Pre-assessment of Middle East countries in the field of using solar water heaters in building façades

Mehdi Jahangiri [1*], Mahshid Babaei [2], Asadolah Fazeli [3]

[1] Energy and Environment Research Center, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran.
✉ mhd.jahangiri@gmail.com

Abstract

The use of solar water heaters (SWHs) in building facades in the Middle East region can significantly reduce energy consumption and carbon emissions. It can also reduce residents' electricity bills and provide a reliable source of hot water. Based on conducted studies, for the first time, the dynamic technical-energy-economic-environmental analysis of SWHs has been carried out in 17 countries in the Middle East region using TSOL PRO5 software. The use of accurate calculation of space heating requirements, among other differentiations from previous work, ensures that the results of this study are highly reliable and realistic. According to the results, Kuwait, Qatar, and Saudi Arabia have been identified as the most suitable countries because they have a higher percentage of heat supplied by solar energy. Turkey, Iran, and Jordan are considered less suitable countries. The average heat supply provided by SWHs in this region is 65.3%, which prevents the emission of more than 23 tons/year of CO_2 pollutants.

Keywords: Auxiliary gas boiler; thermal load; domestic hot water; total solar fraction.

1. Introduction

Solar water heaters are not only environmentally friendly and cost-effective, but also highly reliable. They require very little maintenance and with proper care and maintenance, they can last for 20 years or more. This means that households can enjoy hot water without worrying about frequent repairs or replacements [1]. Solar water heaters are also very versatile and can be used in various settings. They can be installed in homes, businesses, schools, hospitals, and other buildings that require hot water. Additionally, using SWHs can help reduce dependence on fossil fuels and promote energy independence [2].

Solar water heaters are an effective and sustainable solution for reducing greenhouse gas emissions and combating climate change. By significantly reducing the consumption of fossil fuels, which are limited resources and contribute to air pollution, the use of SWHs can make a considerable impact [3]. In regions with high solar radiation, such as the Middle East and North Africa, SWHs can provide up to 80% of a household's hot water needs and reduce dependence on expensive imported fuels [4]. It has been shown that SWHs have a positive impact on overall health by reducing indoor air pollution compared to traditional heating methods such as wood or coal stoves [5].

Installation of SWHs can also create jobs in the renewable energy sector and contribute to local economic development. According to the International Energy Agency (IEA) report in 2019, the global capacity of SWHs was estimated to be around 500 GWhth by the end of 2018 [6]. Regarding Middle Eastern countries, a study by the United Nations Development Program (UNDP) in 2017 showed that SWHs are widely used in countries such as Jordan, Lebanon, and Palestine. In Jordan alone, it was estimated that around 200,000 SWHs have been installed [7].

There are several reasons why the use of SWHs is essential in the Middle East [8-10]:

- Abundant sunlight: The Middle East receives abundant sunlight throughout the year, making it an ideal location for harnessing solar energy.
- Cost savings: SWHs can significantly reduce energy bills and have long-term cost savings compared to traditional water heating methods.
- Environmental benefits: SWHs are a clean and renewable energy source that reduces carbon emissions and helps mitigate climate change.
- Government incentives: Many governments in the Middle East offer incentives such as subsidies or tax credits to encourage adoption of solar technology, making it an attractive option for homeowners and businesses.

Overall, the use of SWHs in the Middle East is a practical and sustainable solution that can help reduce energy costs, promote environmental sustainability, and support economic development. Based on studies, solar water heating systems can meet up to 70% of the domestic hot water demand in the Middle East region. This report demonstrates that Middle Eastern and North African countries have the highest solar radiation levels in the world, making it an ideal location for solar energy utilization [11].

In Table 1, the recent works that have been done in the field of using SWHs in the Middle East countries have been discussed. In order to understand the difference between the works in Table 1 and the present work, the details of each work have been mentioned in detail so that the existing scientific gap can be clearly seen.

Table 1. Recent studies on the use of SWH in Middle Eastern countries.

Country	Authors	Year	Topic	Methodology	Result
Bahrain [12]	Gaaliche et al.	2017	Investigating the performance of an integrated conical SWH with a glass cover	Experimental investigation and mathematical simulation	The daily performance of about 32%, the highest water temperature of about 45°C at 4:00 pm in the system is achieved, depending on the seasons and weather conditions. The results of the simulation method were confirmed using experimental data.
Egypt [13]	Haghani et al.	2023	Investigating the performance of SWHs for domestic use in 35 stations	Simulation with TSOL software	The use of SWHs resulted in the annual production of 134.5 GWh of solar heat. Greenhouse gas emissions decreased by 2.39 tons/year.
Iran [14]	Jahangiri et al.	2021	Investigating the performance of SWHs on a residential scale in 47 stations	Simulation with TSOL software and use of data envelopment analysis method with GAMS V24.1 software for ranking	By producing 223.1 MWh of solar heat annually, the emission of 64.5 tons of CO_2 is prevented every year. The average price of solar heating for homes in Iran is $0.160 per kWh.
Cyprus [15]	Bamisile et al.	2017	Investigating the performance of SWH on a residential scale in the short and long term in order to develop policies for the use of SWH	Questions from 1000 people	50% of households without SWH plan to install soon. 80% of respondents agree to use SWH.
Iraq [16]	Hamdon et al.	2021	Economic study of SWH performance for domestic use in 3 stations	Experimental	For the 3 levels of low, medium and high consumers, the annual electric energy saving is between 20.6-21%.

Israel [17]	Li et al.	2012	Investigating the government's role in accepting green technologies and comparing with other countries	Analytical and statistical review	It is economical to use SWHs. Government support, including promoting green innovations, providing education and training programs, and building adaptive capacity of communities, will increase positive attitudes and responsibilities of the public towards the environment and future generations, thereby accelerating the popularity of SWH, especially in multi-story buildings.
Jordan [18]	Awad et a.	2022	Investigating SWHs in apartments in order to investigate its impact on human development index	Analytical and statistical survey of 1033 households	Despite excellent radiation, the demand for SWH is still not suitable. Increasing the use of SWH will increase the class of the human development index from medium to high class.
Kuwait [19]	Ghoneim et al.	2016	Performance evaluation of vacuum tube solar collector in hot climate	Theoretical modeling and TRNSYS software	The optimal collector with an area of 44 m^2 has been able to provide 74% of the total required heat and has a life cycle saving value of $2300/year.
. Lebanon [20]	Elmustapha et al.	2017	Evaluation of acceptance of solar heating systems among 200 households	questionnaires and statistical studies	65.5% of households have a tendency to use SWHs. Meanwhile, advertisements in mass media stating the advantages increase the propensity to use SWHs, while the complexity reduces the probability of acceptance.
Saudi Arabia [21]	El Assal et al.	2019	Effect of lateral reflectors on the performance of flat plate solar heating system	TRNSYS software	The average thermal efficiency without a reflector was 46%, adding the reflector increases the water outlet temperature by 12 degrees Celsius compared to the inlet water temperature.
Qatar [22]	Gowid et al.	2019	Economic evaluation of solar heating systems in residential villas with zero energy consumption	Cost-benefit analysis	By using SWHs, the total savings per villa will reach 299 Qatari Rials and 21 million Qatari Rials in the country.
Palestine [23]	Elnaggara	2023	Energy-economic-environmental investigation of SWH and solar air heater heating systems	Experimental investigation and mathematical simulation	The maximum annual heating energy obtained for solar air heater was equal to 20,360.7 kWh at the inclination angle of 30° and for SWH was equal to 19,268.9 kWh at the inclination angle of 45°. The return on investment achieved in SWH, and solar air heater is 4.4 and 4 years respectively.
Oman [24]	Wazwaz and Khan	2021	Construction of a sample heating system of flat glass plate	Experimental investigation and mathematical simulation	The maximum water temperature was 73.6 °C, the average efficiency was 57.6%, the optimal angle was 43.4°, and the construction price was $70.
Syria [25]	Skeiker	2009	Examining the tilt angle and optimal orientation of SWHs	Mathematical modeling	Changing the slope monthly has almost the same result as changing the slope on a daily basis and produces about 30% more energy than a fixed solar collector on a horizontal surface.
Turkey [26]	Simapour et al.	2021	Technical-environmental assessments and classification of the use of SWHs on a	Simulation with TSOL software and use of data envelopment analysis method	The efficiency of evacuated tube SWHs is better than flat plate SWHs in all stations. The Sinop station is the most inappropriate station.

			household scale in 45 stations	with GAMS V24.1 software for ranking	
UAE [27]	Aoul et al.	2018	Parametric optimization and economic analysis of using SWHs in different buildings in hot weather	TRNSYS software	For 21000 m of the floor area of spaces such as schools, offices, residences, factories and hospitals, respectively 8 m², 210 m², 14 m², 24 m², and 38 m² solar collectors with a tilt angle of 24° are needed. The investment return period was also estimated to be about 2 years.
Yemen [28]	Al-Abibi and Odhah	2021	Investigating the solar water heating system in a private hospital with 160 beds	TRNSYS software	Evacuated tube solar collectors have an annual capacity of 87.73 MWh with an annual average solar fraction of 63% and an annual average installation efficiency of 68%.

Generally, while some Middle Eastern countries such as Saudi Arabia and Jordan have made significant progress in adopting solar heating technologies, others like Egypt and Iran are still lagging behind. However, with increasing awareness of the benefits of renewable energy and supportive government policies in the region, it is expected that more households will utilize solar heating in the coming years. Based on studies conducted in Table 1, it can be observed that these studies are limited to specific countries and no regional-scale studies have been conducted so far. Considering the very high solar radiation potential of the Middle East region, the present study has focused on analyzing energy, environmental, and economic aspects of 17 countries in this region using TSOL PRO5 software. The scale of the study was residential, with the aim of meeting a portion of the building's heating needs.

2. Location for study

As shown in Figure 1, the Middle East region is located in West Asia and North Africa and consists of 17 countries. The total area of this region is approximately 8.6 million km² and has diverse climates including deserts, mountains, plateaus, and coastal areas [29]. According to the World Bank statistics in 2021, the population of this region was approximately 258 million people, with Egypt and Iran being the most populous countries in this region [30]. The Middle East region experiences considerable fluctuations in solar heating due to its desert climate and lack of clouds. The 20-year average horizontal solar radiation for this region is shown in the figure below, indicating that the radiation ranges from 4.38 to 6.84 kWh/m².

3. Methodology

TSOL software is a simulation software used for analyzing and optimizing the performance of solar heating systems [31]. It is widely used by experts in the field of solar heating due to its ability to model complex solar heating systems [32]. One advantage of this software is its user-friendly interface, as well as the ability to simulate different configurations. However, it has limitations such as the need for accurate input data and the inability to simulate the impact of certain parameters [33]. The performance diagram of this software is shown in Figure 2, and the schematic of the system under study is shown in Figure 3.

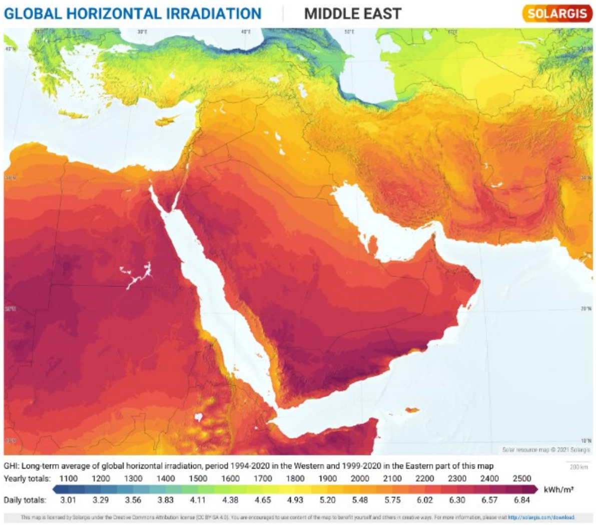

Figure 1: Global solar radiation in the Middle East region

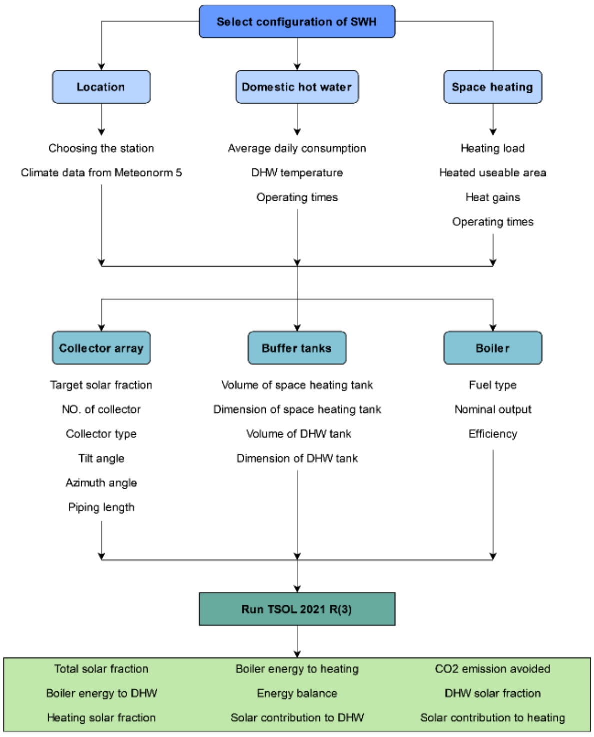

Figure 2: Software performance diagram in dynamic simulation of SWH

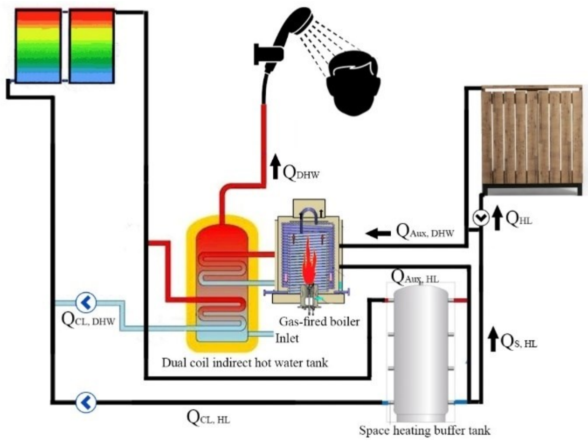

Figure 3:. Schematic of the investigated solar heating system

The software uses equations 1 and 2 to simulate the one-year performance of the solar heating system shown in Figure 2 [34-37]. Equation 1 calculates the total solar fraction supplied by the investigated solar system and equation 2 calculates the energy balance of the investigated system.

$$\text{total solar fraction} = \frac{Q_{CL,DHW}+Q_{S,HL}}{Q_{CL,DHW}+Q_{S,HL}+Q_{AUXH,DHW}+Q_{AUXH,HL}} \quad (1)$$

$$\rho = G_{dir}.\eta_0.f_{IAM} + G_{diff}.\eta_0.f_{IAM,diff} - K_0(T_{cm} - T_A) - K_q(T_{cm} - T_A)^2 \quad (2)$$

4. Required data

The required data for the stations under study, including population, population density, minimum annual temperature, and required heat, are presented in Table 2. Based on the data in Table 2, Cairo has the highest population, while Manama has the highest population density. Ankara and Abu Dhabi have the lowest and highest annual temperatures respectively, corresponding to their respective heat requirements. Other data required for simulation include: average daily hot water consumption (160 L), required hot water temperature (50 °C), required hot water time range throughout the year, area under investigation (120 m²), wall thickness is average, double-glazed windows used, heating time range for all months except May to September, average solar fraction target, azimuth angle towards south, installation angle of 90° (building facade), external pipe length (2 m), internal pipe length (16 m), auxiliary gas-fired boiler capacity (20 kW), sanitary hot water tank capacity (1500 L), space heating tank capacity (3000 L), and heat transfer fluid consisting of a combination of water-ethylene glycol with a ratio of 60%-40%.

5. Results

In Table 3, the results of environmental-energy analysis for 17 Middle Eastern countries are presented. According to the results, Turkey has the lowest percentage of total solar radiation at 90.9%, while Kuwait has the highest percentage at 99.7%. The average percentage of total solar radiation for the stations under investigation is 65.34%. Regarding space heating, it should be noted that SWHs in Cyprus, Iran, Iraq, Israel, Jordan, and Turkey were unable to generate any heat and all the heat produced was used solely for supplying domestic hot water. Syria had the highest amount of solar heat with 6872.1 kWh/year and the average heat supply for space heating for the stations under investigation is 1380.3 kWh/year. In total, SWHs produced 23.5 MWh of solar heat per year in the stations under investigation. In terms of the percentage of heat supply for space heating, it should be mentioned that Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates were able to meet 100% of their space heating needs through SWHs. The average percentage of heat supply for space heating in the stations under investigation is 57.1%.

In terms of producing domestic hot water, Yemen (2708.3 kWh/year) and Syria (3266.11 kWh/year) have the lowest and highest values respectively. The average heat production for domestic hot water in the investigated station is 2895.2 kWh/ year and a total of approximately 49.2 MWh of solar heat is generated. The lowest percentage, highest percentage, and average percentage of solar heating supply for domestic hot water are respectively 83.3% (Turkey), 99.6% (Kuwait), and 90.6% (for all countries).

Table 2: Demographic and climatic data of the investigated stations

Country	Capital [38]	Population 2021 [38]	Density (per km²) [38]	Annual low temperature (°C) [39]	Thermal load for 120 m² (kW) [40]
Bahrain	Manama	1,501,635	1,925	26.31	2.313
Cyprus	Nicosia	888,005	96	17.25	7.992
Egypt	Cairo	102,678,136	102	17.28	7.973
Iran	Tehran	85,022,548	52	10.7	12.098
Iraq	Baghdad	41,190,700	82.7	22	5.015
Israel	Jerusalem	9,443,420	455	16.59	8.406
Jordan	Amman	11,098,276	120	14.31	9.835
Kuwait	Kuwait	4,670,713	262	24.78	3.272
Lebanon	Beirut	6,769,000	648	18.27	7.353
Oman	Muscat	4,520,471	21	26.22	2.369
Palestine	Ramallah	5,227,193	840	19.81	6.387
Qatar	Doha	2,799,202	245	25.85	2.601
Saudi Arabia	Riyadh	35,013,414	16	20.7	5.829

Syria	Damascus	18,276,000	99	12.44	11.008
Turkey	Ankara	83,614,362	107	7.11	14.349
United Arab Emirates	Abu Dhabi	9,503,738	115	26.45	2.225
Yemen	Sanaa	30,491,000	58	15.58	9.039

In general, the minimum and maximum amounts of solar heating production are 2795.4 kWh/year (Oman) and 10138 kWh/year (Syria), respectively. On average, each station produces 4275.5 kWh/year of solar heat, and overall, all the stations under study produce a total of 72.7 MWh/ year of solar heat.

In terms of preventing CO_2 emissions at the stations under study, a total of 23.1 tons/year have been prevented from being emitted. The lowest amount is 901.2 kg/year in Israel, and the highest amount is 2748.8 kg/year in Yemen. On average, each station prevents an annual emission of 1360 kg of CO_2 pollutant.

Regarding the use of gas-fired auxiliary boilers, it should be mentioned that in Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, there is no need to use boilers for space heating. Turkey has the highest usage rate of gas-fired auxiliary boilers with a rate of 24557 kWh/year. Overall, at the surveyed station, more than 77.2 MWh/year are used from gas-fired auxiliary boilers. Kuwait with 13 kWh/year and Turkey with 620 kWh/year have the lowest and highest usage rates of gas-fired auxiliary boilers for supplying domestic hot water consumption respectively. Overall, more than 5.2 MWh/year require gas-fired auxiliary boilers for heating consumed water at the surveyed stations. Overall, the usage rate of gas-fired auxiliary boilers at the surveyed stations is approximately 82.5 MWh/year.

Table 3: The results of environmental-energy analysis for Middle Eastern countries

Station	Total solar fraction (%)	Solar contribution to heating (kWh)	Heating solar fraction (%)	Solar contribution to DHW (kWh)	DHW Solar fraction (%)	CO_2 Emissions avoided (kg)	Boiler energy to heating (kWh)	Boiler energy to DHW (kWh)
Bahrain	95.2	296.84	100	2806.14	94.7	1093.37	0	156
Cyprus	28.2	0	0	2853.75	87	928.94	6823	425
Egypt	83.4	2514.09	78	2812.71	88.9	1605.9	711	353
Iran	16.4	0	0	2933.93	88.3	904.96	14551	389
Iraq	40.8	0	0	2820.5	88.3	912.66	711	353
Israel	22.4	0	0	2899.67	86.2	901.19	9571	464
Jordan	20.5	0	0	2938.71	86.7	927.3	10951	449
Kuwait	99.7	1150.24	100	3013.45	99.6	1343.17	0	13
Lebanon	82.3	2162.73	75	2850.75	88.9	1530.9	721	356
Oman	95	42.21	100	2753.16	94.9	1026.38	0	147
Palestine	73.4	4519.87	65.4	3076.62	89.5	2061.71	2394	360
Qatar	98.1	148.66	100	2866.85	98	1093.21	0	59
Saudi Arabia	96.2	1647.52	100	2784.63	94.1	1403.81	0	173

Syria	61.1	6872.11	52.5	3266.11	93.2	2678.99	6228	237
Turkey	10.9	0	0	3085.14	83.3	906.05	24557	620
United Arab Emirates	94.6	122.92	100	2748.75	94.4	1043.1	0	163
Yemen	92.5	3987.54	99.5	2708.31	83.8	2748.75	19	524

6. Conclusion

Despite the undesirable consequences of using fossil fuels for residential heating, Middle Eastern countries heavily rely on fossil fuels for this purpose. The use of SWHs can be a suitable solution to mitigate the energy and environmental crisis in the Middle East, both for space heating and providing hot water for sanitary use. Considering the importance of these issues, 17 Middle Eastern countries have been evaluated for their use of SWHs in building facades for the first time. The TSOL PRO5 software was used to analyze the thermal, economic, and environmental aspects of the examined stations. The important findings of the study are as follows:

- Turkey has the lowest total solar fraction, while Kuwait has the highest.
- By using SWHs in the examined stations, an annual production of 23.5 MWh of solar heat for space heating and 49.2 MWh for domestic hot water can be achieved.
- The use of gas-fired auxiliary boilers in the examined stations amounts to 82.5 MWh/year.
- Due to the use of SWHs in these stations, an annual CO_2 emission reduction of 23.1 tons is achieved.

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