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TECHNO-ECONOMIC EVALUATION OF SOLAR WATER HEATING APPLICATIONS AT HOSPITALS IN SAUDI ARABIA

Hamad Almahmoud[1], Fahad A. Al-Sulaiman[2] and Hafiz Abd-ur-rehman[1]

[1] Mechanical Engineering Department, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, 31261, (Saudi Arabia)

[2] Center of Research Excellence in Renewable Energy (CoRERE), King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, 31261, (Saudi Arabia)

Abstract

To contribute in reducing the electricity consumption rate and the harmful impacts of fossil fuels, a Solar Water Heating (SWH) technology is recommended to cover around 50% of hot water demand in hospitals in Saudi Arabia. The paper studies the techno-economic viability of two types of SWH collectors in five different cities of Saudi Arabia. Findings indicate that Najran and Tabuk are the most attractive places because they have the highest annual life cycle saving, the highest benefit to cost ratio, and the lowest payback period, while, in contrast, Jeddah is the lowest attractive city to use SWH. Moreover, the economic analysis shows the advantage of using glazed flat plate collector over evacuated tubes because it has shorter payback periods and higher annual life cycle savings.

Keywords: *Solar Water Heating, Evacuated tubes, glazed flat plate collector, Hospital, Saudi Arabia*

1. Introduction

The rapidly increasing demand of electricity and global warming are factors that have brought interests to find an environmental and efficient source of energy. Solar energy is the most abundant source of energy and it will be the future source of energy for countries that receive high amount of solar radiation such as Saudi Arabia. The conventional electric water heating technology is used in Saudi Arabia to meet the demand of the hot water. The process of water heating by electricity in a hospital with 200 beds consumes annually around 450 MWh and, therefore, employment of solar water heating (SWH) systems is recommended.

Oil is the main source of energy in Saudi Arabia, however, the enormous potential of solar energy has brought the government attention in 1980s and, therefore, different solar technologies were developed and tested [Huraib, 1996]. Saudi Arabia receives high intensities of solar radiation in most of its regions that makes it an attractive place for implementing solar energy systems. A study was conducted to assess the daily solar radiation for ten different cities in Saudi Arabia and it was reported that the daily solar radiation varied from 4.73 to 6.94 kWh per m^2 [Bahel, 1986]. Another study selected four different climatic zones in Saudi Arabia and found similar results [Zuhairy, 1995].

In the past decade, attention has been concentrated in optimizing energy consumption in large buildings such as hospitals. Around 5% of the energy consumed in hospitals is for water heating [Čongradac, 2012] with almost constant consumption of 9 GJ per bed throughout the year [Bujak, 2010]. Some studies have developed different technologies to enhance the use of renewable energy in hospitals, such as solar energy in combination with thermal aquifer energy storage [Paksoy, 2000], hybrid plant using solar thermal, photovoltaic, and phosphoric acid fuel cell systems [Bizzarri, 2006].

Solar water heating technology have been widely used for domestic applications. [Kablan, 2004] reported that a continuous rise of solar collector installations in the period 1970 to 1995 was observed in Jordan. Techno-economic evaluation for SWH system of glazed flat plate collectors in Oman was presented by [Gastli, 2011]In a different study, [Hafiz and Al-Sulaiman, 2014] reported the techno-economic evaluation for glazed and evacuated tube collectors for water heating of residential buildings for different cities in Saudi Arabia.

The demands for water heating in hospitals are huge and, therefore, there is a need to seek a cost effective solution based on solar thermal energy. This study evaluates the techno-economic feasibility of using two SWH systems for a hospital with 200 beds at different locations in Saudi Arabia. The findings will help decision makers and engineers to determine the technical and financial viability of potential renewable energy projects in hospitals in Saudi Arabia or other countries that have similar operating and weather conditions. A Solar Water Heating (SWH)

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technology is recommended to cover around 50% of hot water demand in hospitals in Saudi Arabia. This percentage is selected because the sun is available only on the daytime and it is a visible solution to use this percentage; otherwise, using a larger percentage means, a larger solar collector should be installed, which is not practical due to space limitation.

2. Metrological data and simulation

This study is performed to cover a large area of Saudi Arabia, which is situated between latitudes of 17.5°N and 31°N, and longitudes of 36.6°E and 50°E. The findings will also be useful to other locations that have similar weather conditions in other countries. In this study, five different cities were selected to cover different coordinates, which are Tabuk (north), Dhahran (east), Riyadh (center), Jeddah (west), and Najran (south). The metrological data of the five cities selected have been listed in Tab. 1 [NASA RETscreen, Renewable Resource Atlas].

Tab. 1: Climate data for the selected cities.

Location	Jeddah	Riyadh	Dhahran	Najran	Tabuk
Average daily solar radiation (kWh/m^2/d)	5.95	6.2	5.83	6.77	6.33
Air Temp (°C)	30.7	28.6	27.8	26.5	23.4
Earth Temp (°C)	29.8	29.2	28.1	26.7	24
Latitudes (ø)	21.7	24.9	26.3	17.6	28.4
Longitude	39.2	46.7	50.2	44.4	36.6
Elevation (m)	17	614	17	1212	768
Wind speed (m/s)	3.3	2.9	2	2.1	2.8
Relative humidity (%)	56.7	24.9	49.6	22.2	31.7

The metrological data for these cities, including air temperature, average daily solar radiation, atmospheric pressure, wind speed, and relative humidity were imported from NASA database. These data were further crosschecked with the experimentally recorded data by K.A.CARE [Renewable Resource Atlas, 2015] and the data for Tabuk city was corrected. Figure 1 illustrates the daily solar radiation data for a horizontal surface where Tabuk has the highest solar radiation during the summer months whereas, Najran has the highest radiation during the winter months. It also shows that, on average throughout the year, Najran has the highest solar radiation while Dhahran has the lowest solar radiation, which can also be noticed in Tab. 1.

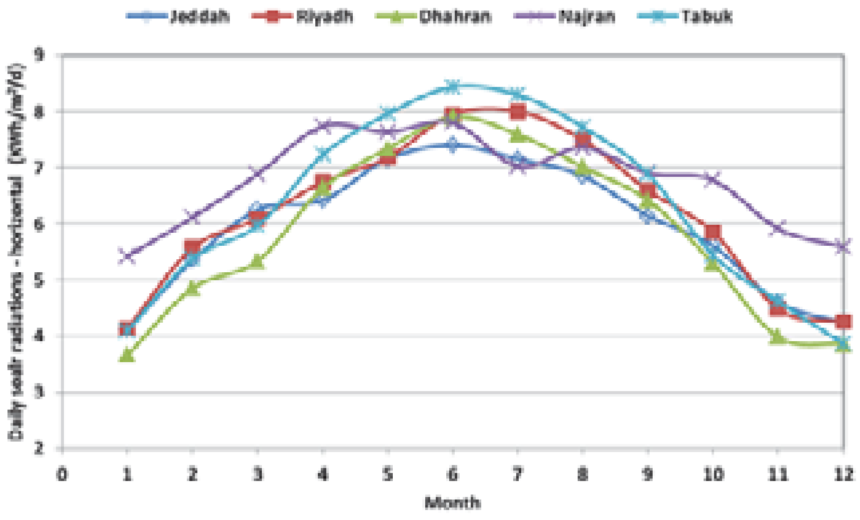

Fig. 1: Monthly variation of daily solar radiations on horizontal surface.

To get the best configuration for the collector, the study evaluated the SHW under two slopes. The first one is tilted at a slope equal to the latitude angle of the city selected, which represents the optimum value of the slope for a system to be used constantly throughout the year, while the other setting is for a horizontal surface. The findings have been shown in Fig. 2, which reveal the difference between the two settings.

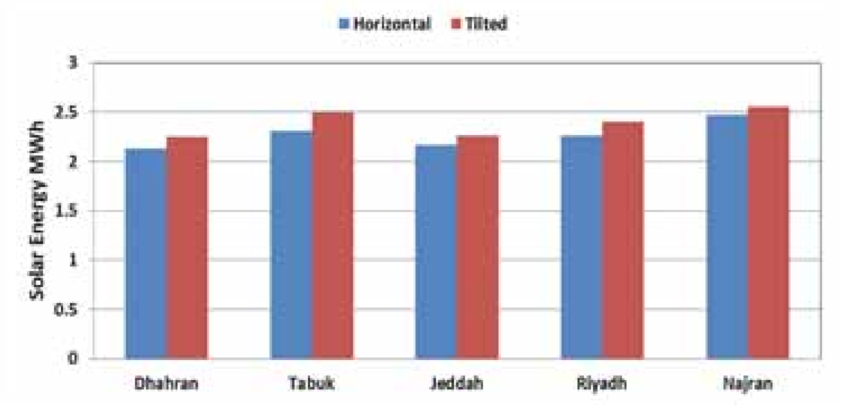

Fig. 2: Annual Solar Energy for horizontal and titled collectors.

There are three commonly used SWH technologies which are evacuated tube, glazed, and unglazed flat plate collectors. The temperature required for hot water in hospitals is between 50 and 60 °C and, therefore, only glazed flat plate collectors and evacuated tube collectors were selected to obtain the required temperature, meanwhile obtaining the required solar fraction with relatively a low aperture area [International Energy Agency, 2012]. Simulations were conducted for both technologies and the input data has been listed in Tab. 2 [Gastli, 2011, Abd-ur-Rehman and Al-Sulaiman, 2014]. Simulations were performed for evacuated tube collector to cover 50% solar fraction of the 200 beds hospital in Tabuk. Results indicate that the desired solar fraction can be achieved by using 21 collectors of evacuated tube type in Tabuk, which was used as a reference to analyze other four cities selected Similarly, simulations were performed for flat plate collectors under the same prevailing conditions and comparative analysis was conducted to obtain the optimum number of the collectors to be used for hospitals under different climatic conditions of Saudi Arabia. The technical and financial characteristics for both collector types have been listed in Tab. 3 [RETscreen].

Tab. 2: Input parameters for the evacuated tube collectors.

Parameter	Value
Number of beds	200
Occupancy rate (%)	80
Daily hot water usage estimate (L/day)	31,500
Hot water temperature (°C)	60
Operating days per week	7
Collector slope	Location latitude
Miscellaneous losses (%)	5
Storage capacity per square meter (L/m^2)	75
Conventional fuel type	Electricity
Seasonable efficacy (%)	90
Electricity rate ($/kWh)	0.03
Initial contingencies (labor, transportation etc.) (%)	5
Annual cost (O & M) (%)	5
GHG emission factor (tCO$_2$/MWh)	0.737
Fuel cost escalation rate (%)	2
Inflation rate (%)	2.5
Project life (years)	20

Tab. 3: Specifications for the evacuated and glazed collectors.

Solar Collector Type	Evacuated Tube	Glazed
Gross area per solar collector (m^2)	12.22	10.7
Aperture area per solar collector (m^2)	9.02	9.52
Fr (tau alpha) coefficient	0.53	0.63
Fr UL coefficient (W/m^2)/°C	1.42	3.88
Number of collectors	21	24
Capacity (kW)	132.5	160
Initial cost (US$)	77000	58500

3. Result and Discussion (results and discussion)

Evaluation and comparisons in terms of performance and economic viability have been conducted for both collector types. The solar fraction is defined as the percentage of the annual energy needs that the SWH system will cover. This value is set for Tabuk to be 50% for both flat plate and evacuated tube SWH systems. This means that the SWH system will cover half of the energy consumption and the rest of the energy requirements are met by a conventional heating system, which is electricity in our case. The findings, as shown in figure 3, demonstrate that the solar fraction varies from 49% to 55%, where Najran has the highest fraction and Dhahran has the lowest fraction. The variations of the solar fraction among the selected cities are relatively small which reflect the viability of using SWH in these cities.

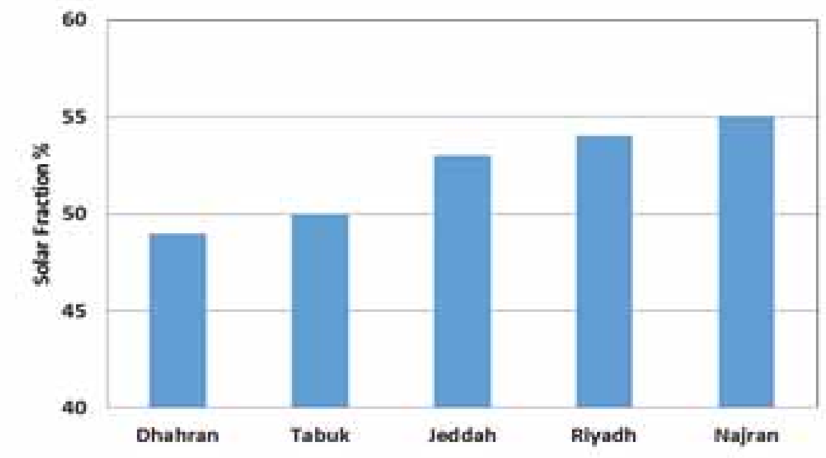

Fig. 3: Solar fraction of the annual energy needs covered by SWH.

The process of water heating to specific temperature by electricity consumes relatively a huge amount of energy, which is also function of input temperature to the system. Another evaluating term for a SHW technology is the electricity saving potential per year, which is the amount of energy that will be saved after using a solar heating system. It is directly proportional to the solar fraction, for example Tabuk has 50% solar fraction and it is expected to save 271 MWh annually, as shown in Fig. 3. Therefore, the conventional heating system will cover the rest of the total consumption, which is 271 MWh per year. Fig. 4 illustrates the annual electricity saving potential for each city on the left y-axis and the potential savings for whole project life on the right y-axis. The average electricity saving potential per year for all cities is 229 MWh and the average saving during the twenty years project life time is 4588 MWh.

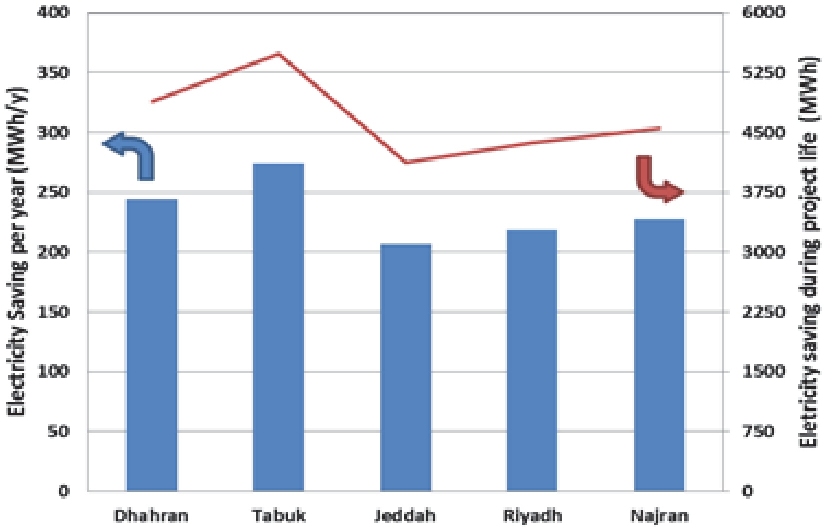

Fig. 4: Electricity saving potential.

The environmental advantages of using the SHW systems were also assessed. The study reports the amount of greenhouse gas (GHG) emissions that will be reduced after installing the environmentally friendly SWH system. Fig. 5 shows the annually expected GHG emissions reduction on the left y-axis while the total reduction of the emissions during the life-time of the project are shown on the right y-axis. It is shown that the highest amount of GHG emissions will be avoided in the cities of Tabuk and Najran, which reach 200 tons of annual CO_2 emissions. In addition, the cumulative reduction over the project life-time for these two cities is expected to be 4000 tons of CO_2 emissions.

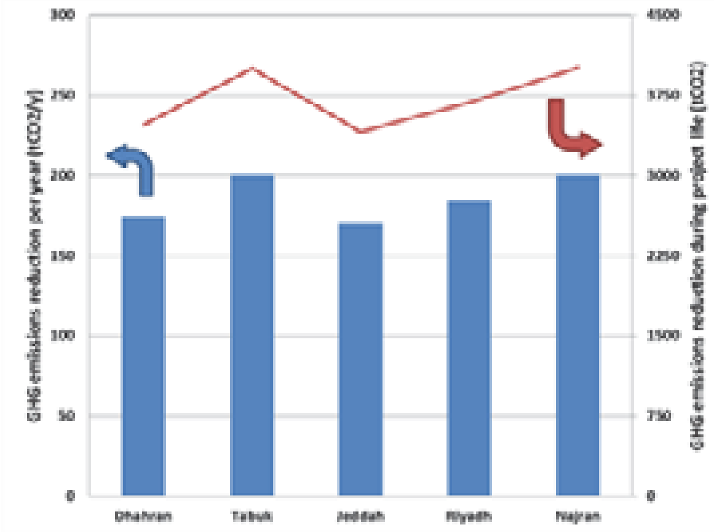

Fig. 5: GHG Emissions Reduction Potential.

After discussing the performance of the SWH technology, the economic viability of the system will be discussed next. It should be noticed the difference between the performance analysis where we have equivalent outputs for both evacuated and glazed collectors; the financial analysis will vary between the two technologies according to the initial cost and the annual saving of the project.

The payback period is the time for an investment to recoup its own initial cost from the savings it generates; the less time it takes the more desirable the project is. Fig. 6 presents the payback period of the project for both collector types. For the evacuated tube system, Najran and Tabuk have the shortest period of 8.9 years while the other cities have slightly longer periods, in which the maximum period takes place in Jeddah. Selecting flat plate collectors reveal better economic option because it recovers the initial cost faster for all the cities selected. The findings show that Najran and Tabuk, in terms of payback period, are the most attractive cities with flat plate collectors at which they recover their initial cost in less than seven years.

Fig. 6: Payback Period.

Another economic evaluation parameter is the annual life cycle savings that would present the yearly cost saved and together with the solar fraction, a project can be evaluated economically. The annual savings for the evacuated tube system varies between $2054 and $3429 for Jeddah and Najran respectively, as shown in Fig. 7. The figure also shows the advantage of the flat plate type where its annual savings varies between $3389 and $5048 for Jeddah and Tabuk respectively.

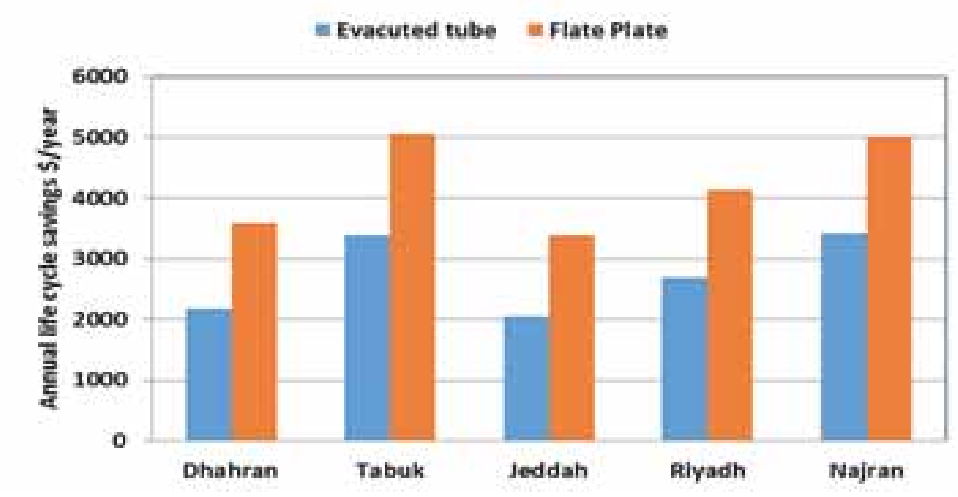

Fig. 7. Annual life cycle savings.

4. Conclusion

The study discussed the techno-economic feasibility of using SWH systems for five different cities in Saudi Arabia. The conclusions obtained from this study are:

- For the same number of collectors, the difference of solar fraction between the selected cities is relatively small which indicates viability of all regions in Saudi Arabia to adopt SWH technology.
- For all cities, the electricity saving potential is high and can reach up to 5400 MWh for project life time of 20 years. This also leads to high reduction in GHG emissions.
- For the same solar fraction in both evacuated tube and glazed SWH technologies, the economic analysis shows the advantage of using glazed flat plate collector because it has shorter payback periods and higher annual life cycle savings.
- Based on techno-economic evaluation, Najran and Tabuk are the most attractive places followed by Riyadh and Dhahran. Jeddah is the least attractive city among the five selected cities due to higher payback period and lower annual life cycle savings.

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