SOLAR WATER HEATING SYSTEM IN LIBYAN BUILDINGS

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(قُلْ إِنَّ صَلاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ * لاَ شَرِيكَ لَهُ وَبِذَلِكَ أُمِرْتُ وَأَنَاْ أَوَّلُ الْمُسْلِمِينَ)

(Say, "Indeed, my prayer, my rites of sacrifice, my living and my dying are for Allah, Lord of the worlds * No partner has He. And this I have been commanded and I am the first of the Muslims).

صَدَق اللّه الْعَظِيْم

DEDICATION

This thesis is dedicated to my beloved father and mother. I also, dedicate this work to my beloved brothers, sisters and my entire family members for tremendous love, care and courage during the cause of my studies and journey to produce this thesis.

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I am grateful to my Mother and father, for their cares and love. I have no suitable word that can fully describe them everlasting love to me I, am also grateful to my sweetest brothers and sisters and my brother Saleem for their prayers all the time.

ABSTRACT

Solar energy is a clean and abundant energy resource that can be used to supplement several energy needs. Solar energy can be utilized as a form of heat, such as solar water heating, and as electricity, such as solar photovoltaic. Solar water heating systems are commonly referred to in the industry as Solar Domestic Hot Water systems. The challenges (increasing demand for energy, sustainable development, low competitiveness, reducing environmental impacts) and the opportunities (value added, job creation, transfer of knowledge and technology acquisition) that North African countries are experiencing today in this field, call for collective action across the whole region, oriented towards tangible results, including Libya faces challenges in providing energy in light of the continuing power outages. The objectives of this research are to identify the current practices of solar water heating system in Libyan buildings, to identify the factors that hinder the application of solar water heating system in Libyan buildings, to suggest on the application of solar water heating system in Libyan buildings. Questionnaires were used to collect the data from contractors and consultants in the construction industry. Ranking and analysis of variance (correlation) were used to analyse the data collected with the use of version 21 SPSS. It was found that the application of renewable energy in construction project is very low. However, the factors that hinder of solar water heating system in Libya were lack of consultant's initiatives, lack of financial commitment, and lack of commitment design team, lack of government interest to promote solar water heating system and high tax on solar energy by government. The result of this finding implicate that the construction industry in Libya need to improve its approach in using solar water heating system by understanding its current practices and finding ways to solve of the factors that hinder.

ABSTRAK

Tenaga solar adalah sumber tenaga yang bersih dan banyak digunakan sebagai tambahan kepada beberapa keperluan tenaga. Tenaga solar boleh digunakan sebagai satu bentuk haba seperti pemanasan air solar dan juga bekalan elektrik seperti solar photovoltaic. Sistem pemanasan air solar biasanya digunakan dalam industri sebagai sistem Solar Air Panas Dalam Negeri. Cabaran (peningkatan permintaan untuk tenaga, pembangunan lestari, daya saing yang rendah, mengurangkan kesan alam sekitar) dan peluang (tambahan nilai, kewujudan pekerjaan, pemindahan pengetahuan dan pemerolehan teknologi) yang negara-negara Afrika Utara alami hari ini dalam bidang ini telah memanggil tindakan kolektif di seluruh rantau ini dengan tumpuan ke arah hasil yang ketara, termasuk Libya yang turut menghadapi cabaran dalam menyediakan tenaga cahaya kepada gangguan kuasa berterusan. Objektif kajian ini adalah untuk mengenalpasti amalan semasa sistem pemanasan air solar dalam bangunan di Libya, untuk mengenalpasti faktor-faktor yang menghalang penggunaan sistem pemanasan air solar dalam bangunan di Libya dan seterusnya mencadangkan beberapa aplikasi sistem pemanasan air solar dalam bangunan di Libya. Borang soal selidik digunakan untuk mengumpul data daripada kontraktor dan perunding dalam industri pembinaan. Peringkat dan analisis varians (korelasi) telah digunakan untuk menganalisis data yang dikumpul dengan menggunakan SPSS versi 21. Didapati bahawa penggunaan tenaga boleh diperbaharui dalam projek pembinaan adalah sangat rendah. Walaubagaimanapun, faktor-faktor yang menghalang sistem pemanasan air solar di Libya adalah disebabkan kurangnya inisiatif daripada pihak perunding, kurangnya komitmen dalam kewangan dan dalam pasukan rekabentuk, kekurangan minat daripada pihak kerajaan untuk menggalakkan sistem pemanasan air solar dan juga pengenaan cukai tenaga solar yang tinggi daripada kerajaan. Hasil dapatan ini mengaitkan bahawa industri pembinaan di Libya perlu memperbaiki pendekatannya dalam penggunaan sistem pemanasan air solar dengan memahami amalan semasa dan mencari jalan untuk menyelesaikan faktor penghalang.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

SDHW	Solar Domestic Hot Water
SWH	Solar Water Heating
ECA	Economic Commission for African
SHW	Solar Hot Water
PV	Powered by Photovoltaic
FPC	Flat Plate Collectors
ETC	Evacuated Tube Collectors
SEF	Solar Energy Factor
SF	Solar Fraction
KNUST	Kwama Nkrumah University of Science and Technology
SWHS	Solar Water Heating System
BIM	Building Information Modelling
IBS	Industrialized Building System
EE	Energy Efficient
RE	Renewable Energy
EWH	Electric Water Heating

SOLAR WATER HEATING SYSTEM IN LIBYAN BUILDINGS

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Solar energy is a clean and abundant energy resource that can be used to supplement several energy needs. Solar energy can be utilized as a form of heat, such as solar water heating, and as electricity, such as solar photovoltaic. Solar water heating systems are commonly referred to in the industry as Solar Domestic Hot Water (SDHW) systems (Atchison, 2009).

Consumers often ask if there is enough sunlight in the world to support solar applications such as water heating. In fact, there is enough solar energy to deliver an average of 2500 kW/h of energy per year. This means that a solar water heater can provide enough solar energy to meet about one half of the water heating energy needs for a family of four (Atchison, 2009).

Water heating is one of the most cost-effective uses of solar energy, providing hot water for showers, dishwashers and clothes washers. Every year, several thousands of new solar water heaters are installed worldwide. Solar water heating is an accepted technology and is increasingly being used as one of the cost-effective means of heating water in residential and public buildings such as hotels, laundries, restaurants, hospitals and health centers (Bennett, 2008).

Solar water heaters, also called solar domestic hot water systems, can be a cost-effective way to generate hot water for homes. It uses sunlight as it energy source which makes it possible to be used in any climate. There are two types of solar water systems active and passive (Chiras, 2002).

An active solar collector system can produce about 80 to 100 gallons of hot water per day, a passive system will have a lower capacity. Solar water heating (SWH) or solar hot water (SHW) systems comprise several innovations and many mature renewable energy technologies that have been well established for many years (Chiras, 2002).

The SWH system is a part of sustainable energy phenomenon. It becomes necessary due the potentialities that were embedded in it. According to the Economic Commission for African (ECA) under the United Nations Decade of Sustainable program that was air marked between 2014 and 2024, it has potential opportunities in the medium and long term as well as existing barriers and perspectives (UNDS, 2013).

Construction industry is one of the most important sectors in socio-economic development of Libya. This is caused by high rate of urbanization which exposes this country to various issues, which are also associated with environmental and natural resources depletion (Eltaief, 2011). This implies that, due to the increase in population, more construction for housing is required and thus the degree of energy consumption has increased.

Due to the increase in global energy demand, the design of energy efficient building is a matter of great concern among scientists and researchers (Alam, *et al.* , 2012).

1.2 Problem Statement

The challenges (increasing demand for energy, sustainable development, low competitiveness, reducing environmental impacts) and the opportunities (value added, job creation, transfer of knowledge and technology acquisition) that North African countries are experiencing today in this field, call for collective action across the whole region, oriented towards tangible results, including Libya faces challenges in providing energy in light of the continuing power outages (Kramer, 2006).

The idea of sustainability, or ecological design, is to ensure that actions and decisions today do not inhibit the opportunities of future generations. Currently, most of the commercial and industrial hot water demands in Libya are met mainly by the use of electric heaters (Hinrichs and Kleinbach, 2012). Therefore, there is need to device an alternative of getting hot water without much reliance on electricity.

Unfortunately, cut off electric almost daily, the rising energy cost, environmental concerns, and the depleting nature of the current primary energy sources in use have made electric heaters less attractive (Asif and Muneer, 2007).

This is because the primary energy sources of electric energy utilised are mainly the fossil fuels. Therefore it is understood that producing this form of energy is expensive and sometimes disappointing (Barry, 2011).

Solar can be used as a clean alternative energy to reduce electrical production and is promising in the effect to establish environmentally friendly for electrical system. It is important to implement this form of energy source because country like Libya has many hours in a day, but the using of solar water heating system not familiar. Libyan people have not realized yet about the benefits of using solar water heating systems. It is important to study about producing hot water using solar water heating system and proving about energy saving of solar water heating system.

1.3 Research question

a. What are the current practices of solar water heating system in Libyan buildings?
b. What are the factors hindering the application of solar water heating system in Libyan buildings?
c. What are the ways to promote the application of solar water heating system in Libyan buildings?

1.4 Research objectives

The aim of this research is to identify the current practices of solar water heating system in Libyan buildings. This can be obtained through the following objectives:-

a. To identify the current practices of solar water heating system in Libyan buildings.
b. To identify the factors that hinder the application of solar water heating system in Libyan buildings.
c. To suggest on the application of solar water heating system in Libyan buildings.

1.5 Significance of Research

Solar water heating system is the key element of green construction and since it can be considered as a new technology in Libya, this research is significant in order to help Libyans, both people and government, and other similar countries to apply solar energy. The result of the research can contribute new knowledge in construction industry by giving possible ways of implementing the solar water heating system techniques. The study intends to provide an inquiry into the current practices of solar water heating in the Libyan construction industry because it contributes to the infrastructural development which is significant to the development of its economy. If there is a failure in the construction industry, it manifests into weak infrastructure which affects productivity and the economy as a whole.

1.6 Scope of the Research

The research work focuses on the current practices of solar water heating system in Libyan buildings. The research is to identify the main factors that are affecting the application of solar water heating in Libyan buildings. The case study for this research consists of the public buildings in Bani Walid city of Libya. The contractors, consultants and clients are the potential respondents of this research.

1.7 Organizational Chapters of the Research

This research work structured into five (5) chapters. Details and specific explanation to every section will be discussed below:

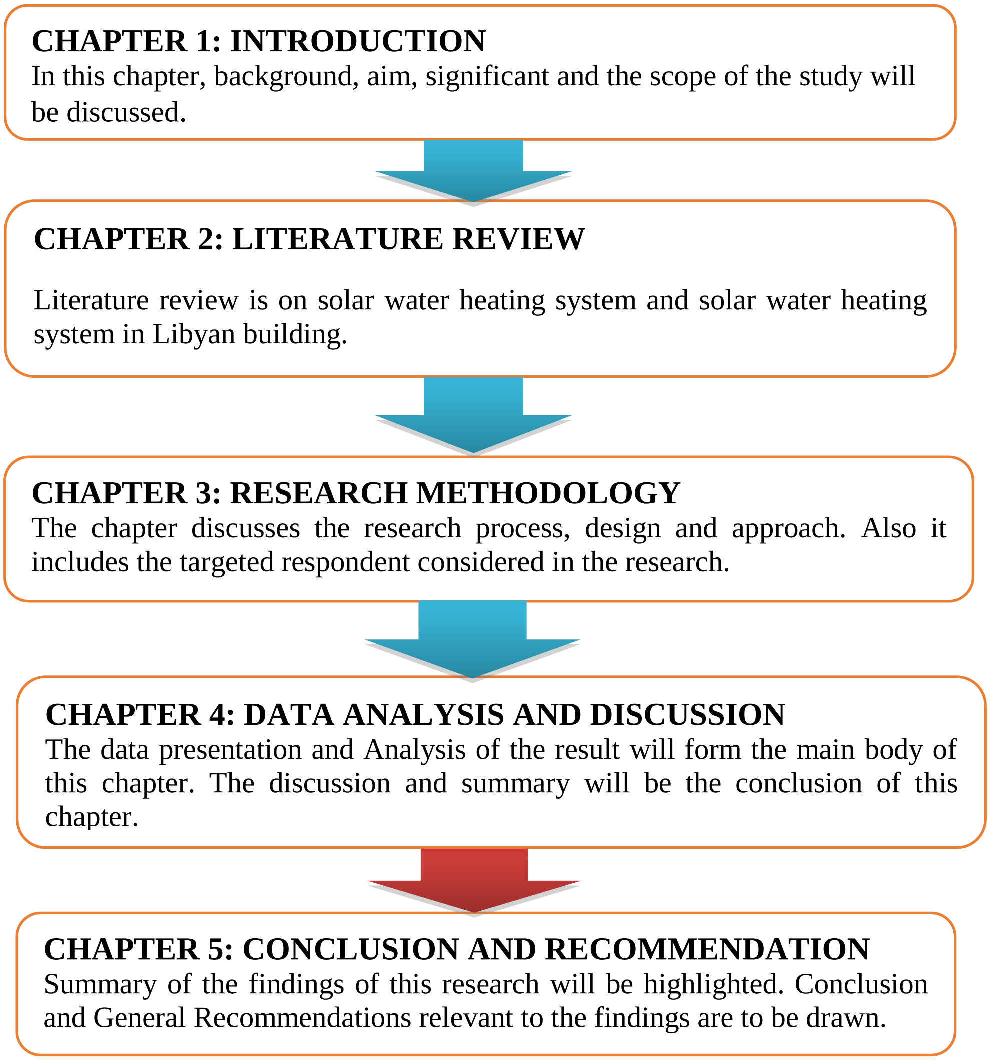

Figure 1.1: Organization of Chapters

Chapter 1: Introducing the subject to be discussed in the opening of this chapter. It consist of background of research which includes the research problem, research questions, research objectives, scope and significance of research, organization of the chapters and conclusion.

Chapter 2: Literature review will look at the previous writing during the past within the solar water heating system in Libyan building. The chapter focuses on identification of the research gaps that have not been discussed by previous researchers or need to be discussed more. The chapter closes with a conclusion.

Chapter 3: The third chapter discusses the research method and methodology. Discussions focus on the research methodology used in this study. It covers the research design, the scope of the study, sampling studies, research instruments, data collection and data analysis methods.

Chapter 4: This chapter presents the collected data and analyses it. The chapter also discusses the result from the survey and findings of the survey. The chapter discusses the main results of the analysis. The discussion in this chapter answers the research question and gives some recommendations for further research.

Chapter 5: This is the last chapter in the research. It summaries the entire research work conducted and the conclusion. The recommendations are given in this chapter for possible actions to be taken. The chapter will end by highlighting furthermore gabs to intensify research on them.

1.8 Expected Outcome

The expected outcome of this research is the identification of current practices of solar water heating system in construction industry in Libya and its factors that hinder. This research will incorporate the ideas and the experiences of the contractors, consultants and clients in order to meet the objectives of this research. The outcome will reveal the current practices of solar water heating system in Libyan buildings. It will also assist in revealing the major barriers affecting the application of solar water heating system. The study will contribute to the development of the economy and highlight the significance of implementing solar water heating system by the public authority.

1.9 Summary

Introduction of the research subject matter was explained above. The explanation in it comprises the problem statement that established to justify the gab of the research. Research aim and objectives, the question to be answered in the research, the significant and also the scope of the research were fully explained. This is necessary for the subsequent chapters to be discussed with justice. The chapter serves as bedrock that will accommodate the literature review which follows in the next chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Libya is a country located in North Africa on the southern coast of the Mediterranean Sea. It is a member of a number of organizations and regional and international groupings, including the United Nations, the African Union, the Arab Maghreb Union, and the League of Arab States, the Non-Aligned Movement, the Organization of Islamic Cooperation, the Organization of Petroleum Exporting Countries (Adepoju, 2006).

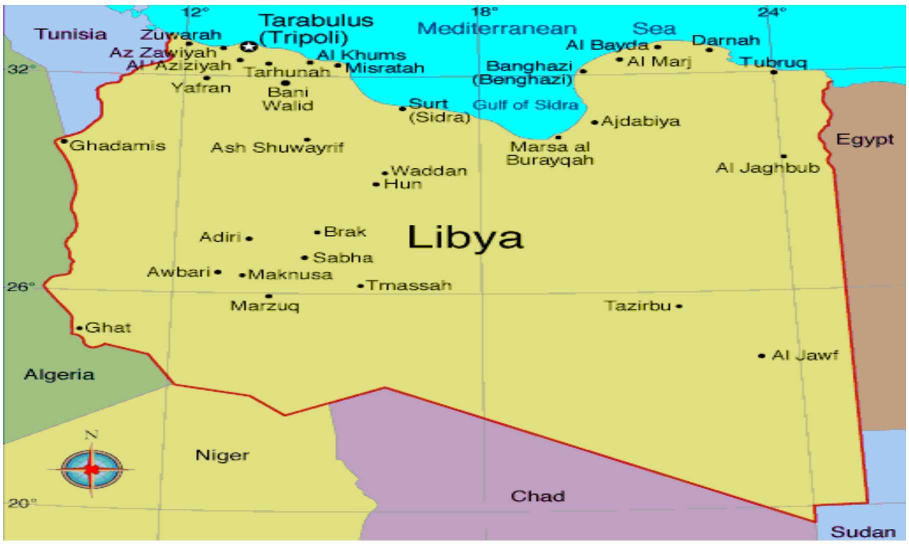

Figure2:1 Location of Libya in the world (Source: www.geo-Libya.yoo7.com).

The number of Libya's population is 6.597 million people, which is tiny compared with an area of the country, which is about (1,800,000 square kilometers), and is the seventh of ten in the world in terms of area, and the fourth largest country in Africa area, as it has the longest coastline between the littoral states Mediterranean with a length of about 1,955 km (Adepoju, 2006).

Population of 143,424 inhabitants area 19,710 sq km population density of 7.276 people / sq km. Bani Walid is located on the junction of longitude 14 east, north and line width 31.48 area.

Figure2.2 Location of Bani Walid in Libya (Laura Ungureanu, 2011)

Located in the north-west of Libya, located about 180 km south from the capital, Tripoli, and the nature mountainous geography and there are several valleys and mountains of semi-desert climate, like most areas of Libya (Laura Ungureanu, 2011).

Renewable Energy Sources (RES) have received considerable attention recently with rising concerns regarding environmental problems and a greenhouse gas effect as well as the limits on existing fossil-fuel reserves (Lloyd and Subbarao, 2009). RES have the potential to make a large contribution to sustainable and independent energy future. Solar energy is one of the main sources of renewable energy that are environmentally friendly in providing electricity, it can be used as a clean alternative energy that will replace conventional energy sources and will allow us to maintain the demand levels of energy consumption (IEA, 2009).

In particular, many technologies already exist that have proven its viability, environmentally friendly, available and affordable, including Solar Water Heating (SWH). For these technologies to have a significant impact on the economic level, it requires the householders' acceptance to use these innovations. The uptake of SWHS remains low in Libya and households are still not realizing the practical of using these technologies, due to the low cost of electricity which is almost fully subsidized by the government (Zaidan, 2012).

The utilization of renewable energy is not a matter of using non exhausting source of energy, but also as economical and environmental issues. The Libyan householders are not concerned about the conservation of energy, as long as they are paying a very low tariff for electricity. However, the concern of the people will be very high when the government subsidy for electricity will be terminated in the near future; therefore the possibility of shifting towards Solar Water Heaters will provide great benefits for government and Libyan households.

2.2 Solar fraction

The solar fraction can be used as an indicative measurement of the relative energy performance benefit of solar hot water heaters, greenhouse gas emission reduction and electric energy cost savings. The solar fraction is calculated as the proportion of the hot water energy demand provided by the solar collectors in relation to the boosting energy required to keep water at the required temperature, (Uihlein and Eder, 2009).

2.3 Development of energy sector of Libya

Libya is facing a new beginning in solar energy and opinions vary on how Libya will develop in the long term and what changes the country.

2.3.1 Electricity

In 2007 total electricity production stood at 25.5 TWh. Installed generating capacity in 2008 was 6196 MW. The growth rate in peak demand over the past 10 years has been between 8 and 10% per year. The shortfall in capacity is around 1,000MW. As a consequence to the power shortages the country has had to ration power. The increasing use of water heating by electric has contributed to the problem and has caused peak demand to shift from the winter to the summer. About 32% of the electricity generated is from light fuel oil burnt in combined cycle plant, (Abbasi and SA, 2010).

2.3.2 Solar

While Libya is heavily dependent upon fossil fuels, it has an abundance of renewable energy sources, especially solar energy. There are few conflicts of land use; 88% of its area is considered desert and much of this is relatively flat". Daily the country receives up to 7.5 kWh/m2 of solar radiation on its horizontal plane and has 3000-3500 hours of sunshine per year. According to the MED-CSP study created by the DLR Libya has a technical solar energy potential of 139600 TWh/year, which is enough to satisfy the world's electricity consumption in 2050 such as:

a. Technical potential: 139600 TWh/year
b. Power demand 2050: 44TWh/year
c. Water demand 2050: 25TWh7year
d. Projected World electricity generation by 2050 42672TWh/year

10% of electricity used in Libya is for domestic hot water yet almost no solar water heaters are installed, because of the expensive initial cost and cheap alternative electricity, (Sorensen *et al.,* 2008).

2.4 Potential of Using Solar Water Heaters in Libya

Libya has a significant geographical location as it is laying in one of the highest solar radiation regions in the world, with a daily average of the sunshine duration of more than 3500 hours per year, and more than 8.1kWh/m2 per day (Saleh, 2006).

The climate is bitterly cold in winter with temperatures below 0° C (LMD, 2000). Libya is an oil exporting country and as is the case with some Middle Eastern countries, suffers from a lack of appropriate national policy to the energy conservation, planning, and numerous economic problems such as reliance on oil and gas revenue as the main source of national income (Zaidan, 2012), but even though the country's overdependence on oil and natural gas poses seriously on economic and environmental problems, solutions do exist. During the last quarter of the previous century, various sectors and economic activities in Libya witnessed rapid and significant development. This development led to the growth in electricity demand. Consumption per capita of energy has been multiplied more than six times during this period, where consumption per capita increased from 338 kWh in 1970 to 4360 kWh in 2008 (Ekhlat et al. , 2009).

Therefore, meeting this demand has become a significant problem of concern, and has an impact on the country economy. Thus, it is clear that Libya will face serious challenges as it attempts to meet the rising demand of energy, at the same time it seeks to decrease its dependence on short lived and potentially volatile oil and natural gas to relieve the negative environmental impacts.

According to a recent report of General Electricity Company of Libya (GECOL), the residential sector represents the highest percentage in electrical energy demand; this reflects the importance of this sector in total energy use (GECOL, 2012). The data contained indicates that electricity has been used heavily in heating and cooling. Water heating consumes 30% of the amount charged on household electricity bills, which accounts for just 12% of the total energy consumption in Libya as shown in Figure 2.3.

Of all the house appliances, an electric water heating (EWH) usually represents the biggest energy consumption (George and Associates, 2009). Thus, the current practice to heat water using EWH is highly inefficient as energy is extracted from fossil fuels and then converted into electricity before it is transmitted across long transmission distances to the end user who eventually uses this electricity to heat water. Hence, domestic water heating represents a real and significant burden on the public network for electricity. This goes to raise the question of what is going to happen if the oil prices spikes to a high level or in view of the fact that the country approaches the end of the oil age. It is expected to be exhausted in 40 years if extraction continues at its present pace (Saleh, 2006), this implies that the demand side management must be directed towards substituting appliances which consume large amounts of electricity with those that use alternative energy sources.

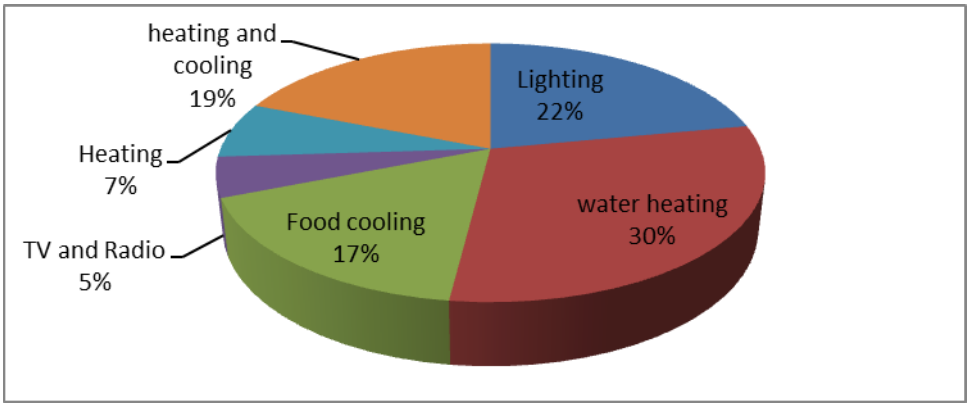

Figure 2.3: Electricity consumption in domestic sector,

Actually, electricity is strongly subsidized by the Libyan government, where the current electricity tariff for the residential sector in Libya is about 2 Libyan cents per kWh whereas the real price is 30 cents per kWh (GECOL, 2010). One of the main obstacles for shifting towards renewable energy measures is the extremely low price for oil and gas that are highly subsidized. These subsidies create some issues to the county, such environmental problems, and the over-usage of energy. Such views are substantiated by the International Energy Agency, which believes that solar energy resources have massive potential as a credible source of sustainable energy in Saharan Africa.

Regarding to the subject of subsidies, on 29 May 2013 Prime Minister mentioned that the Libyan government will publish proposals on energy subsidy reform in October or November of this year, wherein it is thought that targeted cash payments for households will be established in combination with gradual phasing-out. Given this picture, people will go directly towards Solar Water Heating substitute electricity consumption. Consequently, this shifting will provides great benefits to government and Libyan households. SWHS are appliances that utilize the sun's energy directly to heat water and provide it to households, hotels, factories and other recipients (Karagiorgas et al. , 2003).

Widespread SWHS not only help in bridging the gap between demand and supply of electricity during peak demand but also save money in the long run. Thus, a typical family can save 350 USD a year on electricity bills (Philibert, 2005).

These technologies reduce reliance on traditional fossil fuels that provide electricity for water heating systems. Many countries in the world have used SWHS to replace ordinary electric water heaters for example, in Greece and Palestine almost 80% of the houses using SWHS as a way to heat water. Currently, the use of solar energy systems to heat household water in Libya is extremely limited. The usage of solar water heaters started in the early 1980 by installing a pilot project of 30 units installed in the southern part of the country. This pilot project was not successful due to a lack of obvious policy or serious plans to establish such technology. This was followed by some other projects implemented in the city of El-Marge and the town of Al Burayqah. There are all together about 2,000 units spread out in different parts in the country (Siala and Abdurhaman, 1995).

However, despite the large potential that offered by these technologies, the country continues to rely heavily on conventional fuel as well as electricity for water heating. As such, there is considerable scope to increase the application of SWHS in the country. The use of SWHS for the Libyan householder will be reflected on his electric bills by 30% and for the country economic by 12%. Yet the use of SWHS has not been widely used due to many factors that will be analyzed in the following methodology which will promote the use of the SWHS.

2.4.1 Legislation in Libya for solar water heating

The way to move toward Increasing the adoption of SWHS by individuals householders and decrease depends on oil in the Libyan energy mix will make a growing contribution to Libya's economy. To assure the wide use of SWHS and set a national plane toward this goal, Ahmed (2014) suggests the followings:-

a. The Libyan government should move cautiously and determinedly, with an eye to securing a long-term and successful subsidy transition.

b. Subsidies for fuels and electricity should be reduced step by step until that does not make the Libyan poor worse.
c. To avoid negative social effects of higher fuel prices there should be a compensation for households through a direct payment by the government.
d. To avoid negative reactions the cutting of electricity subsidies need to be accompanied by an effective public campaign. If those householders are aware of the compensation mechanism and their income is higher than energy prices, in this case, they may be more easily accepted.
e. The Libyan government should provide financial support for households who plan to install solar water heaters.
f. To encourage households' acceptance of SWH, the government should promote the system's usefulness (performance expectancy), its ease of use (effort expectancy), and these systems are safer than existing systems. Also contribute to conservation of energy (attitudes towards usage) more than promoting the resources needed to use the system (facilitating conditions) (Ahmed, 2014).

Using the sun’s energy to heat water is not a new idea. More than one hundred years ago, black painted water tanks were used as simple solar water heaters in a number of countries (Ramlow and Nusz, 2010).

2.4.2 Energy policies and steps towards development

Even before the revolution began it was suggested that the policy making process in Libya lacks transparency and inter-institutional communication structures and that the country lacks effective coordination and communication among entities in the energy sector; each entity has its own policy and moves in different direction. Energy prices are subsidized heavily in all economic sectors. In such an economic environment it is difficult to foster renewable energies and energy efficiency on a cost-effective basis. Apart from a few pilot projects, renewable energy is not used. Libya also has no efficiency strategies or feed in tariffs, (Missaoui and Mourtada, 2010).

In 2010, government subsidies for fossil fuels were estimated at 18.5% of government expenditure or about 70% of GDP. The country incurs an estimated cost of 3.7% of GDP per year due to it, inefficient use of resources. Libya’s economy is very energy inefficient and that the true costs of electricity are an order of magnitude above existing price levels. Furthermore the heavy dependence on fossil fuels has many negative externalities, such as Libya’s per capita CO2 emissions are higher than most countries in the EU and are by far the highest of the developing countries in the Mediterranean region, (Faraco and Hadar, 2011).

Solar water heating technology has greatly improved during the past century. Solar heaters, or solar thermal systems, provide environmentally friendly heat for household water heating, space heating, and the heating of swimming pools. Such systems collect the sun’s energy to heat a fluid. The fluid then transfers solar heat directly or indirectly to your home, water, or pool Renewable energy technology deployment, (Caldez, 2014).

A schematic diagram of a solar thermal water heating system is shown in Figure 2.3. In addition to an existing conventional hot water heater, the main components are a solar collector panel and an insulated storage tank as well as heat exchanger. These are integrated in Figure 2.3. However, a tank with external heat exchanger could also be used, and such systems are currently on the market (Narbel, 2012).

Also Figure 2.4 shows a small electric recirculation pump powered by a photovoltaic (PV) panel, the advantage being a system that does not rely on external energy for operation. However, the pump can be powered by any means, and often, large scale installations require much larger units than a PV panel can power (Bennett, 2008).

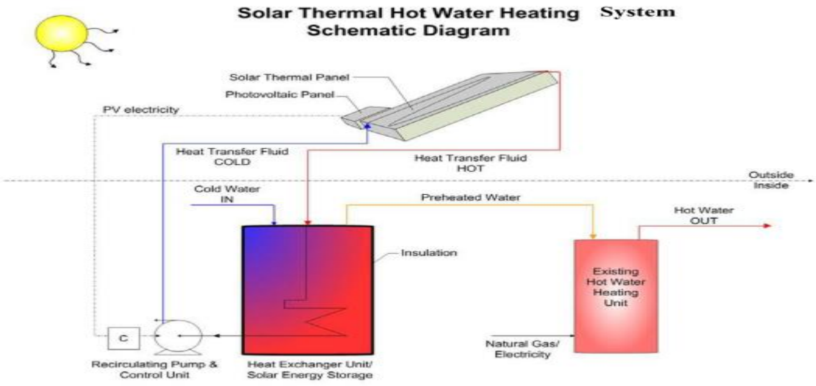

Figure 2.4: Schematic diagram of a solar thermal hot water heating system (Source: Bennet, 2008).

2.5 Benefits from Solar Water Heating

A solar water heater reduces the amount of fuel need to heat water. Because it captures the sun's light and used as renewable energy. Many solar water heaters use a small solar electric (photovoltaic) module to power the pump (Tiwari & Mishra, 2012). The pumps needed to circulate the heat and transfer fluid through the collectors. The use of such module allows the solar water heater to operate even during a power outage. Solar water heaters can also be used in other applications, such as, car washes, hotels and motels, restaurants, swimming pools, and laundry mats (Tiwari and Dubey, 2010).

There are many possible designs for a solar water heater. In general, it consists of three main components:

a. Solar collector, which converts solar radiation into useable heat.
b. Heat exchanger/pump module, which transfers the heat from the solar collect or into the potable water.
c. Storage tank to store the solar heated water.

The most common types of solar collectors used in solar water heaters are flat plate and evacuated tube collectors. In both cases, one or more collectors are mounted on a southerly facing slope or roof and connected to a storage tank. When there is enough sunlight, a heat transfer fluid, such as water or glycol, is pumped through the collector. As the fluid passes through the collector, it is heated by the sun. The heated fluid is then circulated to a heat exchanger, which transfers the energy into the water tank (Iordanou, 2009).

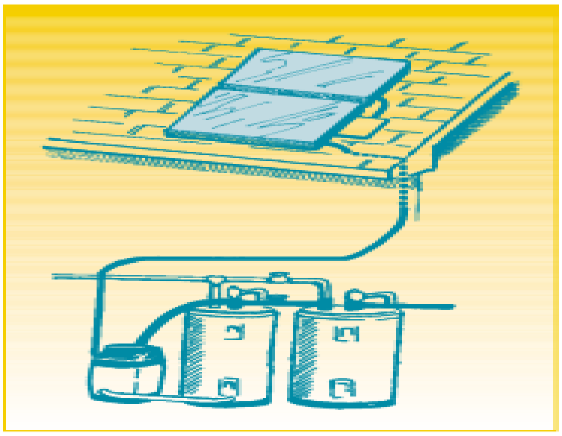

Figure 2.5 flat plates and evacuated tube collectors.

2.6 Solar Collectors

Solar energy collectors are special kind of heat exchangers that transform the suns radiant energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried, (Sözen *et al.* , 2008).

from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days. If radiation is converted into electricity directly, the collector is known as a PV collector but since the emphasis is on collectors for solar water heating, the word solar collector is meant to be solar thermal collector,(Chow, 2010).

There are basically two types of solar collectors; non-concentrating or stationary collectors and concentrating collectors. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the suns beam radiation to a smaller receiving area, thereby increasing the radiation flux (Kaltschmitt, *et al.* , 2007).

In general, under steady-state conditions, the useful heat delivered by a solar collector is equal to the energy absorbed by the heat transfer fluid minus the direct or indirect heat losses from the surface to the surroundings. The useful energy collected from a collector can be obtained from the following formula:

$$Q_{u=}A_c S - A_c U_L\left(T_p - T_a\right) = mC_p(T_o - T_i)$$

Where;

Q_u is the rate of useful energy collected in W, 'S' is the absorbed incident solar irradiance in W/m^2 A_c " is the collector area in m^2, 'T_p' is the average absorber plate temperature in °C, 'T_a' is the ambient temperature in °C, 'U_L' is the Overall heat loss coefficient in W/m^2. °C, 'T_o' is the desired outlet fluid temperature in °C, 'T_i' is the fluid inlet temperature in °C and 'C_p' is the specific heat capacity of the fluid in kJ/ kg.

In the sections following, a review of the various types of collectors currently available will be presented. The review will include flat-plate collectors (FPC), evacuated-tube collectors (ETC), and concentrating collector.

2.6.1 Flat-plate collectors

A typical flat-plate solar collector (FPC) is shown in Figure 2.6. When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptance, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes (Batabyal, 2013).

The transparent cover (glazing) is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect). The glazing with low iron content has a relatively high transmittance for solar radiation (approximately 0.85–0.90 at normal incidence) but its transmittance is essentially zero for the long wave thermal radiation (5.0–50 mm) emitted by sun-heated surfaces (Kalogirou, and Tripanagnostopoulos, 2006).

FPC is usually permanently fixed in position and requires no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10–15 °C more or less depending on the application, (Wadhwa, 2010).

Figure 2.6: Typical Flat-plate solar collector

A properly designed glazed flat-plate collector has a life expectancy of 10 to 25 years or sometimes longer. It is capable of producing temperatures up to 100 °C above the ambient temperature the design is quite simple, and relatively less expensive. These are the most common types of collectors used in solar water heating (SWH) systems in Africa, supplying hot water in hotels, hospitals, and in wealthier households (Chikukwa, 2008).

2.6.2 Evacuated Tube Collectors (ETC) based Solar Water Heaters

Evacuated Tube Collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This helps absorption of solar radiation and transfers the heat to the water which flows through the inner tube. There are 44 MNRE approved ETC based solar water heating suppliers, (Sampathkumar *et al.* , 2010).

Solar water heating is now a mature technology. Wide spread utilization of solar water heaters can reduce a significant portion of the conventional energy being used for heating water in homes, factories and other commercial and institutional establishments. Internationally the market for solar water heaters has expanded significantly during the last decade (Tsikalakis *et al.*, 2011).

2.6.3 Salient Features of Solar Water Heating System.

Solar Hot Water System turns cold water into hot water with the help of sun's rays

- Around 60 deg. – 80 deg. C temperature can be attained depending on solar radiation, weather conditions and solar collector system efficiency
- Hot water for homes, hostels, hotels, hospitals, restaurants, dairies, industries.
- Can be installed on roof-tops, building terrace and open ground where there is no shading, south orientation of collectors and over-head tank above SWH system.
- SWH system generates hot water on clear sunny days (maximum), partially clouded (moderate) but not in rainy or heavy overcast day.
- Only soft and potable water can be used
- Stainless Steel is used for small tanks whereas Mild Steel tanks with anti-corrosion coating inside are used for large tanks.
- Solar water heaters (SWHs) of 100-300 liters capacity are suited for domestic application.

- Larger systems can be used in restaurants, guest houses, hotels, hospitals, industries etc.

2.7 Determination energy efficiency of a solar water heater

Use the solar energy factor (SEF) and solar fraction (SF) to determine a solar water heater's energy efficiency.

The solar energy factor is defined as the energy delivered by the system divided by the electrical or gas energy put into the system, the higher number, more energy efficient. Solar energy factors range from 1.0 to 11. Systems with solar energy factors of 2 or 3 are the most common (Veziroğlu, 2008).

Another solar water heater performance metric is the solar fraction. The solar fraction is the portion of the total conventional hot water heating load (delivered energy and tank standby losses). The higher the solar fraction, the greater the solar contribution to water heating, which reduces the energy required by the backup water heater. The solar fraction varies from 0 to 1.0. Typical solar factors are (0.5–0.75).

Do not choose a solar water heating system based solely on its energy efficiency. When selecting a solar water heater, it's also important to consider size and overall cost, (Hudon *et al*. 2012).

2.7.1 Calculating annual operating cost

Before purchasing a solar water heating system, estimate the annual operating costs and compare several systems. This will help you determine the energy savings and payback period of investing in a more energy-efficient system, which will probably have a higher purchase price. Before you can choose and compare the costs of various systems, you need to know the system size required for your home.

To estimate the annual operating cost of a solar water heating system, you need the following:

- The system's solar energy factor (SEF)
- The auxiliary tank fuel type (gas or electric) and costs (your local utility can provide current rates).

Once you know the purchase and annual operating costs of the solar water heating systems you want to compare, you can find the costs associated with conventional water heating systems and compare the two.

Use the table and calculations below to compare two solar water heating systems and determine the cost savings and payback of the more energy-efficient system model.

2.7.2 Fuel Savings of solar water heating system

Solar water heating systems usually cost more to purchase and install than conventional water heating systems. However, a solar water heater can usually save you money in the long run.

How much money you save depends on the following:

- The amount of hot water you use
- Your system's performance
- Your geographic location and solar resource
- Available financing and incentives
- The cost of conventional fuels (natural gas, oil, and electricity)
- The cost of the fuel you use for your backup water heating system, if you have one.

On average, if you install a solar water heater, your water heating bills should drop 50%–80%. Also, because the sun is free, you're protected from future fuel shortages and price hikes.

If the building a new home or refinancing, the economics are even more attractive. Including the price of solar water heater in a new 30-year mortgage usually amounts to between $13 and $20 per month. The federal income tax deduction for mortgage interest attributable to the solar system reduces that by about $3–$5 per month. So if your fuel savings are more than $15 per month, the solar investment is profitable immediately. On a monthly basis, you're saving more than you're paying.

2.8 Factors Affecting Solar Water Heating (SWH) Performance

The performance of a solar water heating system depends on the following factors

- Ambient conditions
- Collector orientation and tilt
- Collector array arrangement
- Collector and storage tank characteristics
- The transport fluid flow rate

2.8.1 Ambient Conditions

The amount of incident radiation determines the absorbed solar radiation by the collector while the ambient temperature determines the thermal losses from the collector. Cloudy conditions limit the beam insolation levels and thus the radiation absorbed by the collector especially the concentrating collectors, (Kaunda, 2008).

2.8.2 Collector Orientation and tilt

Geographic orientation and collector tilt can affect the amount of solar radiation the system receives. Collector orientation is critical in achieving maximum performance from a solar energy system. In general, the optimum orientation for a solar collector in the northern hemisphere is true south (azimuth of 180°) as illustrated in Figure 2.4.

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