

Research Article

Using Rooftop Solar Heating to Supply Part of a High-Rise Residential Building Heat in the Cold Climate of Iran: One-Year Dynamic Analysis

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Higher energy consumption, especially for heating, in high-rise buildings than conventional buildings, necessitates partially supplying thermal energy by solar water heaters (SWHs). Considering the very high solar radiation potential in Iran, this study used roof solar collectors to partially supply the heat required for domestic hot water (DHW) and heat the indoor space and a swimming pool in a 48-unit building in a cold climate (Shahrekord, Iran). Climatic data were extracted from Meteonorm 7.3, and technical, energy, environmental, and economic analyses were performed with the help of TSOL 2018 R(1). The one-year dynamic analysis was performed, considering all possible losses, and an auxiliary gas boiler (AGB) was also used. According to the results, considering the available roof area, 8.7% of the total required heat equivalent to 82814 kWh is supplied by SWHs with a unit cost of \$0.022/kWh. The AGB supplied 867259 kWh/year, preventing CO₂ emissions by 25.5 tons. This is the first study in this regard in Iran, and the authors hope that the results can be employed as a guideline for decision makers to extend the use of SWHs in Iran.

1. Introduction

In recent years, there has been a great interest in solar thermal energy as a possible alternative to water heating [1]. SWH is one of the best solar thermal collectors in renewable energy technologies. SWH systems have received much attention because of their low cost, negligible impact on global warming, and long lifetime [2, 3]. Moreover, the geographical location, weather conditions, solar radiation availability, and solar collector arrangement significantly affect the system's thermal performance. Multiple factors affecting the technical-economical-environmental performance of SWHs are displayed in Figure 1.

As shown in Figure 2, the global capacity of solar thermal collectors has increased from 62 GWth (89 million m²) in 2000 to 501 GWth (715 million m²) in 2020 [11]. The global market of SWHs is estimated at 2.7 billion dollars in 2020 during the COVID-19 pandemic and is predicted to reach 4.3 billion dollars in 2027 [12].

Figure 3 shows twelve pioneering countries in SWH systems, such as China, Turkey, the USA, Germany, Brazil, and India [13].

Given the water heater market in the Middle East, the ever-increasing demand for SWHs in residential, private, and public buildings is expected to exceed 2.5 million units by 2024, with an investment value of over 2 billion dollars. Iran is located in the Middle East between 25 to 40° northern latitude. Solar radiation in Iran is estimated to vary from 1800 to 2200 kWh/m² per year, which is greater than the global average [14]. The number of sunny days in Iran is 280 days, which is larger than most European countries [15]. About 80% of energy is consumed in the residential sector to produce DHW and heat indoor space [16]. Unfortunately, although Iran has one of the largest oil and natural gas resources globally [17], most Iranians use natural gas for heating water [18], making Iran one of the largest CO₂ producers in the world. Hence, it is crucial to move toward a low-carbon economy to realize Iran's commitment to



FIGURE 1: Effective on the techno-economic and environmental performance of SWHs [4–10].

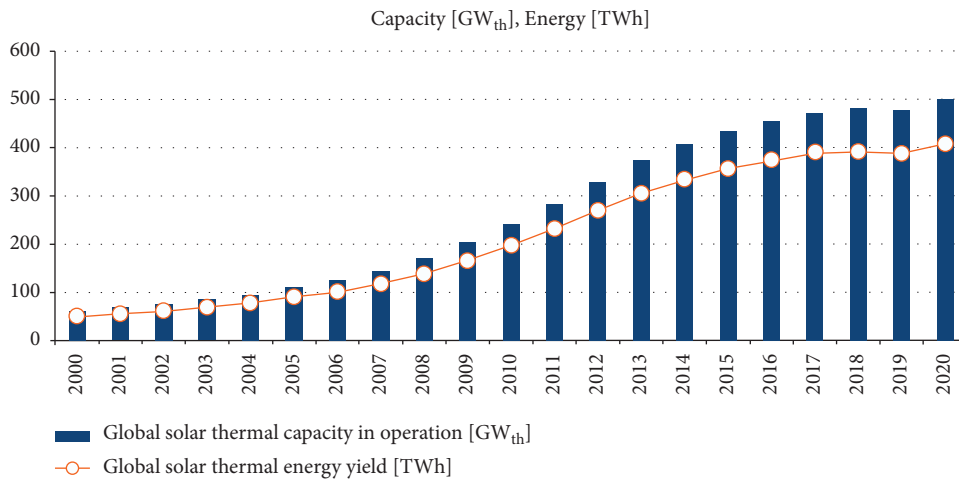


FIGURE 2: Global solar thermal capacity in operation and annual energy yield 2000–2020 [11].

greenhouse emission reduction [19]. Despite the high potential to use this technology in Iran, SWHs are almost moderately used in Iran compared with countries with very-low solar radiation, such as China and Germany.

The literature on the use of SWHs in high-rise buildings is reviewed below.

Mortazavi et al. investigated the effect of the type of hot water storage tank on the technical and environmental parameters of a solar heating system in 3 different climates of

Iran [20]. They used TSOL software to analyze the residential building and evaluated 3 types of hot water storage tanks. The results of the investigations showed that, for each of the hot water reservoirs, a city has the most natural gas reserves (the most prevention of CO₂ pollutant emissions). In other words, for every climate, a type of hot water storage tank is suitable.

Rezapour et al. dealt with the dynamic simulation and ranking of the use of SWH at the residential scale in Iran

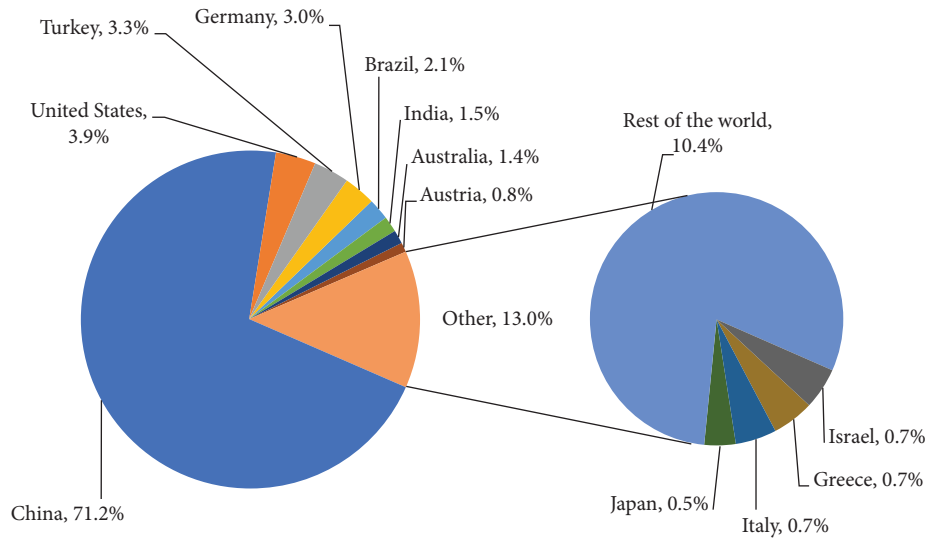


FIGURE 3: SWH systems in the top 12 countries from 2008 to 2018 [13].

[21]. They used TSOL and GAMS software and evaluated 47 stations in Iran. The results showed that 223.1 MWh of solar heat is produced annually in all stations and the average price of each kilowatt hour of solar heat in Iran is \$0.16.

Using TSOL software, Jahangiri et al. analyzed 22 stations located in Zambia in terms of using SWH [22]. Their results showed that, on average, 62.5% of the heat required for space heating and 96.1% of the heat required to supply the domestic hot water required by SWHs are provided. Also, the city of Kabwe had the highest rate of CO₂ emission prevention.

Wang et al. investigated large-scale solar energy consistency for heating water based on environmental, economic, and energy considerations in residential buildings in 31 provincial capitals in China [23]. According to their results, solar radiation intensity, payback period, solar fraction, installation site, and water supply temperature are among the main parameters affecting the use of SWHs in these regions.

Huang et al. evaluated the 3-year performance of an SWH system installed in a multi-family residential complex [7]. Compared to a conventional boiler, this system has a positive environmental impact equivalent to 907.71 L/year on oil reduction, 508 tons of carbon, and 186.3 tons of carbon dioxide. The payout period was estimated at five years for this system.

Huang et al. studied 36 SWH systems (operated for 1 to 14 years) in high-rise buildings in Shanghai, China [24]. The mean solar collector area was 2.17 m² per household, with a mean solar fraction of 52%. According to their results, insufficient hot water in winter (29%), water leakage (21%), and the lack of a professional maintenance workforce (10%) are three major problems affecting the performance of SWH systems.

He analyzed an SWH system with concentrating solar collectors in two projects in Beijing and Tianjin to provide a practical solution to SWH systems installed in high-rise residential buildings [25]. The systems installed in high-rise buildings of this project showed outstanding features of this

type of SWH systems, such as economic efficiency and performance, easy management, balance, reliability, safety, and building integration.

Chow et al. numerically studied the potential application of a concentrating SHW in high-rise buildings in Hong Kong [26]. Useful heat of 904 GJ/year was generated by installing an 840 m² solar collector on the southern and western facades. The overall efficiency of solar collectors was 38.4%, the annual solar fraction was estimated at 53.4%, and the payback period was 9.2 years.

According to the literature, despite the extraordinary potential of solar radiation in the Middle East, particularly in Iran, no feasibility study has been conducted on the use of SWHs in high-rise buildings in Iran. In other words, no estimate of the use of SWH has been made on the scale of a high-rise building in Iran, and the works performed are only related to a residential apartment. For the first time in Iran, economic-energy-environmental (3E) analyses were performed to partially supply heat in high-rise buildings by SWHs in the cold Iranian climate with the help of TSOL and climatic data extracted from Meteonorm.

This study aims to supply the thermal energy required for heating water, the indoor space, and the swimming pool of a 7-story (48-unit) building. The effect of economic parameters on the unit price (\$/kWh) of the generated solar thermal energy is calculated. The overall solar fraction, CO₂ emission prevention, and AGB are also investigated. Despite being a case study, the results of this study can be used for similar climates worldwide. The methodology and analyses can also be used for any point and climate worldwide.

2. Under Study Location and Used Software

This regional study investigates Shahrekord, the capital city of Shahrekord, and Chaharmahal and Bakhtiari Province in Iran. Based on the 2016 Census in Iran, Shahrekord's population was 190441. Shahrekord is the highest provincial capital in Iran, known as the roof of Iran, with a temperate climate in summer and very cold weather in winter [27].

SWHs are suitable for large buildings where hot water is largely used, significantly reducing energy consumption and the negative impact of fossil fuels on the environment [28]. This study investigated supplying hot water in a high-rise building in Shahrekord by SWHs. Figures 4 [29] and 5 show the study area and solar radiation, respectively.

The one-year dynamic simulation was performed with the help of TSOL 2018 R(1), capable of supplying the heat required for the space, DHW, and swimming pool by SWHs. Design, optimization, and exact calculation are other software features [2]. The software database consists of 4000 collectors, 5000 thermal generators, 600 thermal storage tanks, 200 thermal solar systems, and 8000 different meteorological stations. TSOL 2018 R(1) receives the required climatic data from Meteonorm 7.3, installed simultaneously [3].

3. Under Study System and Input Data

Figure 6 schematically displays the studied system. As shown, solar collectors are oriented toward the south with an angle of 32° (latitude) [30] to supply 3960 L of 60°C DHW [31] and heat the space and pool water by solar collectors and 55 10-kW AGBs. Six 300 L hot water storage tanks are used for DHW and six 1000 L storage tanks to heat the indoor space. Given the geographical location, DWH is required

throughout the year, but the indoor space is heated for 7 months from October to April. Heat should be supplied for a surface area of 5260 m^2 , the heat required from the indoor space is 634.5 kW , and the heat gain is 10 W/m^2 . A 100 m^2 vacuum-tube solar collector was used. The daily water volume for the swimming pool is 50 L, and the swimming pool is used throughout the year. The swimming pool dimensions were $12\text{ m} \times 5\text{ m}$ with an average depth of 2 m. The internal and external piping lengths were 450 and 30 m, respectively.

The useful lifetime of collectors is 25 years, the annual interest rate in Iran is 18% [32], and the natural gas price in Iran and the mean global price are $0.001\text{ \$/m}^3$ and $0.058\text{ \$/m}^3$ [33], respectively, the unit price of SWHs is $\$300/\text{m}^2$ by applying 50% subsidy, 7500 \$ loan with an interest rate of 4%, and 25-year payback period. The allowance for solar heating is $0.002\text{ \$/kWh}$ with a maintenance cost of 0.5% of the total cost.

The solar radiation received by collectors is the sum of direct and diffused radiation. Direct radiation was extracted from Meteonorm 7.3. The following relations are used for the incident diffused radiation to the collector surface based on the clearness index (K_t), where α represents the solar collector angle [34]:

$$0 \leq k_t \leq 0.3: \frac{I_d}{I} = 1.02 - 0.245k_t + 0.0123 \sin \alpha, \quad (1)$$

$$0.3 < k_t \leq 0.78: \frac{I_d}{I} = 1.4 - 1.749k_t + 0.177 \sin \alpha, \quad (2)$$

$$k_t > 0.78: \frac{I_d}{I} = 0.486k_t - 0.182 \sin \alpha. \quad (3)$$

As some of the received radiation by the collector is lost, the energy balance is as follows [35]:

$$\rho = G_{\text{dir}} \cdot \eta_0 \cdot f_{\text{IAM}} + G_{\text{diff}} \cdot \eta_0 \cdot f_{\text{IAM,diff}} - k_0 (T_{\text{cm}} - T_A) - k_q (T_{\text{cm}} - T_A)^2. \quad (4)$$

Regarding emissions, the software considers CO_2 emission prevention by 5.14 g/kJ per natural gas as the consumed fuel [2]. The overall solar fraction and the solar

fractions of DHW, the indoor space, and the swimming pool are calculated from the following equations, and their parameters are shown in Figure 6 [36]:

Total solar fracion

$$= \frac{Q_{\text{S,DHW}} + Q_{\text{S,HL}} + Q_{\text{S,SP}}}{Q_{\text{S,DHW}} + Q_{\text{S,HL}} + Q_{\text{S,SP}} + Q_{\text{AUXH,DHW}} + Q_{\text{AUXH,HL}} + Q_{\text{AUXH,SP}}}, \quad (5)$$

$$\text{DHW solar fracion} = \frac{Q_{\text{S,DHW}}}{Q_{\text{S,DHW}} + Q_{\text{AUXH,DHW}}}, \quad (6)$$

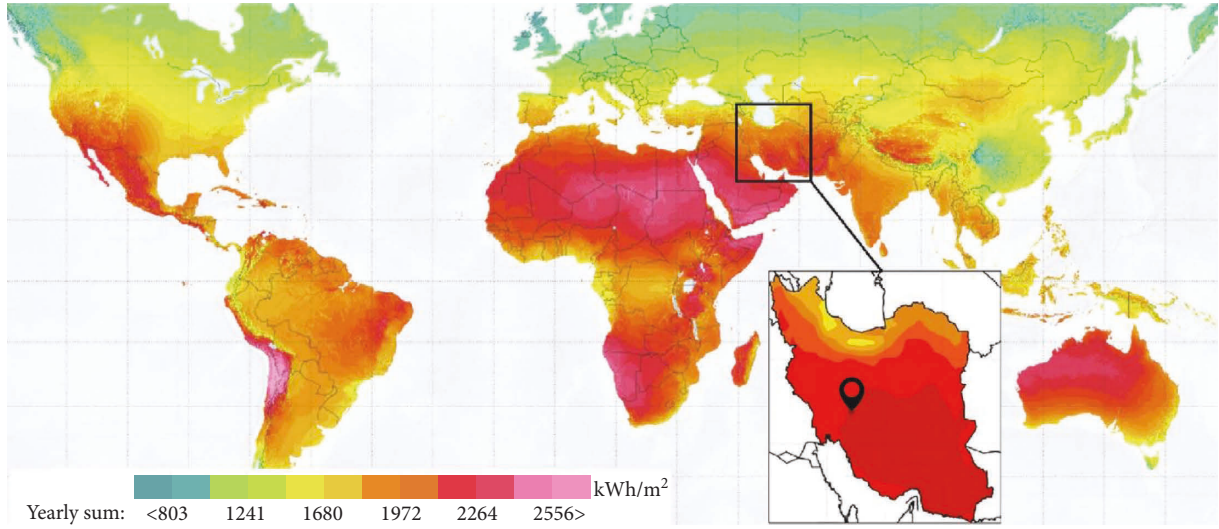


FIGURE 4: Comparing the annual solar radiance of Shahrekord with the rest of the world (kWh/m²) [29].

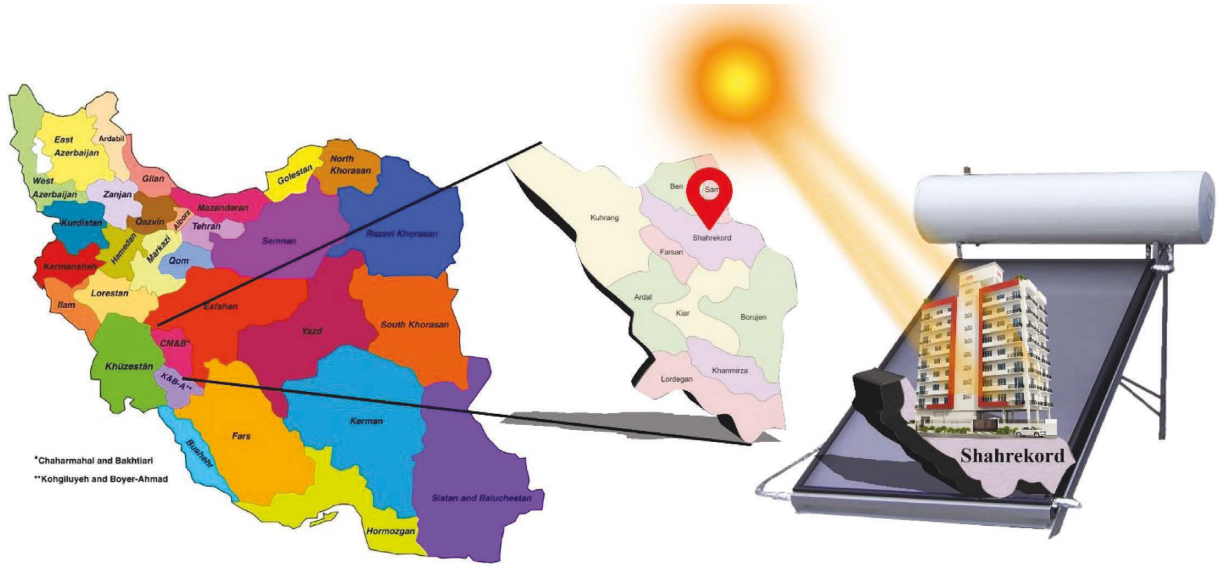


FIGURE 5: Diagram of the study area.

$$\text{Heating solar fracion} = \frac{Q_{S,HL}}{Q_{S,HL} + Q_{AUXH,HL}}, \quad (7)$$

$$\text{Swimming pool solar fracion} = \frac{Q_{S,SP}}{Q_{S,SP} + Q_{AUXH,SP}}. \quad (8)$$

Economic calculations are performed based on the net present value (NPV). NPV is one of the primary, most widely used methods for investment evaluation, which is calculated as follows [36]:

$$NPV = R_t - C, \quad (9)$$

where R_t represents the total revenue and C is the SWH cost, calculated by the following equations:

$$C = C_0 + \sum_{n=1}^N \frac{C_{O\&M} \times (1 + e)^n}{(1 + d)^n}, \quad (10)$$

$$R_t = \frac{Q_u}{\eta_h} \sum_{n=1}^N \frac{(1 + e)^n}{(1 + d)^n}, \quad (11)$$

where C_0 is the total purchasing cost, $C_{O\&M}$ is the total annual operation and maintenance cost, e useful life, d decay

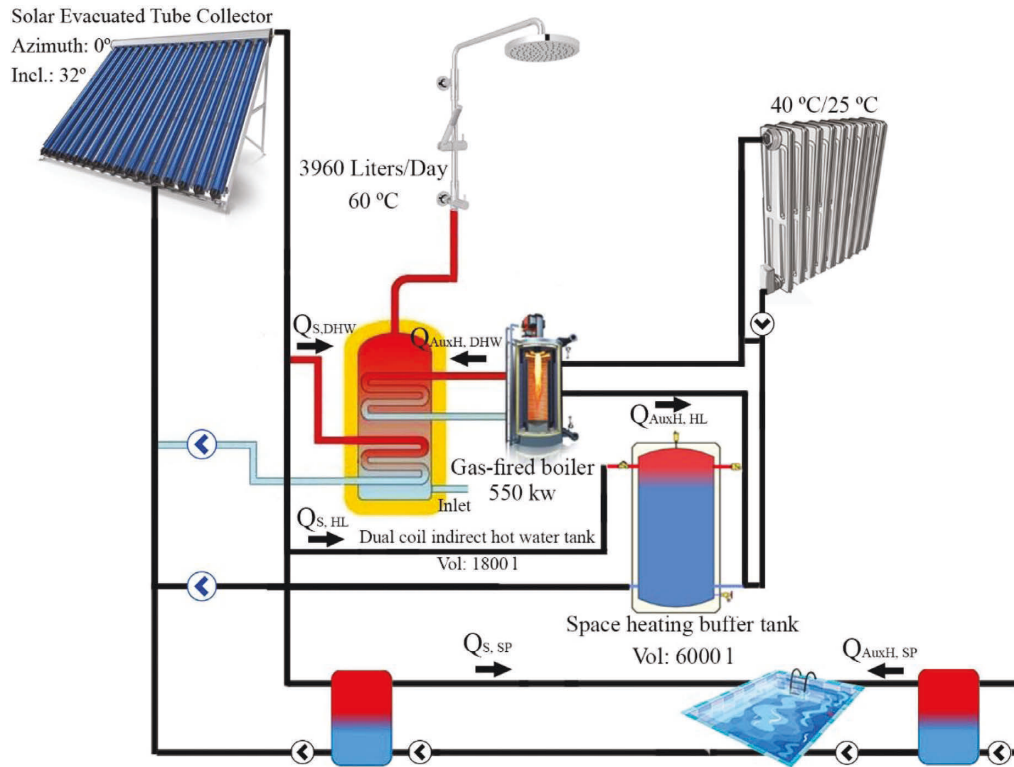


FIGURE 6: Schematic representation of the simulated system.

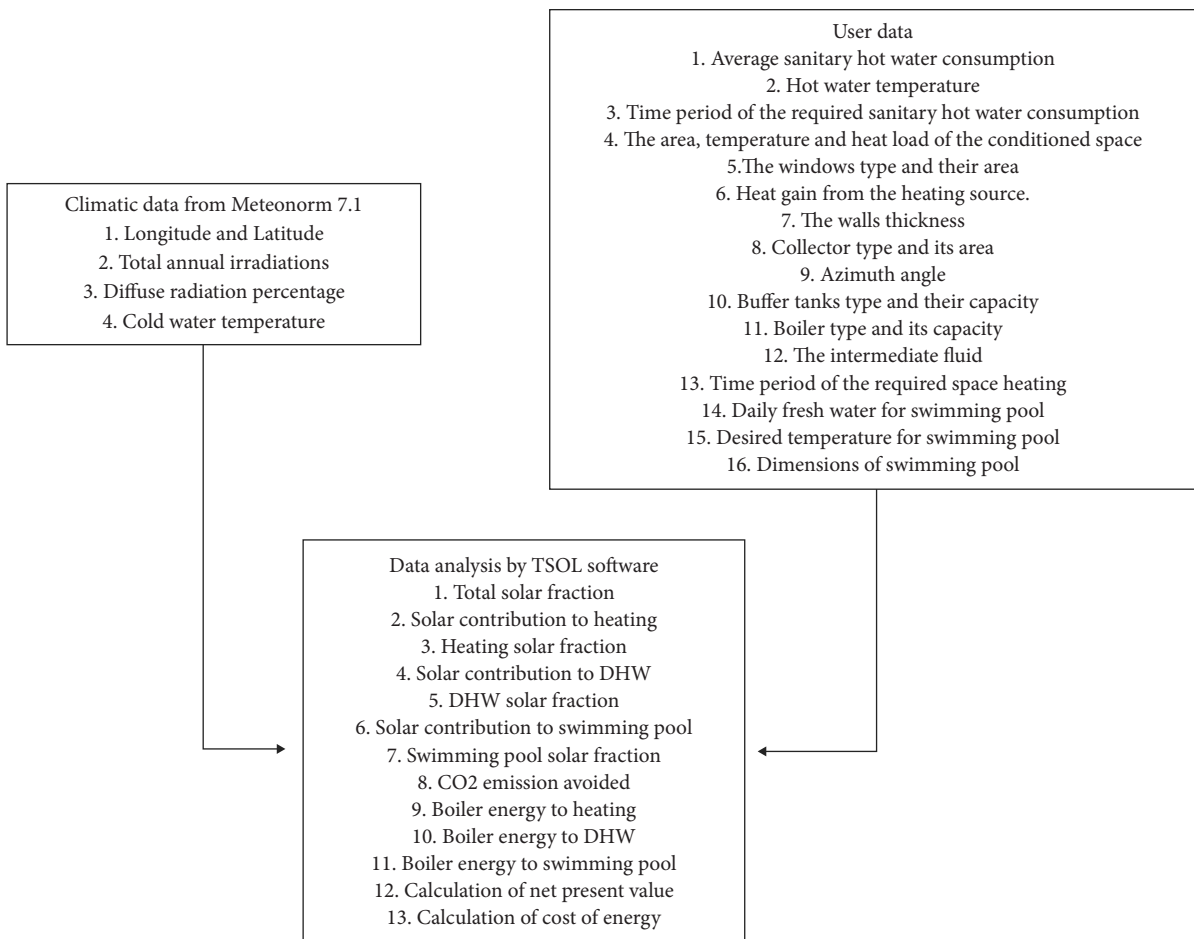


FIGURE 7: Schematic diagram of TSOL software performance.

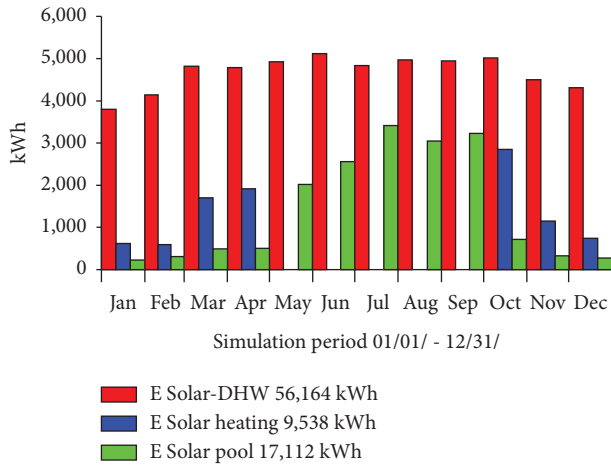


FIGURE 8: Monthly solar thermal energy for different parts of the building.

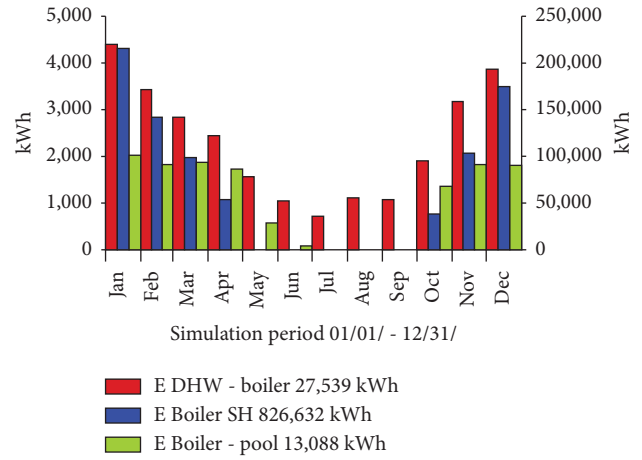


FIGURE 10: The monthly use of the AGB for different parts of the building.

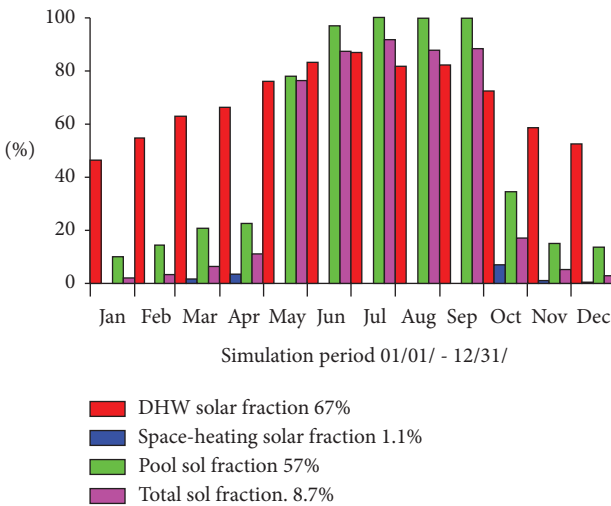


FIGURE 9: The solar fractions of different parts of the building.

rate, n number of years, η_h efficiency of AGBs, and Q_u is useful energy collected by solar collectors.

Based on Figure 7, it can be seen that the input data by the user as well as the climate data extracted from the Meteonorm 7.1 software are combined with each other, and by equations (1)–(11), 3E analyzes are performed on the input data and the designed SWH system is analyzed.

4. Results

Figure 8 shows the heat generated by SWHs used for DHW, the indoor space, and the swimming pool. According to the results, the highest generated heat of 56164 kWh/year is consumed to heat DHW, followed by 17112 kWh/year for the swimming pool, and 9538 kWh/year to heat the indoor space.

As shown in Figure 8, the highest and lowest thermal energies of 5100 and 3800 kWh are produced by SWHs, respectively, in June and January to heat DHW. In July, the highest thermal energy of about 400 kWh is generated to heat the swimming pool. No heat is required for the indoor

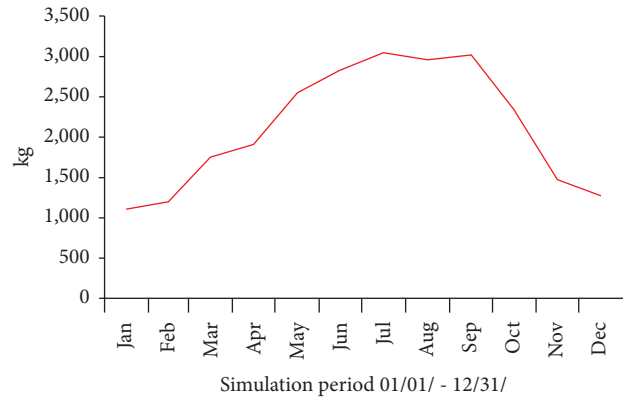


FIGURE 11: Monthly CO₂ emission prevention.

space from May to September, and more thermal energy generated by SWHs is consumed for water evaporation. SWHs produce the highest thermal energy of about 2850 kWh in October to heat the indoor space.

Figure 9 shows the solar fraction supplied by SWHs. According to the results, the overall solar fraction for the designed system is 8.7%. In other words, SWHs have been able to supply 8.7% of the total thermal demands. The solar fractions for DHW, the swimming pool, and the indoor space are 67, 57, and 1.1%. The low solar fraction of the indoor space is due to the large thermal demand of the indoor space. In the absence of space constraints, the solar fraction could be increased by increasing the number of solar collectors.

The highest monthly solar fraction of 87% is observed in July for DHW, 7% in October for the indoor space, and 100% from July to September for the swimming pool. The highest overall monthly solar fraction of 92% is observed in July.

Figure 10 shows the heat generated by the AGB to supply DHW. According to the results, the highest and lowest thermal energies of 4400 kWh and 700 kWh are generated by

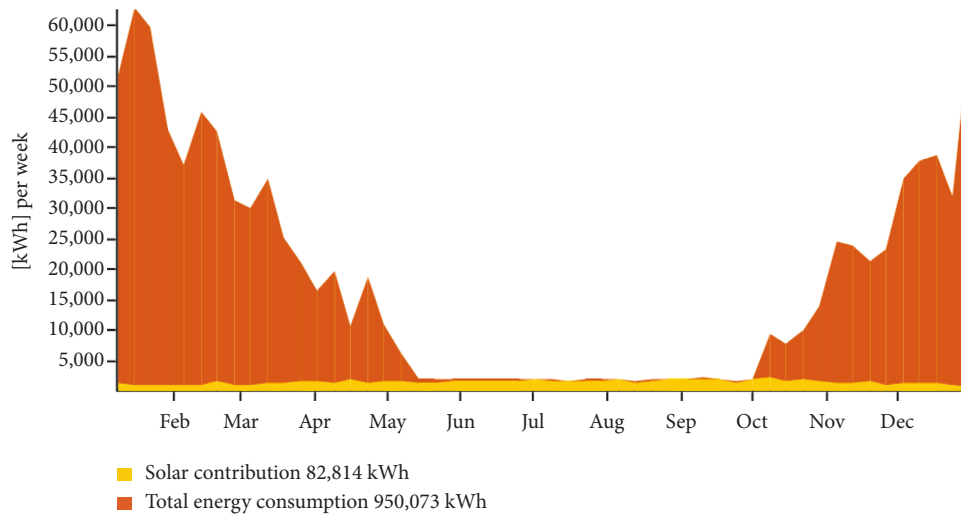


FIGURE 12: Required energy and monthly solar energy generation.

Legend

1	Irradiation on collector surface (active)	226,153 kWh
1.1	Optical collector losses	62,338 kWh
1.2	Thermal collector losses	48,604 kWh
2	Energy from collector array	117,060 kWh
2.1	Solar energy to storage tank	57,678 kWh
2.3	Solar energy to buffer tank	16,186 kWh
2.4	Solar energy to swimming pool	17,112 kWh
2.5	Internal piping losses	23,677 kWh
2.6	External piping losses	2,407 kWh
3.1	Tank losses	4,368 kWh
5.1	Buffer tank losses	6,662 kWh
5.2	Buffer tank to heating	9,538 kWh
6	Final energy	1,025,554 kWh
6.1	Supplementary energy to tank	27,539 kWh
6.4	Supplementary energy to space-heating	826,632 kWh
9	DHW energy from tank	80,848 kWh
10.2	Heat to LT heating.	836,170 kWh
11.1	Supplementary energy to swimming pool (from final energy)	13,088 kWh
11.2	Swimming pool losses	30,157 kWh

FIGURE 13: Energy balance for the studied system.

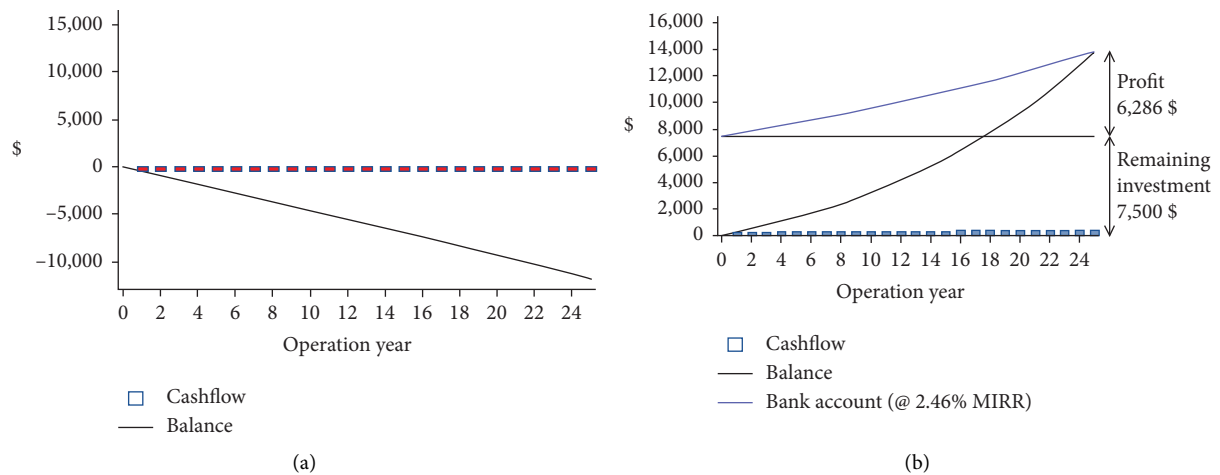


FIGURE 14: Economic analysis during the project’s useful life: (a) natural gas price = $\$0.001/\text{m}^3$ and (b) natural gas price = $\$0.058/\text{m}^3$.

the AGB in January and June, respectively. In total, 27539 kWh is annually consumed to heat DHW, which is not supplied by solar energy but should be supplied by the AGB.

Figure 10 also shows the heat generated by the AGB to heat the indoor space in cold months. As mentioned in Section 4, the indoor space needs no heating in five warm months. In seven months requiring indoor space heating, the highest and lowest thermal energies of 215000 kWh and 38000 kWh are generated by the AGB, respectively, in January and October. In total, 826632 kWh is annually consumed to heat the indoor space by the AGB.

The heat generated by the AGB to supply the thermal energy for the swimming pool is shown in Figure 10. As shown, there is no need for the AGB from July to September, and SWHs have been able to supply heat for the swimming pool. When an AGB is required to heat the swimming pool, the highest and lowest thermal energies of 2000 and 80 kWh are generated by the AGB, respectively, in January and June. In total, 13088 kWh is annually consumed to heat the swimming pool by the AGB.

Figure 11 shows CO₂ emission prevention. As shown, SWHs generate more heat in warm months, preventing CO₂ emissions more than in cold months. The highest and lowest CO₂ emission prevention of 3000 kg and 1110 kg occurred in July and January. In total, SWHs prevented emitting 25.5 tons of CO₂ annually.

Figure 12 shows the thermal energy required in the high-rise building and the energy supplied by SWHs. As shown, 950073 kWh/year of thermal energy is required; of this, 82814 kWh/year is supplied by SWHs. According to the results, in June, July, August, and September, all thermal needs of the building are supplied by SWHs. As shown in Figure 12, the highest thermal energy demand exceeds 60000 kWh in January.

Figure 13 schematically shows the energy balance for the system. As shown, 226153 kWh/year of radiative energy is received by solar collectors, and optical and thermal losses are 62338 and 48604 kWh/year, respectively. Thermal losses in the inner and outer pipes are 23677 and 2407 kWh/year, respectively. The higher thermal loss in the inner piping can be related to its longer length. Thermal (heat) losses from the DHW tank, the indoor space heating tank, and the swimming pool are 4368, 6662, and 30157 kWh/year, respectively.

Based on the results of Figure 13, from the total input energy, about 27.6% is spent on optical losses, about 21.5% is spent on thermal losses, about 11.5% is spent on piping losses, and about 18.2% is spent on hot water storage tank losses. In other words, the total loss is 78.8% and the efficiency of the studied solar heating system is only 21.2%.

Figure 14 shows the results of the economic analysis for two different scenarios. Figure 14(a) shows the scenario in which the current unit gas price is \$0.001/m³, and Figure 14(b) shows the case in which the unit gas price is equal to the mean global price of \$0.058/m³. As shown in Figure 14(a), NPV is negative throughout the project's useful life, equivalent to \$-10014 within 25 years. The unit price of heat generated by solar collectors is \$0.022/kWh, indicating the very low price of natural gas in Iran (one of the three

countries with the cheapest natural gas in the world). NPV equals \$-6065 in the second scenario. Unlike the first scenario in which no payout period is considered, a payout period of 24.7 years was calculated in the second scenario. One of the reasons for the cost ineffectiveness of renewable projects in Iran is the lack of penalties for air pollution.

5. Conclusion

Vast amounts of energy are consumed in buildings, mainly to supply DHW. Consequently, it seems reasonable to use SWHs to produce DHW. This is the first study on the one-year dynamic simulation for supplying heat in a high-rise building using roof solar collectors in Iran. Simulations were performed with the help of Meteonorm 7.3 and TSOL 2018 R(1), considering optimal and thermal losses in collectors, piping losses, and water storage tank losses. A 48-unit building in Shahrekord (Iran) with a cold climate was considered as a case study. Despite the case study nature, the results of this study can be directly used for similar climates. Moreover, analyses and methodologies are applicable to any climate. The main results are summarized as follows:

- (i) Roof solar collectors supplied 8.7% of the total required heat (950073 kWh/year)
- (ii) The solar fraction for DHW, swimming pool, and indoor space was 67, 57, and 1.1%
- (iii) The AGB supplied 27539, 13088, and 826632 kWh/year of heat for DHW, swimming pool, and indoor space
- (iv) The use of SWHs for the partial supply of heat in the building prevented CO₂ emissions by 25.5 tons
- (v) The losses in solar collectors, pipes, DHW storage tank, and swimming pool were 110942, 26084, 11030, and 30157 kWh/year, respectively
- (vi) The unit price of solar thermal energy was \$0.022/kWh

Abbreviations

N :	Project lifetime (year)
ρ :	Collector energy balance (kW)
C :	Cost of the SWH system (\$)
e :	Useful life (year)
n :	Number of years (-)
d :	Rate of decline (%)
NPV:	Net present value (\$)
α :	Tilt angle (°)
I :	Total hourly radiation on a horizontal surface (kJ/m ²)
3E:	Energy, economic, and environment (-)
AGB:	Auxiliary gas boiler
DHW:	Domestic hot water (-)
SWH:	Solar water heater (-)
R_t :	Total revenue (\$)
η_h :	Efficiency of the auxiliary boiler (%)
$C_{O\&M}$:	Total annual operating and maintenance costs (\$)

C_0 :	Total purchase cost (\$)
T_A :	Air temperature (K)
T_{cm} :	Average temperature of collector (K)
k_q :	Quadratic heat transfer coefficient ($W/m^2.k^2$)
$Q_{S,SP}$:	Solar heating for swimming pool (kW)
$Q_{S,DHW}$:	Solar heating for DHW (kW)
$Q_{S,HL}$:	Solar heating for heating load (kW)
$Q_{AuxH,SP}$:	Auxiliary heating for swimming pool (kW)
$Q_{AuxH,DHW}$:	Auxiliary heating for DHW (kW)
$Q_{AuxH,HL}$:	Auxiliary heating for heating load (kW)
I_d :	Hourly diffuse radiation on a horizontal surface (kJ/m^2)
G_{dir} :	Part of solar radiation striking a tilted surface (kW)
η_0 :	Collector's zero-loss efficiency (%)
f_{IAM} :	Incidence angle modifier factor (-)
G_{diff} :	Diffuse solar radiation striking a tilted surface (kW)
$f_{IAM,diff}$:	Diffuse incidence angle modifier factor (-)
k_0 :	Simple heat transfer coefficient ($W/m^2.k$)
Q_u :	Useful energy collected by the solar collectors (kW)
k_i :	Hourly clearness index (-).

Data Availability

All data used to support the findings of the study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

- [1] Y. Pang, J. Zhang, R. Ma, Z. Qu, E. Lee, and T. Luo, "Solar-thermal water evaporation: a review," *ACS Energy Letters*, vol. 5, no. 2, pp. 437–456, 2020.
- [2] M. Naveed Arif, A. Waqas, F. Ahmed Butt et al., "Techno-economic assessment of solar water heating systems for sustainable tourism in northern Pakistan," *Alexandria Engineering Journal*, vol. 61, no. 7, pp. 5485–5499, 2022.
- [3] R. Panahi, M. H. Khanjanpour, A. A. Javadi, M. Akrami, M. Rahnama, and M. Ameri, "Analysis of the thermal efficiency of a compound parabolic integrated collector storage solar water heater in Kerman, Iran," *Sustainable Energy Technologies and Assessments*, vol. 36, Article ID 100564, 2019.
- [4] T. Sokhansefat, A. Kasaeian, K. Rahmani, A. H. Heidari, F. Aghakhani, and O. Mahian, "Thermoeconomic and environmental analysis of solar flat plate and evacuated tube collectors in cold climatic conditions," *Renewable Energy*, vol. 115, pp. 501–508, 2018.
- [5] A. Greco, E. Gundabattini, D. S. Gnanaraj, and C. Masselli, "A comparative study on the performances of flat plate and evacuated tube collectors deployable in domestic solar water heating systems in different climate areas," *Climate*, vol. 8, no. 6, p. 78, 2020.
- [6] Z. Ding, W. Wu, Y. Chen, and Y. Li, "Dynamic simulation and parametric study of solar water heating system with phase change materials in different climate zones," *Solar Energy*, vol. 205, pp. 399–408, 2020.
- [7] J. Huang, J. Fan, S. Furbo, and Q. Li, "A policy study on the mandatory installation of solar water heating systems—lessons from the experience in China," *Solar Energy*, vol. 206, pp. 614–627, 2020.
- [8] Y. Lu, Z. A. Khan, M. S. Alvarez-Alvarado, Y. Zhang, Z. Huang, and M. Imran, "A critical review of sustainable energy policies for the promotion of renewable energy sources," *Sustainability*, vol. 12, no. 12, p. 5078, 2020.
- [9] A. Naidoo, "The socio-economic impacts of solar water heaters compared across two communities: a case study of cato manor," *Renewable and Sustainable Energy Reviews*, vol. 119, Article ID 109525, 2020.
- [10] S. Sathishkumar and T. Balusamy, "Performance improvement in solar water heating systems—a review," *Renewable and Sustainable Energy Reviews*, vol. 37, pp. 191–198, 2014.
- [11] IEA, "Solar heat worldwide 2021: global market development and trends in 2020—supported by the Austrian ministry for climate action," 2021, <https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2021.pdf>.
- [12] Business Wire, "Global solar water heaters industry (2020 to 2027)—market trajectory & analytics," 2021, <https://www.businesswire.com/news/home/20210429005554/en/Global-Solar-Water-Heaters-Industry-2020-to-2027---Market-Trajectory-Analytics---ResearchAndMarkets.com>.
- [13] A. Zervos, *RENEWABLE ENERGY POLICY NETWORK FOR THE 21ST CENTURY*, 2019.
- [14] R. Alayi, N. Khalilpoor, S. Heshmati, A. Najafi, and A. Issakhov, "Thermal and environmental analysis solar water heater system for residential buildings," *International Journal of Photoenergy*, vol. 2021, Article ID 1, 9 pages, 2021.
- [15] H. Taghavifar and Z. S. Zomorodian, "Techno-economic viability of on grid micro-hybrid PV/wind/gen system for an educational building in Iran," *Renewable and Sustainable Energy Reviews*, vol. 143, Article ID 110877, 2021.
- [16] S. Monna, A. Juaidi, R. Abdallah, A. Albatayneh, P. Dutournie, and M. Jeguirim, "Towards sustainable energy retrofitting, a simulation for potential energy use reduction in residential buildings in Palestine," *Energies*, vol. 14, no. 13, p. 3876, 2021.
- [17] R. Hafezi, D. A. Wood, A. N. Akhavan, and S. Pakseresh, "Iran in the emerging global natural gas market: a scenario-based competitive analysis and policy assessment," *Resources Policy*, vol. 68, Article ID 101790, 2020.
- [18] H. Yousefi, S. Roumi, H. Ármannsson, and Y. Noorollahi, "Cascading uses of geothermal energy for a sustainable energy supply for Meshkinshahr city, northwest, Iran," *Geothermics*, vol. 79, pp. 152–163, 2019.
- [19] S. Solaymani, "A review on energy and renewable energy policies in Iran," *Sustainability*, vol. 13, no. 13, p. 7328, 2021.
- [20] M. Mortazavi, S. Yaghoubi, and M. Jahangiri, "Investigating the effect of buffer tank type on technical and environmental performance of solar heating systems in Iran," *International Journal of Smart Electrical Engineering*, vol. 11, no. 2, pp. 55–61, 2022.
- [21] S. Rezapour, M. Jahangiri, A. G. Shahrezaie et al., "Dynamic simulation and ranking of using residential-scale solar water heater in Iran," *Journal of Environmental Engineering and Landscape Management*, vol. 30, no. 1, pp. 30–42, 2022.
- [22] M. Jahangiri, E. T. Akinlabi, and S. M. Sichelalu, "Assessment and modeling of household-scale solar water heater application in Zambia: technical, environmental, and energy

- analysis,” *International Journal of Photoenergy*, vol. 2021, Article ID 6630338, 13 pages, 2021.
- [23] L. Wang, D. Zheng, and G. Cheng, “An adaptability evaluation of large-scale solar energy for hot water application based on energy-economic-environment consideration: a case study of city-residential buildings in China,” *Journal of Cleaner Production*, vol. 296, Article ID 126585, 2021.
- [24] J. Huang, J. Fan, S. Furbo, and L. Li, “Solar water heating systems applied to high-rise buildings—lessons from experiences in China,” *Energies*, vol. 12, no. 16, p. 3078, 2019.
- [25] Z. He, “Solar water heating systems applied in high-rise residential buildings in China,” *Energy Procedia*, vol. 91, pp. 408–414, 2016.
- [26] T. T. Chow, K. F. Fong, A. L. S. Chan, and Z. Lin, “Potential application of a centralized solar water-heating system for a high-rise residential building in Hong Kong,” *Applied Energy*, vol. 83, no. 1, pp. 42–54, 2006.
- [27] K. Alizadeh, M. Jahangiri, and M. Bakhtdehkhordi, “Comprehensive 3E analysis and optimization of off-grid renewable-based microgrids to meet the clinic energy demand, a case study for medical tourism,” *Energy Equipment and Systems*, vol. 9, no. 3, pp. 291–305, 2021.
- [28] B. Lamrani, F. Kuznik, and A. Draoui, “Thermal performance of a coupled solar parabolic trough collector latent heat storage unit for solar water heating in large buildings,” *Renewable Energy*, vol. 162, pp. 411–426, 2020.
- [29] Solargis, <https://solargis.com/maps-and-gis-data/download/iran>, 2021.
- [30] A. Mostafaeipour, M. Qolipour, M. Rezaei, M. Jahangiri, A. Goli, and A. Sedaghat, “A novel integrated approach for ranking solar energy location planning: a case study,” *Journal of Engineering, Design and Technology*, vol. 19, no. 3, pp. 698–720, 2020.
- [31] J. Riahi Zaniani, S. Taghipour Ghahfarokhi, M. Jahangiri, and A. Alidadi Shamsabadi, “Design and optimization of heating, cooling and lightning systems for a residential villa at Saman city, Iran,” *Journal of Engineering, Design and Technology*, vol. 17, no. 1, pp. 41–52, 2019.
- [32] S. Shoeibi, H. Kargarsharifabad, S. A. A. Mirjalily, and T. Muhammad, “Solar district heating with solar desalination using energy storage material for domestic hot water and drinking water—environmental and economic analysis,” *Sustainable Energy Technologies and Assessments*, vol. 49, Article ID 101713, 2022.
- [33] “Natural gas prices: global petrol prices,” 2021, https://www.globalpetrolprices.com/natural_gas_prices.
- [34] L. Siampour, S. Vahdatpour, M. Jahangiri et al., “Techno-enviro assessment and ranking of Turkey for use of home-scale solar water heaters,” *Sustainable Energy Technologies and Assessments*, vol. 43, Article ID 100948, 2021.
- [35] R. Kalbasi, M. Jahangiri, A. Mosavi et al., “Finding the best station in Belgium to use residential-scale solar heating, one-year dynamic simulation with considering all system losses: economic analysis of using ETSW,” *Sustainable Energy Technologies and Assessments*, vol. 45, Article ID 101097, 2021.
- [36] N. Saberi Shahmarvandi, F. Shahrokh Ghahfarokhi, Z. Delshad Chermahini et al., “Effects of different target solar fractions on providing heat required for space heating, sanitary hot water, and swimming pool in Iran: a case study in cold climate,” *Journal of Engineering*, vol. 2022, Article ID 2720057, 10 pages, 2022.