



EXPERIMENTAL STUDY THE PERFORMANCE OF HYBRID SERPENTINE SOLAR COLLECTOR IN AIR CONDITIONING SYSTEM

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ABSTRACT

The present work is an experimental study into the thermal performance of air conditioning system (split unit), bases on using renewable energy as an assisted factor. The serpentine tube flat plate solar collector (STFPSC) is combined with 1-ton capacity split air conditioning system, which is installed after the compressor to superheat the refrigerant that leaves the compressor. The conventional air conditioning (A/C) system is compared with the suggested system. The results show that the coefficient of performance (COP) of the solar assisted air conditioning system (SAAC), is affected by the enhancement of the solar collector, which enrolls the effect of solar collector tilt angle. The COP of the SAAC system is boosted by about 31.5% more than the conventional system at tilt angle 13.5°, also the p-h diagram shows that the power consumption is enhanced at this angle.

Keywords: Serpentine Tube, Solar Collector, Solar Assisted Air Conditioning System, Renewable energy, Thermal Performance

1. INTRODUCTION

A considerable increase in the global electricity demand and depletion of fossil fuel resources have increased the need for the development of eco-friendly and energy-efficient technologies (Desideri, et al., 2009). The consumption of electricity in Iraq is higher than production, and the air conditioning demand has increased rapidly in the recent years, which represents globally about 55% of total building energy consumption due to the demand of higher comfort conditions inside buildings. Hence, a solar hybrid air conditioning system seems to be the solution to electricity leak. Compared with conventional energy, solar energy has many advantages, such as inexhaustibility, cleanness, and cheapness (Al-Abidi, et al., 2012).

Ha and Vakiloroyaya (2012) enhanced the performance of direct expansion air conditioner when combined with a vacuum solar collector that is installed after the compressor. A by-pass line was proposed together with a three-way proportional control valve so the refrigerant flow rate is controlled and then the optimum refrigerant temperature entering the condenser is estimated. Vakiloroyaya et al. (2012) analyzed the performance of a new solar-assisted air conditioner to achieve energy saving. A flat collector storage system was equipped with the evaporator to raise the superheat temperature entering the compressor. They showed that the compressor can be turned off longer and thus reduce the power consumption. The system was promising for saving average monthly electricity by up to 40%. Abd, et al. (2013) studied experimentally the thermal performance of hybrid solar assisted air conditioning system with and without water in the storage tank. They noticed that the refrigerant temperature and pressure leaving the solar collector were decreased, and the average thermal efficiency was fairly acceptable. Vakiloroyaya, et al. (2013) developed a hybrid solar air conditioning system by proposing a new discharge bypass line together with an inline solenoid valve to increase the sub-cooling of the refrigerant at partial loads, the solenoid valve installed after the compressor was to regulate the mass flow rate of the refrigerant. This development is promising between 25 and 43% of monthly electricity can be saved on average. Abid and Jassim (2015) investigated an experimental study of the

thermal performance of air conditioning system combined with a solar collector. The prototype consisted of three different process fluid loops: air conditioning loop, collector loop, and cooling tower loop. The bypass installed after compressor was to control the flow rate of the refrigerant. Results showed that the COP increase from 2.49 to 2.72. The average energy saving of power consumption is between 23% and 32% [7]. Dhiraviam et al. (2016) studied SAAC unit for improving COP to the system of vapor compression at winter. In this system, the outlet refrigerant from the compressor unit was heated, utilizing an evacuated tube-based collector with a storage tank of hot water. Owing to this effect, the amount of released heat will be increased at the condenser to the same input of the work. The released heat used to increase the heat added to the space of conditioned without influencing the input of work cycle at winter conditions. Finally, and for winter applications, an experimental investigation made to get a COP of air conditioning system. Mohammed and Abduljabbar (2018) studied the thermal performance experimentally to the hybrid solar A/C system, to investigate suitability of system to the hot climate in Iraq. The system include the unit of vapor compression combined with solar collector (evacuated tube) and storage tank of liquid. After the compressor, a valve (three-way) was installed to control the flow direction of the refrigerant, directly to the condenser or to the storage tank. The performance parameters are collected via data logger to display and saved in the computer via using of LabVIEW software. The obtained results show that the average COP of hybrid A/C system (R=1) about 2.42 to 2.77, when the ambient temperature about 34.2 to 39.7 °C, while the average COP of conventional system (R=0) is about 3.23 when the ambient temperature is about 30.8 to 34.3 °C. Mohammed and Abduljabbar (2018) presented the performance enhancement of a SAAC system. A three-way valve managed the temperature of refrigerant leaving the condenser; this valve was installed following the compressor to organize the flow rate of a refrigerant towards the solar system. Sensors, data logger and computer were proposed to use in a control system for setting the ratio of the opening valve. The control program function, of LabVIEW software, used to obtain the minimum temperature of the refrigerant exited from the condenser, for enhancing the total COP of the unit via increasing

subcooled refrigerant degree. A variable load heating source (coiled pipe electrical heater) used to replace the solar collector and the solar radiation was simulated by storage tank. The study of system performance based on the experimentally measurement of data. The results of a comparison between the proposed system the conventional one showed that the COP of the proposed system was higher than that of the conventional system by 10 %. In the previous studies, water was used as working fluid in the solar collector. The water heats the Freon which leaves the compressor, but the temperature of Freon in this point is 76 °C or above, while the water temperature in flat plate solar collector is not more 68 oC, so that heat loses in the air conditioning discharge line will occur (Mohsin and Shahad 2019). The present study, air conditioning discharge line is heated by the solar radiation directly. The refrigerant fluid (R22) passes across the solar collector that is installed after the compressor to increase the superheating of the refrigerant fluid, which leads decreasing the load on the compressor and increasing the COP of the air conditioning system.

2 METHLOGY. AND EXPERIMENTAL SETUP.

2.1. Experimental Rig

The experimental work, which includes the air-conditioning system, the solar collector manufacturing, test room and the measurement devices. The experimental work carried out during the hot climate time under the weather condition of Babil province. The system includes a flat plate solar collector integrated with the outdoor unit, by installing it after the compressor. The proposed system exposes the refrigerant that leaving the compressor to the direct solar irradiation to superheat the refrigerant, which leaves the compressor directly, the working fluid of the A/C system, is R22. The flow direction of the refrigerant is controlled by a triple ways valve is installed, therefore the outlet of the compressor is connected either to the solar collector (for the solar A/C cycle) or to the condenser directly (for the conventional cycle).

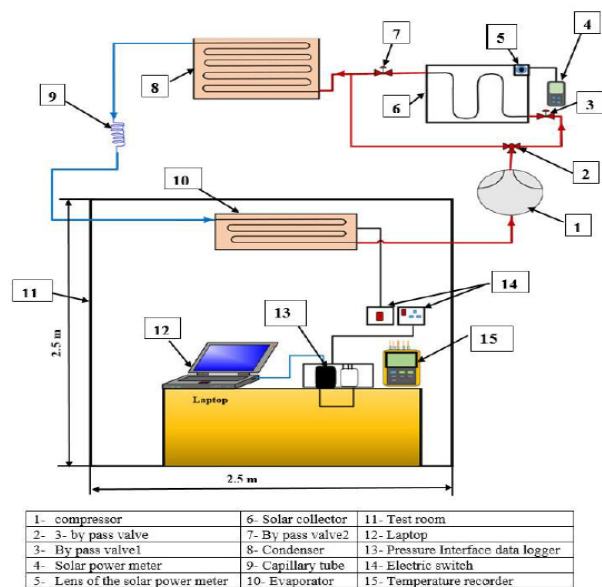


Fig. 1 Schematic diagram of the experimental rig.

2.2 Solar collector Design

The building of the collector includes three parts as shown in Figures 2 and 3. The first one is the collector box, which made of plywood, the surface area with dimensions (50.00 cm x 60.00 cm). The second part is copper-based tube that use for the flow of refrigerant, which fixed on the plate, the solar collector box covers with a single layer of 0.4 cm thickness (Kalogirou, 2004). The last one is serpentine tube has (150.00 cm) length and (0.953 cm) diameter (Gatea et al. 2020). The solar collector supplies with a flexible base of collector, which uses for changing the tilt angle of the solar collector.

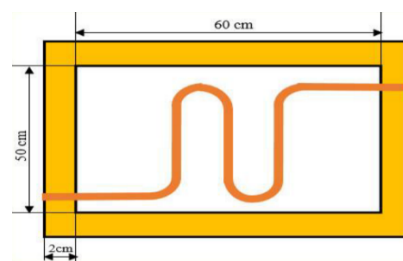


Fig. 2 Schematic diagram to the top view of the solar collector dimensions.

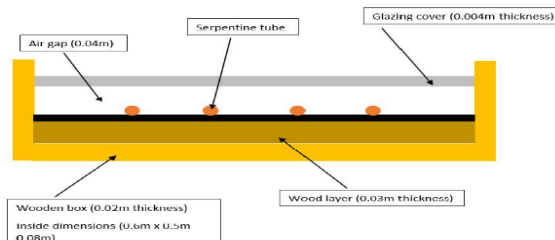


Fig. 3 Schematic diagram to the side view of the solar collector layers.

2.3. Solar Collector Orientation

The solar collector is orientated into the south direction, with azimuth angle equal to 0o. Four tilt angles has been selected during May 2021. The first one is the average tilt angle of month for Babil Governorate, which equals to 13.5° (Almoussawi, 2019). The readings has recorded in 6th and 12nd of May 2021. The second selection is the average tilt angle of year, which equals 30° (Tang et al 2009). The readings of angle 30° records in 9th and 19th of May. The other tilt angles are suggested to study the tilt angle effect on the thermal performance of the solar collector, the tilt angles are 10° and 6°, where the readings for these angles have been recorded two days for each tilt angles in (13th and 22nd), (7th and 23rd) of May respectively.

2.4. Experimental Procedure

The following are the steps that considered in the measurement of experimental test. Firstly, set the solar collector at tilt angle equal to 13.5° Switch on the air condition unit; secondly monitor the variations in temperatures and pressures of air and refrigerant .If the temperatures and pressures readings have no variation within 20 minutes, it will record. Read the value of temperatures and pressures by data loggers. Thirdly, if the solar energy effect is considered the valve between the compressor and air cooled condenser must be closed whenever; the other two valves before and after the solar collector is open. Follow the same procedure at the other tilt angles, 30°, 10° and 6°.

Finally, if the solar energy effect is not considered, repeat steps close the pass the valves before and after the solar collector and open the valve for the conventional cycle. Record the temperature, pressure and solar irradiation.

2.5 Mathematical Calculations

This section deals with the mathematical equations that describe the performance of the SAAC system.

Evaporator Equation

The capacity of the evaporator is given by (Hundy, Trott, and Welch 2008):

$$Q_e = \dot{m}_{ref} (h_1 - h_4) \quad (1)$$

Compressor Equation

The input power to the compression is given by (Hundy, Trott, and Welch, 2008)

$$W_{comp.} = \dot{m}_{ref} (h_2 - h_1) \quad (2)$$

Where ,

W_{comp} : Compressor input power (W)

\dot{m}_{ref} : Refrigerant flow rate (kg/s)

h_1 : Enthalpy of refrigerant out from evaporator (J/kg)

h_2 : Refrigerant enthalpy out form compressor into condenser (J/kg)

Coefficient of the Performance (COP)

The ratio of net heat energy removed at the evaporator to the compressor power supplied is called the Coefficient of Performance (COP) (Stewart, 2003).

$$COP = \frac{Q_e}{W_{comp}}$$

Where :

COP: Coefficient of performance

Q_e : Cooling capacity (W)

W_{comp} : Compressor input power (W)

2.6 Uncertainty Analysis:

In order to estimate the measurement uncertainties of the experimental data results, several dependent and independent variables such as COP and temperature. The uncertainties of these variables (W_{R^+}) can be evaluated, as follows (Holman, J. P. 2011):

$$W_{R^+} = \sqrt{\left(\frac{\delta R^+}{\delta X_1} w_1\right)^2 + \left(\frac{\delta R^+}{\delta X_2} w_2\right)^2 + \dots + \left(\frac{\delta R^+}{\delta X_n} w_n\right)^2}$$

Where R^+ is a function of the independent variables $X_1, X_2 \dots X_n$, and $w_1, w_2 \dots w_n$ are the independent variable uncertainties. The detailed information of uncertainty results of this study are listed in Table 1.

Table 1 : Uncertainty of parameters for experimental work	
Independent variables	Variable errors
(Data Logger) Temperature readers (°C)	± 0.9
Ambient Temperatur (°C)	± 0.4
Room Temperatur (°C)	± 0.3
High pressure gage (Bar)	± 0.001
Low pressure gage (Bar)	± 0.001
Dependent variables	Variable errors
Electric power (W)	± 0.23
Compressor work (kw)	± 0.13
COP(-)	± 0.039

3. RESULT AND DISSCUTION

3.1 Solar Collector Temperature Difference at Different Tilt Angles

Figures 4 to 7 show the results of the relation between the solar collector inlet and outlet temperature with time at different tilt angles and different days during May 2021. The tilt angles are (6°, 10°, 13.5° and 30°).The results demonstrate that the temperature increases with time, and this is due to that, the ambient temperature increases at the noon period as compares with the morning period.

The results of solar irradiation with time, which are recorded, by the power meter device during, May 2021, and discussed, at different tilt angle. The amount of the solar irradiation is affected by many factors, such as the tilt angle during the month, or the day, even though during the hours, also the clarity of the sky, dust, ambient temperature, the wind. All these factors have a significant effect on the solar irradiation. Figures

8 to 11 illustrate the relation between the solar irradiation and time at different tilt angle. The results show that the maximum solar irradiation is achieved at the noon period, and this is due to that the amount of the radiation is high at this period. The maximum solar irradiation is recorded at tilt angle 10° in 22nd on May as it illustrated in Figure 9.

From the mentioned results for the first design of the solar collector, it can be noticed that the tilt angle has a significant effect on the amount of solar irradiation, which is absorbed by the solar collector along the month; hence, it has high effects on the thermal performance of the solar collector. The enhancement in the thermal performance is concerned with the increase in the temperature difference between inlet and outlet of the solar collector; as the temperature, difference increases the thermal performance increases vice versa.

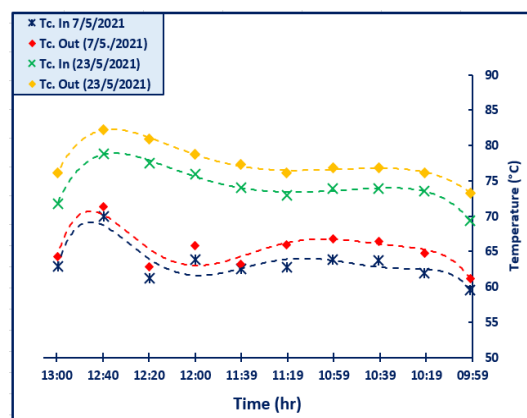


Fig. 4 SC inlet and outlet temperature with time at tilt angle 6°.

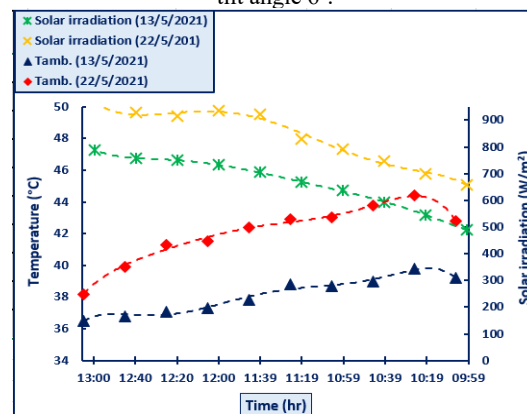


Fig. 5 SC inlet and outlet temperature with time at tilt angle 10°.

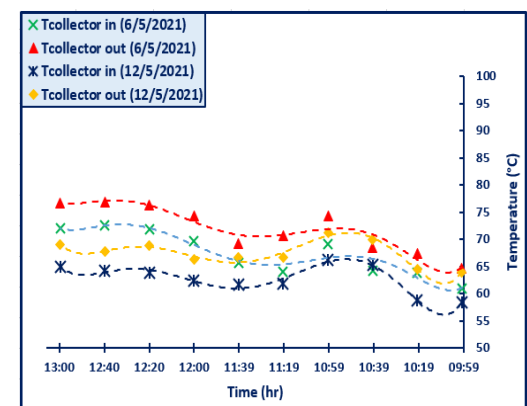


Fig. 6 SC inlet and outlet temperature with time at tilt angle 13.5°.

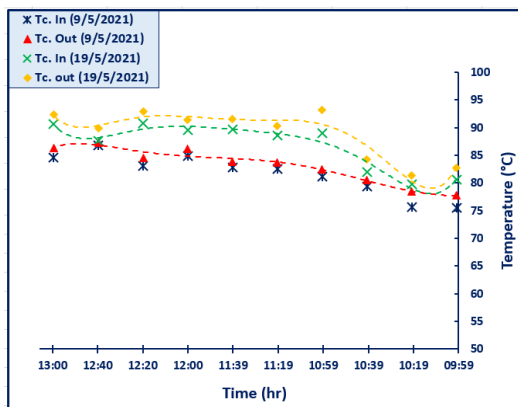


Fig. (7) SC inlet and outlet temperature with time at tilt angle 30°.

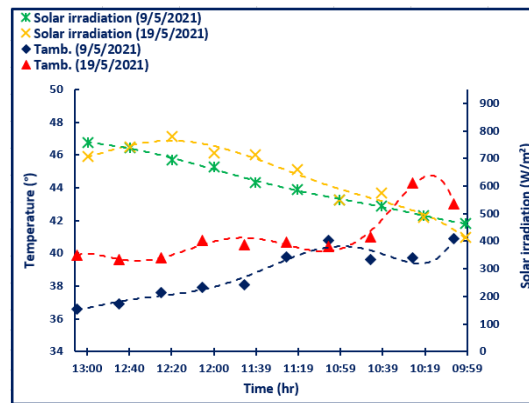


Fig. 11 Solar irradiation with time at tilt angle 30°.

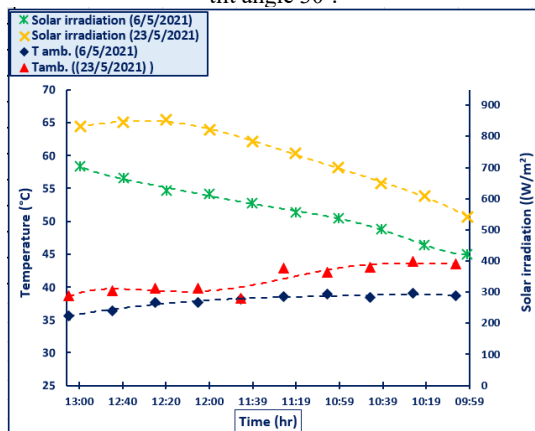


Fig. 8 Solar irradiation with time at tilt angle 6°.

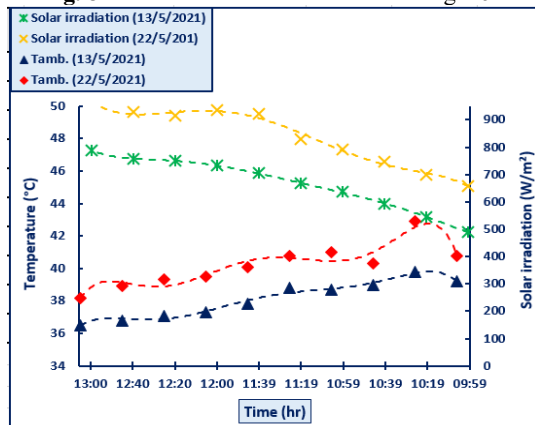


Fig. 9 Solar irradiation with time at tilt angle 10°.

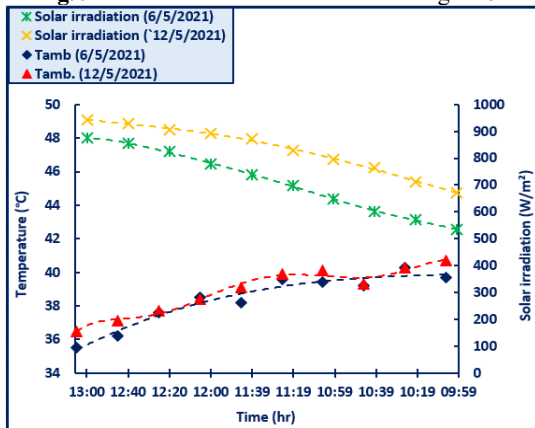


Fig. 10 Solar irradiation with time at tilt angle 13.5°.

3.2 The Effect of First Solar Collector Tube Length without Solar Irradiation.

This paragraph discusses the effect of the serpentine tube length on the thermal performance of the solar collector without solar radiation effect, where the window glass of the solar collector insulates with four layers of the wool glass. This will prevent the solar irradiation transmission through the SC glass.

Figure 12 illustrates the solar collector inlet and outlet temperature with time. From the figure it can be noticed that the increasing in temperature is very small; about 0.8 oC between the inlet and outlet, which is proved that the length has an ignored effect with the absent of the solar irradiation effect.

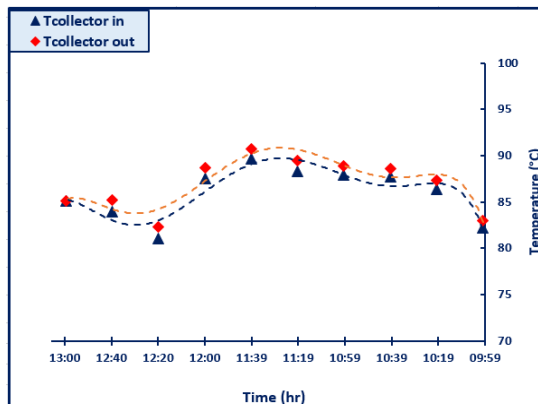


Fig. 12 SC tube length effect inlet and outlet temperature without solar irradiation.

3.3 Coefficient of Performance (COP) of Air Conditioning (A/C)

This section discusses the coefficient of performance (COP) calculations results for both the conventional A/C cycle and the solar assisted A/C cycle, where Engineering Equations Solver (EES) software is used to calculate the properties, which is included in COP calculations, such as the enthalpy.

3.3.1 COP of Conventional Air Conditioning Cycle

Figure 13 illustrates the direct cycle coefficient of performance and ambient temperature with time for two days 5th and 20th, of May 2021. The COP for both days are about 5.1 and 4.5 respectively. The ambient temperature has a significant effect on COP of A/C system, whereas the ambient temperature increases the COP decreases, and vice versa.

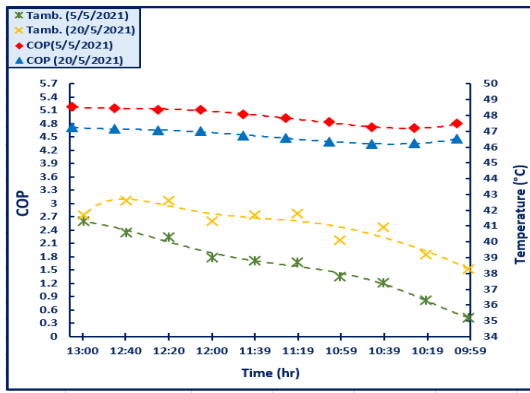


Fig. 13 COP of the conventional A/C cycle.

3.3.2 COP of Solar Assisted Air Conditioning (SAAC) Cycle

Figures 14 to 19 show the coefficient of performance (COP) of the proposed system and ambient temperature with time at four different tilt angles, which are (6°, 10°, 13, 30°). From all the results show that as ambient temperature increases the COP decreases, and vice versa. In addition, it can be noticed that, the maximum COP is achieved at the morning time.

Figure 14 shows the relation between COP of SAAC cycle and the ambient temperature with time at angle 6°, which is in between 5.245 and 5.627. The COP for the SAAC first design at tilt angle 10° is between 6.371 and 5.938 as it is represented in Figure 15, while the COP of SAAC system at the tilt angle 13.5° is in between 6.064 and 5.813, as it is illustrated in Figure 16. Figure 17 shows COP of SAAC at angle 30°, which is between 4.691 and 5.199.

The COP results mentioned below show that the best enhancement is at angle 10° and 13.5°. This is due to the maximum thermal performance of solar collector, occurred at these angles. Whereas, Figures 18 and 19 show a comparison between the pressure enthalpy diagram of the conventional A/C system and p-h diagram of the proposed system, as it is shown can see that there is an enhancement in the cooling process at two tilt angle, 10° and 13.5°. In Figure (18) the ratio of the cooling effect to the effect of the power consumption is more in the solar assisted air conditioning system than the conventional system at tilt angle 10°, the increasing in power consumption in the suggested system is due to increase in ambient temperature. The cooling effect of the SAAC at tilt angle 13.5° increases while the power consumption at this angle decreases if it's compared with cooling effect and power consumption of the conventional air conditioning system.

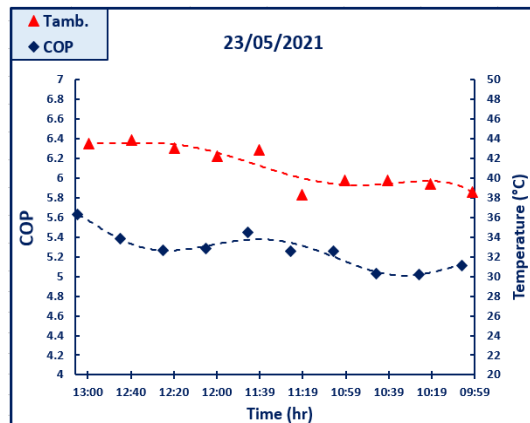


Fig. 14 COP of SAAC with time tilt angle 6°.

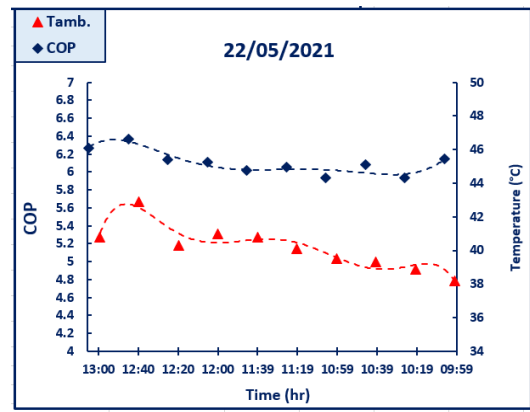


Fig. 15 COP of SAAC with time at tilt angle 10°.

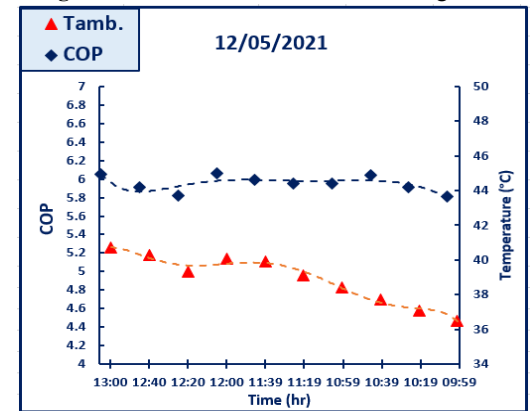


Fig. 16 COP of SAAC with time at tilt angle 13.5°.

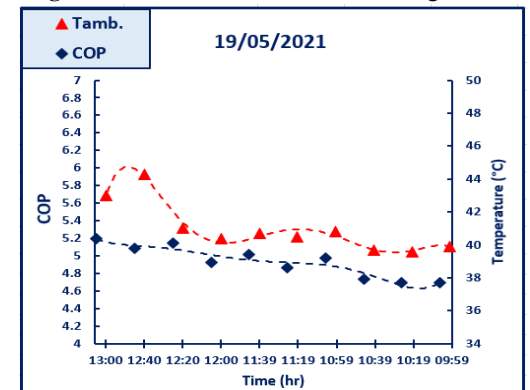


Fig. 17 COP of SAAC with time at tilt angle 30°.

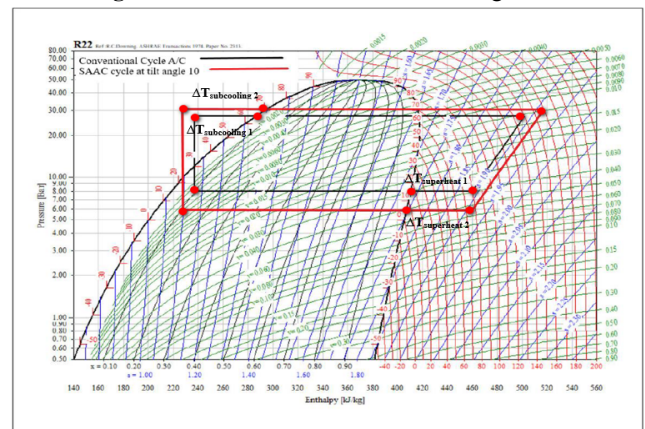


Fig. 18 P-h diagram of a comparison between the refrigeration SAAC at tilt angle 10° and conventional A/C system.

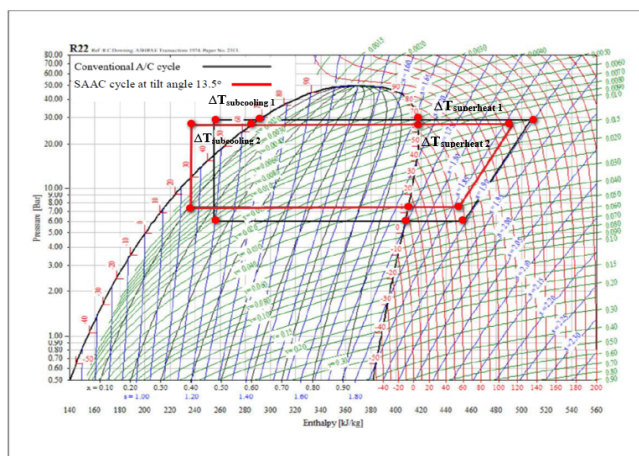


Fig. 19 P-h diagram of a comparison between the refrigeration SAAC at tilt angle 13.5° and conventional A/C system.

4. CONCLUSION

From the present study, it can be concluded that:

The tilt angle has a significant effect on the thermal performance of solar collector along the month. The highest temperature difference between solar collector inlet and outlet is recorded at angle 10°, during May 2021. The tube length without solar irradiation effect has a small influence on the thermal performance of the solar collector. The maximum COP is achieved at tilt angle 10° which it is about 35 % more than the conventional system, while at tilt angle 6°, 13.5°, and 30° they are about 31.5%, 18.75% and 9% respectively, for the first proposed design. The second design is not suitable for this application. The ambient temperature has a significant effect on COP as ambient temperature increases COP decreases and vice versa. The reduction in power consumption and cooling load is achieved at tilt angle 13.5°.

ACKNOWLEDGEMENTS

We would like to express our thanks to the respected editors of International Journal of Heat and Technology and the respected reviewers for their comments that clearly enhance the manuscript. Also, we would like to thank our institution "Al-Mustaqbal University College" for the financial support (<https://www.mustaqbal-college.edu.iq/>)

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