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Review on solar water heating in Libya

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Abstract: This review paper aims to provide a comprehensive review of the history and the best practices of solar water heaters in Libya. Although, Libya is blessed with high solar potential, there is no wide-spread implementation of this technology due to many reasons such as: the cheap price of both electricity and electric water heaters, lack of clear and systematic policy, and lack of environmental awareness. The Center for Solar Energy Research and Studies (CSERS) has given attention to this technology since its establishment in 1978, and the solar water heating system field test project is one of the research projects in the Center. The paper has shown that there was no attention paid to this technology and even to renewable energy in general in the previous years. However, preliminary information clearly shows the importance of continuing research in this field. Numerous valuable information on solar water heating systems from literature were dedicated and made available for researchers and decision makers. The studies conducted in this field for Libya are arranged in this review on the bases of the topic studied: performance evaluation, optimization, on-site measurements and policies and strategies. One of the most important results retrieved from these studies show that the daily quantity of hot water withdrawn per capita at 45 °C is estimated around 60 liters. The estimated annual amount of energy consumed for water heating per person is 510 kWh. For average Libyan family of six persons, the annual amount of energy consumed per dwelling is estimated about 3060 kWh. The review also presented the history of solar water heaters implementation, manufacturing and testing facilities for quality control in Libya. The study calls upon the Libyan decision makers to take their responsibility and put an urgent action plan to help the wide-spread implementation of solar water heaters in the residential, services and industrial sectors. Such a plan will surely alleviate the ever increasing demand for electricity, save fossil fuel reserves and mitigate GHG emissions.

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ورقة مراجعة عن تسخين المياه بالطاقة الشمسية في ليبيا

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ملخص: تهدف هذه الورقة إلى توفير مرجع شامل لأهم الدراسات والتطبيقات الخاصة بمنظومات تسخين المياه بالطاقة الشمسية في ليبيا. وبالرغم من أن ليبيا تنعم بمعدلات إشعاع شمسي عالية، فإنه لا يوجد تطبيق موسع لهذه التقنية لعدة اسباب منها رخص ثمن الكهرباء والسخانات الكهربائية؛ عدم وجود سياسة واضحة؛ وعدم وجود وعي بيئي. أعطى مركز بحوث ودراسات الطاقة الشمسية أهمية بالغة لهذه التقنية منذ تأسيسه سنة 1978، ومشروع التطبيق الميداني لسخانات المياه الشمسية أحد أهم المشاريع البحثية والتطبيقية المستمرة في المركز. وقد وضع العديد من المعلومات القيمة عن منظومات تسخين المياه بالطاقة الشمسية من خلال الدراسات السابقة في متناول الباحثين وصانعي القرار. الدراسات التي أجريت في هذا المجال عن البيئة الليبية رتبت على أساس تقييم الأداء، والتحجيم الامثل، والقياسات الحقلية، والسياسات والاستراتيجيات. وكانت أحدى أهم النتائج المستخلصة من هذه الدراسات أن كمية المياه الساخنة المستهلكة للفرد الليبي في القطاع المنزلي عند درجة حرارة ° 45م تقدر بحوالي 60 لتراً، وتقدر كمية الطاقة السنوية المستهلكة في تسخين المياه لكل فرد بحوالي 510 ك.و.س. وكمية الطاقة السنوية المستهلكة لكل أسرة تتكون من 6 أفراد تقدر بحوالي 3060 ك.و.س. الدراسة ايضا عرضت تاريخ تركيب سخانات المياه الشمسية، وتصنيعها واختبارات الجودة عليها في ليبيا. الدراسة توصي صانعي القرار في ليبيا بتحمل مسؤولياتهم لوضع خطة عمل سريعة لمساعدة الانتشار الموسع لمنظومات تسخين المياه بالطاقة الشمسية في القطاع المنزلي والخدمي والصناعي، وذلك لتخفيف الطلب المتزايد على الكهرباء وتوفير احتياطيات الوقود الأحفوري والتقليل من انبعاث غاز ثاني أكسيد الكربون.

Keywords: *solar water heaters, field study, policy, strategic plans, SWH testing facility.*

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1. INTRODUCTION

Solar water heating systems have been in use for many years in homes, businesses, schools, office buildings, and on a larger scale for industrial processes as well. According to Renewable Energy Policy Network data (2012) [1], over 200 million houses worldwide used SWH systems by 2010, and the total capacity grew to over 410.2 GW_{th} by the end of 2014 which is equivalent to 586 million square meters of collector area [1, 2]. China is leading in SWH market with 78.5% of the total added capacity for the year 2014, and even leading in the total accumulated installed capacity by 70.5%. The leading country in accumulated glazed and unglazed water collector capacity in operation in 2014 per 1,000 inhabitants was Austria (419 kW_{th}/1,000 inhabitants) [2]. Significant expansion has also been reported in the European Union, Japan, India, and Brazil. In MENA region which includes 21 countries, the solar water heating accounts for 9 million square meters of collector area representing 6.3 GW_{th} of installed capacity. In the MENA Arab countries; Palestine is the leader with 1,120 MW_{th} followed by Egypt, Tunisia, and Syria respectively [3]. Another report published by IRENA stated that the total solar water heating installed capacity reached 3.3 GW thermal in 2012[4]. The world's largest solar district heating plant started its operation in 2014 in Denmark; the collector field of 37,275 m^2 area provides 26 MW_{th}, also a seasonal storage was designed to cover around 50% of the total annual heat demand of 1,400 customers. In 2011, Saudi Arabia installed one of the world's largest plant of 36,305m^2 area that provides 25 MW_{th}; this plant provides hot water and space heat for 40,000 students in the university in Riyadh [2]. Currently, this technology is considered mature, technically reliable and economically feasible.

Until 2014, about 69% of solar thermal energy is collected through small individual solar collectors installed on each individual house and about 27% is collected through a relatively large solar collectors that provide thermal energy to group homes, hospitals, schools etc. Unglazed collectors for swimming pool heating represent about 4% [2].

The first use of solar water heating systems technology dates back to 1891 when Clarence patented the world's first commercial solar water heater, called the "Climax". Soon the solar water heating systems technology becomes popular in California, and thousands of Climaxes and similar systems were installed in a short-time. In 1909 the solar water heaters were improved by engineer William Bailey to become similar to systems used today. By the year 1941 more than half the buildings of Miami were using solar water heaters. However, since then and after the discovery of natural gas, gas geysers dominated the market of water heaters and the era of solar water heaters was gradually phased out from the market [5].

This status has changed again after the first oil crises in 1973 when the world started seriously looking for alternative fuels to reduce reliance on oil from the Middle East. Solar water heaters started again to become an important alternative to the electric water heaters commonly used nowadays. The first solar thermal systems for water heating was commercially introduced in the mid-1970s [5].

In Libya, little attention was given to the study and use of solar energy to heat water during the last few decades; however a few PV systems were installed by oil companies in Libya for oil pipelines protection [6] and recently, some small PV solar systems were installed in some remote areas in Libya.

This paper aims to present a comprehensive reference for the most important studies and applications of solar water heating systems in Libya. Such a reference may help researchers to develop and disseminate this technology in Libya

2. SOLAR WATER HEATING TECHNOLOGY

2.1 Types of SWH Systems

Although there are many different types of solar water heating systems, they have a common method of how they work. Most of them are simple in design and easy to install. Solar water heating systems can be active or passive to transfer heat. An active solar water heating system uses pumps to transfer heat from the collector to the storage tank, while in a passive system, the system does not use pumps or control mechanisms to transfer the heat gained to the storage tank. Instead, passive systems use natural forces such as gravity to circulate the water between the collector and the tank. Currently, there are at least six types of solar water heating systems: Direct/Indirect Systems, Thermosyphon, Draindown/Drainback Systems, Integral Collector Storage (ICS) Systems, and Swimming Pool Systems.

Solar water heating systems can be of small-scale like domestic systems or large-scale systems like these used for industrial applications. These systems provide high temperatures ranging from 45 °C to up to 250 °C for different applications such as swimming pools, domestic purposes, and industrial process.

2.1.1 Direct/Indirect Systems

Direct systems: Open-loop active systems use pumps to circulate household water through the collectors and the storage tank as shown in Figure 1. This system is more efficient and lowers operating costs than closed-loop but it is not appropriated if the water is hard or acidic since scale and corrosion quickly disable the system. Thermosyphon system can also be of direct open loop system where no heat exchanger in the storage tank and the used water goes through the collector loop.

Open-loop active systems should never be installed in freezing climates for sustained periods. It can be installed in mild climates and in occasionally freezing climates, but freeze protection must be considered.

Indirect systems: The heat-transfer fluid (usually a glycol-water antifreeze mixture) in the thermosyphon solar system and forced circulation system goes through the collectors and a heat exchanger as shown in Figure 2. The heat exchanger transfers heat from heat-transfer fluid to household water stored in the tanks. These systems are suitable for climates prone to freezing temperatures; because they use antifreeze fluid and anti-corrosion.

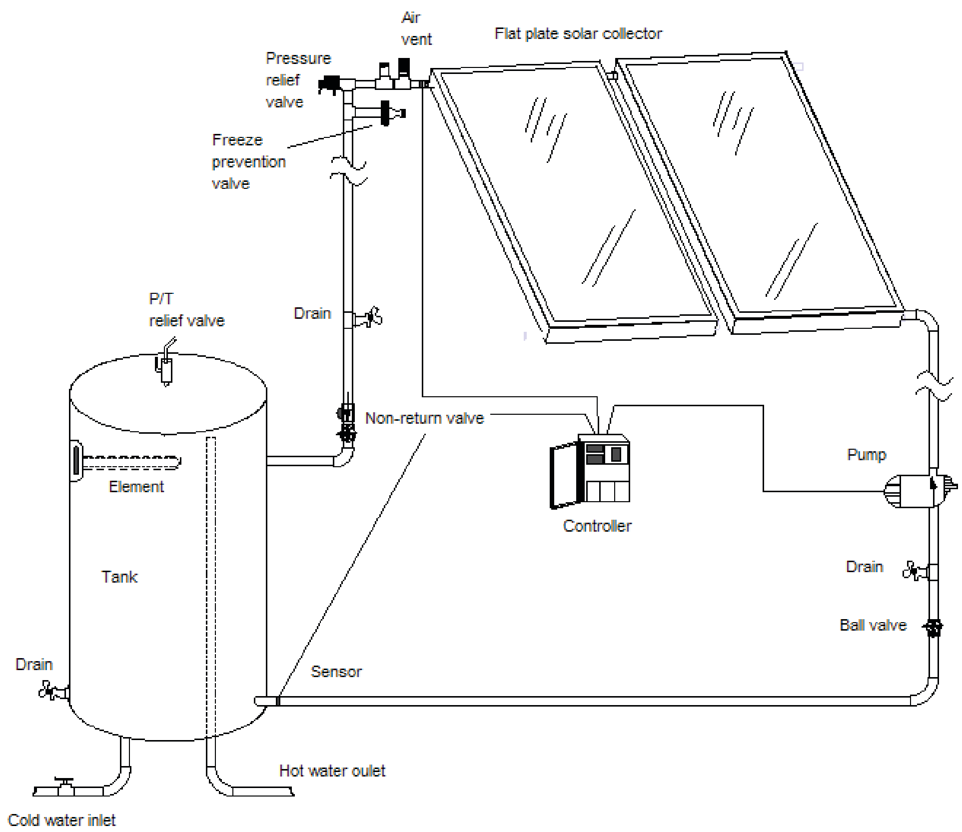

Figure (1). Direct open loop solar water heating system

2.1.2- Thermosyphon Systems

Thermosyphon solar water heating systems (see Figure 3) are the most commonly used in places where climatic temperature remains above freezing. Over 95% of the installed systems worldwide are thermosyphonic type [7]. They are less expensive than forced circulation systems and as they have no moving parts less maintenance is required. These systems are the most suitable to the Libyan environment.

2.1.3- Integrated Collector Storage (ICS) Systems

Integrated collector storage system (ICS or Batch Heater) uses a tank that acts as both storage and solar collector placed in an insulated box with a glazed side facing the sun as shown in Figure 6. Cold water flows progressively through the collector where it is heated by the sun. Hot water is drawn from the top, which is the hottest. They are simple and less costly than flat plate and evacuated tube collectors, but they suffer from significant heat loss at night since the side facing the sun is largely un-insulated, and are only suitable in moderate climates.

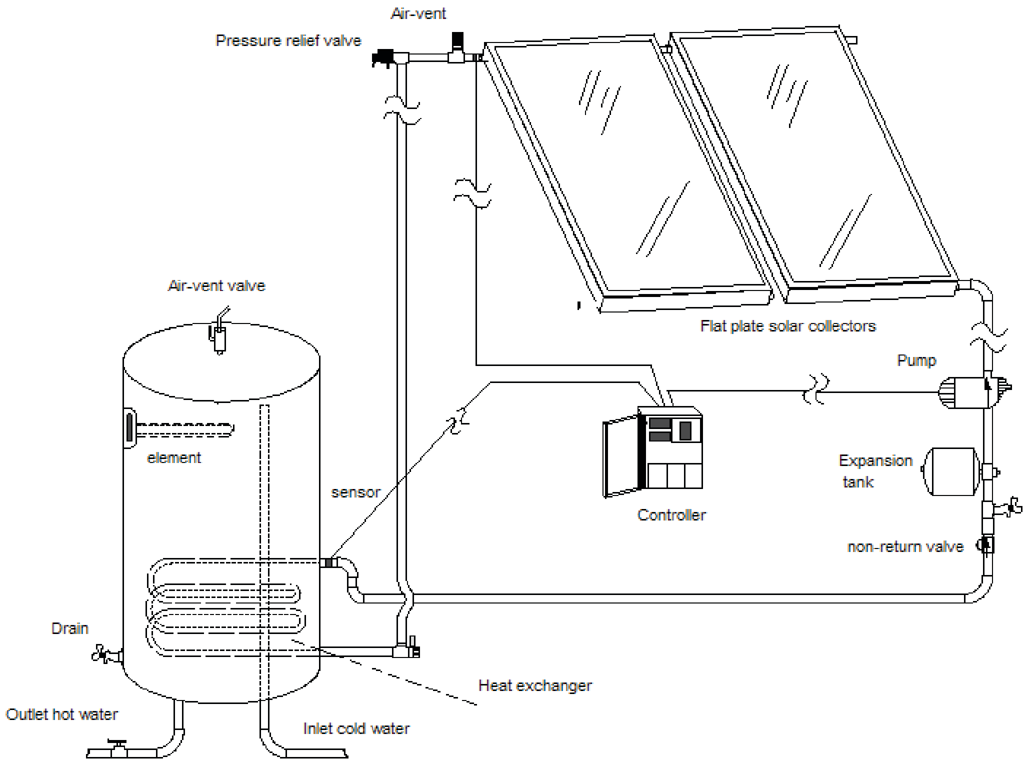

Figure (2). Indirect (closed loop) solar water heating system

Figure (3). General view of the common thermosyphon solar water heating systems

2.1.4 Draindown/Drainback Systems

A draindown system is an open loop system in which the collectors are filled with domestic water under house pressure when there is no danger of freezing (see Figure 4). Once the system is filled, a differential controller operates a pump to move water from the tank through the collectors. This kind of systems doesn't require heat exchanger, which allows efficient heat transfer directly to the water. It does not use anti-freeze or non-potable water. The draindown system offers freeze protection during power outages or malfunctioning of the pump or the control systems [8].

In a drainback system (see Figure 5), the collector fluid, typically demineralized water, is circulated from a reservoir tank through the solar collectors whenever useful heat can be collected. When the pump shuts, the water drains back by gravity to the reservoir tank. The collectors and all other piping exposed to potential freezing conditions are left empty.

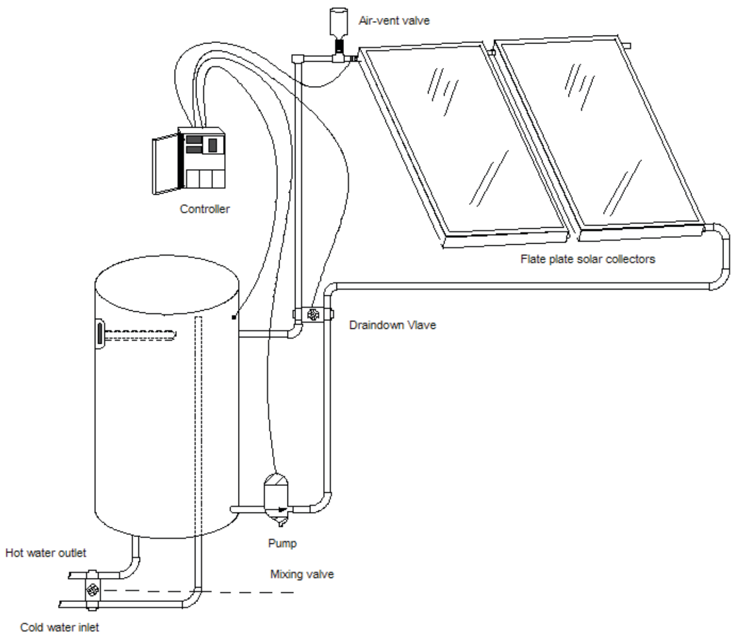

Figure (4). Drain down solar water heating system

2.2- Main system components

2.2.1 Solar collector

Solar energy collectors are a special type of heat exchangers in which they transform one form of energy, solar radiation, to another in the form of hot water. Solar irradiation is absorbed by a solar collector as heat which is then transferred to its working fluid (air, water or oil), flowing through the collector. Solar collectors are usually classified into two categories according to concentration ratios: non-concentrating collectors and concentrating collectors. A non-concentrating collector has the same intercepting area as its absorbing area, whilst a sun-tracking concentrating solar collector usually has reflecting surfaces to intercept and focus the solar irradiation to a much smaller receiving area, resulting in an increased heat flux [10].

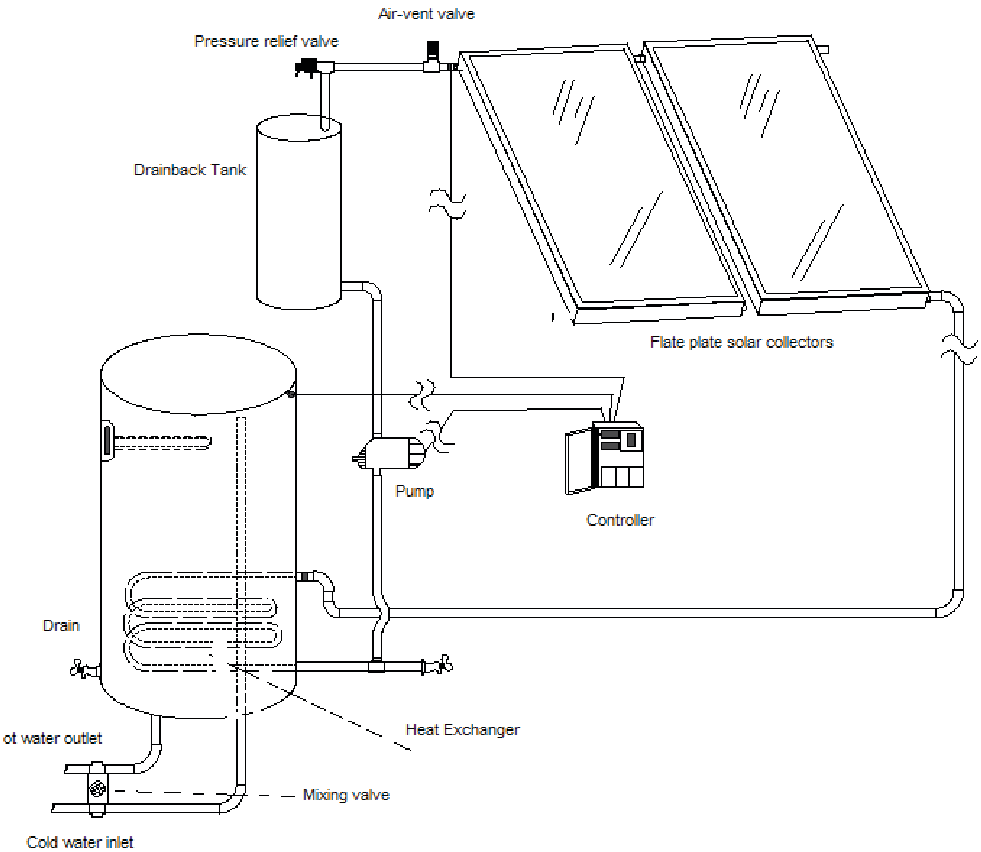

Figure (5). Drain-back solar water heating system

Figure (6). Integrated collector storage system [9]

In most domestic hot water applications, flat plate and evacuated tube collectors are used. Most of the Flat plate collectors as depicted in Figure 7 are similar except for fluid passages where different types are designed such as header and riser, serpentine, sandwich …etc.

Whereas, vacuum tubes collectors can be found in the market as glass in glass, U-type vacuum tubes and heat pipe vacuum tubes technologies as shown in Figure 8.

2.2.2 Storage tanks

Thermally insulated storage tank is one of the main components of solar water heaters. It is the means used to store hot water for later use and it also works to stable and guarantee continuous supply of hot water to the user at any time. In solar systems, the storage tank can be in any of the configurations shown in Figure 9. The main configuration can be an open tank, has one heat exchanger of helical or shell and tubes; has two heat exchangers one for the collector loop and the other for the auxiliary supply; or has a mantle heat exchanger. The tank can be installed in vertical or horizontal mode. The capacity of the tank is dependent on the system size and the demand.

2.3 Benefits of solar energy systems

Solar water heaters have many advantages over the other technologies for providing hot water in the residential, service and industrial sectors, these advantages can be listed through the following subsections

2.3.1 Reducing green-house gas emission

Reduction of pollution and preservation of environmental health are some of the co-benefits of this technology. Based on the average hot water consumption for Libyan family, the family consumption of electricity per year is about 3060 kWh and solar energy can provide about 72% of the demand. It is estimated that the savings in CO_2 emission is about 2.15 tonnes/year in case of electricity backup [11],[12]. One half million SWHSs installed in homes will, therefore, result in reduction of 1.075 million tonnes of CO_2 emission into the atmosphere yearly.

2.3.2 Reducing energy bills

In Libya, a typical family can save appreciable amount on electricity or fuel bills of domestic water heating by replacing its conventional water heater with a solar water heating system. A study conducted by Ekhlat et al [13] has shown that about 30% of the electricity in Libyan houses is consumed in domestic water heating. This means that the installation of solar water heater would reduce the electricity bill by about 22.5%.

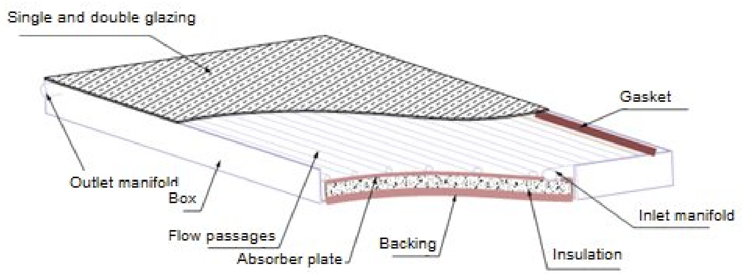

Figure (7). Flat plate collector and vacuum tubes collectors

2.3.3 Energy conservation

In Libya more than 99% of domestic water heating uses electricity. Heat is a low energy grade and electricity is a high energy grade and therefore using electricity to produce heat is considered as a degradation of energy. In this process, the conversion efficiency from the power plant to the end user is between 15 to 30%; therefore the using of direct heating of water by solar energy instead of electricity is economically preferable.

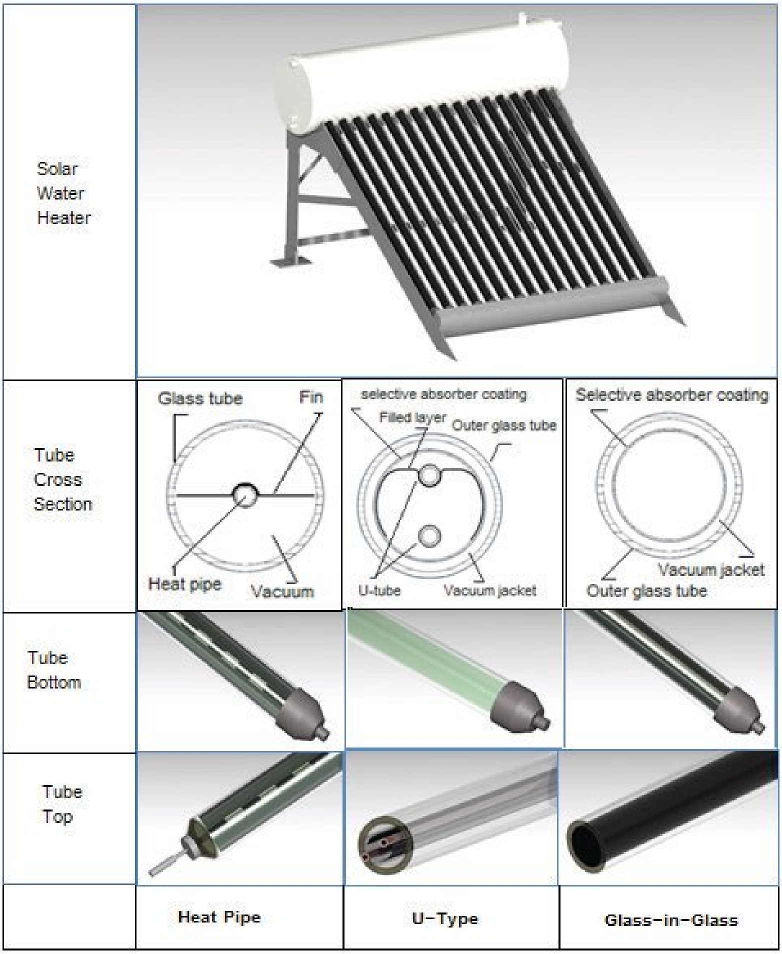

Figure (8). Common types of vacuum tubes collectors

2.3.4 Creating new jobs

Introducing new technology will probably create a domestic employment. By 2014 it is estimated that 730,000 jobs worldwide were created in the field of production, installation and maintenance of solar thermal systems [2].

3. RESEARCH ACTIVITIES

A considered amount of research work has been done on solar water heating in Libya over the past years, covering areas including experimental, theoretical, simulation, policy and strategic plans. Valuable information related to thermal performance, hot water load pattern, load volume per capita and the accompanying operational issues of solar water heaters were obtained from field studies. Research work was conducted to put strategic plans to help large-scale implementation of solar water heaters in the residential sector. Other studies were relating to the optimum design of solar water heaters suitable for Libyan families based on local weather and load conditions are compiled and discussed below.

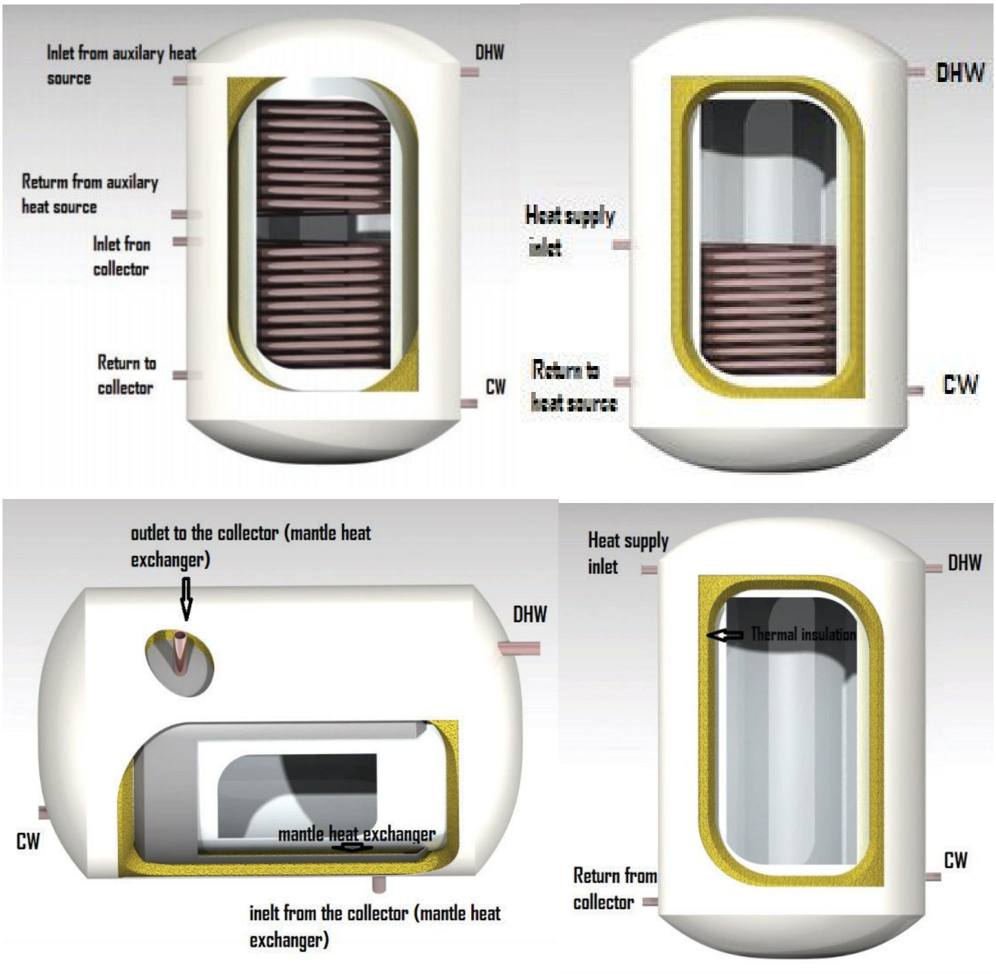

Figure (9). Schematic diagrams of different types of storage tanks (CW: cold water; DHW: domestic hot water

3.1 Modeling, validation, and performance evaluation

A number of research works have been conducted on water heating at Garyounis University. The research works include theoretical and experimental studies related to water heating by solar using thermosyphon systems[14],[15],[16],[17],[18],[19]. A model was developed to evaluate the thermal performance of thermosyphon system and validated through experiments. The model is then used to predict year-around performance. The studies concluded that a tank of 60 liter volume is the optimum for collector of 1 m^2 area installed at Bengahzi city[14]. This result is somehow compatible with the results obtained by Abdunnabi [20]. Abdunnabi conducted his study in Tripoli and the optimum values of tank volume to collector area ratio is found to be 49-60 liter/m^2; the variation is due to the quality of the collector.

Abughres and Hassan[21] studied the natural circulation in a thermosyphon solar fluid heater. The conservation laws of mass, momentum, and energy to a fluid element along the circulation loop at unsteady state were applied. The obtained exact solution under steady state conditions is compared with the existing simplified models, which assume linear temperature distribution in the collector. The study concluded that defects arising from the linear approximation in the simplified models are manifested in predicted temperature differences and highest temperatures in the collector exceeding the maximal possible ones, whereas corresponding values predicted by the model lie within those limits. The solution can only serve as an approximate guide, and proper understanding of the behavior of the system would only be possible when time dependency is taken into account.

Hassan and Abughres[22] have analyzed the conduction and convection heat transfer in finned solar fluid heaters. The variables that affect the performance of these heaters are clearly identified. The authors have come up with dimensionless group's gives generality to the obtained results. They have found that the fluid velocity has a very minor effect on the efficiency for most practical cases.

Smeda M. S., [23] has calculated monthly and annual performance of an open-loop solar water heating system in Tripoli using , f-chart method. The author has used weather data of Tripoli with long term observation temperature for a period of 75 years, and short term observed global solar radiation of 8 years. The author has used five different diffuse models in his analysis and reported their effect on the system performance.

Abdunnabi et al. [12],[24] carried-out an experimental work to validate forced circulation solar water heaters using vacuum tubes collector implemented in the simulation program TRNSYS. The experimental work was carried-out at the Center for Solar Energy Research and Studies (CSERS) in Libya. Experimental work was conducted for six days on a system with four vacuum tube collectors (each collector has 10 tubes) connected in series and a storage tank of 200 liters fitted with the necessary instruments. The system was open loop with no heat exchanger. The same system specifications in addition to weather and operating conditions were implemented in the TRNSYS simulation program for validating and determining the accuracy of the software.

The results have shown that TRNSYS simulation program gives satisfactory performance predictions compared with the experiments. The average discrepancy between predictions and experimental values in the daily energy collected from the system was less than 20%, whereas the average discrepancies incurred in predicting the hot water outlet temperature was less than 16%. The prediction results of vacuum tubes collector model in TRNSYS give an average accuracy better than 13 %.

3.2 Experiments and in-situ measurements

There have been many studies conducted experimentally on solar water heaters to evaluate their in-situ performance in Libya [12],[25],[26]. In a project carried-out by the CSERS, solar water heaters were installed in the residential sector and some of them were equipped with data-loggers and the required sensors to evaluate the real thermal performance and solar fraction of the systems (see Figure 10). The measurements were taken every10 seconds and recorded every 30 minutes for a period of over a year. Results obtained only from five systems for a complete year as listed in Table 1. The collected data were analysed, and the hot water distributions for each season were obtained for an average Libyan family of 6 persons[12]. Figure 11 shows the average annual typical hot water load pattern for Libyan family.

The methodology used to calculate the hot water load pattern and the quantity of water consumed from the measured data was accomplished by unifying the different water quantities at different temperatures from the five systems as energy content, and the quantity of the water consumed was then calculated at a withdrawal temperature of 45 °C.

Figure (10). Solar water heater equipped with measuring sensors and data logger

Based on the complete data listed in Table 1, it has been found that, the daily quantity of hot water withdrawn at 45 °C per person was around 57 liters. The estimated annual amount of energy consumed for water heating per person is 510 kWh. For Libyan family of six persons, the annual amount of energy consumed per family is estimated at about 3060 kWh. The annual energy output of these systems ranges from 233 to 732 kWh/m^2, with an average system specific yield of 437 kWh/m^2. These values greatly depends on the daily and seasonal hot water load profile of the users. These results are slightly different from previously published ones[20],[27].

According to experimental data listed in Table 1, solar water heaters (not properly sized) can provide from 59 to 84% of the hot water needs. Therefore, well designed solar water heating system can properly provide better performance.

Table (1). Daily annual average measured data of solar water heaters field study

Tank volume (L)	Collector area (m^2)	Persons/ family	Ave daily consumption. (L)	Ave. inlet Temp (°C)	Ave. outlet Temp (°C)	Annual Energy kWh	Solar Fraction (%)
240	3.54	6	353	26.3	49.6	3450	75.2
280	4.4	4	274	24.36	47.3	2037	83.6
210	3.4	5	158	20.55	46.4	1698	57.7
240	3.54	4	319	21.82	44.44	2925	66.1
170	3	3	131	21.91	44.2	1190	58.7

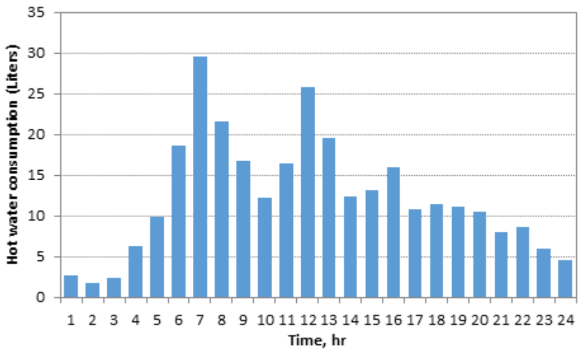

Figure (11). Typical Residential hot water load pattern of Libya [12]

Saied [28] conducted an experimental work to evaluate the performance of local built storage tank of solar water heater (integrated storage and collector) under climate conditions of Benghazi. The heater was a rectangular in shape (144 × 72 × 6 cm) and made from galvanized iron sheets with capacity of 60 liters. The top surface of the heater was painted with black paint to perform the dual function of absorbing the solar energy and storing the heated water. A glass sheet of 2 mm thickness was used to cover the top surface. The sides and bottom of the heater were insulated with fiber glass wool to reduce the heat losses. Experiments were carried out to test the performance of the heater: end-day, hourly and night cooling effect measurements were taken. The results showed that the heater works efficiently under Benghazi climate. The maximum water temperature of the heater was 78°C in shining days and 45°C in cloudy days. The maximum daily efficiency was 76% in bright days.

Saied and Faraj [29] conducted experimental and theoretical work on a thermosyphon solar water heater installed in Al Burayqah oil city. The study aimed to evaluate the thermal performance of the systems theoretically and experimentally. The system was equipped by the necessary measurements. The recorded measurements were four temperature measurements for the water inside the storage tank, four temperature measurements for the absorber plate, the inlet and outlet water of the tank, the ambient temperature, and the solar insolation. The experiment was carried-out during the period from March to June. Every day the tank was flashed at 7:00 am and then the system was left until evening at 5:00 pm, where the water withdrawn from the system.

The highest recorded temperature from the storage tank was 71 °C and the lowest was 40 °C and the calculated average temperature during the measurement period was 53 °C. The system lowest efficiency recorded in cloudy days was 25%, and the highest efficiency was 60% in sunny days with solar insolation of 989 W/m^2. The highest collector efficiency was 61% and the lowest was 55%. Some comparisons with the theoretical model were made. The study has shown a good agreement between the experimental and theoretical prediction of the withdrawal temperature of the storage tank.

Abdunnabi et. al. [30] conducted experimental work on three similar flat plate solar collectors except for absorber coating. The coatings considered in the study were selective, semi-selective, and black painting. The experiments were carried out at the Center for Solar Energy Research and Studies under local outdoor conditions. The study has shown that, by far, selective coating collector outperforms the other collectors. While the semi-selective collector out-performs the matt black collector at high inlet water temperature. The maximum efficiency of the selective collector is increased by 10% compared with the matt black collector. The maximum water temperature differences obtained during the experiments was 10.3, 9.5 and 9.18 °C for selective, semi-selective and black painting collectors respectively. The results were obtained at water inlet temperature of 42 °C and flow rate of 0.03 kg/s.

3.3 Sizing and optimum system designing

Finding the optimum system design of solar water heaters that suits Libyan families requires a lot of information; this information includes design parameter, weather condition, and the operating conditions which are usually influenced by people's habits.

Literature reveals that some work has been done on providing these essential design information such as typical hot water load pattern (HWLP) [12],[20], and typical meteorological year (TMY),[31],[32]. Abdunnabi et al. [31] conducted a study to obtain the typical meteorological year of Tajoura city based on five year solar radiation measurements to be used for designing solar systems. Over 11% of the data were missing and the accuracy of the data was questionable. Domanski and Azzain [32] have generated successfully TMY file using the TRNSYS techniques for Sabha City. The developed TMY agrees with most of the known weather facts in the region of Sebha south of Libya and approximately with Meteonorm results as well.

A number of other studies [20],[33],[34],[35],[36],[37] were published dealing with optimum design of solar water heating systems and the effect of the essential design and operating parameters on the overall system performance. Abdunnabi [20] conducted a study to find the optimum ratio of tank volume to collector area for different collector characteristics performance. The study has shown that the optimum storage tank volume to collector area ratio of thermosyphon systems is between 49 – 60 Lit/m^2 for the most common collector characteristics ratio ($F_R U_L / F_r(\tau\alpha)$=6-8) with the auxiliary heater set point temperature ranging between (45-60 °C), and solar fraction ranging between (84-93%).

Abdunnabi [37] modified the TRNSYS model for simulating the direct thermosyphon system by adding two new components to account for the characteristic performance of the collector and storage tank. The new model was used to conduct a parametric study on the design parameters of thermosyphon solar water heater. The study was conducted for Libya weather conditions and hypothetical load pattern. The effect of different design parameters, such as number of risers, riser diameter, collector aspect ratio, tank volume and tank aspect ratio on the system solar fraction was studied and their behaviors are shown on figures. The ultimate conclusion of the study shows that conducting a single variable optimization without considering the interaction between weather condition, design parameters, and usage data will not give the right system design. However, considering the effect of all the above factors simultaneously by conducting multivariable optimization technique is the only way to get the optimum system design.

An another study by Abdunnabi et al [33], developed a design tool for sizing thermosyphon solar water heaters. The tool is based on TRNSYS simulation program for evaluating the thermal performance of solar systems, using genetic algorithm routine for the optimization process. The design tool was applied to Libya and the trade-off between cost and solar fraction in case of the proposed system was obtained. Figure 12 represents the trade-off curve between the material cost of the system and the solar fraction of the system in which the black circular points represent feasible solutions set (dominated solution), and the solid line and grey circular points represent the Pareto optimal set (non-dominated solution).

Any point at the Pareto optimal set shown in Figure 12 is represented by 13 design parameters provided by the design tool, and it is enough to manufacture the optimum solar water heaters.

The aforementioned studies were dealing with thermosyphon solar water heaters the most suitable systems for providing domestic water heating. However, some other studies were published dealing with forced circulation solar water heaters for domestic purposes, such studies are:

Azzain and Domanski [38] addressed the optimum sizing of forced circulation solar domestic water-heating system (SDWHS) for Sebha city south of Libya using TRNSYS simulation program. The simulation was considered for an average family size of six persons and the system was subjected to four different load profiles. Different measures were used to determine the optimum size of the system such as: the Collector Consumer Factor (CCF) in m^2/consumer and the Collector Load Factor (CLF) in m^2/GJ. The main criteria describing system overall performance used were: the collection efficiency and the solar fraction. The simulation results show the range of optimum size of the SDWHS expressed in terms of CCF and CLF by using of the Life Cycle Savings (LCS) as economic criteria. Moreover, The LCS indicate that, if the annual average of total cost of the system during its life cycle was at least equivalent to the conventional one (e.g. electric energy or natural gas) averaged on the same time period then, the emphasize must go to the use of solar energy, because of at least the environmental features.

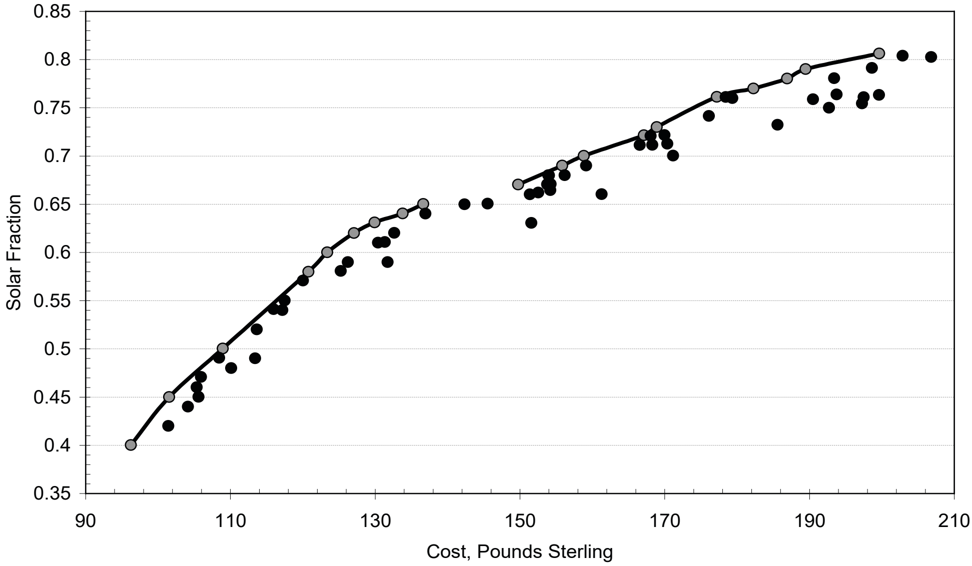

Figure (12). The trade-off between the cost and solar fraction [33]

The study has also shown the best storage collector factor SC for the SDWHS in the range considered from 0.015 to 0.1 m^3/m^2 is 0.025 m^3/m^2 (25 Lit/m^2). This occurs at (LCS = 472 LYD/capita) and the corresponding solar contribution (SF = 98.28 %). The optimum collector tilt angle was found equal to 30°.

Aldelamy and Ibrahim [39] studied theoretically the design of forced-circulation solar water heaters for a single family house. A f-f chart method was used to calculate the monthly amount of hot water that can be provided by solar energy. In the study, the monthly hot water demand was estimated using maximum and minimum daily consumption of 1.3241 GJ and 1.038 GJ respectively requiring collector area of 9 m^2 for an average Libyan family. To be noted is that these estimates are slightly higher than that reported experimentally 918 MJ [12],[25].

Abdunnabi et al. [40] have used genetic algorithm and TRNSYS simulation program to find the optimum forced circulation solar water heaters that suit different Libyan family sizes. The design tool was applied according to the weather and operating conditions of Tripoli, Libya. The quantity of hot water per person per day is taken to be 60 liters at withdrawal temperature of 45 °C. A typical hot water load pattern for Libyan families as depicted in Figure 11 is used. The technical specifications of the system components and cost of the system components is taken from the manufacturer to obtain accurate results. The results of optimum solar water heater are obtained for 4, 6, and 8 people family size. The trade-off between the cost and solar fraction curves for the cases considered is obtained and the system design parameters are listed in tables. In case of family size of six people, the optimum system design parameters that can provide 90% solar fraction are: the optimum tank volume of 300 liters with collector area of 7 m^2. In case of 70% the optimum system required is 235 liters and 4.4 m^2 which is nearly similar to the commonly available thermosyphon systems in the market.

Khalaifa et al [41] studied the design of solar water heating system for Ben-Sina educational hospital which is located in Sirte city. The hospital consists of 261 beds' with total area of 3850 m^2 currently using the conventional energy for both domestic hot water and heating systems. The service water capacity, the type, the number of solar collectors, the number of required tanks, the required pumps and the pipe length of the proposed solar energy system project have been identified. The project's economy study showed that using the solar energy for daily hospital hot water consumption of 42.4m^3 would save energy on annual bases of about 499.52 MJ of conventional energy equivalent to 8,170 LYD obtained at lowest ambient temperature of 15°C. The system total cost is about 37,650 LYD which will have a payback period of 4.6 years and the project's life time considered is 25 years.

Jablalla et al [42] have studied the optimum size of the storage tank of forced circulation solar water heaters in Libya using TRNSYS. Two storage tanks were considered, preheat and main storage tanks. Assistance heating was considered using electric and gas auxiliary heaters. The optimum sizes of the main and preheat storage tanks were obtained in case of both 90 gallons. However, the study didn't mention any thing about the hot water quantity and pattern, and the configuration of the solar water heating system considered is not the commonly used in Libya.

3.4 Policies and strategies of widespread implementation

Large scale deployment of solar water heating systems (SWH) can help to reduce both peak load demand for the electric utility, and the consumption of fuels, and contribute to reduction in degradation of the environment in addition to its potential in increasing the domestic employment. Unfortunately, despite the widespread use of solar water heaters in many places in the world that have less favorable climatic conditions for solar energy compared with that of Libya, still there is no usage of such technologies in Libya. In fact there are reasons that make people not interested in using this technology; such as the low price of the conventional energy in Libya, the government policies and programs towards the renewable energy technologies, and the lack of environmental public awareness. In respect of the aforementioned barriers, a number of studies analyzed the situation in Libya and suggested some strategic plans to help the uptake of this technology. Saleh A. et al [43] used the modified Unified Theory of Adoption and Use of Technology (UTAUT), to provide new insights into predicting adoption and identifying of the factors that may prompt people to accept and use solar water heaters. Saleh paper analyzed the factors affecting the acceptance of this technology among the Libyan household, identifying the barriers to large-scale deployment and made some recommendations for the government to set a national plan towards the widespread use of solar water heaters by 1) reducing the subsidy of fuel and electricity; 2) suggesting incentives to help household to adopt shifting to solar water heaters; 3) intensifying the public campaign to increase the public awareness towards solar water heaters and its benefits.

Abdurrahman and Siala [44] suggested two scenarios of large implementation of solar water heaters in Libya to cover 5% of the demand in 1995: Business as usual scenario (BAU), and Moderate Imaginary Scenario (MIS) with annual of 10.5% and Accelerated Imaginary Scenario (AIS) with annual increase of 22.1%. The study has shown full displacement will occur by the year 2025 in the MIS and by 2010 in the AIS.

Agha et. al. [45] suggested two scenario plans for a period of 20 years, business as usual scenario where the electric water heaters are the common means of water heating in the residential sector and the replacement scenario where solar water heaters replace the electric water heaters gradually using logistic function. The energy savings and the environmental benefits are presented in figures and tables.

Abdunnabi and Musa [46] proposed a strategic plan to help widespread of solar water heaters in Libya. The plan was to provide 25% of existing houses with solar water heating systems, with governmental subsidy of the system cost. The study found that an estimation of technical potential of solar water heaters in Libya is to be over 2.3 million square meters of solar collectors. The money for the program will be obtained from the savings of subsidy used for electricity that would otherwise be used for electric water heaters in the residential sector.

3.5 Economics studies of SWHs in Libya

Some studies conducted to analyse the economic status of solar water heaters in the Libyan environment, and they come out with the conclusion that with the current inputs solar water heaters cannot be implemented economically on a large scale without the intervention of the government.

In Libya, solar water heater with a capacity ranging from 200 to 300 liters can provide over 75% of the hot water demand for family of 3 to 7 persons.

Rajab et al [47] conducted techno-economic feasibility study of using solar water heaters instead of commonly used electric water heaters in Benghazi city. The feasibility study was investigated by using RETScreen simulation software. The authors used only one day measurement of the electric heater power for the calculation of the hot water load pattern and quantity for Libyan household. The average electric water heater power was found to be about 471W; the annual typical average hot water consumption for average Libyan house was found to be 4133.4 kWh per year. This value is different from the measured value obtained by Abdunnabi [27] which is about 3060 kWh/year. The results of techno-economic feasibility study have shown that the total energy savings in Benina region is 767,630 MWh and prevention of emission of 44,765 tons of carbon dioxide to the environment.

Abughres et al [48] presented the results of evaluating solar domestic water heating systems in different regions in Libya. Thirty-six systems were installed in the south and in the coast regions of Libya. The system's performance were monitored periodically during the whole year. However, some of the beneficiaries have failed to maintain the cleanliness of solar collectors from dust and sometimes left them empty without water despite the guidance provided to the owners to avoid such issues. The economic results reported from the feasibility analysis for this application have shown that the cost of each heater can be retrieved after 16 years of operation and provide electrical energy substituted pricing 20 LYD/MWh. However, in case of implementing large-scale program, the expected cost of systems might be reduced by nearly two thirds, resulting in decline for retrieval time by half.

Abou–Zeid and Hawas [49] studied the economics and the optimization of space and domestic water heating system for homes in Benghazi city. 324 cases representing the economic and load factors based on the annual equivalent cost approach. The optimum collector area for each case was determined. The analysis is conducted by a computer program. The results obtained and relationships developed permit generalizations that can be applicable in other locations. The optimum collector area and the corresponding optimum cost were determined for each case considered. In almost all cases, utilizing solar systems were found to be economically acceptable.

4. SOLAR WATER HEATER IMPLEMENTATION

Utilizing solar water heaters in Libya started earlier at the beginning of the 1980's. Until recently one can say that there are no real large-scale implementation of such technology neither in the residential nor in the industrial sectors of Libya. Total systems installed over the past 35 years counted for less than 8000 systems, over third of them was in the Al Burayqah oil city [50]. The most significant installations are given below.

4.1 Marge project

This project was implemented in the early 1980's in the city of Marge, 2,000 thermosyphon open-loop systems of 160 liter storage tank and 2 of collector area are installed. These systems were imported from Metalco Company, Cyprus.

4.2 Al-Burayqah city project

In this project nearly 3000 thermosyphon closed-loop systems (Fyrogenis -Greece) were installed in the new town of Al Burayqah oil city which is located west of Benghazi. About 1,350 systems with 200 liter storage tank and 3 of collecting area. The rest (1550 systems) were with 200 liters storage tanks and $5m^2$ of collector area. Currently, most of these systems suffer from negligiance and lack of maintenance, and even exceeded their expected life time.

4.3 CSERS projects

Since its first establishment, the Center has taken its responsibility to make the public and decision makers aware of the importance and benefits of solar water heaters. A number of small projects were carried-out by the Center under the evaluation project named "filed test project of solar water heaters in the residential sector". Figure 13 shows the kinds of SWH systems installed by the Center. The most important installations are given below:

– The first solar water heaters installed in the residential sector by the Center was in 1983 as part of the evaluation project. 36 thermosyphon open-loop systems were imported from Hitachi Company, Japan and most of them were installed in different areas of the southern and coastal regions of Libya. The capacity of the systems was 200 liters with collection area of 3 m^2 [51].

Figure (13). Solar water heaters installation by CSERS

- In the year 2000, nearly 100 solar water heating systems from different companies and different technologies (forced circulation, natural circulation, heat pipe, integrated collector and storage tank systems) were imported and installed in certain houses in different areas of Libya. Some of these systems were equipped with data logging and full measuring instruments to evaluate thier in-situ thermal performance [12]. Most of these systems are still in good working conditions. The capacities of these systems range from 180 to 500 liters, and the collection area was in the range of 2 to 6.6 m^2.
- In 2010 over 75 systems were also imported from different companies with different technologies (flat plate and vacuum tubes). The capacities of these systems were 200 and 300 liters with collector area ranging from 2.2 to 4.5 m^2. Most of these systems were installed in the residential sector, and some of them were used for experiments at the Center.
- In mid 2014 more than 175 systems were imported from two companies, the systems are 200 liters and 300 liters with collection area of 3 m^2 and 4 m^2 respectively. The systems are of open and close loop thermosyphonic type with vertical storage tanks. Until the writing of this article the systems are not installed or distributed.

4.4 REAOL projects

In 2007 new establishment was created to deal with large-scale implementation of renewable energy applications under the name of Renewable Energy Authority of Libya (REAOL). This establishment belongs to the Ministry of Electricity and Renewable Energies. Since its establishment, REAOL was put plan to help penetration of renewable energies (thermal as well as electrical) into the energy mix of the country. It was expected that 150MW of thermal solar to be achieved by installing solar water heaters in the residential and service sectors by 2015. Whereas, by 2025, this figure was planned to reach 600MW_{th} [52],[53],[54]. This was practically started by a project targeting 3000 SWH system of worships houses (Mosques). The project started in 2013, but unfortunately due to military conflicts and political instability, the project was stopped in the contractual stage. If the project is completed, it would be the first large scale implementation of solar water heaters after Al-Breque oil town project over 20 years ago.

4.5 Other projects

No accurate statistics were reported in the past. However there are small projects created by the government and private sectors; few hundreds of systems were installed by the private sector.

5. THE LIBYAN SWHS INDUSTRY

Only two attempts to manufacture solar water heaters in Libya were reported in the past. Brief details of these factories are given below:

5.1 Tajoura Water Heaters factory

This factory was established in the 1980's to manufacture electric water heaters to cover the local market demand with annual capacity of 90,000 units. In 1994 the factory made a joint venture with a Turkish company called GUNES. The agreement was to add new lines to the existing factory for the production of flat plate collectors, and to benefit from the capabilities of the old factory to manufacture storage tank of 150 to 250 liters. To initiate the market, the factory imported 3000 GUNES flat plate solar collectors, and manufactured few hundreds of 150 liter storage tanks in an attempt to sell these systems in the Libyan market with a subsidized price. Unfortunately, due to the cheap price of electric power in Libya, people didn't pay attention to the use of solar water heaters. Tajoura boiler factory was closed a few years ago, and about 2000 of flat plate solar collectors are still in the storage since 1995 [55]. The details of flat plate solar collectors are given in Table 2

5.2 Military manufacturing factory

In 1993, and in order to utilize the military manufacturing factories capabilities, 3000 units were produced; each solar water heater has a storage of 100 liters and a collector of 1.4 m² area. The units were manufactured under the brand name "Shams" upon a contract with a manufacturer from Jordan and few units were sold [53],[56]. These units were tested at the Center for Solar Energy Research and Studies (CSERS). The CSERS recommended not selling these units to the market due to their poor performance. This decision was due to the bad design and cheap materials used for their manufacturing. The main specifications of solar water heaters manufactured are given in Table 3.

Table (2). characteristics of GUNES collector

Item	Value
Gross area	1.7
Aperture area	1.55
Absorber area	1.5
Cover material	One cover, normal glass, 4
Number of tubes	8
Tube diameter	10
$\bar{\eta}_{0A}$	0.691*
$\bar{a}_{1A}$	6.233* W/m²K
$\bar{a}_{2A}$	0.01141 * W/m²K

*These values are obtained from the collector performance test conducted at CSERS

Table (3). Technical specifications of solar water heater (Shams)

Item	Value
Collector gross area	1.41
Collector absorber area	1.23
Collector cover material	One cover, normal glass, 4
Number of tubes	8
Riser diameter	12.7
Collector back insulation	Mineral wall, thickness 35 mm
Storage tank volume	100 Liters
Storage tank material	Galvanized steel with thickness of 2 mm
Storage tank insulation	Polyurethane foam

6. POLICIES AND LAWS

There are many policies and programs utilized to encourage the widespread of this technology. These programs are divided into two main categories: financial and non-financial. The financial programs include: performance-based incentives, rebates and subsidies, and tax incentives.

The most common non-financial programs are: building code requirement, permitting process simplification, long-term strategy and targets, education, training and certification.

So far there were no clear plans or systematic policy to encourage the widespread of solar water heaters in Libya. The cheap oil and electricity helped disencouragement of the up-take of this technology. Recently, REOAL has announced its plan on the targeted dissemination of renewable energy 2015 -2030 with 150 of solar water heaters [52],[53]. However, due to the instability in Libya; no real installations of solar water heaters are conducted in Libya. Libya was ranked tenth among 13 Arabic countries by RECREEE organization [57].

7. TESTING AND CERTIFICATION

The market has to be protected from low quality products by implementing certification scheme.

The Center for Solar Energy Researches and Studies (CSERS) is equipped with full laboratories for testing the performance of solar water heaters and its components. The most important equipments are illustrated below:

7.1 Indoor and outdoor collector test facility

The mobile collector test stand is designed to evaluate the thermal performance of four collectors simultaneously. The dimension of the test stand is 2.5m x 5m, and with load capacity of 500 kg. The test stand is two-axis sun tracking with precision less than ±0.5° in both axes. The test stand is put on rail way rack for indoor and outdoor testing as shown in Figure 14. The laboratory is also provided with sun simulator with solar irradiance varying from 0 to 1000 W/m^2.

7.2 Solar water heating system test facility

The facility of testing solar water heating systems (as a whole system collector and tank) according to the international standards in this regard is available at CSERS as depicted in Figure 15.

Figure (14). Indoor and outdoor test facility of solar collectors

7.3 Storage tank test facility

The unit of testing the physical and thermal properties of the storage tank is available as shown in Figure 16. The overall heat loss coefficient of the tank, the maximum allowable pressure, the nominal size, the dissipation of heat exchanger can be measured by this facility.

Figure (15). Solar water heating systems test facility

Figure (16). Thermal storage tank test facility

Testing and certifications of solar water heaters and their components can be considered as the safeguard of the successfulness of widespread of solar water heaters by avoiding the market low quality systems. Recently, the Center started to run these laboratories for testing samples of solar water heaters in favor of REOAL.

Accreditation and certification bodies must be implemented in Libya, this is very important for approving laboratories and issuing certifications of solar water heaters and their components. In 2012, SHMCI certification scheme for certification systems and quality label of solar water heaters in the Arab region similar to solar keymark in the European Union is initiated by RCREEE [58],[59].

8. BARRIERS IN WIDESPREADING ADOPTION OF SWHS

Despite the use of solar water heaters in many places in the world, yet their use in Libya is very rare due to many factors among which lack of public awareness and the cheap price of electric power. Only few hundred thermosyphon solar water heaters have been in use in different parts in the country. Some of the obstacles are discussed below.

8.1 Price of conventional fuels

In Libya, the commonly wide method of providing hot water for the residential sector is through the use of electric water heaters, which is the most pollutant and expensive way of providing hot water for domestic purposes. However, solar water heaters are still not competitive due to the fact that the price of conventional energy is subsided in a way that makes other alternatives uncompetitive.

8.2 Financial reasons

Lack of financial incentives: due to the high capital installation cost of solar water heaters, a lack of incentives negatively impacts the payback period in comparison to other technologies. The cost of solar systems in Libya is over five times the cost of the electric water heaters.

8.3 Lack of public awareness

Public unawareness in solar thermal applications may also be attributed to the limited number of real-scale large installations in Libya. In order to overcome this problem, further demonstration projects are required.

8.4 Technical barriers

There is a lack of technical capacity in designing properly sized solar systems and in integrating them with the existing systems, especially in large industrial and commercial systems. In addition, solar water heating systems do not function well if they are not installed correctly. There is shortage of properly trained engineers and installation technicians. The greatest technical challenge for efficient performance of solar hot water systems lies in their planning and installation.

9. CONCLUSIONS

This study attempted to review the accessible literature in the field of solar water heating dedicated to Libya. The study focused on the research activities for the implementation, testing facilities, and policies and laws. The review reveals that there are a large number of studies carried out for utilizing solar energy for heating water for domestic purposes, whereas a limited number of studies were found dealing with larger solar water heating systems for service and industrial sectors. Most of the studies were carried out at the CSESR, and some of them are important for furnishing the base for identifying the hot water load pattern and the consumption per capita of Libyan families. However, more representative hot water load pattern and consumption requires further detailed studies to be considered in the future.

The review presented the previous experience of the Libyan industry for manufacturing solar water heaters in the Libyan market. Quality control of the imported or manufactured systems are among the tasks of the CSERS, the review went through the capabilities of the CSERS and supporting laws and decrees in this regard. The testing facilities are not fully operated, and even there are no supporting laws to force the manufacturers and traders to ratify their pre-marketing systems

From the aforementioned review it is clear that there is a wide gap between the technical institutions and the political authorities and decision makers of Libya. Strategic plans were suggested since earlier stages in the beginning of the 1980's. The technical institutions have to provide very detailed and precise studies and plans regarding the importance of shifting to alternative sources of energy and saving the oil reserves for the future generations and economic development. The widespread of solar water heaters technology is a main priority to be implemented urgently as the current practice of heating water in the residential sector using electric water heaters is very expensive and pollutant.

Libya has to put strategic plan for its energy policy and energy mix to secure its energy resources and guarantee continuous supply of energy for future generations. The literature reveals that a lot of information are available to be exploited to put accurate plan for Libyan energy future and the deployment of solar water heaters.

Various regulatory, awareness, pricing, and other issues pose a barrier towards the wide scale adoption of solar water heaters in Libya. However, the most obvious obstacle of the wide spread of solar water heaters in

Libya has been the absence of actual plan or intention to implement renewable energy technologies.

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