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Research article

Dynamic simulation and energy analysis of forced circulation solar thermal system in two various climate cities in Iraq

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Abstract: This study aimed towards an essential subject in the field of solar energy. The sun is a free clean energy source. This research presents the modeling and simulating of forced circulation solar thermal system for domestic hot water production in Iraq. The TRNSYS dynamic simulation program was chosen as the primary research tool. The TRNSYS model comprises component (collectors, controls, storage tanks, circulation pump, solar radiation processor, printer, equations, and integrators). The study was conducted in two different regions in Iraq (Baghdad and Basrah). The model investigated in many aspects, such as provide the demand of hot water for a family (ten persons) by using 10 m^2 of flat plate collector, stratification effect in a storage tank on the collector's thermal efficiency, and effect of hot domestic water different consumption on solar thermal system performance. Results present that the system could provide hot water demand in Baghdad (67–81% and 39–62%) and Basrah (69–82% and 49–66%) in summer and winter, respectively, by using solar energy. The maximum auxiliary energy was used during the cold months are (2980 MJ/month) in Baghdad and (2607 MJ/month) in Basrah. There was an increase in the isothermal layers in the storage tank due to a rise in collector efficiency. There was a higher performance of forced circulation solar thermal systems (SDHW) when the domestic hot water consumption is lower.

Keywords: solar energy; TRNSYS; solar thermal system; thermal efficiency; simulation

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1. Introduction

Renewable energies from the sun, such as solar, geothermal, and wind sources, are lasting and significantly have a lot less environmental impact than the traditional fossil fuels as the energy resources. In recent decades, solar energy has become the most important renewable energy source in the world. The use of this solar energy includes many fields lately, such as space heating, pool heating, hot water (DHW) production, cooling, and electrical production without polluting the environment [1]. Solar hot water systems exemplify the most widespread application of solar energy in the present time. There are two types of solar water heating systems: an active solar system or a forced circulation system and a passive solar or natural circulation system (Thermosyphon) [2].

Iraq receives temperatures more than 45 ℃ in most of the days, except for the short winter. Inhabitance of Iraq rose from 32 million in 2010 and predictable to grow to approximately 64 million in 2050. Iraq knows for electric power leakage because of its wars, where this problem maximizes through the summer. Iraq is one of the countries to be the richest in renewable energy resources [3].

In many studies around the forced circulation solar system [4], Zeghib and Chaker (2011) used a time-marching model and simulated a forced circulation solar thermal system's performance. In [5], Lima et al. (2006) studied the use of the TRNSYS for optimization of solar thermal flat-plate collector and tank of the solar thermal system. In [6], Yaïci et al. (2012) study used TRNSYS software to create a model and simulation of the solar thermal energy system to optimize key design parameters. In [7], Yang and Shue (2013) studied the effected temperature stratification on collector efficiency. The temperature stratification in the storage tank is vital because mixing cold water with hot water increases the collector's temperature and reduces the system efficiencies. In [8], Mohammed et al. (2011) has configured a model by TRNSYS and confirm the performance of a direct solar thermal system in Baghdad, Iraq. In [9], Fayath (2011) used a mathematical model to predict thermal characteristics for a solar water heater. In [10], Ali (2010) studied the use of the model is (half-sine) for solar thermal water heating for domestic or industrial applications. In [11], Tiwari et al. (2020) developed TRNSYS model of a commercially useful active flat plate collector applied for solar water heating system. The proposed model predicts the efficiency of the solar water heating system for different climates and seasonal changes during a year. The best performance of the solar water heating system is during winter (January-April and October-December). In [12], Babalis and Nielsen (2013) studied validation of a thermosyphon solar water heating using Trnsys model simulation and conformity within 4.7% difference is noted. In [13], Sultana et al. (2015) developed TRNSYS model of a solar system concentrating collector for water heating and solar cooling and studied the impact of various load profiles on the system efficiency. In [14], Abdunnabia et al. (2014) validated of the Trnsys model simulation of forced circulation solar water heating system by comparing the simulated results with the experimental data.The research's primary purposes are summarized as follows:

- The validated model's essential purpose focused on predicting a forced circulation SWH system's long-term thermal performance in different locations.
- SWH system performances simulation under different load profiles and operating conditions for each climate region.
- Appropriate TRNSYS simulation models have been created for the forced circulation solar thermal system in Iraq.
- Predicted monthly and annual auxiliary energy needed by the solar thermal system.

2. Modeling

2.1. Simulation model

Transient simulation (TRNSYS) software was used to create a model for the forced circulation solar water heating system, as shown in Figure 1. The model's major element is solar thermal flat plate collector, storage tank, pump (in forced circulation), and controller. Weather Generator (Type 54) was used to provide a reading of weather data for two cities (Baghdad and Basrah). The forcing function (Type 14) define the hot water draw profile. The controller (Type 2) controls the signal value selected depending on the difference between lower and upper temperatures. The pump of fluid (Type 3) uses a variable control function for determining a mass flow rate. The Integrator (Type 24) is used to define quantities integrated over some time. Type 25 is printing simulation information [15]. The main TRNSYS components for the model of the solar water heating system are summarized in Table 1. Table 2 shows the main design and operating parameters values of the solar system components in the TRNSYS model.

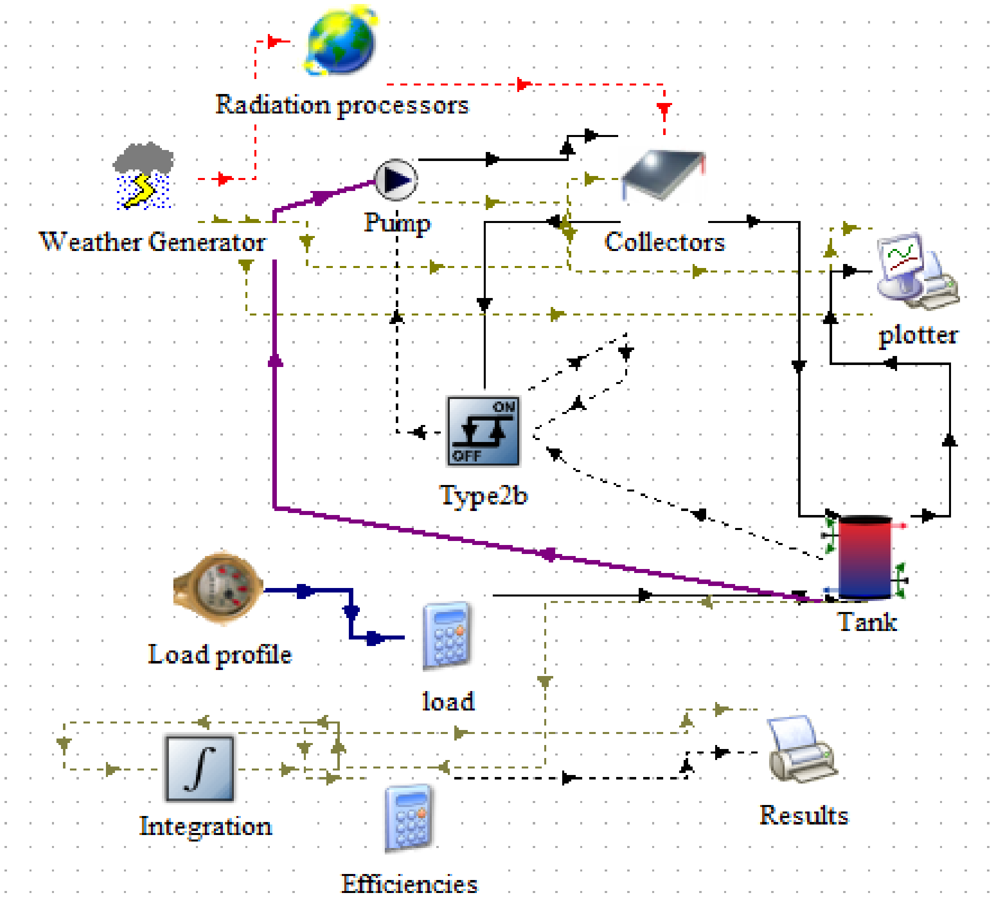

Figure 1. TRNSYS model of forced circulation solar thermal system.

Table 1. Main TRNSYS components for solar water heat system and their symbols.

Component name	Icon	Symbol
Flat-plate collector		Type 1
Solar radiation processor		Type 16
Thermal storage tank		Type 4
Circulation pump		Type 3
Pump controller	ON OFF	Type 2
Plotter		Type 65
Weather generator		Type 54
Forcing function		Type 14
Integration	∫	Type 24
Results		Type 25

Table 2. The values of the main design and operating parameters.

Parameters	Value	Unit
Flat-plate collector		
Collector area	10	m^2
Fluid specific heat	4.190	kJ/kg.K
Intercept efficiency	0.8	
Efficiency slope (Heat transfer coefficient)	13	kJ/hr.m^2.K
Collector slope	17	degrees
Azimuth angle	−22	degrees
Latitude (Baghdad)	33.33°N	degrees
Latitude (Basrah)	30.35°N	degrees
Longitude (Baghdad)	44.44°E	degrees

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Parameters	Value	Unit
Longitude (Basrah)	47.5°E	degrees
Solar constant	4871	kJ/hr.m^2
Thermal storage tank		
Tank volume	0.8	m^3
Fluid density	1000	kg/m^3
Boiling point	100	C
Height	1	m
Pump		
Maximum power	300	kJ/hr
Power coefficient	0.5	

2.2. Hot water load profile

The hourly consumption of hot water differs from a day to another and from family to another. For the present simulation, Hot water consumption profile (100 L/person) is distributed during a day on 15th February, as shown in Figure 2.

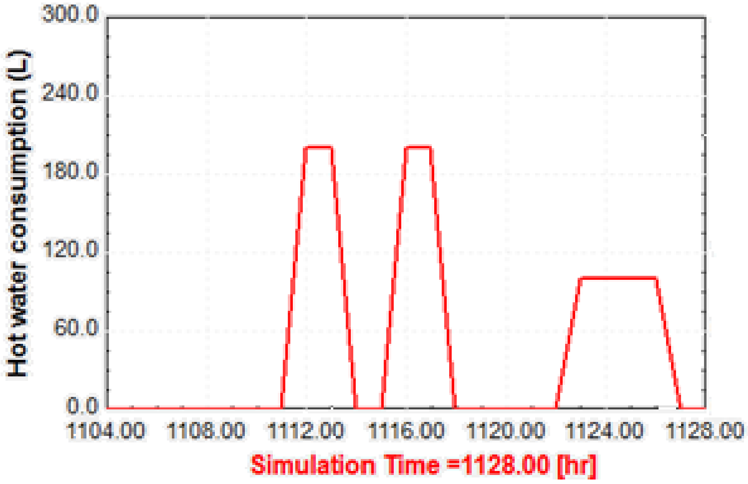

Figure 2. Daily hot water consumption profile (1000 l/day).

2.3. Meteorological conditions

The climate of Iraq is characterized by mild winter and hot, dry summer with maximum summer temperatures of up to (45 °C) and a minimum winter temperature (5 °C). The research is conducted in two cities of Iraq by inputting their weather data. Their primary coordinates are summarized in Baghdad (Latitude of 33.33°N, Longitude of 44.44°E) and Basrah (Latitude of 30.35°N, Longitude of 47.5°E). The ambient temperature and the irradiation data on a horizontal plane for each month of the studied cities are shown in Figure 3. Iraq's daily sunshine duration fluctuates from about 7 hours in winter to about 12 hours in summer [16].

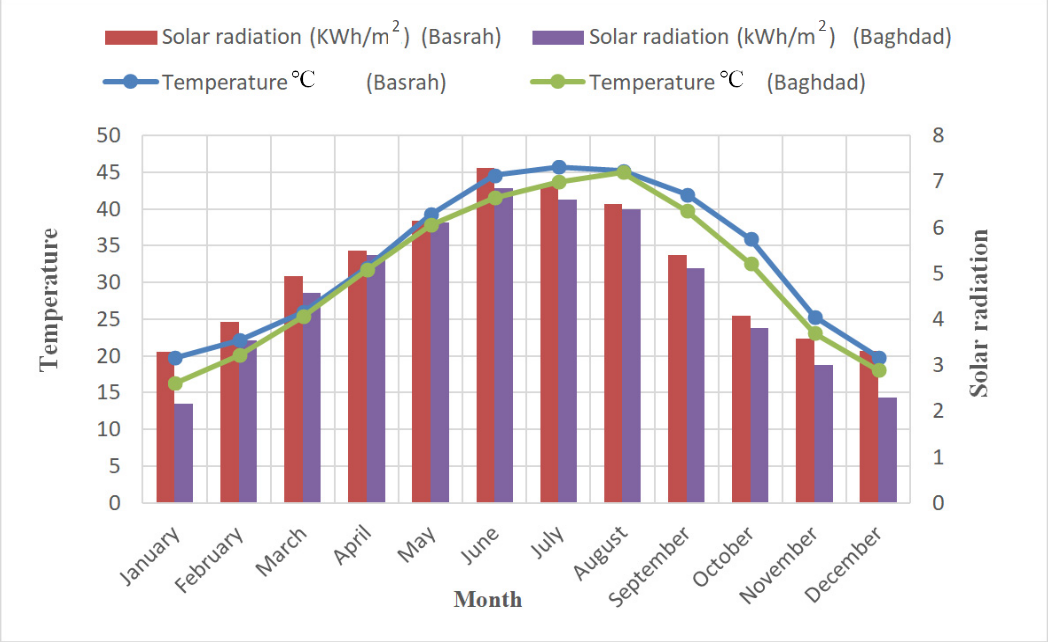

Figure 3. Solar radiation and ambient temperature in the two cities Baghdad and Basrah.

3. Results and discussions

3.1. Energy analysis and collector thermal efficiency

The simulation results are presented in Table 3, which shows the monthly values of auxiliary energy Qaux, hot water load QL, and energy yield Qs. The available energy is maximum in midmost summer when cooling is required, and the sun is approximately least in mid-winter. The energy yield is most significant in mid-summer and least in midmost winter. There is minimum energy available in winter, ambient temperature is low, and the collector's heat loss is maximum. The monthly collector efficiency is maximum (69% in Baghdad and 54% in Basrah) in the summer and minimum (62% in Baghdad and 51% in Basrah) in the winter season. This typical pattern is as would be predictable from the energy analysis and thermal efficiency in Table 3.

Table 3. Energy quantities of forced solar thermal system and collector thermal efficiency.

Month	Auxiliary energy (MJ)		Load (MJ)		Energy yield (MJ)		Thermal efficiency	
	Baghdad	Basrah	Baghdad	Basrah	Baghdad	Basrah	Baghdad	Basrah
January	2980	2607	4846	5826	1857	3273	0.62	0.51
February	2358	2203	5172	5450	2922	3351	0.67	0.51
March	2312	2135	6119	6367	3930	4369	0.68	0.52
April	2024	1933	6185	6330	4300	4541	0.71	0.53
May	1793	1769	6821	6829	5203	5233	0.75	0.53
June	1484	1254	6864	7059	5567	6007	0.78	0.54

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Month	Auxiliary energy (MJ)		Load (MJ)		Energy yield (MJ)		Thermal efficiency	
	Baghdad	Basrah	Baghdad	Basrah	Baghdad	Basrah	Baghdad	Basrah
July	1357	1459	7277	7191	6121	5917	0.79	0.57
August	1416	1676	7226	6970	6006	5463	0.81	0.59
September	1675	1810	6678	6544	5160	4881	0.80	0.56
October	2372	2235	6087	6280	3812	4165	0.78	0.56
November	2657	2404	5338	5863	2757	3560	0.69	0.54
December	2955	2787	4980	5481	2073	2761	0.64	0.52
Total	25387	24279	73598	76195	49712	53527		
Annual average	2115	2023	6133	6349	4142	4460		

3.2. Annual performance of the solar fraction and auxiliary energy

The performance of the forced circulation solar thermal system depends on the solar fraction. Solar fraction and auxiliary energy are evaluated in Baghdad and Basrah and compared with each other. Monthly solar fraction and auxiliary energy values in these cities are fluctuating from (39%, 2980 MJ) to (81%, 1357 MJ) in Baghdad and from (49%, 2787 MJ) to (82%, 1245 MJ) in Basrah, respectively as shown in Figures 4 and 5. It should be noted that solar radiation was very high in summer and heating needs are much higher than in the winter season. Figures 4 and 5 shows that the increase in a solar fraction decreases the quantity of auxiliary energy.

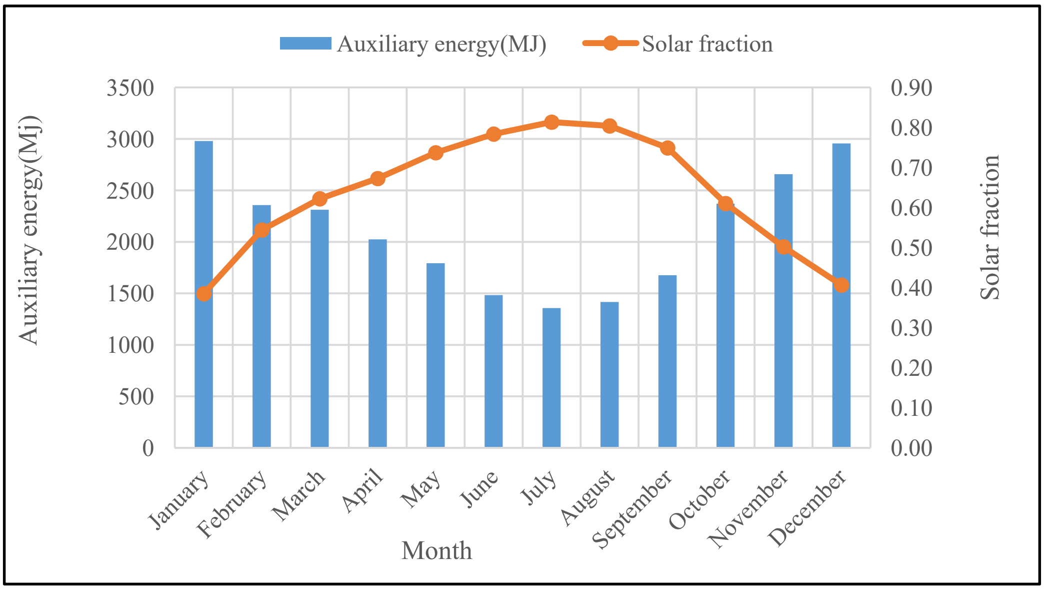

Figure 4. Monthly solar fraction and auxiliary energy in Baghdad.

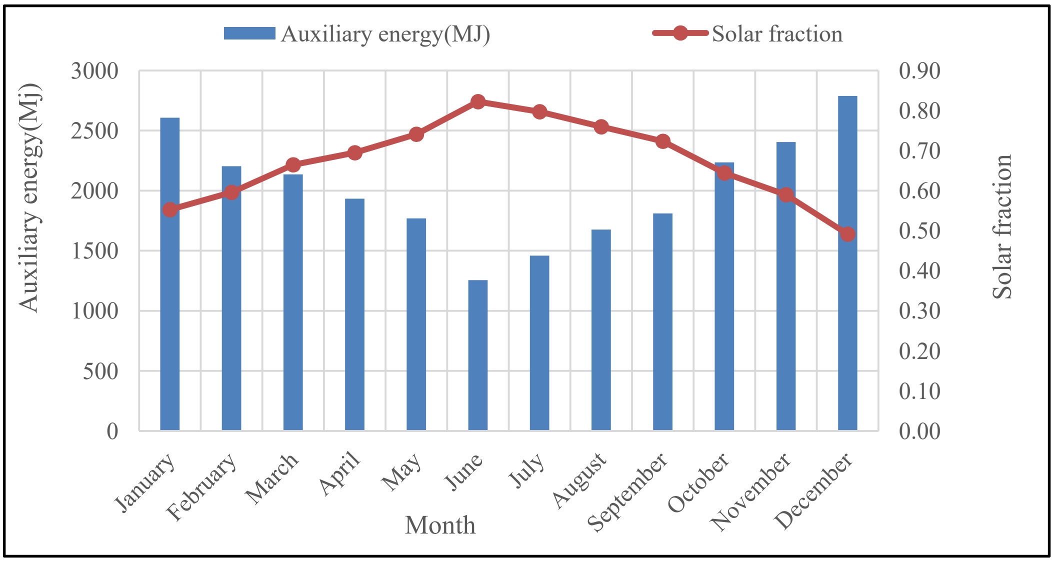

Figure 5. Monthly solar fraction and auxiliary energy in Baghdad.

3.3. Storage tank layers

In this section, the storage tank is supposed to be divided into five cases (2,4,6,8,10) of isothermal layers of equal height tank to investigate the effect of stratification on solar efficiency system in the storage tank. The results of the simulation were used to plot Figure 6. It is interesting to note the difference between the average efficiency of the collector in the five cases. This increase in the isothermal layers in the storage tank is due to the reduced water temperature at the tank's lower level. The temperature supply to the collector is lower than that of the top. The lowered inlet temperature to flat plate collector reduced flat plate collector heat loss, and therefore a rise in collector efficiency.

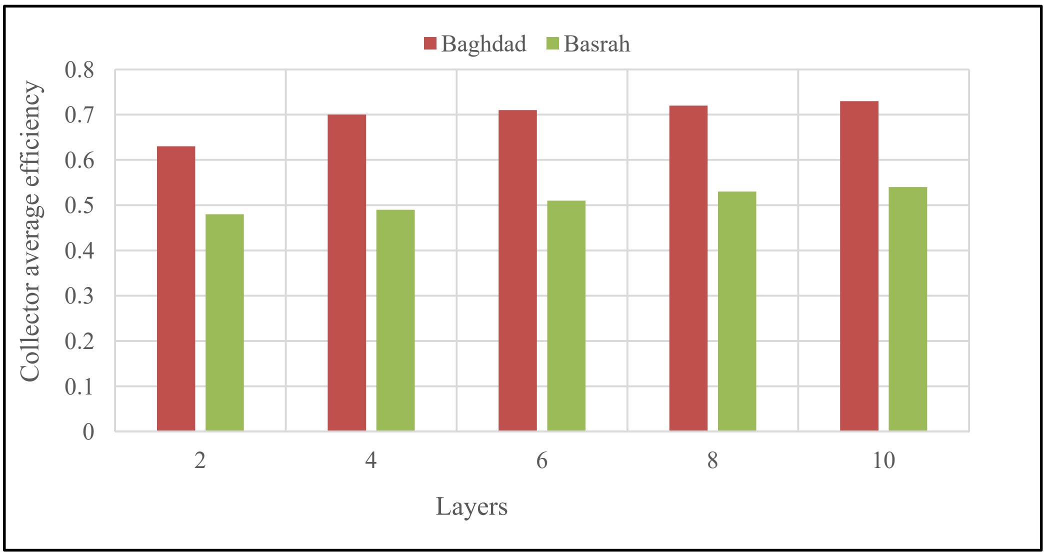

Figure 6. Collector average efficiency in different storage tank layers.

3.4. Temperature profiles and solar pump controller

The solar flat plate collector is considered an essential part of the forced circulation solar water heating system because it simultaneously has two advantages. It gets solar energy immediately, and secondly, it conveyed this solar energy to heat to transport it to the storage tank. Figure 7 shows the development of the outlet temperature from the flat plate collector, outlet temperature from the storage tank, bottom temperature of the storage tank, and the pump's operation during the one day in cold winter month (15th February) in Baghdad city. The flat plate collector's outlet temperature rises during the morning to reach 50 °C at 3 pm and then begin decreasing until sunset. The outlet temperature of the solar thermal collector takes the manner of solar radiation. It can also note a decrease in the top layer's temperature during the hot water consumption periods, and this temperature is approximately constant. For example, at 12 h (the highest daily consumption load), the top layer's temperature in the storage tank decreases from 60 °C to 45 °C. The switch on and off the pump's operation by using a solar pump controller adjusts within the solar circuit when the temperature of the outlet in the solar thermal collector is greater than the temperature in the bottom tank. Two temperature sensors are required: one located at the solar thermal collector outlet measures the temperature outlet collector (T1), and one located at the bottom of the storage tank measures the temperature (T2). The signals coming from the two temperature sensors in the collector and tank are compared in a control unit. The solar pump is turned on at a temperature difference (T1–T2) equal to or higher than 5 °C and is switched off when the same temperature exceeds a minimum of 5 °C.

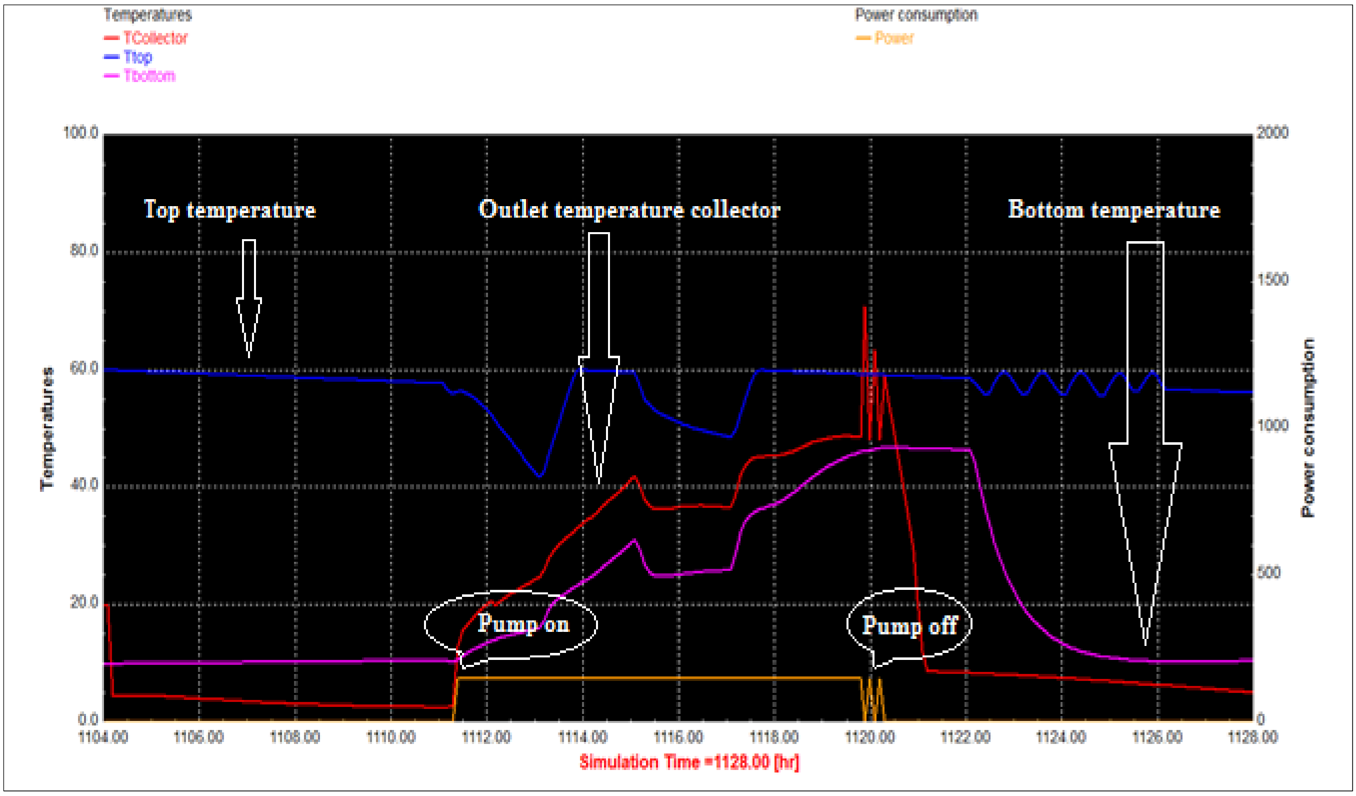

Figure 7. Temperature profiles and operation of the pump.

3.5. Effect of domestic hot water consumption

It should be noted that the daily consumption of hot water affects a solar thermal system's performance. The model has been simulated on average daily consumption in three cases ranging from 40 l/day (1 person, low consumption), 70 l/day (1 person, regular consumption), and 100 l/day (1 person, high consumption). The results obtained from the simulation under Baghdad and Basrah conditions are presented in Figures 8 and 9. It is important to note that domestic hot water consumption is lower achieved a higher solar fraction and noted that the solar fraction in all three cases is higher in the summer season and gets lower in the winter months. For the high-profile consumption case, the yearly solar fraction is approximately (64% in Baghdad and 67% in Basrah) compared with (85% in Baghdad and 91% in Basrah) in the low-profile consumption case.

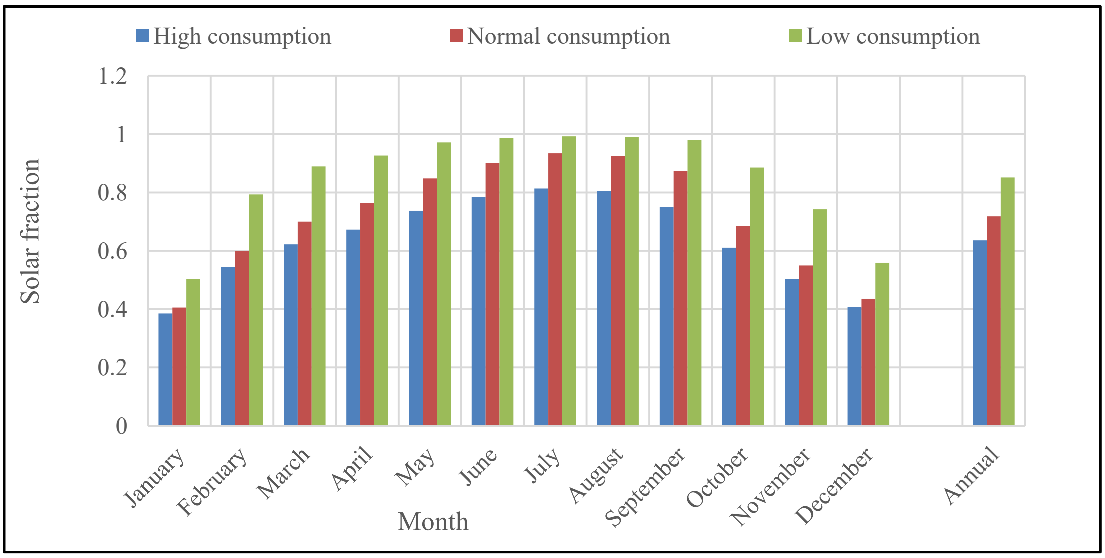

Figure 8. Annual and monthly solar fraction at various hot water consumption in Baghdad city.

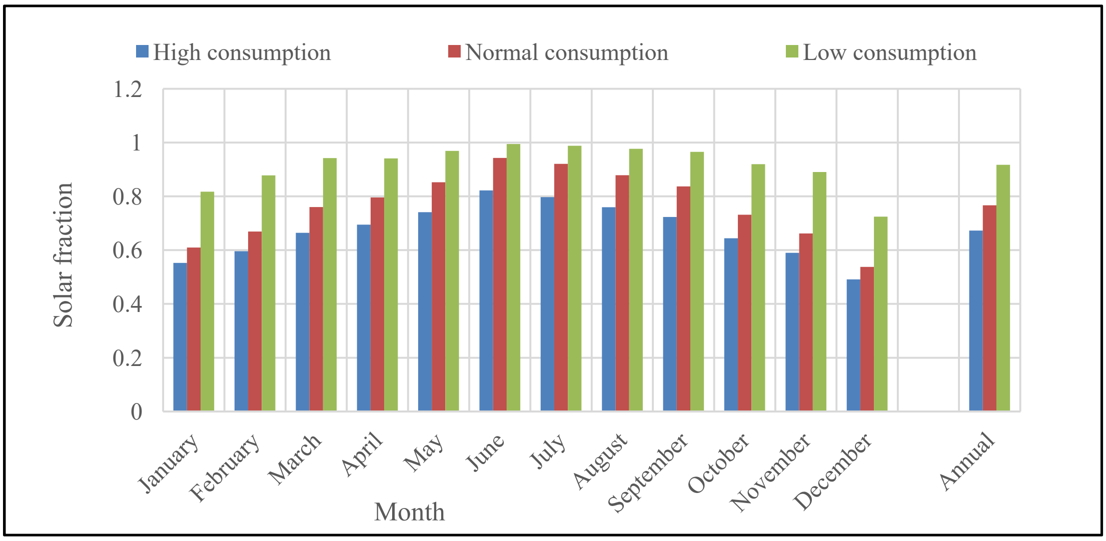

Figure 9. Annual and monthly solar fraction at various hot water consumption in Basrah city.

4. Conclusions

It is a significant benefit of solar energy and its practical applications since it is an influential sustainable energy source in the latest years. One of the critical targets of this research was determining the accessibility of solar energy and solving power reduction that adversely influences people's comfort. Several conclusions have discovered and can be summarized as follows:

- The primary conclusion from the simulation results in this paper is that almost all Iraq cities have substantial potential in applying solar water heating systems.
- According to the simulation results, the solar fraction's maximum values were obtained by the solar water heating system in the Basrah city due to the high solar energy. The average solar fraction value in the winter season is 66%.
- Efficiency of solar energy to heat the water, the system could provide in Baghdad city (67–81% in summer and 39–62% in winter) and (69–82% in summer and (49–66% in winter) in Basrah city.
- During the cold months, (2980 MJ/month) in Baghdad and about (2607 MJ/month) in Basrah, the maximum auxiliary energy was used.
- Increased isothermal layers in the solar thermal system's storage tank can increase the collector efficiency by 6–8% for Baghdad and Basrah.
- The simulations present a higher performance of the solar water heating system (SDHW) if the domestic hot water consumption is low.
- The validated TRNSYS model can predict solar thermal systems' performance at various locations and conditions of operation.

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Conflict of interest

The authors declare no conflict of interest.

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