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EXPERIMENTAL EVALUATION OF THE PERFORMANCE OF A DOMESTIC WATER HEATING SYSTEM UNDER BAGHDAD CLIMATE CONDITIONS

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The aim of the current study is to evaluate the performance of a domestic water heating system for residential areas in Baghdad climatic conditions for substituting electric water heaters with solar-powered water heaters using solar collectors. Many countries, such as Iraq, are sluggish with electric power issues while receiving very high solar insolation. Solar energy is a clean, non-depleting and low-cost source that can be used especially in residential areas, which forms a great percentage of energy consumption by replacing electric water heating with solar water heating to reduce electricity usage. Therefore, six flat plate solar collectors with an absorbing area of 1.92×0.85 m with one 4 mm thick glass cover are utilized for experimental investigation under the Baghdad climatic conditions. The collector was tested under steady-state settings, which assumed that sunlight intensity, ambient temperature, and inlet-outdoor temperature difference in each collector in the system were constant throughout the operation. According to the experimental results, during the test months of November, December, January, and February, the time-weighted experimental daily average collector array efficiency is found in the range of 40 % to 60 %. Furthermore, the greater energy gain and performance of the solar collector array attain a peak value at solar noon. Additionally, a solar collector with flat plates can easily achieve relatively high water temperature levels of 70 °C in the winter season. In addition, using a solar domestic hot water system as a water heater in Baghdad climatic conditions by substituting electric water heaters is useful for saving power consumption

Keywords: domestic hot water, flat plate solar collector, solar energy, power consumption, Baghdad

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1. Introduction

Significant advances in living standards have resulted in increased energy sources usage such as domestic hot water (DHW), air conditioning, and electricity. There is an imperative necessity to accelerate the evolution and developed clean energy technologies deployment to deal with global issues such as energy supplies, environmental degradation, and long-term development [1, 2].

In developed countries, buildings need 30–40 % of annual primary energy, and around 15–25 % in developing countries [3–5]. However, it should be noted that the energy needed to prepare domestic hot water has a large share in the yearly energy consumption of construction [6, 7]. In that consideration, there is a comprehensive tightening and restriction of the national building standards. As a result, the space heating requirements of newly constructed and renewed buildings are reduced dramatically, which tends towards nearly Zero Energy Construction standards [8]. Whereas energy consumption for building space heating has declined significantly over the previous decades, the energy requirements to produce DHW have stayed essentially constant. As a result, the contribution of energy for DHW in the overall energy balance of buildings is growing more and more dominant [9].

Globally, lowering energy consumption in buildings helps to reduce greenhouse gas emissions, fossil fuel extraction and environmental costs of transporting them [10]. There is an important requirement for extra energy storage, which could be accomplished in a variety of ways including thermal storage, electric batteries, flywheels, dams, etc. [11, 12]. A significant portion of this thermal energy is utilized for space heating [13].

Water heating is one of the most important applications to use energy in homes, and domestic electric water heating systems (DEWH) provide a considerable heat reserve for transferring electric load throughout the day [14]. Replacing electric water heating with solar water heating can reduce electricity usage [15]. The use of solar water heaters is suitable for many countries sluggish with electric power issues such as Iraq. Due to the geographical position and suitable weather conditions, most sections of Iraq have very high solar isolation [16]. As a result, it is important to turn to solar energy choices in order to decrease the usage of fossil fuels [17]. Therefore, studies on domestic water heating systems (DHWS) are of scientific relevance, which is associated with reducing electric power consumption through the use of solar energy, especially for high solar isolation countries such as Iraq.

2. Literature review and problem statement

The global market potential, thermal engineering and economic viability of solar water heaters (SWH) are discussed [18]. Globally there are opportunities for further adoption of SWH to supply hot water in residential and commercial sectors [19]. In many countries, realizing these opportunities requires improved economic viability. This entails a combination of lower installed cost, improved system efficiency, durability and ease of maintenance [20].

The building sector is responsible for about 40 % of the overall final energy consumption, mostly due to space heating and domestic hot water (DHW) heating.

Electric water heaters are substituted by SWHS to support space heating and domestic hot water (DHW) heating [21].

In this case, a solar water heating system (SWHS) as an application of solar thermal technology provides some of the heat energy requirements for domestic hot water (DHW) and space heating, supported conventionally by electricity or natural gas, or even other fossil fuels. Therefore, in the Middle East region and during the winter days, the increased demand for electrical energy can be reduced by using the SWHS system from an economy view [22].

The SWHS is known as a common application of solar energy where the received radiation is converted into heat and then transferred into a circulated medium, mostly water and air [23]. By this means, electric water heaters are substituted by SWHS to support space heating and domestic hot water (DHW) heating [24]. According to the aforementioned advantages and extensive developments in solar water heaters' design within the last 15 years, the global solar water heating market has been raised drastically [22, 25].

Iraq's climate is characterized by a moderate winter with a minimum temperature of 5 °C and a hot and dry summer with a maximum temperature of 45 °C. The daily sunshine period in Iraq varies from 7 to 12 h in winter and summer, respectively. The average daily solar irradiance is 6.5–7 kWh/m^2 and the total annual sunshine period is at least 2,800 h [26].

The lack of power supply in Iraq, the abundant sunshine hours throughout the year, and the reasonable cost of the system are the motivations to install the SWHS to meet domestic and industrial hot water demands [27]. Accordingly, various techno-economic analyses of SWHS have been conducted by [28] using domestic hot water to reduce electric power consumption, while [29] studied a solar water heater to meet domestic requirements for industrial areas in Iran [30]. However, the solar water heater was an efficient system to produce hot water in the winter season [31]. Due to the geographical position and suitable weather conditions, most sections of Iraq have very high solar isolation [16]. As a result, it is important to turn to solar energy choices in order to decrease the usage of fossil fuels [17].

As absorbing from previous studies, high solar isolation countries such as Iraq depend mainly on electric energy to heat the water used even in residential areas, and the use of a water heating system using solar energy needs an actual and practical assessment to show that electricity can be dispensed with by using solar energy as a substitute in heating the water used in residential areas, and thus solar energy is a successful alternative to fossil fuels, which greatly reduces global warming and reduces environmental pollution. Therefore, in crowded cities such as Baghdad, this system needs an actual and practical assessment to figure out its importance in reducing the consumption of electric energy.

3. The aim and objectives of the study

The aim of the study is an experimental evaluation of the performance of a domestic water heating system under Baghdad climate conditions. This will make it possible to substitute electric water heaters with solar-powered water heaters using solar collectors.

To achieve this aim, the following objectives are accomplished:

– to identify the climatic parameters during the study period;

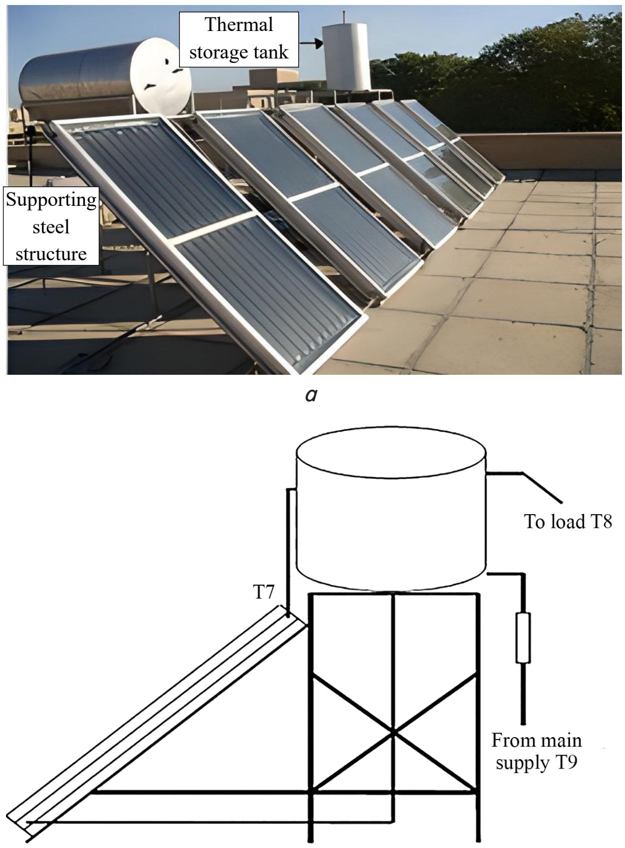
– to evaluate the performance of a domestic water heating system.

4. Materials and methods

4. 1. Fabrication of a domestic water heating system and study hypothesis

Six flat plate solar collectors are used in this work as shown in Fig. 1, *a*, *b*. Each collector has an absorbing area of 1.92×0.85 m with one 4 mm thick glass cover. The absorber of each collector consists of ten equally spaced parallel aluminum risers of 10 mm outer diameter and 1.92 m long. These risers connect the lower header with the upper header made from aluminum risers of 18.75 mm outer diameter and 0.85 m long, the joints between headers and risers ends are welded by using aluminum alloy. The solar collector is insulated from the back and sides using glass wool insulation of 50 mm thickness. Two vertical cylindrical aluminum tanks with a thickness of 2 mm were used. The internal tank has an inner diameter of 500 mm, a length of 1 m, and a capacity of 170 liters while the outer tank has an inner diameter of 600 mm and a length of 1.1 m. The internal tank is employed for the open-loop (direct) water storage tank whereas glass wool is used to fill the annular gap between the internal and exterior tanks. Each tank has four holes for inlet and outlet points and also each tank has a ventilation hole. A glass wool insulator of 50 mm thickness is used to insulate the tank's external wall, and the storage tank can be positioned vertically as needed. The storage tanks are presented in detail in Fig. 2. Plastic pipes with a nominal diameter of 12.5 mm are utilized as linking pipes between system components. As a closed loop, the storage tank, flow meter, water circulation pump, and solar collectors are linked with each other. Fittings such as bends, elbows, and valves are employed as connecting parts. In each system, a small MARQUISE MKP60-1 type water circulation pump is utilized to circulate water in the closed loop. The pump consumes 370 Watts of electricity, has a maximum head of 40 meters, and a maximum flow rate of

40 liters per minute. Moreover, valves are used to control the flow rate in the closed loop.



a

b

Fig. 1. The main experimental setup:
a – general view; *b* – graphical scheme

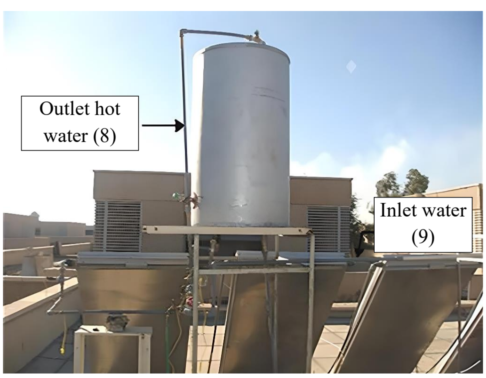


Fig. 2. First thermal storage tank in a vertical orientation

The temperature is measured utilizing type *k* thermocouples (copper-constantan) at specific points in the heating system. The solar meter is utilized to measure the solar radiation that falls on the collector's surface. While a ZYIA-type flow meter with a range of 1 to 7 L/min was used to measure the mass flow rate of the forced circulation flat plate collectors. All instruments are calibrated in the Central Organization for Standards and Quality Control (COSQC).

The hypothesis of the study can be summarized as follows:

1. There is no effect of accumulated dust on the system despite that Baghdad city faces a high rate of accumulated dust.

2. The collector was tested under steady-state settings, which assumed that sunlight intensity, ambient temperature, and inlet-outdoor temperature difference in each collector in the system were constant throughout the operation.

3. The interior tank is employed for the open-loop (direct) water storage tank whereas glass wool is used to fill the annular gap between the internal and exterior tanks.

4. No pressure is lost during water circulation.

5. Solar intensity completely reaches the pipes and no radiation is lost between these pipes.

4. 2. Test procedure

The solar water flat plate collectors with forced circulation were linked in a closed loop. The tests were conducted between October 2020 and February 2021, with most of them taking place on sunny days.

The collector was tested under steady-state settings, which assumed that sunlight intensity, ambient temperature, and inlet-outdoor temperature difference in each collector in the system were constant throughout the operation. On a clear day, this period was generally 15 minutes:

1. The sort of test used to assess the immediate efficiency of a solar collector system.

2. The heater is fixed in the second tank to heat the water before it is circulated to the system and to investigate the influence of inlet temperature on system efficiency, as illustrated in Fig. 3.

3. The following preparations were conducted prior to each test. The closed collectors loop was full of water, the collector's glass cover was cleaned thoroughly and the measuring instruments and apparatus were checked as described in the previous section.

4. The storage tanks have been full of water, and the pump has been turned on for one hour prior to the start of the readings.

5. The experimental data were recorded at variable inlet temperatures in the system.

6. Three various mass flow rates of the load water withdrawal profile were used to test the system, these profiles are: the continuous load of 60 L/h, the continuous load of 80 L/h, which is equal to the daily usage of a single storage tank volume.

7. The load profile was recorded experimentally in winter and summer in the home of a family of 17 occupants, the experiments were recorded during the day.

8. In all the above cases, in each test and at every 15 minutes, all the measurements of ambient temperature, solar radiation, and temperatures of each point in the system were recorded.

Fig. 3. Second storage tank containing a heater

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.

4. 3. Load profile

Regarding the thermal load, although hot water consumption varies greatly from day to day and from user to user, the water usage trend during the summer is slightly greater than during the winter. However, during this time the temperature need for hot water is considered very low in comparison to winter. For the present work, three types of water withdrawal patterns are adopted, namely:

1. Continuous water withdrawal with a flow rate of 60 L/h.
2. Continuous water withdrawal with a flow rate of 80 L/h.
3. Daily water consumption taken for a family of 17 occupants for the summer and winter seasons.

5. Results of evaluation of the domestic water heating system

5. 1. Evaluaton of climatic parameters during the study period

Global solar radiation, ambient temperature and wind speed were measured as shown in Fig. 4–7 on 1-7-2020, 15-6-2020, 15-7-2020 and 5-8-2020, respectively. The test of PV panels was conducted. The global solar radiation was taken at the horizontal surface and calculated for the tilted panel. Fig. 4 shows that the maximum solar radiation was at solar noon (985 W/m^2), it decays after that. The ambient temperature rises from 36.6 °C at 9:00 AM to 44.1 °C at 1:30 PM. Fig. 8 shows the maximum daily solar radiation (17,043 W/m^2) at a 15° tilt angle due to the maximum power generated at this angle. Fig. 9 shows oscillated values of wind speed taking 1.111 m/s as a minimum and 6.944 m/s as the maximum value.

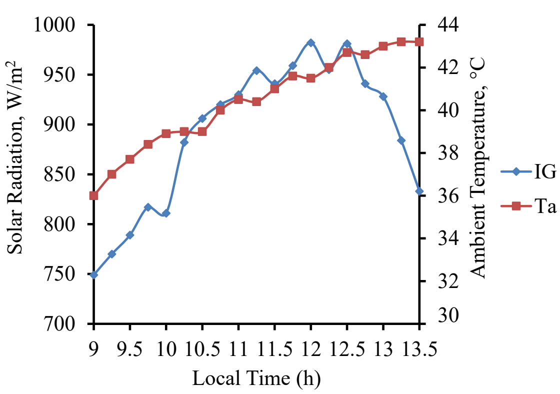


Fig. 4. Ambient temperature and solar radiation measured experimentally on 1-7-2020

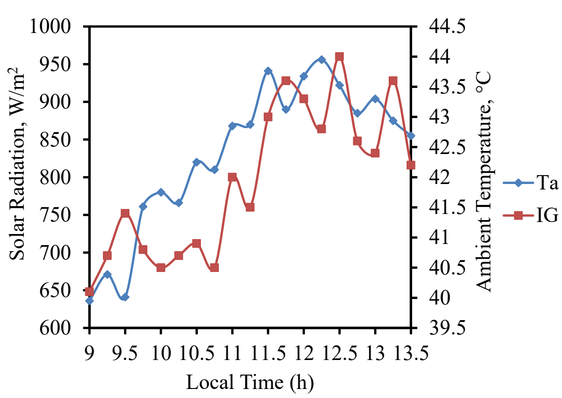


Fig. 5. Ambient temperature and solar radiation recorded experimentally on 15-6-2020

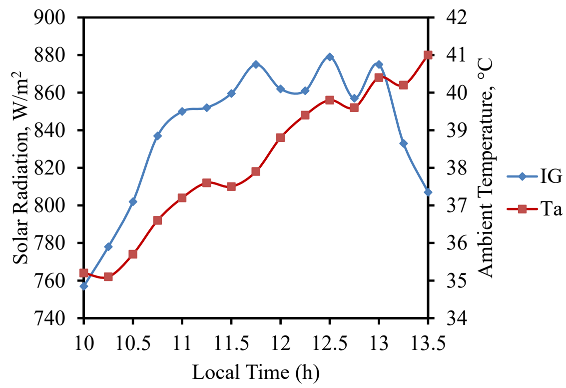


Fig. 6. Ambient temperature and solar radiation measured experimentally on 15-7-2020

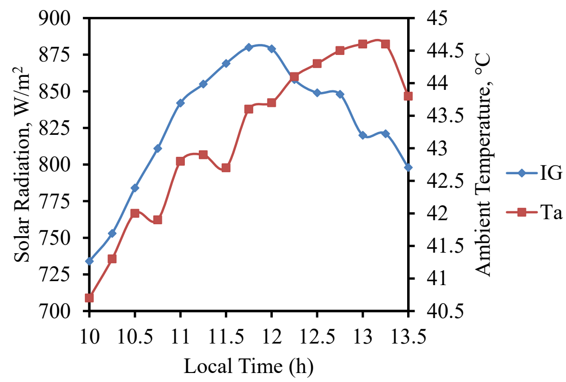


Fig. 7. History of experimentally recorded ambient temperature and solar radiation on 5-8-2020

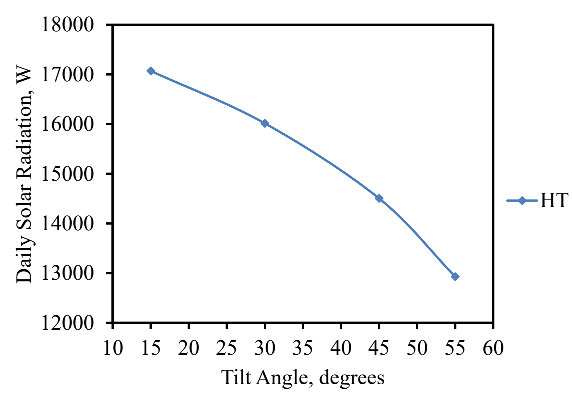


Fig. 8. History of experimentally measured daily solar radiation with different tilt angles on 1-7-2020

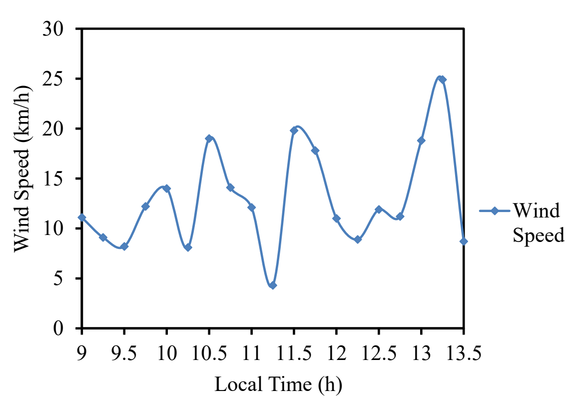


Fig. 9. History of experimentally measured wind speed on 1-7-2020

Another group of measuring solar radiation and ambient temperature data was conducted from 9-11-2020 to 20-1-2021, for testing series-connected flat plate collectors. A sample of these data measured on 9-11-2020 is shown in Fig. 10. The maximum solar radiation was 797 W/m^2 at 11:45 AM. The ambient temperature raises from 23.3 °C to 29 °C during the measured period.

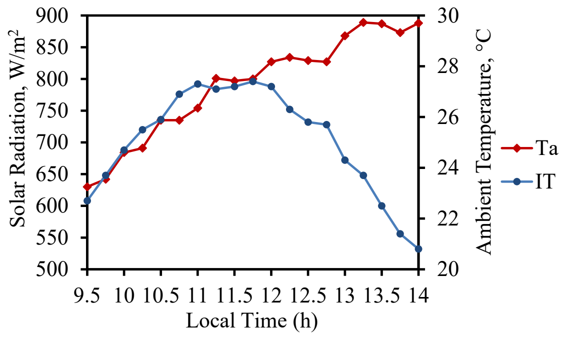


Fig. 10. History of experimentally measured solar radiation and ambient temperature on 9-11-2020

All climate parameters change arbitrarily and depend mainly on daily time. The values of these variables cannot be easily fixed and adopted as climate data, but can be read through practical experiments due to climate pollution in the city of Baghdad.

5. 2. Evaluation of the performance of the domestic water heating system

5. 2. 1. Evaluation of the inlet and outlet temperature for each collector

Fig. 11–14 show the measured temperature at the inlet and outlet of each of the six flat plate collectors linked in sequence for the selected days, namely: 9-11-2020, 14-12-2020, 5-1-2021 and 19-1-2021. When the system is under an 80 L/h load profile (on 9-11-2020 and 5-1-2021), variable load on 14-12-2020 and 60 L/h on 19-1-2021. It is observed that each collector is responsible for raising the water temperature partly. Table 1 shows the maximum and minimum temperature rises for the six collectors during the day test. It is obvious that the effect of the sixth collector on water heating is lesser than that of the first. The total temperature rise for the selected days is shown in Table 2 for the supply load of 80 L/h.

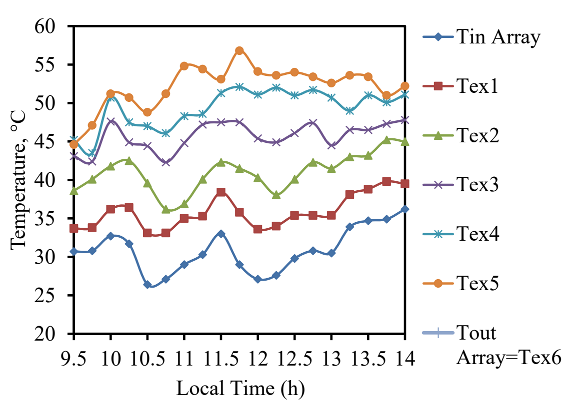


Fig. 11. Experimentally measured temperature at the inlet and outlet of each of the 6 series-connected flat plate collectors on 9-11-2020

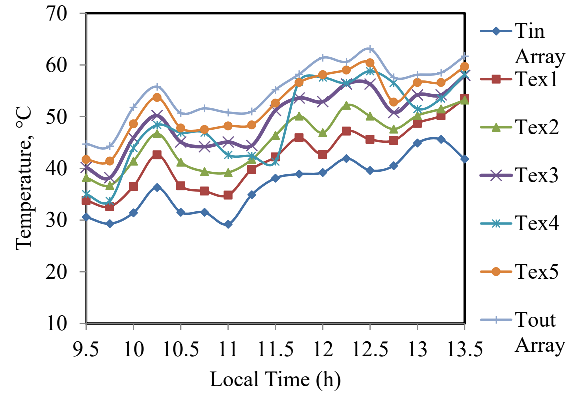


Fig. 12. Experimentally measured temperature at the inlet and outlet of each of the 6 series-connected flat plate collectors on 14-12-2020

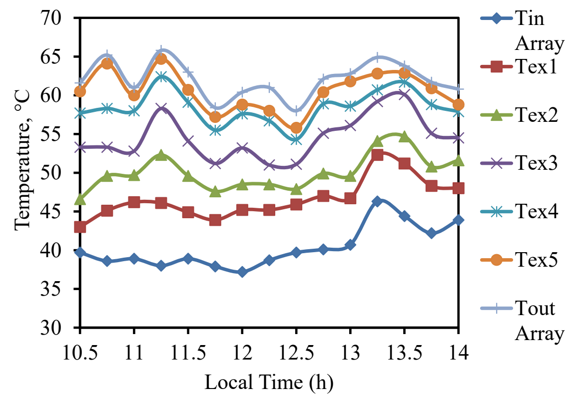


Fig. 13. Experimentally measured temperature at the inlet and outlet of each of the 6 series-connected flat plate collectors on 5-1-2021

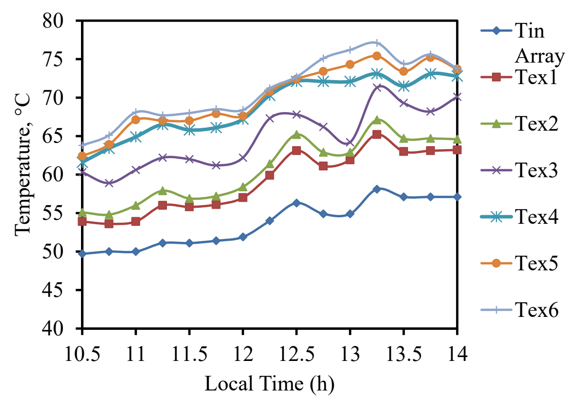


Fig. 14. Experimentally measured temperature at the inlet and outlet of each of the 6 series-connected flat plate collectors on 19-1-2021

Table 1

Experimental results of maximum and minimum temperature for the solar collectors array on 9-11-2020

Collector No.	Min. Temp. rise (°C) (ΔT)	Local Time	Max. Temp. rise (°C) (ΔT)	Local Time
1	2.8	9:30 AM	7.5	10:30 AM
2	2.7	11:00 AM	7.2	12:00 AM
3	1.4	1:45 PM	7.4	11:00 AM
4	1.1	9:45 AM	7.2	12:15 PM
5	0.5	9:30 AM	6.4	11:00 AM
6	0.9	9:45 AM	6.4	10:30 AM

Table 2

Experimental results of maximum temperature rise of the whole collectors array for selected days

Date	Maximum rise (°C)	Time
9-11-2020 (80 L/h)	33.2	12:00 AM
14-12-2020 (variable)	33	12:30 PM
5-1-2021 (80 L/h)	28	11:15 AM
19-1-2021 (60 L/h)	21	1:00 PM

During the winter season (January-April and October-December), the best performance of the solar water heating system with good insulation of the storage tank was observed. The flat plate collector's outlet temperature rises during the morning to reach 60 °C and then begins decreasing until sunset. The outlet temperature of the solar thermal collector takes the manner of solar radiation. A decrease in the top layer's temperature during the hot water consumption periods can also be noted, and this temperature is approximately constant.

5. 2. 2. Effect of the inlet temperature on the array efficiency

Fig. 15, 16 display the influence of the inlet temperature on the solar collector heat efficiency for an 80 L/h water load.

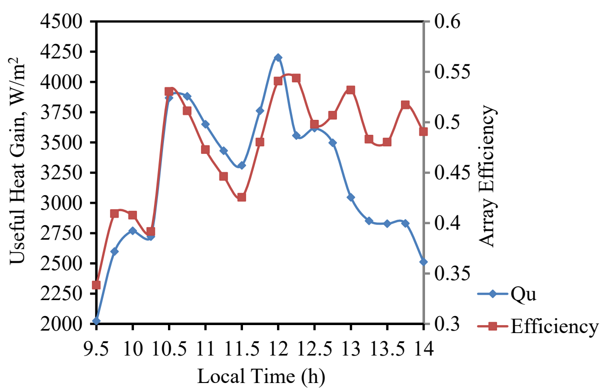


Fig. 15. Effect of the experimental inlet temperature on the useful heat gain of the array of solar collectors for an 80 L/h water load on 9-11-2020

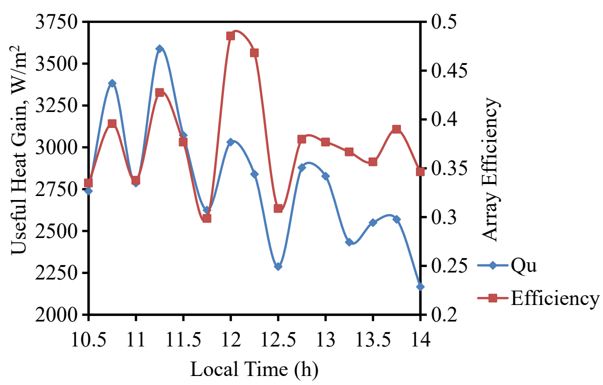


Fig. 16. Effect of the experimental inlet temperature on the useful heat gain of the array of solar collectors for an 80 L/h water load on 5-1-2021

The heat gain of the collector array increases with decreasing inlet water temperature to collectors. The maximum calculated heat gain was Qu=4,192 W for 30.8 °C Tin at 12:00 AM on 9-11-2020 as shown in Fig. 15 while that calculated for Tin=40 °C was Qu=3588.7 W at 11:15 AM on 5-1-2021 as a maximum value as shown in Fig. 16. This is due to a decrease in heat absorbed due to increasing inlet water temperature for the same water flow rate through the collectors (112 L/h).

Fig. 15, 16 present the thermal efficiency of the collectors array showing the same behavior as the useful heat gain, higher values are obtained for Tin=30.8 °C (54.2 % at 12:00 AM) than for Tin=40 °C (η_t=48.9 % at 12:00 AM).

5. 2. 3. Effect of the load profile

Fig. 17, 18 show the effect of the load profile on the thermal performance, useful heat gain, and thermal efficiency of the array of solar collectors at the same inlet temperature. For an 80 L/h water load, the heat gain of the collector array increases with decreasing water inlet temperature to the collector. The maximum calculated heat gain was Qu=4192 W for 80 L/h at 12:00 AM on 9-11-2020 as shown in Fig. 17, while that calculated for the variable load was Qu=2868.7 W at 11:15 AM on 25-11-2020 as a maximum value. This is because the constant load of 80 L/h was more suitable than the variable load.

Fig. 18 shows that the thermal efficiency of the collectors array has the same behavior as the useful heat gain.

The thermal efficiency of the collectors array has the same behavior as the useful heat gain as shown in Fig. 18, higher values were obtained (54.2 % at 12:00 AM) for 80 L/h while that obtained for the variable load was η_t=36.3 % at 11:15 AM.

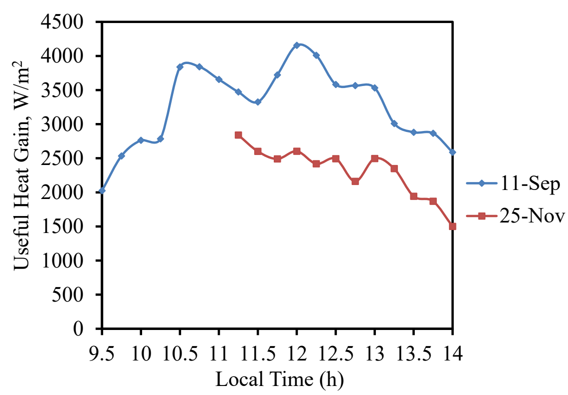


Fig. 17. Effect of 80 L/h load and variable water load on the experimental useful heat gain of the array of solar collectors

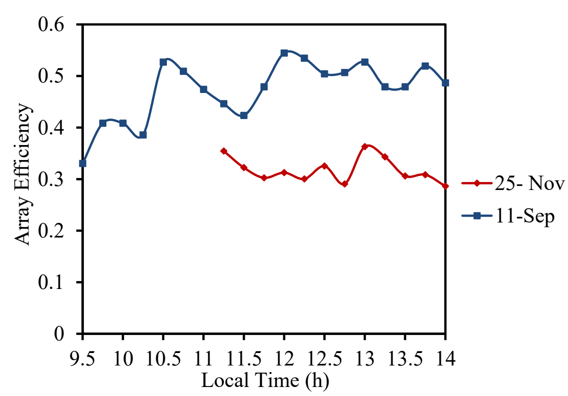


Fig. 18. Effect of 80 L/h load and variable water load on the experimental thermal efficiency of the array of solar collectors

Fig. 19 shows a comparison between the results of two days conducted at the same variable load.

The maximum calculated heat gain was Qu=4234.4 W at 12:30 PM on 14-12-2020, while that calculated for other variable loads at the same inlet temperature of 23 °C was

Qu=4672.6.7 W at 11:45 AM on 20-12-2020 as a maximum value. This is due to the effect of the load profile on the heat gain values.

For the same days, as demonstrated in Fig. 20, the highest heat efficiency of the collector array was η_t=51.1 % at 10:30 AM on 14-12-2020 while that obtained for the same variable load was η_t=61.4 at 12:45 PM on 20-12-2020.

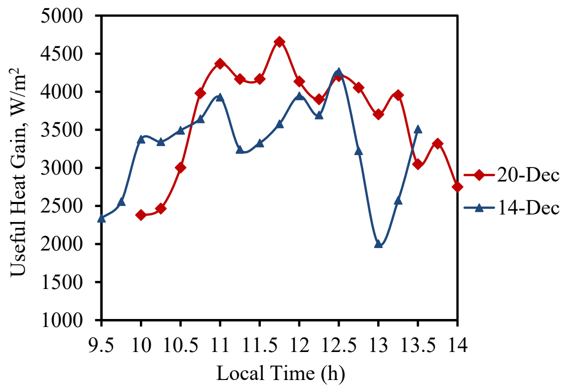


Fig. 19. Effect of the variable water load on the experimental useful heat gain of the array of solar collectors

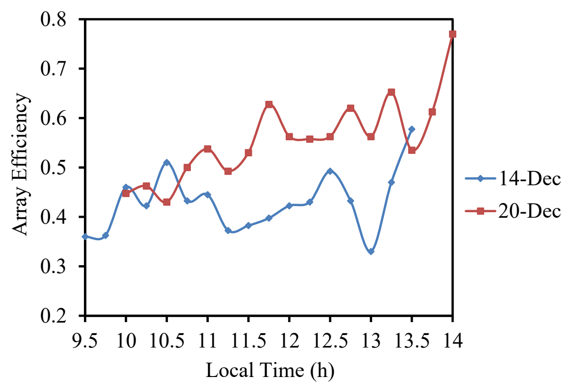


Fig. 20. Effect of the variable water load on the experimental thermal efficiency of the array of solar collectors

The thermal efficiency of the domestic hot water system increases during daily time as a result of observing solar energy. It should also be noted that the daily consumption of hot water affects the solar system thermal performance.

5. 2. 4. Thermal performance with and without preheating

Fig. 21 depicts the impact of preheating on the heat efficiency of solar collectors for the variable load.

Preheating impact on the heat efficiency of solar collectors for the variable load is shown in Fig. 21. The maximum calculated heat gain was Qu=2439.9 W when using a heater at 13:00 PM on 16-12-2020, while that calculated when without using a heater was Qu=2614.7 W at 13:15 PM on 29-12-2020 as a maximum value. This is due to a decrease in heat absorbed due to increasing inlet water temperature when using the heater in the solar collector array for the same water flow rate of 112 L/h.

The main purpose of using an auxiliary heater in the solar collector array is to raise the temperature in the collector on days of no or weak solar radiation. The second target for using it in the solar array is to present the performance of the solar collector array in the summer season when the inlet temperature is high.

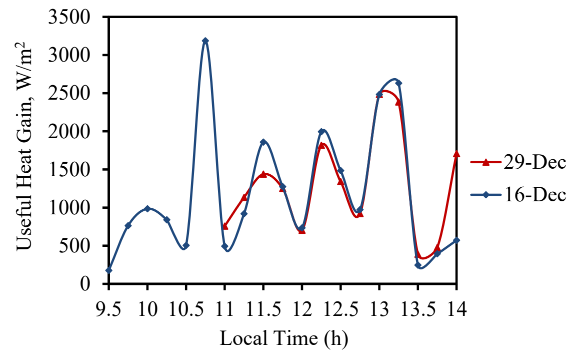


Fig. 21. Effect of preheating on the experimental results of useful heat gain of the array of solar collectors

5. 2. 5. Effect of heater setting temperature

Fig. 22 shows the influence of the heater setting on the thermal efficiency of the array of solar collectors for an 80 L/h water load. The heat gain of the collector array increases with decreasing water inlet temperature to collectors. The setting of the heater temperature must be suitable and not high. The maximum calculated heat gain was Qu=1980.1 W for the 40 °C heater setting at 12:00 AM on 5-1-2021 as shown in Fig. 22, while that calculated for the 50 °C heater setting was Qu=985 W at 13:15 PM on 14-1-2021 as a maximum value. This is due to a decrease in heat gain due to increasing inlet water temperature for the same water flow rate through the collectors of 112 L/h.

Fig. 23 shows the same behavior of both thermal efficiency of the collectors array and useful heat gain, higher values are obtained for the 40 °C heater setting (32.0 % at 12:00 AM) while that obtained for the 50 °C heater setting was η_t=14.7 % at 13:00 PM.

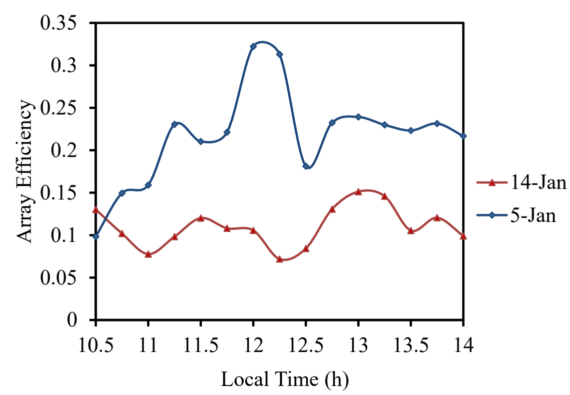


Fig. 22. Effect of heater setting on the thermal performance of the array of solar collectors

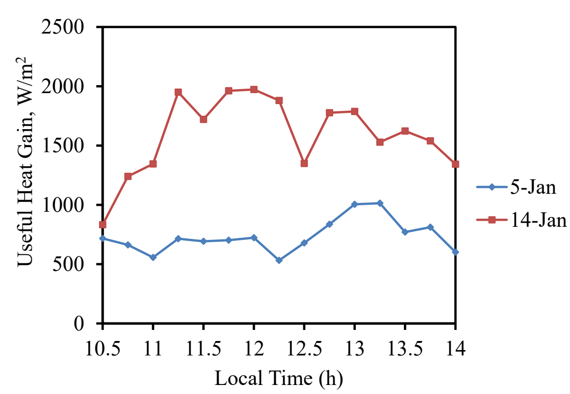


Fig. 23. Effect of heater setting on the experimental results of the thermal efficiency of the array of solar collectors

The thermal efficiency of the collector depends on solar radiation during the testing period inspite of the inlet collector temperature.

6. Discussion of the evaluation of the domestic water heating system

All climate parameters change arbitrarily and depend mainly on daily time. The values of these variables cannot be easily fixed and adopted as climate data, but can be read through practical experiments due to climate pollution in the city of Baghdad (Fig. 4–10). The thermal efficiency of the collectors array shows the same behavior as the useful heat gain, higher values are obtained in the summer season. However, the measured temperature at the inlet and outlet of each of the 6 series-connected flat plate collectors for the selected days. When the system is under an 80 L/h load profile, variable and 60L/h (Tables 1, 2, Fig. 11–14). It is observed that each collector is responsible for raising the water temperature partly, while the effect of the sixth collector on water heating is lesser than that of the first.

The heat gain of the collector array increases with decreasing inlet water temperature to collectors. This is due to a decrease in heat absorbed due to increasing inlet water temperature for the same water flow rate through the collectors. Therefore, the thermal efficiency of the collectors array shows the same behavior as the useful heat gain due to the effect of the load profile on the heat gain values. However, the effect of preheating on the thermal performance of solar collectors for the variable load is due to a decrease in heat absorbed due to increasing inlet water temperature when using the heater in the solar collector array for the same water flow rate additionally. The main purpose of using an auxiliary heater in the solar collector array is to raise the temperature in the collector on days of no or weak solar radiation. The second target for using it in the solar array is to present the performance of the solar collector array in the summer season when the inlet temperature is high.

The thermal efficiency of the collectors array has the same behavior as the useful heat gain with a great impact on the magnitude of load reduction, which was higher in the evening than in the morning, as a sufficient amount of hot water was provided by SWHs during the afternoon, depending on the pattern of household use of hot water. While, the average consumption of hot water is 40–50 L per person per day (Fig. 17, 18). Therefore, the solar water heating system is designed to supply a single-family detached house with 200 L of hot water at 50 °C per day (Fig. 19, 20). Many variables have an effect on the hourly distribution of DHWS consumption for a day and mainly depend on heated water consumption. This typically varies from day to day, season to season, and family to family. However, the total heat losses of the solar water heating system include the loss of heat to the indoor room and the loss of heat to the atmosphere without the collector's loss. Hence, this system can heat water in residential areas, buildings, and elsewhere, which represents a great energy backup and thus saves money for a longer time. However, the energy efficiency concept for SWHs provides sufficient information to establish a detailed study.

The current study takes into consideration water heating for personal usage in residential areas according to the family persons, while area heating is not included especially in the winter season. On the other hand, this system is easy to modify for water desalination in the summer season in Baghdad city, which suffers from high dust accumulation rates and frequent dust storms. The system performance can also be enhanced by an optimum selection of the water tank capacity and the number of solar collectors with an increase of the tank isothermal layers. It is also recommended that further research should focus on the integration of these systems in other sectors (on a large scale) by improving their energy performance and taking into account the technical and economic situation of each country.

Finally, several benefits have been cited that the DHW system is attributed to the exploitation of the region's unique renewable energy potential, the development of a sustainable economy, and ultimately the protection and conservation of the environment through the use of solar water heating. However, it is also recommended that further research should focus on the integration of these systems in other sectors (on a large scale) by improving their energy performance and taking into account the technical and economic situation of each country.

7. Conclusions

1. All climate parameters change arbitrarily and depend mainly on daily time. The values of these variables cannot be easily fixed and adopted as climate data, but can be read through practical experiments due to climate pollution in the city of Baghdad. Despite that, solar energy has a significant effect on DWHS in Baghdad climate conditions.

2. The thermal efficiency of the collectors array shows the same behavior as the useful heat gain, higher values are obtained in the summer season with a high surface temperature. While the thermal efficiency of the collectors array has the same behavior as the useful heat gain in the winter season according to the solar radiation and its tilt angle. The thermal efficiency of the collectors array has the same behavior as the useful heat gain with a great impact on the magnitude of load reduction, which was higher in the evening than in the morning, as a sufficient amount of hot water was provided by SWHs during the afternoon, depending on the pattern of household use of hot water. While the average consumption of hot water is 40–50 L per person per day.

Many variables affect the hourly distribution of DHWS consumption for a day and mainly depend on heated water consumption. This typically varies from day to day, season to season, and family to family. However, the total heat losses of the solar water heating system include the loss of heat to the indoor room and the loss of heat to the atmosphere without the collector's loss. However, the effect of accumulated dust leads to a decrease in the collector efficiency, while Baghdad weather is classified as a dusty climate. Meanwhile, the proposed model for higher occupancy areas is required for saving electric power.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

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