# Performance Analysis of Solar Water Heating System in Erbil, Kurdistan Region of Iraq

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**Abstract: This study evaluates optimum performance and determines the parameters of solar water heating system (SWHS) of Erbil climate condition. The proposed SWHS is demonstrated through the efficiency of the flat plate solar collector, the capacity of the storage tank, the useful heat gains from the solar collectors, the outlet temperature of the solar collector and heat transfer rate for the loading zone. The results of the experimental case study showed that the outlet collector temperature is 69.5°C with total global irradiance which is 631 W/m^2, while, the optimum value of collector efficiency is 0.93, the amount of useful heat gains is 10.238 kW and heat transfer rate for loading zone 7.56162 kW. The solar energy system is adorable system to provide the best products of heating and gets the best useful heat source as quantity as well as quality of energy in Erbil City in Kurdistan region of Iraq. Erbil governorate is a suitable place to receive and store energy, this system is installed in Erbil City at the Research Center of Kurdistan Region.**

**Keywords: Solar Energy, Energy Analysis Evaluation, Flat Plate Solar Collector, Hot Water Storage Tank with Heat Exchangers (Upper and Lower) Unmixed Fluid, Heat Transfer Rate, Working Fluid through the Pipes.**

## 1. Introduction

Solar energy system is one of the most significant sources of the renewable energy that includes solar energy, wind energy, geothermal energy… etc. that is used in commercial or industrial and residential sectors to provide thermal energy or to store energy by the SWHS. The system has been installed in Research Center of Erbil Polytechnic University. The latitude of Erbil is 36.191113, and the longitude is 44.009167. (JAWHAR, 2018). The climate of Erbil city is warm and the SWHS is a suitable location zone for installation system to provide the useful heat gain through the flat plate solar collector. Reasonable solar intensity is available in cold seasons. The SWHS consists of two cycles. Firstly, is between the flat plate solar collector and the hot water storage tank. Also the pump system is used to circulate hot water through the pipes or tubes. Secondly, is between the hot water storage tank and the loading zone area. The pump system is used to circulate hot water for destination place.

The SWHS, also called solar domestic hot water system, is widely used for residential sector to provide hot water for residents. It can be used in any climate. Theoretical and experimental data case study of

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energy analysis of flat plate solar collector includes important parameters for calculating the performance of solar collector and efficiencies of collector of the system. Thermodynamics can be considered as the science of energy. One of the most important laws to obtain the conservation of energy principles is the first law of thermodynamic**.** Energy can change from one form to another form but the overall amount of energy remains constant, i.e., energy can change from kinetic energy to potential energy and to internal energy. The energy cannot be created nor destroyed, it can be only conserved from one form to another. The energy can be measured to calculate the quantity as well as the quality of energy product (Farahat, Sarhaddi, & Ajam, 2009).The flat plate solar collectors energy analysis has been demonstrated for the solar water heating system. The aim of the study was to determine the performance and design parameters of the system. The study demonstrated the absorber flat plate area of solar collector, pipes diameter, water mass flow rate, a fluid inlet, and outlet temperature as geometric and operating variables. The results showed the maximum energy efficiency based on the mass flow rate, the date and the time. (Farahat, Sarhaddi, & Ajam, 2009). Gilani and Hoseinzadeh (2021) studied numerically the visibility of using pound parabolic collectors (CPC) in the SWHS in several locations worldwide with high and low availability of solar radiation. The authors compared the results of system performance with typical flat plate collectors. The aim of the study was to reduce the cost of the auxiliary heating system which is used. It showed that the CPC is highly recommended for the end-user save money especially when high rate of electricity rate is applied. Struckmann et al. (2008) explained and demonstrated the active solar energy system, which includes the integration of several subsystems: solar collectors, hot water storage tanks, heat exchangers, fluid transference and distribution systems through the pipes and to the loading zone. The main component of solar water heating active system is the flat plate solar collector. The solar intensity absorbed by the collector is converted into heat at the absorbing collector surfaces and transfers the heat by a fluid through the pipes or tubes through the collectors. The warmed fluid carries the heat to each of the hot water storage tanks or air-conditioning equipment (fan-coil unit) or a subsystem from which can be drawn for use at night and on cloudy days (Struckmann, 2008). This study defines the optimum performance analysis of the SWHS for Erbil climate conditions. The experimental study has been used to evaluate the technical characteristics including the capacity of the storage tank, the efficiency of the flat plate solar collector, the useful heat gain, the outlet temperature and heat transfer rate for the loading zone (green house).

## 2. Energy Analysis

The energy balance for the system is defined as:

$$\Delta E_{sys} = E_{in} - E_{out} \qquad [1]$$

The equation of useful heat gain from the working fluid can be used as: (Duffie & Beckman, 2013). The useful heat gain is:

$$Q_{use} = \dot{m}\, C_p\, \Delta T \qquad [2]$$

$$Q_{use} = \dot{m}\, C_p\, (T_{fo} - T_{fi}), \qquad [3]$$

Where, $(T_{fo}, T_{fi})$ are inlet and outlet fluid temperature through the collector, $(C_p)$ specific heat of water is assumed that $(4.18\ kJ/kg.k)$, and $(\dot{m})$ water mass flowrate $kg/s$.

The Hottel-Whillier-Bliss equation for the useful heat gain $(Q_u)$ from the flat plate solar collector to the atmosphere is defined as (Duffie & Beckman, 2013):

$$Q_u = \text{Absorbed} - \text{Losses}$$

$$Q_u = A_p F_R [S - U_L(T_{fi} - T_a)] \quad [4]$$

$$Q_u = A_P F_R \left(I_T(\tau\alpha) - U_L(T_{fi} - T_a)\right) \quad [5]$$

Where, $(S), (U_L)$ are solar radiation flux absorbed by unit area of the absorber flat plate solar collector and overall loss of heat transfer coefficient. $(T_a)$ is the ambient temperature. $(T_{fi})$ is fluid inlet temperature. $(A_P)$ is flat plate collector area and $(F_R)$ is the heat removal.

Radiation absorbed flux per unit area of flat plate collector $(S)$ is defined as:

$$S = I_T(\tau\alpha)$$

Where, $(I_T), (\tau\alpha)$ are the total solar radiation. $(w/m^2)$ is the incident solar ration of the transmittance-absorbance product. But, in this experimental case study the total solar radiation will be calibrated.

heat removal factor is defined as:

$$F_R = \frac{m^{\cdot}\, C_P}{U_L\, A_P} \left\{1 - \exp\left(-\frac{F^{/}\, U_L\, A_P}{m^{\cdot}\, C_P}\right)\right\} \quad [6]$$

Where $(F^{/})$ is the flat plate collector efficiency factors and flat plate effectiveness

The overall loss of heat transfer coefficient $(U_L)$ is given by:

$$U_L = U_{top} + U_{bottom} + U_{edge} \quad [7]$$

To evaluate the thermal efficiency of solar water heating system on flat plate solar collector is defined by:

$$\text{Energy Efficiency} = \frac{\text{Useful Output Energy}}{\text{Total Input Energy}} \quad [8]$$

$$\eta_{coll} = \frac{Q_u}{T_T * A_{Pnet}} \quad [9]$$

## 3. System Description of SWHS

### 3.1 Overall Setup

Solar water heating system is one of the adorable systems of saving thermal energy that is used in this significant study of the solar system. It involves flat plate solar collectors that is fixed on the top floor of Erbil Research Building Center of Kurdistan region (36.19 N Latitude, 44 E Longitude). The flat plate solar collectors are installed with a slop of $60^{\circ}$ from the horizontal facing South East. In laboratory on the first-floor, it has a pair of large hot water storage tanks with helical tube heat exchangers unmixed fluid inside tank for destination loading zone area which is greenhouse. The system involves water pump system to circulate working fluid (water) through the pipes or tubs inside the SWHS. Generally, the system contains piping system with its accessories as temperature sensors (thermostat), water flow meter sensors, pressure sensor, three-way valve with electro-motoric actuator, residential water softener, expansion vessel and controller that sensation or sensed the temperature difference in the system to turn (on/off) the system. And all the data from the temperature sensor or flowmeters and pressure sensors are demonstrated on a screen by a computer program: DESIGO$^{TM}$INSIGHT provided by SIEMENS.

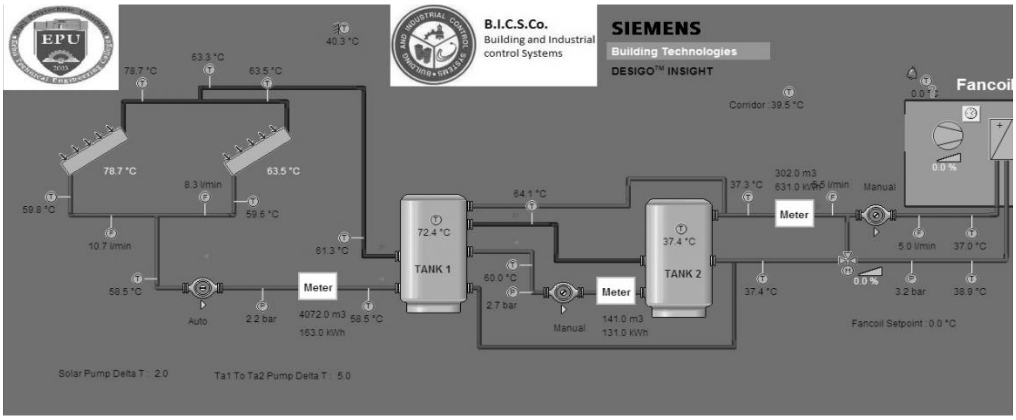


Figure 1: Computer program DESIGO$^{TM}$INSIGHT

Figure 2: Flat plate solar collectors of SWHS

Table 1: Description of the properties of the flat plate solar collector and parameters

| | |
|---|---|
| Collector type | WIKOSUN 2020 − MI/2340 − |
| Collector area | $2m^2$ |
| Fluid through the tubes | water |
| Collector tilt | $60^{\circ}$ |
| Fibber-glass | $70\ kg/m^3$ |
| Maximum heating water capacity | 120 ℃ |
| Maximum working pressure | 10bar |
| Highest standstill temperature | 209 ℃ |
| External profile frame | aluminium |
| Rear wall is insulated with mineral wool | 40mm |
| Side wall is insulated with mineral wool | 30mm |
| No. of flat plate solar collectors in series | $5 \times 5$ |
| No. of covers | 2 |

**3.2 Hot Water Storage Tanks**

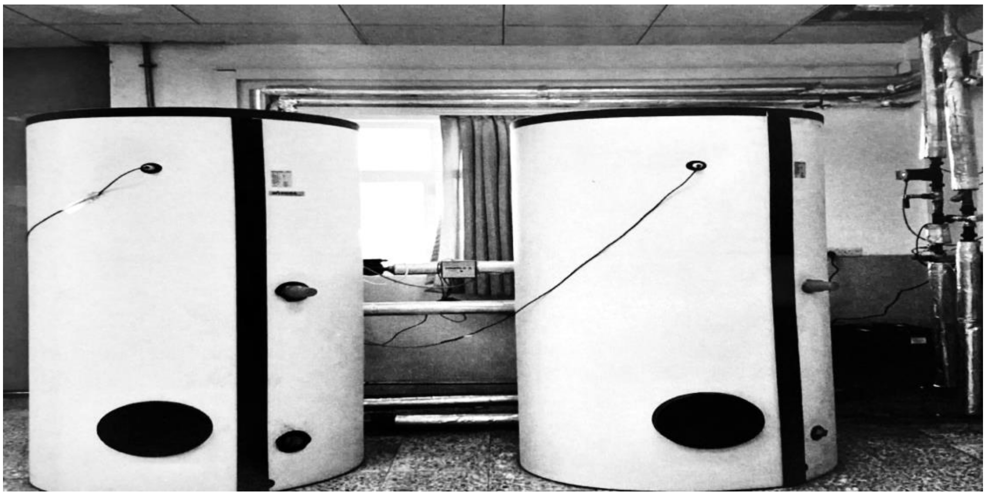

Figure 3: Hot water storage tanks of SWHS

Table 2: Description of the properties of hot water storage tank and parameters

| | |
|---|---|
| Tank type | WBO1005 UNO/DUO, |
| Maximum working pressure | 16 bar |
| Unmixed-fluid through the heat exchangers | Water |
| Maximum temperature | 130°C |
| Tank capacity | 1000 L |
| Storage tank diameter | 79 cm |
| Tank highness | 200cm |
| Insulated with fleece | 10cm |
| The heat exchanger type | helically coiled |
| The lower heat exchanger capacity | 19.8 L |
| Surface area of lower HX. | $3m^2$ |
| The upper heat exchanger capacity | 13.3 L |
| Surface area of upper HX. | $2m^2$ |

Table 3: Description of the properties of water pump and parameters

| | |
|---|---|
| The pumps type | (SPERONI)SCR 25/40 |
| The pump is used to | circulate working fluid (water) |
| The maximum pressure | 10bar |
| The system is containing of | three pumps |
| The first pump is used to | circulate the water from the first storage tank to the flat plate solar collectors |
| The second pump is used | between the first and second storage tanks |
| The third pump is used to | circulating heated water from storage tank to the greenhouse zone (loading zone) |
| The pump has three speeds from | (low, medium and high). |

### 3.3 Temperature Sensor (Thermostat)

Immersion Temperature sensor    Cable Temperature Sensor

Figure 4: Temperature sensor (Schlipf, 2016)

Table 4: Description of the properties of the thermostat and parameters

| | | | |
|---|---|---|---|
| Immersion temperature sensor type is | SIEMENS of QAE26.9 | Cable temperature sensor type is | SIEMENS of QAP212 |
| Designed to measure a degree of | hotness or coolness in an object | Designed to measure a degree of | hotness or coolness in an object |
| The immersion sensor is made of | stainless steel | The cable sensor is made of | nickel |
| The immersion sensor is mounter | with a stem immersed inside the pipe | The cable mounted | on the outside wall |
| The measuring accuracy temperature is | $\pm 0.4$ kelvin | | |

### 3.4 Flow-Meter (Water Flow Sensor)

Figure 5: Water flow sensor (Ballard, 1996)

Table 5: Description of the properties of the flow-meter and parameters

| | |
|---|---|
| The type of the flow sensor | QVE3100 from SIEMENS |
| A flow-meter sensor is used to | measure the water mass flow rate |
| The unit of flow-meter sensor is | kg/s $or\ l/min$ |
| A measuring accuracy is lower than | 2% |
| The flow-meter sensor is made of | brass |

### 3.5 The Pressure Sensor


Figure 6: Pressure sensor (Kharlamov et al., 2014)

Table 6: Description of the properties of the pressure sensor and parameters

| | |
|---|---|
| The pressure sensor type is | QBE2002 − P10 from SIEMENS |
| A pressure sensor works by | converting pressure into an analogue electrical signal |
| The pressure sensor measuring accuracy is | ±0.4% |
| The first pressure sensor is used | before flat plate solar collectors |
| The second pressure sensor is used | between the hot water storage tanks |
| The third pressure sensor is used | at greenhouse zone area (loading zone) |

### 3.6 Energy-Meter (MW.hr):


Figure 7: Energy-meter (Hubbard, Munday, Hemminger, & Holdsclaw, 2000)

Table 7: Description of the properties of the energy-meter and parameters

| | |
|---|---|
| The energy-meter type is | UH50 − A65 from SIEMENS |
| The energy-meter is used to | measure the amount of electrical energy |
| The first energy-meter is used | between solar collector and first hot water storage tank |
| The second energy-meter is used | between the two hot water storage tanks |
| The third energy-meter is used | between the storage tank and loading zone |

### 3.7 Piping System (Pipe Connection System)

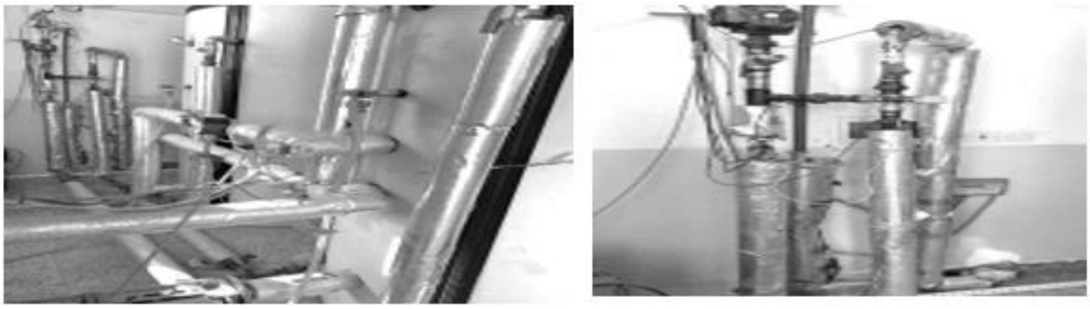

Figure 8: Pipe connection system of SWHS

Table 8: Description of the properties of the pipe connection system and parameters

| | |
|---|---|
| A piping is a system used to | transfer fluids (water) from one location to another by connection pipes |
| The pipe type is | black steel |
| The diameter of connection pipe is | 25.4mm (2.54cm) |
| The pipe connection is insulated with | fiberglass to minimize heat losses |
| The exterior pipe is insulated with | fiberglass and covered with an aluminum sheet to protect the fiberglass from outside conditions |

## 4. Results and Discussion

Thermal analysis of SWHS is carried out experimentally to evaluate the performance of operating factors of the system. The most relevant factor is to provide sufficient useful heat gain through the flat plate solar collectors and storage tank to transfer the hot water to the loading zone through the process of heat transfer. The experimental case study was implemented during April-June. The experiment result was recorded on $7^{th}$ of June 2021 which showed the optimum performance of the SWHS for destination zone (greenhouse) and the study data started from 9:00am till 14:00pm. So, all data from the temperature sensors, water flow sensor and pressure sensors were recorded through an intelligent data acquisition system called 〖DESIGO〗^TM INSIGHT. The flat plate collector surface area is 20 $m^2$ and the fluid is water while the layer glasses of the flat plate solar collector is double glasses cover. Figure 1 presents the global irradiance versus time on $7^{th}$ of June 2021. The figure shows that the maximum value of the solar global irradiance for Erbil climate condition at 11:30am was about 631 W/m^2 that have been calculated by daystar-meter that is calibrated by SWHS. The Figure 2 is the variation of inlet and outlet temperature of the solar collector with the ambient temperature on $7^{th}$ of June. So, the maximum rate of outlet temperature of the solar collector is 69.5℃ at 13:00pm. The Figure 3 presents the collector efficiency performance. The optimum collector efficiency is 0.93 at 14:00pm. The collector efficiency has direct relation with useful output energy and reverse relation with total input energy. Figure 5 provides the useful heat gain from the flat plate solar collector. Hence, the maximum useful heat gain that is obtained from the solar collector is 10.238 KW at 12:00pm. The parameters that affect the useful heat gain are mass flowrate, specific heat of water and change of the collector temperatures. Moreover, Figure 6 shows the capacity of hot water storage tank. When the system raises the temperature of water inside the storage tank until the second circle starts to circulate the water from the storage tank to the greenhouse heat exchanger, the maximum average tank temperature recorded was 68.7 °C at 9:00am. Figure 7 shows the flow of water through pipes. Since the flow of water can be controlled manually by the pump, the flow rate changed every 30 minutes. The designed flow rate was (0.33, 0.31, and 0.27 kg/s). In Figure 9, the variation of inlet and outlet of temperature from the loading zone with time was explained, the maximum inlet temperature is 72.3 °C at 9:00am. In this study, no auxiliary heater was used and the system operated only by the heat gained from the collectors.

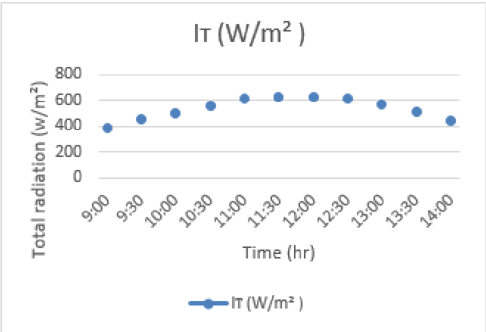


Figure 9: Total radiation I_T  (W/m^2) with time (hr.)

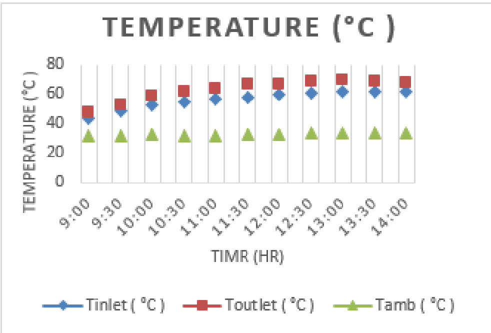


Figure 10: Inlet and outlet temperatures (°C ) with ambient  temp. and time (hr)

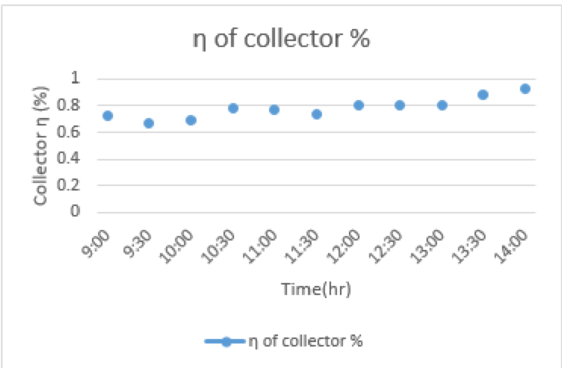


Figure 11: Collector efficiency η (%) with time (hr.)

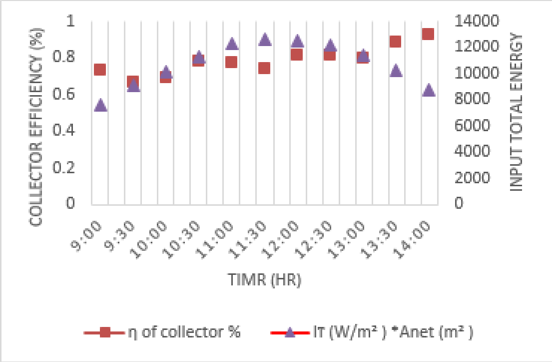


Figure 12: Variation of collector efficiency (η) and total

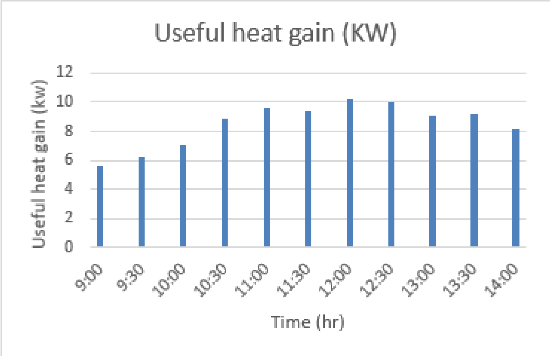


Figure 13: Useful heat gain (KW) with time (hr.)

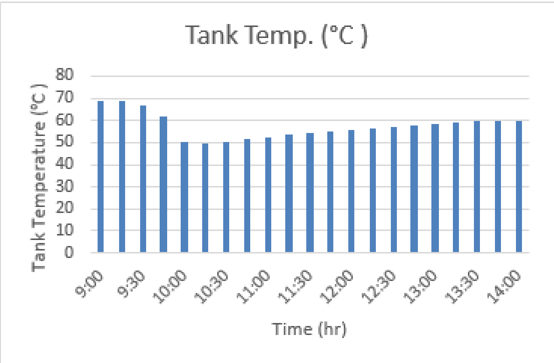


Figure 14: Tank temperature (℃ ) with time (hr.)

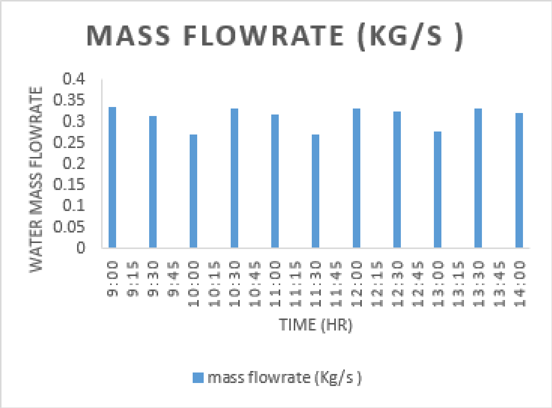


Figure 15: Water mass flowrate (kg/s) with time (hr.)

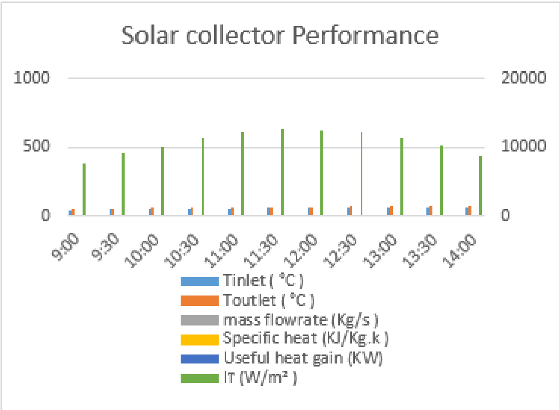


Figure 16: Flat plate solar collector performance of SWHS

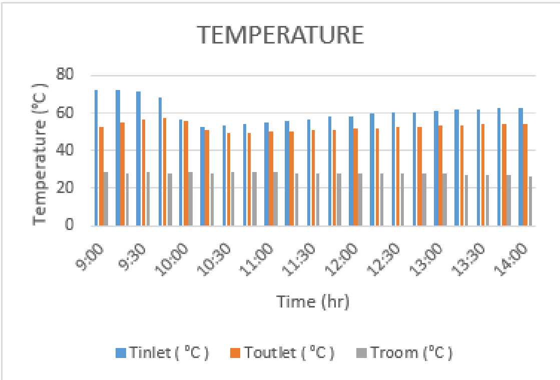


Figure 17: Inlet, outlet and room temp.(°C ) with time (hr. )

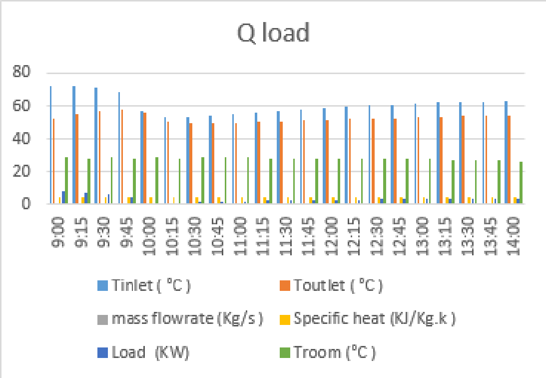


Figure 18: Thermal load zone (kw) with time (hr.)

## 4. Conclusion

The comprehensive method for evaluating performance and operation conditions for solar water heating system was presented. The proposed process consists of mathematical modelling for main parameters and components that influence the whole system of solar water heater and thermal solar energy performance. The following conclusions have been found.

1. The maximum value of the total global irradiance for Erbil climate conditions on 7th of June 2021 was 631 W/m^2.
2. The value of outlet temperature from the solar collector varies from 47.5 °C to 68.4 °C.
3. The optimum collector efficiency that is performed is 0.93.
4. The amount of useful heat gain obtained from the solar collector at 12:00 o'clock was 10.238 KW on 7th of June 2021.
5. The optimum of tank temperature was about 72.3 °C.
6. The maximum heat transfer rate for loading zone was 7.56162 KW.

Nomenclature

| Symbol | Definition | Unit |
|---|---|---|
| $A_P$ | Flat plate Collector Surface Area | $m^2$ |
| $C_P$ | Specific heat of water | KJ/Kg . KA |
| E | Energy Rate | J/s |
| $Q_u$ | Useful Heat Gain | KW |
| m· | Water Mass Flowrate | Kg/s |
| $T_a$ | Ambient Temperature | °C |
| $T_{fi}$ | Inlet Fluid Temperature | °C |
| $T_{fo}$ | Outlet fluid temperature | °C |
| $I_T$ | Intensity of Solar Radiation | $W/m^2$ |

## References

Azad Gilani, H., & Hoseinzadeh, S. (2021). Techno-economic study of compound parabolic collector in solar water heating system in the northern hemisphere. *Applied Thermal Engineering, 190*, 116756. https://doi.org/10.1016/j.applthermaleng.2021.116756

Ballard, S. (1996). The in situ permeable flow sensor: A ground-water flow velocity meter. *Groundwater*, *34*(2), 231-240.

Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes*. John Wiley & Sons.

Farahat, S., Sarhaddi, F., & Ajam, H. (2009). Exergetic optimization of flat plate solar collectors. *Renewable Energy, 34*(4), 1169-1174.

Hubbard, V. A., Munday, M. L., Hemminger, R. C., & Holdsclaw, S. T. (2000). System and method for automatically determining the electrical energy service type to which an energy meter is connected: Google Patents.

Jawhar, S. S. (2018). *The effect of the roof and glazing type of traditional courtyard houses on energy efficiency. A case of Erbil City, Iraq.* Near East University.

Kharlamov, E., Solomakhina, N., Özçep, Ö. L., Zheleznyakov, D., Hubauer, T., Lamparter, S., . . . Watson, S. (2014). *How semantic technologies can enhance data access at siemens energy.* Paper presented at the International Semantic Web Conference.

Schlipf, A. (2016). Immersion temperature sensor: Google Patents.

Struckmann, F. (2008). Analysis of a flat-plate solar collector. *Heat and Mass Transport, Project Report, 2008MVK160*.