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Effect of Collector Tilt Angle on the Performance of Solar Water Heating System in Erbil of Iraq

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ABSTRACT

Solar energy is a fascinating green energy source. the most basic use of solar energy is to convert it into usable heat. Domestic hot water is the second-largest source of household electricity after lighting. The subject of this research is the thermosiphon theory of normal water circulation. An experimental setup and a computer program (POLYSUN) of a solar thermal system are presented in this work in Erbil city of Iraq. A four-person single-family house with a flat-plate solar thermosiphon water heating system and a water capacity of 200 L and also had a total surface area of 2 m^2. All simulations are conducted with the collector tilt angles of 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, and 90° for the whole year. In January 2021, the experimental work was also taken out in Erbil. The optimum tilt angle of the solar collector is estimated to be close to 40o. the overall energy savings, solar fraction, and collector efficiency are 1284 kWh, 29.6%, and 37.9%, respectively, for the entire year. Polysun Software and the experimental setting of the solar thermal system were compared on the basis of electricity consumption.

1. INTRODUCTION

The most prevalent use of solar energy is to heat water for home usage. This arrangement includes a solar collector and a tank for storing the energy. Solar collectors heat water by absorbing solar energy and transferring it as heat to the flowing water. The water is cycled in the system in two ways: by pump and by natural circulation produced by buoyant force. SWHs with natural circulation is the most intriguing of all because they are a simple and widely used technology for solar energy applications.

Over the past three decades, Iraq's energy crisis has been rising due to the massive demand in power consumption and the extreme deficit over the past century. The household sector has absorbed a major share of Iraq's electrical supply over the last two decades. SWHs are a potential solution to rising demand due to their simple form and inexpensive cost when compared to other clean energy technologies now in use throughout the world [1].

The standard flat plate solar thermal collector is intended for low and medium-temperature applications with temperatures ranging from 40 to 70 degrees Celsius [2].

The use of SWHs was tested in an experimental environment in Baghdad, Iraq. Water flowing at 5.33 L/min heats up faster than water flowing at 6.5 L/min, leading to greater collector-effective utilization [3].

Thermal energy is converted by solar collectors into liquid. A collector solar water heater, an accumulator, and a hot water tank have been used in these systems as auxiliary sources (thermal storage devices) [4].

The optimum energy altitude angle in January is around 40 degrees, and the maximum tilt angle of the collector is close to 50 degrees, according to the results of a numerical simulation of such a solar water heating system in Basra. For the parameter ranges studied, the temperature of the storage water was determined to be between 65 and 95℃ [5].

Duhok city of Iraq is putting a combined photovoltaic thermal direct solar system to the test on April 29th. The output of thermal and electrical energy is influenced by the cover glass. The pace of production of thermal energy is around three times that of electric energy. The payback approach allows for the system's cost to be recovered in less than ten years [6].

Using TRNSYS modeling tools, improving architectural design parameters set by two cities for a two-region solar thermosiphon water heater in Jordan, which encompasses Amman and Aqaba. The results demonstrate that by properly specifying each parameter, the solar fraction of the device may be enhanced by 10% to 25%. Also, the solar fraction of a system established in Amman is less resistant to such characteristics than the SF of a system established in Aqaba (high temperature) (cold environment) [7].

As part of the demand-side control scheme in Erbil, it is proposed that solar water heaters be installed and supplied to residents without cost. The winter peak load is estimated to be reduced by 54 MW if this project is successfully launched. According to the author's study, the project seems to have a net present value of $776.6 million [8].

In household savings in Brazil, solar power is a suitable candidate for heating water. In spite of its enormous potential, however, its application in the country is still limited. They directly affect the development of SWHs, which are analyzed in a report. It shows that for 17.9% of the current capacity taken by 2020, SWH systems are technically sustainable. According to the report, this could lead to savings of up to 15.54 TWh/yr. The country's southern region has the best places, while the most economic opportunity is in the southeastern region [9].

A geyser in South Africa consumes 40% of a household's electricity. A household's energy consumption must be reduced urgently. Solar energy could be used to achieve this goal. proposed that South African households could reduce their energy consumption by using solar water heaters [10].

The software is simple to use and gives constant and relaxing feedback on all device parameters via a graphical interface. Throughout every aspect of simulation, physical models are used to establish correlations without the need for a single word to describe them. Inputting the required data into a ready-made graphical environment is very easy [11].

In addition, the plan conducts economic feasibility research and ecological balancing, involving pollutants from the eight major greenhouse gases, and it is possible to match pollutants from technologies that operate only with fossil fuels and solar-using schemes. Dziugaite-Tumeniene and Streckien (2014) tested the Polysun system and found it to be within (5-10) % reliable [12]. Thermal solar systems are commonly used in many countries to improve energy production in the residential sector. Several models are being produced to enhance their efficiency and deployment. It addresses two complex approaches to solar thermal systems. Hourly design review of the component system's energy balance and the Polysun software used for the simulation. Different district heating consumption profiles are tested for sensitivity. The results reveal that solar thermal systems are being tested and scaled using the hourly model that was built. However, based on the control sheet, Polysun's approach to artificial heating contributes to higher or lower electric auxiliary heating [13].

In China, solar energy for building heating has a significant market. Polysun was able to determine the required size of three main components of a solar thermal power plant using simulation. The tilt angle of the collectors, the buffer capacity, and the collecting area are all important aspects of the process [14].

In Erbil, Iraq, 99% of people use electrical heating water systems to heat their homes. The purpose of this study is to numerically model a thermosiphon flat plate solar water heating system in a single Erbil family. The aim of this research is to explain a one-year numerical simulation of a flat plate of SWHs and experimental in a family house in Erbil, Iraq. The simulation system is used to determine the best tilt angle and to analyze the technical parameters including solar thermal collectors, energy saving, and the average solar fraction using tools from the Polysun program. In addition, experimental data for one month for Erbil city was incorporated in this work for January 2021.

2. METHODOLOGY

2.1 The system's description

In Iraq's Kurdistan region, solar water heaters of the thermosiphon type are used. Thermosyphon solar systems are solar energy devices that operate without a mechanical pump by utilizing the fluid's natural circulation. Convection currents that occur in fluids at various temperatures are the foundation of this circulation. The complexity of using thermosiphon systems to harness solar energy is reduced. Thus, thermosiphon systems are more dependable and require less upkeep. Since we require hot water for most of the year in my nation, this technique is quite helpful. In Erbil, a typical Setups consists of a flat solar collector with a 2 m^2 surface area and a 200-liter insulated hot water reservoir. A 5000-liter cold water storage tank is also included. Optional, an auxiliary electrical heater of 3 KW is used for low insolation of the solar system. Figure 1 shows a more complete description of the solar water heating system [15], The data on SWHs was read and saved using an Arduino microcontroller. The experimental setup includes three temperature sensors, one flow meter, and one power wattmeter. The cold water intake is regulated by the first temperature sensor, the hot water outflow is regulated by the second, and the ambient air temperatures are regulated the third. As illustrated in Figure 2, the flow rate was connected to heating water output and the system's house entry. Every minute, the data logger saved data from the Arduino microcontroller to an SD card, which was then converted to a PC. The Electrical schematic diagram (Data logger) of the experimental devices is shown in Figure 3.

Figure 1. Main system of flat plate solar water collector

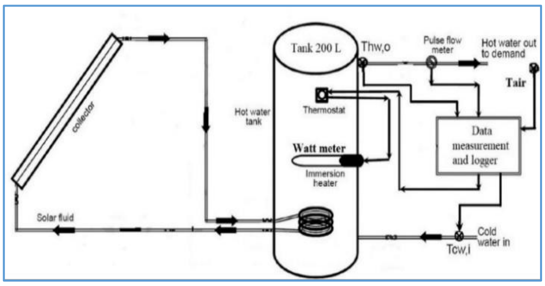

Figure 2. The experimental setup is described in this diagram

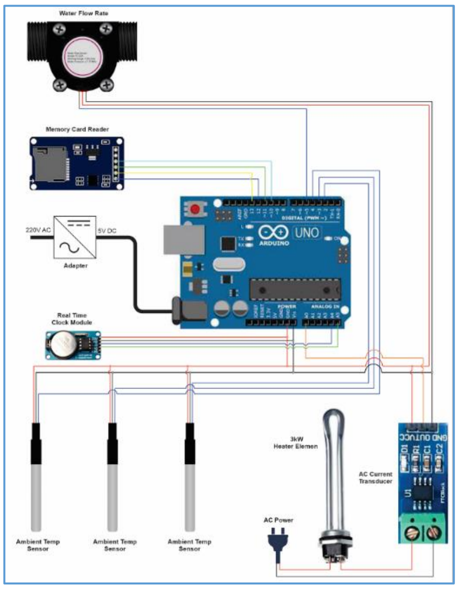

Figure 3. Electrical schematic diagram (Data logger) of the experimental devices

2.2 Solar thermal collector and energy equations

In order to design and test a solar energy system economically, detailed knowledge of current solar radiation is critical in every location. As shown in Figure 4, the sun's solar energy upon that surface is modified by the direction of the sun in the atmosphere and the surface direction. Theoretical analysis Detailed information about solar radiation availability at any location is essential for the design and economic evaluation of a solar energy system. It is known that the direct solar radiation on a surface depends on the sun's position in the sky and the orientation of the surface. The determination of the best angle is done theoretically by the Polysun software, after finding the best angle the system should be placed at this angle for the experimental data recording.

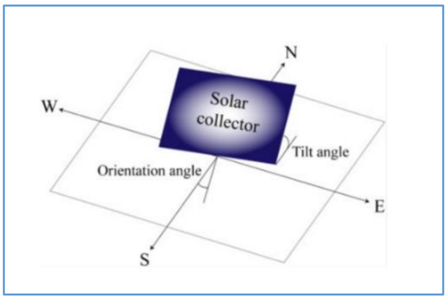

Figure 4. Solar angles for a tilted surface

In addition to latitude (L) and solar declination (δ), the sun's position is a function of time (t). The following formulas can be used to calculate the parameters of solar geometry [16].

$$\delta = 23.45 \sin\left(360 \frac{384 + n}{365}\right) \quad (1)$$

$$\tau = 15(t - 12) \quad (2)$$

$$\sin\beta = \sin L \sin\delta + \cos L \cos\delta \cos\tau \quad (3)$$

The solar beam incident angle θ on a horizontally tiled surface at an angle is given by the equation [17]:

$$\text{co } \theta = \cos \beta \cos \gamma \sin \phi \sin \beta \cos \phi \quad (4)$$

To measure the electrical resources, POLYSUN tools and solar weather data must be used to determine the electrical resources saved by employing SWHs for the system. The data of Erbil city weather was entered as boundary and initial conditions to start the numerical simulation of Polysun software like longitude, latitude, and location of the solar water heating system with orientation, tilt angle, number of the panel, number of the person living in this location, the volume of the tank, and set point temperature of the thermostat.

An SWH Solar Collector part's useful energy is provided by [8].

$$Q_{sol} = E_{sol} - Q_{ext} \quad (5)$$

The collector's efficiency is calculated to be

$$\eta_{\text{Collector}} = \frac{Qsol}{Esol} \quad (6)$$

The solar fraction SF is computed as follows:

$$\text{SF} = \frac{Esol}{Esol + Eaux} \quad (7)$$

2.3 Simulation

Vela Solaris in Switzerland used the software POLYSUN 11.2 (Velasolaris.com 2018). The weather data input to the numerical simulation of Polysun software is the longitude, latitude, and location of the solar water heating system with orientation, tilt angle, number of the panel, number of the person living in this location, the volume of tank, and set point temperature of the thermostat. With time steps between 1 second and 1 hour, the software can simulate solar thermal systems in transient mode. Solar systems can also be optimized with the help of this tool. Gantner (2000) has already considered and validated the Polysun simulation program with an accuracy of 5-10%. The Polysun simulation software has a user-friendly graphical user interface and the ability to layout building-specific devices. As a result, all system parameters may be quickly and clearly entered, enabling the design of new energy systems as well as the study of existing ones [8].

Figure 5 depicts the solar water heating method employed in this paper. The main components of this system are solar collectors and a storage tank with an auxiliary 3 kW heater. This presented work uses Natural Circulation or passive Solar Water Heating Systems. There is a thermostat inside the storage tank that switches off the electric heater as the temperature of water temperature reaches the setpoint. The device's main component is a solar energy collector, which is a form of heat exchanger. The solar collector transforms the sun's energy into useful energy.

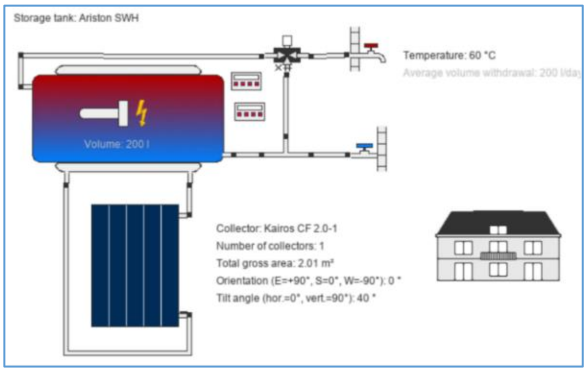

Figure 5. Solar water heating system based on the four persons per household

3. RESULT AND DISCUSSION

Regular simulations are carried out with the Polysun simulation software. Polysun is a kind of software that allows users to the annual dynamic thermal systems model and intends to automate them. The simulation software Polysun is different from the thermodynamics system model. The simulation software Polysun provides a comfortable and attractive graphical user interface, in which different system models could be created. Even more, it permits a comfortable and clear input of all system parameters and the analysis and design of energy systems. It runs with time steps from 1 second to 1 hour, thus simulation can be more stable and exact. The results of the Erbil City simulation in Iraq were examined in co-ordinates (Latitude: 36,221° N and Length: 44,021° E).

Figure 6 demonstrates that as the tilt angle is increased to around 40 degrees, the amount of solar energy conserved on the tilted collection surface increases. It began to deteriorate after that. This is because when the collector is exposed to regular direct sunlight, the maximum quantity of solar energy is obtained. It is obvious that when the tilt angle is equal to 40 deg., which means that the usual (maximum) saving of solar energy is 1,298 kWh.

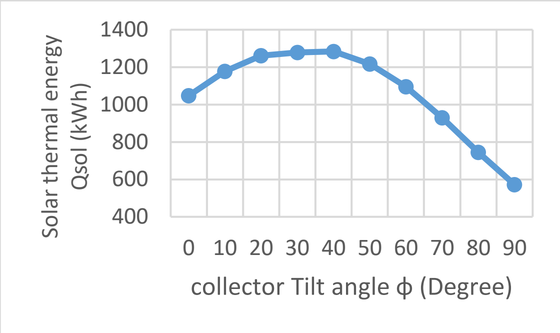

Figure 6. Variation of solar thermal energy savings with collector tilt angle

Figure 7 indicates that the overall solar fraction on the collector's tilting angle surface increases by raising the tilted angle to achieve a maximal value of approximately 40 degrees. And after that, it decreases. It is obvious that the overall solar fraction is 29.6% while the tilt angle is 40 degrees.

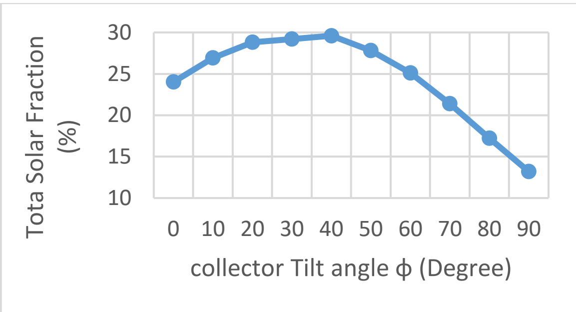

Figure 7. Variation in solar fraction as a function of collector tilt angle

The collector efficiency rises as the tilted angle increases to a maximum value of roughly 40 degrees, as shown in Figure 8 and then decreases as the tilted angle (ϕ) decreases. The maximum collector efficiency is 37.9% when the tilt angle is 40 degrees.

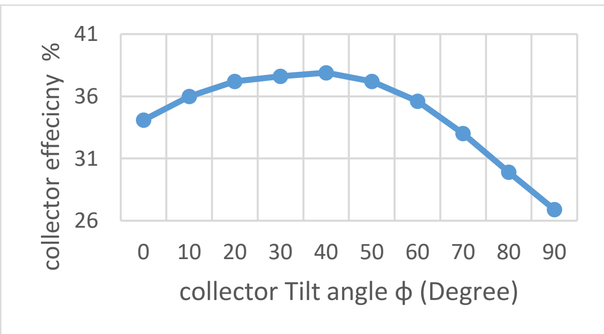

Figure 8. An effect of the collector tilt angle on the efficiency of the collectors

Figure 9 illustrates the influence of the global irradiation tilt angle on the collector area of the system**.** It is noticed that the overall global irradiation is higher when the tilt angle is 40 degrees than when the tilt angle is 20 or 60 degrees. The total value of irradiance of 40 degrees. Tilt angle is 3,390 kWh, which is higher than the 2,380 kWh and 3,302 kWh for both 20 and 60 degrees, respectively. In addition, the maximum global irradiation on the collector area was recorded in September, while the minimum was recorded in January.

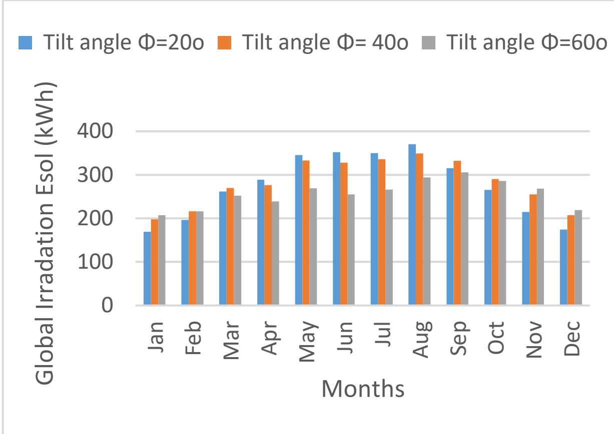

Figure 9. Effect of collector tilt angle on the global irradiation onto collector area

Figure 10 displays the impact of the system's solar collector on the tilt angle of electricity consumption. It should be noted that the system's overall electricity consumption has decreased when the tilt angle is at 40 degrees for the whole year. In addition, the minimum annual electricity consumption was recorded at 3,259 kWh when the tilt angle was 40 degrees.

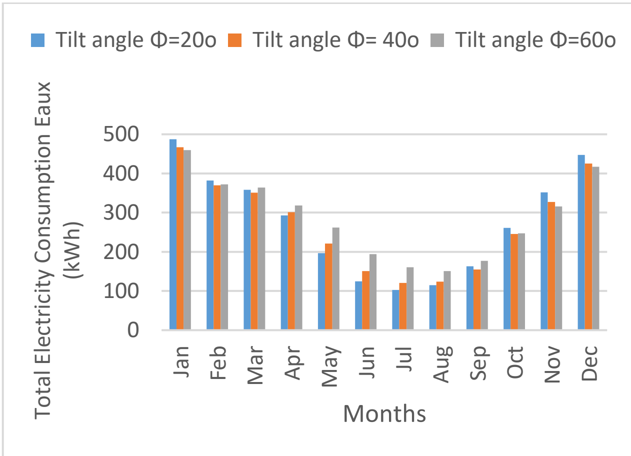

Figure 10. Effect of collector tilt angle on the total electricity consumption

Figure 11 indicates the domestic hot water profile of a day in a year in a one family residence in Erbil, which consists of four people. Erbil's overall demand for electricity is 3,259 kWh for hot water preparation during the year. The average person uses 50 liters of hot water every day. As a result, the SWH system is designed to provide 200 liters of 60°C hot water per day to a single-family detached house. The hourly distribution of DHW usage over the course of a day is influenced by a number of factors. From one day to the next, from one season to the next, and from one family to the next, numerous profiles of cyclic loads were shown, including early morning and early afternoon loads, as well as late morning and nighttime loads.

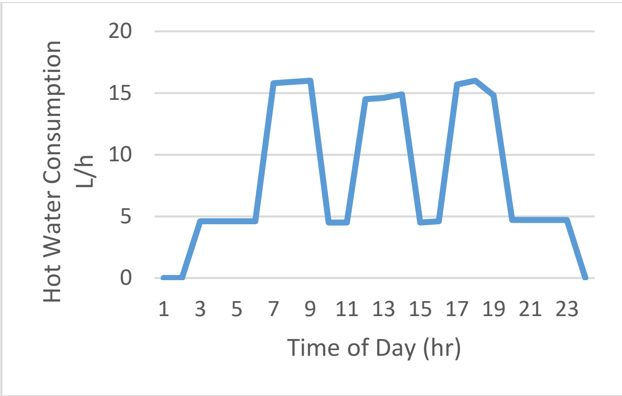

Figure 11. Domestic hot water consumption based on four persons per house

As shown in Figure 12, the current study shows the difference in heat losses of the solar collector system over the year, which includes heat loss to the interior room and heat loss to the surrounding area without loss of the collector.

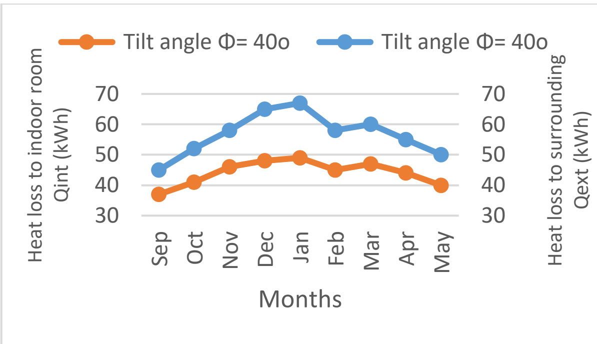

Figure 12. The heat loss to the indoor room and the heat loss to the outdoors varies when the tilt angle is 40 degrees

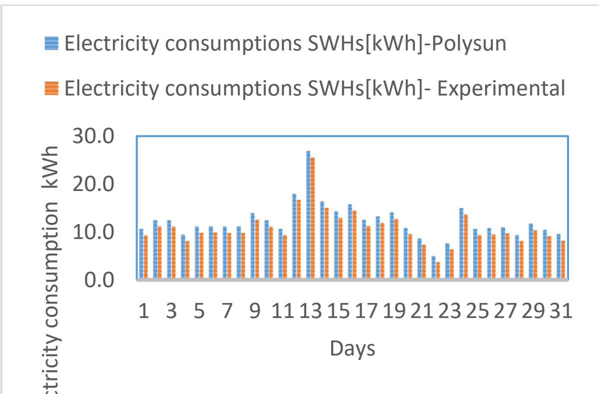

Figure 13. Solar water heating system of electricity consumed by experimental and Polysun software

Figure 13 displays the total amount of power consumed in January. The comparison between tests and Polysun in the solar water heating system is extremely near or similar. The largest and smallest variations in power usage between Polysun and experiments are 1.3 kWh and 0.4 kWh, respectively, in terms of power consumption. Polysun and experimental errors account for about 9% of the total.

In addition, the maximum and minimum heat losses to indoors and surroundings were recorded in January and July, respectively. In this simulation, the flat plate solar collector for the water heating device had been investigated. The energy flow diagram for the entire year is shown in Figure 14.

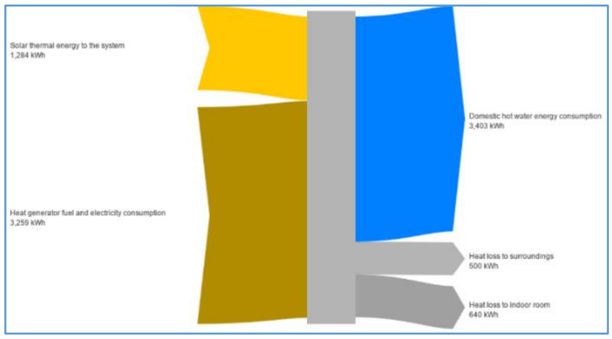

Figure 14. Energy flow diagram of the system when the tilt angle is 40 degrees

4. CONCLUSION

In this study, a flat-plate solar thermal collector was constructed in a single-family residence in Erbil city of Iraq, to provide domestic hot water for four persons. With a collector surface of 2 m^2, the solar water heating system produces 200 liters of water per day at 60°C, which is sufficient for household usage. Polysun software ran a year-round computer simulation to determine the best and optimum angle of tilt, maximize solar fraction, and reduce electricity use. The following summary can be drawn from Erbil City:

1. The solar collector should be tilted at around 40 degrees to the horizontal plan.
2. The total solar fractions are approximately 29.6% when the tilt angle is 40 degrees.
3. The total saved energy is about 1,284 kWh when the tilt angle is 40 degrees.
4. The average collector efficiency of Erbil city is about 37.9% when the tilt angle is 40 degrees.
5. The total reduction in CO_2 emissions of the systems is about 725 kg.
6. The Polysun results and the experimental results were nearly identical. For example, the difference in percentage between the two settings is over 9%.

Finally, this technology has been utilized to heat water and use it in homes and buildings, which conserves energy and saves money.

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NOMENCLATURE

SWHs	Solar water heating system
DHW	Domestic hot water
Q_{sol}	Solar energy of the system (kWh)
E_{sol}	Solar collectors are irradiated (kWh)
E_{aux}	Electricity usage and heat generator (kWh)
Q_{use}	Energy consumption for domestic hot water (kWh)
Q_{int}	Heat loss in an enclosed room (kWh)
Q_{ext}	Heat loss to the environment (kWh)
SF	Solar Fraction of the system (%)
Q	Flow rate (L/h)
T	Temperature (°C)
h	Hour (h)
t	Time
A_c	Area of the collector (m^2)
V	Volume of storage tank (L)
L	Latitude angle (deg.)

Greek symbols

δ	The sun's declination angle, (deg.)
τ	The hour's angle (deg.)
β	Altitude angle of the sun, (deg.)
θ	Surface incident angle, (deg.)
γ	Surface-Solar azimuth angle, (deg.)
ϕ	The inclination of the collector plane to the horizontal (deg.)
n	Number of day
η	Efficiency of the collector (%)