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On-Grid Flat Plate Solar Water Heater Collector Application for Electrical Energy Saving Contribution

Aed Ibrahim OWAID *, Sabah M. HADI, Mohamed S. MAHDI, Husam Sabeeh AL-ARAB, Hassan Issa MOHAMMED

Research and Technology Center of Environment, Water and Renewable Energy, Scientific Research Commission, Baghdad, Iraq.

Highlights

- For the first time, on-grid flat plate solar collector was performed.
- A new approach for saving energy was presented.
- High electrical energy saving around 55 % was achieved without thermal storage tank cost.

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Keywords

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Electrical water heater
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Abstract

This study introduces a novel approach in Baghdad, Iraq, where flat plate solar heaters are directly connected to the electric heater without the use of storage tanks. This setup operates in a manner similar to solar cells connected to the electric grid, without the need for electrical energy storage during daylight hours (on-grid). A series of solar heaters, covering a total area of 3 m^2, have been linked to the electric water heater. This arrangement allows the water supplied to the electric heater to either be pre-heated by the solar heaters or delivered directly. The percentage of electrical energy saved to obtain 100 liters of hot water at 40 °C using a water mixer was 53% and 57% when adjusting the electrical heater thermostat to 60 °C and 80 °C, respectively. This was found by comparing the electrical energy usage of the electric heater in both cases (preheating and direct supply).

1. INTRODUCTION

Over the past few decades, global energy consumption has experienced a significant and robust growth. Conventional fossil fuels are the primary sources of energy that are used at the highest rate worldwide [1]. In general, the utilization or combustion of fossil fuels poses significant environmental challenges, including elevated temperatures, air pollution, acid rain resulting from an escalating CO_2 concentration, and the release of other gases. [2, 3]. Rapid population expansion is driving up energy consumption in developing economies. Using fossil fuels to meet this need has resulted in environmental and economic issues. To avoid these issues, there is a shift to renewable energy sources such as solar, wind, and geothermal [4-10]. Solar energy has various advantages, including being clean, abundant, and renewable. Additionally, utilizing solar energy in various applications is cost-effective [11]. Nowadays, Iraq's electricity generation is unable to meet commercial and domestic power needs. Solar energy is a highly potential renewable energy source in Iraq. Exploiting this source offers green energy and avoids harmful emissions from power plants that use fossil fuels. The yearly average of incident solar radiation in Baghdad is around 5.02 kWh/m^2/day, implying that Iraq has an opportunity to become a global renewable energy source by depending on the sun's energy [12].

Solar water heating systems (SWHS) are widely employed in places with abundant solar radiation, such as the middle east region. SWHS are frequently feasible substitutes for electricity and fossil fuels utilized in a

*Corresponding author, e-mail: aedaltaher@gmail.com

variety of residential applications. In a SWHS, traditional flat plate solar collectors (FPSCs) with a metal absorber plate and covers are applied to convert solar energy into heat. In an FPSC, incident solar energy is transformed into heat and supplied to a transfer medium, such as water [13].

Solar energy is a time-dependent source of energy. Energy requirements for a broad variety of applications fluctuate with time, but not in the same manner that energy supply does. Consequently, storing energy is necessary if renewable energies are to supply a considerable percentage of the energy demand [14].

In residential applications, the thermal storage tank was typically used in conjunction with the flat-plate solar system (off-grid) [15,16]. However, to the authors' knowledge, no experiments on using a flat plate without a thermal storage tank (on-grid) have been reported in the literature. The flat plate collector system, on the other hand, is more expensive when a thermal storage tank is included.

The goal of this research is to find a new way to use the flat-plate solar water heating system with a direct connection without a storage tank (on-grid) and make it more economically appealing to consumers by lowering both the startup and operational costs. The collected results showed that there is a considerable ability to save electrical energy, approximately 55%. It should be noted that this strategy was used while setting the electrical water heater to 60 and 80 °C.

2. MATERIALS AND METHODS

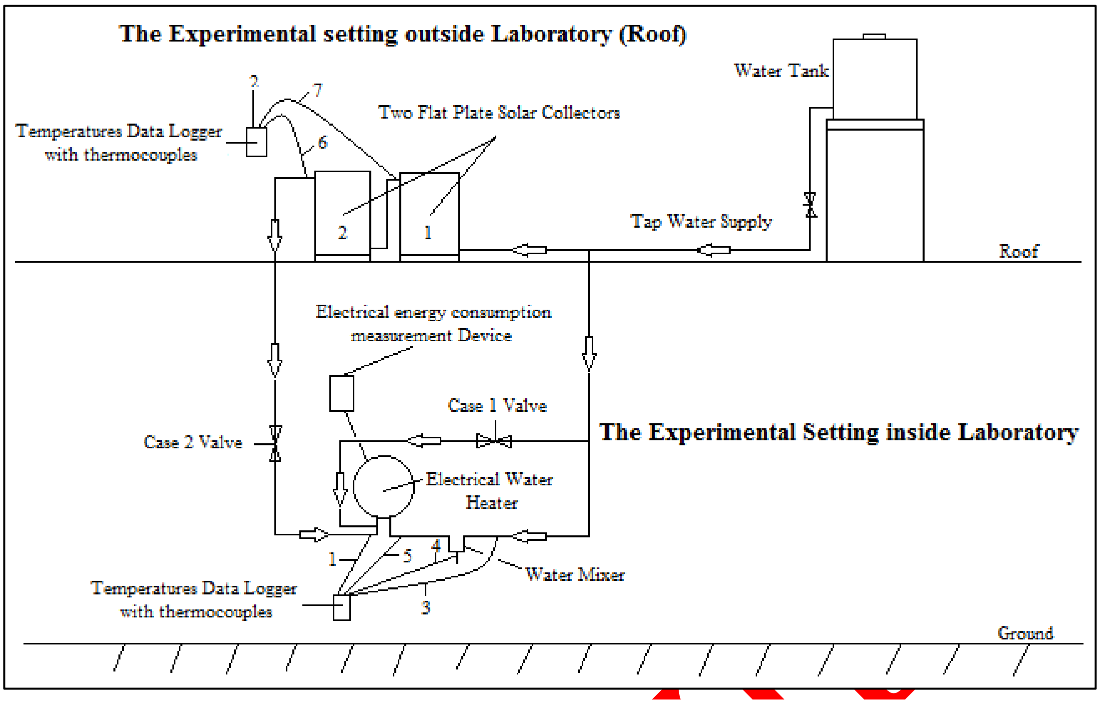
Figure 1 (a and b) illustrates the schematic diagram and the experimental setup, respectively, of the two locally manufactured flat plate solar collectors used in this study. These collectors have a 3 m^2 aperture area and are connected in series to accelerate the rise in water temperature to the appropriate level. To evaluate the energy usage of the 12.5-liter electrical water heater with a 3-kW power, two options are being considered: using tap water directly (case 1) or using flat plate solar collectors to pre-heat the water supplied to the electrical water heater (case 2). The experiment was carried out at two different operating temperatures for the electrical water heater, specifically 60 and 80 °C. The Em 501 single-phase electromechanical meter was used to measure electrical energy consumption. Data loggers with seven thermocouples type K (working in the temperature range of -50 to 150 °C) were used to record temperature changes at various points in the system. The thermocouples were distributed according to the following: The water temperatures of the electrical heater's input and output were measured using 1 and 5, respectively. whereas 2, 3, and 4 were used to measure the ambient temperature (T_{amb}), the temperature of the cold-water input to the first solar collector (T_{in}), and the needed mixed water temperature, respectively. Meanwhile, 6 and 7 were employed to measure the hot water temperature from the solar collectors (T_{out}) and the hot water temperature between the first and second collectors (T_{betw}). A solar power meter (TES-1333R) was set up to determine how much solar radiation the collectors received. In addition, a pipe insulator (1/2" W - 210 C.P.V.C. SCH 80) was put in place to prevent heat loss. To get a residential hot water temperature of 40 °C, the hot water from the electrical water heater was paired with tap water via the water mixer.

Data that are applied in the current investigation correspond to the case of normal winter days (February and March), measured in Baghdad (33.27 °N, 44.38 °E), Iraq. The collectors were oriented towards the south at a 45° angle to the horizontal surface since maximum collector efficiency occurred at that angle during the winter [17].

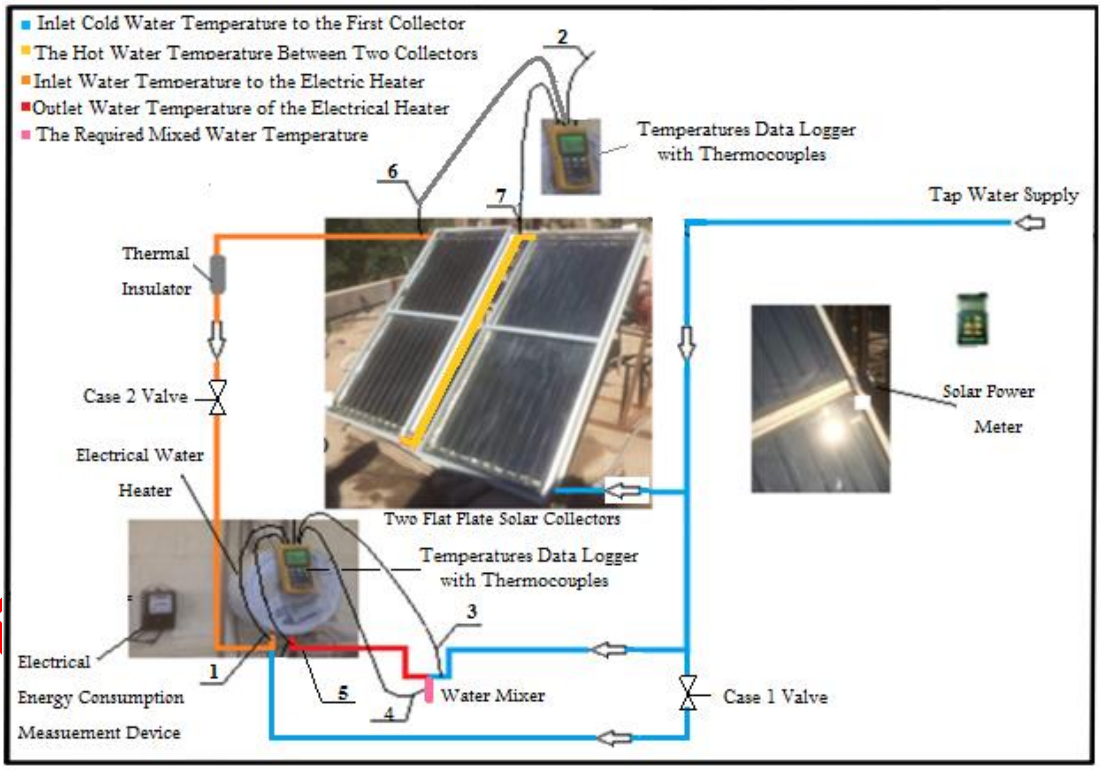
An empirical equation has been developed to determine energy savings ($Q_{sav.}$), expressed as follows:

$$Q_{Sav.} = Q_E - Q_{E\_S} \quad (1)$$

where (Q_E) is the required electrical energy to heat tap water and (Q_{E_S}) is the total of electrical and solar energy consumption to heat the same amount of tap water by collectors and electrical water heaters. Noting that both (Q_E) and (Q_{E_S}) will be measured using the Em 501 single-phase electromechanical meter.



(a)



(b)

Figure 1. (a) the schematic diagram of the work, and (b) the experimental setup

3. RESULTS AND DISCUSSIONS

Figure 2-a shows the water temperature fluctuation at different points during five consecutive cycles of the hot water on/off withdrawal process at 80°C. Starting at 10:13 a.m., the initial withdrawal cycle shows a clear increase in both (T_{out}) and (T_{betw}) as hot water is drawn. Upon stopping the withdrawal at 10:16 a.m., these temperatures decrease. Subsequently, the temperatures remain relatively stable while the hot water system is idle. In other processes, the values of (T_{out}) and (T_{betw}) consistently increase. This behavior is linked to the gained solar energy, which almost offsets the energy used by the electric water heater. Additionally, the significant increase in T_{out} and T_{betw} values at the start of water withdrawal is due to the accumulated solar energy gathered before water is drawn. This contributes to heating the withdrawn water. Additionally, the (T_{out}) value fluctuates between 31 and 39 °C. Temperature measurements were taken multiple times while setting the electric water heater to 60 °C, as depicted in Figure 2(b). Typically, the (T_{out}) and (T_{betw}) values increase and decrease similarly when adjusted to 80 °C (Figure 2(a)). However, the (T_{out}) value is designed to range between 28 and 35 °C. The temperature range difference is due to the energy accumulated from solar radiation during the morning hours before the first 100-liter hot water withdrawal. During the second 100 liter withdrawal, the energy required for water preheating is nearly equal to the solar energy captured by the collectors.

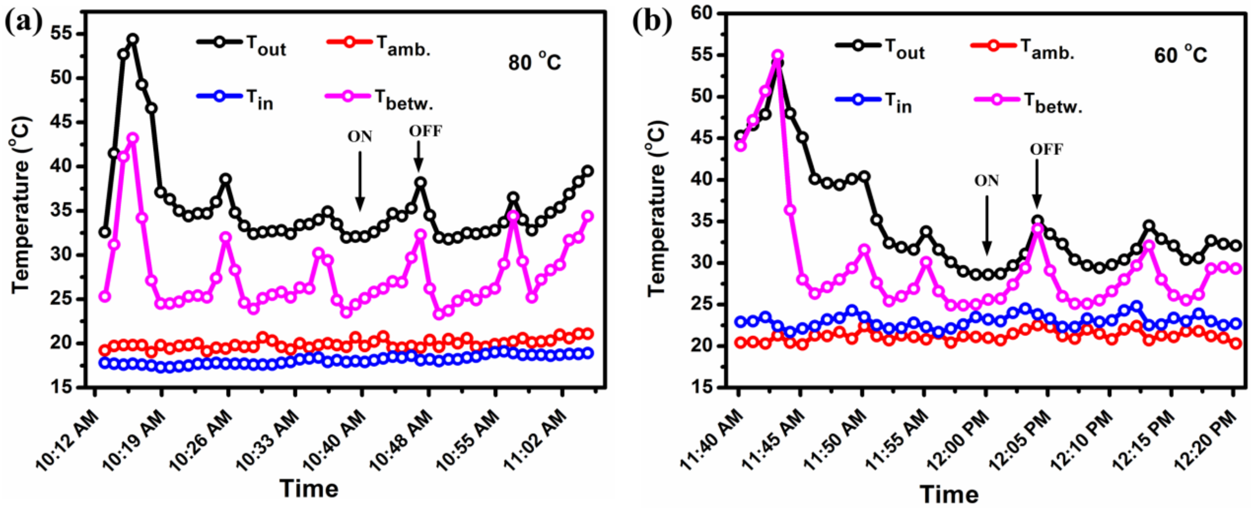


***Figure 2.** (a) - Declining and rising hot water temperatures in solar collector at start and stop water withdrawal by electrical water heater at adjusting 80 ºC. (b) - Declining and Rising hot water temperature in solar collector at start and stop water withdrawal by electrical water heater at adjusting 60 ºC*

The electrical energy consumption of an electrical water heater used to heat 40 °C of household hot water at an 80 °C adjusted temperature is displayed in Figure 3(a). It shows that Q_E was 3.6 KWh, whereas Q_{E-S} was 1.7 KWh, or nearly half the value. This suggests a significant difference in energy consumption between the two scenarios. This can be explained by the large amount of energy required to raise the water temperature in case 1. likewise, the difference between Q_E and Q_{E-S} values demonstrates the importance of employing solar energy in water heating; therefore, a significant reduction in electrical energy consumption has been achieved. Additionally, a sub-linear proportionate relationship between the magnitudes of electrical energy consumption and the volume of heated water can be noticed in both examples (1 and 2), which is attributed to the link between the needed energy value and water volume. Furthermore, the slope of the curve varies slightly; in case 1, the slope is steeper since it requires more energy to raise the water temperature. To investigate the effect of the adjusted electrical water heater on the Q_E and Q_{E-S}, measurements were taken at 60 °C, as shown in Figure 3(b). Overall, the behavior of Q_E and Q_{E-S} values with volume of hot water is similar to that of adjusting at 80 °C, but there is a significant difference in the quantity of Q_E and Q_{E-S}, with Q_E (2.8 KWh) exceeding Q_{E-S} (1.2 KWh) by more than doubling.

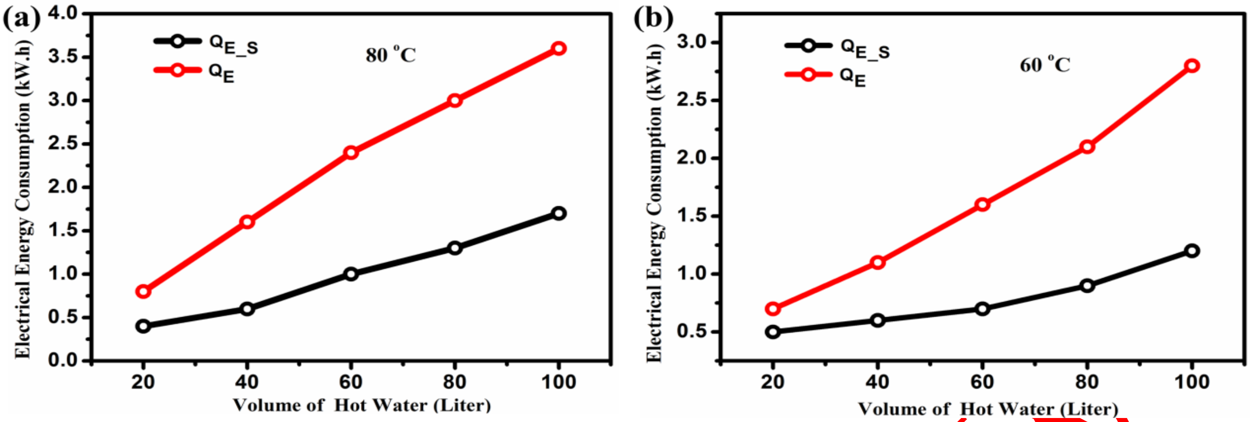


Figure 3. *(a) - The electrical energy consumption in electrical water heater at adjusting temperature 80 °C with and without solar collector (b) - The electrical energy consumption in electrical water heater at adjusting temperature 60 °C with and without solar collector*

Figure 4 illustrates the calculated electrical energy savings (from Equation (1)) against the volume of hot water for two different temperature settings of the electrical water heater. The rate of energy savings for 100 liters of hot water varies slightly between two adjusting temperatures, with 1.6 KWh at 60 °C and 1.9 KWh at 80 °C, representing 53% and 57%, respectively. The difference in energy savings is due to the more energy required to reach hot water at 80 °C.

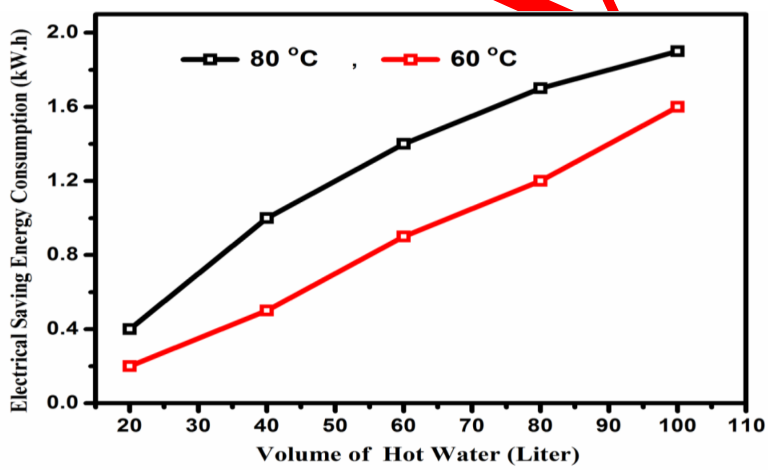


Figure 4. *Electrical saving Energy consumption with electrical water heater adjusting at 60 and 80* °C

Furthermore, the amount of electrical energy saved is proportional to the volume of hot water. Thus, these findings are highly encouraging for future large-scale studies.

Temperature measurements were collected at various points to explore the relationship between the energy gained from solar radiation and the energy consumed for water preheating, as described in the experimental section.

4. CONCLUSION

In this investigation, the aim was to utilizing a novel on-grid method to save electrical energy using storage-free flat-plate solar collector with electrical water heater. The findings of this study manifest that for heating 100 liters of water at 40 °C, the saving of electrical energy consumption is found to be 53 and 57% at adjusting the electrical water heater at 60 and 80 °C, respectively. In addition, we found that the amount of saved electrical energy increased with the increase in hot water consumption. The promising performance of the proposed approach demonstrates its future effectiveness in the field of solar water heating.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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