daily hot water requirements, fuel consumption and system efficiency. The analyzed data together with solar resource data obtained from online renewable energy software – RETscreen was used to size and optimize a SWH system to meet up to 60% of the hotel's hot water demand load. The results indicated that the hotel's average hot water requirement was $48.06m^3$ and the corresponding energy demand load was 1955kWh/day. The designed solar hot water system was sized at $284.6m^2$ collector area and the system performance was evaluated to be 314.4MWh per year. The system cost was estimated at around 83,508.28 USD and the annual financial savings were around 29,756.55 USD. The results of this study were validated through a site visit to a hotel with an already installed SWH system which concurred that the sized SWH system for the case study hotel was reasonable. In conclusion, the use of solar water heating to meet hotel hot water demand load was found to be a viable undertaking based on the evaluated financial indicators.

ABBREVIATIONS

ASHRAE – American Society of Heating, Refrigeration and Air- conditioning Engineers

BOQ – Bill of Quantities

EPRA – Energy & Petroleum Regulatory Authority

ETC – Evacuated Tube Collector

EUI – Energy Use Intensity

FPC – Flat Plate Collector

GHG – Greenhouse gases

IRR – Internal Rate of Return

HVAC – Heating Ventilation and Air conditioning

HTF – Heat Transfer Fluid

KJ – Kilo Joules

KWh – Kilowatt-hour

Kshs – Kenya shillings

LPG – Liquefied Petroleum Gas

MWh – Megawatt hour

NASA – National Aeronautics and Space Administration

NPV – Net Present Value

O&M – Operation and Maintenance

SWH – Solar Water Heating

USD – United States Dollar

1.0 INTRODUCTION

1.1 Background

It is estimated that residential and commercial buildings account for between 30% and 40% of the global energy consumption with associated carbon emissions of between 25% and 35% [1, 2, 3]. Hotels are classified as one of the most energy intensive buildings in the commercial sector. This is due to the various energy-consuming appliances operated to meet the thermal and visual comfort of guests as well as for food preparation and preservation. Nevertheless, studies have shown that significant energy savings can be achieved by adopting energy saving practices such as lighting control, regulating space heating and cooling, use of energy efficient appliances among others [4].

The main energy consuming systems in hotel buildings are water heating, HVAC, lighting and cooking. These energy needs are met by various energy sources such as electricity, gas and oil. The high cost of electricity and fluctuating cost of oil and gas increases the operation cost. It has been reported that the cost of energy accounts for up to 20% of the total operational cost in Kenyan hotels [5]. Water heating is a key system in hotel operations as majority of activities such as cooking, guest showers and laundry require hot water. Studies have shown that water heating accounts for between 12% and 17% of the total hotel energy consumption [6] [7]. Furthermore, most of the fuels used in water heating such as biomass fuels, oil, LPG and electric geysers are unfavorable in terms of health, price and environmental issues [8, 4].

Sustainable operations have become a focal point for the hospitality industry in the pursuit to cut down operations cost and ensure maximum profits. Furthermore, hotel guests have become increasingly aware and interested in issues concerning environmental protection, greenhouse gas emissions, renewable energy and waste treatment measures [4]. This means the world population is becoming more conscious of environmental sustainability and would prefer eco-friendly hotels at any given time. As a result, therefore, incorporating renewable energy sources in the hotel energy mix will not only help reduce the operation cost but also act as a marketing strategy.

Solar energy is one of the widely used renewable energy resource for both commercial and domestic applications. Globally, solar thermal technologies have gained attention to provide low and medium temperature heat for hot water, space heating, cooking and drying [8]. Such thermal technologies include solar water heating (SWH) which has proven to be cost efficient in terms of installation expenditure and energy cost over the total life of the system [9].Technically, SWH systems have advanced from simple designs to more efficient systems capable of meeting large scale hot water demands at affordable costs.

In summary, reliance on the conventional energy sources pose serious threat to the environment due to associated greenhouse gas emissions. Energy consumption in buildings and especially hotels is fundamental and hot water production consumes a big share of this energy. Use of renewable energy sources to meet these energy needs will not only save on cost but also help mitigate environmental pollution associated with conventional sources. Besides, hotel owners and guests have become increasingly aware and committed to green practices. Solar thermal technologies have been proven to cost effectively convert solar energy into useful heat for low and medium temperature applications. The combination of these factors places hotels at the forefront in utilizing solar water heating systems to meet daily hot water demands. This study involved assessment of a hotel hot water system and the feasibility of incorporating a solar water heating system to displace the intake of the conventional fuels.

1.2 Problem Statement

Water heating in hotels make up a significant portion of the overall energy consumption. To meet the hot water needs, hotels burn fossil fuel such as gas and oil in boilers or operate electric water heaters. High electricity prices and volatile fuel prices expose hotels to increased operation costs and hence reduced profits. Moreover, burning of the conventional fuels to meet hot water needs or generate electricity which would be used for water heating result in greenhouse gas emissions. Solar water heating provides a clean and cost-effective way of utilizing the sun energy to meet a fraction, if not all, of the hotel hot water needs. Sarova hotel, Nairobi is located within the tropics where annual daily solar insolation ranges from 4 to 6 kWh/m^2/day with no significant variations throughout the year. In view of the ongoing, implementation of solar water heating is expected to cut down the operation cost by reducing diesel intake in addition to conserving the environment.

1.3 Objectives

The main objective of this study was to analyze the existing hot water system at Sarova hotel, Nairobi and assess the viability of using a solar water heating system to meet the hot water demand.

The specific objectives were;

i) To determine the average daily hot water requirements of the hotel
ii) To evaluate the existing hot water system in terms of fuel consumption and system efficiency
iii) To determine the viability of using a solar water heating system to meet the hotel hot water demand load.
iv) Validation of the research work

1.4 Research Questions

i) What is the average amount of hot water required in the hotel per day
ii) At what temperature is the hot water required
iii) What are technical and economic issues of the existing hot water system
iv) What fraction of hot water energy load can be met using a SWH system
v) What are the economic and environmental benefits of SWH systems in hotels

1.5 Justification

The intense energy use in hotels especially for water heating cumulatively add to the overall operation cost. Use of conventional energy sources to meet these energy needs negatively impacts the environment and significantly contribute to adverse climate change. On the other hand, renewable energy sources such as solar, wind, geothermal and hydropower can help reduce greenhouse gas emissions and consequently mitigate climate change. Solar thermal technologies, especially solar water heating, have gained global attention due to their cost effectiveness and efficiency. Use of solar water heating in hotels can significantly reduce the operation cost, maximize profits and ensure competitiveness. Despite its immense benefits, SWH is still underutilized in Kenyan hotels. Hotels still rely on fossil fuels such as gas and oil to meet hot water needs, this could be attributed to inadequate feasibility studies. Therefore, a case study assessment of a hotel hot water system and viability of using SWH to meet the hot water needs will give a much-needed insight.

1.6 Scope

The scope covers a case study hotel hot water system to determine hot water demand and evaluate the system efficiency. Existing data on water heating was statistically analyzed to determine average daily hot water consumption as well as fuel consumption rate. A SWH system was then sized to meet a fraction of the hot water requirements of the hotel. Economic indicators namely Net Present Value, Internal Rate of Return and Payback period were computed and used to determine the viability of the SWH system.

1.7 Project Organization

The remaining part of the report comprises of literature review, methodology, results and discussion and lastly conclusions and recommendations. The literature review chapter covers the basic concepts in SWH systems such as system components and classification of SWH systems. Next an evaluation of the energy use and management in hotels is done to ascertain the major contributors of energy use in hotels and possible energy saving opportunities and finally a review of previous research work done on SWH systems in hotels to identify the research gaps. Chapter three on methodology reviews previous methods used in various research work on SWH in hotels and describes the adopted research design used to achieve the study objectives. Problem formulation and design considerations are also included in the chapter. Chapter four presents and discusses the results of the study as well as the SWH system design. The conclusions and recommendations for further work are given in the last chapter. A list of references and appendices are also listed.

2.0 LITERATURE REVIEW

2.1 Solar Water Heating Systems

Solar Water heating is a cost effective and environmentally friendly way of heating water for use in residential and commercial buildings such as hospitals, hotels and institutions. It is the most commonly used solar thermal technology owing to its simplicity and technological advancements [9]. The systems operate on a basic principle of absorbing and converting sun's energy into heat through solar collectors. The heat energy is then transferred to potable water directly or to a heat-transfer fluid (HTF) such as a water-glycol antifreeze mixture, which then transfers the heat to the potable water. Due to the intermittent nature of solar energy, a preheat or conventional hot water tank is usually incorporated into the SWH system to store hot water during periods of high insolation to be used when the sun energy is unavailable. Furthermore, electric heaters or fossil fuel boilers are used to supplement the solar hot water system during periods of increased hot water demand or overcast weather conditions.

The direct heating of the potable water by the heat transfer fluid makes SWH more energy efficient as compared to use of solar PV panels to generate electricity to be subsequently used for water heating. Additionally, it is common knowledge that PV panels captures 15-25% of the available sunlight whereas solar thermal panel can capture up to 90% of the available sunlight energy [10]. Over and above, if PV panels are used to generate electricity for use on an electric boiler or heat pump, there can be inevitably large energy conversion losses which could be avoided by heating the water directly using solar thermal panels. As such solar water heating is considered not only a reliable way of harnessing sun's energy but also a cost effective and efficient technology.

The global SWH market is growing rapidly; particularly in Kenya, over one-third of homes in urban areas are equipped with SWH systems. Study has shown that as of April 2017, there was about 77,000 SWH systems equivalent to approximately 457,076m^2 collector area installed in Kenya [11]. It is worth noting that a bigger share of this installed capacity comprises mostly domestic solar systems. The uptake by large scale commercial entities such as hotels and educational institutions remains rather low. This even after the Kenya government enforced a regulation titled "The solar water heating regulations 2012" which required buildings with daily hot water demand exceeding 100 litres to install SWH systems. This regulation was however repealed. The low uptake of SWH by commercial buildings was attributed to the high initial cost associated with such systems as well as lack of sufficient feasibility studies.

2.2 Components of Solar Water Heating Systems

Typically, a solar water heating system consists of solar collectors, hot water storage tank (usually with internal heat exchanger), solar pump and control equipment, pipework and an auxiliary heating unit as illustrated in Figure 2.1.

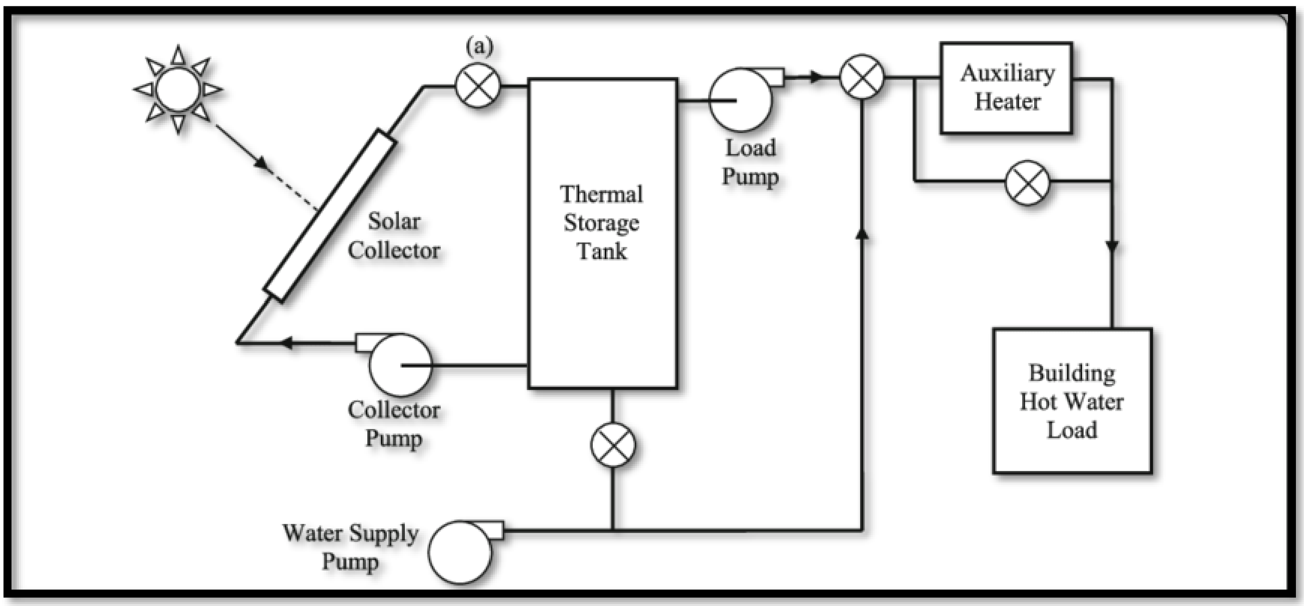


Figure 2. 1: Schematic Diagram of Solar Water Heating System [11]

The design and functionality of the components is as discussed [12, 13, 14]

2.2.1 Solar Collectors

Solar collectors are the most important component of a SWH system as they collect and convert sun's electromagnetic energy into thermal energy. They can be mounted on the rooftops, on the ground or integrated directly into a building. Primarily, there are two types of solar collectors used in solar water heating; evacuated tube (ETC) and flat plate (FPC). A FPC consists of a glass covered black absorber plate which absorbs the solar energy, copper or aluminum tubes underneath the plate for the circulation of HTF and a metal housing to protect the components from foreign matter. The base and sides of the collector are covered with an insulation material to reduce heat loss to the surrounding. Just like flat plate collectors, ETC consists of copper pipes for carrying the HTF and an aluminum casing to support and protect the components. Insulation is however achieved by creating a vacuum between two concentric glass tubes hence the name evacuated tube collectors. The superior construction of ETC makes them quite favorable in much colder climates while FPC are more commonly used in warmer moderate climates.

2.2.2 Hot Water Storage Tank and Heat Exchangers

The storage tank stores the heated water at the elevated temperature awaiting distribution to the various points of use. Essentially, the tank incorporates a heat exchanger, which transfers the solar heat from the heat transfer fluid to the potable water. The heat exchangers are often made from copper which is a good thermal conductor and corrosion resistant. The storage tanks are made of stainless steel or mild steel coated with a heat resistant protective coating on the inside to prevent corrosion. An insulation material such as rockwool or polyurethane foam is placed on the outside of the tank to reduce heat loss to the surrounding. Additionally, thermal stratification can be done on the storage tank to improve thermal efficiency by ensuring the colder water at the bottom of the tank is the one that enters at the collector inlet.

2.2.3 Solar Pump and Controllers

Pumps and controllers are used in active systems to move the heat transfer fluid from the storage tank to the collector and control the flow of the HTF through the collector respectively. The size of the pump used depends on the static and pressure head to be overcome to meet specific system design and performance flow rates. The controllers use sensors and switches to regulate the flow of the HTF and hence prevent freezing or extremely high temperatures in the collectors. When the controller senses that sufficient solar energy is available at the collector, it activates the pump to circulate water to the collector and back to the storage tank. The most common controller used in large-scale SWH systems is the differential controller, which measures the temperature difference between the collectors and the storage tank. Based on the temperature difference measured, the pump is activated either to start the pumping or to stop pumping.

2.2.4 Pipework

The pipework provides a network for the transmission of water in the system. The piping must be compatible with other system components and capable of withstanding the associated high temperatures and pressures. Copper pipping is mostly preferred due to its durability corrosion resistance and stability at high temperatures. Galvanized iron pipes and fittings can as well be used since they are quite affordable compared to copper. To reduce thermal losses in the piping system, the pipes should be well insulated and the insulation covered by suitable material such as high-density polyethylene (HDPE).

2.2.5 Auxiliary Heating Unit

An auxiliary or backup heating unit is incorporated in the solar water heating system to cater for variations in hot water demand and weather conditions. The backup heater maybe electric or fossil fuel fired boilers. Given the seasonal fluctuations in hot water demand, it is not economically prudent to design SWH systems to meet 100% of the hot water demand all year round. Consequently, a solar fraction is factored in during the design to represent the percentage of energy supplied from solar. During periods when solar water heater can meet all the hot water demand the auxiliary heating unit is bypassed otherwise the auxiliary heater is actuated to provide the additional heat.

2.3 Classification of Solar Water Heating Systems

SWH systems are broadly classified as active or passive systems depending on mechanism of HTF circulation, open loop (direct) or closed loop (indirect) systems depending on the way the water is heated.

2.3.1 Passive Systems

These systems use energy from the sun to move water or the HTF in a vertical direction by the principle of varying temperatures, which cause variations in density as well. Passive systems are further classified as **thermosiphon systems** and **integral collector storage (ICS)** or **batch systems** [15]. In batch systems, the tank serves as both the collector and the storage unit such that water is heated directly by the sun at the tank. They are quite simple and efficient but only work in climates with little risk of freezing temperatures. On the other hand, in thermosiphon systems the collector and the storage tank are physically separated. Figure 2.2 illustrates the operation principle of a thermosiphon hot water system whereby the heated water at the collector becomes lighter and thus moves upwards displacing the cold water in the storage tank. Cold water from the mains is supplied at the bottom of the storage tank and then flows by gravity into the collector to be heated. For effective functionality, the storage tank must be placed at higher level than the collector in thermosiphon systems. This presents a design challenge for large-scale hot water systems, which require lots of space. Additionally, passive solar water heating systems can only be used on individual buildings or for single heating demand, this makes them unsuitable for largescale hot water generation. However, these systems require no external energy to move the HTF through the system implying less moving parts and hence less maintenance/ longer lifespan. Moreover, the installation cost is relatively low.

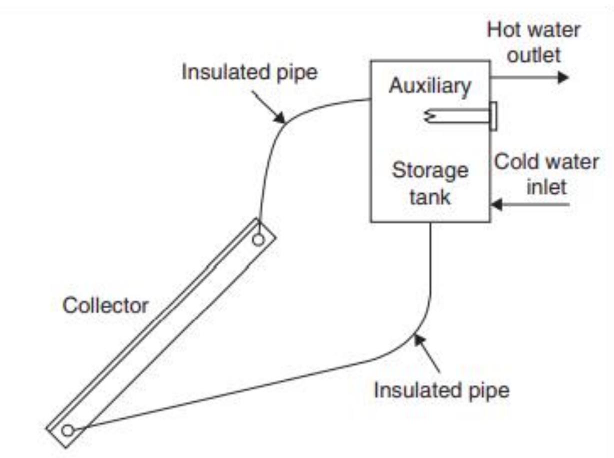


Figure 2. 2: Schematic Diagram of Thermosiphon System [15]

2.3.2 Active Systems

These systems require external energy to function, generally from a pump (either electrically or solar powered) that pushes the HTF through the collector. Active systems are quite versatile especially for large scale designs, however, the incorporation of a pump makes them expensive to install and maintain [13]. Active systems can be either direct or indirect systems depending on the mode of heat transfer. Whether direct or indirect, active systems can be easily retrofitted to already existing water heating systems because the storage tank can be located at any place unlike thermosiphon systems, which require a storage tank always above the collector [15].

2.3.3 Direct Systems

Also referred to as open loop systems whereby the HTF, usually water, is still the one utilized at the end use points. Since the water is heated directly in the collector array, no heat exchanger is required hence reduced costs and improved thermal efficiency. However, given that the HTF is water these systems face the risk of water freezing in the collector in regions that experience extremely low temperatures. To mitigate the freezing problem, direct systems are designed with freeze protection mechanisms such that during periods of very low temperatures, hot water from the storage can be re-circulated through the system or the system can be drained completely. A second drawback associated with direct systems is the scaling and corrosion of the pipes due to use of water as the HTF, which can be reduced by use of copper piping though quite costly. A combination of these factors makes direct systems unsuitable for regions that experience below zero temperatures or have acidic water [16].

2.3.4 Indirect Systems

In these systems, the HTF remains in a closed loop and heats the potable water indirectly through a heat exchanger. The heat exchanger can be either integrated to the storage tank (internal heat exchanger) or fitted outside the storage tank (external heat exchanger). As the HTF passes the storage tank, it gives up the heat to the water in the tank and cools off. The cooled HTF is then recirculated through the collector field to harness more heat. Just like direct active systems, pumps are required to circulate the HTF through the collector. The HTF is usually an antifreeze mixture and therefore the risk of the fluid freezing within the system is eliminated. As a result, these systems are most suitable in climates that are prone to extremely low temperatures and regions with acidic or lime water. A disadvantage of the indirect systems is that they are complex hence expensive to install and maintain.

2.4 Energy Consumption and Management in Hotels

Hotels and restaurants are significant contributors to global energy consumption and associated greenhouse gas emissions. [17] Generally, most of the energy consumed in hotels comes from burning of fossil fuels such as oil and LPG, which have massive carbon footprint. Besides, the conversion of fossil fuels to heat or electricity is associated with quite low efficiencies in addition to being very costly.

Energy consumption accounts for between 3% and 6% of the total operation cost in hotels [18]. The breakdown of energy use in a typical hotel constitutes water heating, HVAC, lighting, kitchen, laundry equipment and other building services as illustrated in Figure 2.3.

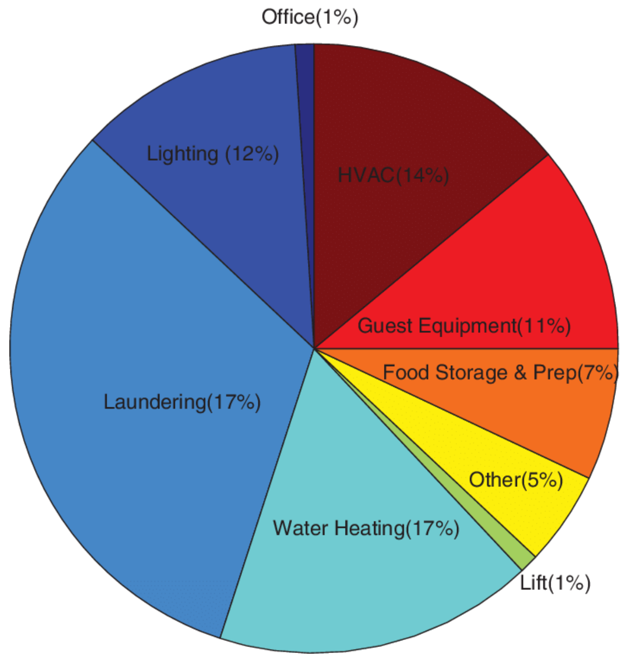


Figure 2. 3: Typical Hotel Energy Consumption Breakdown

Air conditioning systems, lighting, laundry equipment and water heating accounts for more than 50% of hotel energy consumption. Therefore, hotels can leverage on energy saving opportunities in these systems to reduce energy cost.

Energy consumption in hotels is influenced by various factors among them building characteristics, hotel features, location and operations [2]. A study on energy use characteristics of hotel buildings in Shanghai indicated that the average annual EUI increased gradually for 3-star, 4-star and 5-star hotels [19]. Furthermore, it was noted that the EUI followed the fluctuations of outdoor temperature and greatly increased in periods of low outdoor temperatures. The obvious reason for this phenomenon was the intensive use of HVAC equipment to maintain thermal comfort. However, the relationship between occupancy and EUI was difficult to identify, as it did not follow any relatable pattern.

A similar study carried out in Vietnam [1] to determine EUI and percentage of end-use energy consumption in hotel buildings across three cities reported an average EUI of 151 kWh/m^2. A variation in EUI across the three locations was recorded which was attributed to varying climatic conditions as well as star rating of the hotels in those regions. Further, the end-use energy consumption structure indicated that 54% of the energy consumed in the hotels was by the HVAC equipment, 10% by lighting, 19% by plug in equipment and 17% by lifts.

As illustrated in previous paragraphs, hotels consume significant amounts of energy in their operations. To reduce energy consumption and consequently energy cost, hotels have continuously adopted energy management practices as well as on site renewable energy generation. Energy management practices range from simple initiatives such as switching off lights and equipment when not in use to capital-intensive initiatives such as retrofitting. On the other hand, on site renewable energy generation involves use of green sources such as hydro, wind and solar to meet part if not all the energy needs.

2.5 Review of Solar Water Heating in Hotels

Solar water heating in hotels has been embraced as an alternate green energy source owing to its simplicity, low maintenance requirements and high efficiency. A considerable number of studies have been conducted on solar water heating in hotels, which give indispensable perspective on the topic.

A research on investigating the viability of using a solar water heater in place of an instant electric water heater in a hotel shower indicated that for a hotel room with an average shower water consumption of 47.17 litres per day, a solar heater could meet most of the hot shower needs in the period between 9am and 6pm [20]. The study demonstrated that even though supplemental electricity was required to heat the water during not so sunny hours, there still was some power savings that could be realized considering that the instant heater would heat the water from some elevated temperature. The study computed a payback period of 6.5 years based on the financial savings, which could be realized by foregoing the use of electricity on the instant showers. The study however, is limited to shower hot water requirements and therefore leaves room for further research on viability of using a solar water heating system to meet entire hot water needs for the hotel.

Furthermore, a case study on the feasibility of using SWH in a hotel deduced that the system could reduce the hotel's electricity demand with respect to hot water production by approximately 60%, which equated to about 312 MWh per year of reduced demand [16]. However, the researcher acknowledged that the specific analysis on the savings was based on the hotel's actual hot water load and local conditions, which were likely to vary across hotels and regions. The study therefore recommended that individual solar hot water systems design be based on analysis of measured demand data for any feasibility study. The research concluded that despite the significant electricity savings, the investment was at that moment not economically attractive. Further, it was noted that the results of one hotel's SWH feasibility study could not necessarily be applicable to other hotels.

The significant growth in the hospitality industry globally necessitates more research and investment on renewable energy to help reduce carbon footprint and ensure sustainable global environment. In a study conducted on hotels in Libya to estimate the energy potential of hot water in the hotel sector and the opportunities of saving part of the energy by utilizing solar energy, it was concluded that financial savings of upto70% could be realized by using solar as an alternate energy source. The hot water potential was evaluated to be over 18.54 GWh/year and the corresponding annual electricity cost was 1.3 million Libyan Dinars based on the prevailing electricity tariff of 7 Libyan cent/kWh [21]. The technical potential of using solar energy as an alternate source for heating water was estimated as 25,386 m^2 of collector area. The study considered hotels with over eight storeys technically unfeasible to install SWH systems, however not enough information was provided to validate this assumption.

A case study carried out in a beach hotel in Sri Lanka to identify opportunities to minimize the energy utilized in hospitality industry revealed that approximately 22% of the total energy consumption in the hotel was used in hot water production [7]. The study entailed evaluation of hot water production in the selected hotel and analysis of the suitability of an alternative energy source, a solar hot water system, to meet the hot water demand. Detailed design calculations for the solar hot water system based on the available hotel data was undertaken and simulation using various software (Polysun, Kolector, SAM and RETscreen) was carried out to validate the designed system. In conclusion, the proposed solar hot water system was expected to save around 5,400USD per annum and reduce CO_2 emissions by 33 Tons per year. The payback period for the system was estimated to be about 4 years and the system was deemed to be economically viable based on the calculated NPV and IRR values.

Further, a case study to assess the effectiveness of the use of solar panels to heat water for sanitary needs in hotels of Durres area indicated significant reduction of annual expenses, up to 3 times compared to traditional methods of water heating [22]. Vacuum tube solar collectors whose efficiency was estimated to be about 40% higher than other collector types were selected for the study. To assess the effectiveness of the use of vacuum tube collectors, the energy demand of hotels in Durres area was analyzed and the annual cost of electricity needed to meet the energy demand calculated. Both systems were then compared in terms of initial installation cost, expenses incurred during the annual usage and maintenance cost. This revealed that despite the high initial investment of solar panels, the annual savings could help recover the investment cost in 3 years.

The review of research work carried out on solar water heating in hotels revealed various research gaps as summarized in Table 2.1. This proposed study seeks to address gaps identified in [16] and [20].

Table 2.1: Research Gaps

Reference	**Identified gap(s)**
[7]	Location of case study hotel in Asia leaves room for further feasibility study locally.
[16]	Feasibility was analyzed based on existing electric water heaters, comparison can be done based on steam boilers
[20]	The viability assessment focused on showers only and not on the entire hot water system
[21]	Hotels higher than 8 storey were considered unfeasible for SWH, however, not enough information was provided to validate this
[22]	Vacuum tube collectors were used in the study more research can be carried out using flat plate collectors.

2.6 Chapter Conclusion

The high energy use in hotels coupled with environmental concerns have compelled hoteliers to embrace renewable energy sources in their operations. Solar water heating is one of the widely adopted RET to meet hot water requirements in hotels. The review of literature regarding SWH in hotels indicate that the size, design and components of a SWH system are unique to a hotel depending on hotel size, class, location among other factors. Consequently, relying on a feasibility study done for one hotel on another hotel application can be misleading. To effectively assess the viability of a SWH system in Sarova hotel, Nairobi, it is important to analyze the hot water demand load and evaluate the existing hot water system.

3.0 METHODOLOGY

This chapter describes the study design used to achieve the study objectives. It defines the considerations, scope of study and type of data collected. Problem formulation is also included in the chapter to effectively size the required system.

3.1 Review of Previous Methods

In a study to assess the feasibility of SWH in a case study hotel, the researcher used power-metering devices to measure electricity consumption of both the entire facility and the existing hot water system. This helped determine the electricity portion consumed in water heating. Further, a SWH system was designed in consideration of the site conditions, solar collector efficiency and hot water demand. To effectively design the system, published literature on existing similar systems was reviewed and solar engineering companies carrying out similar designs and installation consulted. The system cost was then determined based on prevailing market prices and an economic analysis carried out using NPV, IRR and payback period [16].

To design a suitable solar water heater, which would replace an instant electric heater, the researcher installed a flow meter, a thermometer and a power meter at the shower head to determine the quantity, temperature and power required respectively. After the installation of the solar water heater, water temperatures at the shower head were monitored to estimate the savings that would be realized by foregoing the use of instant electric heater. Based on the system cost and savings realized, the payback period was determined [20].

3.2 Study Considerations and Assumptions

To achieve the study objectives, the following considerations and assumptions were employed;

i) The technique used to meet the study objectives was a case study of a hotel's hot water system.
ii) Recorded hot water data for a case study hotel was analyzed to determine the hot water requirements and hence the demand load.
iii) Historical solar resource data from existing literature was used in the design of SHW system.
iv) In sizing the solar collector area, a solar fraction (percentage of total hot water energy demand met by SWH system) of 60% was be assumed [23]

3.3 SWH Design and Installation Considerations

An optimum design of SWH systems is important to assure reliability and maximum economic benefits to the users and investors respectively. Designing and sizing the most efficient and effective solar hot water system for a given application involves appropriate selection of each component for the desired capacity and optimal location and orientation of the solar panels to capture as much of the solar energy as possible. Several key factors are considered in the design and installation process including but not limited to the amount of solar radiation, geographical location, hot water demand load, building roof's orientation, slope, and shading factors.

3.3.1 Design Considerations

To effectively design and size the solar water heating system the design procedure illustrated in Figure 3.1 was adopted [24]

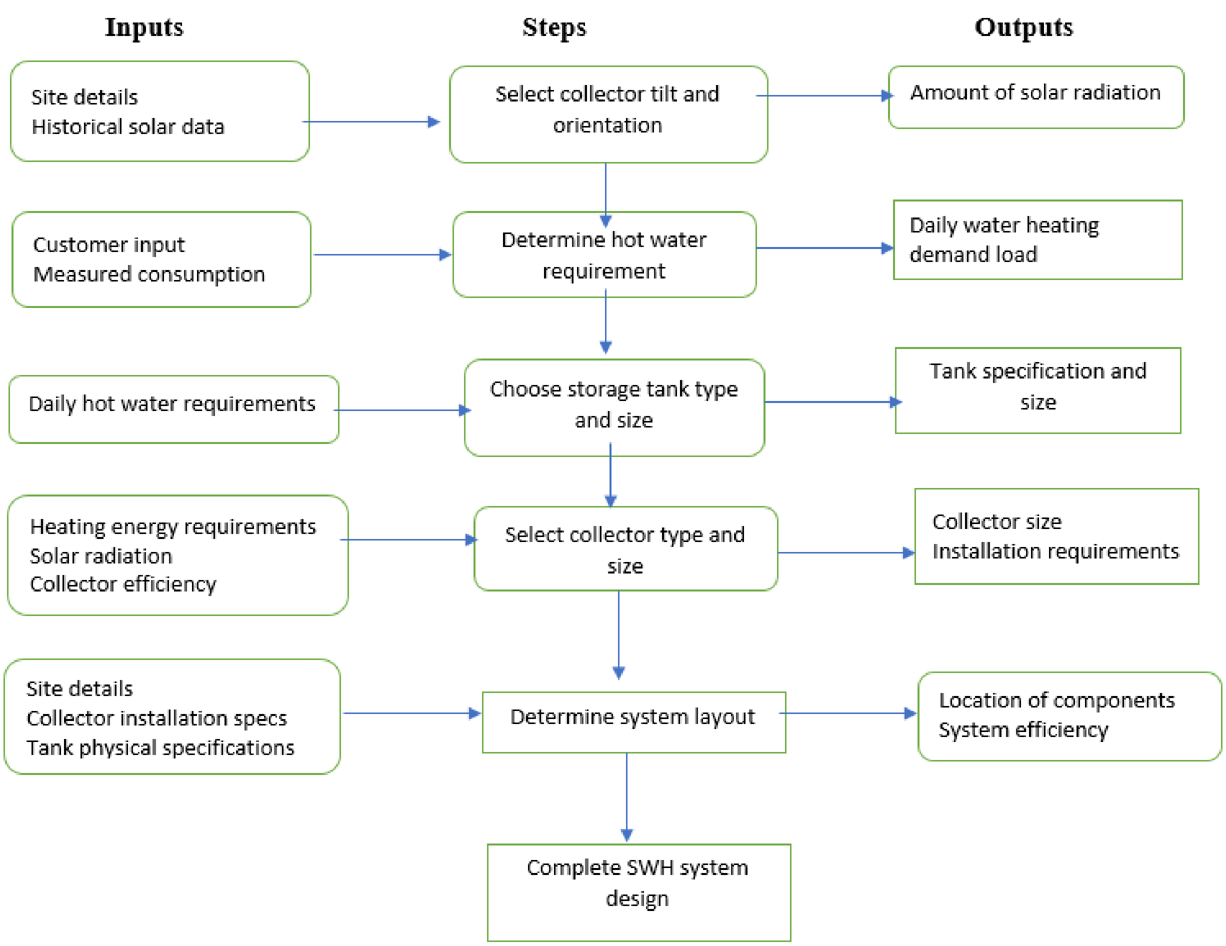


Figure 3. 1: SWH Design Procedure [25]

The daily hot water requirements for each end use point had been recorded on excel spreadsheet. This data was analyzed to determine average monthly consumption and consequently average daily consumption. Solar resource data was then obtained from RETScreen software. This package is a clean energy management software used to determine the feasibility of clean energy projects as well as energy performance analysis for on-going projects. It incorporates NASA satellite climate data for over 6700 ground stations. For the case study, climate data for Nairobi- Dagoreti station was chosen because it was the nearest ground station to the hotel. The hot water consumption data and the solar resource data were used to size a SWH system to take up a fraction of the total hot water demand load.

To validate the design data, a site visit was made to a hotel with installed SWH system. The visit involved observation and collection of information such as type and size of solar collectors, the temperature and quantity of hot water produced and the approximate system cost.

3.3.2 Installation Considerations

To maximize the use of the available solar resource, solar collectors should be positioned to face south over the course of each day. The location, orientation and inclination of solar collectors is affected by; (i) the available installation space, (ii) local shading and (iii) the building roof design. Knowing the dimensions of the available space will ensure that the solar collectors will fit on the roof space. Local shading considerations will ensure that collectors will receive as much solar radiation as possible during peak sunshine hours. Obstructions such as tall buildings, chimneys, ventilation shafts and trees should be avoided and if impossible to avoid, necessary adjustments to the number of collectors should be made. The roof design should also be considered to ensure it is sturdy enough to carry the collector weight. Moreover, any anticipated adverse weather conditions such as strong winds or storms which are likely to affect the collectors should be accounted for. In this study, the hotel’s roof was inspected through observation to determine the slope, orientation and any sources of shading such as buildings and trees.

3.3.3 Problem Formulation

The Energy demand load was calculated using equation 3.1 [23]

$$Q_{load} = C_p \rho v (T_h - T_c) \tag{3.1}$$

Where; Q_{load}= *Total energy required in a day (kJ),* C_p= *Specific heat capacity of water (*kJ/kg°C), *p= density of water (kg/m^3), v= volume of hot water demanded (m^3)* T_h= *hot water temperature (*°C*) and* T_c= *cold water temperature* (°C)

The collector area was determined using equation 3.2, taking into consideration the solar fraction (the percentage of total energy demand load taken up by solar) [23]

$$A_c = \frac{Q_{load} \times F_{solar}}{\eta_{solar} \times I_{av}} \tag{3.2}$$

Where; A_c= *collector area (m^2),* F_{solar}= *solar fraction,* η_{solar}= *solar system efficiency,* I_{av}= *average daily solar insolation (*kwh/m^2/day)

The daily useful heat energy delivered by the solar collectors was determined using equation 3.3 [25]

$$Q_U = A_c F_R [G_T(\tau\alpha) - U_L(t_i - t_a)] \tag{3.3}$$

Where; Q_u=*daily useful heat delivered by collectors,* A_c= *collector area (m^2),* F_R= *Heat removal factor,* G_T=*solar radiation(W/m^2),* $\tau\alpha$=*Transmission absorption coefficient,* U_L=*heat loss coefficient(w/m^2)/°C* t_i=*inlet water temperature(°C),* t_a=*ambient temperature(°C)*

3.4 Case study

This study was based at Sarova Hotel located in Nairobi, Kenya. The hotel is five stars rated with a vast range of amenities among them a heated swimming pool, a health club, restaurants as well as conference facilities. The hotel's capacity consists of 217 individually air-conditioned rooms contained in 8 floor high-rise building. It is strategically located in the central business district with close access to major airports (JKIA and Wilson) and railway stations. Geographically, the hotel is located within the tropics (1.2842^{0}S, 36.8229^{0}E) with daily solar insolation of about 4-6kwh/m^2/day. The hotel's location coupled with the fact that it still uses conventional fuels to meet the hot water needs informed its choice for the case study.

3.4.1 Hot Water Demand

Two approaches were used to estimate the hot water demand in the hotel; statistical analysis of recorded hotel's hot water daily logs and use of international guides or standards on hot water demand approximation for different buildings. Secondary data obtained from the hotel's daily logs for a period of one year (January- December 2019) were summarized and analyzed using statistical tools to determine the average daily hot water consumption, the standard deviation and the peak demand load. The choice of 2019 data was informed by the current Covid 19 pandemic, which is believed to have affected the hotel's operations in the year 2020 and hence no consistent logs that were made. Additionally, the use of the recorded data provided a wide range of data set, which could have taken a long period to obtain. The hot water consumption analysis factored in all the end use points data, namely; swimming pool, health club, kitchen, laundry and guest rooms. The daily average hot water demand obtained was verified using ASHRAE design guide for hot water demand and use for various types of buildings [26]. A Table obtained from the guide listing the average hot water demand for different buildings is found in Appendix B. The estimates were calculated based on the number of rooms and restaurants in the case study hotel. The information on the hotel's room capacity is given in Appendix C.

3.4.2 Conventional Hot Water System

A site survey of the facility was carried out to establish the type and quantity of fuel used to generate hot water as well as the amount of hot water generated in a day. The survey was conducted using unstructured interviews to the hotel facility engineer and through observation. Additionally, fuel consumption daily logs were statistically analyzed to determine the average daily fuel usage. Data recordings of the boiler feed water meter readings together with that of calorifier meter readings were evaluated to estimate the average daily hot water production. The hot water production and fuel consumption rates were then used to estimate the system efficiency using equation 3.4;

$$\eta = \frac{mc_p(T_h - T_f)}{m_{fuel} \times GCV} \tag{3.4}$$

Where; *η= system efficiency, m= mass of supply water (kg), c_p= specific heat capacity of water (kJ/kg°c), T_f= feed water temperature* (°C) *and T_h=hot water temperature* (°C), *m_{fuel}= mass of fuel (kg), GCV= gross calorific value of the fuel (kJ/kg)*

3.5 Economic Analysis

Large-scale SWH systems are characterized by high initial investment cost and low operating cost. The system cost was estimated using component prices obtained from online market platforms such as Alibaba as well as reference to a BOQ for an already installed large scale SWH system. To establish the economic viability of the proposed system, analysis of the projects' NPV, IRR and PBP was carried out.

NPV represents the positive and negative future cash flows throughout a project's lifecycle, considering inflation and returns. IRR is the break- even interest rate, which equates the net present value of a project's cash inflows;

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \tag{3.5}$$

Where; *NPV= Net Present Value, N= Total number of periods, n= non-negative integer and* C_n= *net cash flows and r= Internal Rate of Return*

Payback period is the length of time it takes for a project to recover the initial investment cost through the positive cash flows it generates, calculated using the equation;

$$PBP = \frac{Investment\ cost}{Net\ annual\ cashflows} \tag{3.6}$$

3.6 Conceptual Framework

This study incorporated both dependent and independent variables as indicated in Figure 3.2 to achieve the study objectives. The independent variables include the solar resource data of the location, the temperature of the required hot water and the solar fraction which determined the dependent variables. The dependent variables were the hotel hot water demand load and the size of the solar water heating system. A representation of the relationship among these variables and how they affect the main objective is as indicated in Figure 3.2

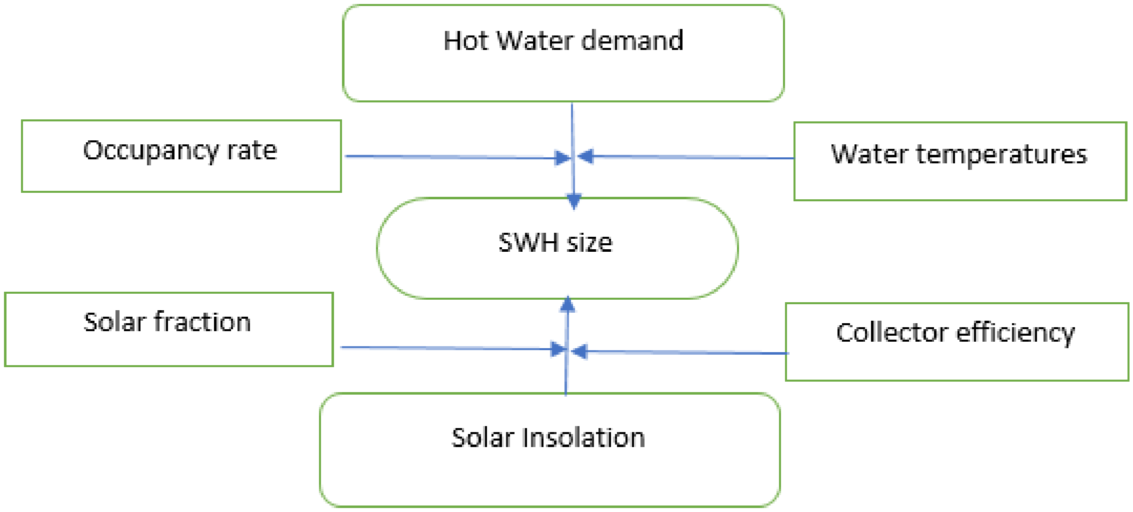


Figure 3. 2: Conceptual Framework

3.7 Chapter Conclusion

The chapter covers a review of previous methods used in study of hotels' hot water systems and feasibility of solar water heating. Based on the review, a methodology was adopted and problem formulation for the research topic was presented. The design considerations and conceptual framework of the study have also been highlighted

4.0 RESULTS AND DISCUSSION

This chapter comprises the analysis of recorded data obtained from the facility on hot water and fuel consumption daily logs for the year 2019. Thereafter, the results of the analysis were used to size a solar hot water system to be used to supplement the existing conventional hot water system. An economic analysis of the designed system was also carried out to assess the feasibility of the system.

4.1 Hot Water Demand

The daily hot water consumption for the various end use points was computed as the arithmetic difference in the meter readings between two consecutive days. Cumulatively, the monthly totals for each end use point were determined and the total hot water consumption in a month was then evaluated. Table 4.1 gives a summary of the monthly hot water consumption for each end use point, the average daily consumption for each month and subsequently the average daily consumption in the year.

Table 4. 1 Hot Water Consumption

Month	**Kitchen (m^3)**	**Pool (m^3)**	**Calorifier (m^3)**	**Health club (m^3)**	**Laundry (m^3)**	**Totals (m^3)**	**Av hot water/day (m^3)**
Jan	122	24	886	60	132	1224	39.48
Feb	128	13	971	70	137	1319	47.11
Mar	156	16	822	52	171	1217	39.26
Apr	137	37	782	44	192	1192	39.73
May	165	11	1216	72	164	1628	52.52
Jun	146	12	1148	85	139	1530	51.00
Jul	162	1	1303	93	175	1734	55.94
Aug	138	13	1211	80	135	1577	50.87
Sep	170	14	1091	63	139	1477	49.23
Oct	153	13	948	45	176	1335	43.06
Nov	163	5	1324	47	160	1699	56.63
Dec	178	15	1191	32	191	1607	51.84
Average							**48.06**
Standard deviation							**6.28**

The daily average hot water consumption in the year was computed as 48.06 m^3, with a minimum monthly consumption of 39.26 m^3 and a standard deviation of 6.28 m^3. It was observed that hot water consumption varies considerably throughout the year, which is expected since hot water use is a function of other hotel factors such as occupancy and environmental conditions.

The calorifier, which store heated water for use in the guest rooms was the greatest contributor to the overall monthly consumption with monthly consumption ranging between 782m^3 and 1324m^3. Figure 4.1 graphically represents the monthly variation in hot water consumption for the various end use points. The months of May, July, November and December had the highest consumption which could be attributed to the low temperatures experienced in such months and increase in the hotel occupancy as well. The kitchen and laundry consumption remained moderately low throughout the year, slightly below 200m^3 which could be explained by the fact that the machines used in these end points (for example dish washer or washing machine) operate on a certain load capacity irrespective of the hotel occupancy or environmental conditions.

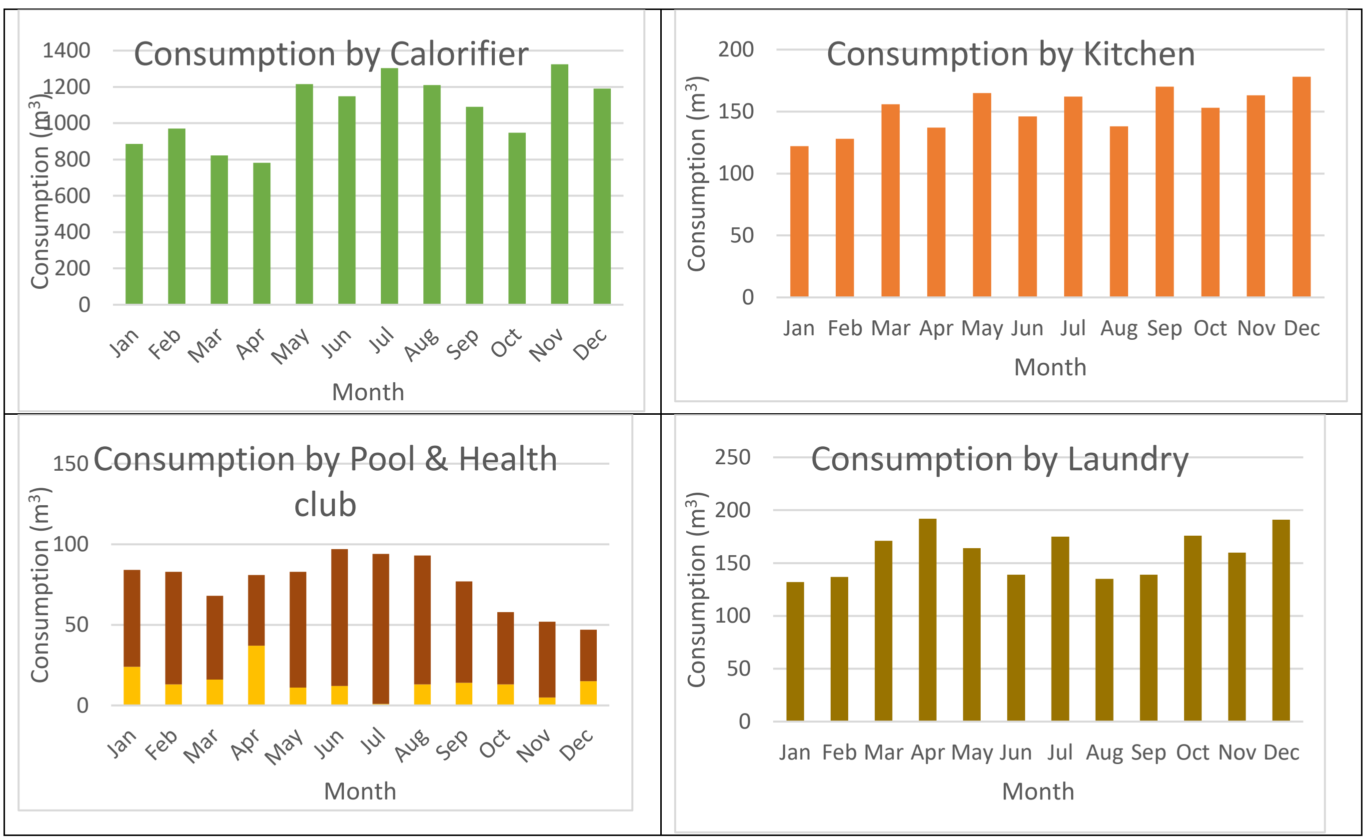


Figure 4. 1 Hot Water Consumption by End Use Points

To verify the results obtained in Table 4.1, standard design guides such as ASHRAE and The Energy (Solar Water Heating) Regulations, 2012 [23, 26] were used to calculate the daily hot water consumption for the hotel. Table 4.2 gives a summary of the various hotel amenities in the case study hotel and the corresponding estimated hot water consumption based on the standard guides.

Table 4. 2 Hot Water Demand Calculation

1. Hotel guest rooms			
	Number of rooms	Daily hot water demand in litres (60°C) per room	Total consumption (litres)
Guest rooms	217	75.8	16,448.6
2. Banquets/Conference rooms/Ballrooms			
	Average number of guests	Daily hot water demand in litres (60°C) per guest	Total consumption (litres)
The Exchange bar	225	15	3,375
3. Restaurants/Kitchens			
	Average number of guests	Daily hot water demand in litres (60°C) per guest	Total consumption(litres)
Thai Chi	100	9.08	908.4
Thorn Tree Cafe	150	9.08	1,362.6
Pool Deck Restaurant	70	9.08	635.88
4. Laundry			
	Weight of clothes (Kgs)	Daily hot water demand in litres (60°C) per Kg	Total consumption (Litres)
Washing machines	250	15	3,750
5. Health club/ Spa			
	Average number of people	Daily hot water demand(60°C) per person	Total consumption (Litres)
Steam rooms	15	100	1,500
6. Swimming pool			
	Pool Surface Area	Daily hot water demand per unit area	Total consumption (Litres)
Maintenance heating	$72m^2$	15	1080
7. Changing rooms			

	Number of staff	Daily hot water demand in litres (60°C) per staff	Total consumption (litres)
	80	20	1,600
Total hot water demand per day			**31,740.48**

To estimate the average daily hot water demand, ASHRAE hot water demand and use guidelines for various types of buildings as listed in Appendix B were used [26]. The number of guest rooms and other amenities is as listed in the hotel fact sheet in Appendix C. The computed daily hot water consumption was approximately 31.7m^3.

The disparity in the two computed values was attributed to the fact that losses were not accounted for in the computation using the standard design guides. Additionally, the occupancy rate was an approximation based on the room capacity which is most likely to vary in real world. Nonetheless, the average daily consumption computed in Table 4.1 was higher by almost 16 m^3 since it represented the actual scenario on the ground (with regard to occupancy and thermal losses) and thus was used in the sizing of the solar hot water system.

4.2 Existing Hot Water System Performance

The existing hot water system consists of two fire tube diesel fired steam boilers. Figure 4.2 is a photo of the system showing the two steam boilers and the distribution system. From an interview with the facility engineer, it was reported that the system is served by one boiler at a time except for rare occasions when the hot water demand is extraordinarily high. During these times, the two boilers run concurrently. The produced steam is used to heat water through heat exchangers to be utilized in five sections of the hotel; the guest rooms, kitchen, laundry, pool and health club. For the guest rooms, the hot water is stored temporarily in calorifiers at a temperature of 55°C awaiting distribution to the guest rooms upon demand.

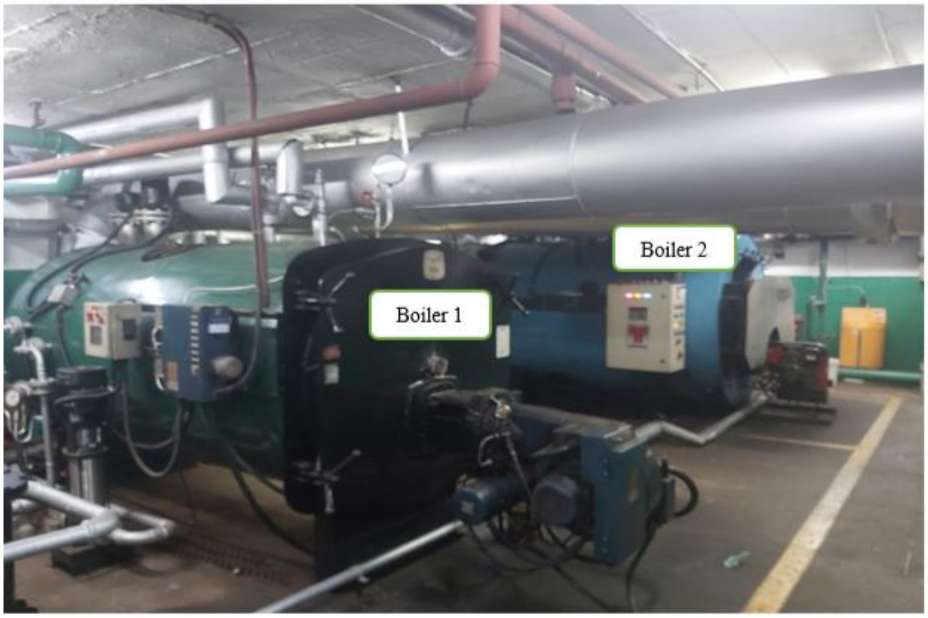


Figure 4. 2 Existing Hot Water System

The name plates of the two boilers have the technical data presented in Table 4.3;

Table 4. 3 Boiler Specifications

	Boiler 1 (Wellman Robey)	Boiler 2 (Shellmax)
Model	220407	SM-10DH/10.54/46
Output	2000lbs/hr	1000kg/hr
Design pressure	157.5psig	10.54 kg/cm^2
Design temperature	188°C	150°C
Maximum working pressure	150psig	9.79 kg/cm^2
Fuel	Fuel oil	FO
Year	1996	2013

Upon conversion of steam production rate of boiler 1 into kg/hr, it was noted that both boilers' output rating was nearly the same at 907kg/hr and 1000 kg/hr for boiler 1 and 2 respectively. Additionally, the operating pressure for both boilers was approximately 10 bar and it was therefore presumed that they had equal capacities. However, the facility engineer pointed out that boiler 2 was commonly used because it consumed less fuel compared to boiler 1. This could be explained by the fact that boiler 2 was a more recent model and therefore utilized more efficient technology.

4.2.1 Fuel Consumption

Boiler fuel consumption simply refer to the amount of fuel a boiler burns in a specific period, say an hour or a day. For the case study hotel, the fuel consumption was monitored on 24-hour intervals by use of a graduated feed tank. The amount of fuel consumed was evaluated as the difference between the feed tank full capacity and the remaining fuel in the feed tank after 24-hour operation. The consumption daily logs for the year 2019 were analyzed to determine the total monthly consumption and consequently the average daily consumption as shown in Table 4.4. The annual average daily fuel consumption was computed as 510.39 litres with a standard deviation of 28.13 litres and a minimum of 467.74 litres. It was noted that daily fuel consumption varied between 400 and 750 litres. The periods of high fuel consumption were explained to be due to periods of boiler changeover or when the two boilers were operating concurrently.

Table 4. 4 Fuel Consumption

Month	**Monthly totals (Litres)**	**Daily average (Litres)**
Jan	14500	467.74
Feb	14255	509.11
Mar	14550	469.35
Apr	14325	477.50
May	16105	519.52
Jun	15820	527.33
Jul	16950	546.77
Aug	16055	517.90
Sep	15655	521.83
Oct	15270	492.58
Nov	16575	552.50
Dec	16200	522.58
Average		**510.39**
Standard Deviation		**28.13**

Line graphs of monthly fuel and hot water consumption for the year were plotted to establish the consumption patterns throughout the year as represented in Figure 4.3. It was observed that the fuel consumption graph experienced sharp rise in the months of February and November compared to the hot water consumption graph during the same months. This phenomenon was explained to be due to periods of boiler changeover which led to sharp increase in fuel consumption without necessarily a sharp increase in hot water consumption.

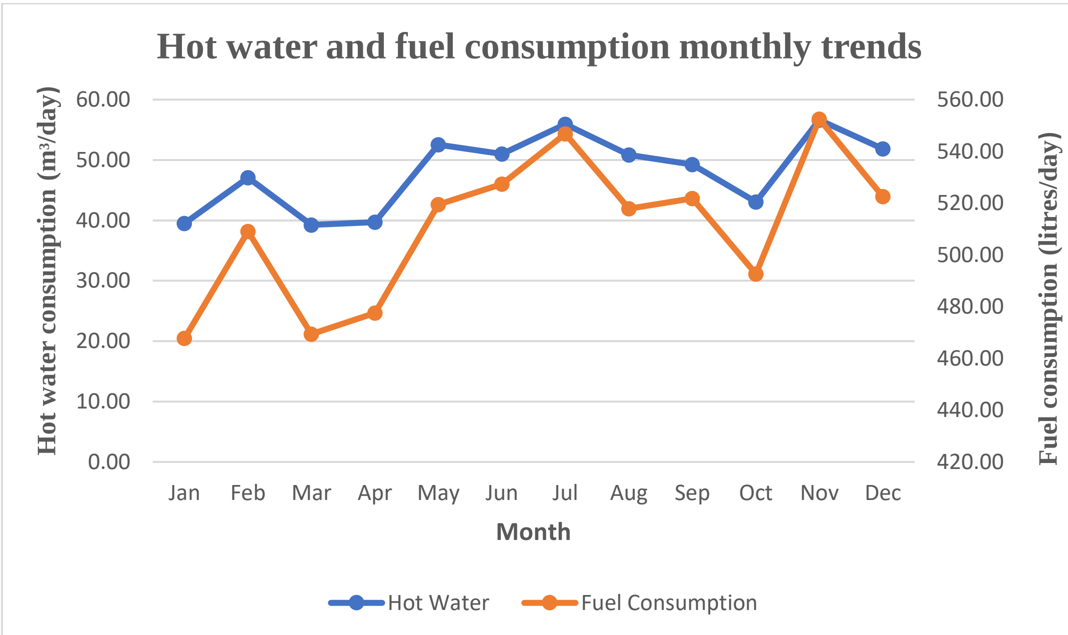


Figure 4. 3 Hot Water and Fuel Consumption Monthly Trends

Further, it was observed that an increase in hot water consumption led to an increase in the fuel consumed. A scatter graph was plotted to assess the relationship in the quantity of fuel consumed with respect to the hot water consumed in a month as indicated in Figure 4.4. A positive correlation was established and the line of best fit indicated a gradient of 4.4021 and a y intercept of 298.84 litres. This implies that the minimum quantity of fuel that would be required to keep the boilers running even without hot water consumption was 298.84 litres.

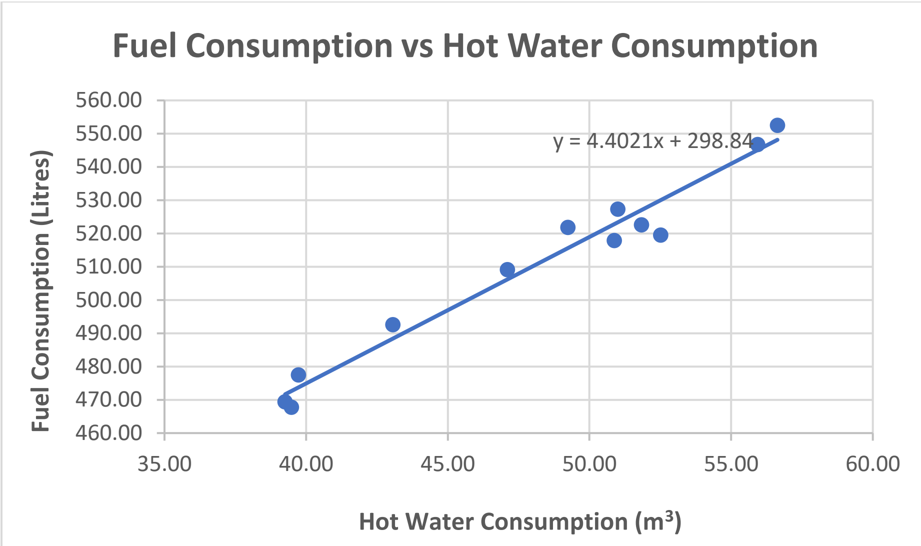


Figure 4. 4 Fuel Consumption vs Hot Water Consumption

4.2.2 System Efficiency

To evaluate the system performance, the average fuel consumption in a month was compared to the corresponding hot water consumption. This was done so because the steam production was not metered hence it was a challenge to estimate the total steam produced. Therefore, it was assumed that the hot water consumed at the various points of use was equal to the total hot water produced. The system efficiency was calculated using the direct (input-output) method stipulated in equation 3.4 whereby the energy gain of the working fluid was compared with the energy content of the boiler fuel.

$$\eta = \frac{mc_p(T_h - T_f)}{m_{fuel} \times GCV}$$

The density of water was taken as $1000 kg/m^3$ hence the daily average mass of hot water is given by; 48.06×1000= 48,060kg and specific heat capacity is 4.184kJ/kg℃

The density of diesel is $840 kg/m^3$ and hence the daily average mass of diesel consumed was calculated as; 0.51×840= 428.4 kg and gross calorific value of diesel is 43020KJ/kg [1]

$$\eta = \frac{48060 \times 4.184 \times (55-20)}{428.4 \times 43020} \times 100\% = \mathbf{38.19\%}$$

[1] See Appendix D

The calculated system efficiency was quite low, this could be attributed to system losses such as piping insulation losses and hot water storage tank losses. Moreover, there is inevitable thermal loss at the heat exchangers as the steam heats up the cold water hence a more accurate efficiency would have been obtained if the steam production rate was being monitored.

4.3 Solar Hot Water System Design

The design of the solar hot water system was based on the existing solar data (insolation and solar hours) of the location and the analyzed hot water requirement of the case study hotel. The daily hot water demand load was calculated using equation 3.1

$$Q_{load} = 4.184 \times 1000 \times 48.06(55°C - 20°C)$$

= 7037906.4 kJ

=7037906.4/3600 = 1955kWh/day

The calculated daily hot water load was based on the computed average hot water consumption. To ensure the system is not oversized, design consideration (iv) under clause 3.2 was applied; therefore, the design hot water demand load Q_{load} becomes

$Q_{load} =$ 60%×1955kWh = 1173kWh/day

The solar collector area required depend upon the hot water demand load, type of the system adopted and type of collectors used. The choice of collectors and system type in turn depend on several factors, key among them the climatic conditions of the area under study. In literature review, the various solar water heating systems were discussed at length as well as the types of solar collectors.

The location climate data was obtained from RETScreen project analysis database as shown in Table 4.5. RETScreen is a clean energy management software used to model clean energy projects in order to determine their feasibility before the actual execution of the projects. It integrates extensive built-in project database such as benchmark, cost, hydrology and climatic data to assist project implementers on site assessment. Table 4.5 shows a typical climatic data obtained from the software; the location is Dagoretti area, Kenya. This location was chosen because it is roughly 8km from Sarova hotel hence the climatic conditions are not expected to vary as much. This data was verified by comparing it with solar insolation data available from the Kenya Meteorology department (Appendix E) and was found to be comparable.

Table 4. 5 RETscreen climate data for site

RETScreen - Location — **Subscriber: Viewer**

Site reference conditions

Climate data location	Kenya - Nairobi/Dagoretti	Facility location	Kenya - Nairobi - Nairobi

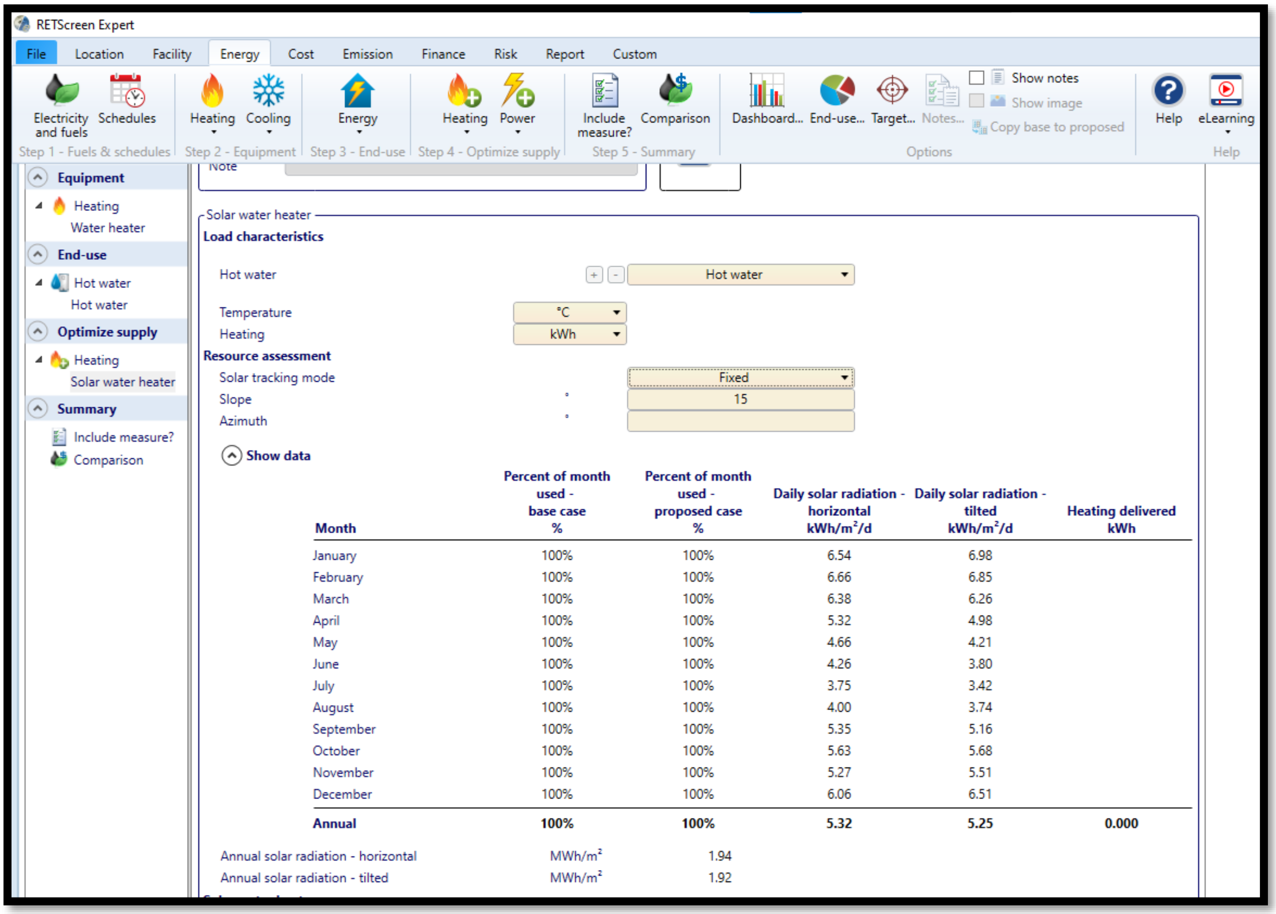
	Unit	Climate data location	Facility location	Source
Latitude		-1.3	-1.3	
Longitude		36.8	36.8	
Climate zone		3A - Warm - Humid		Ground+NASA
Elevation	m	1798	1811	Ground – Map
Heating design temperature	°C	10.6		Ground
Cooling design temperature	°C	28.5		Ground
Earth temperature amplitude	°C	13.5		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	18.0	60.0%	52.70	6.54	84.3	4.5	20.7	0	248
February	18.8	56.0%	33.60	6.66	84.3	4.5	22.2	0	246
March	19.4	61.5%	78.74	6.38	84.3	4.5	22.4	0	291
April	19.2	71.0%	135.30	5.32	84.4	4.0	21.1	0	276
May	17.8	73.0%	99.82	4.66	84.5	3.5	19.6	6	242
June	16.3	72.5%	31.50	4.26	84.6	2.9	19.1	51	189
July	15.6	73.0%	25.11	3.75	84.6	3.0	19.2	74	174
August	15.9	70.5%	29.76	4.00	84.6	3.4	20.3	65	183
September	17.3	63.5%	26.70	5.35	84.5	4.0	22.0	21	219
October	18.5	62.5%	63.24	5.63	84.4	4.5	22.1	0	264
November	18.4	70.5%	111.30	5.27	84.4	4.7	20.7	0	252
December	18.1	66.0%	76.57	6.06	84.4	4.7	20.3	0	251
Annual	**17.8**	**66.7%**	**764.34**	**5.32**	**84.4**	**4.0**	**20.8**	**218**	**2,835**
Source	Ground	Ground	NASA	Ground	Ground	NASA	NASA	Ground	Ground
Measured at					m	10	0		

It was observed that the ambient temperature does not fall below 15.6°C while the minimum daily solar radiation-horizontal varies between 3.75kWh/m^2/day to 6.66 kWh with an average of 5.32kWh/m^2/day. It was also evaluated that the daily solar radiation- horizontal was greater than 3.5 kWh/m^2/day for each month which is sufficient to generate hot water for the hotel.

Existing literature on solar installation indicate the optimum tilt angle to be equal to the absolute value of latitude of the location [14, 24]. The latitude of the location of the case study was about 1.28°S and the corresponding daily average solar radiation is 5.32kWh/m^2/day as indicated in appendix F from RETscreen climate database. This was exactly the same as the daily solar radiation- horizontal given in Table 4.5. Additionally, Table 4.6 shows the average daily solar radiation at 15° tilt angle which was evaluated to be 5.25kWh/m^2/day. Consequently, 15° tilt angle was chosen to estimate the number of collectors and the system performance because there was no significant variation of the average daily solar radiation between 1.3° and 15° tilt angle. Besides, a greater inclination would help prevent stagnation of rainwater or dust on the solar collectors which would otherwise reduce the amount of daily solar radiation received by the solar collector.

Table 4. 6 RETscreen radiation data for site at 15^0 tilt angle



Month	Percent of month used - base case %	Percent of month used - proposed case %	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Heating delivered kWh
January	100%	100%	6.54	6.98	
February	100%	100%	6.66	6.85	
March	100%	100%	6.38	6.26	
April	100%	100%	5.32	4.98	
May	100%	100%	4.66	4.21	
June	100%	100%	4.26	3.80	
July	100%	100%	3.75	3.42	
August	100%	100%	4.00	3.74	
September	100%	100%	5.35	5.16	
October	100%	100%	5.63	5.68	
November	100%	100%	5.27	5.51	
December	100%	100%	6.06	6.51	
Annual	**100%**	**100%**	**5.32**	**5.25**	**0.000**

Annual solar radiation - horizontal	MWh/m²	1.94
Annual solar radiation - tilted	MWh/m²	1.92

In view of the foregoing, flat plate solar collectors were chosen as they are also relatively cheap. An active direct system was also chosen so as to take advantage of the existing hot water distribution system and also because direct systems do not involve heat exchangers hence minimal thermal losses. A typical flat plate collector (Solarbayer®) data obtained from local solar equipment dealers was used to determine the collector area and consequently the number of collectors needed. The technical data is as presented in Table 4.7

Table 4. 7: Technical Data of a Flat Plate Collector (Solarbayer)

Technical Data	
Gross Area	2.517m²
Aperture Area	2.404m²
Absorber Area	2.314m²
Collector Dimensions (L x W x D)	2.15m x 1.17m x 0.083m
Weight	39kg
Max Operating Pressure	10bar
Recommended Operating Pressure	6bar
Recommended Flow Rate	1L/min/m²
Fluid Volume in Collector	1.95l
Rated Heat Output	1.81kW

Materials	
Absorber	Aluminium
Coating	Highly Selected Vacuum Coated
Absorbance	95%
Emissivity	5%
Mounting Frame	Extruded Aluminium
Glass	3.2mm Tempered Solar Safety Glass
Mounting inclination	15°-75°
Inlet Outlet Dimensions	3 ¼ bracket male
Stagnation Temperature	181°C
Insulation Material	40mm Mineral Wool
Heat Transfer Fluid	Propylene Glycol / Water mix
Efficiency Constants for G=8000W/m²	η0 = 0.785 a1 = 3.594 a2 = 0.014 (W/m2K)

The specification indicates the collector efficiency to be 0.785 and the transmittance and absorptance coefficients as 95%. Therefore, the required flat plate collector area was calculated using equation 3.2 in chapter three.

$$A_c = \frac{Q_{load} \times F_{solar}}{\eta_{solar} \times I_{av}}$$

$$= \frac{1955 \times 0.6}{0.785 \times 5.25}$$

$$= 284.62\text{m}^2$$

The aperture area of a single collector is 2.404m^2 as indicated in Table 4.7 hence the number of collectors required is

$$\text{No. of collectors} = \frac{Collector\ Area}{Area\ of\ an\ individual\ collector}$$

$$= \frac{284.62}{2.404} \quad = 118.4 \approx 118$$

4.4 System Thermal Performance

Solar thermal performance is a function of site climatic conditions, efficiency of the collectors as well as the orientation and tilt angle of the collectors with respect to the ground or roof on which they are mounted. As discussed in section 4.3, a 15° tilt angle was chosen for this study. Regarding orientation, study has shown that collectors on the northern hemisphere should be installed facing south while those on the southern hemisphere to be installed facing north [14, 24]. Given the geographical coordinates of the case study location (1.2842°S, 36.8229°E), it is recommended that the collectors face north since the location is slightly in the southern hemisphere.

The system thermal performance was analyzed using collector energy balance equation under steady state conditions. At any given moment the rate of useful energy gain from the collector is the positive difference between the energy absorbed by the plate and the energy lost to the atmosphere by the collector as defined by equation 3.3

$$Q_U = A_c F_R [G_T(\tau\alpha) - U_L(t_i - t_a)]$$

In the equation, G_T, t_i and t_a are the parameters characterizing the external/site conditions while $\tau\alpha$, F_R and U_L represent the collector thermal characteristics. Generic values relating to flat plate collectors for $F_R(\tau\alpha)$ and $F_R U_L$ are given as 0.68 and 4.9W/m^2/°C respectively [28].

Table 4.7 shows the average monthly solar radiation for the site (Nairobi – Dagoreti meteorological station) at the chosen tilt angle (15° from the horizontal), the ambient temperature and the average inlet temperature as per data extracted from RETScreen. The energy output per month of a single collector based on these values is also shown and the cumulative annual output was calculated as 2664.6 kWh/year. The total output of the entire system was then calculated by multiplying the output of a single collector with the total number of collectors to give 314419.2kWh/year which is equivalent to 314.4MWh/year.

Table 4. 8: Solar System Thermal Output

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily solar radiation - tilted ($kWh/m^2/day$)	6.98	6.85	6.26	4.98	4.21	3.8	3.42	3.74	5.16	5.68	5.51	6.51
Monthly solar radiation ($kWh/m^2/month$)	209.4	205.5	187.8	149.4	126.3	114	102.6	112.2	154.8	170.4	165.3	195.3
Ambient Temp (°C)	18	18.8	19.4	19.2	17.8	16.3	15.6	15.9	17.3	18.5	18.4	18.1
Inlet water Temp(°C)	20.8	22.2	22.4	21.1	19.6	19.1	19.2	20.3	22	22.1	20.7	20.3
Output (kWh/Month)	309.3	295.9	271.7	221.8	185.3	153.4	125.3	131.6	197.7	236.1	243.1	293.3

Figure 4.4 is a graphical representation of the monthly output for the system whereby higher outputs are received in the summer months of January to March and October to December. It was noted that in the said months, the system output was sufficient to meet and even exceed the set solar fraction of 60%.

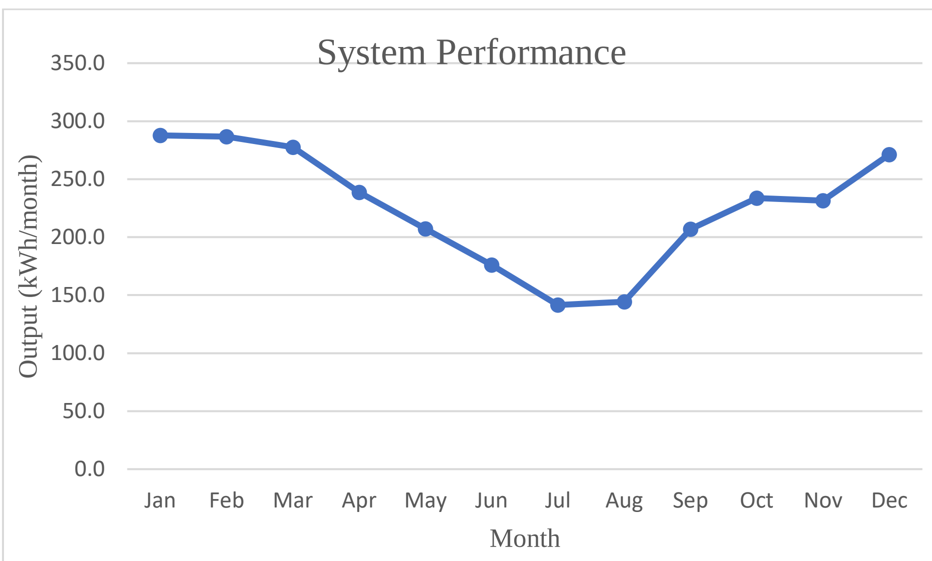


Figure 4. 5 System Thermal Output

In the periods of low solar radiation, it was noted that the system output was drastically reduced, even below the expected solar fraction. This is because the solar radiation value used in sizing the system was an average and therefore insolation values below this average were likely to yield a lower output. However, to ensure the system is not oversized which would lead to wastage in case of surplus, this thermal performance and size of the system was deemed satisfactory.

4.5 Economic Analysis

To evaluate the financial viability of the solar hot water system, the system cost was estimated based on prevailing market rates of the various system components. The annual savings realized with the solar hot water system in place were also calculated. This was then compared with the cost of heating water for the hotel using the conventional diesel boilers to determine the payback period, the NPV and the IRR.

4.5.1 System Cost

To reduce the capital expenditure of installing the solar hot water system, this study recommends that the existing hot water storage (calorifiers) and distribution system be adopted and incorporated to serve both the SHW system and the conventional hot water system. This therefore means that the major investment cost would be for the purchase of solar thermal collectors, pumps, controllers as well as the installation cost.

The system cost was divided into fixed and marginal costs, where the latter varied with the number of collectors to be installed while the former was fixed regardless of the number of collectors installed. Table 4.9 gives a breakdown of the total cost which was based on;

i) Bill of Quantities obtained from an already installed largescale solar hot water system project
ii) Cost estimates from online marketing platforms such as Alibaba and India Mart[2].

The operation and maintenance costs were not included since the proposed system would be a direct active system that does not require HTF monitoring hence minimal O&M costs. The variable cost was estimated to be Kshs 6,686,960 (57,646.21 USD)[3] whereas the fixed costs was Kshs 3,000,000 (25,862.07 USD) and the total cost for the entire system was Kshs 9,686,960 (83,508.28 USD). It should however be noted that these costs are based on estimates and that they could vary

[2] Online survey carried out between 24/04/2022 to 27/04/2022
[3] The exchange rate used was 1 USD = Kshs 116

during actual implementation of the project. Nevertheless, the costs were believed to be accurate estimates and would thus suffice for a feasibility analysis of the proposed system.

Table 4. 9 Estimated System Cost

Fixed cost		
Description	Unit cost (Kshs)	Total cost (Kshs)
Design and Development	500,000	500,000
Installation, testing and commissioning	2,500,000	2,500,000
Marginal cost		
118 no. Solar panels	35,000	4,130,000
6 no. Differential Controllers	135,200	811,200
4 no. Solar circulating pumps	155,000	620,000
40 no. Air vents	8,000	320,000
10 no. pressure relief valves	3,500	35,000
10 no. Temperature gauges	17,500	175,000
10 no. Pressure gauges	19,576	195,760
Pipe fittings and accessories	300,000	300,000
Miscellaneous	100,000	100,000
Total		**9,686,960**

4.5.2 Financial Indicators

The financial indicators used to assess the viability of the investment were NPV, IRR and payback period. The analysis entailed evaluation of net cash flows without a SWH system and with a SWH system in place. Net cash flows without SWH refer to the payments the hotel would make to produce hot water without a SWH system in place. This was evaluated based on the average daily fuel consumption;

Annual cash outflows = 510.39×365×1.08 = 201,195.74 USD (1.08 USD being the diesel price in the period between 15th April and 14th May 2022) as per EPRA April 2022 press release. An extract of the press release is as indicated in Appendix G.

Net cash flows with SWH refer to the payments the hotel would make to produce hot water with the proposed SWH system in place. The annual energy savings with the solar system in place equals the annual thermal output of the system which equals 314.4MWh/year. To evaluate the amount of fuel saved the GCV of diesel fuel as indicated in Appendix D (41.08MJ/l) was used.

Energy content in a litre of diesel = 41080/3600 = 11.411 kWh.

Therefore, the amount of diesel saved annually = 314400/11.411 = 27,552.36 litres and the associated annual financial savings = 27,552.36×1.08 = 29,756.55 USD. Therefore;

Annual net cash outflows = 201,195.74 -29,756.55 = 171,439.19 USD

The payback period for the proposed system was then evaluated as;

$$PBP = \frac{Investment\ Cost}{Annual\ savings} = \frac{83{,}508.28}{29{,}756.55}$$

$$= 2.8 \approx 3 \text{ years}$$

The project NPV and IRR were evaluated using excel spreadsheets as shown in Table 4.10 for a project life of 5 years. A discount rate of 15% and an interest rate of 11% were used.

Table 4. 10 IRR and NPV Results

IRR computation with Excel IRR Function & Verification with NPV calculation				
Year	Date	Cash Flows (USD)	Present Value of cashflows discounted @ **15.00%**	**A**
Year 0	Year 0	-83,508.28	83,508.28	
Year 1	Year 1	29,757	25,875.26	Discounted from Year1 to Year0
Year 2	Year 2	29,757	22,500.23	Discounted from Year2 to Year0
Year 3	Year 3	29,757	19,565.41	Discounted from Year3 to Year0
Year 4	Year 4	29,757	17,013.40	Discounted from Year4 to Year0
Year 5	Year 5	29,757	14,794.26	Discounted from Year5 to Year0
Total negative cash flows or outflows		0	99,748.57	
Total positive cash flows or inflows		148,783	99,748.57	
Sum of positive and negative discounted cash flows			**16,240.29**	***<=Net Present Value (NPV)***
Internal Rate of Return (IRR)		**22.95%**		

The evaluated NPV was found to be 16,240.29 USD with a corresponding IRR of 22.95%. The results indicate that the IRR is greater than the anticipated interest rate and the NPV analysis yielded a positive value. This therefore implied that the project was a viable investment and would completely pay off within 3 years.

4.6 Results Validation

The results obtained in the study were validated using two methods;

i) Comparison with results from similar studies.

ii) A visit to an already installed SWH system to gather information on the design and performance of the system and establish whether any similarities exist.

The average daily hot water consumption was evaluated to be 48.06m^3, this was comparable to the 31.74m^3 computed using ASHRAE guideline on hot water use for different buildings. Additionally, a study carried out on technical, financial and environmental feasibility of SWH [8] estimated the hot water use for a 300-roomed hotel to be 34.11m^3 which is very close to the value obtained for this case study. The annual energy output from the sized SWH system for the case study hotel was estimated as 314.4MWh/year and the corresponding number of flat plate collectors was 118 each of 2.4m^2 aperture area. These values were found to be very close to the ones obtained in [8] which were reported as 314MWh/year and 139 evacuated tube collectors each of 2.1m^2 aperture area.

A site visit conducted at Sarova Panafric hotel, Nairobi which has a similar star rating as the case study hotel revealed that the installed solar collector area was 130m^2 with a total of 56 flat plate solar collectors. The nameplate of the collectors installed is as indicated in Appendix H. The adopted system was a direct solar water heating system which incorporated 4 hot water storage tanks each having a capacity of 2000 litres. These tanks were placed on the rooftop. The number of rooms served by this system was reported to be 100 and the daily hot water production by the system was 10 m^3 per day. Photos taken from the site are given in appendix H. Given the room capacity of the case study hotel (217 rooms) the sized solar collector area of 284.62 was considered appropriate. Moreover, the collector nameplate technical data was also comparable with the technical data of the collector used in the sizing of the system.

4.7 Chapter Conclusion

The chapter examined secondary data acquired from the facility engineer with an aim to size a solar water heating system to supplement the daily energy load required for water heating. The average daily hot water consumption in the hotel was computed as 48.06m^3 and was verified to be reasonable for such size of a hotel using ASHRAE hot water guidelines. The corresponding average daily fuel consumption was evaluated to be 510.39 litres resulting in a system efficiency of 38.19%. The average daily energy demand load for the hotel was 1955kWh/day based on the computed average daily hot water consumption. An estimated 284.62 m^2 flat plate collector area was proposed for a solar hot water system to meet 60% of the average daily energy demand load over an entire year. The number of flat plate collectors required was 118 and the annual thermal performance of the proposed system was approximately 314.4 MWh/year. This system was estimated to cost roughly 83,508.28 USD based on component costs from online marketing platforms and Bill of Quantities (BOQ) of already installed solar hot water system. The research paper proposed incorporation of the existing hot water storage and distribution system in the solar system. As such, a big share of the total investment cost was made up of the collector and installation cost. The associated annual financial savings were 29,756.55 USD resulting in a payback period of 3 years.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Commercial buildings especially hotels are very energy intensive and are therefore important targets for reducing demand on conventional fuel sources and their associated GHG emissions. Renewable energy technologies especially solar water heating is considered mature having been utilized for over a century. Hot water and fuel consumption for a case study hotel were statistically analyzed to determine the daily average consumption and system efficiency. The daily average hot water consumption was computed as 48.06m^3 and was verified to be reasonable for such size of a hotel using ASHRAE hot water guidelines. The corresponding daily average diesel consumption was evaluated to be 510.39 litres and the overall system efficiency was 38.19%. It was noted that the calculated system efficiency was quite low and this was explained by the fact that the hot water generated value used in the efficiency calculation was assumed to be equal to the hot water consumed. This in essence did not factor in the system losses thereby reducing the overall efficiency.

The energy mix in hotels revealed that water heating consumes a substantial amount of energy compared to other systems such as lighting. The proportion of energy consumed for water heating in the case study hotel was estimated at 1955kWh/day. A proposed solar water heating system to take up approximately 60% of the hot water demand load was sized at 284.62m^2 collector area with a total number of 118 collectors. Each collector was estimated to generate around 2.67MWh per year based on the climate data for the location of case study. This translated to approximately 314.4MWh for the entire solar hot water system in a year. However, this design was based on specific analysis of the hotel's actual hot water demand load and local conditions. It should be noted that despite hotels having different hot water demand loads, hotels of similar star rating have been found to have roughly the same size of solar hot water system. The results can therefore be extrapolated for other hotels in the same category as the case study hotel.

The research proposed that the designed solar hot water system incorporate the existing hot water storage and distribution system so as to optimize the system cost. The system cost was estimated to be roughly 83,508.28 USD based on component costs from online marketing platforms and Bill of Quantities (BOQ) of already installed solar hot water systems. This cost comprised of both fixed and variable costs which were evaluated as approximately 25,862.07 USD and 57,646.21 USD respectively. From the financial analysis it was evident that a bigger share of the total cost was made up by the collector and installation cost since the existing hot water storage and distribution system was to be incorporated in the design. The associated annual financial savings were 29,756.55 USD resulting in a payback period of 3 years.

Nevertheless, the aim of this research work was to determine the hot water consumption and assess whether a SWH would be a good investment for a case study hotel. The conclusion is that it is an economically viable project given the 3-year payback period evaluated and the positive NPV and IRR values obtained.

5.2 Recommendations for Further Work

The following recommendations are proposed for further work;

i) The system efficiency of the existing conventional hot water system was quite low and this was partly because the steam output was not metered. A more accurate value would be obtained if the efficiency was based on steam flow rate instead of hot water consumption rate. It is recommended that further analysis of the system efficiency of the case study hotel be done based on measured steam flowrate while accounting for heat losses as well.

ii) The orientation and tilt angle of the proposed system was based on the recommendations from existing literature on solar installation. A study to optimize the installation parameters of the panels so as to reap maximum benefits from the sun is recommended.

iii) Renewable energy modelling and simulation software can be used to validate the design results of the case study hotel

iv) A comprehensive survey into the local hotel industry to evaluate the core barriers to SWH would also be valuable.

5.3 Contribution

This research project adds to the existing studies carried out on viability assessments of renewable energy especially solar water heating. It will therefore assist hotel managers in decision making on projects involving large scale solar hot water installations.

REFERENCES

[1] Mac Van D., Tran Ngoc Q., "A Study on Energy Consumption of Hotel Buildings in Vietnam," *Science and Technology in Civil Engineering,* vol. 12, no. 5, pp. 109 - 116, 2018.

[2] Ürge-Vorsatz, D., N. Eyre, P. Graham, D. Harvey, E. Hertwich, Y. Jiang, C. Kornevall, M. Majumdar, J. E. McMahon, S. Mirasgedis, S. Murakami and A. Novikova, "Energy End - Use: Buildings," in *Global Energy Assessment - Toward a Sustainable Future*, Cambridge, Cambridge University Press, 2012, pp. 649 - 760.

[3] A.I. Shehu, I.I. Inuwa, I.U. Husseini, I. Yakubu, "Relationship of Hotel Energy Management Strategies and Hoteliers' Perception on Sustainable Energy Management in Abuja Nigeria," *Resources and Environment,* vol. 9, no. 1, pp. 19 - 26, 2019.

[4] Vlatko Cingoski, Biljana Petrevska, "Making Hotels More Energy Efficient: The Managerial Perception," *Economic Resesarch,* vol. 31, no. 1, pp. 87-101, 2018.

[5] M. Mudi, "Coast Hotels Seek Cheaper Power as Bills Soar," *The Star,* 30 March 2019.

[6] Mariah Michael, Lijun Zhang, Xia Xiaohua, "An Optimal Model for a Building Retrofit with LEED Standard as a Reference Protocol," *Energy and Buildings,* vol. 139, pp. 22-30, 2017.

[7] B. Jayasinghe, "Energy Saving Methods in Hot Water Supply for Hospitality Industry," Stockholm, 2010.

[8] Shailendra S., Abhishek A., Atul S., "Technical, Financial and Environmental Feasibility of Solar Water Heater for Residential, Commercial and Industrial Application: A Theoritical Approach," *Materials Science for Energy Technologies,* vol. 3, pp. 648 - 671, 2020.

[9] Islam R.M., Sumathy K., Samee U.S., "Solar Water Heating Systems and their Market Trends," *Renewable and Sustainable Energy Reviews,* vol. 17, pp. 1-25, 2013.

[10] R. Whitfield, "Solar Thermal Hot Water for Hotels," *Academia Letters,* vol. 511, pp. 1- 8, 2021.

[11] "Study of the Solar Water Heating Industry in Kenya," www.eedadvisory.com, Nairobi, 2017.

[12] Cho Heejin, Smith Aaron,Luck Rogelio and Mago Pedro, "Transient Uncertainty Analysis in Solar Thermal System Modeling," *Uncertainty Analysis and Applications,* vol. 5, no. 1, 2017.

[13] G. K. Serem, "Evaluating the Performance of Solar Water Heaters in Nairobi County, Kenya," JKUAT, 2019.

[14] K. N., "Hot Water From the Sun for Hotels: Basic Facts for the Management," Exergia S.A, Athens, 2003-2004.

[15] O. K. A., "Assessing The Feasibility of a Solar Water Heating System Based on Performance and Economic Analysis," Kwame Nkurumah University of Science and Technology, 2012.

[16] G. L. Fahy, "An Analysis of the Feasibility of Using a Solar Water Heating System in a Hotel: A Case Study," University of Cape Town, 2010.

[17] Styles D., Schonberger H., Galvez Martos J.L., "Best Environmental Management Practice in the Tourism Sector," European Union , 2017.

[18] K. Soultana, "Energy Management in Hospitality: a Study of the Thesaloniki Hotels," *Economics and Organization of Future Enterprise,* p. 78, 2010.

[19] Zhuxian Y., Zhuang Z., Wen G., "Study on Energy Use Characteristics of Hotel Buildings in Shanghai," *Procedia Engineering,* vol. 121, 2015.

[20] M. E. K., "Investigestion of the Viability of a Solar Water Heating System When used as a Replacement of an Instant Electrical Water Heating System," University of Nairobi, 2016.

[21] Abdunnabi Mohammad, Abdulfatah Idweib, Abdulghani Ramadan, "Solar Energy Potential for Hot water in the Hotel Sector in Libya," *International Renewable Energy Congress, IREC,* vol. 6, 2015.

[22] Hajderi Asllan and Gjevoric Shkelqim, "The effectiveness of the Use of Solar Panels in Hotels of Durres Area," *International Journal of Business and Technology,* vol. I, no. 1, 2012.

[23] Robert K. and Harun W., "Solar Water Heating Training Manual for the Kenyan Industry," Government of Kenya, Nairobi, 2017.

[24] H. Wade, "Solar Water Heaters Selection and Installation Guidelines," World Bank Group, 2019.

[25] K. A. Soteris, "Solar Water Heating Systems," in *Solar Energy Engineering - Processes and Systems*, Elsevier, 2014, pp. 257-320.

[26] ASHRAE, "Service Water Heating," in *ASHRAE Pocket Guide for Air Conditioning, Heating, Ventilation, Refrigeration*, Atlanta, SI, 2017, p. 115.

[27] Idowu, O.S., Olarenwaju, O.M. & Ifedayo, O.I. , "Determination of Optimum Tilt Angles for Solar Collectors in Low-Latitude Tropical Region," *International Journal of Energy and Environmental Engineering,* vol. 4, no. 29, 2013.

[28] "Solar Water Heating Project Analysis," in *RETScreen Engineering & Cases Textbook*, ISBN: 0-622-35674-8, 2004, p. 26.

DR. P. MUSAU.

21/11/22

APPENDICES

Appendix A : Similarity Index report

MSc (Energy Management) Proposal

ORIGINALITY REPORT

13%	9%	7%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	hdl.handle.net Internet Source	3%
2	"Proceedings of ISES World Congress 2007 (Vol. I – Vol. V)", Springer Nature, 2009 Publication	2%
3	tsapps.nist.gov Internet Source	1%
4	www.wbdg.org Internet Source	1%
5	Mohammad J. R. Abdunnabi, Abdulfatah A. Idweib, Abdulghani M. Ramadan. "Solar energy potential for hot water in the hotel sector in Libya", IREC2015 The Sixth International Renewable Energy Congress, 2015 Publication	1%
6	www.solmed.info Internet Source	<1%
7	Submitted to Intercollege Student Paper	<1%

8	erepository.uonbi.ac.ke:8080 Internet Source		<1 %
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Appendix B : Peak hot water demand and use for various buildings types

Table 6.4 Hot-Water Demands and Use for Various Types of Buildings*
[2015A, Ch 50, Tbl 6]

Type of Building	Maximum Hourly	Maximum Daily	Average Daily
Men's dormitories	14.4 L/student	83.3 L/student	49.7 L/student
Women's dormitories	19 L/student	100 L/student	46.6 L/student
Motels: Number of units[a]			
20 or less	23 L/unit	132.6 L/unit	75.8 L/unit
60	20 L/unit	94.8 L/unit	53.1 L/unit
100 or more	15 L/unit	56.8 L/unit	37.9 L/unit
Nursing homes	17 L/bed	114 L/bed	69.7 L/bed
Office buildings	1.5 L/person	7.6 L/person	3.8 L/person
Food service establishments:			
Type A: Full-meal restaurants and cafeterias	5.7 L/max meals/h	41.7 L/max meals/day	9.1 L/average meals/day[b]
Type B: Drive-ins, grills, luncheonettes, sandwich and snack shops	2.6 L/max meals/h	22.7 L/max meals/day	2.6 L/average meals/day[b]
Apartment houses: Number of apartments			
20 or less	45.5 L/apartment	303.2 L/apartment	159.2 L/apartment
50	37.9 L/apartment	276.7 L/apartment	151.6 L/apartment
75	32.2 L/apartment	250 L/apartment	144 L/apartment
100	26.5 L/apartment	227.4 L/apartment	140.2 L/apartment
200 or more	19 L/apartment	195 L/apartment	132.7 L/apartment
Elementary schools	2.3 L/student	5.7 L/student	2.3 L/student[b]
Junior and senior high schools	3.8 L/student	13.6 L/student	6.8 L/student[b]

*Data predate modern low-flow fixtures and appliances.
[a]Interpolate for intermediate values.[b]Per day of operation.

Appendix C : Sarova hotel room capacity

SAROVA STANLEY FACT SHEET

SAROVA STANLEY
P.O.BOX 30680 00100, Nairobi, Kenya
Tel: +254 20 316377 / +254 20 2757000
Fax: 254 (0)20 229388 / 219860
E-mail: thestanley@sarovahotels.com

Access

- Distance: 18km from Jomo Kenyatta International Airport.
- 7 km from Wilson Airport.
- 1km from Kenya Railway Station

Site

- Nairobi city center: Corner of Kimathi Street and Kenyatta Avenue (a graceful boulevard).

Locale

- Centrally located in Nairobi's shopping and central business district.
- Easy access to CBD attractions, international organizations, financial institutions including the Nairobi Stock Exchange, government ministries, and historical landmarks.

Climate

- Warm days average 24°C.
- Cooler nights average 12°C.
- Cold months June- July.
- Long rains March – June.
- Short rains October – December.

Reception

- Check-in time is 12:00 pm
- Check-out time is 10:00 am
- Concierge service
- Luggage storage facilities available for late checkouts.

Accommodation

- 217 individually air-conditioned rooms on 8 floors including:
- 160 Deluxe
- 2 Courier Single – Single beds
- 32 Club Rooms
- 16 Executive Suites, 3 junior suites, 2 State Suites
- 1 Presidential Suite
- 1 Penthouse

Guest Services/ Facilities

- Currency Exchange.
- Same day laundry and valet services.
- Baby-sitting services.
- Wake – Up Service and Turn – down service
- Frequent Flyer claim points
- Wi Fi connectivity

Shopping Arcade

- Gift shops, Newspaper stand, Beauty Salon, Bookshop, Boutique, Curio shop, Chemist, Optician

Room Features And Facilities

- Direct dial telephone
- Wireless Internet access
- A safe in every room
- Satellite TV
- Bath, Shower, WC, & Hair dryer
- Voltage of 240 volts and 50 cycles – razor outlets separate
- Minibar
- Tea & Coffee making facilities
- Blackout Curtains
- Sound proofing (Double glazed windows)
- Smoke detectors and sprinkler systems,
- Key card system & Automatic self – locking doors
- Security personnel on each floor

Thai Chi

- On the 1st floor, one of the city's most elegant dining establishments, The Thai Chi Restaurant boasts the finest in authentic Thai cuisine

Thorn Tree Café

- Bistro style featuring great food and entertainment.
- Historic landmark in the history of Nairobi and indeed East Africa.

The Exchange Bar

- Elegantly decadent and plush lounge bar overlooking the graceful Kenyatta Avenue Boulevard.
- Original home of the Nairobi Stock Exchange
- Preferred networking venue with a refined ambiance set in early 19th century decor

Pool Deck Restaurant

- Al fresco restaurant on the 5th Floor serving healthy buffets & salads, Tandoori and grill specialties.

Room service

- Available 24 Hrs

Conference & Banqueting

- 9 meeting & conference rooms including a 227m² ballroom.
- Fully-fledged Business Center with computers,
- e-mail/internet, fax, photocopier, personalized secretarial services etc.
- State-of-the –art presentation and audio visual equipment (Motivator)

Recreation

- Heated swimming pool
- Modern, state-of-the-art health club with sauna & steam bath.
- Massage, Pedicure and Manicure services available
- Yoga and aerobic classes

Car Parking

- Highly organized, secure and efficient Valet parking service
- Car parking space available

Personnel On Call

- Duty Manager, Security personnel.
- Clinical Officer & Hotel Doctor
- Hotel Assistant Manager

ACCEPTED HERE

Appendix D: Oil fuel properties

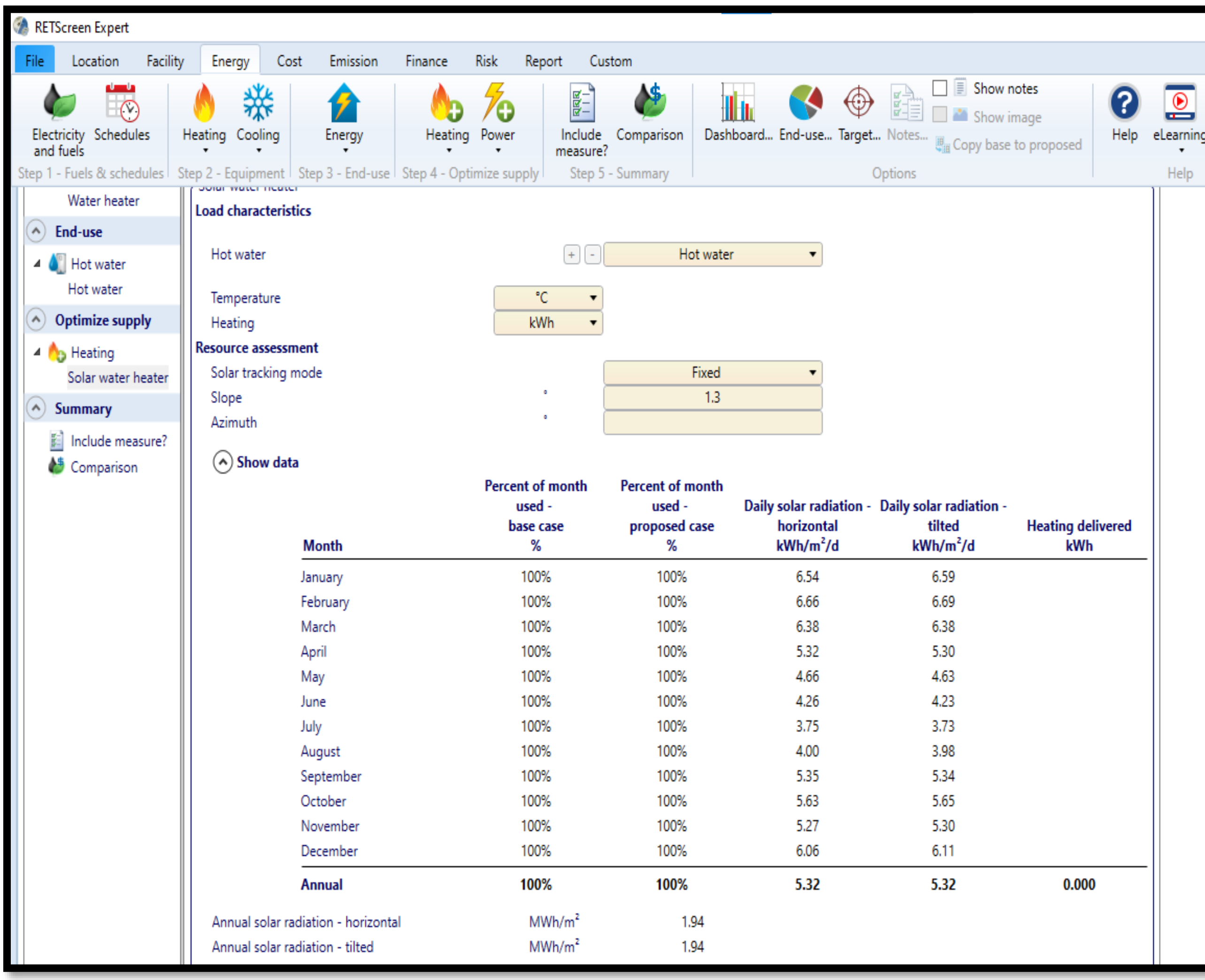
Property	Units	Diesel Oil (Gas Oil)	Light Fuel Oil (LFO)	Medium Fuel Oil (MFO)	Heavy Fuel Oil (HFO)
Composition:					
Carbon	%C	85.7	85.5	85.3	85.1
Hydrogen	%H	13.4	11.5	11.2	10.9
Sulphur	%S	0.9	3	3.5	4
Density @ 15C	kg/l	0.84	0.96	0.98	1
Specific Gravity		0.84	0.93	0.95	0.97
Combustion : Air Requirements per kg of fuel :					
kg of dry air	kg	14.8	13.88	13.78	13.68
dry air @ 0C and 760mmHg	m3	11.46	10.74	10.66	10.56
waste gas @ 0C and 760mmHG containing:					
m3/kg of fuel	m3/kg				
Carbon Dioxide + Silicone Dioxide	%CO2 + SO2	1.66	1.62	1.62	1.62
Water	%H2O	1.49	1.28	1.24	1.21
Nitrogen	%N2	9.05	8.48	8.42	8.36
Total		12.2	11.37	11.28	11.19
Composition of wet waste gas:					
Carbon Dioxide + Silicon Dioxide	%CO2 + SO2	13.6	14.2	14.3	14.5
Water	%H2O	12.2	11.2	11	10.8
Nitrogen	%N2	74.2	74.6	74.7	74.7
Total		100	100	100	100
Calorific Value:					
Gross CV	MJ/kg	43.02	43.02	42.26	41.83
	MJ/l	41.08	41.08	41.44	41.83
Net CV	MJ/kg	42.8	40.6	40.13	39.57
	MJ/l	35.95	38.77	39.17	39.57
Stoichiometric Air Requirement:					
vol / mass fuel	m3/kg	11.94	11.51	11.38	11.29
mass / mass fuel		14.6	14.06	13.91	13.8
Adiabatic Flame Temp in Air	K	2295	2301	2301	2301
Flash Point (Pensky-Martens)	F	170	180	200	240
Mean Specific Heat between 0-100C	cal/g.C	0.48	0.48	0.47	0.47

Source: Global combustion systems

Appendix E : Monthly solar insolation for selected towns in kenya

Solar insolation for selected towns in Kenya (kWh/m²/day)													
Town	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Av**
Nairobi	5.76	6.34	5.97	5.26	5.01	4.54	4.40	4.65	5.61	5.33	4.69	5.20	**5.23**
Nakuru	6.19	6.67	6.47	5.92	5.95	5.61	5.49	5.85	6.58	6.07	5.43	5.76	**6.00**
Eldoret	5.94	6.37	6.21	5.70	5.60	5.21	5.10	5.45	6.16	5.82	5.40	5.66	**5.72**
Kisumu	5.92	6.33	6.27	5.64	5.45	5.06	4.91	5.11	5.91	5.73	5.42	5.76	**5.63**
Homa Bay	6.20	6.55	6.57	6.06	5.90	5.67	5.74	6.11	6.47	6.20	5.92	6.13	**6.13**
Mombasa	6.23	6.54	6.48	5.64	4.84	4.75	4.90	5.65	6.35	6.45	6.37	6.20	**5.87**
Mandera	6.23	6.67	6.62	5.75	5.53	5.06	5.02	5.59	6.17	5.49	5.35	5.81	**5.77**

Appendix F: RETscreen Climate Data for site at 1.3^{0}tilt angle



Month	Percent of month used - base case %	Percent of month used - proposed case %	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Heating delivered kWh
January	100%	100%	6.54	6.59	
February	100%	100%	6.66	6.69	
March	100%	100%	6.38	6.38	
April	100%	100%	5.32	5.30	
May	100%	100%	4.66	4.63	
June	100%	100%	4.26	4.23	
July	100%	100%	3.75	3.73	
August	100%	100%	4.00	3.98	
September	100%	100%	5.35	5.34	
October	100%	100%	5.63	5.65	
November	100%	100%	5.27	5.30	
December	100%	100%	6.06	6.11	
Annual	**100%**	**100%**	**5.32**	**5.32**	**0.000**

Annual solar radiation - horizontal MWh/m² 1.94
Annual solar radiation - tilted MWh/m² 1.94

Appendix G : Extract from the EPRA April Press Release

ANNEX I

	15th April 2022- 14th May 2022			
	TOWNS	MAXIMUM PUMP PRICES		
		Super Petrol (PMS)	Automotive Diesel (AGO)	Kerosene (IK)
		KShs/L	KShs/L	KShs/L
1	**Mombasa**	142.36	123.26	111.19
2	Kilifi	143.07	123.97	111.91
3	Likoni Mainland	142.72	123.61	111.55
4	Kwale	142.72	123.61	111.55
5	Malindi	143.28	124.17	112.11
6	Lungalunga	143.43	124.33	112.26
7	Voi	143.84	124.74	112.67
8	Taveta	145.25	126.14	114.08
9	Lamu	145.66	126.56	114.5
10	Hola	145.95	126.84	114.78
11	Mpeketoni	145.66	126.56	114.5
12	Minjila	144.63	125.52	113.46
13	Garsen	144.72	125.61	113.55
14	Samburu	142.66	123.56	111.5
15	Taru	142.84	123.74	111.68
16	Mwatate	144.18	125.07	113.01
17	Wundanyi	144.34	125.24	113.18
18	Kaloleni	142.51	123.42	111.35
19	Marereni	143.94	124.84	112.77
20	**Nairobi**	144.62	125.5	113.44
21	Thika	144.62	125.51	113.44
22	Machakos	144.86	125.74	113.68
23	Kajiado	145.04	125.92	113.86
24	Makuyu	144.91	125.79	113.73
25	Muranga	145.14	126.02	113.96
26	Sagana	145.35	126.25	114.18
27	Embu	145.72	126.6	114.54
28	Kerugoya	145.64	126.53	114.47
29	Narok	146	126.9	114.83
30	Nyeri	145.99	126.87	114.81
31	Namanga	146.16	127.05	114.98
32	Kiganjo	145.96	126.84	114.78
33	Chuka	146.25	127.13	115.07
34	Kitui	146.15	127.04	114.97
35	Mwingi	146.53	127.43	115.36
36	Nanyuki	146.55	127.44	115.37

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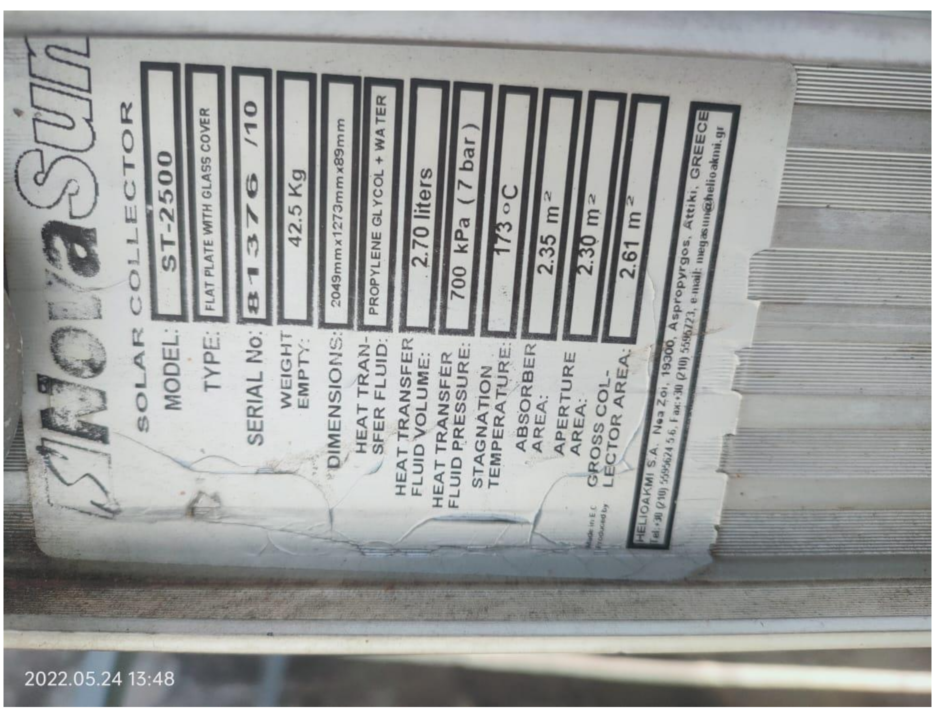
Appendix H : Installed Solar Water Heating System



Appendix I : Questions/Comments raised during defense and how they have been addressed

SNo.	Question/Comments	Corrections made
1.	Wood has been used in major hotels as a source of fuel for water heating, explain why this was not considered as a suitable alternative for the case study	Wood is considered bulky and the operational and maintenance costs are quite high compared to SWH
2.	The sizing of the system considered the daily average hot water consumption, how did you cater for periods of full occupancy	Periods of fully occupancy would necessitate the use of auxiliary system. This is because if the system was designed to cater for full occupancy, then it would be oversized
3.	What informed the choice of 60% as the solar fraction to be used in the sizing of the SWH system	This was based on existing literature in SWH training manual for Kenya market and was appropriately referenced in page 15 bullet (iv)
4.	The graph on hot water use (Figure 4.1) seems to have constant values, does this mean that no hot water is used in the hotel	The end use point graphs were plotted separately so that the variations can be clearly visible – Figure 4.1
5.	Plot a graph of hot water consumption versus fuel consumption so as to accurately represent the correlation between the two.	Scatter graph (fuel consumption vs water consumption) plotted and discussed - Figure 4.4
6.	Change the annual financial savings to be in terms of cost of diesel fuel saved as opposed to cost of electricity saved since the existing system uses diesel fuel.	Financial savings calculated based on diesel fuel price – section 4.5.2 Financial indicators