Investigation of Solar Water Heating System in Erbil City: An Experimental and Numerical Study

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Abstract- Solar energy is one of the most important sources of energy, and Erbil, city in north of Iraq (Kurdistan region), has a good location for solar radiation throughout the whole year. In which the maximum average monthly solar radiation in winter was found to be around 700 W/m^2. In this study, a solar water heating system has been built to heat a hall with a dimension of (14.5×7×3.5) m. The hall is located in the Scientific Research Centre building in Erbil Technical Institute. This system consists of 10 flat plate collectors, two storage tanks, three fan-coil units used for heating the hall, and measuring devices. A TRNSYS program was used to simulate this model and the results were validated with the experimental part. The results showed that using this system will reduce the energy consumption to 8% in December and to 14% in January and February. While in the remaining nine months, there was no consumed energy. Also, using this system will reduce the amount of CO_2 emission. Where, 86.4% reduction in CO_2 emission was found in January, and this percentage reduction increased for the other months until reaching 100%. The estimation of the payback period in years was found to be 4.65 which is acceptable relative to the size of the system and the number of people benefiting from it.

Keywords Solar energy; solar water heating system; flat plate solar collector; energy consumption; gas emission; payback period.

1. Introduction

Energy consumption is increasing dramatically because of worldwide population expansion, accompanied by significant technological changes that promote improved living standards [1]. The existing energy system, on the other hand, is unsustainable since it is dependent on finite conventional energy sources and causes grave environmental harm. Therefore, considerable efforts have been placed at the forefront of global political agendas and international conferences for the development of renewable energies, especially solar energy [2, 3]. As a result, different technologies have been developed so as to take advantage of the power of the sun [4–6]. Because of a variety of factors ranging from economic efficacy to long-term technological dependability, solar energy contributes just a small portion of overall energy consumption.

The incident solar radiation energy on the roof of a typical house is much more than the energy consumed by a typical family living in this house. Space and water heating account for a significant portion of energy demand, which may exceed 80% [7]. As a result, there is an urgent need to transform solar energy into useable sensible heat utilizing solar thermal technology. Nevertheless; in order to minimize poisonous gases emissions into the environment, fossil fuel usage must decline. Moreover, diminution of natural resources, environmental degradation, and economics are some of the problems that are restricting this energy source [8].

One of the most prevalent uses of solar energy systems nowadays is for heating water, most likely due to the reduction of emissions and conserving of ecosystem quality, which are some of the co-interests of this technology [9]. Solar collectors have shown to have significant uses in water heating and desalination, heat pumps, refrigeration, room heating and cooling, and other areas in the quest for renewable and sustainable energy technology [10]. The most common application of solar energy is solar water heaters (SWHS), a consequence of the economic benefits they afford and their technological feasibility [11].

Collectors are the main component of any solar-thermal system, where they gather solar radiation and transfer heat to a fluid [12]. Flat plate collectors, evacuated tube collectors, and compound parabolic collectors are the three most popular types of fixed collectors utilized in SWH systems. Thermal energy storage can be employed in regions where there is a large fluctuation in temperature between day and night or where there is a variance in solar energy [13].

SWH systems have been highlighted in both the residential and industrial sectors due to their ease of operation and maintenance, as well as their usage of renewable energy [14]. In the residential sector, SWH is a commonly used and established technique, and it provides for both fossil fuel savings and significant reductions in Carbon Dioxide emissions [15, 16]. SWH systems are categorized into two types based on their heat transfer fluid circulation mode: active and passive. Active systems circulate the water using a mechanical mechanism (circulating pumps), whereas passive systems employ gravity forces [17, 18].

In recent years, the net energy scrutiny and life cycle investigation of the SWH system are the two that are gaining a lot of interest [19-21]. The performances of running, which include the yearly power cost [22], average of inner return [23], solar portion [24], and design space [25], are the optimum parameters were typically calculated in previous researches on SWH systems. Also enhancing the thermal performance of the SWH system was the main objective of many researchers [26]. Where some added a PCM [27] and other used nanofluid [28] to increase the performance of the system.

Clean energy research has risen dramatically during the previous fifty years, notably after the 1973 World Oil Crisis [29]. Industrial, commercial and residential sectors are among the most applications that employing solar energy. Energy consumption in air conditioning, heating, water heating, lighting and other applications are examples for domestic applications. Here in Iraq particularly in Kurdistan Region, there are large amounts of energy consumption in residential sector which accounts for approximately 70% of the total energy consumption [30]. Despite the huge amount of solar irradiation of about 3.4×10^6 EJ received per year [31], Iraq and specifically Kurdistan region is one of the least countries using solar energy. Therefore, it requires an economic and efficient system to persuade households to employ solar water heating.

The aim of the current study is to build a solar water heating system and investigate all factors that impact on the effectiveness of system experimentally and theoretically to achieve minimum using of electricity and reducing energy usage for heating, which eventually reduces costs and increases sustainability in Erbil City.

2. Mathematical Formulation

2.1. Total Heat Load Calculation

Depending on the geographical site, a significant percentage of thermal energy is utilized for area heating and producing heated water in the domestic energy system. As a result, evaluating the heating capacity is the first stage in the design process. The thermal energies that must be delivered to the inside of a space or a structure so as to keep the ideal comfort levels are known as heating loads. These heating loads can be calculated for all the room sides (windows, door, external and internal walls, roof, and floor) using the following equation [32];

$$Q_{loss} = U_o \times A \times (T_{in} - T_{out}) \quad (1)$$

Where U_o is the overall heat transfer coefficient, A is the surface area, and T_{in} and T_{out} are indoor and outdoor design temperature, respectively.

2.2. Total Solar Radiation

Direct, diffuse, and reflected solar radiation are the three types of solar radiation that impact a surface. The term "beam radiation" refers to the solar radiation that has not been dispersed by the atmosphere which is often referred to as a direct solar radiation symbolized by (I_b). Whereas if it is dispersed by the atmosphere, it is called diffuse radiation and symbolized by (I_d), also sometimes known as sky radiation. The third component of solar radiation which is called reflected radiation and symbolized by (I), produce when the incident solar radiation on the surrounding surfaces are refracted and strikes on the concerned surface. During an hour, the total solar radiation, (I_T), is given as follows [33]:

$$I_T = I_b R_b + I_d \left(\frac{1+cos\beta}{2}\right) + I_{\rho g} \left(\frac{1-cos\beta}{2}\right) \quad (2)$$

Where R_b is the geometrical factor, β is the surface tilt angle, which is equal to (Latitude - Declination) for winter.

The product of the extraterrestrial solar radiation, I_o and the clearness index, K_T gives the ground reflected solar radiation as follows:

$$I = K_T \times I_o \quad (3)$$

And to calculate the dispersed or diffused radiation the following equation is applied:

$$I_d = I \times (0.9511 - 0.1604 \times K_T + 4.388 \times K_T^2 - 16.638 \times K_T^3 + 12.336 \times K_T^4) \quad (4)$$

Finally, the following equation is used to find the beam or direct radiation:

$$I_b = I - I_d \quad (5)$$

3. Experimental Procedure

The system of the solar water heating was run in the Research Center Building located in Erbil city (36.2 °N latitude, and 44 °E Longitude). This room was chosen to represent a study hall in schools, institutes or universities. The dimensions of this room are 14.5 m length, 7 m width, and

3.5m height, and it is located on the second floor in yellow color as shown in Fig. 1.

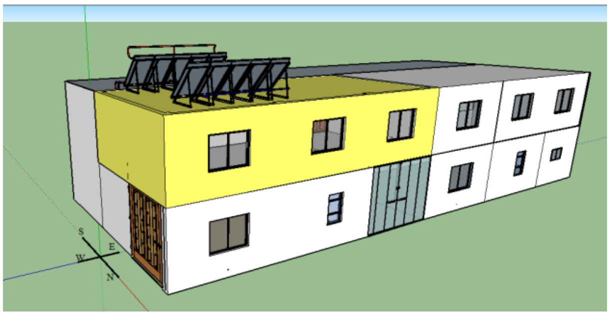


Fig. 1. The sketch of the room selected within the Research Center building.

The layout of the solar system adopted in this work is represented in Fig. 2. This system composed of ten collectors of flat plate type placed on the roof of the Scientific Research Center Building / Erbil Polytechnic University (as seen in Fig. 3a). Also, the specifications of these collectors are given in Table 1.

Table 1. Properties of the solar collectors

Collector Parts	Value	Unit
Collector gross surface	2.353	m^2
Absorber surface	2.138	m^2
Frame: (Aluminum extrude profile)	-	-
Weight	44	kg
Cover: (safety glass, super transparent, hailstone safe)	3.2	mm
Connection: Cu- tubes diameter	22	mm
Rear wall insulation: mineral wool,	40	mm
with fiber glass	70	kg/m^3
Side wall insulation: mineral wool	30	mm
Absorber: copper on copper plate coated with Tinox	-	-
Efficiency	80.1	%
Capacity	1.6	Liter
Maximum working pressure	10	bar
Stagnation temperature	208	°C

These collectors were tilted (60°) face to the south. Two water-storage tank at the first floor, as shown in Fig. 3b. Each tank is 1 m^3 in capacity with two inside straight-tube heat exchangers, to storing solar-heated water. Also, three fan-coil units each of (7 kW) were placed in the office room with dimensions of 14.5×7×3.5 m as demonstrate in Fig. 3c.

A circulation pump is needed to circulate water inside the system, where the working fluid (water) transfers heat from solar collectors to the storage tank as it circulates through the system. In addition, this system has a set of piping with their fittings, a number of sensors for temperature, flowrate, and pressure measurement, an electrometric actuator valve, a softener for water, and a 50-liter expansion tank ZILMET Hydro type. All the data of temperatures, flowrates and pressures taken from sensors are shown on a computer desktop screen using a DESIGO INSIGHT program, as indicated in Fig. 4.

In this system, there were three water circulation closed loops using three recirculation pumps. The first loop was formed by connecting the solar collectors to the first storage tank. Where in a sunny and clear day, the circulating water through this loop absorbs heat from the solar collectors and gather it in the first storage tank by using a heat exchanger. In this loop, the operation of the first circulating pump was controlled by the temperature difference of water leaving and entering the solar collectors which was set at 2°C to prevent energy loss at day and water freezing at night. The second water circulation loop occurs between the first and second storage tanks. In this loop, when the water temperature was increased up to 50°C in the first storage tank, the second circulation pump will turn on automatically to transfer heat to the second storage tank. The third circulation pump, which was located between the storage tanks and the fan-coil units placed in the office room, will turns on automatically when the tank temperature reaches 50°C. In this last circulation loop, the hot water from the storage tanks will supply to the fan-coil units, where it transfers heat to the room air, and back again to the storage tank. When the temperature in the room reached the room setting temperature, the electrometric actuator will automatically close the path between the fan-coils cold water and storage tank, meanwhile opening the path for the cold water from the fan-coils to return back to the fan-coils in a close loop. This was continued, until the room temperature was dropped down the setting temperature, where the electrometric actuator will permit the cold water to pass from the fan-coil to the storage tank and also pumping the heated water from the storage tank back to the fan-coil. The automatic operation of the pumps can be stopped by setting it on the manual state.

The experimentally solar collector useful heat energy gain can be found as [33];

$$Q_u = \dot{m}_w \times C_p \times (T_{wo} - T_{wi}) \quad (6)$$

Where $\dot{m}_w$ is the water mass flowrate, C_p is water specific heat, and T_{wo} and T_{wi} are the collector water outlet and inlet temperature, respectively.

4. TRNSYS Simulation Program

A complete system of a numerical model using TRNSYS program was built identically to the experimental work, as illustrated in Fig. 5. The model adopted here comprised of a reader (Type15-2) utilized to offer reading of meteorological data for the specific zone which was linked to a load (Type 56) which represented the office room. A third part which was represented by a flat plate solar collector (Type1b) was linked with the system and modeled as the thermal performance, and its output was connected with the storage tank (Type 534). As explained in the practical aspect, also in this model there were three water circulations. The first connect the solar collectors

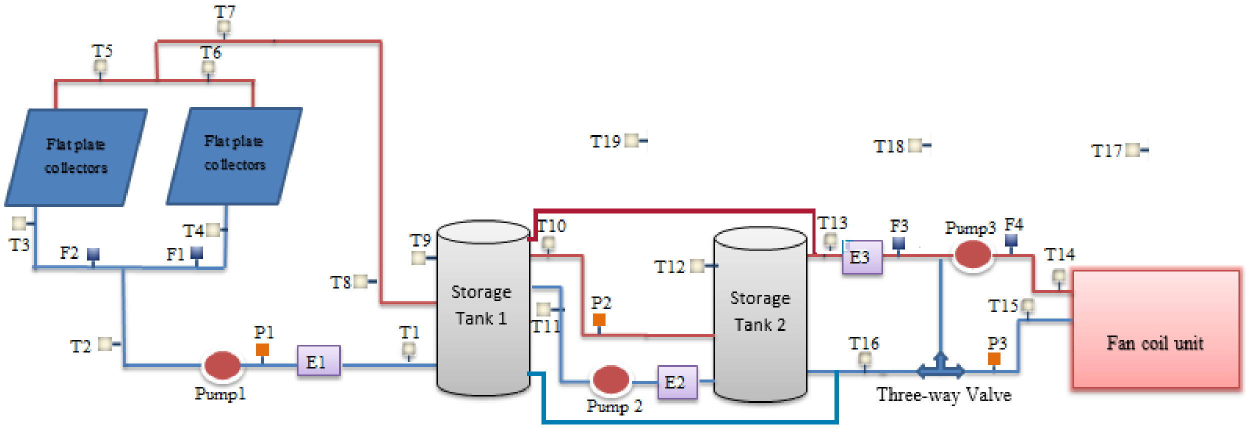


Fig. 2. Solar water heating system layout.

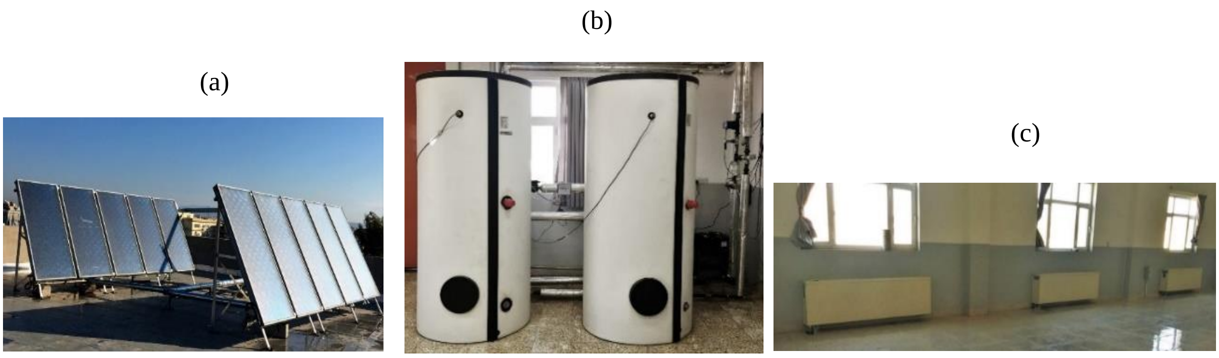


Fig. 3. Main components of SWHS: (a) solar collectors, (b) storage tanks, and (c) fan coil units.

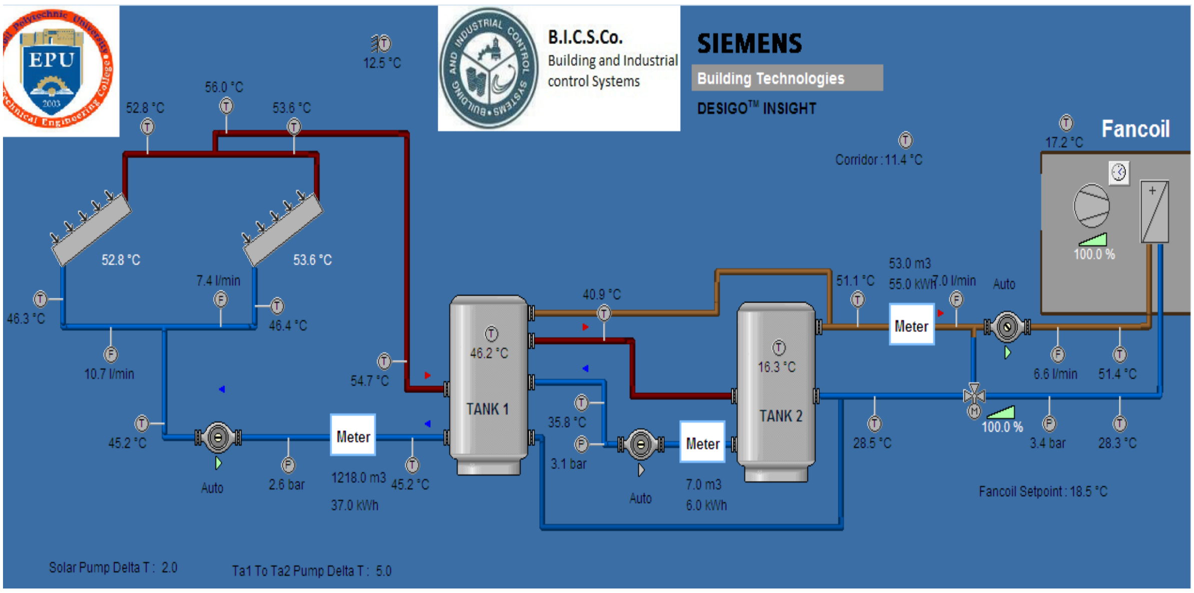


Fig. 4. A screen shoot of the computer program software (DESIGO INSIGHT).

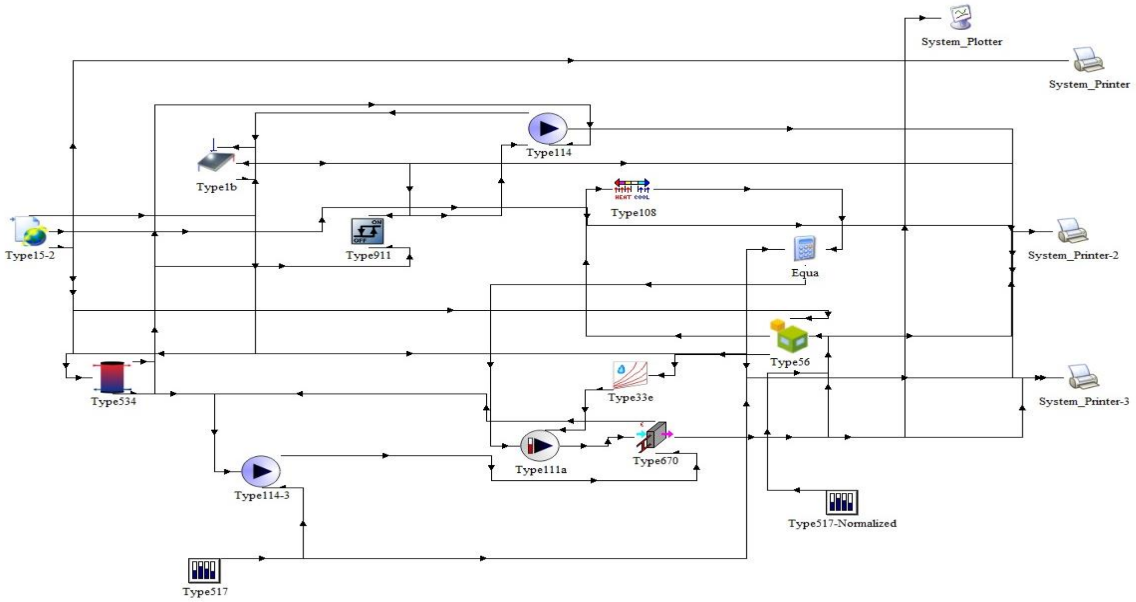


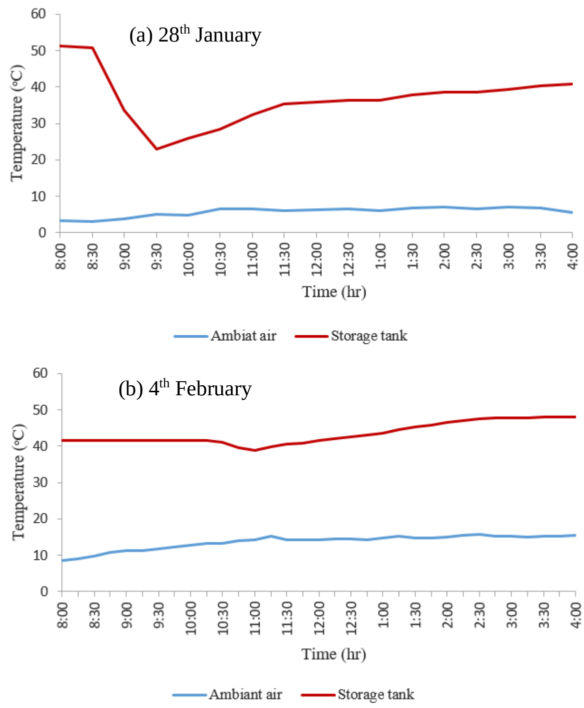
Fig. 5. Schematic diagram of TRNSYS model.

with the storage tanks, while the second connect the storage tanks with the heating load which represented by the office room. The third circulation which was between the two storage tanks has been cancelled because one storage tank was only considered in this simulation model.

A single-speed pump (Type 114) was utilized in the first circulation to pump the working fluid between the tank and the solar panels. The operation of this pump was controlled by using a differential thermostat (Type 911). The heat collected in the storage tank should be used to get rid of the heating loads from the office room (Type 56). This was done by using a single-speed pump (Type 114-3) to transfer heated water from the tank to the fan-coil unit (Type 670). The power of these fan-coil units was 21 kW and were placed in the selected room. Also, there is a fan (Type 111a) with three variable speeds (low, medium, and high), used to pull the air from the room into the fan-coil unit. A timer (Type 517) is linked to a thermostat (Type 108) to measure the room temperature. It is worth mentioning that this pump and the thermostat only operated from 9:00 a.m. to 4:00 p.m., and they turn off out of this time period. From 5:00 p.m. to 8:00 a.m., the circulation between the storage tank and load was out of work. Therefore, an electric heater (Type 17-Normalized) was used to heat the office room (Type 56), in order to compensate for the shortage in heat load withdrawn from solar energy.

5. Results and Discussion

The experimental outcomes over three different days are shown in Fig. 6. In this figure a comparison between the ambient temperature and storage tank temperature during the working time (9:00 a.m. to 4:00 p.m.) is shown for 28th January, 4th February, and 16th February, respectively. It can be noted from this figure that the highest temperatures recorded in the storage tank at 8 a.m., which are stored in a day before, are 51.5°C, 42°C, and 55.4°C for 28th January, 4th February, and 16th February, respectively. On the other hand, the average ambient air temperature is 5°C, 13.5°C, and 18°C, respectively. Since 8:00 a.m., the heat stored in the storage tank is used to remove the heating loads from the office room. Also, because of the low ambient air temperature and the lack of solar radiation in the early hours of the day, the storage tank temperature drops significantly at this time, as shown in Fig. 6a. As a time goes by, the temperature of the storage tank begins to rise up with an increase in the incident solar radiation. As can be seen in Figs. 6b and 6c, this drop in storage tank temperature is reduced in the days when the ambient air temperature is high.



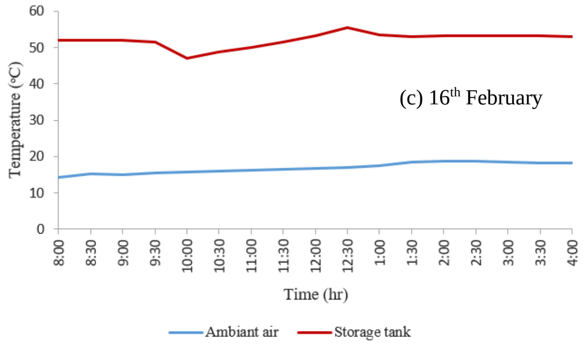
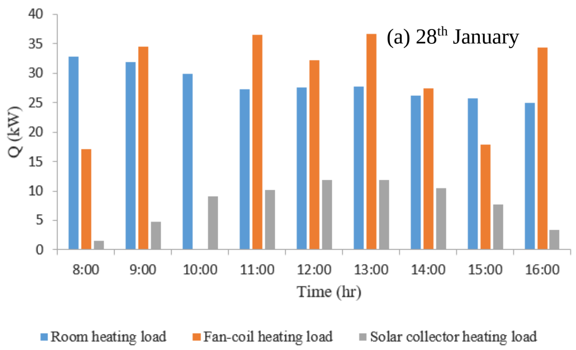
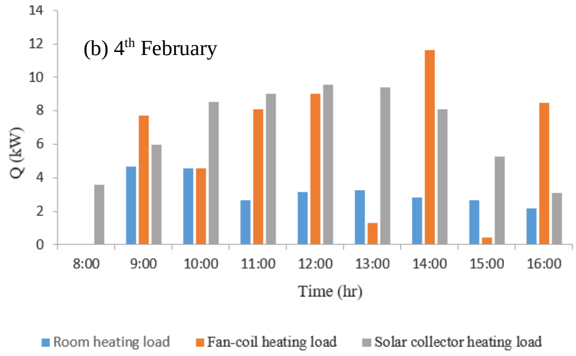


Fig. 6. Ambient air and storage tank measured temperatures for (a) 28th January, (b) 4th February, and (c) 16th February.

The heating loads experimental results that are required for the room, supplied by the fan-coil units, and available in the solar collectors for 28th January, 4th February, and 16th February are shown in Figs. 7a, 7b, and 7c, respectively. As can be seen from this figure, the 28th January is recorded as the coldest day in which the temperature of the ambient air is 3°C, which is the minimum temperature recorded during the test, (Fig. 7a). Outside the working hours, i.e. between 5 p.m. to 7 a.m., there are no any source of energy to remove the heating loads from the office room, as a consequence and before running the system, both the room and ambient air temperatures are nearly the same. Therefore, in the first hours of operating the system (i.e. 8 a.m.), the heating loads required in the room are higher than that supplied by the fan-coil units and available from the solar collectors. Because of the sun location, the heating load from solar collector is at its lowest value in the morning, and at noon it is at its highest value. The figure also demonstrates that even at the lowest ambient air temperatures, this system (SWHS) can achieve 7 hours of heating loads out of 8 working hours. For 4th February, the minimum ambient air temperature recorded is approximately 8°C. In this day and specifically at 3:00 PM, the fan-coil units are automatically turned off because the room temperature has approached the set point temperature, till the room temperature was dropped below the room setting temperature then the fan coil units will turn on again.





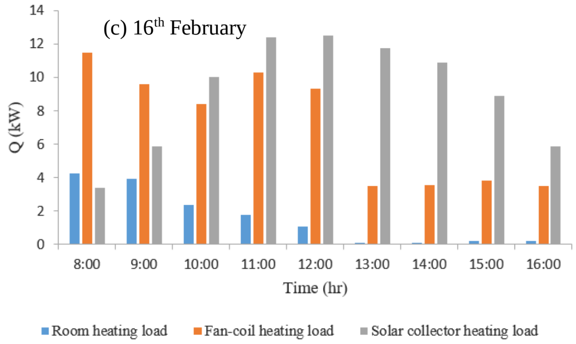


Fig. 7. Room, fan-coil, and solar collector heating loads for (a) 28th January, (b) 4th February, and (c) 16th February.

The simulation model adopted in this work was solved using TRNSYS software and their results were verified with the experimental outcomes. Fig. 8 shows this verification for collector inlet and outlet water temperatures in January, where a good convergence was obtained. To find out the heating loads required for the room, Fig. 9 shows the differences between the required room load, the supplied load from the solar collectors, and the supplementary (accessory) load from kerosene heater over the course of seven months. The results show that, with the exception of December, January, and February, there is no need for supplementary heater since the heat collected from the system is sufficient to meet the room heating loads. However, for the three months mentioned above, supplementary heater with a ratio of 8 percent, 14 percent, and 14 percent is necessary, respectively.

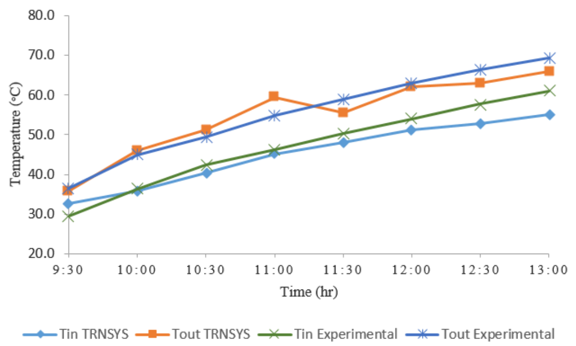


Fig. 8. Verification between experimental and simulated solar collector average inlet and outlet water temperature.

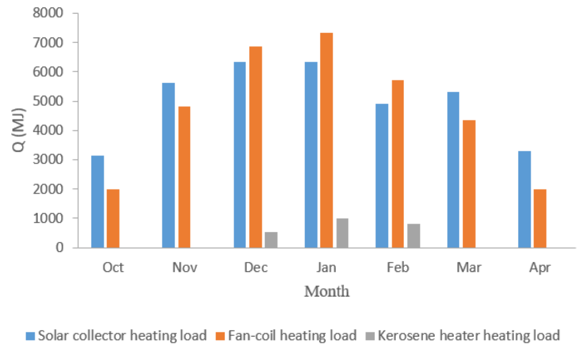


Fig. 9. Heat energy required from heaters to recover room heating load.

The amount of fuel required to get over the room heating loads using an electric or oil heater depends on the room heating loads, which in turn depends on the season of the year. Fig. 10 shows the impact of utilizing solar water heating system (SWHS) on the amount of fuel required for supplementary (accessory) heater. As can be noticed in this figure, the amount of oil (kerosene) needed to get over the room heating loads in January is about 196 liters without using the SWHS. Meanwhile, this amount is reduced to approximately 27 liters when the system is utilized. This means that kerosene heaters are needed to get 14 percent of the room heating loads, and these quantities will reduce further in the remaining months.

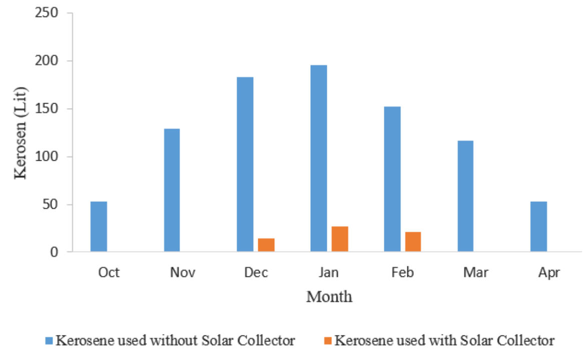


Fig. 10. Kerosene used with and without using the solar collector.

Figure 11 compares the amount of CO_2 released by burning fuel with and without the use of the SWHS. The figure shows how adopting a solar water heating system reduces CO_2 emissions. When using the solar water heating system to heat the room in January, only 72 kg of CO_2 is created instead of 1058 kg, resulting in a reduction of CO_2 emission of about 93%. The increase in this percentage will continue for the rest of the months until it reaches a 100% decrease, where there is no any emission of gases.

6. The System Costs and Payback Period

The period in years required to cover the total running cost of the system is known as payback period [34]. In this section, the cost of the SWHS will be compared with the cost of electrical energy consumption for heating the room. The total cost (*TC*) of this system, including purchasing value and installation fees, is $50,400 (for 20 m^2 flat plate collectors, 2 m^3 of tank capacity, pumps, measuring devices, and piping system). This system is sufficient per day for heating a hall with a maximum capacity of 40 people. According to the Ministry of Electricity in Kurdistan region, the electricity cost (*EC*) is $0.68 per kWh, and based on the experimental data and simulation results, the total electrical energy saving (*EES*) is 15942.38 kWh per year. Then the annual payment saving (*APS*) can be found as,

$$APS = EES \times EC = 10840.8\ \$/year$$

So,

$$Payback\ period\ (\text{in years}) = \frac{TC}{APS} = \frac{50400}{10840.8} = 4.65$$

Although the payback period of this project is a little bit more than that found in the different literature [20, 34], it is considered appropriate as comparing the size of the system and the number of people benefiting from it with its counterparts in the different literature.

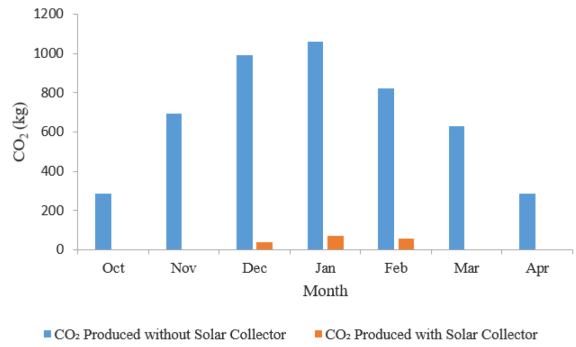


Fig. 11. CO_2 emission with and without using the solar collector.

7. Conclusions

The conclusions drawn from the current practical and simulated study about the use of solar water heating system to heat an office room in the city of Erbil are as follows;

1. The temperature attained in this system is approximately 50.7°C on the coldest and clear day. Therefore, the solar water heating system employing flat plate collectors is acceptable for usage in Erbil city.
2. The results of using TRNSYS program were validated against the experimental data, resulting in a significant convergence.
3. Depending on a clear day before, this system (SWHS) can achieve 7 hours of heating loads out of 8 working hours even at the low ambient air temperatures.
4. The results showed that there is no need for supplementary heater since the heat collected from the system is sufficient to meet the room heating loads except for December, January, and February, were supplementary heating ratio of 8%, 13.6%, and 14% was needed respectively to recover room heating loads
5. The results showed that in January there is about 93% scaling down in CO_2 emission when adopting the SWHS and therefore reducing the pollution in the city of Erbil. The increase in the percentage will continue for the rest of

the months until reaching a 100% decrease, where there is no any emission of gases, which is critical for slowing the rate of global warming.

6. Relative to the size of the system and the number of people benefiting from it, the payback period is considered appropriate compared to its counterpart in literature.

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