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Design of a solar powered water heating system for existing UK and Kuwait houses.

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- حاصل على شهادة البكالريوس في الهندسة الميكانيكية من الولايات المتحدة الأمريكية.

- حاصل على شهادة الماجستير في الهندسة الميكانيكية من المملكة المتحدة.

- موظف في وزارة الكهرباء و الماء و الطاقة المتجددة.

- عضو جمعية المهندسين الكويتية.

-عضو الجمعية الأمريكية للمهندسين الميكانيكيين.

تصميم نظام تسخين المياه بالطاقة الشمسية للمنازل الموجودة في المملكة المتحدة والكويت.

هناك اهتمام كبير بمصادر الطاقة المتجددة، حيث أن إستخدام هذه الطاقات في تلبية الطلب على الطاقة في مختلف القطاعات يسمح بتقليل الاعتماد على الوقود الأحفوري مما يؤدي إلى تحقيق فائدة اقتصادية أعلى مع تقليل الظروف البيئية السلبية الناجمة عن إحتراق الوقود التقليدي في محطات الطاقة.

واستناداً إلى الحقيقة العلمية المذكورة الأخيرة، تقرر أن يوجه هذا المشروع إهتمامه إلى الأنظمة المستدامة لتسخين المياه مثل أنظمة الثيرموسيفون والمضخات الحرارية. أتاحت هذه الأنظمة المستدامة تسخين المياه العذبة في القطاع المنزلي بشكل مستدام، فضلاً عن تقليل استهلاك الوقود في محطات الطاقة التقليدية عن طريق تسخين مياه التغذية الداخلة قبل غليها في الغلايات. وتتميز هذه الأنظمة بالكفاءة وتتميز بالموثوقية العالية والتوفر ويمكن أن تحقق فوائد اقتصادية وبيئية عالية. ومع ذلك، يعتبر الموقع الجغرافي لنظام الطاقة الشمسية مسألة رئيسية لجدوى المشروع. ومن ثم، فإن تحليل الأداء المتوقع تحقيقه بواسطة محطة الطاقة الشمسية قبل التثبيت أمر حيوي لضمان تجنب الخسائر البيئية والاقتصادية غير الضرورية. تم اتخاذ القرار للنظر في دراسة فعالية التكلفة والفعالية البيئية لهذه الأنظمة للإشارة إلى جدواها في المملكة المتحدة والكويت. وسيتم تحليل الظروف الجوية للموقعين الجغرافيين المعنيين للتنبؤ بأداء محطة الطاقة الشمسية في كل منهما لاتخاذ القرار المناسب الذي يؤدي إلى تعزيز إنتاج المحطة. ختاماً، تدوين النتائج و التوصية بأفكار للأعمال العلمية المستقبلية.

Abstract

A noticeable interest was directed to renewable energy technologies, which is subjected to their ability of satisfying the recently seen energy demand. Harvesting renewable energies to be consumed instead of electricity would be highly beneficial regarding reducing the energy demand, which converted into lower dependency on fossil fuels and lower environmental impacts. The aforementioned criteria can be achieved through prioritizing the attention to the energy consuming sectors according to their energy demand. This research mainly concerned about studying the economic effectiveness and environmental effectiveness of two conventional water heating systems (electrical water heating system and natural gas fired boilers) and other two sustainable techniques (thermosiphon system and solar assisted heat pump). Obtained results allowed recognizing that, using solar assisted heat pumps would provide the highest safety level comparing with either the electrical heating elements or the natural gas fired boilers. In addition, the solar assisted heat pumps are estimated to be characterized by very high reliability and dependency, which satisfies the recently seen luxurious lifestyle. Unfortunately, using solar assisted heat pump is predicted to be high respect to both the initial and running cost. Two different geographical locations had been considered in the proposed study as well aiming to investigate the effect of the system installation location on the performance, economic benefits and environmental impacts of the designed sustainable systems. Obtained results showed that, getting closer to equator (Kuwait) would result in attaining a better performance, economic benefits and lower environmental impacts comparing with Nordic countries (UK) due to the higher solar irradiance and ambient temperature.

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Chapter One: Introduction

1.1. Background

It is known that over the last 100 years, modern technologies developed by humanity not only offers unparalleled economic growth capacity, but also gives humanity a tremendous opportunity to be in balance with the world. Modern world has to be a sustainability-oriented society, and everyday life should be fuel-saving. As a limitless source of new environmentally friendly energy sources, solar power is an important energy source that attracted the civilized community and had become an important research issue in the world. Solar power is a sustainable and renewable energy source that allows generating electricity or collecting heat energy without producing such emissions that are estimated as being the main source of low air quality, climate changes, global warming and greenhouse gases. It can be estimated as being a safe, non-transport and no emissions to the atmosphere energy source. Solar technology provides a new way of life for humanity and brings civilization and human beings into an age of energy efficiency in order to reduce emissions. Systems' industry tends to fulfil its promise in the domestic sector by satisfying the heat water demand and supplying the HVAC systems installed in modern buildings [1].

Energy consumption increased significantly last few years, which is highly related to the recently seen luxurious lifestyle. Referring to data provided by IRENA, the energy consumed to heat water is estimated to reach about 4.6 % of the global energy consumption in 2014. Reducing the dependency of fossil fuels in heating water is predicted to help in enhancing the heating processes' environmental and economic benefits [2].

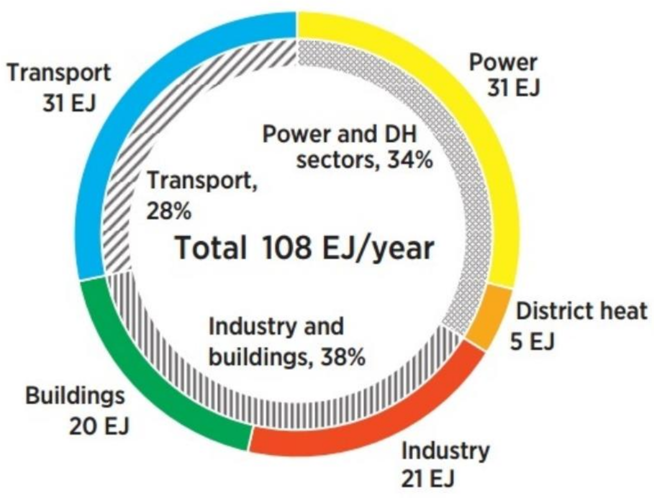

Figure 1. Global energy consumption in 2014 by sector [2].

Actually, the attention paid to the renewable energy sources is subjected to main two issues; the first (figure 2) is related to the environmental negative circumstances resulted from combustion of fossil fuels in conventional power stations to generate electricity while the second (table 1) is subjected to the possible depletion scenario of the fossil fuel resources. The latter discussed two issues pushed researchers to reduce the fossil fuels dependency as possible as it could be without reducing the luxury and comfort level had been achieved in the 21st century. This can be achieved either by improving the recently utilized devices or by figuring out alternative, green and renewable energy sources such as solar energy, wind, hydropower, etc. [3] and [4].

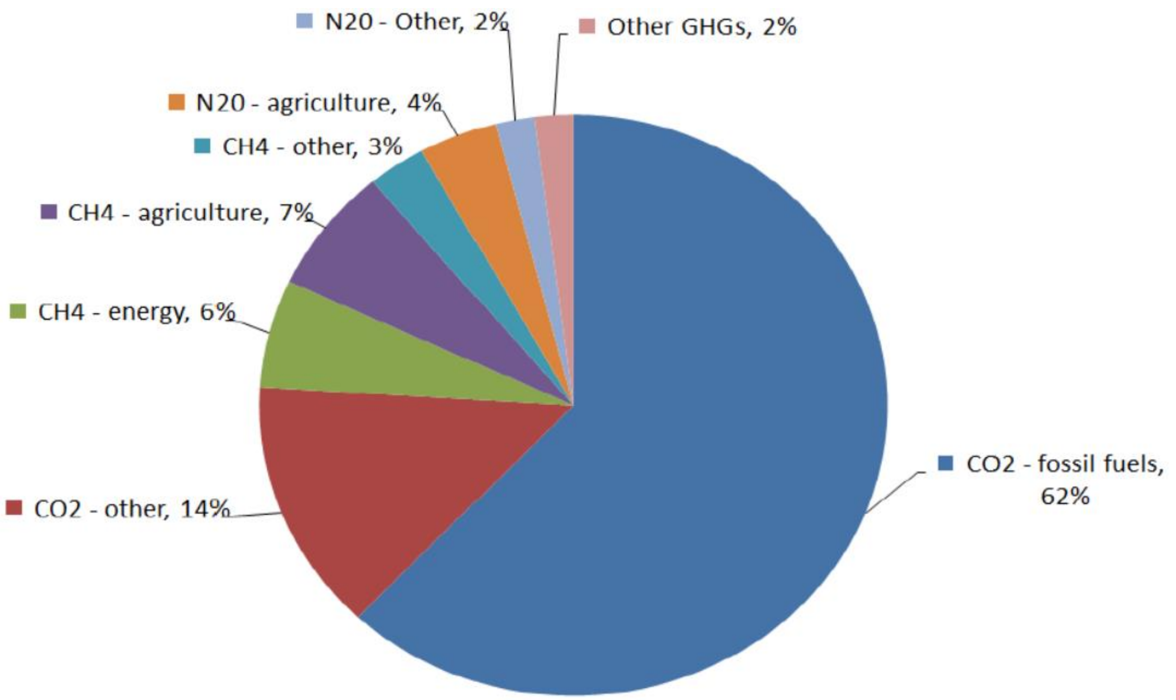

Figure 2. CO2 emissions released due to combustion of different fuels [3].

Table 1. Fuels expected depletion scenarios provided by [4].

Fuels	Total reserves	Production/day	End (date)[a]
Oil	1.689 Tb	86.81 Mb	2066
Gas	6558 TCF	326 BCF	2068
Coal	891.531 BT	21.63 MT	2126

[a] End dates may shift ahead after new discoveries.

1.2. Project Motivation

Although renewable energy is estimated as being one of the most important sector had been attracted the civilized community's attention, it is challenged and limited by such issues that should be taken into consideration during taking a construction decision. Solar power plants are able to satisfy high energy demand, but they are expensive and their output highly related to the geographical location of the plant (or the system). Hence, not all renewable energy plants are feasible to be constructed that pushed researcher to simulate their performances before taking the construction decision. However, the key issues that indicate the solar energy plant feasibility is related to the environmental and economic benefits that pushed the proposed study to direct its attention to study the economic and environmental feasibility of heating water using solar energy instead of using conventional water heating techniques. The study would help in allowing engineers to attain accurate predictions of the outcomes and performance to be achieved by these modern renewable energy harvesting techniques.

1.3. Project Scope

There is a significant interest is paid to renewable energy sources, using these energies in satisfying the energy demand in different sectors allows reducing fossil fuels dependency that resulted in a higher economic benefit while reducing the negative environmental circumstances of combusting conventional fuels in power stations. Based on the latter mentioned scientific fact, this project is decided to direct its attention to the water heating sustainable systems such as thermosiphon systems and heat pumps. These sustainable systems allowed heating fresh water in the domestic sector sustainably as well as reducing fuel consumption in conventional power stations by heating the inlet feed water before it is being boiled in boilers. These systems are efficient and characterized by high reliability, availability and can achieve high economic and environmental benefits. However, the geographical location of a solar power system is considered as being a key issue of the project feasibility. Hence, analysing the performance predicted to be achieved by a solar power plant before installation is vital to assure avoiding unnecessary environmental and economic losses. The decision is taken to consider studying the cost effectiveness and environmental effectiveness of these systems to indicate its feasibility in the UK and Kuwait. The two concerned geographical locations' weather conditions will be analysed to predict the performance of the solar energy plant in each one to make an appropriate decision that results in enhancing the output of the plant.

1.4. Project aim and objectives

The planned project aims to investigate the economic and environmental feasibility of a solar heating system (Thermosiphon system) analytically. This aim is decided to be achieved based on satisfying the following objectives;

1. Carrying out a literature Review regarding renewable energy sources in generation and solar heating systems in specific.
2. Reviewing related studies and investigations regarding thermosiphon systems and heat pumps to be aware of the constructional components.
3. Geographical location comparison between the UK and Kuwait in accordance with the solar irradiance over the year based on the available weather data.
4. Identifying the product design specifications of each component.
5. Sizing and selection of a thermosiphon system to be installed for a purpose of satisfying a domestic energy demand.
6. Analyzing results to predict the environmental and economic feasibility of the designed solar heating system.
7. Remarking outcomes and recommending ideas for the future scientific works.

Chapter Two: Literature Review

2.1. Overview

Sun is considered as being the most abundant energy source had been known by humanity. The solar energy consists of radiant light and heat, and is traditionally used with a range of such technologies as solar heating systems, photovoltaic panels, molten salt (which is used as a heat transfer fluid) power generation plant, etc. The wide range of solar power is a highly attractive electricity source. The annual solar energy capacity was estimated to reach from 1575 to 49,837 (Exa Joule), according to the UN Development Programme. The overall energy consumption in the world, which was estimated to reach 559.8 EJ in 2012, which is much higher than the solar energy emitted by the sun. Utilizing such an efficient technique to harvest solar energy is predicted to help in satisfying the entire global demand greenly, sustainably and forever [5].

Harvesting solar energy using modern techniques and methods allowed attaining a group of advantages that enhanced the concerned techniques' effectiveness. Comparing with conventional fossil fuels, solar plants are estimated to be less expensive and able to achieve a higher sustainability level. In addition, solar power can be provided free of charge once a solar panel is installed. In other words, the running and maintenance cost is very low comparing with conventional power stations. Solar power will last indefinitely and the world's oil reserves are expected to last 30 to 40 years. Solar power does not pollute, as they are not expected to release toxic emissions to the atmosphere during electricity generation. This is investigated to help in reducing the recently seen climate changes, global warming and greenhouse gases. Very little maintenance is needed to ensure the operation of solar cells. In a solar cell or solar collectors, there are no moving parts which prevent them from being damaged due to mechanical stresses. Solar power plants are expected to serve for long term, as the amount of free energy that a solar plant can produce can lead to a higher return on investments; it is estimated that 50% of its energy will come from solar panels from the average household [5].

Unfortunately, the construction of solar plants is expected to consume a lot of time for savings on electricity costs to balance initial investments. This is subjected to its very high initial cost and long period until reaching the payback target. In addition, the generation process of electricity entirely depends on sunlight exposure countries; the climate may be limited to such countries that reduce the concerned renewable energy technique reliability, availability and dependency. Solar power plants are not comparable to traditional power stations of a similar size; they can also be highly expensive to build that resulted in preventing extending its dependency especially by the private sector. Moreover, constructing a solar power plant highly requires installing an energy storage system (either batteries for PV solar plants or Thermal energy storage for concentrated solar power plants). Both of batteries and thermal energy storages are charged with solar energy, which allows solar powered devices to be used at nights, winters and cloudy days. These energy storage techniques often take up space and need to be replaced occasionally and can be large and heavy that resulted in increasing the initial cost of the plant. However, installing an energy storing system would enhance the system's reliability and dependency [5].

Heating demand was investigated to be increased continuously due to the significant increase in the world population and level of comfort and luxury. In fact, this heating demand can be satisfied efficiently using solar heating energy systems in such locations that are characterized by their hot weathers. The following table shows the estimated residential heating demand in different countries [6].

Table 2. Estimated residential heating demand in different countries [6].

Country	% global heating demand	Cumulative % global heating demand
China	39.2	39.2
Russian Federation	9.8	48.9
United States	6.6	55.5
Germany	3.1	58.6
Japan	2.9	61.5
India	2.8	64.3
Pakistan	2.1	66.4
Ukraine	2.1	68.5
United Kingdom	1.8	70.3
Iran	1.7	72.0

2.2. Thermosiphon systems

2.2.1. Description

Thermosiphon system is one of the most common applications of solar energy. In this system, solar energy is collected to heat inlet water. Implementation of the concerned technology can be achieved economically and its design is not complex as well, which pushed researchers to enhance its performance for a purpose of increasing its efficiency leading to a higher level of reliability, sustainability and dependency. This system is commonly classified as being a solar water heating system (SWHS), which includes many types of sustainable and renewable systems. These systems are distinguished by the way of transporting the heat transfer fluid which includes two systems natural or passive and forced circulation systems. Thermosiphon is characterized as being a passive system. In the latter mentioned type, natural circulation occurs because of buoyancy due to the temperature difference between the upper regime and the lower regime without using any type of energy such as pumps or fans to circulate the heat transfer fluid. Factually, the aforementioned advantage is a key issue of the high performance achieved by the concerned renewable and sustainable system. Figure 1 shows the typical Thermosiphon system schematic diagram [7].

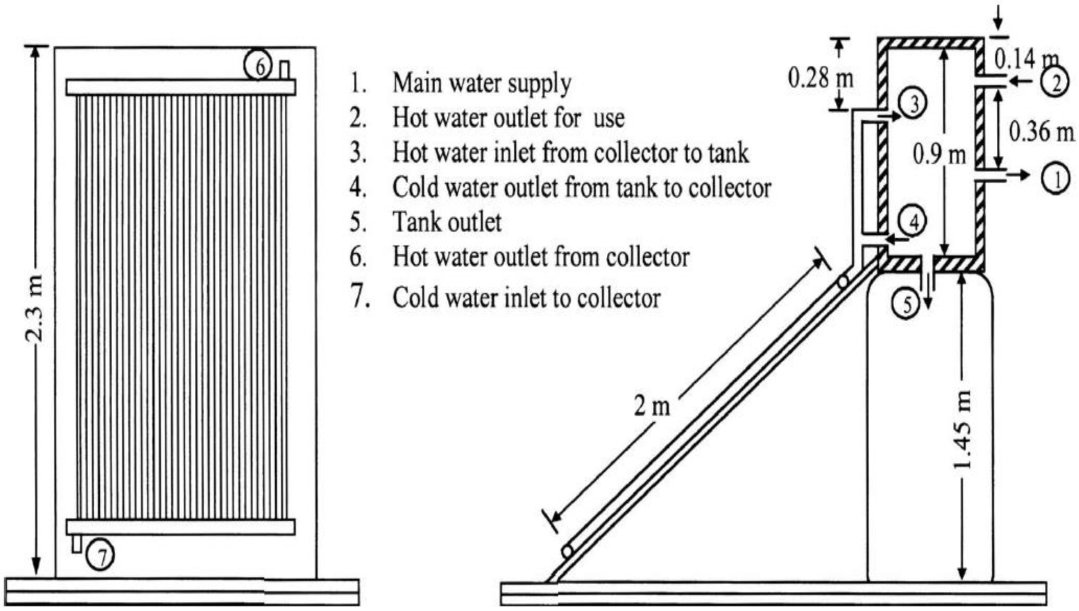

Figure 3. Typical Thermosiphon system schematic diagram [7].

2.2.2. Thermosiphon system components

Thermosiphon systems are advantaged by their simple designs, their configuration mainly constructed from four basic elements. These elements are [8];

I. Solar collector

Solar collector is the main component of the Thermosiphon system. In the solar collector, solar radiation is being absorbed and turns into heat energy and then the water is being heated till it either vaporized or heated then it moves up to storage tank. Two types of solar collector are commonly supplied to the global market [8];

➢ **Flat plat collector:**

In this type of collector, solar radiation is collected at low grade temperature. It basically consists of flat plat absorber that is especially designed for a purpose of absorbing solar irradiance. Its cover should be transparent to be able of absorbing the solar heat energy, which is predicted to result in reducing the heat losses. It should be characterized by high mechanical performance to result in reducing the possibility of mechanical fracture. The heated fluid (commonly known as the heat transfer fluid) used to harness the collected solar energy from the absorber. The installed tubes or pipes in reducing the heat loss and circulating the working fluid [8]. The following schematic diagram shows the construction of flat plate collectors mainly used in thermosiphon systems [9].

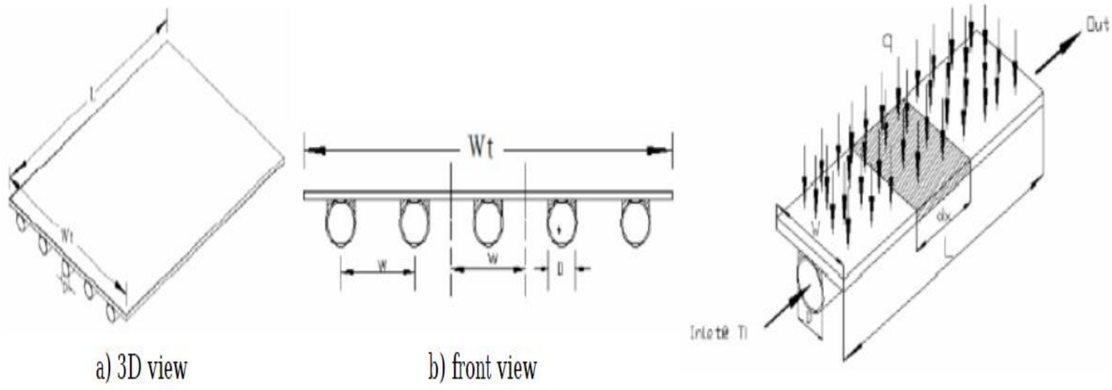

Figure 4. Schematic and dimensioned representation of the flat plat solar collector [9].

➢ **Evacuated tubes:**

This type of collector is characterized by a lower number of heat losses sources if it is compared with flat plat collector. However, it has a relatively higher initial cost that should be taken into consideration during designing such a renewable and sustainable system. This type is basically consists of evacuated tubes used to reduce heat losses due to the lower thermal resistances achieved by reducing air existence between the collector and the absorber. On the other side, the heat pipes used to transfer the selected working fluid, and aluminium casting used to support and integrate other components of the system [8]. For a deeper comprehension, the following figure shows a schematic representation of the evacuated tubes.

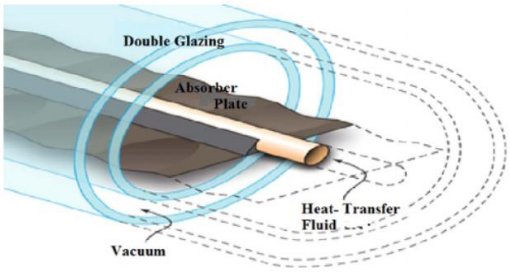

Figure 5. Schematic representation of the evacuated tubes [10].

II. Thermal energy storages:

A thermal energy storage (TES) is considered as being one of the most important constructional element of any renewable and sustainable energy system. It enables storing energy for such days that are cloudy or wintery. Solar energy harvesting techniques are mainly challenged by the seasonal fluctuations leading to reducing their dependency and reliability. Thermal energy storages enabled enhancing solar energy systems' reliability and dependency by storing thermal energy in hot days to be consumed in winters, nights or cloudy days. The key parameter that indicates the performance to be achieved by a thermal energy storage is the related to its ability to insulate the collected heat energy from being dissipated to the atmosphere. Different enhancements had been applied on thermal energy storages aiming to reduce the energy losses. This is achieved either by enhancing their design or the material used in its construction. The material used in manufacturing such a storage tank should be characterized by high thermal and mechanical properties, which enables satisfying the optimum performance. The following figure shows the main configurations used in thermosiphon systems [11].

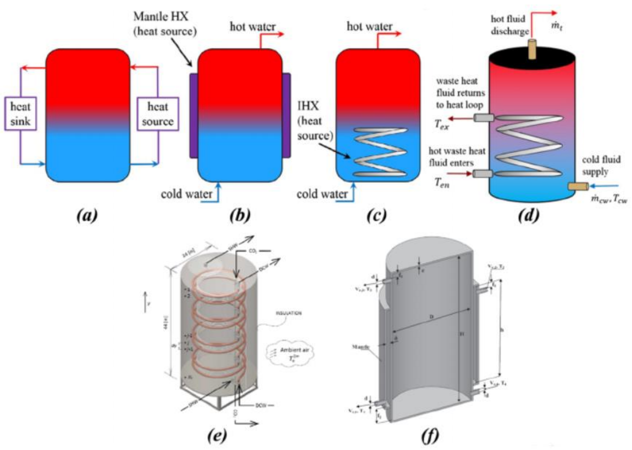

Figure 6. The most common configurations of heated water storage tanks used in thermosiphon systems [11].

III. Heat exchanger

Heat exchangers mainly constructed for a purpose of transferring heat energy from a hot fluid to another relatively colder fluid. Their performances are subjected to the thermal properties of the material used in the construction process. It is worthy to mention that, a heat exchanger material should be able to resist mechanical stresses, corrosion and characterized by low thermal conductivity to prevent heat energy from being dissipated outside it. This part is generally used in closed-loop thermosiphon systems with a working fluid that is mainly responsible of harnessing the collected solar energy. It is used to transfer the absorbed energy between the collector and the storage tank. Anti-corrosion and conductive materials are required to this part of the system to ensure good energy transfer. The heat transfer surface area is the key parameter that should be maximized as possible as it could be to enhance the heat exchanger's effectiveness. The following figure shows the basic construction of shell and tube heat exchanger (the most common used type) [8] and [12].

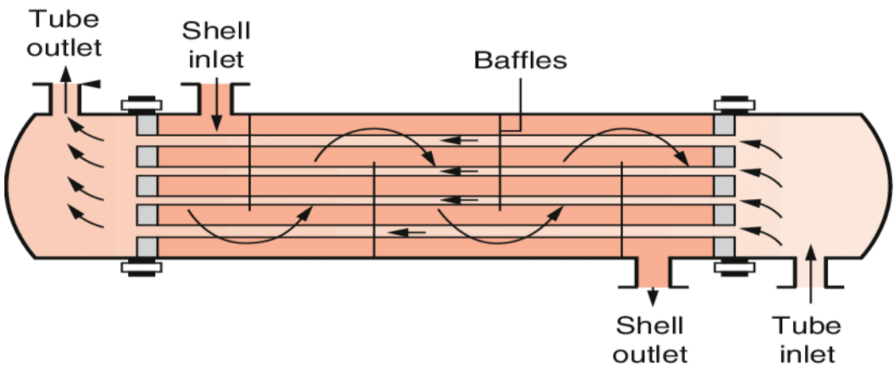

Figure 7. Schematic representation of shell and tube heat exchanger [12].

2.2.3. Heat transfer fluid

A heat transfer fluid is mainly selected based on its ability to carry heat, which is commonly known as specific heat. A heat transfer fluid is responsible of transferring the collected solar energy by the collector. Heat is transferred to the working fluid from the absorber and then the fluid transfer heat via the heat exchanger to the water in the tank. Several fluids can be used as a heat exchanging fluid such as water, air and hydro-carbon oils. However, there are parameters that should be taken into consideration to choose heat exchanger fluid. Such as viscosity, freezing point, boiling point and thermal capacity. Water and air are widely used as they are non-expensive, less toxic, less corrosive and characterized by very high availability [8] and [13].

2.2.4. Concept of operations

Absorbed solar radiation caused in decreasing the water density and raising its temperature. The water is then vaporized and rising from the collector to the thermal storage where it is replaced by relatively cooler water and then it goes back to the collector again. This operation is continuous when the sun is shining. The main disadvantage of this system is the reversed cycle during the night where the water is being cooled. Thermosiphon system is divided into two main types based on the circulation concept, Single phase and two-phase. By comparing these types it was found that, the two-phase thermosiphon system has more advantages than one phase, as it has faster response, small heat capacity and resistance to corrosion [14].

I. Single-phase thermosiphon system (direct type);

In this system, the direct loop type means that the working fluid circulates between the water storage and the collector where the solar collector is located at a higher level. Energy transfer in this system occurs by natural convection as the result of bouncy. The following figure shows the schematic diagram of the single-phase thermosiphon system [14].

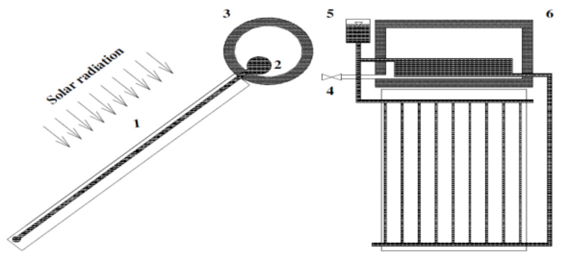

Figure 8. Single phase thermosiphon system schematic diagram [14].

Where: 1 refers to solar collector, 2 refers to heat exchanger, 3 refers to storage tank, 4 refers to cold water inlet, 5 refers to Expansion Tank and 6 refers to storage tank isolation [14].

II. Two phase thermosiphon system (indirect type)

Two-phase thermosiphon system is an efficient device for heat transfer. This devise make use of phase change material in order to transfer heat between water being heated and the solar collector. Heating in this system is generated by the latent heat that carried out by vaporizing of the condensing fluid. The heat transfer fluid vaporizes in the collector then by the effect of buoyancy it is delivered to the thermal storage where the latent heat moves to services water and then by the effect of the gravity, heat transfer fluid returns to the collector. The figure below shows the schematic diagram of the two-phase thermosiphon device [15].

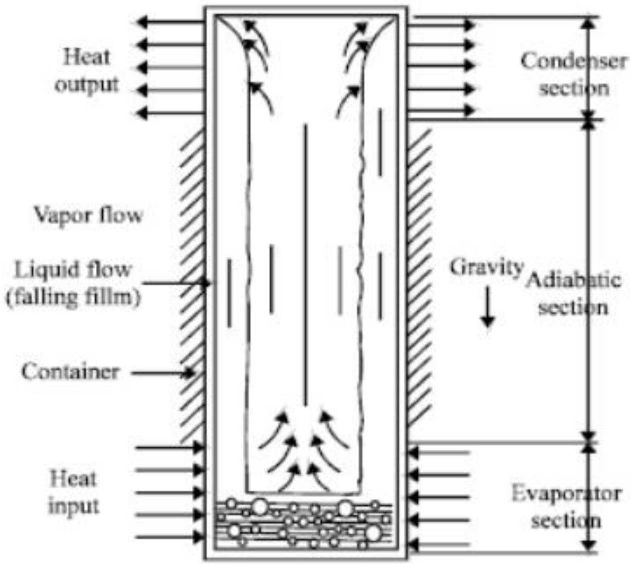

Figure 9. Two phase thermosiphon system schematic diagram [15].

As shown in the figure the evaporator is filled with working fluid. In this section, the fluid absorbs the heat input and after working fluid is vaporized, it raised to condenser section where it is converted into liquid. And in this way the latent heat delivers to the coordinator. The working fluid is then returned to the collector by the effect of the gravity [15].

2.3. Heat pumps

2.3.1. Description

Solar-assisted heat pump system SAHP combines the heat pump technology and solar water heating system technology. The major function of SAHP system is to use the evaporator to extract thermal energy at low-grade temperature from the solar collector and waste heat in order to use in the heating applications. SAHP is advantaged by its higher coefficient of performance (The ratio between heating performance to electrical energy used) and lower environmental pollution compared to expensive fuels and electrical resistance heating. Therefore, this system allows for saving energy. Figure 10 shows the schematic diagram for typical Solar-assisted heat pump system [16].

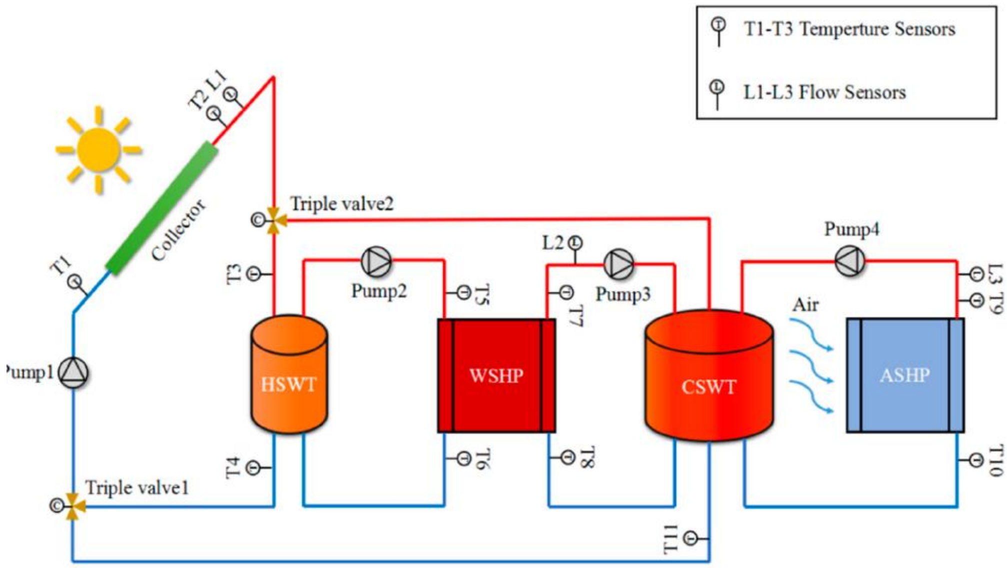

Figure 10. The schematic diagram of solar pumped heating system [17].

(SAHP) is a complex system constructed from six basic components. These components are solar collector, Hot water storage, Compressor, Expansion valve, Evaporator or heat exchanger and condenser. The description of these components is mentioned below, however solar collector and Hot water storage description is same as thermosiphon system [18]. a detailed description of these components are mentioned as follow;

2.3.1.1. Compressor

Compressor is the major part of the heat pump system. It is the most stressed and expensive part of the system. The major function of the compressor in the system is increasing the temperature and the pressure of the refrigerant and then transporting it to the condenser. There are several types of compressor. However, scroll compressor and piston compressor are the most common type that is used in HP system [18].

- **Scroll compressor**

The concept of scroll compressor is to use two metal spirals to compress air by using an electrical motor to rotate the shaft through the drive as shown in figure 11. The upper and lower scroll flanks vane form crescent-shaped pockets. When the scroll at the lower part orbits, the Points of sealing on the flanks that were vanned are then moved to push crescent-shaped towards the involute centre. That causes to decrease the volume and thus compress the refrigerant [19].

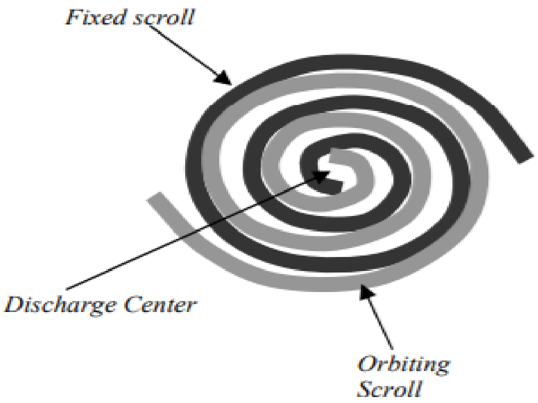

Figure 11. Schematic representation of the compression process [19]

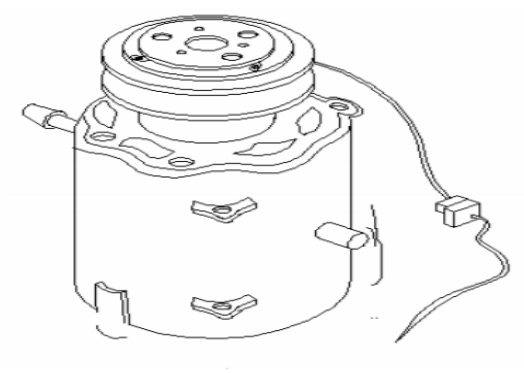

Figure 12. Scroll compressor assembled [19].

- **Piston compressor**

In this type, a piston is driven by a crankshaft that is used to convert the driver rotational motion. The motion of the pistons pushes the gas into a cylinder where the gas is compressed. Valves are used in this type to allow the gas to move in only one direction. Figure 13 shows the schematic diagram of the piston compressor [20].

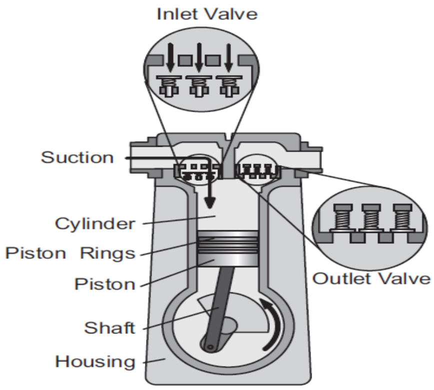

Figure 13. Piston compressor schematic diagram [20].

2.3.1.2. Condenser

The condenser in (SAHP) is considering a type of heat exchanger which delivers the heat from the pressed hot refrigerant to the medium of the heating system of the pump. The major function of the condenser is to change the refrigerant from the gas state to the liquid state. Two main constructions are available for the heat exchanger that acts as condenser, plat heat exchanger and tabular heat exchanger [18].

- **Plat heat exchanger**

This type of condenser is usually constructed from thin plates. These plates may be smooth or have corrugation form. This type is advantaged by high transferred power, low dimension and high effectiveness. The main disadvantage of this type is that it can't accommodate very high temperature and pressure. This type of the condenser can be classified as welded or Gasket. This classification depends on the required tightness of the leak. Gasket plate heat exchanger is the most common use around the world, this type constructed from thin metal rectangular plates that are using gaskets to be tight around the edges. The plates are held in a frame together. The frame has movable end cover and fixed end cover as shown in figure 14 [21].

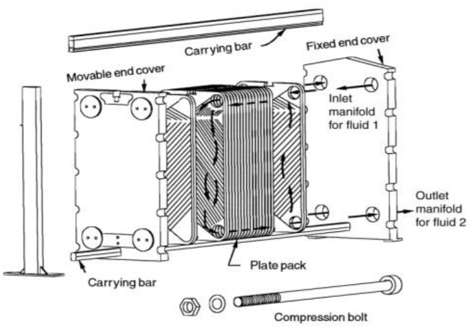

Figure 14. Schematic representation of the gasket-plate heat exchanger [21].

- **Tabular heat exchanger**

This type is generally constructed from circular tubes. The design of this type has considerable flexibility because its geometry could be easily varied by changing the diameter of the tube, arrangement and tube length. This type is designed for high temperature and high-pressure differences between the refrigerants. Figure 15 shows the schematic diagram of the tabular heat exchanger [21].

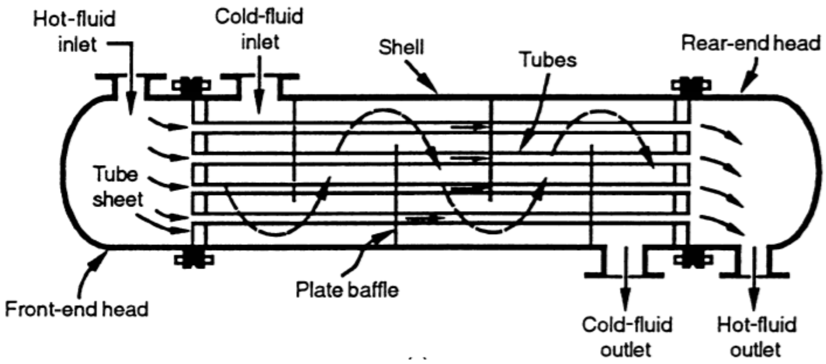

Figure 15. A schematic representation of tabular heat exchanger [21]

2.3.1.3. Expansion valve

The expansion valve is a narrowness of the pipe that transporting a refrigerant. The condensed refrigerant is partially sprayed by the nozzle of the valve. Therefore, the gas state changed effectively in the evaporator. The nozzle is considered as the major part of the expansion valve that either closes or opens the input of the refrigerant. The function of the nozzle is controlled by three applied forces. The temperature is obtained by a temperature sensor which is then changed to pressure applied on the top of the membrane causing the valve to open. The other two forces are the valve spring force and the pressure force from the pipe. These forces are applied on the bottom of the membrane causing the valve to close. The condition of the valve is obtained by the resultant force when the refrigerant overheating increasing in the evaporator, the temperature increases and then the valve is opened and vice versa [18].

2.3.1.4. Evaporator

The evaporator is as condenser which belongs to the heat exchangers. Therefore, plate heat exchanger and tabular heat exchanger can act as evaporator. The major function of the evaporator is to increase the refrigerant temperature to change its state from liquid to gas [18].

2.3.2. Configuration

Various configurations of (SAHP) have been implemented and investigated in the past. Many researches implemented in order to develop the system configuration to enhance the COP of the system. “Series” and “parallel” systems are the most common applicable systems of

(SAHP). In “Parallel” system when solar energy is sufficient, it is provided directly to the load. However, when the solar energy is insufficient to meet the load, ground-source (or air source) heat pump is operated in parallel to supply the system. In “series” configuration the evaporator works as an absorber and transfer the solar energy to the load via the condenser of the pump. The unglazed solar collector is recommended for the evaporator so it can absorb solar energy. Series configuration system can also be further sub-classified as direct-expansion (DX-SAHP) or indirect-expansion (IDX-SAHP) type [22].

2.3.2.1. DX-SAHP

In (DX-SAHP) system the solar collector and the evaporator work as one unit in order to enhance the system performance. The refrigerant is circulated directly through the solar collector. The main advantage of (DX-SAHP) system is that it has high COP because the solar energy increases the evaporating temperature of the system. Figure 16 shows the schematic diagram of (DX-SAHP) system [22].

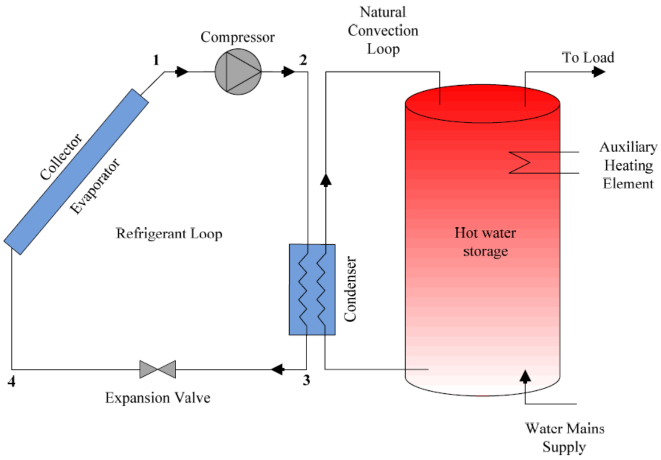

Figure 16. The schematic diagram of (DX-SAHP) system [22].

As shown in the figure, the condenser is arranged as heat exchanger in order to supplying the hot water tank. The major problem of (DX-SAHP) system is that, many climates require return lines and long supply between the roof-mounted. Therefore, the installation becomes more difficult as these lines require to be charged with refrigerant. This problem has limited the penetration of the market for (DX-SAHP) system. (IDX-SAHP) is constructed in order to overcome these limitations [22].

2.3.2.2. IDX-SAHP

The purposed system uses a conventional solar collection loop (i.e., non-refrigerant based) to deliver the energy absorbed by the collector to the evaporator. This way provides the availability to charge the heat pump unit with refrigerant at the manufactory time and only liquid-circulation piping will be needed to be installed on the installation site. Propylene glycol /A-freeze-proof water solution is used in the solar collector loop to transfer the heat from the collector to the evaporator. Figure 17 shows the schematic diagram of (IDX-SAHP) system [22].

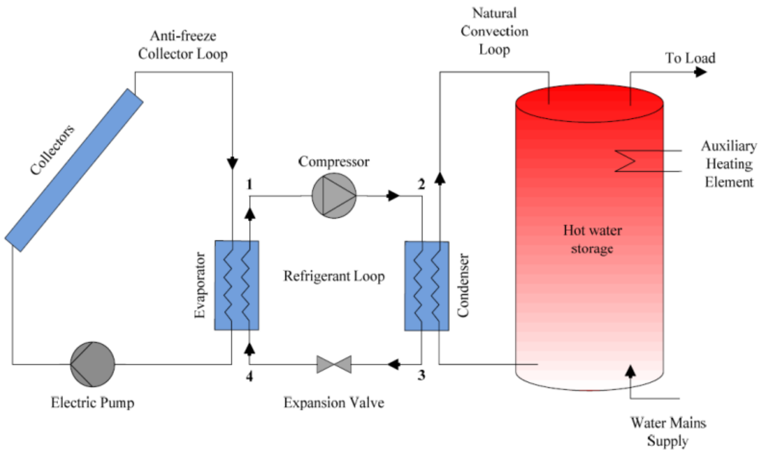

Figure 17. The schematic diagram of (IDX-SAHP) system [22].

During the operation, water/glycol solution delivers the energy absorbed by the collector to the heat exchanger that works as the evaporator. Concept of operation of the (IDX-SAHP) system is that the low-pressure refrigerant (working fluid) is circulating through the evaporator (which works as heat exchanger) absorbs the input heat then it vaporizes and superheats. The electrical compressor is then used to compress the super-heated vapour to high pressure where it flows into the heat pump condenser [22].

2.3.3. Types of heat pump

Heat pump systems are categorized by the heat source. Several types of the source of heat for HP are provided systems however Air-source Heat Pumps and water-source Heat Pumps are used widely in pumped solar water heating systems [23].

2.3.3.1. Air source Heat Pumps

Air-source heat pump collects heat from the air in order to use in heating applications. Two types of (ASHP) are provided, air-to-air heat pump and air-to-water heat pump. The concept of operation of this system is that, heat is collected from outside air and then it pumped indoor.at first the refrigerant transfer to the expansion device in order to change into liquid which has low pressure, then it is delivered to the evaporator in order to absorb heat from outdoor air and turn into vapour. The vapour is then goes to the accumulator through the expansion valve to collect the liquid that was remaining in the vapour before entering the compressor. Vapour is then entering the compressor to be compressed causing it to raise its temperature. The refrigerant then goes through the expansion valve to the condenser where the heat from the refrigerant is transferred to be used in heating applications [23] and [24].

2.3.3.2. Ground source heat pump

This system is making use of the earth or the ground water as the heat source. This system has two main parts, the heat pump and the underground piping circuit. The concept of operation of this system is that, the heat is collected by the underground piping using the refrigerant which is then after absorbing heat transferred back to the pump in the house. This system is considered as direct expansion type where the refrigerant is transferred to the compressor directly without using heat exchanger. The heat is then collected from the refrigerant in order to use in heating application [23] and [24].

2.4. Solar assisted heat pump types

The major problem in Air source Heat Pump is that, when the temperature drop below 5°C, a observed drop of the (COP) is then demonstrated. In ground source system, the major problem is that the ground source heat pump requires ground heat exchanger. This type of heat exchanger is expensive and may be not feasible. To overcome these problems, two advanced solar assisted heat pump systems are produced, solar-assisted air source heat pump and Solar assisted water/ground source heat pump [23] and [24].

2.4.1. Solar-assisted air source heat pump

This type of SAHP utilizes solar energy to minimize the difference between the evaporator temperature and the condenser temperature. Therefore, enhancing the performance of the system and heating capacity at low-grade temperature. Solar collector is used to heat the ambient air and the circulating fluid (the refrigerant) via the outdoor unit. A control system is used to make the pump work when the heat energy collected from the collector is available [23].

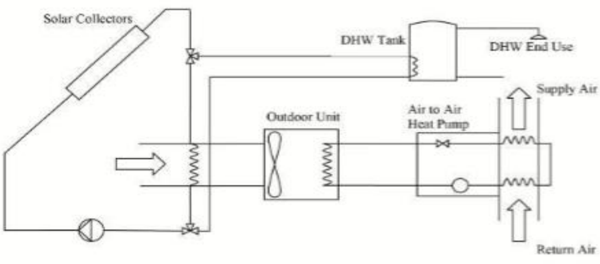

Figure 18. Solar-assisted air source heat pump [23].

2.4.2. Solar assisted water source heat pump

The concept of this system is utilizing the energy absorbed by the collector to deliver the refrigerant to the heat pump. This makes dispensing of heat changer possible. Therefore, enhancing its economic performance and the (COP) of the system [23].

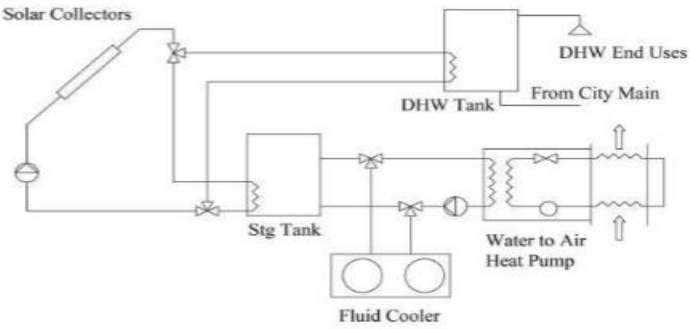

Figure 19. Solar-assisted water source heat pump [23].

2.5. Geographical location

Solar heating systems are mainly established to collect solar irradiance for a purpose of either heating a working fluid (such as water or oil) or generating electricity. A concentrated solar power system is investigated to be affected significantly by its installation location. This variation is related to the solar irradiance change from a location to another as well as the seasonal fluctuations over the year. Hence, considering the optimizing the geographical location of the plant is vital to assure achieving high performance. As the plant economic and environmental feasibility is highly subjected to its output, which can be enhanced by selecting such locations close to the equator. The following figure shows the average annual solar irradiance distribution in the world, which is maximized near to equator and minimized near to Nordic countries [25].

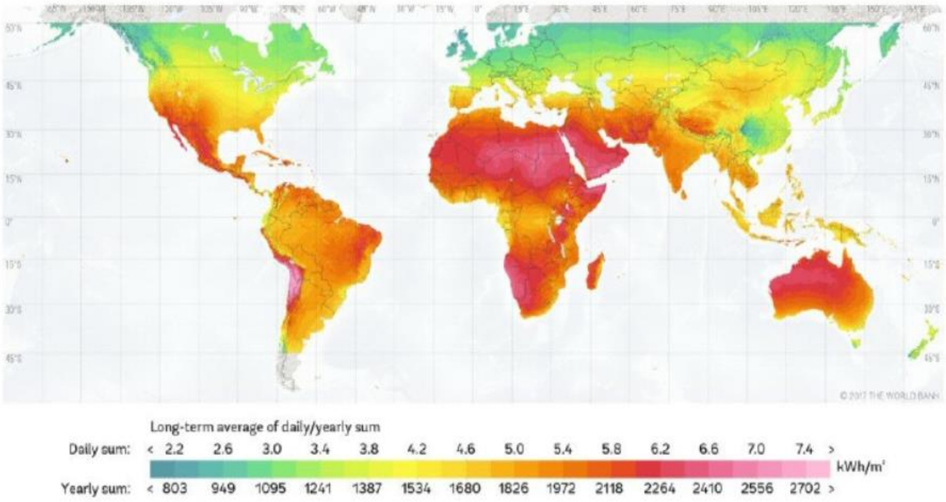

Figure 20. Average solar irradiance distribution over the world (KWh/m^2) [26].

In fact, not only the solar irradiance of the location is the only parameter should be considered during taking an appropriate decision. As the land use and cost should be considered as well, which highly influences the initial cost of the plant (or the system). In addition, the regulations and laws sat by the country should be reviewed to assure that, the project is feasible in accordance with the legalisation. The distance to water resources should be taken into account, as supplying water for long distances would increase the running cost significantly leading to increasing the payback period (the main parameter that attract decision makers especially in the private sector). The following flow chart shows the technical approaches followed during studying the feasibility of establishing a PV solar power plant. The obtained results are estimated to help in help decision makers in taking suitable decisions that prevent unnecessary economic and environmental losses [27].

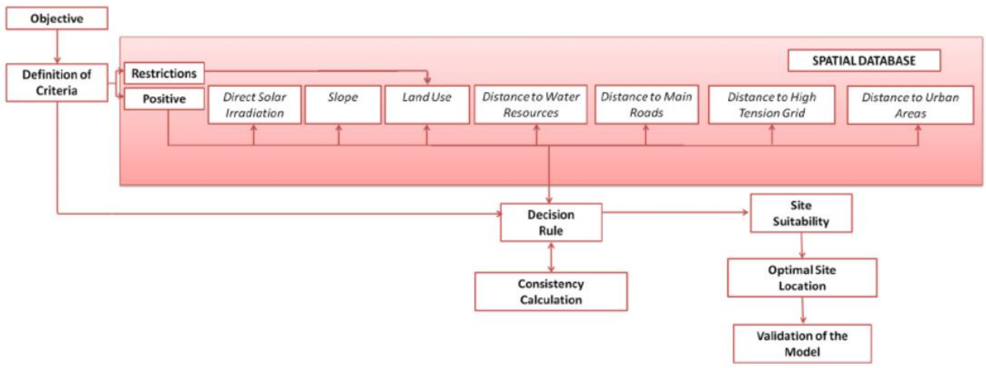

Figure 21. Scientific approaches followed during optimizing the geographical location of a solar power plant [27].

2.6. Performance criteria

A solar heating system should consider achieving such performance that enhances the environmental and economic benefits may be achieved by using it. Designing such a solar energy plant is not simple as it seems to be, it requires satisfying a group of constraints and requirements that fit with the duties should be fulfilled [28]. Stating the problems is the first step of the design process of any engineering application. This step involves determining the given parameters, the requirements of design, constrains had been determined by the client or limitations that involve the project available budget, environmental regulations of the country and fact of safety of the operating system. The following statements are a summary of these considerations [29], [30] and [31];

- Thermosiphon design should not be installed by either fans or pumps to circulate the working fluid, which is considered as being a valuable opportunity to reduce the running cost of the designed system.
- The installed solar collector control system should be designed to endure the maximum solar energy, which may be achieved using solar tracking systems. Although installing a solar tracker is estimated to increase both of the system's initial and running costs, it assures enhancing its performance significantly as the solar irradiance is maintained perpendicular to the solar collector for much longer time.
- All components should be equipped with flowmeter and thermocouples, which enables acquiring the data of the system to be able of analysing their performances.
- The materials should have high resistance to corrosion and should endure the variation of the temperature. In addition, the selected materials should be characterized by high thermal conductivity, which enhances the system's effectiveness. Moreover, the mechanical properties of these materials should be able of resisting such unexpected collisions that may take place due to seasonal fluctuations (i.e. winters and high wind speeds).
- Fittings and tubes should be optimized to lower initial and running costs. This can be achieved through optimizing the power losses by insulating them perfectly while considering the economic benefits of the selected insulations.

After stating the problems and design considerations each critical component should be evaluated.

2.6.1. Solar collector

The solar collector is the most critical component of the solar heating systems. Therefore, improving its design is vital to enhance the performance of the system leading to enhance its output. The amount of energy absorbed by a solar collector basically depends on the efficiency of the absorber surface and the cover material transmittance. The absorber material should have good thermal conductivity, low emissivity and should be thermally stable during the absorbance. It should also have a low weight per unit area and should be coated with black to absorb as much radiation as possible. There are different materials had been developed by researchers that can be used as absorbers such as corrugated galvanized iron sheets, plastic sheets and black-painted rocks. The accessibility and the cost of these new materials are estimated as being the most important considerations should be taken into consideration during selecting the absorber material. According to the cover material, it has been recommended that cover material should have high transmittance of the electromagnetic spectrum. There are other parameters affect the efficiency of the cover material such as low absorbance of infrared radiation, resistance to breakage, stability during the operation and low cost. Glass is commonly used as cover material [32].

2.6.2. Storage tank

A thermal storage tank is mainly installed for a purpose of increasing the reliability and dependency of the solar heating system. However, there are such considerations should be taken into account during designing a storage tank. Heat losses from the storage tank are the most significant problem of the system, which should be reduced as possible as it could be. Several studies were performed to enhance the tank performance and to overcome this problem and it has been found that, heat losses per unit volume in large tanks are less than heat losses in small tanks. Stratification also has been considered a solution to this problem. The material of Storage tank should also be well insulated to reduce the heat loss so fibre glass and concrete are commonly used [8].

2.6.3. Inlet and Outlet Piping

The design of this piping allows water to flow from the solar collector to the storage tank [29]. Increasing distance between the pipe inlet and outlet allows increasing both of the heating time and heat transfer surface area leading to achieving a higher effectiveness of the system. The length of the pipe should fit with the available ground surface area. Although increasing fittings and curvature of the pipe would result in a higher energy losses, it is vital to satisfy the desired outlet temperature of the system that is mainly controlled depending on both of the heat transfer surface area (pipe length) and the velocity of flow [33].

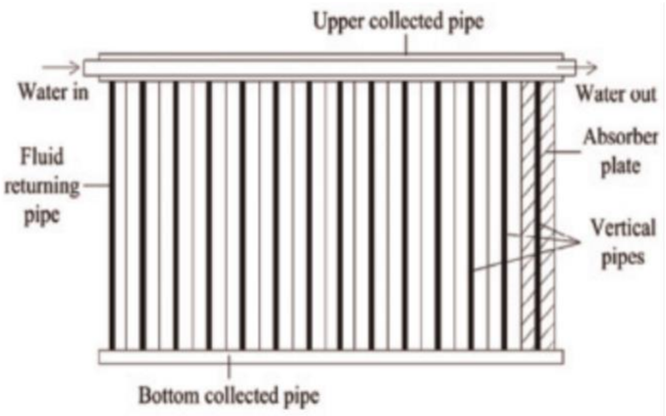

Figure 22. A schematic representation of the main components of heat pipe solar collector [33].

2.6.4. Control system

The DC servomotor that is used to adjust solar collector to be perpendicular to the solar irradiance is one of the most important components of these type of solar heating systems. The installed servomotor should be revisable in case switching the leads. Relay circuit shown in the following figure is developed to allow it to be reversing [29].

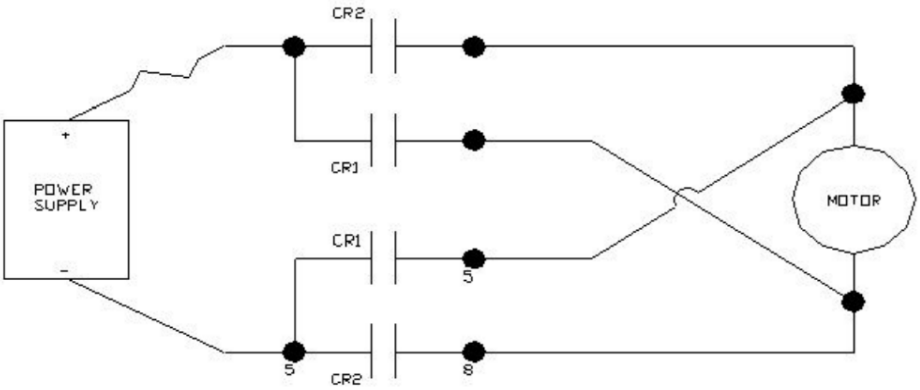

Figure 23. Developed relay circuit [29].

Where CR1 & CR2 are the control relays. Brake should be included for quick stopping and to enhance the availability of these control two switches are added. The motion of the motor will occur using sensor but in areas with dimly light sensor will not work and to overcome this problem manual switch are added [29].

Chapter Three: Approaches and Calculations

3.1. Overview

Sun is one of the most abundant energy source had been known by humanity, sun's extremely high energy potential attracted energy engineers to make the best use of it with the purpose of reducing the dependency of fossil fuels aiming to achieve higher sustainability level, avoiding the expected scenario of fossil fuels depletion, reducing the environmental negative circumstances resulted from combusting petroleum, coal and natural gas in conventional power stations and maximizing the economic benefits. This research is established to investigate the latter mentioned advantages may be achieved through installing a solar water heating system. Aiming to satisfy the research aim, the following flow chart summarizes its approaches;

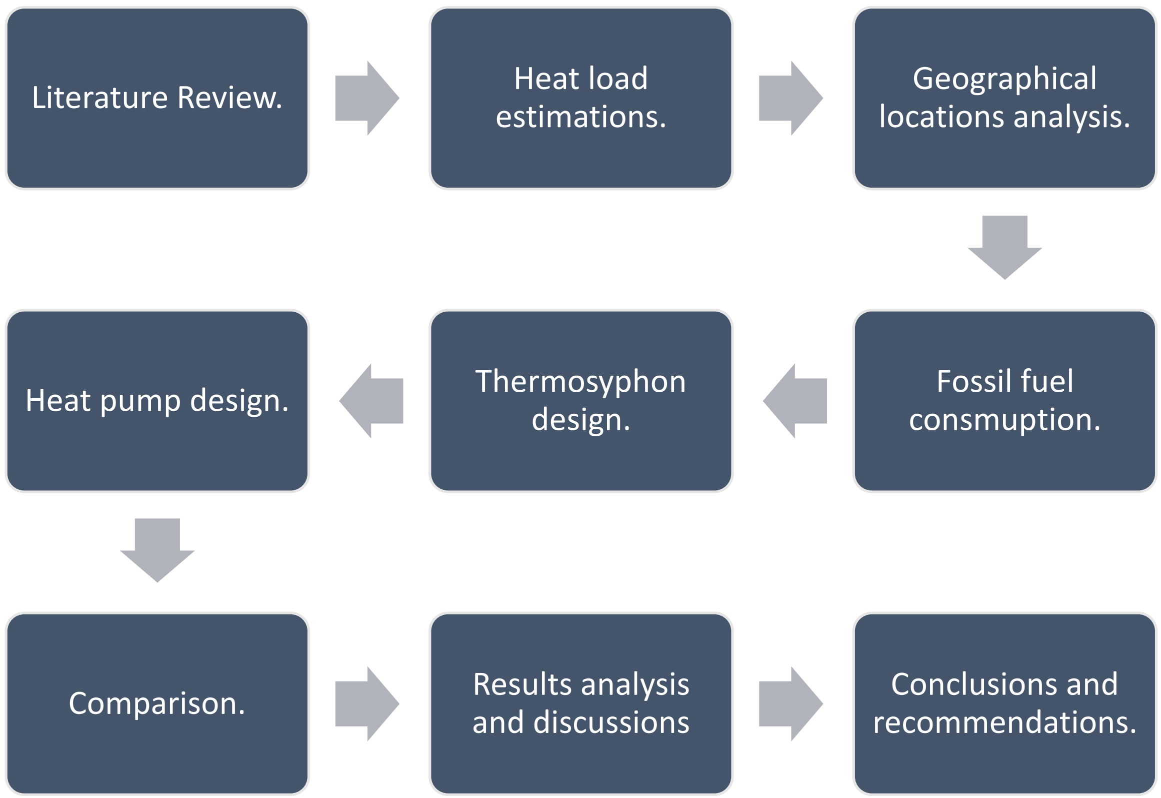

Figure 24. A flow chart of the research approaches.

3.2. Studies and researches review

Designing, developing or investigating the feasibility of such an engineering application should be mainly based upon deep recognition of the operating and environmental conditions in addition to the performance criteria should be satisfied. This research mainly tends to compare among the environmental and economic benefits may be achieved by three different water heating techniques, the first uses fossil fuels that is estimated to be combusted in a conventional boiler, the second is decided to heat water sustainably depending on collecting the solar heat energy using thermosiphon systems while the third technique tends to heat water using heat pump. The latter two water heating techniques had been reviewed in details in chapter two, the performance criteria of each of them had been investigated based on the previously published researches and studies. The theoretical comprehension of these systems will help in designing such efficient systems that are estimated to serve for long lifespans. The geographical location effect on the performance of solar based water heating systems was investigated to be highly influencing parameter, which pushes towards reviewing it as well.

3.3. Weather data analysis

Solar heating systems are primarily designed to gather solar irradiance for the purpose of either heating working fluids (such as water or oil) to be consumed directly or to be used in producing electricity indirectly depending on heating the boiler inlet water. The concentrated solar energy system is examined to be greatly influenced by the location of its deployment. Such variability is due to the increase in solar irradiance from location to another, as well as seasonal variations over the year (summers, winters, cloudy and shiny days). Considering the optimisation of the geographical position of the factory, therefore, it is important to ensure that high output is achieved. As the plant's economic and environmental viability is highly subject to its production, it can be improved by choosing locations near to the equator.

Hence, the output of a solar based water heating system is to be subjected to the solar irradiance of the installation location. Solar energy harvesting techniques had been paid a significant interest last few decades. One of these interests is subjected to the detailed weather data records had been saved in the databases of the European commission.

In order to be aware of the weather data in such a geographical location, it just requires indicating it on the map represented in figure 25. The weather data is then downloaded as an EXCEL datasheet.

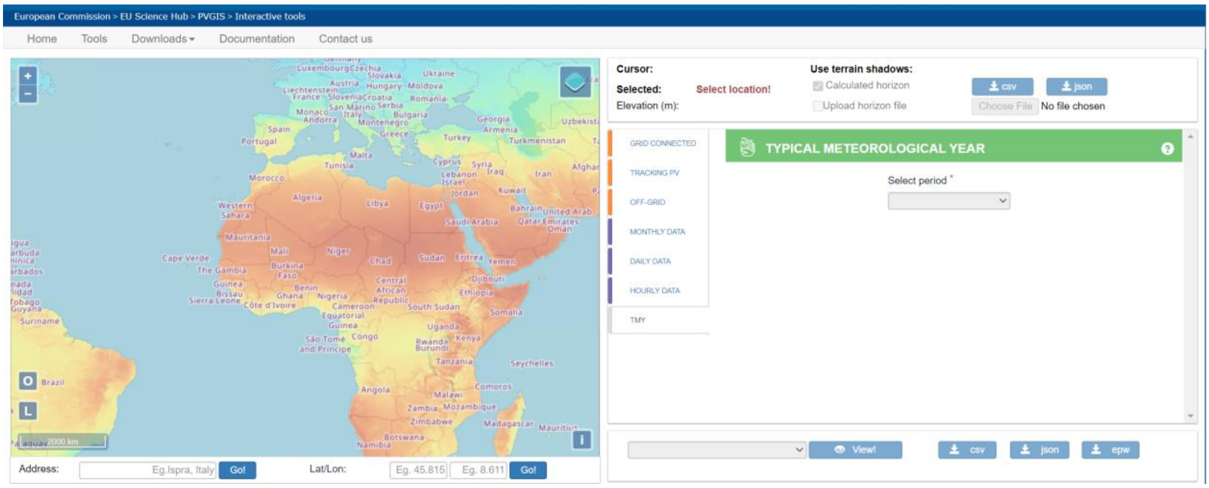

Figure 25. Gathering weather data recorded by the European commission [34].

The decision was taken to analyze the recorded weather data for two different geographical locations, which helps in widening the comprehension of the deployment location of the designed solar power plants.

3.3.1. United Kingdom

The English city (Canterbury) had been decided to be considered in the proposed analytical study. The decision was subjected to the higher distance between the selected city and the North Pole. The selected geographical location latitude is 51.093 (decimal degrees), longitude is 0.725 (decimal degrees) and an elevation of 15 metres.

Figures 26 and 27 show the recorded ambient temperature (°C) and solar irradiance (W/m^2) over the year in the selected location respectively.

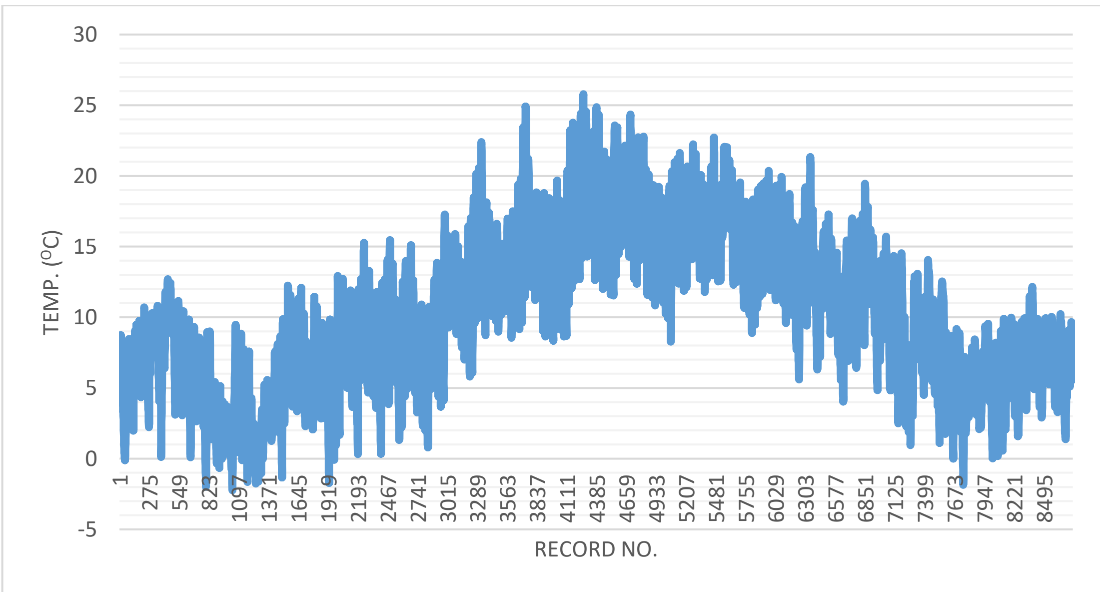

Figure 26. Recorded ambient temperature (°C) over the year in Canterbury, UK.

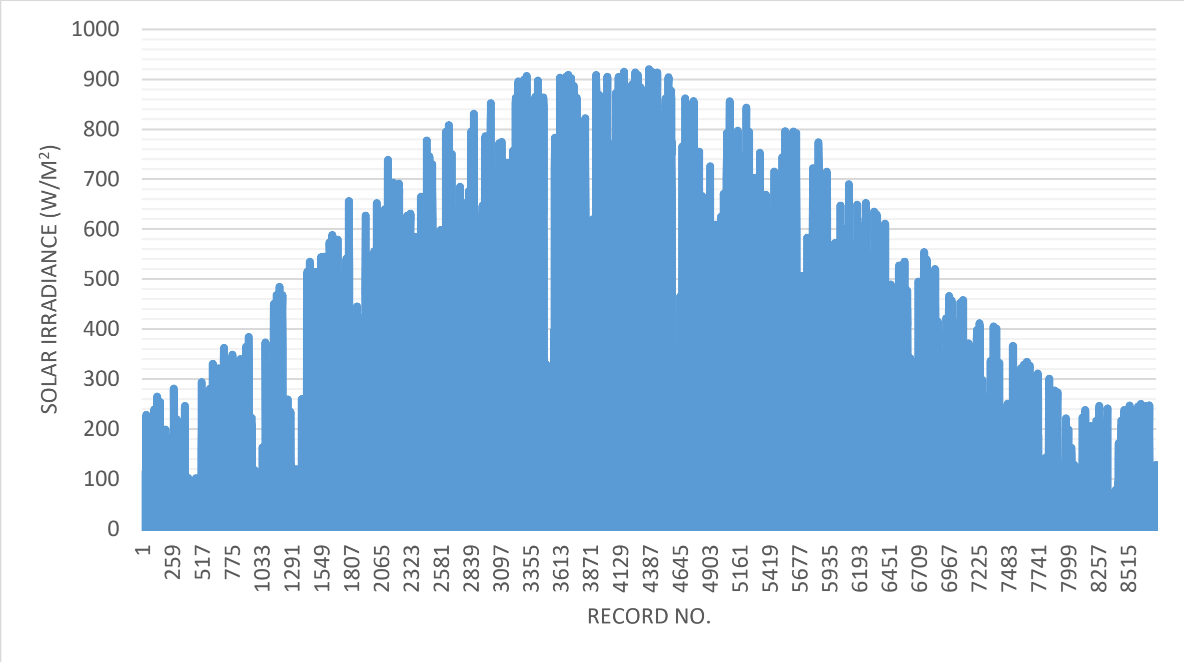

Figure 27. Recorded solar irradiance (W/m^2) over the year in Canterbury, UK.

The data had been represented graphically in figures 26 and 27 would help in predicting the average values of the location, which would be considered in the research. The following table shows the average weather conditions in the targeted geographical location.

Table 3. Average weather conditions for the second selected geographical location [Canterbury, UK].

Condition	Average Value
Relative Humidity (%)	79.90
Ambient temperature (°C)	10.35
Solar irradiance (W/m^2)	127.92

3.3.2. Kuwait

Similarly, The Kuwaiti city (Al-Ahmadi) had been decided to be considered in the proposed analytical study. The selected geographical location latitude is 29.079 (decimal degrees), longitude is 48.073 (decimal degrees) and an elevation of 86 metres. Figures 28 and 29 show the recorded ambient temperature (°C) and solar irradiance (W/m^2) over the year in the selected location respectively.

The data had been represented graphically in the following two figures would help in predicting the average values of the location, which would be considered in the research. The following table shows the average weather conditions in the targeted geographical location.

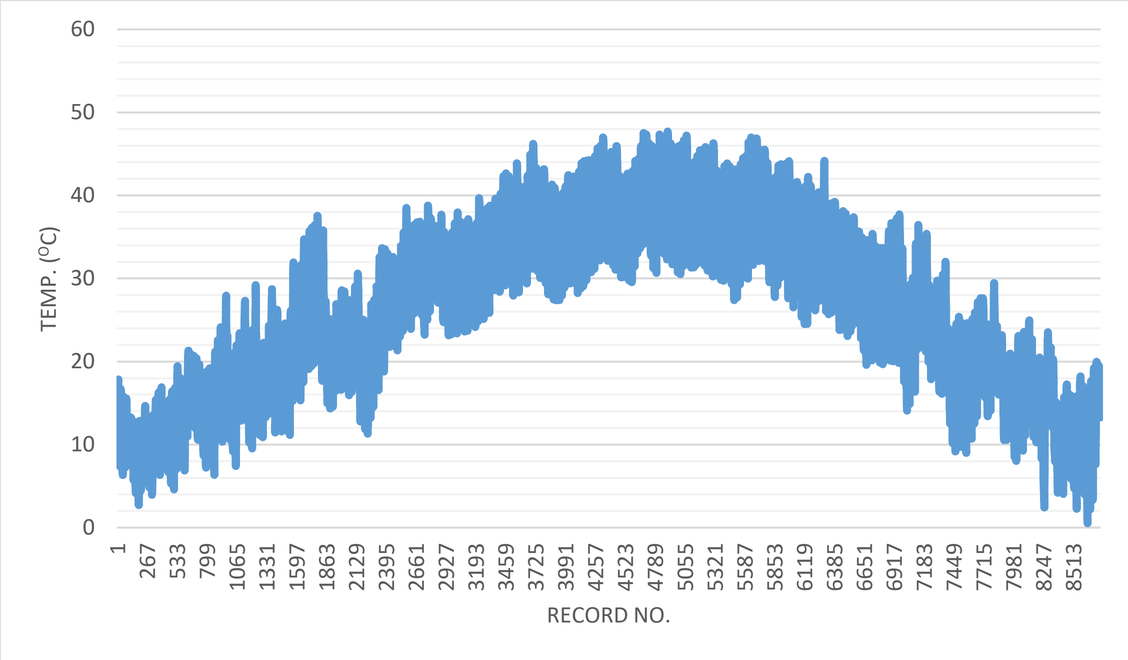

Figure 28. Recorded ambient temperature (ºC) over the year in Al-Ahmadi, Kuwait.

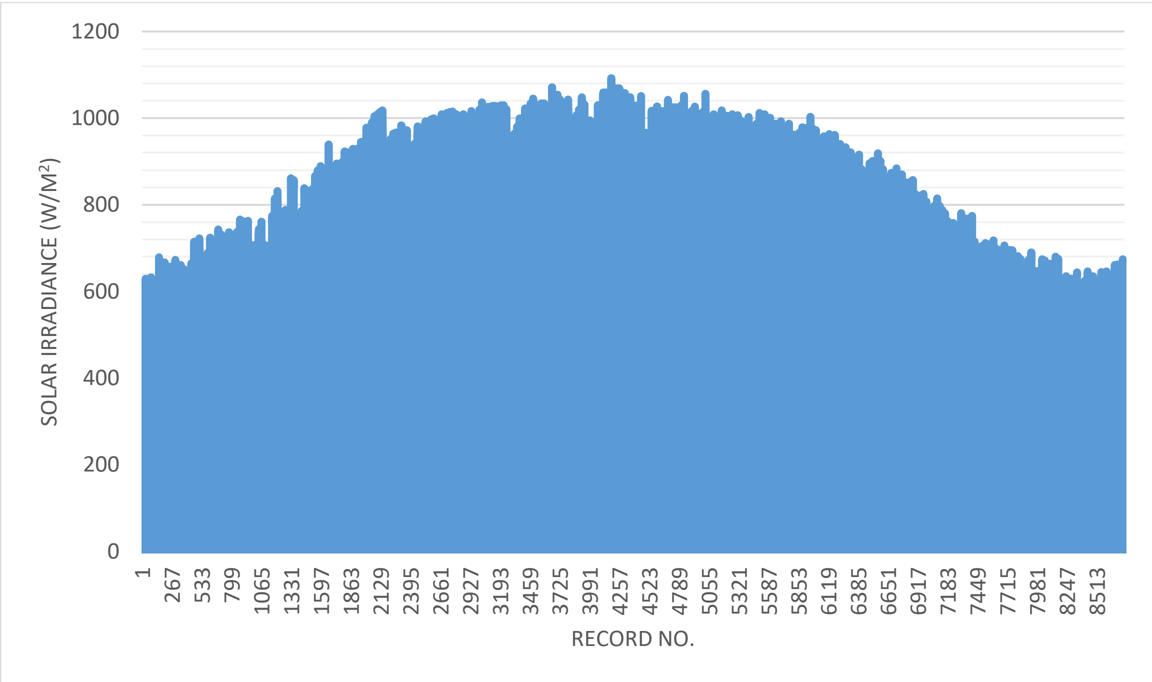

Figure 29. Recorded solar irradiance (W/m²) over the year in Al-Ahmadi, Kuwait.

Table 4. Average weather conditions for the second selected geographical location [Al-Ahmadi, Kuwait].

Condition	Average Value
Relative Humidity (%)	30.36
Ambient temperature (ºC)	26.56
Solar irradiance (W/m²)	249.70

3.4. Heat load estimations

The heat load calculation is considered as being the key issue of the design process for either the heat pump or the thermosiphon system. It was planned to pay the attention to the domestic sector, which is one of the most important energy consumers in the world. The dependency and reliability required to be enhanced to the solar based water heating systems would help in reducing the fossil fuel's consumption in the domestic sector. The domestic sector was investigated to consume about 21.4% of the global energy demand and satisfying this high percentage of energy demand sustainably using renewable energy harvesting techniques would maximize the environmental and economic benefits noticeably [35].

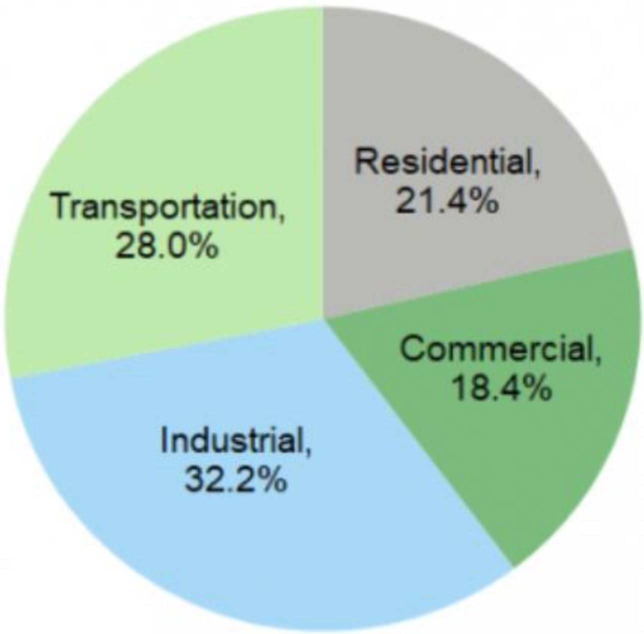

Figure 30. Global energy demand by sector in 2018 [35].

According to data provided by [36], about 21.7% of the energy consumed in the residential sector is used in heating water only. Based on these published data, the decision is taken to consider designing such a sustainable water heating system that helps in reducing the fossil fuels dependency.

According to data provided by [37] and [38], the average household members in the UK and Kuwait is 2.3 and 5.7 respectively. Aiming to provide a reliable design and effectiveness investigation of concerned systems, it was planned to consider four members (average value).

According to data provided by [39], the energy consumption to satisfy the hot water demand for a household with three persons is represented in the following table. Based on these data, the energy demand for four persons had been assumed.

Table 5. Assumed hot water energy demand for different household numbers of persons.

Usage	Daily consumed energy for three persons (KWh / day)	Daily Consumed energy for four persons (KWh / day)
Ref.	[39]	Calculated based on [39].
Bath/shower	1.1	1.375
Wash hand basin	1.4	1.75
Dish washing	2.3	2.875
Clothes washing 50%	2.0	2.5

Based on the assumptions had been represented in table 5, the total energy demand should be satisfied by the designed solar based energy system is calculated as follow;

Total energy demand = Summation of the hot water usages

= 1.375 + 1.75 + 2.875 + 2.5 + 0.00

= 8.5 KWh/day

According to the weather data had been analysed in section 3.3, it was decided to consider the annual usage of the hot water. Consequently, the annual energy consumption is predicted to reach 3102.5 KWh.

3.5. Heating water using fossil fuel

Boilers are basically assumed as being specially designed heat exchangers, with water boiling to steam or turning to high-pressure hot water. Heat energy used in heating inlet water is traditionally generated through a chemical reaction between air and different types of fossil fuels. This is predicted to be achieved by the burning of a fossil fuel; the combustion gas can be ducted around the water-containing tube (water-tube boiler) or the hot gas can pass through the tubes with the water in the shell (fire-tube boiler) [40]. Unfortunately, heating domestically used fresh water using boilers is not safe and estimated to require different safety regulations to assure smooth operation of the water heating process. In addition, heating water in boilers require combusting fossil fuels that may result in negative environmental circumstances such as reducing air quality, greenhouse gases, climate changes and global warming [41]. Boilers are not estimated to provide ideal performance, as there are such heat energy losses resulted from the thermal conductivity of the materials used in fabricating the boiler. However, boilers are estimated to be characterized by an efficiency reaches 90%. Consequently, the total energy demand should be satisfied by the boiler can be calculated as follow;

$$Annual\ energy\ demand = \frac{required\ heat\ energy}{\eta}$$

Generally, boilers can be fired using any type of fossil fuels and the recently most commonly used is natural gas. As it provides a relatively cleaner combustion comparing with either coal or petroleum. Natural gas is characterized by its high heat content, which reaches 13.1 KWh per each combusted Kg [42]. According to data provided by [43], about 117.00 Pounds of carbon dioxide (CO_2) gas are generated for each million British thermal units (BTU) of natural gas.

Based on data had been collected, the energy demand of the water heating process using conventional boilers fired using natural gas had been calculated to reach 3,447.22 (assume 3500) KWh. The aforementioned energy demand is predicted to be satisfied by firing about 267.175 Kg of natural gas.

According to the environmental vision, combusting 267.175 Kg to generate 3500 KWh (11.942 million BTu) of natural gas would result in emitting 633.765 Kg (1397.214 pounds) of CO_2 gas annually.

According to the economic vision, combusting 267.175 Kg to generate 3500 KWh of natural gas would cost about 207.38 $ annually. As generating KWh of thermal energy using natural gas is estimated to cost about 0.059 $ according to [44]. The initial cost of the gas fired boiler decided to be installed to serve in the targeted house is estimated to reach 128.88 $ with an operation and maintenance cost reaches to 100 $ annually [45].

3.6. Heating water using electrical power

Heating supplied water to the domestic sector can be achieved depending on an electrically energized heater. The electric heating process is considered as being an energy conversion process, where the electrical energy is converted into thermal energy due to the electrical conductivity of the material used in manufacturing the electric heating element. Conventionally, an electrically energized heating system can be used in space heating, water heating and industrial processes. The electrical heater is therefore a system that transforms electrical energy into heat. Electric heaters are mainly designed with the purpose of containing electrical resistors, which are known as being a heating element. The use of electricity for heating is becoming increasingly common in both homes and public buildings. While electrical heating typically costs more than the energy obtained from fuel combustion, its use is often justified by the ease, cleanliness and reduced space requirements of electrical heat. Heat may be supplied from electrical coils or strips used in a number of configurations, such as convectors in or on walls, under windows, or as baseboard radiation in part or in any room. Heating devices or wires can also be built into ceilings or floors to radiate low-temperature heat into space. Furthermore, by adding a heat pump, the overall cost of electrical heating can be greatly reduced [46].

According to calculations had been applied in section 3.5, the annual energy consumption is predicted to reach 3102.5 KWh. Assuming that, the electrical heater has an energy conversion efficiency of 95%. Then, the annual electrical power should be supplied to the electrical heater is calculated to be 3270 KWh.

According to data provided by [47], generating KWh of electricity would result in releasing CO_2 emission weigh about 0.281 Kg. Hence, the electrically energized water heating system would result in generating 918.87 Kg of CO_2 gas annually.

The consumed 3270 KWh of electrical energy would cost about 621.3 $ annually as the electrical energy unit (KWh) is estimated to cost about 0.19 $ according to data provided by [48]. The initial cost of the electrical heater is 141.76 $, while the operation and maintenance cost was assumed to be similar to the natural gas fired water heating system.

3.7. Thermosiphon Design

Thermosiphon systems operate mainly depending on the solar irradiance, which is highly affected by the geographical location of the plant. A lower solar irradiance is estimated to require higher heat transfer surface area. Hence, it is predicted to obtain two different heat transfer surface areas due to the two geographical locations had been taken into consideration (UK and Kuwait).

In fact, the design of thermosiphon systems should be applied based on such assumptions that are decided to be as follow;

- The outlet temperature of the heated water is assumed to be 60 Celsius degrees [39].

- According to the weather data analyzed for both UK and Kuwait, the ambient temperature of the 10.35 and 26.56 Celsius degrees respectively.
- The designed thermosiphon system should be able of collecting about 8.5 KWh daily.
- The sun is estimated to be shinny for six hours a day. Hence, the solar collector should be able of collecting 1,416.7 watts.

Consequently, the heat transfer surface area of the solar collector can be calculated from the following equation;

$$Q_c = m_w \ x \ Cp \ x \ \Delta T$$

Definitions;

m_w^o	→	Mass flowrate of the water required to be heated using thermosiphon system (Kg/s).
I_s	→	Solar irradiance (depends on the geographical location) (w/m^2).
A	→	Heat transfer surface area of the solar collector installed in the designed thermosiphon system (m^2).
Cp	→	Water specific heat (≅ 4.18 KJ/Kg.K).
ΔT	→	Temperature difference between the water outlet and ambient temperature.

Kuwait	United Kingdom
The assumed heating water load is estimated to be able of heating $\boldsymbol{m_w}$ that can be calculated as follow; $\boldsymbol{Q_c = m_w \ x \ Cp \ x \ \Delta T}$ $\boldsymbol{m_w = \frac{30600}{4.18 \ x \ 33.44}}$ = 218.91 Kg. For the assumed six hours of operation; $\boldsymbol{m_w^o}$ = 0.0101 Kg/s. Hence; $\boldsymbol{A = \frac{Heat\ demand}{I_s}}$ A = 5.67 ≅ **6** m^2	The assumed heating water load is estimated to be able of heating m_w that can be calculated as follow; $Q_c = m_w \ x \ Cp \ x \ \Delta T$ $m_w = \frac{30600}{4.18 \ x \ 49.65}$ = 147.44 Kg. For the assumed six hours of operation; m_w^o = 0.006 Kg/s. Hence; $A = \frac{Heat\ demand}{I_s}$ A = 11.07 ≅ 6 m^2

By surveying the global market, it was planned to consider the following solar collector;

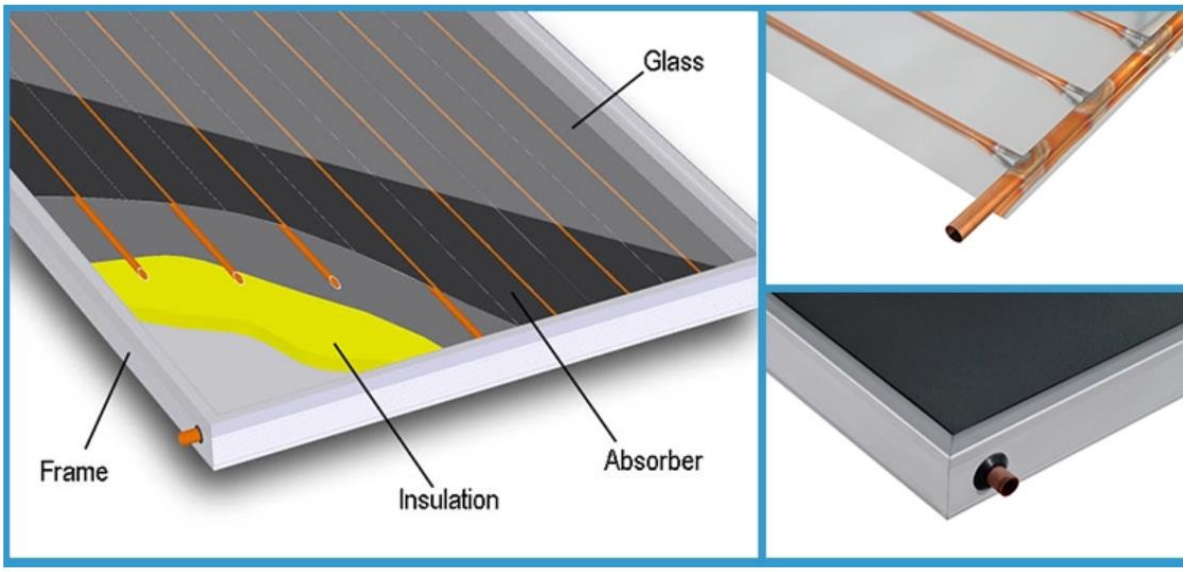

Figure 31. Detailed description of the selected solar collector [49].

The selected solar collector detailed technical description is attached in Appendix A section, where the aperture area of the collector is designed to be 2.32 m^2.

Aiming to achieve a high reliability of the designed system, the decision was taken to consider three identical solar collector to be installed in Kuwait.	Aiming to achieve a high reliability of the designed system, the decision was taken to consider six identical solar collector to be installed in the UK.
Total Area = 2.32 * 3 = 6.96 m^2	Total Area = 2.32 * 6 = 13.92 m^2
Collected heat power = 1.736.52 Watts.	Collected heat power = 1780.64 Watts.
Collected heat energy = 10.41912 KWh/day.	Collected heat energy = 10.68384 KWh/day.
Initial price = 88.0 $ per solar collector.	
Running cost = 0.0 $	

Heated water should be stored in a thermally insulated tank, which considered as being the key parameter of the reliability of the designed system. The decision was taken to consider purchasing the tank installed by its control system, which costs about 480 $ according to its supplier [50].

Installing the designed thermosiphon system would result in preventing emitting about (688.656) Kg and (706.15) Kg of carbon dioxide in Kuwait and UK respectively.

3.8. Heat pump design

Solar-assisted heat pump system (SAHP) combines the heat pump technology and solar water heating system technology. The major function of SAHP system is to use the evaporator to extract thermal energy at low-grade temperature from the solar collector and waste heat in order to use in the heating applications. Solar assisted heat pumps are estimated to be energized using electricity in winters (Oct, Nov, Dec, Jan, Feb and March) due to the very low solar irradiance. On the other side, the solar collector would energize the heat pump in summers (the rest of the year).

Kuwait	United Kingdom
Weather data analysis in summer	
Average temperature = 34.47 ^oC Average solar irradiance = 308.61 W/m^2	Average temperature = 14 ^oC Average solar irradiance = 195.99 W/m^2
The assumed heating water load is estimated to be able of heating $\boldsymbol{m_w}$ that can be calculated as follow; $\boldsymbol{Q_c = m_w \; x \; Cp \; x \; \Delta T}$ $\boldsymbol{m_w = \frac{30600}{4.18 \; x \; 33.44}}$ = 218.91 Kg. For the assumed six hours of operation; $\boldsymbol{m_w^o}$ = 0.0101 Kg/s. Hence; $\boldsymbol{A = \frac{Heat \; demand}{I_s}}$ A = 4.59 m^2	The assumed heating water load is estimated to be able of heating m_w that can be calculated as follow; $Q_c = m_w \; x \; Cp \; x \; \Delta T$ $m_w = \frac{30600}{4.18 \; x \; 49.65}$ = 147.44 Kg. For the assumed six hours of operation; m_w^o = 0.006 Kg/s. Hence; $A = \frac{Heat \; demand}{I_s}$ A = 7.2 m^2

The same solar collector had been selected for the thermosiphon system is decided to be considered in the solar assisted heat pump, where the aperture area of the collector is designed to be 2.32 m^2.

Aiming to achieve a high reliability of the designed system, the decision was taken to consider two identical solar collector to be installed in Kuwait.	Aiming to achieve a high reliability of the designed system, the decision was taken to consider four identical solar collector to be installed in the UK.
Total Area = 2.32 * 2 = 4.64	Total Area = 2.32 * 4 = 9.28
Collected heat power = 1,431.95 Watts.	Collected heat power = 1818.88 Watts.

Collected heat energy = 8.59 KWh/day.	Collected heat energy = 10.91 KWh/day.
Heat pump price = 300	
Solar collector price = 196.00 $	Solar collector price = 392.00 $
Total initial cost = 496.00 $	Total initial cost = 692 $
Running cost for the integrated system = 310.65 $/Year (6 months depending on electricity as being the power source).	
CO2 gas emissions release rate = 459.43 Kg/Year (6 months depending on electricity as being the power source).	

3.9. Analysis and discussion

As soon as designing the concerned heating water techniques and investigating their environmental and economic effectiveness, it is decided to compare among them with the purpose of investigating the highest performing technique. Analytical results for each studied water heating technique will be analysed individually, which enables achieving accurate predictions of the designed technique. It was planned to attach the results analyses, discussions and comparison in chapter four.

3.10. Conclusions and recommendations

This section is planned to concern about remarking the concluded points of the research in addition to a summary of the collected theoretical data. In addition, a group of ideas and suggestions will be recommended for the future researchers to help them covering such scientific points that would widen the comprehension of the interested field.

Chapter Four: Discussions

4.1. Overview

This chapter mainly concerns about analysing and discussing the obtained analytical results aiming to clarify the weakness and strength points of each studied water heating system. It was decided to compare the electrical water heating system with the conventional water heating technique using natural gas. In addition, it was planned to compare between the environmental and economic effectiveness of both the solar assisted heat pump and thermosiphon system and the gas fired boilers. The impact of the geographical location on both the environmental and economic effectiveness of the two designed suitable systems will be discussed as well.

4.2. Electricity Vs Gas fired boilers

The comparison decided to be applied between the two concerned water heating systems is subjected to the environmental and economic effectiveness, which is applied as follow;

- According to the economic point of view: the studied two systems are not predicted to provide the same economic performance. As it was investigated that, the natural gas fired boiler is less expensive and require lower annual running cost. However, both of the two systems are estimated to require the same operation and maintenance costs. Both of the compared systems are not estimated to be sustainable or clean, which refers to their lower dependency in the future (After fossil fuels depletion).

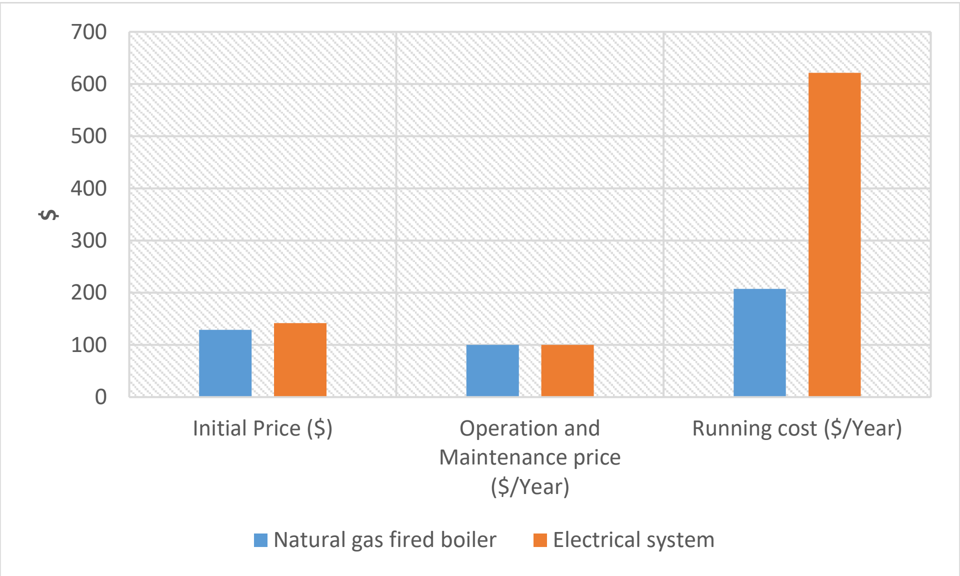

Figure 32. Comparison between the electrical water heating systems and gas fired boiler according to their economy.

- According to the environmental point of view: both of the two concerned water heating systems were investigated to result in emitting toxic gases to the atmosphere. That is resulted from either the direct combustion of natural gas in boilers (gas fired boilers) or due to the electricity generation in conventional power stations. However, using natural gas in generating electricity in the power stations to be used in heating domestic water using electrical heating elements was investigated to result in a higher emissions release rate.

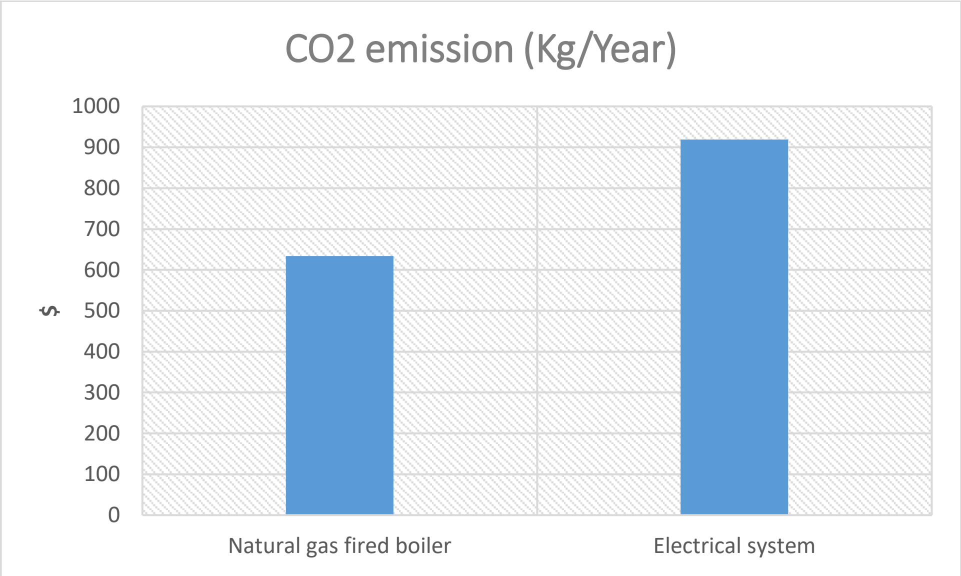

Figure 33. Comparison between the electrical water heating systems and gas fired boiler according to their environmental impacts.

Gas fired boilers are not estimated to be as safe as the electrical water heating systems, especially in gas leakage operation scenarios. Both of the compared systems are estimated to be characterized by high dependency and reliability in the recent days. However, they are not estimated to operate anymore after the fossil fuels' depletion.

4.3. Thermosiphon system Vs Gas fired boilers

The comparison decided to be applied between the thermosiphon system and gas fired water heating boilers is subjected to the environmental and economic effectiveness, which is applied as follow;

- According to the economic point of view: Obtained analytical results allowed investigating that, the initial price of the natural gas fired boiler was much lower than the initial cost of the thermosiphon system. Alternatively, the designed thermosiphon system was not estimated to require either operation and maintenance cost or running costs. The payback period of the plant (in average between the two studied geographical locations) was calculated to be 2.15 years. After the latter mentioned period, the output of the system would be free leading to enhance the economic benefit noticeably.

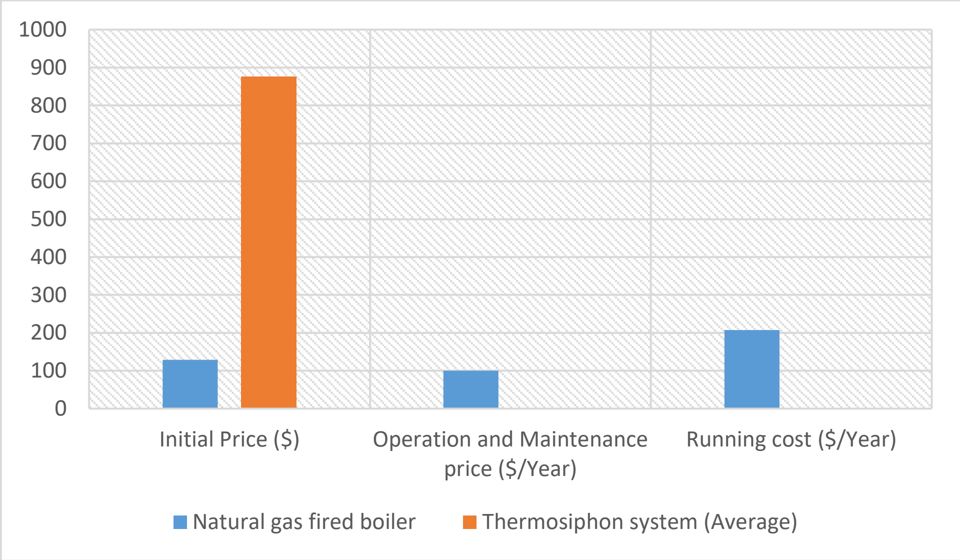

Figure 34. Comparison between the thermosiphon water heating systems and gas fired boiler according to their economy.

- According to the environmental point of view: Unlike the electrical water heating system, using thermosiphon systems in heating the domestic water is estimated to result in zero emissions to be released to the atmosphere. The collected thermal power using the installed collectors (sustainably) allowed preventing emitting about 697 Kg of CO2 gas annually.

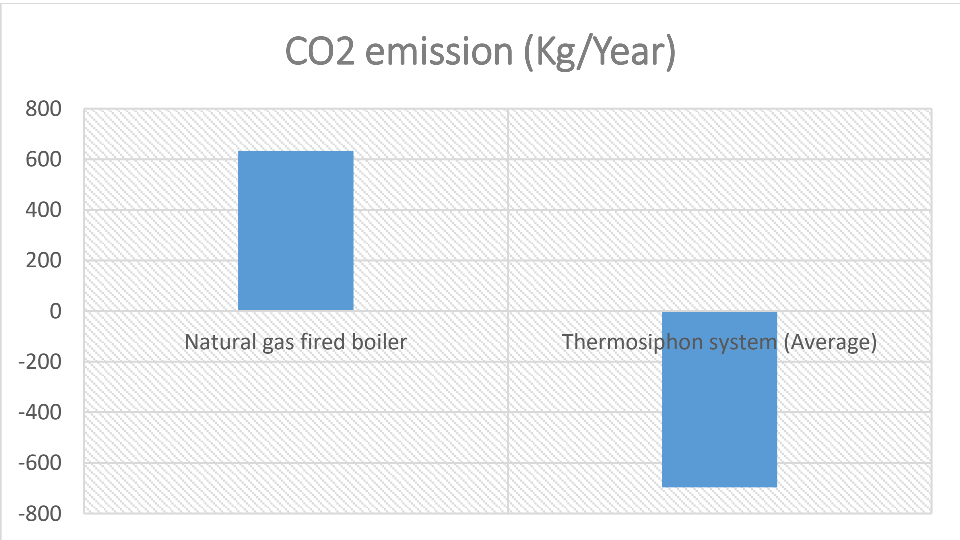

Figure 35. Comparison between the thermosiphon water heating systems and gas fired boiler according to the environmental impacts.

Thermosiphon systems are sustainable, safe and efficient water heating systems, which had been paid a significant interest last few years. Unfortunately, they are not estimated to provide as reliable and dependent performance as either the electrical water heating systems or natural gas fired boilers. This is predicted to be obtained due to the seasonal fluctuations and weather changes from a season to another. Hence, the designed thermosiphon plant would not be able of heating the domestic water in such cloudy days, winters or nights.

4.4. Solar assisted heat pump Vs Gas fired boilers

The comparison decided to be applied between the solar assisted heat pump system and gas fired water heating boilers is subjected to the environmental and economic effectiveness, which is applied as follow;

- According to the economic point of view: Obtained analytical results allowed investigating that, the initial price of the natural gas fired boiler was much lower than the initial cost of the solar assisted heat pump. Alternatively, the designed solar assisted heat pump was not estimated to require operation and maintenance cost. It mainly depends on both the solar energy collected by the installed solar collector as well as the electricity. This energy management process had been applied depending on the control circuit installed in the selected tank. The payback period of the solar assisted heat pump (in average between the two studied geographical locations) was calculated to be 2.94 years. Although the running cost of the solar assisted heat pump is higher than the gas fired boiler, the operation and maintenance price of the solar assisted heat pump is lower than it leading to a total lower running cost of the system.

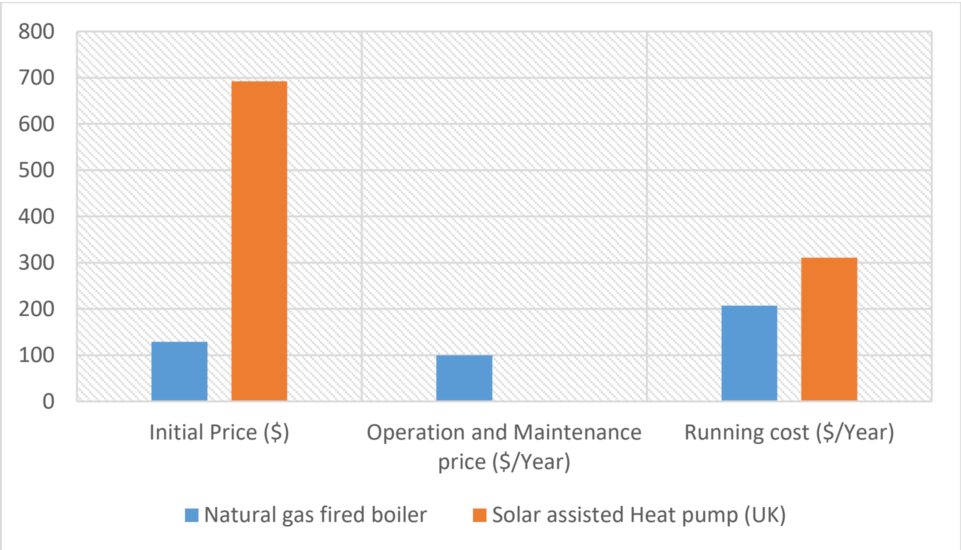

Figure 36. Comparison between the solar assisted heat pump and gas fired boiler according to their economy.

- According to the environmental point of view: the designed solar assisted heat pump was investigated to result in reducing the electrical power consumption rate over the year. As in summers, it was designed to be powered using solar collectors while to be energized using electricity in winters. The designed solar assisted heat pump was investigated to be able of reducing CO2 emissions release rate from 633 to be 459 Kg annually.

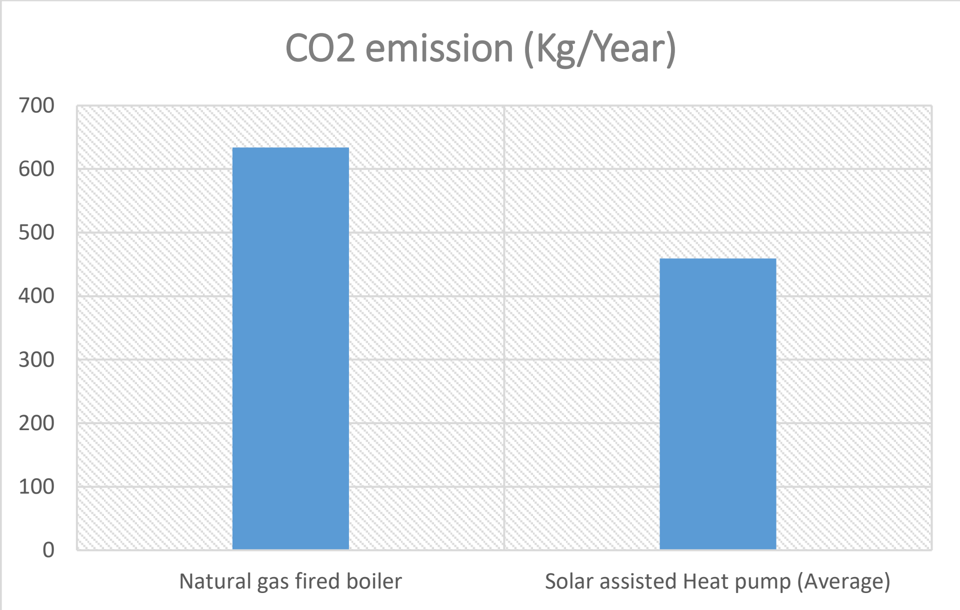

Figure 37. Comparison between the solar assisted heat pump and gas fired boiler according to the environmental impacts.

Solar assisted heat pumps are estimated to be able of providing a relatively higher reliability and dependency level comparing with thermosiphon systems. In addition, it is more sustainable and less pollutant comparing with the natural gas fired boilers. Connecting the heat pump to the electricity source would result in increasing the dependency of the system.

4.5. Geographical location effect

The geographical location effect on the studied suitable systems' performance, economic effectiveness and environmental effectiveness were noticed significantly. Although the price of natural gas and electricity also varies from a country to another, it was investigated that; the solar irradiance variation resulted in changing the performance of each system as well. Referring to the two concerned systems, it was predicted that; Kuwait is estimated as being a better location comparing with UK due to its geographical location near to equator resulting in a higher solar irradiance as well as ambient temperature.

Referring to the thermosiphon system, the initial price of the system in UK was predicted to be higher with a purpose of satisfying the same energy demand. In addition, the higher solar irradiance and ambient temperature in Kuwait resulted in reducing the initial cost of the solar assisted heat pump. The following figure represents a graphical comparison among the studied systems in accordance with their initial prices.

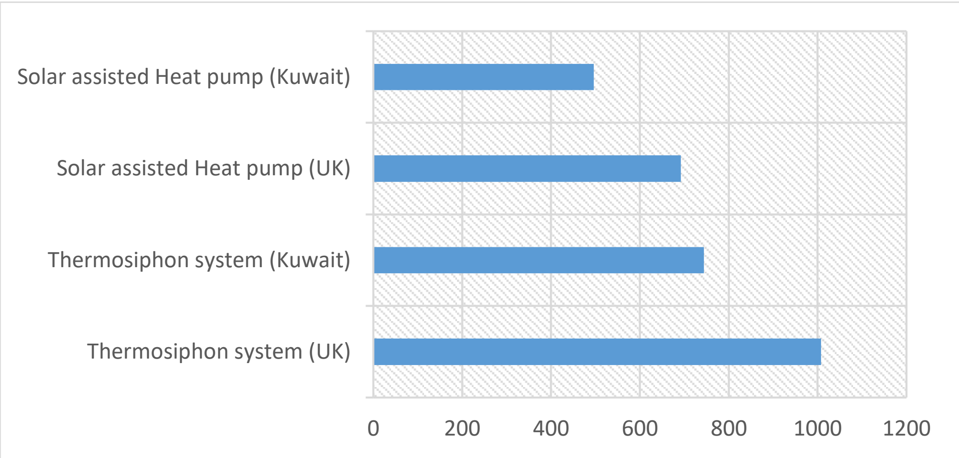

Figure 38. Geographical location effect on the initial prices of thermosiphon systems and solar assisted heat pumps in UK and Kuwait.

4.6. General comparison

According to the performances had been analysed for each studied system, it was investigated that; using solar assisted heat pumps would provide the highest safety level comparing with either the electrical heating elements or the natural gas fired boilers. In addition, the solar assisted heat pumps are estimated to be characterized by very high reliability and dependency, which satisfies the recently seen luxurious lifestyle.

Table 6. General performance comparison among the studied water heating systems.

	Dependency	**Reliability**	**Safety**
Natural gas fired boiler	High	High	Low
Electrical system	Very High	Very High	Moderate
Thermosiphon system (Average)	Moderate	Moderate	Very High
Solar assisted Heat pump (Average)	Very High	Very High	Very High

Unfortunately, using solar assisted heat pump is predicted to be high respect to both the initial and running cost. As the initial cost of the system is the highest, while its running cost comes at the second rank after the electrical water heating systems.

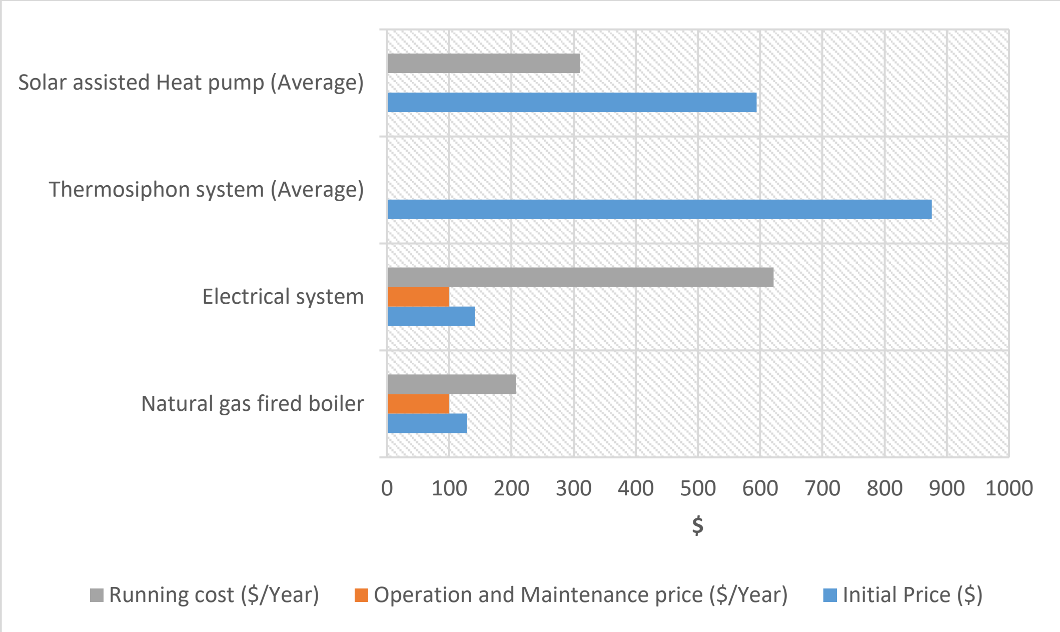

Figure 39. General comparison among the studied water heating system according to their initial and running costs.

On the other side, the environmental impacts of the targeted solar assisted heat pump is moderate. Thermosiphon systems are estimated to provide the best environmental performance as it is estimated to result in reducing the CO2 generation rate, which makes it a totally green and sustainable water heating system. Unfortunately, they are not estimated to provide as reliable and dependent performance as either the electrical water heating systems or natural gas fired boilers. This is predicted to be obtained due to the seasonal fluctuations and weather changes from a season to another. Hence, the designed thermosiphon plant would not be able of heating the domestic water in such cloudy days, winters or nights.

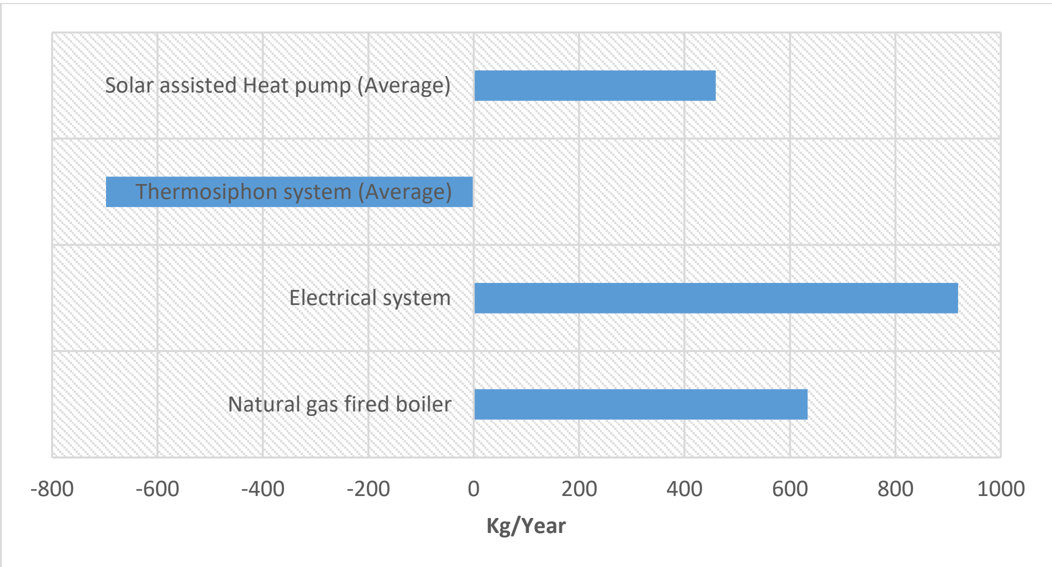

Figure 40. General comparison among the studied water heating system according to their expected environmental impact.

Chapter Five: Conclusions and recommendations

Energy consumption has risen dramatically in the last few years, which is very much linked to the recently seen luxury lifestyle. Reducing the reliance of fossil fuels on heating water is expected to help increase the environmental and economic benefits of heating processes. The processing of solar energy using modern techniques and methods has facilitated the achievement of a group of advantages that have enhanced the efficiency of the techniques concerned. Comparable with traditional fossil fuels, solar power plants are projected to be cheaper and able to reach a higher degree of sustainability. In fact, solar power can be given free of charge when a solar panel is installed. In other words, the operation and operating costs are very low relative to traditional power stations. Solar power will last forever and the oil reserves of the planet are estimated to last 30 to 40 years. Solar power does not pollute, because it is not supposed to release harmful pollutants into the environment during the production of electricity. It is being studied to help reduce recent climate change, global warming and greenhouse gas emissions. Almost no maintenance is necessary to ensure the operation of the solar panels. For solar panels or solar collectors, there are no moving parts that prevent them from being damaged due to mechanical stress. Solar power plants are intended to operate long term, because the amount of free energy that a solar power plant will generate will lead to a higher return on investment.

Unfortunately, the construction of solar power plants is projected to take a lot of time to save on energy prices in order to offset the initial investment. It is due to an extremely high initial cost and is due to a lengthy period of time before the payment threshold has been met. In addition, the method of producing electricity relies entirely on countries exposed to sunlight; the environment could be limited to countries that minimize the efficiency, availability and reliance of the renewable energy technology concerned. Solar power plants are not comparable to traditional power stations of a similar size; they can also be very costly to install, which has stopped the expansion of their reliance on private resources, in particular the private sector. In addition, the construction of a solar power plant includes the installation of an energy storage system (e.g. batteries for PV solar power plants or thermal storage for concentrated solar power plants). All batteries and thermal energy storage units are filled with solar energy, which enables the use of solar energy during nights, winters and rainy days. Such energy storage technologies also take up space and need to be replaced regularly and can be big and heavy, resulting in an rise in the initial cost of the plant. Nevertheless, the installation of an energy storage system will increase the efficiency and reliance of the system.

This work was primarily concerned with the study of the economic performance and environmental performance of two traditional water heating systems (electrical water and natural gas boilers) and two other innovative techniques (thermosiphon and solar-assisted heat pumps). The findings obtained made it possible to realize that using solar-assisted heat pumps would have the highest degree of protection compared with either electrical heating elements or natural gas boilers. In addition, it is estimated that solar-assisted heat pumps are characterized by very high efficiency and dependence, which fits the recently seen luxury lifestyle. However, the use of a solar-assisted heat pump is estimated to be high compared to both the initial and operating costs. In the proposed analysis, two separate geographical locations were considered, with the goal of investigating the effect of the system installation location on the efficiency, economic benefits and environmental impacts of the built sustainable systems. The findings showed that moving closer to the equator (Kuwait) would result in better efficiency, economic benefits and lower environmental impacts compared to the Nordic countries (UK) due to higher solar irradiance and ambient temperature.

For the future researches, it is recommended to consider the following;

1. Using CFD simulation tools such as ANSYS or Solidworks to simulate the heat transfer fluid thermal performance aiming to optimize it.
2. Considering studying the environmental effectiveness and environmental effectiveness of forced convection thermosiphon systems.
3. Experimental investigation of the dependency and reliability achieved by both thermosiphon systems and solar assisted heat pumps in each of the studied geographical location.

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Appendix A: Solar collector technical description

Table 7. Detailed technical description of the selected solar collector [49].

Product name	Millionsun black flat plate solar collector		
Description	Unit	Specification	
Dimension (LXW XH)	mm	2000X1000X80	2000X1250X80
Gross Area	m²	2.0	2.5
Aperture Area	m²	1.84	2.32
Absorber Area	m²	1.76	2.22
Total weight of the empty	Kg	29	34
Collector connection (Inlet /	mm	Φ22	Φ22
Max.idle temperature	℃	152	152
Liquid content	L	1.6	2.0
Operating pressure	Bar	12	12
Nominal volume flow		50-300	50-300
Cover	Cover material	Low iron patterned tampered glass	
	Cover thickness	3.2 mm	
	Cover	≥92%	
Absorber	Material	Copper sheet strip / Full Aluminium	
	Surface	Black Chrome coating	
	Absorptivity	95%±2%	
	Emissivity	8%±2%	
Frame	Material	Aluminium alloy 6063	
	Colour	Silver or Black	
Insulation	Material	Glass wool (30mm,35Kg/ m³)	
Back plate	Material	Aluminium sheet (0.5mm)	
Glass sealing	Material	EPDM	