Renewable and Sustainable Energy Reviews 62 (2016) 336–349

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimum selection of solar water heating (SWH) systems based on their comparative techno-economic feasibility study for the domestic sector of Saudi Arabia

Hafiz M. Abd-ur-Rehman [a,b], Fahad A. Al-Sulaiman [a,c,*]

[a] Mechanical Engineering Department, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia
[b] School of Mechanical & Manufacturing Engineering (SMME), National University of Sciences & Technology (NUST), H-12 Campus, Islamabad, Pakistan
[c] Center of Research Excellence in Renewable Energy, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form
6 April 2016
Accepted 26 April 2016

Keywords:
Solar water heating system
Evacuated tube collectors
Flat plat collectors
Solar fraction
Domestic sector
Saudi Arabia

ABSTRACT

The aim of this work is to evaluate the optimum selection criteria for domestic solar water heating (SWH) systems based on the techno-economic aspects of evacuated tube and glazed flat plat solar collectors. Ten different cities in Saudi Arabia are considered. Choices were made to cover different geographical co-ordinates of Saudi Arabia under different climatic conditions. Simulations were performed to obtain at least 50% solar fraction and the rest of the need was fulfilled by electricity. Simulated results based on solar radiation on the horizontal and tilted surface, solar fraction, greenhouse gas (GHG) emissions, and energy savings are used for comparative performance analysis of the SWH systems while payback period, benefit to cost ratio, annual life cycle savings, and number of occupants are the deciding factors for economic viability of these systems. Findings indicate that under the same prevailing conditions Nejran, Bisha, and Madina are the most feasible cities while Sulayyil is the least suitable place for SWH system. Riyadh, Dhahran, and Gaseem show noticeable financial advantages by using evacuated tube collectors over glazed flat plate collectors. The findings demonstrate that a higher number of occupants gives a lower payback period and a higher benefit to cost ratio; as long as the number of collectors are not increased to a limit where higher initial cost dominates and decreases the economic viability of the project.

Contents

Abbreviations: B-C, Benefit to cost; CSI, California solar initiative; GHG, Greenhouse gas; KSA, Kingdom of Saudi Arabia; kWh, Kilowatt hour; MBOE, Million barrels of oil equivalent; MWh, Megawatt hour; PV, Photovoltaic; RHI, Renewable heat initiative; SWH, Solar water heating; tCO_2, Tons of carbon dioxide; VAT, Value added tax

* Corresponding author. Tel.: +966 13 860 4628.
E-mail address: fahadas@kfupm.edu.sa (F.A. Al-Sulaiman).

http://dx.doi.org/10.1016/j.rser.2016.04.047
1364-0321/

1. Introduction

The energy crisis, drinking fresh water scarcity, and climate change are some of the most intimidating issues of the present time. The challenge is to provide sustainable solutions to balance the requirements for secure, affordable energy with the pressing issue of climate change. One potential solution to meet this challenge is to implement policies that favor renewable energy sources over fossil fuels. Among the renewable energy sources, solar energy seems to be an attractive alternate energy source that can help to increase energy independence and reduce the consequences of global warming.

The Kingdom of Saudi Arabia (KSA) has massive proven reserves of fossil fuel [1,2], which is about 265 billion barrels of oil and 290 trillion standard cubic feet of natural gas. Irrespective of the enormous availability of the fossil fuel, the Kingdom is intuiting the energy sustainability concerns in the near future due to remarkable growth in demand for power in the previous decade [3]. The average yearly increase in KSA domestic energy usage is about 4.8% in the last decade whereas the country oil and gas production is increased by only 1.36% in the same time frame. The present domestic fossil fuel consumption is about 3.4 Million Barrels of Oil Equivalent (MBOE) and is anticipated to rise around 8.3 MBOE by 2028 [4]. It is projected that the peak power demand will rise from 55 to 121 GW by 2032 [5]. This notable increase in peak power demand will encounter a gap of 61 GW between the strategic supply and anticipated demand. This alarming situation is not only a threat to KSA oil export revenues [6] but could also force the Kingdom to import oil if existing supply-demand circumstances extends for coming two decades [7]. Therefore, there is a need to build policies that strengthen the energy security conditions of KSA. Loss in export revenues and increases in GHG emissions due to the extensive use of petroleum products are issues that can be resolved by implementing policies that favor renewable energy resources. One initiative in this concern is the use of solar water heaters to meet the hot water requirements in the domestic sector.

Hot water requirements are an important segment of energy consumption in the domestic sector of KSA where the majority uses electric water heaters in winter. Solar water heaters are a better alternate to electric water heaters [8]. Solar water heating (SWH) is the most widely spread use of solar thermal energy and has many applications like domestic water heating, space heating, and pool water heating. Among all its applications, domestic water heating experiences the highest penetration in the solar thermal market [9]. SWH systems work on heat transfer fundamentals through a solar collector that is the main component of SWH systems. SWH systems are of two types. One is an active SWH system or forced circulation SWH system that consists of controls and pumps while the other type is a passive SWH system that does not contain pumps and controls. The thermo-siphon SWH system is a passive water heating system that is extensively used in countries with higher solar potential [10]. Simple configuration of the thermo-siphon SWH system is shown in Fig. 1. It consists of a water tank placed above the collector or made integral to it. The system takes the advantage of natural circulation of water due to its thermo-siphon property. That is, when water is heated in the solar collector, it becomes less dense and rises into the tank above. In the meantime, the cold water from the tank flows downwards into the collector and causes circulation of water throughout the system. No controller or pump is required in this system, which makes it simple and less liable to fail.

Significant research has been carried out toward the advancement of SWH systems and a mature technical platform has been established. A detailed literature review on solar water heaters was carried out by various author's (e.g. [11–13]) who discussed

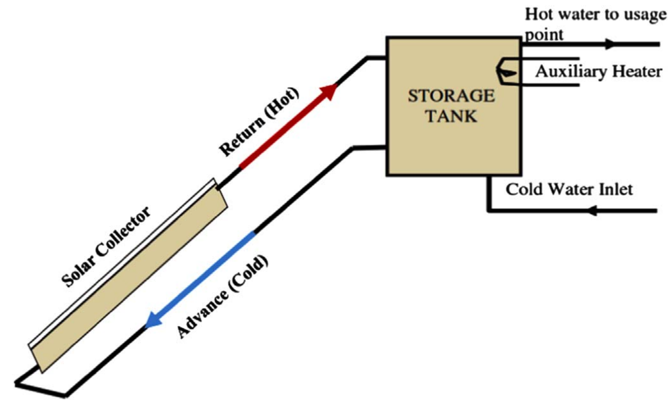

Fig. 1. Schematic of a passive solar water heater.

several techniques to improve the performance of SWH systems, limitations of existing technologies, and possible modifications that could further improve the overall efficiency of SWH systems. These studies emphasized that further research should be carried out on thermo-siphon SWH systems, as these systems are the most suitable options for the domestic sector due to the simplicity of operation and minimum maintenance requirements. Although a mature technical platform for SWH systems has been established, financial feasibility is an important factor that needs to be examined carefully for the dissemination of SWH systems. The financial feasibility of SWH system is highly dependent on the subsidies given by the government and the cost of auxiliary energy source for water heating. To substantiate the cost of establishing renewable energy systems, many countries have started incentive programs. In Europe, all member countries, except Denmark, Greece, and Finland, offer financial incentives for SWH system installation [18]. Most of the European countries have lowered their Value Added Tax (VAT) on solar equipment's. In 2003, Austria and Spain fully exempted the VAT from solar equipment's [14]. From 2006, France established a 50% tax rebate program for SWH systems. According to that program, 50% of SWH system cost can be deducted from the household's income tax [15]. In 2008, Taiwan implemented a rebate program in Kaohsiung City (2nd largest city in Taiwan) to subsidize 50% cost of SWH installation in residential sector. The rebate program strengthen the SWH market in Kaohsiung and resulted in more than 18,000 new SWH system installations over the next two years of this rebate program [16,17]. The United Kingdom initiated a performance based Renewable Heat incentive (RHI) program for domestic sector in 2014. According to this program, the SWH system owner is provided with quarterly payments for each kWh of generated thermal energy. The owner are eligible to get payments after seven years of domestic SWH system installation [18]. In United States, the California Public Utilities Commission started a hybrid financial incentive program known as California Solar Initiative (CSI) Thermal Program. The program aimed to replace approximately 100 thousand electric and 200 thousand natural gas heaters. According to this program, the SWH system owner is provided with the upfront payment that is equivalent to the cost of kWh expected to be displaced by the system. In July 2015, the estimated annual energy savings was over 940,000 kWh by the replacement of electric eater heating system with SWH system [19]. Most of the Gulf countries are unable to develop policies that encourage the usage of SWH system. This is due to the abundant availability of fossil fuel and highly subsidized cost of electricity [20]. KSA spends around 33 billion US dollars annually on subsidies for electricity and desalination [21]. Low pricing policy for domestic fuel in the Kingdom caused an extravagant consumption of energy resources and turned the 20th largest economy of the world into 6th largest consumer of oil [22].