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Simultaneous Production of Heat Required for Space Heating, Sanitary Water Consumption, And Swimming Pool in Different Climates of Iran

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Abstract

Due to the increasing reduction of fossil energies such as oil and gas and the pollution caused by these fuels' consumption, nowadays the use of renewable energies to meet energy needs has been considered, and solar energy is one of the cheapest and cleanest of them. The share of energy consumption in the building sector is very high and is about 40% of the country's total energy consumption, and the implementation of projects to reduce energy consumption in this sector is very significant in terms of cost, and the goals of reducing energy consumption in this sector can be achieved at a lower price. In this study, for the first time, the production of part of the required heat of a residential building with a pool and sanitary water consumption in different climates of Iran was investigated by Valentin T*SOL 2018 R(4) software in two separate solar heating systems and 4 cities of Isfahan, Babolsar, Tabriz, and Abadan. The results showed that the city of Tabriz performed better in system #1 and Isfahan and Tabriz in system #2. For all 4 cities, system #2 has a higher efficiency than system #1.

Keywords: Energy, Solar water heater, Climate, Solar heat, Buffer tank.

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1. Introduction

In the future, energy and the environment are the two main concerns [1, 2], and it is essential to develop sustainable renewable energy technologies [3, 4]. Solar energy is the most useful source because of its environmentally friendly nature and also its abundance [5-7].

To increase efficient electricity generation, combined heat and power (CHP) systems, are applied. These systems can be powered by fossil-based or renewable sources and provide heat and electricity to the energy system [8, 9]. CHP systems for improving the efficiency of renewable energy systems and energy storage technologies can be an effective help [10].

Due to the importance and usefulness of solar energy in the world, in 2019 it was reported as illustrated in Figure 1 that solar heating systems generated 479GW of heat. It is equivalent to 43 million tons of oil which are saved, and it also prevented the release of 138 million tons of CO_2 [11].

Figure 2 provides a visual report of the Cumulative geographic separation installed solar water heating capacity until the end of 2018 [12]. By the

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end of this year, China had installed the highest rate of solar water heating (337.6 GW) compared to other countries. This country has allocated 70% of global capacity which is illustrated in Figure 3 [13].

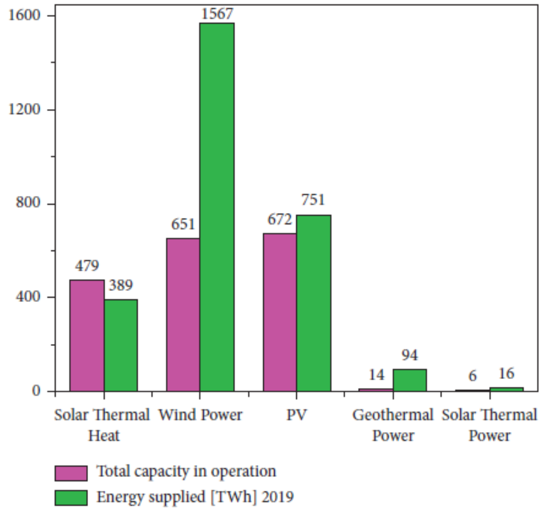


Figure 1. Global capacity in operation (GW) and energy supplied (TWh) [11]

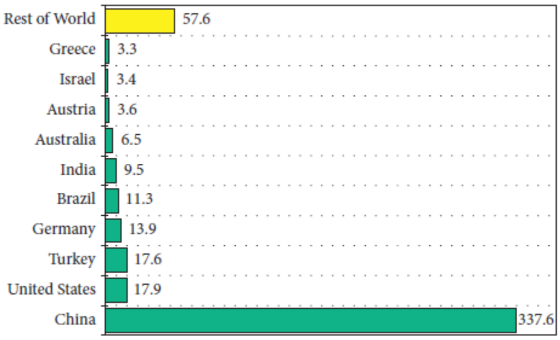


Figure 2. Global solar water heating capacity (in GW) by country, 2018 [12]

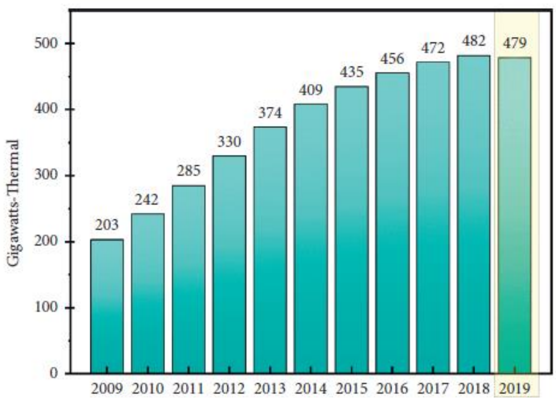


Figure 3. Solar water heating collectors' global capacity, 2009–2019 [13]

The role of climatic conditions in the design and implementation of buildings that are used by humans with different applications is undeniable. In the studies that are conducted to investigate the effect of climatic conditions, the effect of the elements on human comfort and the thermal performance of building elements in adjusting to adverse weather conditions are considered measurement criteria and conclusions [14-16].

The country of Iran has different climates in different parts and has been divided into 4 categories in terms of climate [17-19].

1) The temperate and humid climate that includes the southern shores of the Caspian Sea (Like the city of Babolsar).

2) Cold and mountainous climate, the western mountains that include the western slopes of the central mountain ranges of Iran (Like the city of Tabriz).

3) Hot and dry climate, in this climate, which includes most of the subtropical regions (Like the city of Isfahan).

4) Hot and humid climate, the southern coasts of Iran, which are separated from the central plateau by the Zagros Mountains (Like the city of Abadan).

Due to the use of non-renewable resources, Iran is facing challenges such as air pollution, climate change, and energy security. As an exporter and consumer of fossil fuels, Iran is also trying to use renewable energy as part of its energy mix for energy security and sustainability. Due to its favorable geographical features, Iran has diverse and accessible renewable resources, which are suitable alternatives to reducing dependence on fossil fuels [20].

Ramezi et al.'s study [21] aims to investigate the Ahvaz metropolis in Khuzestan province, to use solar energy in Afaf girls' high school. The results showed that the sunniest days are in August and the cloudiest days are in January. From the results, it can be seen that Ahvaz had a clear and cloudless sky for more than 60% of the year, indicating that it has a high talent and ability to use renewable solar energy in educational spaces. Also, the average monthly radiation and wind speed drawn with the help of GIS software show that Khuzestan province has a high potential for using wind and solar energy in a combined configuration. Finally, by using HOMER software, they have simulated and optimized the energy supply of an educational building in Ahvaz. As a result, we have come to the point that it has been determined from the obtained data that 71% of the year in Ahvaz city is sunny and suitable for using solar energy.

Zaniani et al. [22] investigated the possibility of using solar energy to provide hot water for consumption using RETscreen software in a 90-person primary school located in Chaharmahal and Bakhtiari province. The results showed that the increase in investment return time was accompanied by a decrease in the inflation rate. Also, the results showed that if half of the cost is covered by the government, the return on investment occurs 2 years earlier.

Nilieh et al. [23] investigated the use of solar water heaters (SWHs) in the cold climate of Shahrekord, by using T*SOL software to reduce energy consumption in an elementary school. The results of their research showed that the efficiency of the system used to evaluate the heat loss for the solar system designed to provide sanitary spa and heating of educational space is on average about 17.4%. Also, during the year, an average amount of 8592 m^3 of hydrogen gas will be stored and the production and release of 18168 kg of CO_2 gas will be prevented.

Pahlavan et al. [24], simulated a residential apartment for using SWH in Algeria at 37 stations using T*SOL and MeteoSyn software. They found that using SWH in 37 stations, will generate 150160 kWh of thermal energy for space heating and 99861 kWh for sanitary hot water, which will prevent 56783 kg of CO_2 emissions annually.

Jahangiri et al. studied [25] the provision of thermal needs in sanitary hot water and warm space in a family of 4 people in 10 Canadian provinces. For this purpose, T*SOL Pro 5.5 and MeteoSyn software were used. They understood the most appropriate station in terms of uses SWH is Regina which provides 35% of the total heat for space heating and sanitary hot water.

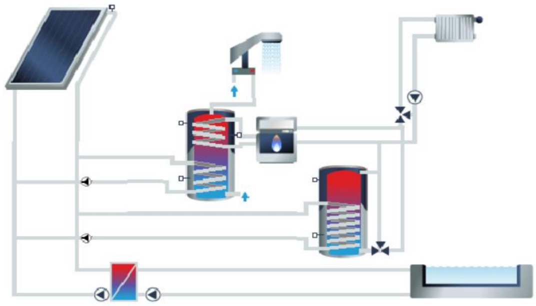
In the research of Saberi et al. [26], the use of flat plate SWHs in Shahrekord, located in the cold climate of Iran, was investigated. The purpose is to provide space heating, sanitary hot water, and a swimming pool in a residential apartment. Three scenarios of the low, medium and high solar fractions are selected for evaluation, and a one-year dynamic analysis is carried out by T*SOL 2018 commercial software. The required climatic data was extracted by Meteonorm 7.3 software. The results showed that in most cases of heat supply, i.e. high solar deficit scenario, the percentage of solar heat supply for sanitary hot water, space heating, and swimming pool is 97.8%, 22.3%, and 44.3% respectively. The total solar fraction is 41%. Also, in this case, the emission of more than 4 tons of CO_2 pollutants has been prevented. The energy balance diagrams for different scenarios showed that 60% of losses are related to optical and thermal and the highest amount of losses is related to the swimming pool. The lowest cost of produced heat and the lowest payback time were $0.028/kWh and 11.4 years, respectively, corresponding to the high solar fraction scenario.

Since Iran is in a very good state in terms of solar radiation, the use of these systems has been receiving attention in the past years. In the range of SWH equipment, you can choose different types of collectors, tanks, etc. according to the needs and climatic conditions of that place. The collector and the design of solar heating systems are different depending on the geographical location, and factors such as the angle of the sun, the average daily sunlight, the amount of cloudiness of the days throughout the year, and other atmospheric and environmental factors affect the design of the collector as well as their efficiency [27-30]. Based on the studies, solar heat generation for domestic hot water, space heating, and a swimming pool has rarely been investigated. Also, it is the first time to investigate the effect of parameters such as different climates and the effect of using two common types of hot water storage tanks in Iran. In the present work, the production of part of the required heat of a residential building with a pool and sanitary water consumption in different climates of Iran was investigated by Valentin T*SOL 2018 R(4) software in two separate solar heating systems and in 4 cities of Isfahan, Babolsar, Tabriz, and Abadan.

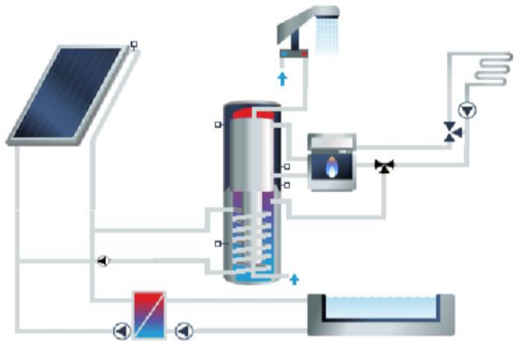
2. Research materials and methods

2. 1. Different configurations to investigate

To carry out the present work, two different configurations were considered for 4 cities (Isfahan, Abadan, Tabriz, and Babolsar) (Figure 4). The first system consists of a solar collector, an indirect water storage tank, a pool, a water storage tank (buffer tank), and a gas boiler. The second system consists of a solar collector, a tank-in-tank combination tank, a pool, a water storage tank (buffer tank), and a gas boiler.



(a)



(b)

Figure 4. Schematic of (a) system #1, (b) system #2

The plan of a residential house is shown in Figure 5. This residential house in the northern location has 2 bedrooms, a length of 15 m, a width of 9 m, and a total area of 135 m^2. This plan is assumed to be fixed and is studied in the conditions and geographical locations of the cities. The special features of that climate, such as temperature difference, it is included in the simulation for both configurations of the system. The geographical characteristics of the cities selected for research in this study are listed in Table 1. To determine the heating load of the building, and to provide hot water for consumption, a one-story building is considered for a 6 people family (Figure 5). The average consumption of water per person is 45 liters.

By simulating the proposed systems for the solar heating system in Valentin T*SOL 2018 R(4) software and considering a gas boiler as a backup system, the results are obtained for both systems in the studied cities. The solar collector used in both systems is a standard flat plate collector.

To better describe the methodology, a flowchart of inputs and the performance of T*SOL 2018 R(4) software was presented (Figure 6). All the inputs and assumptions of the problem that are needed to solve the problem again are presented in Table 2.

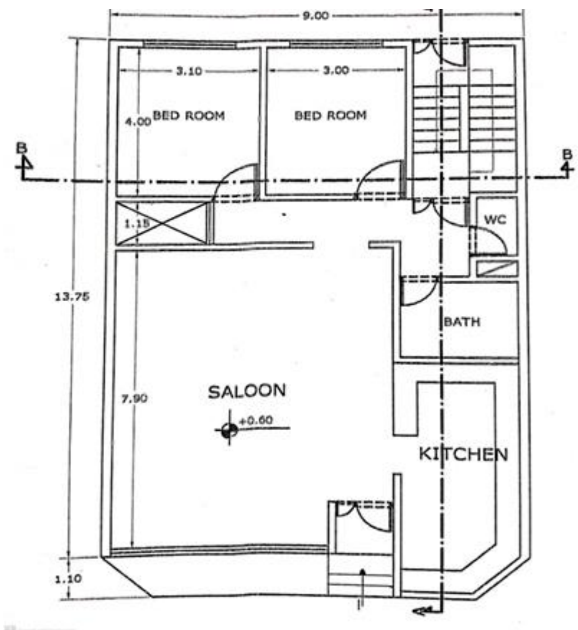


Figure 5. Plan of a two-bedroom residential house

Table 1. Geographical characteristics of the cities selected for research in this study

City Name	Climate type	Above sea level (m)	Longitude (°)	Latitude (°)	Average annual temperature (°C)
Isfahan	Warm and dry	1557	51.7	32.4	16
Abadan	Hot and humid	1	48.2	30.3	26
Babolsar	mild and humid	-21	52.6	36.6	18.4
Tabriz	Cold and mountainous	1402	46.3	38.07	12

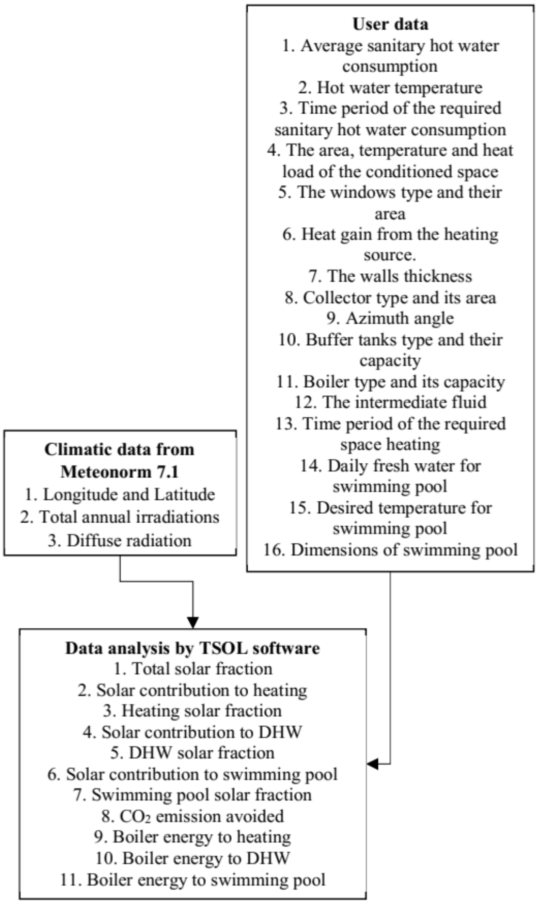


Figure 6. Methodology flowchart of simulation

Table 2. Data required for thermal calculations

Data	Type/ amount
Heated usable area	135 m^2
Indoor temperature	21 °C
Building type	Average wall thickness
Internal heat gain	5 W/m^2
Window type	1 pane of float glass
Space heating operating times	Jan. to May & Oct. to Dec.
Hot water consumption	270 lit/day
DHW temperature	40 °C
DHW operating times	All months
Collector area	Abadan: 25 m^2 Babolsar: 38 m^2 Isfahan: 26 m^2 Tabriz: 33 m^2
Azimuth angle	0° [31-33]
Tile angle	Equal to latitude [34]
FP conversion factor	78 %

2. 2. Governing equations

The radiation received by the collectors is equal to the sum of direct and diffused radiation. Direct radiation is calculated from Meteonorm 7.3 software, and for the diffused radiation colliding with the surface of the collectors, there are the following equations based on the air clearness coefficient (K_t), where α is the angle of the solar collector [35, 36]:

$$0 \le k_t \le 0.3 : \frac{I_d}{I} = 1.02 - 0.245 k_t + 0.0123 \sin\alpha \tag{1}$$

$$0.3 \le k_t \le 0.78 : \frac{I_d}{I} = 1.4 - 1.749 k_t + 0.177 \sin\alpha \tag{2}$$

$$k_t \succ 0.78 : \frac{I_d}{I} = 0.486 - 0.182 \sin\alpha \tag{3}$$

In the above equations, I is the total radiation on a horizontal surface in terms of $\frac{kj}{m^2}$ and I_d is the diffused radiation on a horizontal surface in terms of $\frac{kj}{m^2}$.

Since some of the received radiation is dissipated by the collector, the energy balance is expressed by the following equation [37]:

$$\rho = G_{dir} . \eta_o . f_{IAM} + G_{diff} . \eta_o . f_{IAM.diff} - k_o (T_{cm} - T_A) - k_q (T_{cm} - T_A)^2 \tag{4}$$

In the above equations, G_{dir} is the direct incident radiation on the collector surface, G_{diff} is the diffused radiation incident on the collector surface, η_0 is the collector efficiency, f_{IAM} is the direct radiation correction factor, $f_{IAM.diff}$ is the diffused radiation correction factor, k_0 is the first order losses factor, k_q is the second order losses factor, T_{cm} is the average temperature of the collector and T_A is the air temperature.

Also, in the pollution discussion, it should be mentioned that the software considers the amount of preventing CO_2 emissions per fuel consumption of natural gas equal to 5.14 g/kJ [38, 39]. The parameters such as the total solar fraction, the solar fraction of sanitary water, the solar fraction of space heating, and the solar fraction of the swimming pool are obtained by the following equations, which their parameters are given in the references [40, 41].

$$Total\ Solar\ Fraction = \frac{Q_{S,DHW} + Q_{S,HL} + Q_{S,SP}}{Q_{S,DHW} + Q_{S,HL} + Q_{S,SP} + Q_{AUXH,DHW} + Q_{AUXH,HL} + Q_{AUXH,SP}} \tag{5}$$

$$DHW\ Solar\ Fraction = \frac{Q_{S,DHW}}{Q_{S,DHW} + Q_{AUXH,DHW}} \tag{6}$$

$$Heating\ Solar\ Fraction = \frac{Q_{S,HL}}{Q_{S,HL} + Q_{AUXH,HL}} \tag{7}$$

$$Swimming\ pool\ Solar\ Fraction = \frac{Q_{S,SP}}{Q_{S,SP} + Q_{AUXH,SP}} \tag{8}$$

3. Results and Discussion

3. 1. The first system

The system consisting of the solar collector, an indirect water storage tank, a pool, a water storage tank (buffer tank), and a gas boiler was simulated for the cities selected in the present work. The results are shown in Figures 7 to 14.

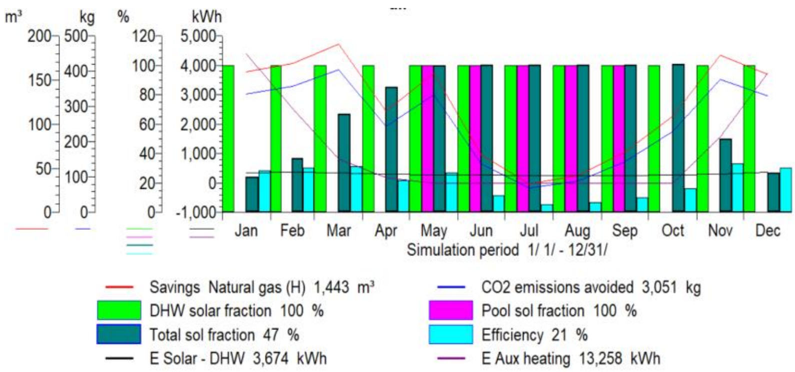


Figure 7. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #1 for Isfahan city

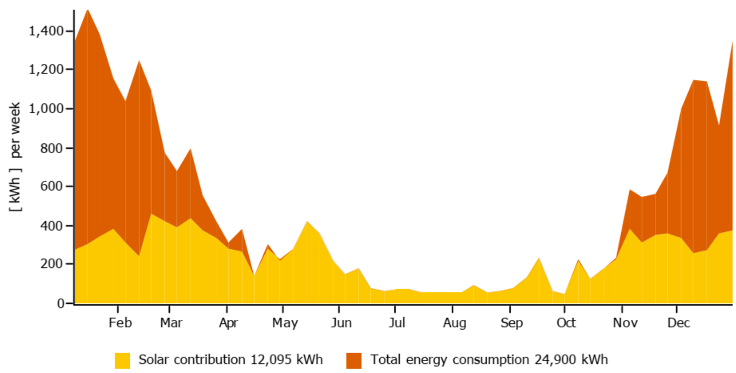


Figure 8. Solar energy production percentage for system #1 for Isfahan city

In the city of Isfahan, according to Figure 7 and Figure 8, in January, February, March, and May, and also in August, September, October, and November, the graph of natural gas storage and prevention of CO_2 emission has an upward slope. The reason for this upward slope is due to the greater use of the solar heating system in these months, which results in a reduction in the use of fossil fuels. The total percentage of heat supply in system #1 for the city of Isfahan is 47%, which leads to the prevention of the emission of more than 3 tons of CO_2 pollutants.

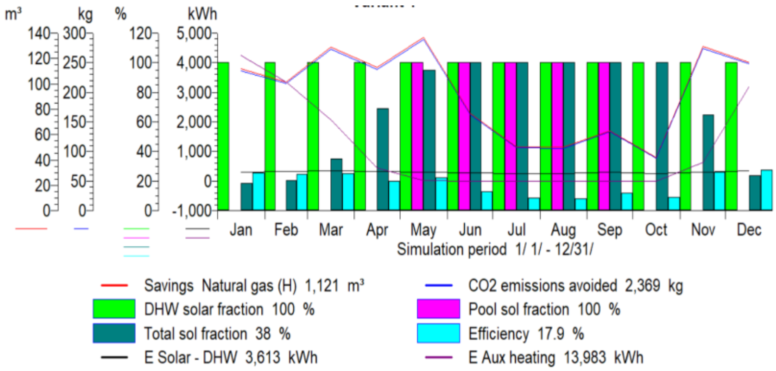


Figure 9. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #1 for Babolsar city

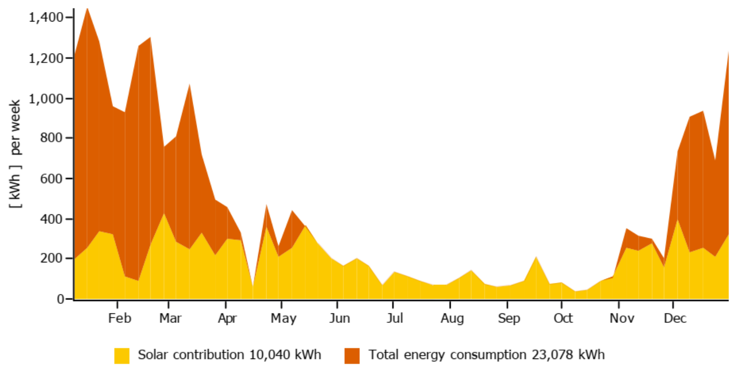


Figure 10. Solar energy production percentage for system #1 for Babolsar city

In Babolsar city, according to Figure 9 and Figure 10, solar heating system #1 has been able to provide 100% sanitary hot water and swimming pool heating to the determined and expected amount. Also, in the parameters of natural gas storage and preventing the emission of CO_2, the system shows a slight drop compared to Isfahan city, which is related to reasons such as weather and the amount of use of the solar heating system in this city. The total percentage of heat supply in system #1 for the city of Babolsar is 38%, which leads to the prevention of the emission of about 2.4 tons of CO_2 pollutants.

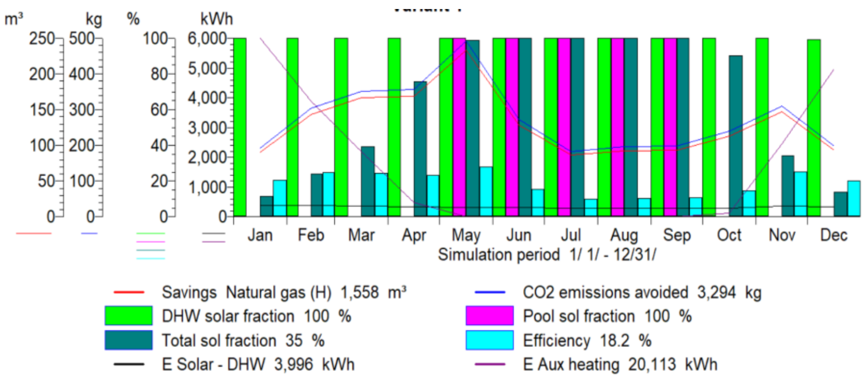


Figure 11. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #1 for Tabriz city

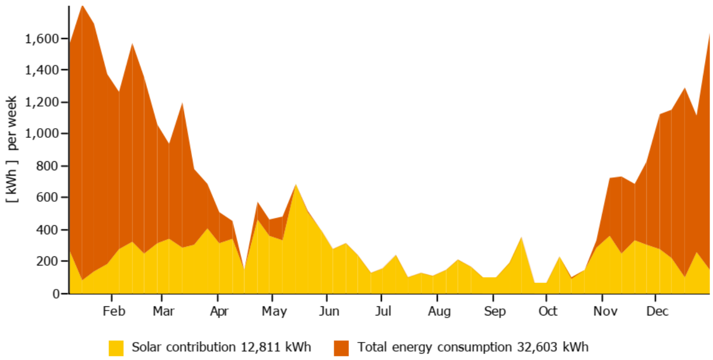


Figure 12. Solar energy production percentage for system #1 for Tabriz city

According to Figure 11 and Figure 12, in Tabriz city, as in Babolsar city, the supply of hot water for consumption and a swimming pool is 100%. In May, due to the high radiation in this area in this month, the highest efficiency has been recorded. On the other hand, due to the cool weather in this city, the solar heating system is working at different rates during the months. Because of this, the solar heating system has been able to prevent a large amount of fossil fuel consumption. The total percentage of heat supply in system #1 for the city of Tabriz is 35%, which leads to the prevention of the emission of about 3.3 tons of CO_2 pollutants.

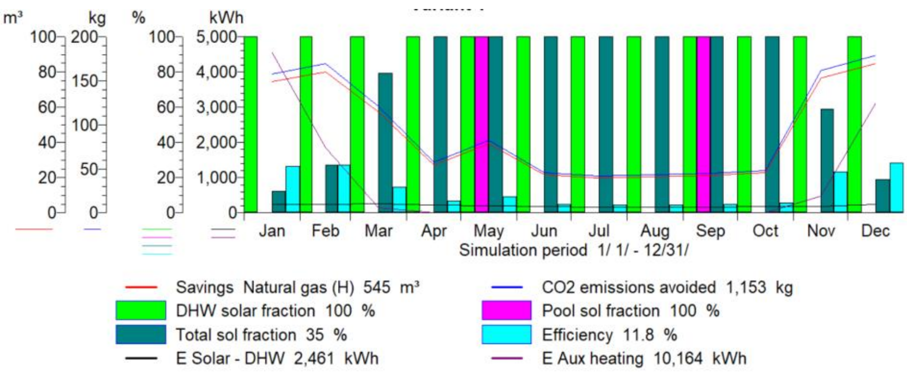


Figure 13. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #1 for Abadan city

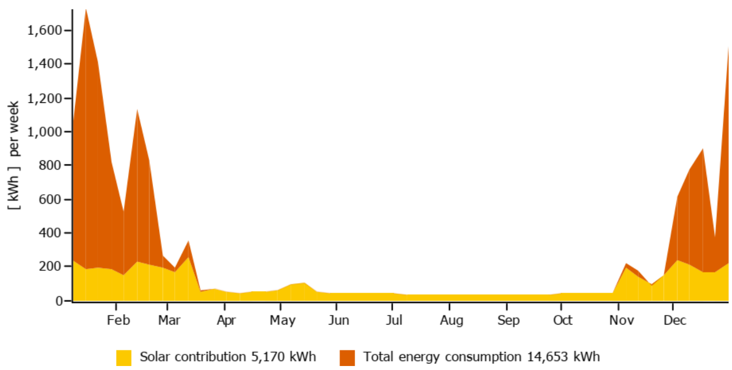


Figure 14. Solar energy production percentage for system #1 for Abadan city

According to Figure 13 and Figure 14, the total percentage of heat supply in system #1 for Abadan city is equal to 35%, which leads to the prevention of the emission of about 1.2 tons of CO_2 pollutants.

Despite the high efficiency in Isfahan city, the use of the solar collector system, an indirect water storage tank (buffer tank), and a gas boiler has better performance in Tabriz city (in the field of natural gas storage, preventing the emission of CO_2 gas and energy storage). Isfahan, Babolsar, and Abadan are ranked after Tabriz.

3. 2. The second system

The system consisting of a solar collector, a pool, a tank-in-tank combination tank, a water storage tank, and a boiler was simulated for the understudy cities. The results are shown in Figure 15 to Figure 22.

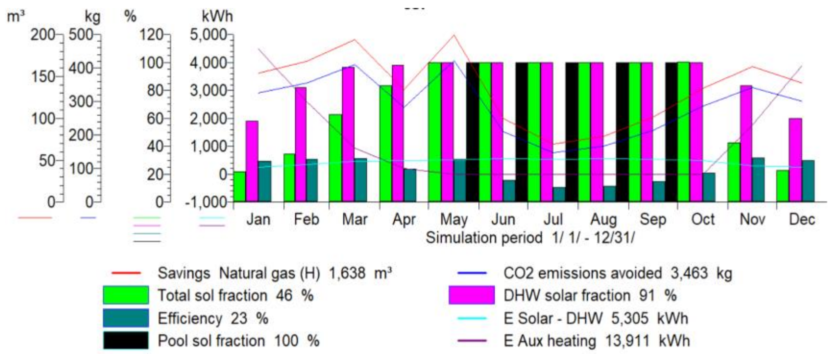


Figure 15. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #2 for Isfahan city

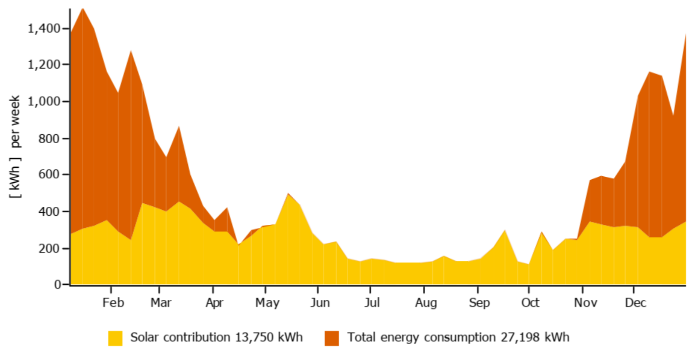


Figure 16. Solar energy production percentage in system #2 for the city of Isfahan

In the city of Isfahan, according to Figure 15 and Figure 16 related to solar heating system #2, there is an increase in the absorption and use of solar radiation. The supply of hot water for consumption and the swimming pool has been evaluated between 90% and 100%. In May, June, July, August, September, and October, the highest percentage of required energy supply has been recorded using this type of system. The total percentage of heat supply in system #2 for the city of Isfahan is 46%, which leads to the prevention of the emission of about 3.5 tons of CO_2 pollutants.

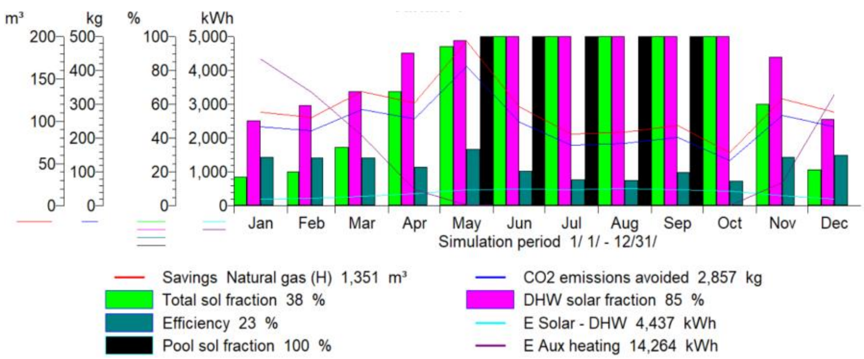


Figure 17. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #2 for Babolsar city

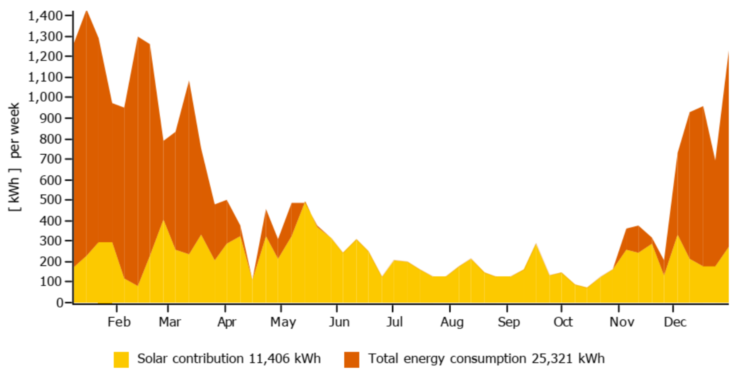


Figure 18. Solar energy production percentage for system #2 for Babolsar city

According to Figure 17 and Figure 18, in the city of Babolsar, the amount of required energy supply has reached the highest level in the months of June, July, August, September, and October, and the domestic hot water consumption and pool needs are more than 80% provided. It is expected that due to the cloudiness and weather conditions of the region in the winter months, the solar heating system will not be able to record a peak in the graph, which is also true according to the graph. The total percentage of heat supply in system #2 for the city of Babolsar is 38%, which leads to the prevention of the emission of about 2.9 tons of CO_2 pollutants.

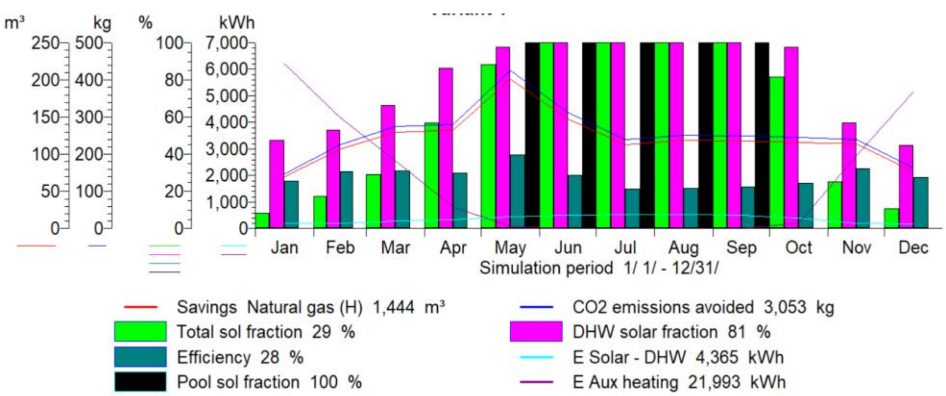


Figure 19. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #2 for Tabriz city

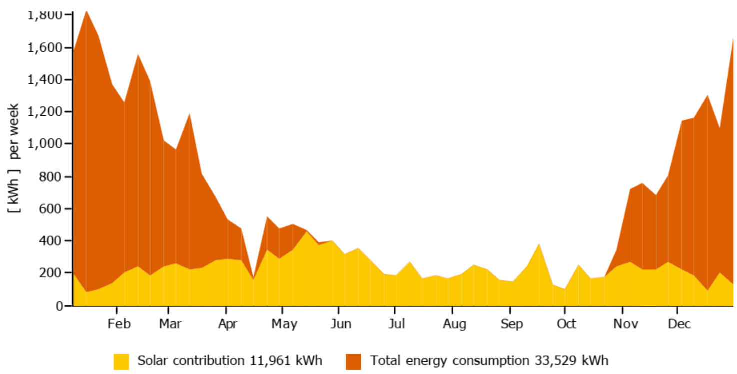


Figure 20. Solar energy production percentage in system #2 for Tabriz city

According to Figure 19 and Figure 20, in the city of Tabriz, as well as in the city of Isfahan and Babolsar, solar heating system #2 has been able to increase the supply of domestic hot water and the pool by more than 80% in June, July, August, and September. The supply is high and indicates more use of solar heating in these months. It also recorded the highest efficiency in May. The total percentage of heat supply in system #2 for the city of Tabriz is 29%, which leads to the prevention of the emission of about 3.1 tons of CO_2 pollutants.

According to Figure 21 and Figure 22, the total percentage of heat supply in system #2 for Abadan city is equal to 31%, which leads to the prevention of the emission of about 1.3 tons of CO_2 pollutants.

The city of Abadan in the field of natural gas storage and prevention of CO_2 emissions has a lower performance. Tabriz city ranks first due to its efficiency and energy storage and higher energy consumption, followed by Isfahan, Babolsar, and Abadan.

The efficiency of solar heating systems, natural gas storage, energy stored in the system, and the amount of prevention of CO_2 gas emissions for 4 studied cities, Isfahan, Babolsar, Tabriz, and Abadan given in Table 3 and Table 4.

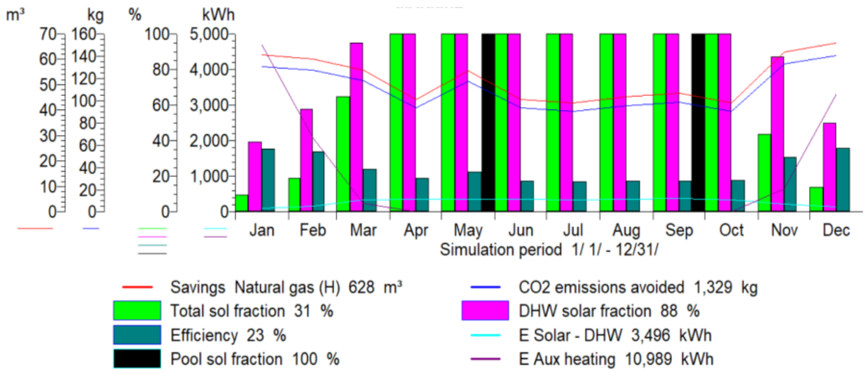


Figure 21. The system efficiency, natural gas storage, CO_2 emission prevention, different percentages of solar radiation, hot water, and energy storage in system #2 for Abadan city

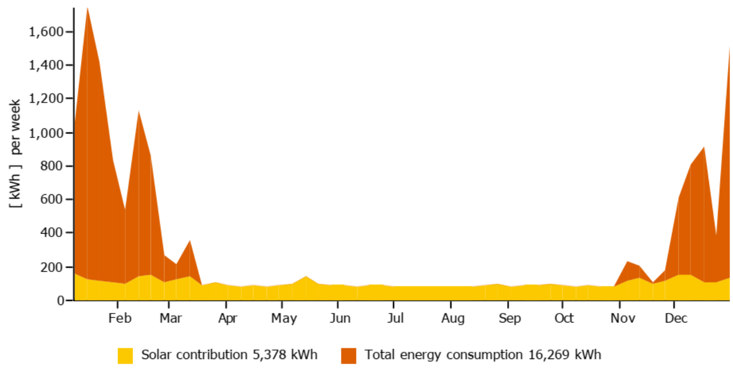


Figure 22. Solar energy production percentage in system #2 for Abadan city

Table 3. Simulation results of System #1

City	System efficiency (%)	Energy saving (kW)	Natural gas storage (m^3)	CO_2 emission (kg)	The amount of energy consumed (kW)
Esfahan	21	13258	1443	3051	24986
Babolsar	17.9	13983	1121	2369	23090
Tabriz	18.2	20113	1558	3294	32773
Abadan	11.8	10164	545	1153	14596

Table 4. Simulation results of system #2

City	System efficiency (%)	Energy saving (kW)	Natural gas storage (m^3)	CO_2 emission (kg)	The amount of energy consumed (kW)
Esfahan	23	13911	1638	3463	27220
Babolsar	23	14264	1351	2857	25244
Tabriz	28	21993	1444	3053	33728
Abadan	23	10989	628	1329	16096

According to Tables 3 and 4, it is clear that in the first system, Isfahan has the highest efficiency and Tabriz has the highest energy storage. Also, in the second system, Tabriz has the highest efficiency and Isfahan has the highest amount in the prevention of CO_2 gas.

In general, according to the results, the combined system of tanks, i.e. system #2, has shown better performance in different climates of Iran.

Carbon dioxide gas is the most important greenhouse gas produced by humans, the production of each ton of this gas has a fine of about 100 dollars, and so by looking at the results, we can see how useful the use of the solar heating system is in this field. The most cost-effective steps to reduce energy consumption in a building usually occur during the design process. Therefore, in this project, first, the design of systems for heat production in different climates of Iran was carried out, and then, using T*SOL 2018 R(4) commercial software, a parametric study of the use of SWHs was carried out in it. The results of the simulations showed that the annual average of different amounts of heat in different climates can be supplied by the solar system, which is not the total energy needed, and only a part of it can be supplied by this method. This method is used as an aid in the direction of low usage of fuels like natural gas.

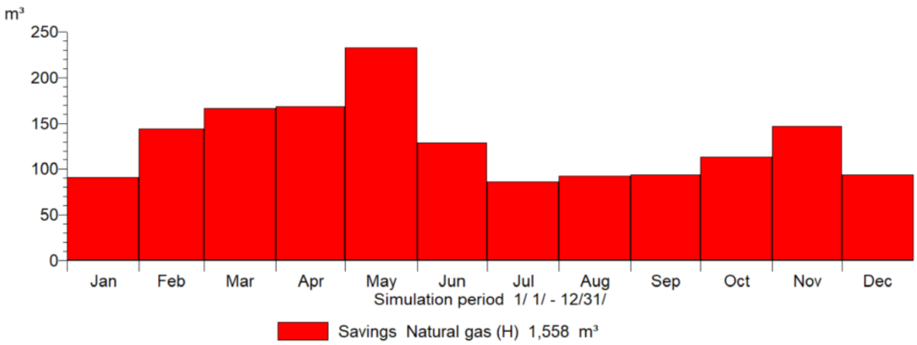


Figure 23. Tabriz natural gas storage as the largest amount of storage in the first system

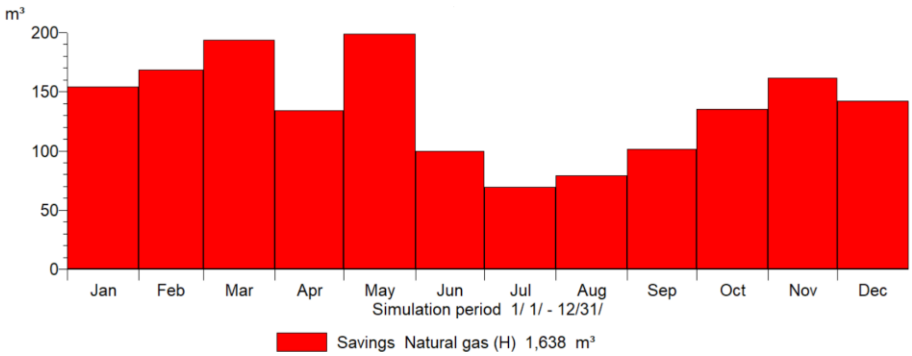


Figure 24. Isfahan natural gas storage as the largest amount of storage in the second system

In Figure 23 and Figure 24 natural gas storage is shown for the cities with the highest amount (Tabriz and Isfahan). According to the graphs, Tabriz city is in the first system and Isfahan city is in the second system with the highest amount of gas storage.

According to the graphs, it is clear that the city of Tabriz had the highest amount of gas storage in the first system from May 12 to June 11. It is also the lowest from July 11 to August 10. The city of Isfahan has the highest amount of gas storage from March 11 to April 12 and from May 12 to June 11. From July 11 to August 10 Isfahan has the lowest amount of natural gas storage.

Figure 25 and Figure 26 show the prevention of CO_2 emissions for the cities with the highest amount. According to the graphs, the city of Tabriz in the first system and the city of Isfahan in the second system are shown as the highest amount of gas emission prevention.

According to the graphs, it is clear that the city of Tabriz recorded the highest amount of gas emission prevention in the first system from May 12 to June 11 and the lowest amount from July 11 to August 10. For the city of Isfahan, in the second system, from March 11 to April 12 and from May 12 to June 11, it has the highest amount of gas emission prevention and from July 11 to August 10, it recorded the lowest amount.

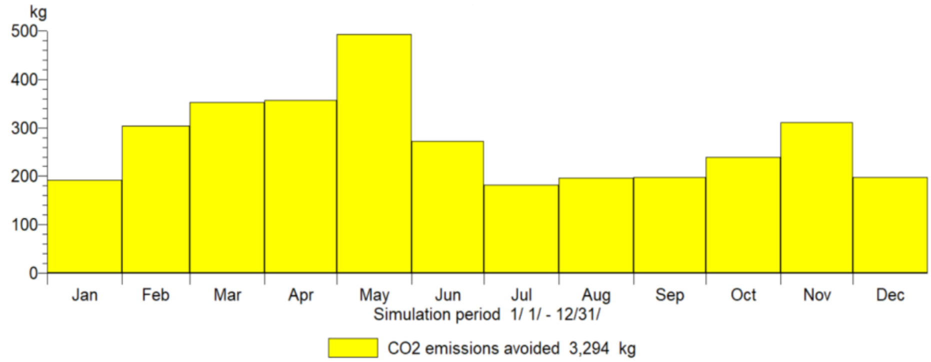


Figure 25. The rate of prevention of CO_2 gas emission in Tabriz city as the highest rate in the first system

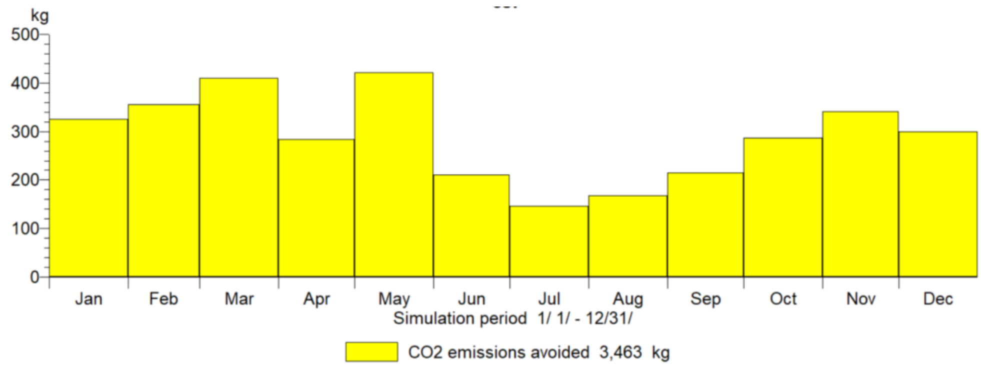


Figure 26. The rate of prevention of CO_2 gas emission in Isfahan city as the highest rate in the second system

4. Conclusions

In the present work, the production of part of the required heat of a residential building with a pool and sanitary water consumption in different climates of Iran was investigated by Valentin T*SOL 2018 R(4) software in two separate solar heating systems and in 4 cities of Isfahan, Babolsar, Tabriz, and Abadan. The results showed that:

- In the field of natural gas storage, prevention of CO_2 gas emission, and energy storage, Tabriz has performed better and Isfahan, Babolsar, and Abadan are ranked after Tabriz.
- The city of Isfahan has a higher performance in the use of a system consisting of a solar collector and a tank-in-tank combination tank in the field of natural gas storage and preventing the emission of CO_2 gas.
- The city of Tabriz performs well in the second system due to its efficiency and energy storage and higher energy consumption. Isfahan, Babolsar, and Abadan are ranked after Tabriz.
- In general, the combined system of tanks, i.e. system #2, has shown better performance in different climates of Iran in terms of different parameters.
- The results of the simulations showed that, on average, different amounts of heat can be supplied annually in different climates by the solar system, which is not the total energy needed, but it helps a lot in the field of heat production and saving fossil fuel consumption.

5. Future Works and Limitations

In the continuation of this work, ranking methods can be used, and also compared the results from the point of view of economics. Then check all the stations in Iran and find the superior point in Iran. Also, the following are recommended:

- The effect of using different types of solar collector technologies,
- The effect of using different hot water storage tanks,
- The effect of working fluid.

Regarding the limitations of this work, the following can be mentioned:

- Limited capacity of SWH,
- The high price of SWHs in Iran compared to fossil fuels,
- The general public's low willingness to buy an SWH,
- Limited working fluid (combination of ethylene glycol and water),
- Lack of accurate calculation for heat gain of people and equipment in space heating calculation.

Nomenclature

ρ	Collector energy balance (kW)
α	Tilt angle (°)
I	Total hourly radiation on a horizontal surface (kJ/m^2)
SWH	Solar water heater (-)
T_A	Air temperature (K)
k_t	Hourly clearness index (-)
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)
CHP	Combined heat and power (-)

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