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Sizing of a Solar Water Heater – Heat Pump Water Heater Hybrid Design; Case Study of Comfort Gardens Hotel

By

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F56/11914/2018

Report Submitted in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Energy Management of the University of Nairobi

MAY 2022

DECLARATION

I **JAPHETH SANG KIPTOO, F56/11914/2018** declare that this research is my original work and has not been presented in any other university for examination.

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SIZING OF A SOLAR WATER HEATER – HEAT PUMP WATER HEATER
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ABBREVIATIONS

EU - European Union.

GHG – Green House Gases.

CO_2 – Carbon Dioxide.

HPWH – Heat Pump Water Heater.

KW – Kilowatts.

LTWPP – Lake Turkana Wind Power Project.

EPRA – Energy Petroleum and Renewable Energy.

VAT – Value Added Tax.

WARMA – Water Resource Management Authority.

UNEP – United Nations Environmental Programme.

NPV – Net Present Value.

IRR – Internal Rate of Return.

SWH – Solar Water Heater.

IRENA – International Renewable Energy Agency.

SAM – System Advisor Model.

ETC – Evacuated tube collector.

STG – Steam Turbine Generator.

HFC – Hydrofluorocarbons.

ODP – Ozone Depletion Potential.

GWP – Global Warming Potential.

COP – Coefficient of Performance.

GPS- Global Positioning System.

FPC – Flat plate collector.

ABSTRACT

Project title: Sizing of a Solar Water Heater – Heat Pump Water Heater Hybrid Design; Case Study of Comfort Gardens Hotel.

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Heating requirements in particular, water heating in hotels constitutes approximately 28% of the total energy costs, which translates to higher emission levels to the environment. These high costs of energy have necessitated the use of energy and environmental management systems to curb the energy costs. Hoteliers have adopted the use of emerging and popular technologies mostly renewable energy technologies. They include the use of solar water heaters, heat pump water heaters, and efficient boiler among others. This research focuses on the viability of using a combined SWH and a HPWH in a hybrid setup for a hotel. Comfort Gardens hotel was used as the case study for this research, providing the data required for design. A hybrid water heating system was sized, designed and was guided by the use of software RET screen, Polysun and SAM. The designer selected two HPWH with a heating capacity of 90 KW each to compliment the 17 solar panels sized to meet the demand of 118.47 Kwh/day. The total demand to be supplied by the HPWH is 78.98 Kwh/Day with one HPWH acting as a backup. An economic analysis done found the NPV and IRR for scenarios A and B were estimated to be Kshs 5,121,699 ($ 44,536), Kshs 6,599,700 ($ 57,389) for the NPV and 33.06%, 39.63% for the IRR respectively. Payback periods for Scenarios A and B computed gave an estimated 2.85 and 2.43 years respectively. From all the financial evaluations, a positive NPV for both scenarios confirm the viability of the project while the payback of approximately 2 years for both scenarios was realized. Recommendations on areas of further studies are proposed in the report.

Keywords: Solar Water Heaters (SWH), Heat Pump Water Heaters (HPWH), Payback Period, Net Present Value (NPV), Internal Rate of Return (IRR).

CHAPTER 1
1.0 INTRODUCTION

1.1 Background

Energy is considered a key player in the creation of wealth and economic development. Its importance is universally recognized with past data proving the existence of a potential connection between economic activity and energy availability. In the past the rising cost of energy was a major concern, however in the past two decades environmental concerns have become more apparent. This has been attributed to a combination of several factors caused by growth in human activities. Increased human population and industrial growth over the past century has led to increased energy usage and demand. This has translated to increased demand of earth's fossil fuel like oil, biomass and coal causing the depletion of these resources. Research shows that fuel like coal has approximately 250 years before its completely depleted while oil has an estimated to 40 – 50 years before depletion. This has caused the energy sector to shift their focus to other energy production sources like the renewable energy that includes wind, solar and geothermal generation. Recent discussions on global warming and climate change have propelled the use of renewable energy as compared to dependence on oil and other fossil fuels as they have proven to be the most effective and efficient in combating the increase in global warming [1]. Solutions to this concern requires long-term potential actions for possible sustainable developments.

The European Union (EU) through an agreement signed in Paris in 2015 intends to minimise the global warming down to 2 degrees by reducing emissions to the environment by 80% by the year 2050 [2]. Studies have shown that majority of the GHG originates from the use of fossil fuels to generate power required. This has called for renewable energy sources to substitute fossil fuels and hence there has been a reduction of CO_2. There has been consensus that the use of this low carbon electricity can be applied in the heating sector, a major energy consumer. This has not only contributed to reduction in emissions but also to energy savings and integration of renewable energy into the industry [3]. It is evident that the decarbonising of the heating sector is essential in meeting the climate targets.

To provide heating requirements in particular water heating, a large amount of energy is required thus translating to high emissions. In a study in Hong Kong, Deng and Burnett in their paper found out that water heating constituted an approximate 28% of the energy costs [4]. In the UK, it amounted to 20% of the total energy used. Due to this expense, most hoteliers established measures to curb the energy usage by formulating environmental management systems. This was achieved by use of energy saving and efficient equipment in their premises. They include LED saving light bulbs, ballast lamps and water heater heat pumps. HPWH have emerged as a new and popular technology to replace diesel and gas fired boilers as a measure of energy savings and curbing environmental impacts. Heat pump water heater (HPWH) is form of renewable energy as classified by the European climate change programme concluded June 2001 [5]. HPWH uses the familiar refrigeration cycle to move energy from a source at low temperatures to a sink at high temperatures. It is a system for extracting heat from source (ambient air) and applying it to water. They have proven to be 2-3 times, efficient when compared to conventional water heaters [6].

Kenya has over the years relied on hydropower and fossil fuel (thermal generation) for generation of electricity while also receiving supplement power from neighbouring countries like Uganda’s Jinja power station. However, with development the country has shifted from imports to local generation with new ventures into the geothermal generation and other form of renewables, wind and solar power to supplement hydropower [7]. The energy mix as at October 2019 stands at 2819 MW which constitutes of 826 MW hydropower (29.3%), 828 MW geothermal power (29.4%), 335 MW wind energy (11.88%), 720 MW fossil fuels (incl. gas, diesel and emergency power) constituting (25.54%), 28 MW bagasse (0.99%), 50 MW solar energy (1.77%) and other sources 32 MW takes up (1.14%) [8]. The above data clearly shows that renewable energy contributes 73% of country’s energy mix.

Increased demand for energy in Kenya has been on the rise due to more households connecting to the grid, technological advancement and acquisition of more electrical appliances to serve various needs. These appliances could include air conditioners, refrigerators, entertainment sets and most notably water heating appliances (kettles and instant showers). Some of them are low consuming while some like the water heating appliances contributes to increased electrical bills for households and premises in Kenya. This phenomenon is due to most households, utilising the electric induction heater to provide hot water. Electric heaters consumption leads to these high bills as most of these heaters are rated between 2.5 KW – 7.5KW that classifies them as high consuming appliances. To manage this demand the Kenyan government has embarked on educating households on the importance of energy conservation and efficiency. Various water-heating technologies have been adopted to try reducing this burden of high bills and demand. These may include solar water heating, gas fired water heaters, biomass heaters and a new technology thermodynamic water heater [9].

1.2 Problem Statement

The energy sector in Kenya remains a key driver for achieving sustainable development and therefore identified as an enabler in the realisation of vision 2030. The sector is key in transforming the economy into an industrial middle-income economy. Energy demand has since been on the rise due to programmes initiated by the government such as the last mile, 'boresha na umeme' and slum electrification project. The government had an aim of achieving 70% electrification by 2017 which it has successfully attained as current connectivity rate stands at 74.7% with an estimated aim of universal connectivity by 2022 [8].

Kenya has an installed capacity of 2686.1 MW as at 31st January 2019. This includes renewable energy with the commissioning of 300MW Lake Turkana wind power project (LTWPP) and a 50MW solar power plant in Garissa by REREC. The current energy mix includes 826.2 MW of hydroelectric power, 742.46 MW geothermal power, 662MW thermal power, 325.5 MW wind power and the remaining from sources like cogeneration and biogas plants. Statistics from EPRA indicates that Kenya recorded a demand of 1888MW in 2018. It also shows that the demand has been on a steady rise over time with projections showing that as of 2023 the demand will increase to 2461, which will be so close to the installed capacity [10].

In Kenya, EPRA has the mandate to regulate the cost of electricity through energy tariffs. The Energy tariffs defines how an energy provider charges a customer for electricity or gas usage. Section 11(b) of the energy act 2019 gives EPRA the authority to set, review and adjust electrical power tariffs [11]. They classify consumers in different categories based on the amount of consumption. Consumers between 0-100 Kwh a month are charged at a rate of Kshs 10 per unit while those above 100 kWh are charged Kshs 15.8 per unit for domestic and small industrial category. Commercial users of 101-15000 Kwh are charged Kshs 15.6 per unit. These rates are exclusive of monthly pass-through costs, taxes and levies. Monthly pass-through costs include fuel cost charge, forex levy, inflation adjustment while taxes include 16% VAT, EPRA levy, rural electrification programme REP charge and WARMA charge. For a domestic user less than 100 kWh per month a transaction of Kshs 500 will attract all these deductions leaving the user with a token amount of Kshs 284.43 hence only receiving 28.43 Kwh [12]. For the hotel industry, they are more likely to consume more than 100 Kwh per month; the cost implications of using electrical heaters are massive. Water heating constitutes a big part of energy consumption in the hotel industry.

In Kenya, hotels are keen to reduce their cost by trying alternative methods to substitute or supplement the use of electrical heaters.

With all these considerations of price implications and rising demand, it is imperative that users resort to economical alternatives for industrial, commercial and residential applications. Regardless of the alternative used, energy saving and improving efficiency is key in coping with the rising costs. The heat pump water heater becomes a key component in the realisation of energy savings and has a great potential to reduce power consumed and emissions from conventional sources of water heating. Hotels with restaurants, kitchen and laundries, hot water production consumes up to 12% of the total consumed energy. In a study conducted in Barbados for UNEP, a hotel with 75% occupancy consumes 1500-2300 Kwh per year for hot water production [13]. This study aims at evaluating the potential of energy saving in a hotel setup by incorporating a heat pump water heater to compliment conventional water heaters, boilers and solar water heaters as a hybrid setup and to reduce the energy consumed by an estimated 20%.

1.3 Objectives

1.3.1 Main Objective

This study's main objective is sizing a solar water heater – heat pump water heater hybrid system in a hotel setup in Kenya and to estimate the expected energy saving.

1.3.2 Specific Objectives

(i) To determine the hot water requirements for a hotel setup and associated costs.
(ii) Design a SWH-HPWH system to provide the hot water requirements.
(iii) Perform an economic evaluation of the hot water system.

1.4 Research Questions

This study is carried out with the aim of answering the following research questions

(i) In a hotel setup what are the hot water requirements and how much does it cost to produce it?

(ii) Does the introduction of a HPWH reduce the energy consumption?

(iii) From the economic analysis using payback period, NPV and IRR is it a viable option to install a heat pump water heater?

1.5 Justification

In a hotel, the expenditure incurred in producing hot water makes a significant part of the total operating expenses. The hotel industry has over time introduced the use of various technologies like the solar water heaters, efficient boilers and preheating of water by heat recovery methods amongst others with the sole aim of cutting down these costs and bringing about profit making. Hot water delivered to clients ranges from 45 - 55 degrees that is considered satisfactory for comfort of the guests. Hot water is required for bathing, swimming pool, laundry, washing and meal preparation. Consumption is estimated at 0.2-0.3 Kwh per meal [14]. In a study by IRENA, it was found out that 60 % of the total electricity usage is for production of hot water and climatic controls in hotels. It also estimated that hotels that installed solar water heaters (SWH) reduced their costs by 27%. Energy audits carried out proved that hotels were recovering their initial cost of installations with an estimated payback period of a year [13]. This realisation of cost cutting can be increased further by pursuing other upcoming technologies. This study therefore aims at reducing further the cost of producing hot water by retrofitting design by use of a HPWH to supplement the existing boilers and solar water heaters already in use. In doing so, it also aims at reducing the use of a boiler to a minimum, which will in turn reduce the gas emission to the atmosphere.

1.6 Scope

This project aims at determining the cost of energy consumed in the hotel attributed to production of hot water and propose the percentage of hot water to be produced by the solar water heater from the total. By sizing a HPWH to supplement the solar water heater to reduce the dependence of conventional water heaters. Software like System Advisor Model (SAM), Polysun and RET screen to be used to aid in the design of the system. Economic analysis is applied to determine the viability of the system.

1.7 Report Organisation

This report consists of Chapter 1-5, References and Appendices. Chapter 1 provides the background of the report introducing energy demands and mix in Kenya. It gives a problem statement and justification aimed at explaining the need for using a HPWH in the hotel. Objectives and related research questions are stated in this chapter scope of study. The second chapter provides the literature review explaining the basic concepts on the HPWH, solar water heaters and other water heating techniques. Hotel hot water demand and associated costs are mentioned here. Previous methodologies and studies are reviewed. The third chapter reviews previous methodologies used in the study of the hot water system and proposes a method for the research. It gives a detailed design and sizing formulation and further gives a brief explanation of the economic evaluation techniques to be utilised. The Chapter four of the report contains the findings of the design and the evaluation of the financial viability. Chapter 5 gives the conclusions of the research with recommendations also given in the chapter. The researcher further gives the main contribution of the report. References and appendices are provided for all the work quoted in the report.

CHAPTER 2
2.0 LITERATURE REVIEW

2.1 Water Heating Technologies

The process of water heating comes at an enormous cost incurred by hotels and domestic households. This cost has necessitated the use of efficient water heating technologies or the use of renewable energy technologies to assist in bringing down the expenses. Conventional water heating by use of induction water heaters is a major contributor to the rising cost of heating water. This is due to the rising cost of electricity experienced in Kenya. Adoption of alternatives methods is on the rise in Kenya, which has been supported by enacting laws that require use of these technologies [15]. The upcoming renewable energy technologies operate by converting natural environmental phenomenal into usable and useful forms of energy. They use direct or indirect effects of the sun like irradiation and ambient air as the source from which energy is produced. These technologies include solar water heaters (SWH), efficient boilers and use of heat pump water heaters (HPWH), which can be utilised as a hybrid system to compliment the production and ensure users, are reliably supplied with hot water.

2.2 Solar Water Heaters (SWH)

A SWH is a device that utilises the solar radiation by collecting or concentrating it hence allowing them to be used for the heating of water. SWH comprises of collectors, storage tank, controllers, auxiliary heaters, optional circulation pump and pipework. The collectors are mounted in an open area often the roof and has to be very sturdy due to their exposure to various climatic conditions. Consumers that use SWH as an alternative to the normal water heaters have a potential of reducing the energy costs [16]. There are three types of solar collectors widely in use for heating water. They include flat-plate collectors (FPC), evacuated-tube collectors (ETC) and parabolic collectors.

2.2.1 Flat Plate Solar Collectors

FPC are the most commonly used kind of collectors for domestic consumers due to the low cost of purchasing and installation. FPC are typically insulated metal boxes with glass or plastic cover and a dark coloured absorber plate. The glazing and insulation used in the FPC is to prevent heat escaping the metal box. The FPC designs can be either open or closed loop, passive or active type. The Figure 2.1 illustrates the components of an FPC [17].

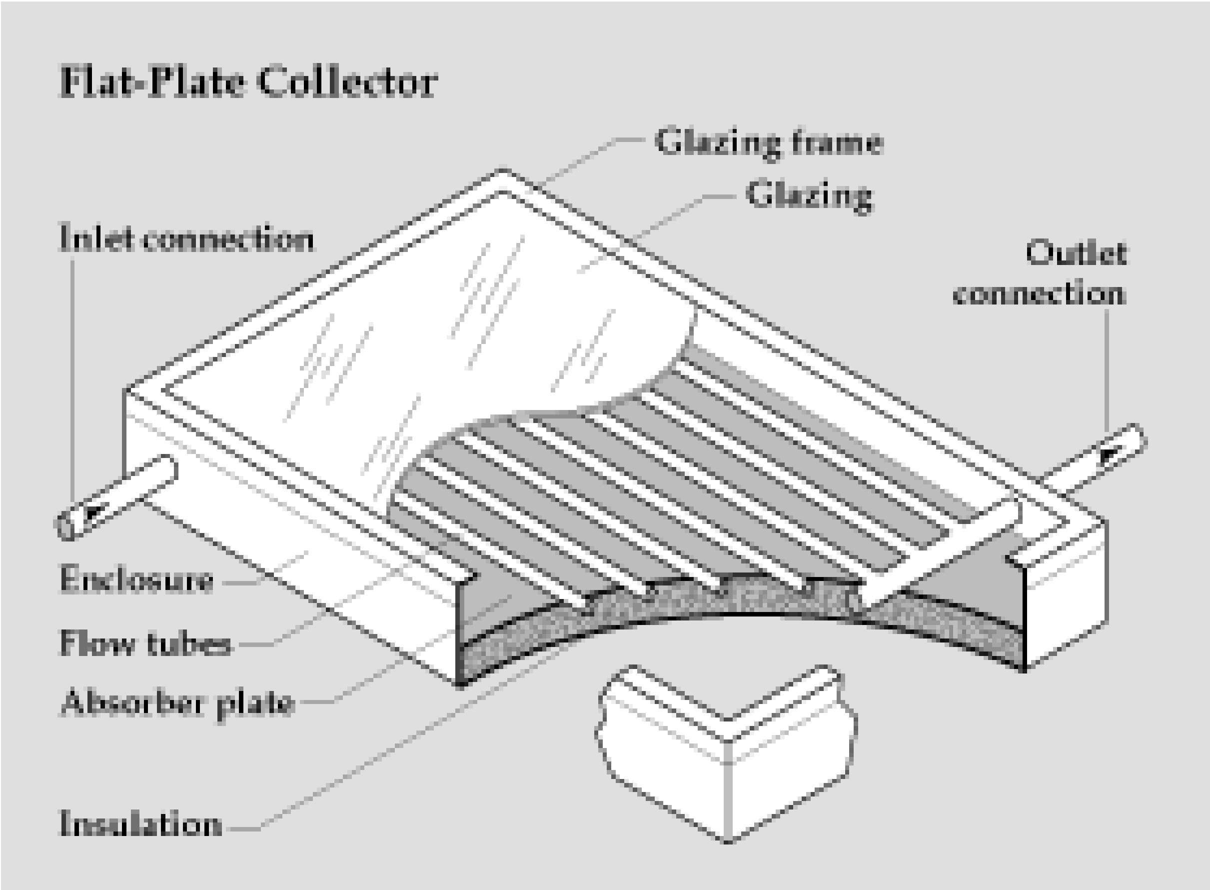

Figure 2. 1: Flat Plate Collector Components. [17]

The performance of the FPC can be affected by several factors. These factors are, the surface of the absorber plate, number of covers used, the spacing between the covers and the absorber plate and the effects of shading on the FPC. Additionally, the collector tilt angle as they do not track the sun, dust settled on the collector, working fluid temperature and transmissivity of the cover [18]. These parameters may affect the efficiency of the FPC and translate to the performance.

2.2.2 Concentrating Collector

These types of collectors utilise a surface parabolic in shape and reflective to concentrate the sun's radiation. Sun energy is concentrated to a focal point where an absorber plate is placed. They are fitted with a sun-tracking device that will guide the collector to achieve maximum derivation of the solar energy throughout the day.

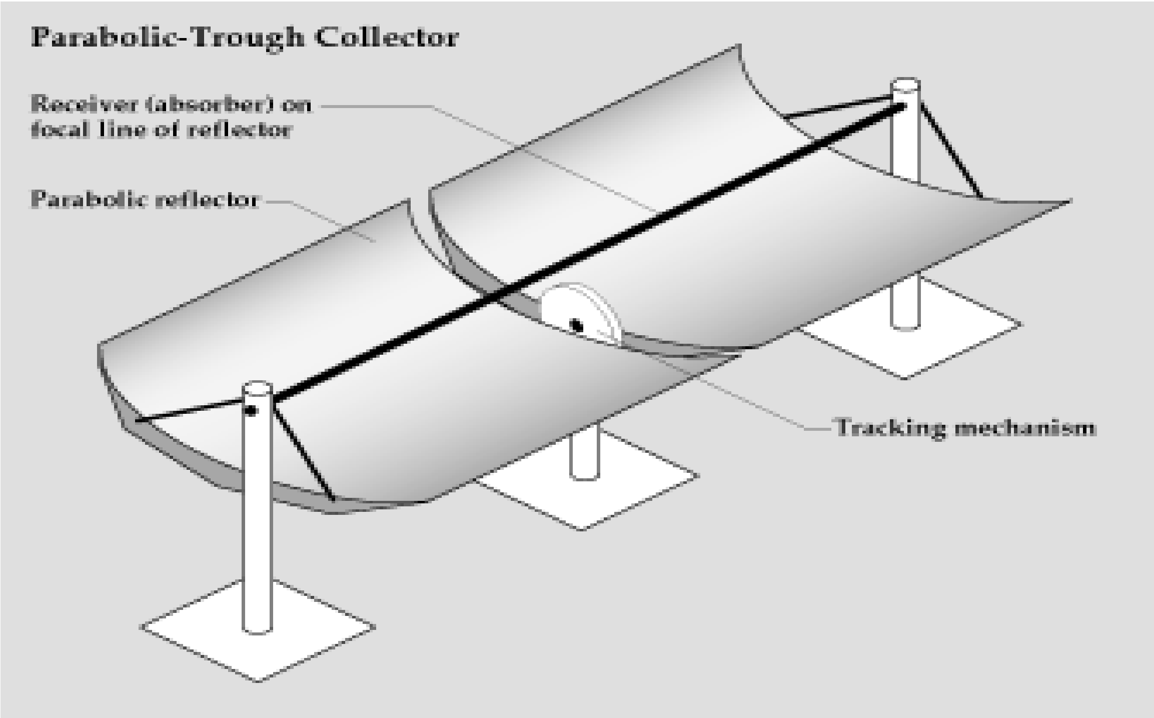

Figure 2. 2: A Parabolic Solar Collector. [18].

Concentrating collectors comprises a central receiver, trough, fixed reflector, moving receiver and a Fresnel lens. A diagrammatic representation is shown in Figure 2.2. [18].

2.2.3 Evacuated Tube Collectors

ETC consists of a number of sealed glass tubes attached to a header pipe. Heat from the sun heats up the working fluid and then transfers it to the water through a heat exchanger. They have proven to have a higher efficiency than FPC but are also expensive which may cause the reduction in the users who opt to use this kind of SWH [19].

2.3 Boilers

A boiler is a closed vessel under high pressure that transforms water supplied into steam by use of different heating methods. Open vessels and devices that generate steam at low-pressure i.e., atmospheric pressure is not considered boilers. In the boiler, chemical energy in fuel through combustion process in a furnace is converted into heat energy in hot gases. The energy in the hot gases is then transferred to water in the heat exchanger part of the boiler to form steam. Boiler are designed to use different types of fuels i.e., coal, biomass, fuel oil and electricity. Most boiler design use only one type of fuel but some advanced designs can be adapted to burn coal, oil or gas. The boilers are classified into four main groups - that is, Fire-tube boilers most commonly used as shown the Figure 2.3, Water tube boilers, coil tube boilers and electric boilers. Boilers are also categorized based on circulation, draft, and type of support and furnace construction [20].

Figure 2. 3: Fire Tube Boilers [21]

2.4 Heat Pump Water Heaters

HPWH technologies dates back to 1935 when the patent was issued. It was then put to work, commercialised in the 1950s, and has since been improved to improve on the efficiency and reliability. HPWH is a device that operates on an electrically driven vapour-compression cycle and pumps energy from the air in its surrounding to water, thus raising the water temperature. A typical HPWH will be as shown in Figure 2.4.

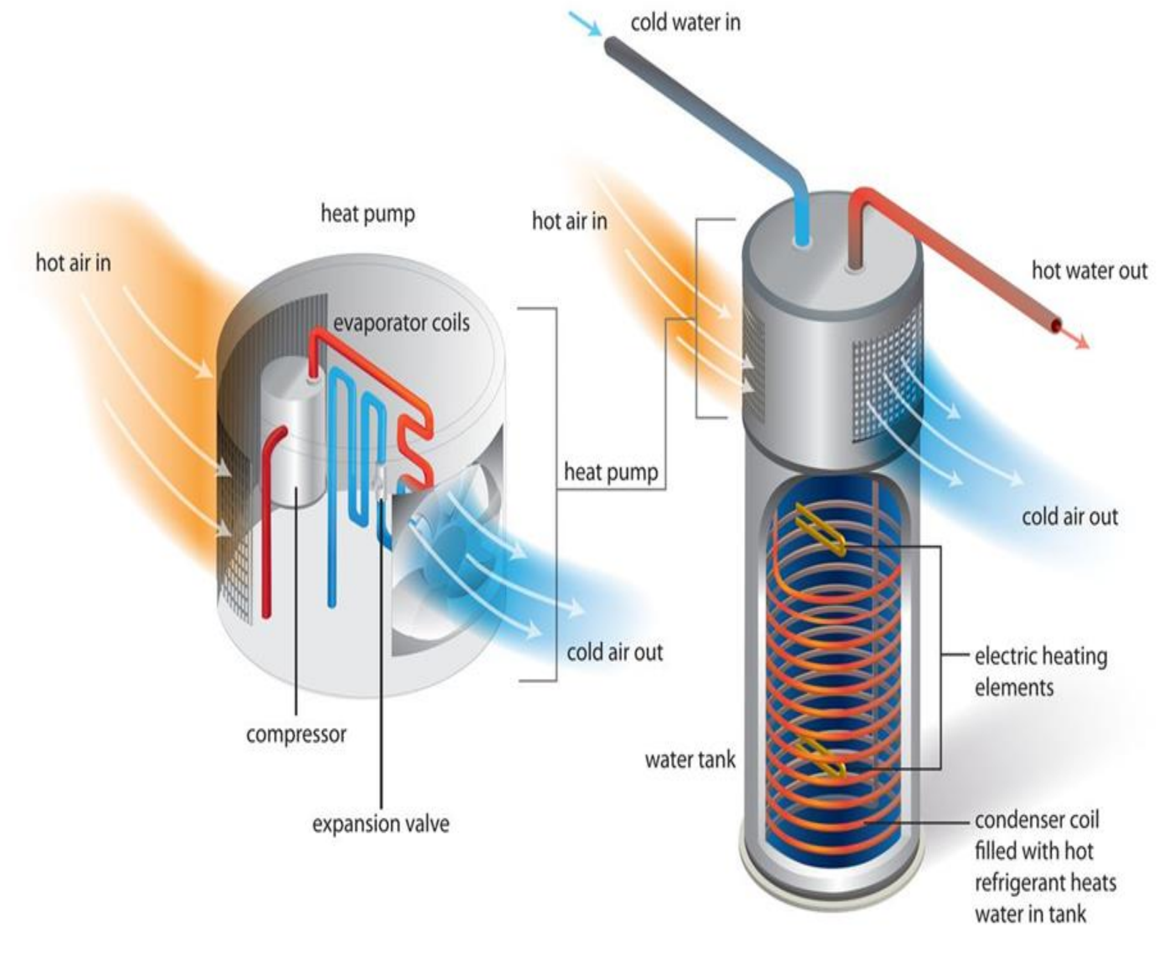

Figure 2. 4: A Heat Pump Diagrammatical Representation [22]

HPWH uses electrical energy to move heat from the source to the sink instead of generating the heat directly. This mode of operation makes it at least 2-3 times more efficient than electrical resistance heaters. HPWH working mechanism is like a refrigerator in reverse. While a fridge extracts the heat from a space and expels it to the surrounding, the HPWH pulls the heat from ambient air and transfers it to the water in the storage tank. To operate optimally, HPWH should be installed in area with temperature conditions of 4.4 – 32.2 degree Celsius.

Most HPWH designs are hybrid combining a backup heating element, heat pump and a storage tank. Historically heat pump water heaters have been differentiated into two categories, integrated and remote. These categories describe the relationship between the HPWH and the storage tank. Remote tank also known as add-on device can be used as retrofits to an existing system at a lower cost while integrated devices include the heat pump, electrical resistance heater and storage tank all in one as a package. The Diagram 2.5 shows the different types as discussed above.

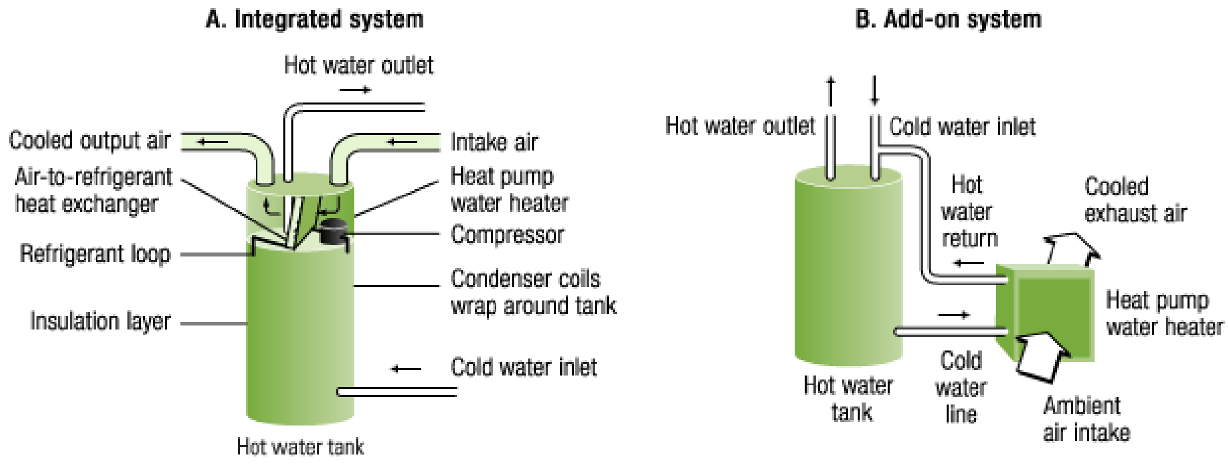

Figure 2. 5: Types of HPWH Systems [23]

Heat pumps can also be classified according to the source from which they derive their energy. Researchers in their study of HPWH, classified them as geothermal HPWH, air source HPWH, water source HPWH also hydrothermal and solar assisted HPWH. Among the name categories air source and geothermal heat pump water heater were the most common due to their performance and ease of use [24, 25].

2.4.1 Operation of the Heat Pump Water Heaters and Its Components

The heat pump water heater operates using a vapour-compression refrigeration cycle. It utilises a reverse Carnot cycle which reverses the directions of heat and work interactions. The components of the HPWH includes an expansion valve, compressor, condenser, evaporator and a working fluid mostly R- 410a and R-134a.

A simple definition of the HPWH as discussed by Ashdown in their paper, it is a device where air thermal energy gained at the evaporator is absorbed by the refrigerant and converted to vapour while gaining sensible thermal energy through an isothermal process. The refrigerant flows to the compressor where it is compressed to a superheated gas and flows to the condenser where heat is dissipated to the water in the water storage. The water temperature rises while refrigerant's temperature is reduced as it flows to expansion valve where the temperature and pressure are reduced. The process is repeated until the set heater temperature is achieved. This process is made possible as electric energy is fed to the compressor and constitutes work input. This conforms to the requirements of the second law of Thermodynamics [26].

The compressor is a mechanical device used in the heat pump as a core component in the operations of the system. It conveys refrigerant in the form of vapour at a low temperature and pressure to a high pressure and temperature as it circulates to the condenser. There are different types of compressor types depending on the working mechanism, which includes reciprocating, centrifugal, rotary, scroll and screw type. Some of the types are more preferred to others depending on the efficiency and lifespan of the devices.

Condenser is part of the heat pump where heat exchange to the water occurs. The water absorbs the heat rejected by the condenser at high pressure and high temperature as it circulates to the expansion valve. The condenser is mostly formed in the shape of a coil to increase the surface in contact with the water in the storage tank to increase the rate of heat exchange.

Evaporator is part of the heat pump that interact with the ambient air. Refrigerant from the expansion valve that exhibits low temperature and pressure circulates in a heat exchanger. This heat exchanger forms the evaporator of the heat pump and absorbs heat from the ambient air increasing the temperature of the refrigerant as it circulates to the compressor.

Expansion valves also called a throttle valve's function is to allow the circulating refrigerant under high pressure and temperature to pass through and cause reduction of both as it enters the evaporator.

A simple schematic representation of the components of a HPWH are shown in Figure 2.6.

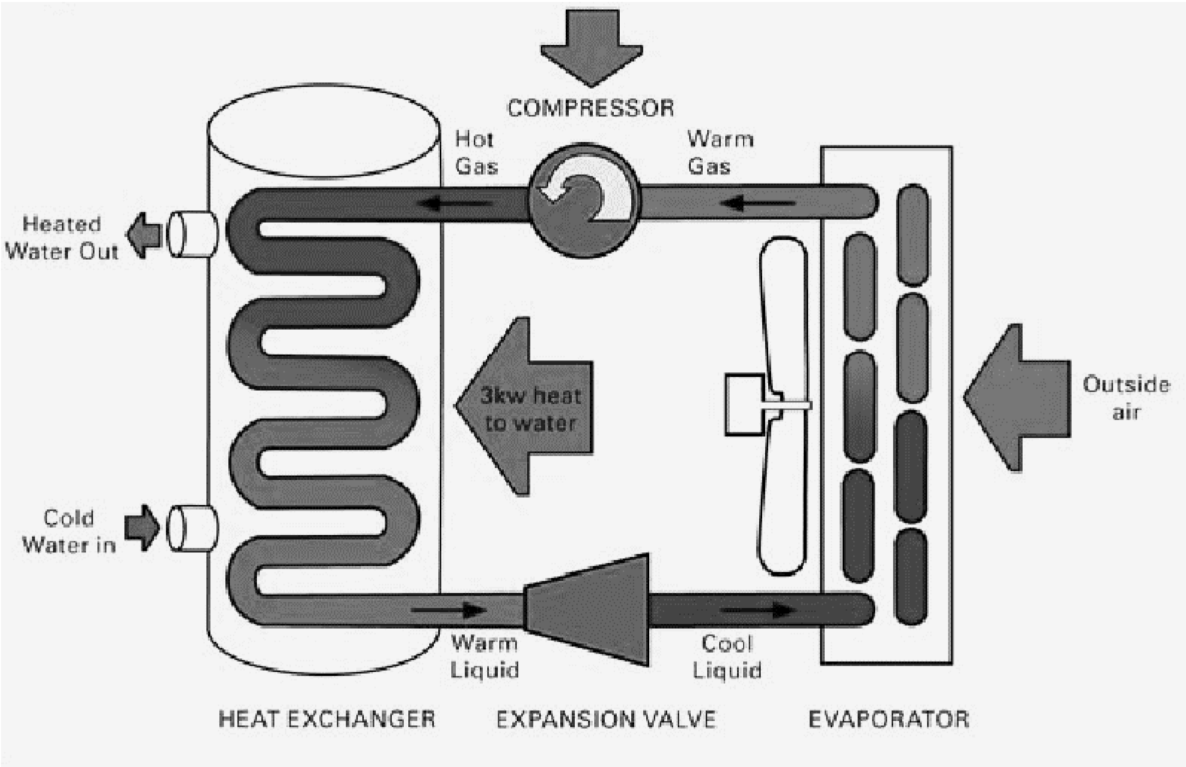

Figure 2. 6: Simple Schematic Representation of the Component of a Heat Pump [26]

Refrigerant also the working fluid absorbs and repels heat more efficiently at different stages of the process. They are mainly hydrofluorocarbons (HFC) which does not cause harm to the environment. Earlier refrigerants like the R-12 contained chlorine, which were realised to harm the ozone layer and thereafter discontinued after the Kyoto and Montreal protocols were operationalised. Refrigerants R-134a (CF3CH2F) Tetraflouroethane and R-410a Freon which is a zeotropic HFC blend of R-125 and R-22 are the two most commonly used in the HVAC industry. Both refrigerants are not harmful to the ozone layer, as they have zero ozone depletion potential (ODP). They both have very low boiling point enabling them to be used as a working fluid in the HPWH. R-134a boiling point is -26.1 ^{o}C and R-410a at -51.5 ^{o}C.

Controllers and thermostats are electronic devices that monitor and control the overall operations of the HPWH. These controls dictate the levels of operations by switching on and off depending on the usage and set profiles by users.

2.5 Review of Previous Works

Several studies have been carried out, both the experimental and theoretical analysis on the improvement of water heating and influence of new technologies used in this field. Various hybrid system configurations are being suggested as the best way of improving reliability and reducing cost of water heating. Design, simulation and experimental studies indicate that hybrid systems could be a combination of more than one heating techniques. Users of such systems have realised higher energy and cost savings. The potential of adding solar thermal to a HPWH has been studied largely in several cities of Europe. The studies focused on the climatic condition of Europe and the various categories of hot water demand, which included small, medium and large consumers. Simulation of the energy demands in all the categories indicated potential benefits of combining the solar thermal and heat pumps water heaters. System performance improvements were evident in all the simulations. The study indicated that annual savings of 1.98-2.51 Mwh of electricity were realised. This clearly shows the effectiveness of combining these systems and how they are beneficial. In a different report by Ozgener and Hepsbasli, the study shows that a hybrid solar collector with a heat pump system, the economic analysis conducted gave a payback of 3-5 years. This illustrates how viable the project is and the user is able to recover initial cost of investment in a very short time period [24].

HPWHs have proven to be a robust product in hot water production in the industry. In a study which was conducted for a period of 9 months, it was found out that components of the HPWH like the compressor fan or the electric heater experienced no failure during the entire period. All the units continually produced hot water throughout the stages of the test protocol. The unit’s efficiency was about 1.4 times that of electric water heaters for add-on HPWH while the integral HPWH, 2.3-2.4 times higher than the electric resistance heaters, which is approximately 260% higher. The heat pumps were subjected to 7000 cycles during the test. The results indicated that integral HPWH maintained their efficiency while for the add-ons, the energy factors did not appear to degrade significantly, as it showed 2-6 % variations, which is very low. This small degradation was attributed to scaling in hot water tubes and is a correctable case by limiting the temperatures in the condenser, which will in turn reduce the depositing. Control units operated robustly for both the add-ons and integral units throughout the entire process [27]. This shows on the reliability and assurance on what they offer to the client.

In a study of hotels in the Nordic regions between years 2015-2019, research indicated that there was shift towards the use of renewable energy regarded as sustainable technologies. The study shows that 70 percent of the total energy consumption was the electricity energy consumption. This was gradually reduced by the adoption of the renewable energy technologies by 8% rather than the use of conventional methods. Hotels in the region that relied fully on electric heating were reduced in number by a significant 50 percent over the five-year period. Data from the study indicates that up to 70 percent of the hotels applied this new technology in their heating systems by 2019. It also indicated that 9 percent of those hotels adopted the use of heat pump water heaters as their primary heating system. Heat pump technology adopted by these hotels reduced their heating cost and made them realise the highest savings compared to the other hotels [28].

Two hotels investigated that applied the HPWH technology with CO_2 as the primary refrigerant realised a saving of approximately 90 Kwh/m^2/year. Both hotels energy consumption reduced by 60 percent which shows the potential of using an integrated CO_2 heat pump system as an alternative solution for hotels. It was concluded that it is a sustainable solution for hotels to use this type of HPWH as their main thermal energy generator. The HPWH proved to be highly energy efficient and operates well in the cold Nordic climatic conditions [28].

In an experiment by Huang and Chyng to study an integrated solar assisted HPWH, it was characterised by the use of a Rankine refrigeration cycle integrated with a thermosiphon loop hybrid heating setup. They used a capacity of 105l, reciprocating compressor type rated at 250W and a refrigerant R-134a in their experiment. The experiment yielded values of 2.5- 3.7 COP depending on the water temperature requirements. The experiment was studied further to determine the reliability of the system. They were tested for a period of over 20000 hours, which is approximately 5 years. During this period, no machine failure occurred; this clearly shows that these systems can be relied upon to produce hot water for long times. The results achieved also gave a consumption average of 0.019 Kwh per litre of hot water production at 57 ^{0}C which is much less compared to that of an electric induction backup heater [29].

In a study investigating performance of a combined solar thermal and HPWH, the researchers reported significant energy savings. The savings achieved were the highest as compared to using electric induction heater or gas fired heaters as backup for heating systems. Calculations in the report indicate that an amount up to 70% annual savings are achieved for a climatic data of Athens [30]. The review of literature can be summarised in table form as in Table 2.1.

Table 2. 1: Summary of Review of Previous Work

REFERENCE	DESIGN	GAPS
O. Ozgener & A. Hepbasli Ref 23.	Combined hybrid solar collector with heat pump system.	Further research on different financial evaluation techniques.
V. Baxter & D. Linkous Ref 26	Heat pump water heater durability testing.	Further study into the energy savings & financial evaluation.
S. Smith, I. Tolstorebrov, A. Pardinas, A. Hafner Ref 27	Energy use and retrofitting potential of heat pumps in cold climatic hotels.	Research of the system in different climatic conditions.
B.J. Huang & J.P. Chyng Ref 28	Performance characteristics of integral type solar assisted heat pump.	Performance of the system in a commercial setup.
G. Panaras, F. Mathioulakis & V. Belessiotis Ref 29	Performance of a combined solar thermal heat pump hot water system.	Validation with the use of simulation software.

2.6 Research Gap

This study has focused on several reports, journal and experiments to come up with the exact position of the utilisation of combined water heaters and solar water heaters. From the research, a gap identified is that there was no simplified global model for calculating the benefits of using a solar water heater-HPWH hybrid system. A simple model with variables like the user loads and climatic conditions without the use of annual simulations needs to be developed and deployed. In research by Afarin Amirirad et al submitted to the IEA heat pump conference, the authors were investigating indoor air source HPWH in a Canadian climate. A gap identified from the research is that the authors did not validate the findings by use of a simulation software. This gap can be filled by the use of TRNSYS and RET screen software. They can determine the performance of the system and the data can be used to simulate and estimate the performance in different climatic conditions.

2.7 Chapter Conclusion

This chapter discusses the specific heating techniques that hotels use to produce hot water in their facilities. The heating techniques that are boilers, solar water heaters and heat pump waters are discussed giving the types in each category and specific components in their setup up and operation mode. Previous literature is reviewed and appropriate finding mentioned in the chapter with a summary table provided.

CHAPTER 3
3.0 METHODOLOGY

3.1 Review of Previous Methods

3.1.1 Previous Method 1

In a study of solar collectors in Southern China, the researcher focused on assessing the thermal performance of a solar collector in a five-star hotel and proposed economic measures. Hot water output requirements were set at 60°C and discharged to a central hot water storage. The researcher recorded inlet water temperature, solar insolation and this was validated with the output of the solar collector. The study adopted the use NPV, IRR and simple payback periods. The difference in the heating costs realized was interpreted as the savings in the study and was used in the calculation of the payback and subsequently IRR. The study in the recommendations indicated the use of heat pump water heaters as a suitable hot water provider in future studies [31].

3.1.2 Previous Method 2

Heat pump water heater running on R-22 refrigerant and with a heating peak of 30 KW was tested in a four-star hotel to determine the energy savings in supporting tourism sustainability. The researcher installed a power meter, two temperature probes and a flow meter. This was to monitor and record the water flow rate, energy consumed by the HPWH and the inlet and outlet water temperatures. This was used to compute the COP of the device and compute an economic analysis of the HPWH. A life cycle of 10 years was considered and a discount rate of 7.3%. Heating requirements was compared to the existing system, which was an electric boiler, and the NPV, IRR and payback period computed [32].

3.2 Design and Sizing of the Hot Water System

Hot water production for both domestic and commercial facilities come at a cost to the clients and hence sizing is a requirement. Sizing of the system to be used will make sure the client receives what they require and by use of the optimal design without wastage and unnecessary cost. In the sizing of systems, a site visit is a recommended requirement to determine the demand accurately by use of scientific measuring methods. The sizing of any system is done with client’s objectives and needs as the baseline point of view.

In solar energy systems, the largest single expense is the acquisition of solar collector panels and the supporting structure to be used. This cost will therefore necessitate sizing the system in terms of collector panel area, pumps, heat exchanger and the storage tanks to match the budget and water requirements. In studies reviewed, it is rare for a solar thermal system to provide up to 100 % of the requirements for a given application due to limitations caused by climatic conditions and solar irradiation. Optimum sized systems are considered the most economical and they take into consideration the life cycle cost, payback time and the best return rate with focus on the largest annual savings. Computation carried out involves costs like the initial cost of acquisition or investment cost, maintenance costs, fuel prices and related costs and most important energy savings realised by employing solar water heaters. Technical improvements and low investment costs have the highest impact on the economics and hence viability of the systems.

The sizing and design of a solar heating application focus on the daily hot water demand and the available insolation at the site. Kenya has an average annual insolation of approximately 4-6 Kwh/m^2/day [33]. According to the solar manual, the daily hot water demand will be calculated as shown in the Equation 3.1.

$$L = V * \rho * C(T_{hot} - T_{cold}) \tag{3. 1}$$

Where; L=Daily water demands in Kwh/day, V- Water volume supplied M^3/day, ρ-Water density Kg/M^3, C- Water specific heat capacity usually 0.001167 Kwh/Kg^{o}C, T_{hot} – Temperature of hot water ^{o}C and T_{cold}- Temperature of cold-water temperature ^{o}C.

The solar collector area is also calculated to determine the required solar collector panels and sizes. It is calculated as shown in Equation 3.2.

$$A_c = \frac{L * F_{solar}}{I * \gamma_{solar}} \tag{3. 2}$$

Where; L=Daily water demands in Kwh/day, A_{c}- Collector area, I-Average insolation Kwh/m^2/day, γ_{solar}- Solar system efficiency usually 40 % and F_{solar}- Solar fraction with a minimum of 60%.

The solar collector area is used to calculate the number of panels required using Equation 3.3.

$$N = \frac{A_C}{S_P} \tag{3. 3}$$

Where; A_C= Collector area in M^2, N- The number of collectors required and S_P- Solar panel size in M^2.

From the above calculations, the design will follow the common code of practice that recommends under sizing rather than oversizing. This will be achieved by using the maximum insolation of 6 Kwh/m^2/day and incorporating the solar fraction factor in the computations.

Water storage size is also a requirement in design of the system. As a rule of thumb in design, regulations require a minimum size of the tank to be 1.5 time that of the hot water demand.

Pump sizing in solar water heating is not a mandatory requirement. It is the designer job to recommend to the user whenever the pump is required to supplement low feed water pressure. For commercial applications, it is recommended to install a pump in their solar water heater design to ensure optimal flow of water in the system and improve on the system efficiencies [33].

In this project design, solar water heating is supplemented by use of a heat pump in a hybrid setup. Solar water heaters cannot be relied upon on its own to produce hot water due to limitations caused by climatic and weather condition and its reliance on solar insolation to work. This design aims at combining the solar heater with a heat pump in support. The design will utilise the heat pump water heater as a standby and to complete the heating process to the required temperature. Like in the SWH sizing, sizing of the HPWH heater is necessary to be able to meet the user needs. Sizing in HPWH usually follows seven major steps as shown in Figure 3.1. Steps 1-4 shown in the figure involves defining the configuration of the HPWH, choosing between the split and integrated models, determining the heating loads requirements and determining the size, target and capacities requirements [34].

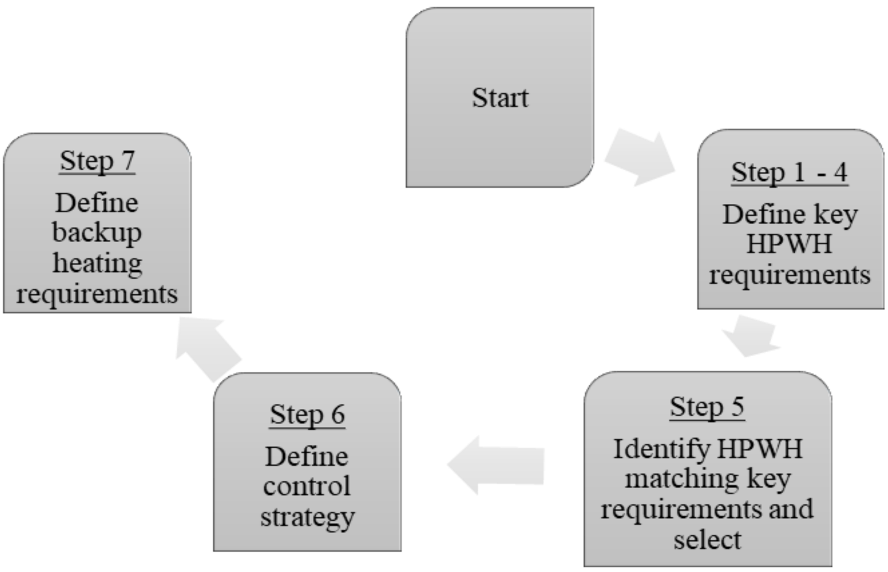

Figure 3. 1: Seven Major Steps in Sizing a HPWH

Sizing the water demand will resemble that of solar with a few adjustments to suit the scenarios.

Two scenarios will be utilised. The first scenario (scenario A) is when the heat pump is fully required to produce the hot and has to raise the temperatures from the ambient to the required 60 ^{o}C. Equation 3.4 will be used to calculate the water demand of scenario A.

$$L = V * \rho * C(T_{hot} - T_{cold}) \tag{3. 4}$$

The second scenario (scenario B) is when the solar water heater is fully functioning especially during the day with solar presence. The heat pump will be in standby and only providing supporting in heating the water to the required where the solar does not. Equation 3.6 will be used to determine the water demand in scenario B.

$$L = V * \rho * C(T_{hot} - T_{solar\ output}) \tag{3. 5}$$

Where; L=Daily water demands in Kwh/day, V- Water volume supplied M^3/day, ρ- Water density Kg/M^3, C- Water specific heat capacity usually 0.001167 Kwh/Kg^{o}C, T_{hot} – Temperature of hot water ^{o}C required is 60 ^{o}C, T_{cold}- Temperature of cold water ^{o}C and $T_{solar\ output}$- This will be the temperature of solar output that has not reached the required temperature.

For commercial use where this project is focusing, a hotel set up, a mix of both parallel and series connections will be considered. During installation, codes recommend up to a maximum of five sub-systems. In all systems that are designed, the objective has been to achieve the client’s goal. To prevent cases of failure of the system, the design will include a backup heating element. In cases where the solar water heater and the HPWH fail to meet the demand, the backup will be put to use by controllers set. Heaters could be electric or fuel fired, however the electric heater is the preferred of the two due to the ease of retrofitting, maintaining and operating. The cost incurred during this process can be negated by use of solar panels to aid in the production of electrical energy used in other areas in the site hence reducing the cost of operation.

3.3 Proposed Case Study: Comfort Garden Hotel

The study’s objective was to design a hybrid system of a SWH and HPWH at Comfort Gardens Hotel. This hotel is a prestigious and luxurious guesthouse located in the UNON neighborhood, close to a host of embassies, international organizations and Village Market. It offers a choice of accommodation designed as an ideal space combination for work and relaxation. All rooms are ensuite and equipped with modern TV sets, DSTV connection for the football enthusiasts, free Wi-Fi connection, minifridge and safety deposit box. The hotel also offers a range of services that includes conference rooms, lounge, swimming pool and restaurant services. The GPS coordinates (-1.2311674208325443, 36.804175847436596).

A site visit to the hotel was conducted to determine the current methods of water heating technologies in use at the facility. Data useful in the design was mapped out and collected. Data included the occupancy rate, hot water daily demands, energy bills relating to the hot water production, rated output of the heaters in place, temperature of hot water, inlet water and the various sections hot water is required in the premises [30].

Energy estimation was applied to determine the energy requirements to heat up the fresh water supply to the required hot water temperatures. This was estimated by computing using data collected from the site visit. Additional data aiding in the design includes the number of rooms, mean volume of hot water per guest and other areas that consume the hot water.

This study proposes the best design to be used to produce hot water, sizing of the design and the best hybrid setup to be used. Proposed schematics are provided to aid in the sizing of the hot water system. The sizing relies on factors like the cost of the components, the climatic conditions and maintenance cost of the design. Design software RET screen, Polysun and SAM are used to aid in the optimization of the design. Economic analysis is done to determine the viability of the design by using techniques like the NPV, IRR and payback period.

3.4 Economic Evaluation

To ascertain the viability of the proposed project, the researcher carried out a financial assessment of the system by adopting the use of NPV, IRR and payback period techniques. The research proposed a period of five years for the analysis of the NPV [31, 32].

3.4.1 Payback Period

Payback is simply the expected time for the investment to cumulate energy saving. Payback is represented with the Equation 3.7.

$$Pb = \frac{CI}{S} \tag{3.7}$$

Where; Pb is the payback period in years, CI – is the cost of investment and S – is the annual energy savings of the system.

3.4.2 NPV

The NPV, net present value can be defined simply as the present value of the investment over the period defined at a discounted market rate of return. NPV is computed using formula 3.8.

$$\sum_{n=1}^{10} \frac{S}{(1+r)^t} - CI \qquad (3.8)$$

Where r = Market discounted rate, t = year i.e., year 1, 2, CI – is the cost of investment of the project inclusive of installation fees and S – is the annual energy savings of the system.

3.4.3 IRR

The IRR is the discount rate at which the net present value (NPV) equates zero.

3.5 Conceptual Framework

The study depends on variables both dependent and independent. These variables will determine the relationships between the dependent ones and how they affect the main goal. The Figure 3.2 represents the study's conceptual framework presented as a flow chart.

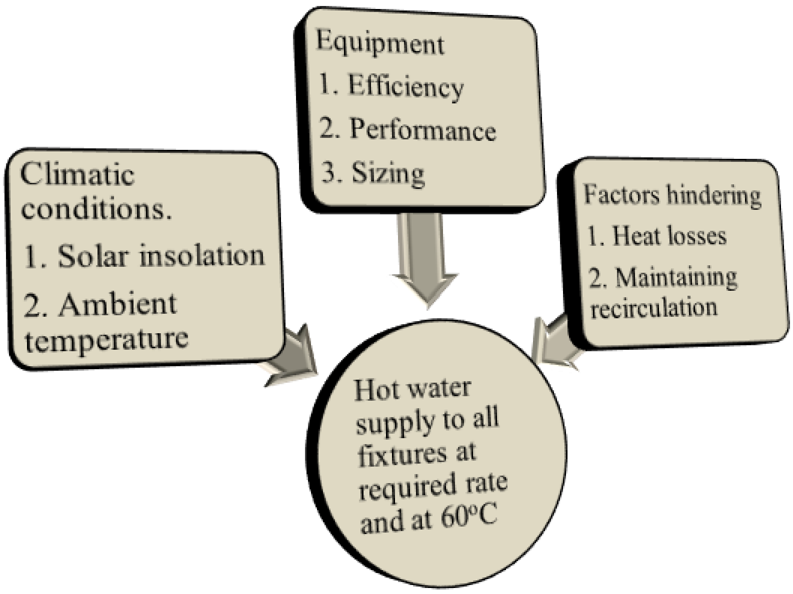

Figure 3. 2: Diagrammatic Representation of The Study's Conceptual Framework

3.6 Chapter Conclusion

This chapter has reviewed previous methodologies applied by researchers in their study of hot water production in hotels. This review has guided the study in proposing the study methodology and expected data analysis. Sizing of the system in accordance to the required code of conduct is covered with mathematical calculations given focusing on HPWH and solar water heaters (SWH) and a conceptual framework provided. Financial evaluation to be used are discussed in the chapter.

CHAPTER 4
4.0 RESULTS AND ANALYSIS

The researcher to determine the actual position of hot water production in the facility conducted a site visit. Interviews were done and confirmations carried out by physically checking data provided at site.

4.1 Hot Water Requirements

The hot water was calculated in the Table 4.1 guided by Energy solar water heating regulation of 2012 where design parameters are given summarized in Table 4.2.

Table 4. 1: Hotel Water Requirements

AH	NP	DWD	THWD
H	75	40	3000
C	100	5	500
K	150	5	750
CH	10	15	150
L		5	300
THWD (Liters)			4700
THWD (M^3)			(4700/1000) =4.7

Where, AH - Area hot water is required in the Hotel, NP - Number of people to be served, DWD - Daily water demand in liters at 60^0C as per EPRA regulations, THWD - Total hot water demand, H - Hotel guest rooms, C - Conference rooms and meeting facility, K - Kitchen and catering section, CH - Changing room for the staff, L - Laundry facility (handles 60 kg per day of load).

Table 4. 2: Energy Demand Estimates Per Facility Per Day [35].

Type of Building Premises	SDHWD
D	30 per person
E	5 per student
HHC	50 per bed
HHL	40 per bed
RC	5 per meal
L	5 per kilo of clothes

Where, SDHWD - Specific Daily Hot Water Demand in litres per day at 60^{0}C, D - Domestic residential houses, E - Educational institutions such as colleges and boarding schools, HHC - Health institutions such as Hospitals, Health Centres, clinics and similar medical facilities, HHL - Hotels, Hostels, Lodges and similar premises providing boarding services, RC - Restaurants, Cafeterias and similar eating places and L – Laundries.

4.2 Sizing of The Water Heater System

From the data above, the hotel's demand was computed using Equation 3.1.

Demand = (1000*4.7*0.001167*(60-15))

= 246.82 Kwh/Day

Regulation states that an occupancy factor of >0.7 has to be considered. The project considered using 0.8, which was the average occupancy at the hotel. Therefore,

Demand = (0.8*246.82) = 197.47 Kwh/Day.

The regulations require at least 60% of the demand to be supplied by solar water heaters. This study adopted this model and the remaining 40% to be supplied by the HPWH [35].

Therefore, Demand supplied by SWH = (0.6*197.47) = 118.47 Kwh/Day while that supplied by HPWH = 78.98 Kwh/Day.

The demand calculated was used in the Equation 3.2 to compute the solar collector area and hence the number of collectors required using Equation 3.3.

Collector Area = $\frac{118.47*0.6}{0.4*5.3}$ = 33.52 M^2

Therefore, the number of panels = $\frac{33.52}{2}$ = 16.76 approximately 17 panels. Where a panel area was taken as 2*1 M^2 as per research on available ones on the market and the solar insolation as 5.3 as per average climatic data shown in Figures 4.1 and 4.2.

Climatic data was retrieved from System advisor model software (SAM) and the data are as shown below in Figure 4.1. This was validated by counterchecking on the RETSreen application and is as shown in Figure 4.2.

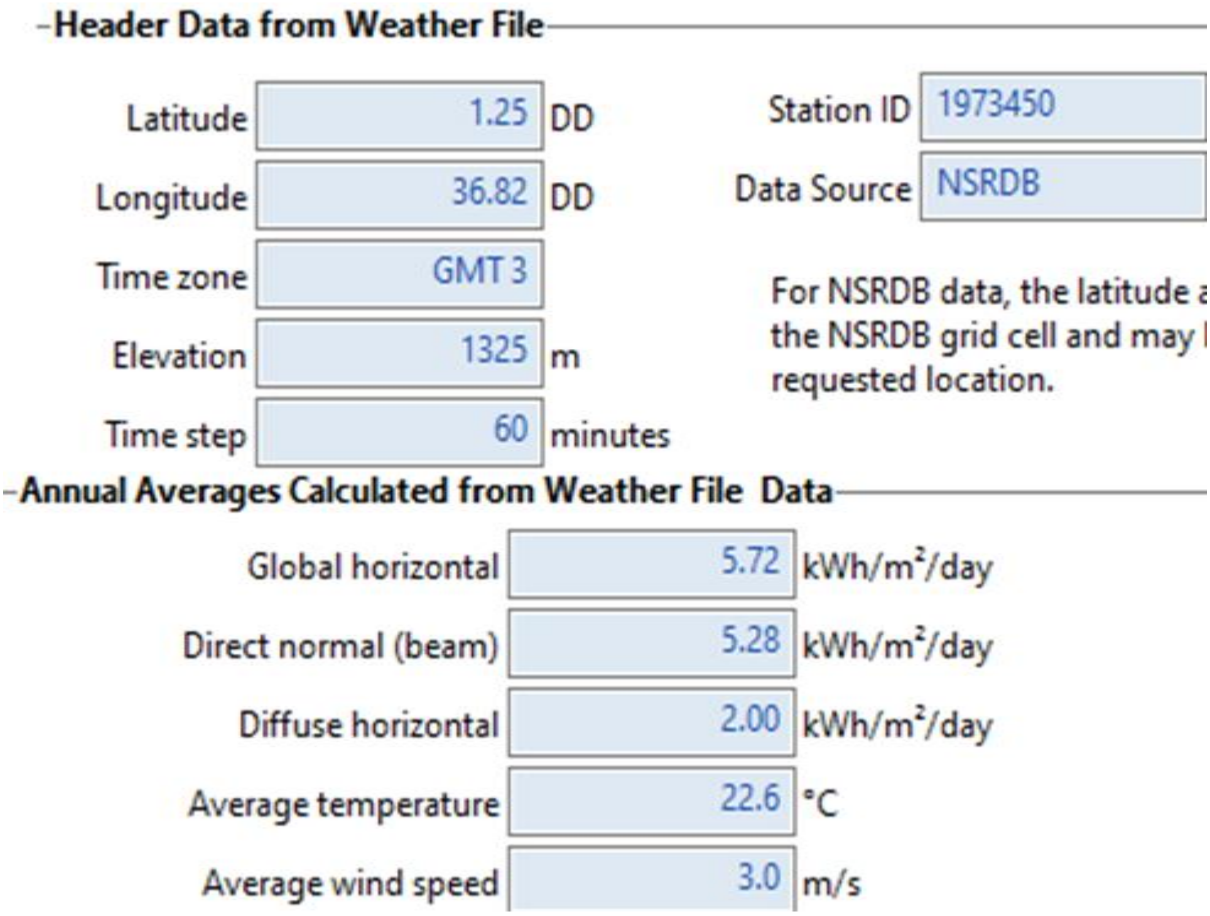

Figure 4. 1: System Advisor Climatic Data.

	Unit	Climate data loca
Latitude		-1.3
Longitude		36.8
Climate zone		
Elevation	m	1798
Heating design temperature	°C	10.6
Cooling design temperature	°C	28.5
Earth temperature amplitude	°C	13.5

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	At
	°C	%	mm	kWh/m²/d	
January	18.0	60.0%	52.70	6.54	
February	18.8	56.0%	33.60	6.66	
March	19.4	61.5%	78.74	6.38	
April	19.2	71.0%	135.30	5.32	
May	17.8	73.0%	99.82	4.66	
June	16.3	72.5%	31.50	4.26	
July	15.6	73.0%	25.11	3.75	
August	15.9	70.5%	29.76	4.00	
September	17.3	63.5%	26.70	5.35	
October	18.5	62.5%	63.24	5.63	
November	18.4	70.5%	111.30	5.27	
December	18.1	66.0%	76.57	6.06	
Annual	**17.8**	**66.7%**	**764.34**	**5.32**	
Source	Ground	Ground	NASA	Ground	

Figure 4. 2: RET Screen Software Climatic Data.

HPWH will be required to meet the remaining 78.98 Kwh/Day to compliment the SWH. From manufacturers catalogue two HPWH with a combined heating capacity of 200 KW were selected to meet the demand and act as a backup for the system. The second HPWH will operate fully in backup mode to ensure sufficient water production if the solar water heater does not produce at all due to climatic conditions and at night.

Water storage size is also a requirement in designing of the system. As a rule of thumb in design, regulations require a minimum size of the tank to be 1.5 time that of the hot water demand was selected. The capacity required would translate to (1.5*4700 litres) that represents an approximate capacity of 7050 litres. The design will propose 2 hot water storage tanks of 3000 litres each installed in the different wing of the hotel. The tanks have been selected based on the occupancy rate of 0.75 to minimize the likelihood of over-design. A circulation pump will also be proposed to aid in raising showerhead pressure for maximum comfort of the guests.

4.3 Design of the Hot Water System

In the design of the hot water system, the researcher was guided by the sizing and hot water demands. This also depended on technical specifications of the components and their effectiveness to achieve the desired goal. Financial aspect was also a major factor in the research of the components. A proposed schematic was drawn using Polysun software and is as shown in figure 4.3.

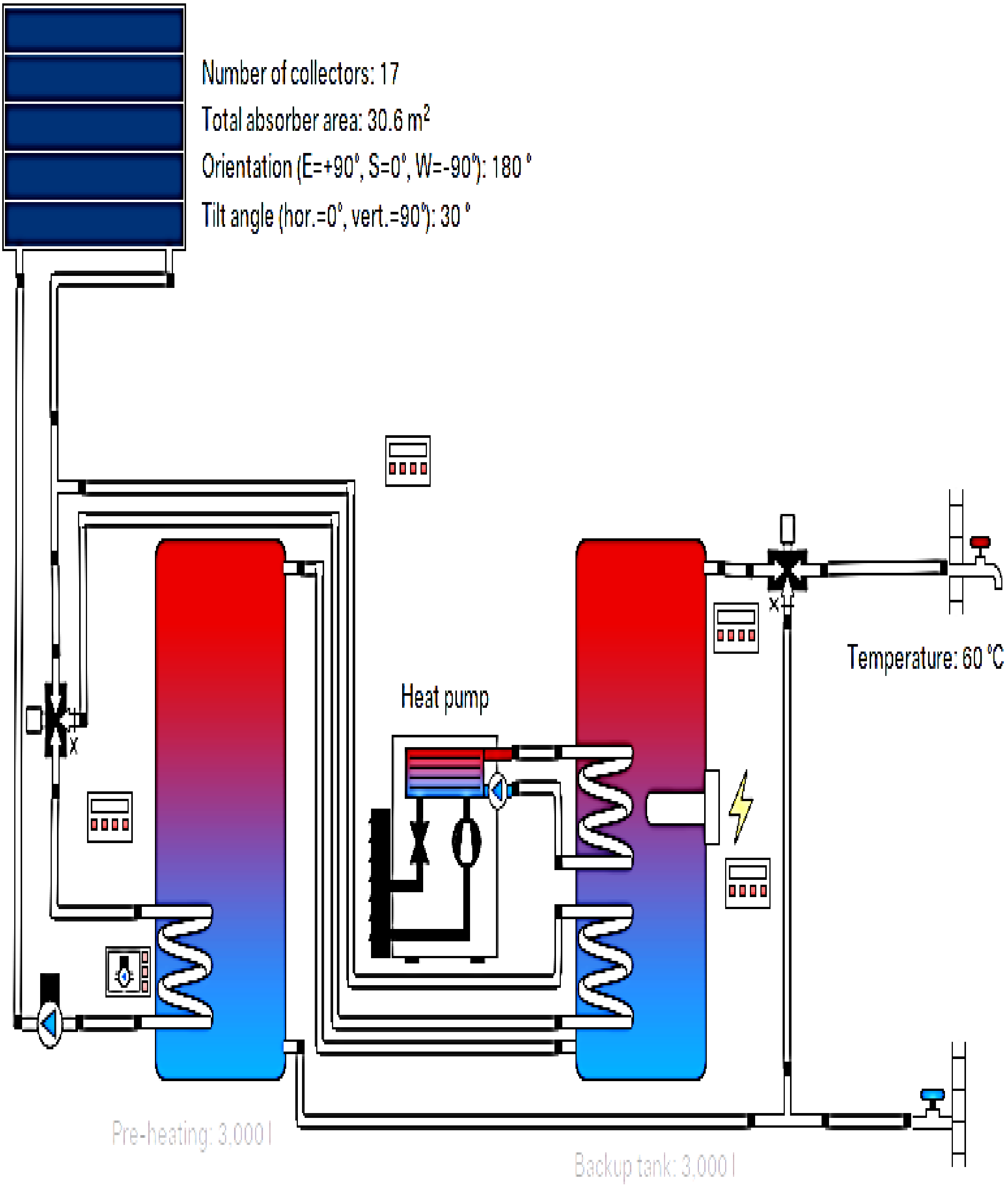

Figure 4. 3: Proposed Design Schematics for the Hot Water System

Research based on the performance, cost and availability; Table 4.3 specifies a proposed technical specification for the solar water heater panel including the price for purchasing the same.

Table 4. 3: Technical Specifications for the Solar Water Heater Panel and Price [36].

Specification	Model (BTEB-I/0.6-L-2.0)
Film	Black Film
Overall Size(Mm)	1000x2000x80/95
Frame	1.0mm Aluminium
Absorption Area(M^2)	1.89
Header Pipe	CopperTP2 Φ22x0.6
Grid Pipe	CopperTP2 Φ10x0.5
Cover Material	3.2 Low-iron tempered -glass
Transmittance	≥92%
Bottom Cover	0.50mm Hot galvanized plate
Insulation	Bottom: glass fiber frame: polyester fiber
Working Pressure	0.8MP
Price	$95 (conversion to Kshs based on current rate) = Kshs 10,950

The sizing of the HPWH above proposes that it meets a demand of approximately 78.98 Kwh/Day to compliment the SWH. A backup HPWH is also proposed in cases of extreme weather conditions the system is able to meet the desired goal. From research conducted 2 HPWHs of 90 KW heating capacity each are chosen for the research. The Figure 4.3 gives the details of the selected heaters, column under model 250ZB/S(E) which also gives critical technical specifications that include the COP, power input, hot water production rate, refrigerant used, the pipe connections, flow rate and dimensions of the heater [37, 38].

Model	MAHW	150ZB/S(E)	200ZB/S(E)	250ZB/S(E)	500ZB/S(E)
Power supply	V/PH/Hz	380/3/50	380/3/50	380/3/50	380/3/50
Hot water production (ambient 20℃)	L/H	1155	1540	1925	3850
Hot water production (ambient 7℃)	L/H	840	1120	1400	2800
Heating capacity ①	KW	54.0	72.0	90.0	180.0
Power input ①	KW	11.74	15.65	19.57	39.13
Current input ①	A	22.3	29.7	37.2	74.3
COP ①	W/W	4.60	4.60	4.60	4.60
Heating capacity ②	KW	45.0	60.0	75.0	150.0
Power input ②	KW	11.84	15.79	19.74	39.47
Current input ②	A	21.9	28.9	35.6	72.2
COP ②	W/W	3.80	3.80	3.80	3.80
Heating capacity ③	KW	30.0	40.0	50.0	100.0
Power input ③	KW	12.77	17.78	21.74	43.48
Current input ③	A	24.2	33.8	41.3	82.6
COP ③	W/W	2.35	2.25	2.30	2.30
Maximum current input	A	31.5	43.9	53.7	107.3
Sound level	dB(A)	60	64	68	72
Water connection	inch	1-1/2"	2-1/2"	2-1/2"	3"
Water flow volume	m3/h	5.16	6.88	8.60	17.20
Refrigerant		R410a/R32	R410a/R32	R410a/R32	R410a/R32
Unit dimensions (L/W/H)	mm	1485/780/1165	1700/850/1265	2036/1103/2020	2350/1200/2205

Remarks:
① Heating: DB 20℃/WB 15℃, water heating from 15℃ to 55℃.
② Heating: DB 7℃/WB 6℃, water heating from 15℃ to 55℃.
③ Heating: DB -12℃/WB -14℃, water heating from 15℃ to 55℃.
Working ambient temperature: -25℃ ~ 43℃.
If any unit is improved and optimized, the specific parameters shall be subject to the nameplate.

Figure 4. 4: Heat Pump Water Heater Technical Specifications [37].

Hot water storage tanks are sized in Section 4.2 and the design proposed 2 tanks 3000L each to be installed in the different wings of the hotel. The tanks will be installed alongside booster pumps to aid in creating the required water pressure for maximum comforts at the shower head and to make sure all areas requiring the hot water are served adequately. Table 4.4 gives the proposed technical specifications of the hot water storage tanks. The design proposes the pumps to be used in boosting the water circulation to have a flow rate of 8 M^3/h to match the flow rate requirements of the HPWH as stated in Figure 4.4.

Table 4. 4: Technical Specifications of the Hot Water Tanks [39].

Specifications	Model 3000L
Nominal Capacity (L)	3000
Actual Capacity (L)	2940
Material	Stainless steel Gr 304 or Gr 316
Price (Kshs)	360,000

4.3.1 Pump Sizing

Design of hot water system for commercial projects should include a pump for the circulation of the hot water to all fixtures at all times. Hot water of desired temperature and desired pressure should be readily available at any given time for maximum comfort of the guests in the hotel. Design of a pump for the circulation of hot water reduces the frustration of waiting for the desired water temperature and reduces the wastage of water in cases where customers have to run the cold water out of the supply to reach the hot water.

To address this, hot water circulation is applied to the system. It involves the selection of a pump, sizing the supply, recirculation piping for the system and choosing the right insulation for the pipes to reduce heat loss. Proper sizing of the circulation is required for efficient and economical hot water system design. Oversizing of a system will lead to unnecessary heat loss, purchase of expensive equipment and hence increasing on the cost of the system while under sizing of a system will hinder the circulation starving the fixtures of the desired hot water. Velocities of water in the system should not exceed 5ft/s to avoid noise and damaging pipes and fittings [40].

Sizing of the pump as recommended by American society of plumbing engineers (ASPE) involves calculating heat loss rates for the main supply, circulating pipes and recirculation lines, determining the allowable uniform friction head loss and the total head required to overcome the friction losses in the piping. The researcher chose 25 risers to supply from the main supply line because the hotels is a 3-storey building with 75 rooms. Calculations were computed as recommended using excel and the results are as represented in Table 4.5.

4.3.2 Design Optimization

Hot water design should aim at providing hot water throughout the day regardless of climatic conditions, time of day or any other factors likely to hinder the objective. Systems with more than one heater have to set priorities on the order of heating and which heater would be preferred, which would act as a backup and timelines of when each heater would start producing the hot water. The hybrid design of this project consists of solar heaters and heat pump water heater as the primary heaters while a backup heater is also proposed. The solar water is set as the primary heater and expected to meet 60% of the demand hence the other heaters will aid them in cases of extreme weather conditions or any other scenario where it fails to meet the projected demand. This will be done by optimizing the system by use of controllers and thermostats, which are electronic devices that monitor and control the overall operation of the system. They will dictate the levels of operations by switching on and off depending on the usage and set priorities set. Water from the solar water heater can be monitored and when it's not at the required temperature it will follow the process as shown in the flowchart Figure 4.5. The output will always be the set temperature hence the clients will never miss hot water for maximum comfort.

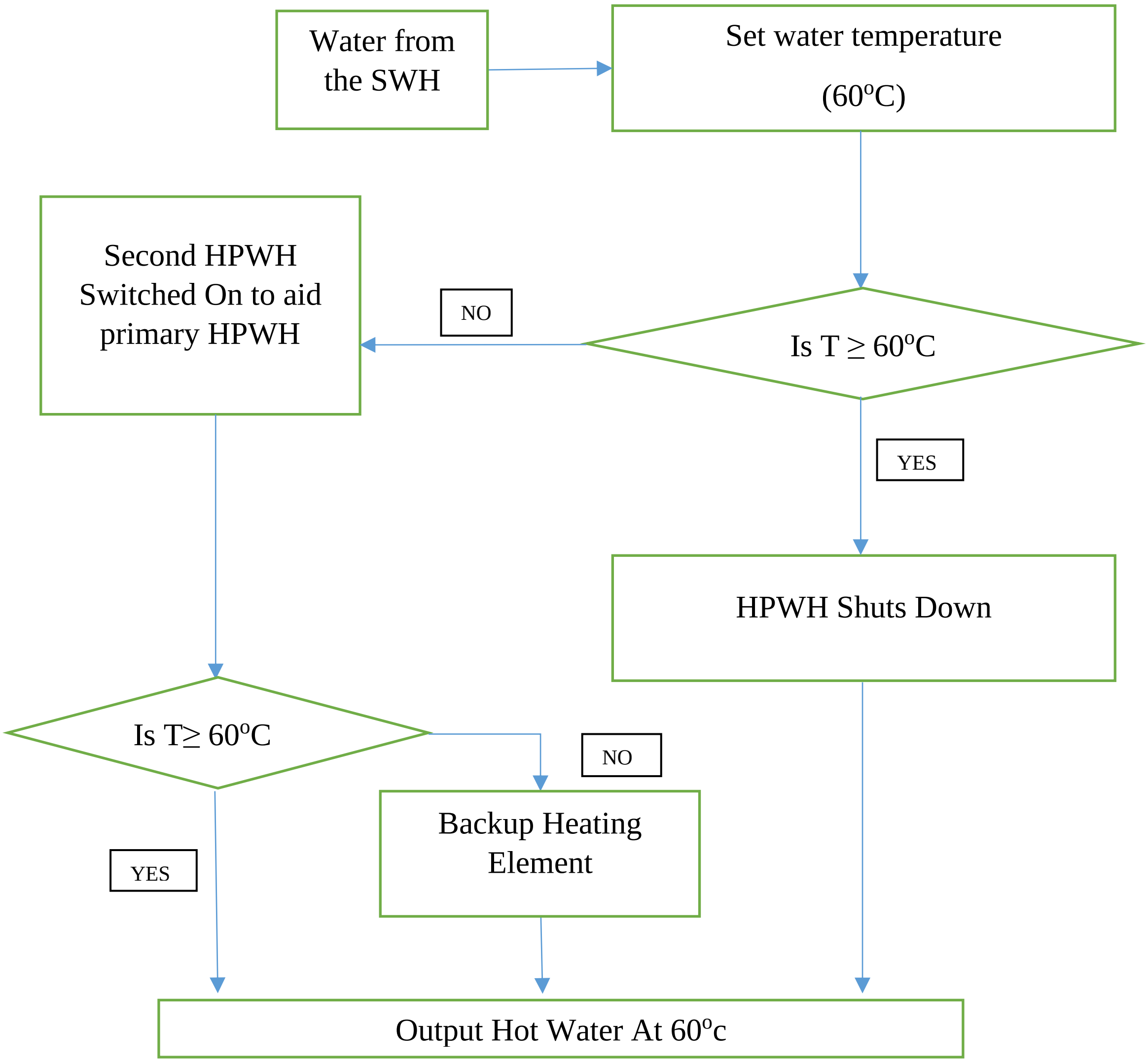

Figure 4. 5: Flowchart of the operation controls for the design.

In order to maintain the temperature of the hot water not to scald the hotel clients and to ensure its to the satisfaction of the clients, a thermostatic mixing valve (TMV) is installed in all showers and sinks. It is a device that automatically controls the temperature and flow of water in your shower and sink. A TMV works by maintaining a set temperature, so you can enjoy comfortable showers without worrying about scalding.

Table 4. 5: Friction Losses Calculations and Required Flowrate

Description	Pipe size (inch)	BTU loss/hr/unit	Pipe length (ft)	Total BTU loss/hr	Recirculating water BTU loss/hr	GPM to overcome losses(10 degrees)
Main Heater to Riser 1	3	38	30	1140	760	0.38
Riser 1 - 2	3	38	20	760	506.67	0.253
Riser 2 - 3	3	38	20	760	506.67	0.253
Riser 3 - 4	3	38	20	760	506.67	0.253
Riser 4 - 5	3	38	20	760	506.67	0.253
Riser 5 - 6	3	38	20	760	506.67	0.253
Riser 6 - 7	3	38	20	760	506.67	0.253
Riser 7 - 8	2	28	20	560	373.33	0.187
Riser 8 - 9	2	28	20	560	373.33	0.187
Riser 9 - 10	2	28	20	560	373.33	0.187
Riser 10 - 11	2	28	20	560	373.33	0.187
Riser 11 - 12	2	28	20	560	373.33	0.187
Riser 12 - 13	2	28	20	560	373.33	0.187
Riser 13 - 14	2	28	20	560	373.33	0.187
Riser 14 - 15	2	28	20	560	373.33	0.187
Riser 15 - 16	2	28	20	560	373.33	0.187
Riser 16 - 17	2	28	20	560	373.33	0.187
Riser 17 - 18	2	28	20	560	373.33	0.187
Riser 18 - 19	2	28	20	560	373.33	0.187
Riser 19 - 20	2	28	20	560	373.33	0.187
Riser 20 - 21	2	28	20	560	373.33	0.187
Riser 21 - 22	2	28	20	560	373.33	0.187
Riser 22 - 23	2	28	20	560	373.33	0.187
Riser 23 - 24	1.5	25	20	500	333.33	0.167
Riser 24 - 25	1.5	25	20	500	333.33	0.167
Riser (1 - 25)(Each Riser)	1	19	15	285	190.00	0.095
Total(Risers)			375	7125	4750	2.375

From the calculations in the Table 4.5, the total head required to overcome the friction losses in the piping and the required circulation rate are computed and represented in Table 4.6.

Table 4. 6: The Total Head, The Friction Losses and The Required Circulation Rate

Hot water piping heat loss	22785
Hot water circulation piping heat loss	15190
Total hot water circulation rate (BTU loss/hr.)	37975
Required circulation rate (GPM)	7.595
Uniform friction head loss	3ft/100ft
Developed length of run	525 ft
Equivalent length of run including fittings	577.5 ft
Total head required	17.325 ft

Recommendations from the ASPE guide were followed during the calculations. Assumptions made during the computation are given in Table 4.7

Table 4. 7: Assumptions Made During the Pump Sizing

Assumptions made
Pipe size is uniform for all risers to fixture units
Fittings are 10% of developed length
Uniform friction head of 3ft/100ft
Temperature Drop of 10 degrees(5000 BTU/Hr - 1 GPM)

The calculations shows that the system will require a pump that has a capacity to overcome a head of 18 ft while ensuring the flow rate is maintained at 8 gpm. To select the pump, the researcher used the two parameters as a guide to make sure the hotel clients receive the hot water at the desired pressure and at times. Manufactures guide was used to select the pump by selecting the pump that meets both conditions. Charts with pump curves are provided by manufacturers to guide the buyers in selecting the right product and is as shown in Figure 4.6.

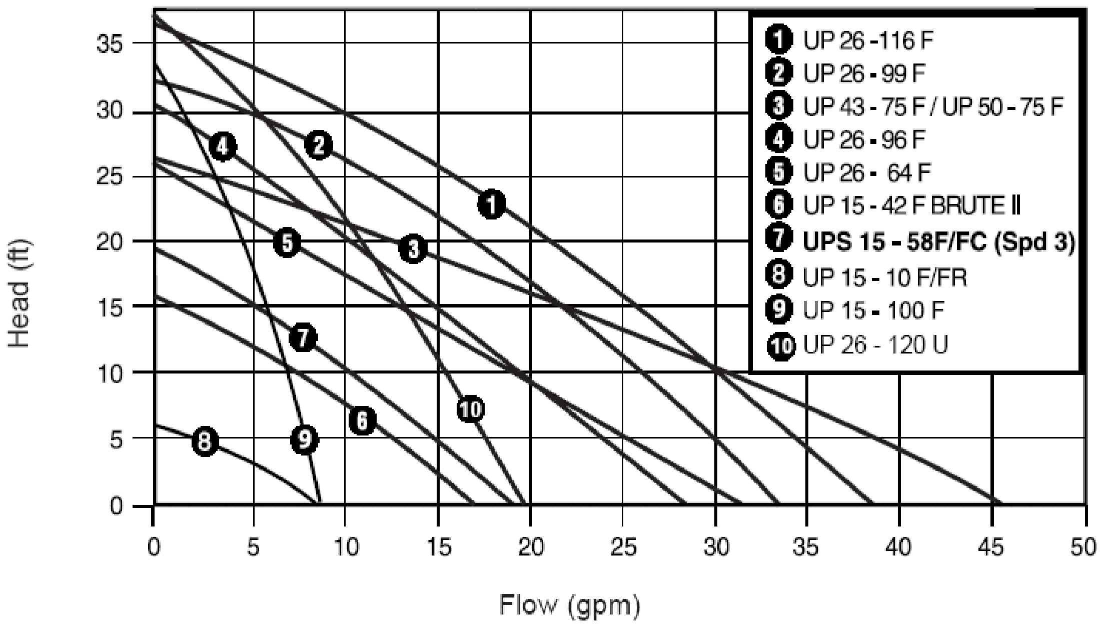

Figure 4. 6: Manufacturer's Pump Curves for Selecting Product [41]

From the chart, curve 5 was selected as it meets both the head and circulation rate. This curve is for Grundfos Circulation pump UP 26- 64 F model. Research on the manufacturer's website on the pump's technical specifications was done and a summary is given in Table 4.8.

Table 4. 8: Pump Technical Specifications

Parameters	
Material:	Cast Iron
Poles:	2
Mount:	In-Line
Frequency:	60 Hz
Application:	Heating
Voltage:	230v
Max Pressure (PSI):	145
Type:	3-Speed Pump
Features:	Integral Check Valve
Horse Power:	1/6
Flow Range (GPM):	0-33
Max Flow (GPM):	33
Max Head (Ft):	29
Head Range (ft.):	0-29
Hertz:	60
Phase:	1
RPM:	3380
Temperature Range (F):	36°F - 230°F
Connection Type:	Flanged x Flanged

4.4 Financial Evaluation

In the site visit, the hotel was found out to be using 14 calorifiers of 3KW each to generate hot water distributed among the 3 wings. To estimate the energy consumed by the hotel, Equation 3.1 approximated the demand for hot water at approximately 200 Kwh/Day. The cost for producing the hot water can then be calculated as follows;

Cost of electricity consumed = (200 x 21.62) = Kshs 4,324 ($ 37.46) per day.

Where the cost for a small commercial consumer is Kshs 21.62 ($ 0.19) as per the current tariff inclusive of the taxes and levies.

Annual cost consumed = (4324 x 365) = Kshs 1,578,260 ($ 13,672.88) p.a.

From the proposed design, two scenarios are analysed. Scenario A, the HPWH produces all the hot water in cases of extreme weather conditions and at night. Scenario B using the hybrid system with the SWH meeting the 60% and HPWH the remainder of 40%.

4.4.1 Scenario A

From the technical specifications, the HPWH of 90 KW heating capacity utilises approximately 20 KW of power when compared with the normal heater. Therefore, the energy consumed by the HPWH is calculated as follows;

Cost of electricity consumed =($\frac{20}{90}$ x 200 x 21.62) = Kshs 960.9 ($ 8.32) per day

Annual cost consumed = (960.9 x 365) = Kshs 350,724($ 3,038.41) p.a.

4.4.2 Scenario B

The proposed system hybrid design SWH 60% and HPWH 40%. The computation of costs will be SWH to produce 120 Kwh/Day. No electrical consumptions are used as no backup heating element is to be used in the design. Maintenance costs are not factored in the design.

The remaining 80 Kwh/Day is to be produced by the HPWH as follows;

Cost of electricity consumed =($\frac{20}{90}$ x 80 x 21.62) = Kshs 384.36($ 3.33) per day

Annual cost consumed = (384.36 x 365) = Kshs 140,290($ 1215.37) p.a.

From the research in Section 4.3 of the report, the research estimated the cost of investment as follows;

- 2 Macon HPWH of 90 KW heating capacity each cost Kshs 632,500 ($ 5479.51) [37].
- 17 Foshan panels of Flat SWH each cost Kshs 10,950 ($ 94.86) [36].
- 2 stainless steel insulated hot water tanks each cost Kshs 360,000 ($ 2079.18) [39].
- Grundfos pump, accessories and fittings at Kshs 500,000 ($4347.82) [41].
- Insulation and miscellaneous charges budgeted at Kshs 500,000 ($4347.82) [39].

The total cost of the investment would be;

Investment cost = [(2 x 632,500) + (17 x 10,950) + (2 x360, 000) + 2(500,000)] = Kshs 3,171,150 ($ 27,575)

The installation charges are to be factored in the cost of purchase. This was guided by the Engineers Act on professional fees chargeable on the cost of the project at 10% and factored miscellaneous charges, which is to cover all other overhead charges of the project. This will bring the total investment cost to a value of Kshs 3,500,000 ($ 30,434.78). The piping works of the system and pump will be upgraded as the hotel has a small pump which may not be efficient for this system. A retrofit will only be done if necessary but the design does not change the existing system other than replacing the calorifiers, replacing the pump and insulating pipes where necessary.

4.4.3 Financial Implications

From the computations of energy savings and the cost of investment in Section 4.4.2, the research calculated the payback period, NPV and IRR as in Subsections 4.4.3.1, 4.4.3.2 and 4.4.3.3 respectively.

4.4.3.1 Payback Period

Payback period for the Scenario A would be represented as;

$$\text{Payback} = \frac{3{,}500{,}000}{(1{,}578{,}260 - 350{,}724)} = 2.85 \text{ Years.}$$

Therefore, the Scenario B would be represented as;

$$\text{Payback} = \frac{3{,}500{,}000}{(1{,}578{,}260 - 140{,}290)} = 2.43 \text{ Years.}$$

4.4.3.2 NPV and IRR for Scenario B

The NPV and IRR for both Scenarios B and A were calculated and represented in Tables 4.9 and 4.10 respectively.

Table 4. 9: IRR Computation with Excel IRR Function & Verification with NPV Calculation for Scenario B

IRR computation with Excel IRR Function & Verification with NPV calculation for Scenario B		
Year	Cash Flows	Present Value of cash flows discounted @ market rate below
Market discounted rate at 7.00%		
Year 0	-3,500,000.00	3,500,000.00
Year 1	1,437,970	1,343,897.20
Year 2	1,437,970	1,255,978.69
Year 3	1,437,970	1,173,811.86
Year 4	1,437,970	1,097,020.43
Year 5	1,437,970	1,025,252.74
Year 6	1,437,970	958,180.13
Year 7	1,437,970	895,495.45
Year 8	1,437,970	836,911.63
Year 9	1,437,970	782,160.40
Year 10	1,437,970	730,991.03
Total positive cash flows or inflows	14,379,700	10,099,699.55
Sum of positive and negative discounted cash flows		6,599,699.55 ($ 57,389) <=*Net Present Value (NPV)*
Internal Rate of Return (IRR)	39.63%	*Equivalent to the discount rate NPV=0*

4.4.3.3 NPV and IRR for Scenario A

Table 4. 10: IRR Computation with Excel IRR Function & Verification with NPV Calculation for Scenario A

IRR computation with Excel IRR Function & Verification with NPV calculation for Scenario A		
Year	Cash Flows	Present Value of cash flows discounted @ market rate below
Market discounted rate at 7.00%		
Year 0	-3,500,000.00	3,500,000.00
Year 1	1,227,536	1,147,229.91
Year 2	1,227,536	1,072,177.48
Year 3	1,227,536	1,002,035.03
Year 4	1,227,536	936,481.34
Year 5	1,227,536	875,216.20
Year 6	1,227,536	817,959.07
Year 7	1,227,536	764,447.73
Year 8	1,227,536	714,437.13
Year 9	1,227,536	667,698.25
Year 10	1,227,536	624,017.06
Total positive cash flows or inflows	12,275,360	8,621,699.19
Sum of positive and negative discounted cash flows		5,121,699.19 ($ 44,536) <=*Net Present Value (NPV)*
Internal Rate of Return (IRR)	33.06%	*Equivalent to the discount rate NPV=0*

From both scenarios A and B, the findings of the project, an IRR of 39.63% and 33.06% are very positive as the rate of return. The project will be able to recover the purchase costs and the installation very fast as shown by the payback of approximately 2 years computed. Positive NPV also helps the client in the decision making and this proves the viability of pursuing a hybrid HPWH – SWH to meet the hot water demands.

4.5 Summary of the Financial Evaluation

The findings of the financial evaluations of this research have been summarised in Table 4.11

Table 4. 11: Table of Financial Evaluations Summary

	Annual cost of hot water production Kshs ($)	Savings realised Kshs ($)	NPV Kshs($)	IRR (%)	Payback period (Years)
Current heating method	1,578,260 ($13,675)	-	-	-	-
Scenario A	350,274 ($3,038.41)	1,227,536 ($10,674)	5,121,699 ($44,536)	33.06	2.85
Scenario B	140,290 ($1215.37)	1,437,970 ($12,504)	6,599,700 ($57,389)	39.63	2.43
Cost of retrofitting inclusive of the installation and commissioning costs			3,500,000 ($30,435)		

From the summary table, the project is a viable one to pursue. This is shown by the positive NPV found during the estimation with also a short period of 2 years and a few months for the investment to pay itself. The IRR also proves that this project has a potential of saving the customer high energy bills.

4.6 Validation

The researcher carried out comparison of this report to other reports by various writers to ascertain the similarities and variation in the findings as a means of quality check and data validation. The following observations were made:

(i) The researcher used two software applications to provide data for the solar insolation in the study area. RET Screen and SAM software were used to simulate the annual solar insolation and were found out to be 5.31 and 5.28 Kwh/M^2/Day. This amounts to a deviation of 0.56. This value is less than 1% hence either of the value can be used to determine the solar insolation of the case study. Further, the values also have a deviation of 1.5% and 0.95% from the value provide from the meteorological department. The project considered using the average of the solar insolation a value of 5.30, which has a deviation of 1.3%. These results as compared to the Meteorological department data, which was given as an average of 5.23 Kwh/M2/Day means that the data were comparable and verified hence, can be used in projects investigating solar insolation [33].

(ii) The design adopted the use of the solar water heating regulations guide of 2012 to estimate the hot water requirement per guest in the hotel. This can compare to a study where the researcher was investigating replacing existing induction heaters with solar water heaters. The researcher's experimental findings gave a consumption of 47.17 L/ Day and they gave a comparison to a study they relied on where a consumption of 52L/Day was realised. This can show that the values are validated and comparable and also proposed to be used for future research [42].

(iii) The report findings on the payback period averaged about 2 years for the investment to recover its initial costs. Studies by a researcher investigating the energy saving opportunity by replacing hot water geyser with solar water heater indicated a payback period of 24 months. This verifies that the findings of this report are comparable to other findings hence can be relied upon [43].

A summary of the validation is provided in the Table 4.12

Table 4. 12: Summary of The Validation

Research	This Report Findings	Other Reports Findings
Annual solar insolation	5.3 Kwh/M2/Day	5.23 Kwh/M2/Day
The hot water requirement per guest in the hotel	40 litres for the shower	47.17 litres and 52 litres
Payback period	2.64 years	2 years

4.7 Chapter Conclusion

This chapter four discusses the results of the design, extracts from the software for the design are provided and the computed energy saving from the design are also provided. The financial evaluation is in this chapter, tables with detailed NPV and IRR computations are provided. The technical specification of the components of the design are found here, the sizes and number of the components as per design are mentioned. A validation of the research is found here with a brief chapter conclusion provided.

CHAPTER 5
5.0 CONCLUSIONS AND RECOMMENDATIONS
5.1 Conclusions

From the design calculation and sizing of the hot water system, the aim was to produce water 24 hours a day at the lowest cost possible. The designer selected two HPWH with a heating capacity of 90 KW each to compliment the 17 solar panels sized to meet the demand of 118.47 Kwh/day. The total demand to be supplied by the HPWH is 78.98 Kwh/Day hence it will be met by the system. However, solar system is not always reliable due to changing climatic situation. This will need a standby producer of hot in the second HPWH. In the case where solar fails to produce, the two HPWH with a heating capacity of 180 KW will meet the demand comfortably and hence the system will achieve the objective.

Economic evaluation carried out by the research determined a demand of 197.47 Kwh/Day, which translated, to a cost of Kshs 1,578,260 per annum ($ 13,682) to produce hot water for the hotel. An investment cost of Kshs 3,500,000 ($ 30,435) was proposed as the cost of purchasing the SWH, HPWH, recirculation pump and hot water tank including the installation costs and miscellaneous charges. The NPV and IRR for scenarios A and B were estimated to be Kshs 5,121,699 ($ 44,536), Kshs 6,599,700 ($ 57,389) for the NPV and 33.06%, 39.63% for the IRR respectively. Payback periods for Scenarios A and B computed gives an estimated 2.85 and 2.43 years respectively.

From all the financial evaluations a positive NPV for both scenarios confirm the viability of the project while the payback of approximately 2 years and a few months for both scenarios mean the client will realize quickly hence also confirms how viable the project is.

5.2 Recommendations

To further build on the findings and design proposed in this research, it is recommended that:

(i) The researcher proposes the findings of the project to be adopted by hoteliers in their decision making when looking for alternatives in the hot water production.

(ii) Further studies be conducted on the performance of the HPWH in the Kenyan climate to determine the COP and other performance characteristics to guide buyers when choosing the optimum and most efficient water heating system.

(iii) Comparisons of the SWH in different climates in Kenya needs to be conducted, compared and proposal made on the best design to use for producing hot water.

(iv) Simulations of the hybrid system designs need to done by use of transient simulation software like TRNSYS which was not used in the project due to its cost.

5.3 Main Contribution

The research main contribution is the provision of a design, a hybrid system comprising a solar water heater and a heat pump. The study will provide vital information to decision makers to consider use of this hybrid system for their production of hot water to curb rising costs. It will also provide a starting point for research on the hybrid system in the Kenyan climatic data.

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8/6/22
DR. D. MUSAU

APPENDICES

Prof. Cyrus Wekesa sign.................... 07/06/2022

Appendix A1: Similarity Index Report

Energy savings by use of Heat pump water heater to compliment solar water heaters as a hybrid design.

ORIGINALITY REPORT

12%	9%	7%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.hindawi.com Internet Source	1%
2	H. Willem, Y. Lin, A. Lekov. "Review of energy efficiency and system performance of residential heat pump water heaters", Energy and Buildings, 2017 Publication	<1%
3	Submitted to University of Sheffield Student Paper	<1%
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Appendix A2: Table of Corrections.

Questions/Comments Raised During Project Defense.
1. Solar fraction of 60%, give an explanation why this figure was chosen. (Dr Kivindu)
2. How do you maintain the temperature of the hot water not to scald the hotel clients and to ensure its to the satisfaction of the clients? (Prof Wekesa)
3. Referencing of the components and computation of the cost of investment. (Dr Kivindu)
4. Centre the main topics i.e., Chapter 4, Results. (Dr Kivindu)
5. Enhance the design by providing a section on the optimal design of the system. (Dr Musau)