Karbala International Journal of Modern Science

Volume 8 | Issue 4 Article 4

Investigation of a Solar Space Heating System Based on an Evacuated Tube Collector for Baghdad Climatic Conditions

Alaa H. Shneishil
Department of Physics, College of Education, Mustansiriyah University, Baghdad

Jaber O. Dahloos
Environment Researches Center and Renewable Energy, University of Kerbala, Kerbala, jaber.o@uokerbala.edu.iq

Khalid G. Mohammed
Department of Physics, College of Education, Mustansiriyah University, Baghdad

Recommended Citation

Shneishil, Alaa H.; Dahloos, Jaber O.; and Mohammed, Khalid G. (2022) "Investigation of a Solar Space Heating System Based on an Evacuated Tube Collector for Baghdad Climatic Conditions," *Karbala International Journal of Modern Science*: Vol. 8 : Iss. 4 , Article 4.
Available at: https://doi.org/10.33640/2405-609X.3261

Investigation of a Solar Space Heating System Based on an Evacuated Tube Collector for Baghdad Climatic Conditions

Abstract

The current work aims at evaluating the overall experimental performance of the solar space heating system regarding the local meteorological conditions of Baghdad. Two types of systems have been considered, namely, the thermal radiator with and without a fan. Indeed, a thermal radiator is connected to evacuate the tube solar collector through a circulating pump to distribute the heat into a room with dimensions of (3×3 m^2). The experimental measurements for the current research were carried out during a period of six days in February and March, i.e., under mild conditions where the weather ranged between sunny and cloudy during the day. In order to find out the system performance, the solar radiation intensity, wind speed, inlet and outlet temperatures from solar collectors, inlet and outlet temperatures from thermal radiators, room temperature, and ambient temperature have been measured using specific instruments. The results revealed that, under sunny conditions, the room temperature of the system without a fan changes from 16.2 ^{o}C to 23.9 ^{o}C with a temperature difference of 7.7 ^{o}C. However, when a fan is used, the temperature difference reaches 10 ^{o}C. Such an improvement in the performance of the solar heating system that characterized the current work in comparison with its counterpart research is a direct result of the adoption of two main ideas. The first of them is the use of a modern metal heat exchanger that contains vertical and horizontal tubes. In addition to that, it is equipped with a fan that helps to increase the heat exchange between the heat radiator and the room space due to forced convection. Furthermore, the fan works to distribute the heat homogeneously inside the room, thus increasing the efficiency of the system. The second idea, however, is the use of a modern system represented by software that analyzes the results and evaluates the values of solar radiation and wind speed.

Keywords

Solar Energy, Solar Space Heating System, Evacuated Tube Solar Collector

RESEARCH PAPER

Investigation of a Solar Space Heating System Based on an Evacuated Tube Collector for Baghdad Climatic Conditions

Alaa H. Shneishil [a,*], Jaber O. Dahloos [b], Khalid G. Mohammed [a]

[a] Department of Physics, College of Education, Mustansiriyah University, Baghdad, Iraq
[b] Environment Researches Center and Renewable Energy, University of Kerbala, Kerbala, Iraq

Abstract

The current work aims at evaluating the overall experimental performance of the solar space heating system regarding the local meteorological conditions of Baghdad. Two types of systems have been considered, namely, the thermal radiator with and without a fan. Indeed, a thermal radiator is connected to evacuate the tube solar collector through a circulating pump to distribute the heat into a room with dimensions of (3×3 m^2). The experimental measurements for the current research were carried out during a period of six days in February and March, i.e., under mild conditions where the weather ranged between sunny and cloudy during the day. In order to find out the system performance, the solar radiation intensity, wind speed, inlet and outlet temperatures from solar collectors, inlet and outlet temperatures from thermal radiators, room temperature, and ambient temperature have been measured using specific instruments. The results revealed that, under sunny conditions, the room temperature of the system without a fan changes from 16.2 °C to 23.9 °C with a temperature difference of 7.7 °C. However, when a fan is used, the temperature difference reaches 10 °C. Such an improvement in the performance of the solar heating system that characterized the current work in comparison with its counterpart research is a direct result of the adoption of two main ideas. The first of them is the use of a modern metal heat exchanger that contains vertical and horizontal tubes. In addition to that, it is equipped with a fan that helps to increase the heat exchange between the heat radiator and the room space due to forced convection. Furthermore, the fan works to distribute the heat homogeneously inside the room, thus increasing the efficiency of the system. The second idea, however, is the use of a modern system represented by software that analyzes the results and evaluates the values of solar radiation and wind speed.

Keywords: Solar energy, Solar space heating system, Evacuated tube solar collector

1. Introduction

One of the most important factors in determining a country's progress is its energy usage. Non-renewable energy sources are currently being employed predominantly for energy generation in most countries all over the world [1]. It is worth mentioning that global energy demand is increasing all the time whilst as fossil fuels are non-renewable and hence they will eventually run out [2]. This issue has considerably raised public awareness of the use of alternative energy in recent years, coupled with the high cost and limited supply of electricity being some of the other key contributing factors [3].

Solar power is one of the renewable sources of energy. It is stated that the Earth's surface receives about 69% of the total energy given by the sun, which amounts to 3×10^{24} J per year (equal to 2×10^{17} W) [4]. Solar energy has been the main energy source in many studies because it is clean, accessible, non-polluting, and environmentally friendly [5,6]. Solar energy can help buildings meet their heating and cooling needs by providing

Received 12 March 2022; revised 14 August 2022; accepted 17 August 2022.
Available online 10 November 2022

* Corresponding author at:
E-mail addresses: dralaa@uomustansiriyah.edu.iq (A.H. Shneishil), jaber.o@uokerbala.edu.iq (J.O. Dahloos), khalidg.m@uomustansiriyah.edu.iq (K.G. Mohammed).

https://doi.org/10.33640/2405-609X.3261

Nomenclature

E_{in}	Inlet energy (J)
E_{out}	Outlet energy (J)
Q_s	energy gain (J)
$\dot{m}$	Volumetric flow rate (kg/s)
C_p	Specific heat capacity (J/kg.K)
T_o	outlet temperature of collector (°C)
T_i	inlet temperatures of collector (°C)
η_s	Solar collector efficiency
ϱ_u	useful energy output (J)
ϱ_{abs}	absorbed solar radiation
$\varrho_{therm-loss}$	thermal loss energy
A_{sc}	solar collector area
ϱ_{abs-og}	absorbed solar irradiance by external glass tube (W)
ϱ_{abs-ig}	absorbed solar irradiance by internal glass tube (W)
$\varrho_{rad-og-sky}$	Heat transmission from an exterior glass tube by radiation (W)
$\varrho_{conv-og-air}$	convection heat transfer from internal glass tube (W)
Q_{net}	Net energy gain (J)
A_{sc}	Solar collector area (m^2)
G_T	Total Solar radiation (W/m^2)
F_R	Heat removal factor
U_L	Heat loss coefficient ($W/m^2.°C$)
T_a	Ambient temperature (°C)
$(\tau\alpha)_e$	Transmittance absorbance product of outer glass tube
F'	collector efficiency factor

domestic hot water and space heating. Furthermore, it can be used indirectly for heating purposes by employing solar thermal collectors. In such a sense, solar water heating is a relatively simple and efficient approach to harvesting and utilizing solar energy. Solar thermal collectors have an average efficiency of around 4−5 times that of PV, a factor that makes them substantially less expensive per unit of energy produced [7]. Because of the low initial costs and relatively simple structure, the adoption of solar heating systems has increased. In today's heating systems, the solar collector is regarded as the most crucial component [8].

The most popular solar collectors used in solar thermal systems are evacuated solar tube collectors (ETSCs) and flat plate collectors. Flat plate collectors work best at low temperatures, so they are only useful for hot water and space heating. A vacuum can be produced between the glass cover and the absorber plate in order to reach the high temperatures needed to reduce or eliminate convection losses. Solar high-temperature applications include solar power production, air conditioning systems, and solar industrial heat processes [9]. The ETSC is employed for applications that require very high temperatures due to its simplicity to install, high efficiency, lower thermal losses, low-maintenance, as well as reliable solar thermal production [10]. ETSCs are typically manufactured in conventional sizes and placed at a tilt angle that is calculated based on the latitude of the location. It is worth mentioning that system tilt angle, weather conditions, system dimensions, and other factors can all affect the overall performance of systems. In addition, it is well known that the optimum results are obtained when the solar radiation strikes the collecting elements at a straight angle, maximizing the energy absorption mechanism [11].

As far as Iraq is concerned, solar energy is currently not being harnessed to its full potential. However, because worldwide solar radiation ranges from 2000 kWh/m^2 to 2500 kWh/m^2 on an annual average, this energy source can play a vital part in energy production in Iraq. In addition, many studies highlight Iraq's current restricted solar energy efforts [12].

Aed et al. started with design calculations for the needed building space heating load in 2014. The energy required by evacuated tube solar collectors to supply the heating requirement for 6 h till the temperature reaches 22 °C is 46,332 kJ/day, or 12.87 kWh/day [13].

Dhananjay utilized the Solar PVHFC program in 2016 to investigate theoretically simple solar thermal systems used for space heating. According to the findings, a rather large solar thermal system is required to supply 20%−50% of domestic heating needs [14].

In 2016, Evangelos used a dynamic simulation model in Greece to examine the viability of using conventional radiators and solar thermal collector systems with storage capacity to support space heating applications in office buildings. Solar coverage can result in additional thermal energy savings of 29%, which will significantly reduce CO_2 emissions for offices nationwide by 184 kt annually [15].

In 2017, Vikas et al. investigated the efficiency of a solar-assisted ground source heat pump system that was used for daytime solar energy storage and nighttime space heating. The experimental data has been used to compute the system's COP as well as the heat absorbed by the solar collector, heat injected into the ground, heat retrieved from the earth, and heat injected into the ground. As the mass flow rate rose, the solar collector's heat absorption went from 2.07 to 2.56 kW. Due to heat losses, only 1.991−2.414 kW of solar heat could be pumped into the ground during the day [16].

Shahnaz et al. planned, built, and tested two solar air heaters (black painted wood and black painted aluminum sheet absorber plate) in the Jordanian climate in 2018. Wood and metal air heaters were found to be 94.6 and 87.6 percent efficient, respectively [17].

Using Sketchup, Trnsys, and PVsyst, Osama et al. built and simulated solar thermal and PV systems for the building in 2019. A thorough comparison of solar systems and five conventional systems was done in terms of primary energy ratio and levelized cost of energy (LCOE). Solar thermal and electric systems in Amman saved 29 percent and 100 percent of nonrenewable primary energy, respectively, and 15 percent and 62 percent of LCOE, respectively, when compared to the best conventional system [18].

On the TRNSYS simulation platform in 2020, Jinling et al. developed a simulation model for a solar heating system with a self-programmed control module. The simulated model's designated collector area in China's cold regions is 8000 m^2, and its seasonal storage pool has a 13,300 m^3 capacity. Modeling and evaluating the year-round performance allowed for the determination of several variables, including the dynamic heat load of the building and the water temperature at the collector output. The results show that the system's monthly average solar energy guarantees rate ranges between 70% and 75% [19].

Mohammed et al. incorporated a solar water heating system based on 4 m^2 flat plate collectors into an office building in 2021 to meet the heat requirement. TRNSYS models are created and tested against experimental data before being utilized for optimization. The solar fraction metamodels were then created for three collector area ranges: [2–10] m^2, [10–20] m^2, and [20–30] m^2. The results show that the storage volume and collector area have a substantial impact on the solar percentage. The best design parameters for reaching the required solar percentage of 60% were determined using the fitted models [20].

In order to achieve multi-objective optimization of the solar collector area and the volume of the water thermal energy storage tank, Zhaoyu et al. built a solar space heating system for a cottage with radiant floor heating in 2022 using TRNSYS simulation. The outcomes showed that multi-objective optimization produced the most suitable design scheme, with a payback period of only 3.70 years, and the ability to reduce carbon emissions by 5480.6 kg CO_2eq/year [21].

This article deals with the development and implementation of a solar space heating system (solar collector systems for space or room heating) with the help of ETSC. The system is connected to a thermal heater to warm a small room. The performance efficiency of the presented system was evaluated in the local weather conditions of Baghdad City. The new addition in the current work in comparison with the previous works is the use of a fan with the heat radiator for the purpose of increasing the efficiency of the system through the homogeneous distribution of the heat emitted from the thermal radiator to the space of the room to be heated and reducing the time period for heating. In addition to that, a new heat radiator is used that contains horizontal and vertical tubes, which in turn leads to an increase in heat distribution.

2. The theoretical part

2.1. Solar space heating

Solar space heaters depend on the sun's energy to warm a building. When compared with solar thermal for the sole purpose of providing hot water, they typically demand a bigger collector area and, as a result, more roof space, see Fig. 1.

The thermal energy is gathered by means of the collectors and used to heat the working fluid, which is then cycled to distribute the absorbed heat to the various zones of the building [15].

The majority of solar space heating systems distribute heat to the residence via a thermal energy storage tank. Water storage solar heating is, thus, a sort of space heating that allows the system to satisfy a larger share of the winter heating needs. Another method for space heating is direct solar heating, which is considered the simplest and least expensive. This system does not feature a storage unit [14].

For domestic and industrial heating applications, the flat plate and the ETSCs are the most commonly utilized types of solar water heaters. The efficiency of evacuated tube collectors is better at low incidence angles, providing them with a day-long performance advantage over flat plate collectors [22].

2.2. Solar thermal collector

Indeed, several authors state that both direct and diffuse radiation can be collected by ETSCs. In

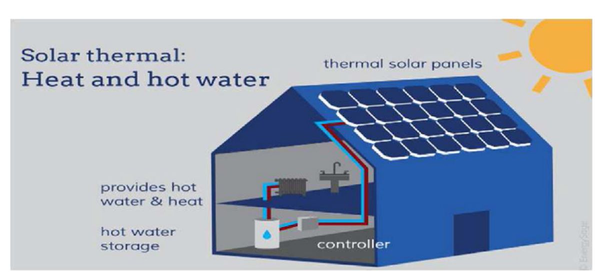

Fig. 1. A schematic representation of a low-temperature solar thermal system [15].

addition to having outstanding thermal performance, ETSCs are easy to install and move [23−25].

In fact, the parallel evacuated glass tube is the most significant component of the evacuated solar collector. The exterior pipe is translucent, but the inside pipe has a selective covering material that absorbs as much light as possible. Between the outer and inner pipes, a vacuum is created, allowing only solar energy but not heat to flow through [26].

To assess collector performance, some calculations are necessary, since they offer information regarding the amount of energy received and utilized by the collector. Based on the first rule of thermodynamics the balance relation between the input E_{in} and output E_{out} energy, can be expressed as follows [27]:

Some calculations are necessary to assess collector performance since they offer information regarding the amount of energy received and utilized by the collector. Based on the first rule of thermodynamics, the balance relation between the input and output energy can be expressed as follows [27]:

$$\sum E_{in} = \sum E_{out} \tag{1}$$

In the sense of the presented system, the output energy is usually called useable thermal energy and is denoted by Q_u. Actually, it can be calculated by the following equation [28]:

$$Q_u = Q_{abs} - Q_{therm-loss} \tag{2}$$

Where, Q_{abs} is the absorbed solar radiation and $Q_{therm-loss}$ is the thermal loss energy.

Indeed, the absorbed solar radiation by the glass envelope Q_{abs-og} (outside glass tube), and the absorber tube Q_{abs-ig} (inner glass tube) may be computed using the following equation (3):

$$Q_{abs} = Q_{abs-og} + Q_{abs-ig} \tag{3}$$

In fact, the energy loss from the glass envelope is caused by convection, and the radiation from the glass to the environment is estimated using the formula below; see Fig. 2 [28].

$$Q_{therm-loss} = Q_{rad-og-sky} + Q_{conv-og-air} \tag{4}$$

Where the radiation heat transfer from the outer glass tube is represented by ($Q_{rad-og-sky}$). The convective heat transfer from the outer glass tube is, however, described by the second term in the final equation. It is important to note that all of the contested quantities are expressed in Watt. The net energy gain Q_{net} by the system can be defined as [29]:

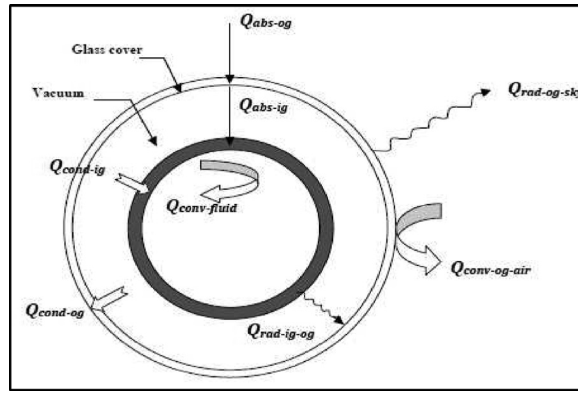

Fig. 2. Energy components in an evacuated tube [28].

$$Q_{net} = \dot{m} C_p (T_o - T_i) \tag{5}$$

T_i and T_o are the collector inlet and outlet temperatures, respectively. The following equation can be used to determine the system efficiency [30]:

$$\eta_s = \frac{Q_{net}}{A_{sc} G_T} = \frac{\dot{m} C_p (T_o - T_i)}{A_{sc} G_T} = F_R (\tau\alpha)_e - \frac{F_R U_L (T_i - T_a)}{A_c G_T} \tag{6}$$

Where F_R is the heat removal factor and can be calculated by using the following equation [31]:

$$F_R = \frac{\dot{m} C_p}{A_P U_l} \left[1 - \exp\left(-F' U_L A_p / \dot{m} C_p\right)\right] \tag{7}$$

$\dot{m}$ is the volumetric flow rate, C_p specific heat capacity, A_{sc} solar collector area, U_L is the heat loss coefficient, F' collector efficiency factor, and $\tau\alpha$ is constants that represented the transmittance absorbance product of the outer glass material. The error analysis can be calculated by using the following equation [32]:

$$Relative\ Uncertainty = \left|\frac{Uncertainty}{Measured\ quantity}\right| \tag{8}$$

3. Materials and methods

To achieve the required aims of the present research, the systems that have been adopted and experimented with are as follows:

3.1. System components

The solar space heating system consists of many components, which can be represented in the schematic diagram shown in Fig. 3.

3.1.1. Evacuated tube solar thermal collector

The evacuated tube solar thermal collector has been fixed on the building roof of the College of

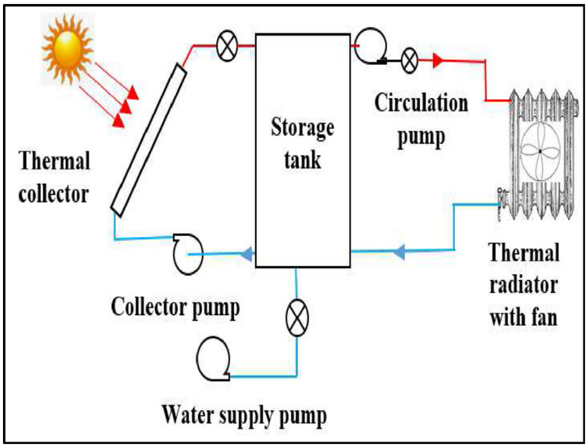

Fig. 3. A schematic diagram of the solar space heating system.

Education at Mustansiriyah University. The orientation, however, has been set towards the south in order to allow the maximum amount of sunlight to be received through the surface of the tube. This allows the most incident sun rays on the tubes' surfaces, which are used for heating water. It consists of twenty evacuated tubes, connected to upper storage. Each tube is designed with two parts (external cylindrical tube as well as internal cylindrical tube), where both tubes share the same center with a separated empty region, see Fig. 4. The water flows through the inner tube, where its surface is covered by a black layer to increase the absorbed solar radiation. Each tube is connected to the storage by its upper edge, where water automatically cycles between the storage and the tubes according to the density difference of water that has boiled in them.

3.1.2. Thermal radiator

The solar thermal collector has been joined to a thermal radiator with dimensions of 50 cm in length and 30 cm in width. Actually, it is mounted inside a small room with dimensions of 3 m × 3 m with isolated thermal tubes and a thermal circulation pump (to circulate water between the solar collector and thermal radiation) as shown in Fig. 5. The thermal radiator consists of many layers and contains a copper tube to circulate the hot water. The tube has been synthesized to be in a spiral shape to delay the water flow speed in order to get optimum heat exchange inside the building. The radiator is supported by a fan in order to distribute heat inside the room from the radiator.

3.1.3. Circulation pump

The ETSC and the thermal radiator are joined with a circulation pump and isolated connection pipes as illustrated in Fig. 6.

3.2. Measuring instruments

3.2.1. Solar power meter

A solar power meter from the Hukseflux thermal sensors company is utilized, with a measuring range of 0−2000 W/m^2 and a resolution of 1 W/m^2 to measure the solar radiation intensity throughout the period of the experiment. Its probe is located close to the evacuated tube solar collector, see Fig. 7. Table 1 shows the technical specifications of the solar power meter.

3.2.2. Anemometer

In this research, a vane anemometer device with an accuracy of ±0.1 is used to measure the wind speed, see Fig. 8. It has a vertical axis of rotation, similar to a windmill or a propeller anemometer. The vane anemometer has a horizontal axis parallel to the wind direction. Furthermore, because the

Fig. 4. An evacuated tube solar thermal collector fixed on the building roof.

Fig. 5. The thermal radiator with fan.


Fig. 6. The circulation pump with connection pipes.


Fig. 8. Vane Anemometer device.

Fig. 7. Solar power meter.

wind changes direction and the axis must follow it, a wind vane or some other device must be used to accomplish the same goal.

3.2.3. Thermometer

A contact thermometer with a 12-channel BTM-4208SD has been used to monitor the solar collector inlet and outlet temperatures, thermal radiator inlet and outlet temperatures, room temperature, and ambient temperature, see Fig. 9. Table 2 lists the technical specifications of this device.

Fig. 9. Thermometer.

Table 1. Technical specification of solar power meter.

Model	SPM-1116SD
Spectral response	400–1100 nm
Measuring unit	Solar power (W/m^2)
Solar power range	2000 W/m^2
Solar power accuracy	±10 W/m^2
display	LCD size: 52 mm × 38 mm LCD with green backlight (ON/OFF)
Operating temperature	0–50 °C
Operating humidity	Less than 85% R.H.
Power supply	Akaline or heavy duty DS 1.5 V battery (UM3, AA) × 6 PCs, or equivalent

Table 2. Technical specification of the used thermometer.

Model	BTM-4208SD
Display	LCD size: 82 mm × 61 mm with green color backlight
Channels	12 channels
Resolution	0.1 °C
accuracy	0.4 °C
Operating temperature	−100 to 1300 °C
Operating humidity	Less than 85% R.H
Power supply	Alkaline or heavy duty DS 1.5 V battery (UM3, AA) × 8 PCs or equivalent
Weight	827 g
Dimensions	225 × 125 mm

4. Results and discussions

The experimental configuration is highlighted to measure the performance of the solar space heating system in variable operating conditions of sunny and cloudy days. Indeed, the measurements obtained throughout this work were accomplished during February and March of 2021.

Fig.10 shows the solar radiation intensity (SR), ambient temperature (T_{amb}), inlet and outlet water temperature of the thermal radiator without fan, and wind speed as a function of time from 11:00 am to 1:30 pm on February 18. The weather was cloudy with a high wind speed (13 m/s), and the tubes of the collector were covered by dust. There is a clear trend that the outlet temperature is to be decreased from 50.4 °C at 11:00 am to 49.4 °C at 12:11 pm. It is also found that the inlet temperature decreases from 53.7 °C to 51.4 °C for this period. These results indicate that the temperature difference changes from 3.3 °C to 2 °C due to the drop in temperature difference between the thermal radiator and the room space. The solar radiation intensity fluctuates between a maximum value ~768.7 W/m^2 at 11:00 am to a minimum value ~432 W/m^2 at 11:20 am which is due to the cloudy weather.

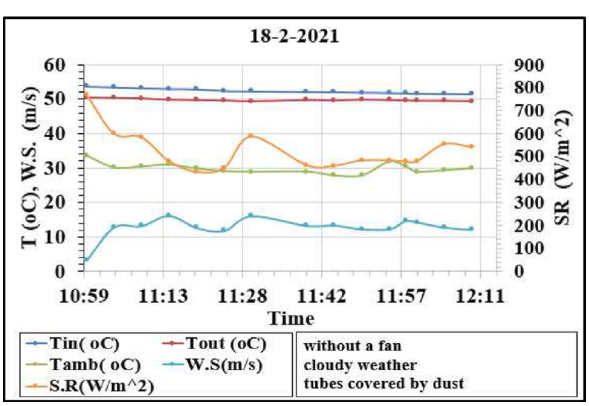

Fig. 10. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of February 18.

The measurements mentioned above were re-conducted on February 25, where the weather was sunny with a lower average wind speed (1.2–3.4 m/s) and the tube was clean (uncovered by dust). The outcomes of these measurements are plotted in Fig. 11 in the period of time 9:38am–1:30pm. It is seen that the room temperature varies from 16.2 °C to 23.9 °C with a temperature difference of 7.7 °C. Obviously, such a difference is approximately twice the value of its counterpart in the previous case. However, the reason behind it is the clean surface of the tube. Solar radiation, on the other hand, decreased from ~741.3 W/m^2 at 10:00 am to ~820 W/m^2 at 13:30 pm during the measurement period.

Anyway, on March 11, the weather was cloudy, with an average wind speed of 3.7 m/s, and the solar collector tube had been cleaned. The measurements are carried out for this case, and their own results are plotted in Fig. 12. Obviously, the solar radiation intensity values fluctuate during such a day between the maximum value of ~789 W/m^2 at 1:00 pm and

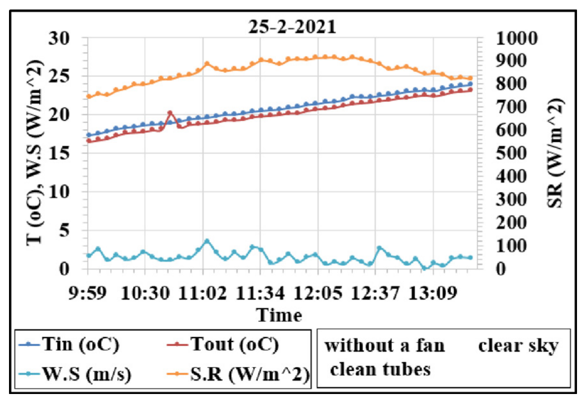

Fig. 11. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of February 25.

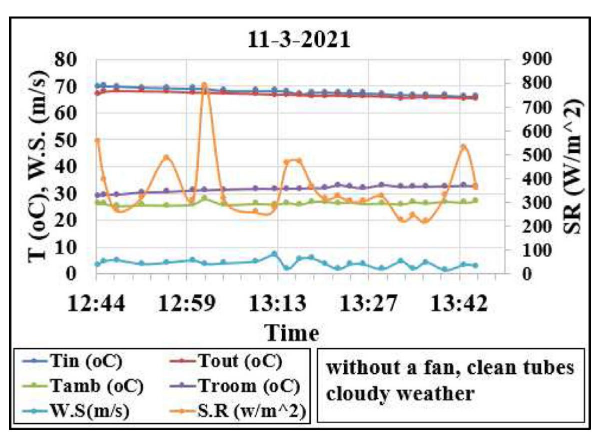

Fig. 12. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of March 11.

the minimum one of ~220 W/m^2 at 1:37 pm. It is seen that the inlet temperature of the thermal radiator decreases from 70 °C at the beginning of the measurement to 66 °C after an hour has passed. While the outlet temperature deviates from ~66.9 °C to ~65.3 °C which means that the maximum temperature difference between the inlet and outlet water is ~2 °C. On the other hand, the maximum room temperature (T_{room}) was up to 32.7 °C in comparison to the ambient temperature (T_{amb}) of up to 26.5 °C, which indicated that the temperature difference is 2.2 °C. It should be mentioned that, these measurements have been done without using a fan.

The experimental measurements of the solar space heating system under partial cloud weather and an average wind speed of about ~1.2 m/s were executed on March 17, where the results are represented in Fig. 13. It is seen that, the room temperature increases from 28.1 °C up to 31.6 °C during the selected period of time (11:30am–12:15pm), and the temperature difference is 3.1 °C. The temperature difference between T_{out} and T_{in} is approximately constant because of the heat dissipation from the thermal radiator into the room is almost absent. Therefore, the fan has been connected to the system in order to increase the heat transfer between the thermal radiator and the room space, as shown in the figures below.

On March 18, the weather was clear with an average solar radiation of about 950 W/m^2 and an average wind speed of about 3 m/s. The measurements have been implemented for 3 h, starting from 10:00 am to 1:00 pm. The results are shown in Fig. 14, which indicates that the difference between room temperature and ambient temperature is about 5 °C at the beginning of measurements at 10:00 am and increases to 10 °C after 3 h. This enhancement in the performance of the space heating system occurs because of using the fan. Actually, the fan leads to increasing the heat transfer between the radiator and the room space.

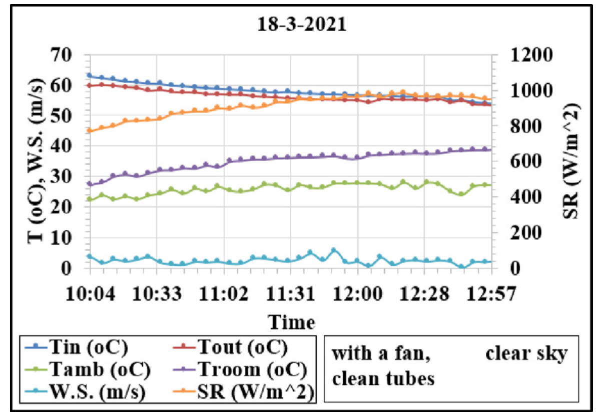

Fig. 14. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of March 18.

Another different case has been chosen where the weather was cloudy, combined with an average solar radiation of about 500 W/m^2 and an average wind speed of about 3.8 m/s on March 24. The temperature difference between the surroundings and the room is about 5 °C at the starting operation, while it becomes 11.8 °C at 1:00 pm, as indicated in Fig. 15. It is clear that, the heat exchange is effectively influenced by using the fan. Because the distribution of the heat energy from the thermal radiator to the room space is due to forced convection. This, however, reveals the nature of the heat transport mechanism inside the thermal radiator tubes.

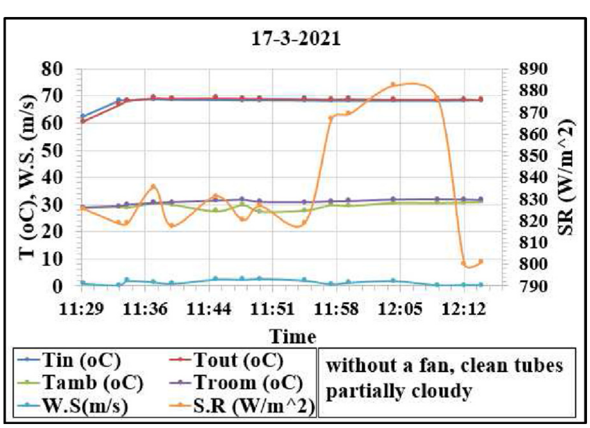

Fig. 13. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of March 17.

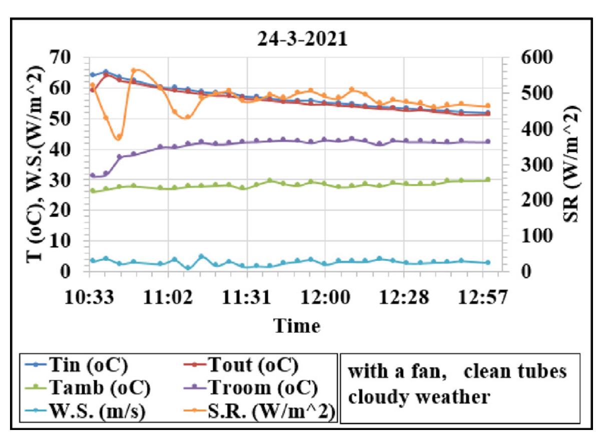

Fig. 15. The solar irradiance, thermal radiator inlet and outlet water temperature, ambient temperature and the wind speed versus the time daytime of March 24.

Table 3. Error analysis of measured data.

Device type	Measured data	Error analysis
Thermometer	**Temperature (°C)**	
	50.4	0.0079
	49.4	0.008
	53.7	0.0074
	51.4	0.0077
	16.2	0.024
	23.9	0.016
	70	0.0057
	66	0.006
	66.9	0.0059
	65.3	0.0061
	32.7	0.0122
	26.5	0.015
	28.1	0.0142
	31.6	0.0126
Solar power meter	**Solar irradiance (W/m^2)**	
	768.7	0.013
	432	0.0231
	741.3	0.0134
	820	0.0121
	789	0.0126
	220	0.0454
	950	0.01
	500	0.02
Anemometer	**Wind speed**	
	13	0.0076
	1.2	0.0833
	3.4	0.0294
	3.7	0.0270
	1.2	0.0833
	3.8	0.0263

It is worth mentioning that, the difference between the inlet and outlet water temperatures of the system gets lower whenever a fan is removed. Actually, such a result proves the necessity for adding the fan to be a main part of the system, especially when the radiator size is relatively small and the water flow speed is high.

The energy delivered by the solar space heating system to heat a room is about 64000 kJ/day, which is equal to 17.77 kWh/day. This value is better than the value obtained by Aed et al. (12.87 kWh/day) because of the use of metal thermal radiator with a fan. The error analysis of the measured data is listed in Table 3.

5. Conclusions

According to the results mentioned above, several remarks could be made concerning the parameters that influence the efficiency performance of the presented system. Indeed, the collector tube should always be clean and free from dust in order to increase the heat transfer between the tube surface and fluid, hence enhancing the evacuated tube efficiency. Furthermore, the thermal insulation of the pipes that connect the solar collector and the thermal radiator has considerable importance in reducing the heat losses and thus enhancing the efficiency of the solar heating system. In addition, the thermal insulation of the room space is also required to enhance the system performance.

Results have clearly shown that the use of the fan significantly leads to discharging the heat from the radiator and thus enhancing the system efficiency. On the other hand, increases in the amount of radiation that is received by the collector, operating time, and the heat accumulation in the storage tank effectively enhance the system performance.

It is necessary to pay attention to the engineering design of the system, as the use of a thermal radiator that has vertical and horizontal tubes, which leads to a slowdown in the flow of the heat transfer fluid inside the thermal radiator, leads to an increase in heat transfer from the radiator to the space of the room and thus leads to an increase in the efficiency of the system.

In the case of using a heat pump with a different flow rate, this leads to controlling the temperature inside the room, and this method can be used in future research.

Acknowledgments

Finally, The researchers would like to acknowledge Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad-Iraq for its support in the present work.

References

[1] A. Sharma, A. Avadav, Experimental study of a solar oven based on evacuated tube collector in Indian climatic conditions, J Phys Conf 1240 (2019), 012124–1–9, https://doi.org/10.1088/1742-6596/1240/1/012124.

[2] N.K. Kasim, A.F. Atwan, A.H. Shneishil, System sizing of solar water heating system in Iraq, national renewable energies conference and their applications, Energy and Renewable Energies Technologies Center (2013), 136–149, https://www.researchgate.net/publication/331952956.

[3] O.O. Craig, A stand-alone parabolic dish solar cooker for African conditions, Master's thesis, Stellenbosch University. 2015. https://www.crses.sun.ac.za/files/research/completed-research/eppei/OOCraig.pdf.

[4] C.J. Cleveland, Ch Morris, Handbook of energy evaluation, Gainesville: Center for Environmental Policy, Elsevier Science, USA. 2013, https://doi.org/10.1016/C2009-0-16729-6.

[5] J.G. Cervantes, E.T. Reyes, Experiments on a solar-assisted heat pump and an exergy analysis of the system, Appl Therm Eng 22 (2002) 1289–1297. https://www.mdpi.com/2673-4931/9/1/16/pdf.

[6] L. Ni, D. Qv, Y. Yao, F. Niu, W. Hu, An experimental study on performance enhancement of a PCM based solar-assisted air source heat pump system under cooling modes, Appl Therm Eng 100 (2016) 434–452, https://doi.org/10.1016/j.applthermaleng.2016.02.001.

[7] A.H. Shneishil, Design and fabrication of evacuated tube solar thermal collector for domestic hot water, J College Edu

Issue 3 (2016) 287−302. https://www.iasj.net/iasj/download/790beadaa2cf100c.
[8] F. Jafarkazemi, E. Ahmadifard, Energetic and exergetic evaluation of flat plate solar collectors, Renew Energy 56 (2013) 55−63, https://doi.org/10.1016/j.renene.2012.10.031.
[9] A.A. Ghoneim, Optimization of evacuated tube collector parameters for solar industrial process heat, Int J Energy Environ Res 5 (2017) 55−73, in: https://www.eajournals.org/wpcontent/uploads/Optimization-of-Evacuated-Tube-Collector-Parameters-for-Solar-Industrial-Process-Heat.pdf.
[10] T.Z. Fouda, M. Darwesh, N. Gremida, Study on the thermal performance of evacuated solar collector system, J Ag Eng 33 (2016) 589−602. https://mjae.journals.ekb.eg/article_98009_e5031e85121ed1e3b8457ba54ecd55db.pdf.
[11] M. Hayek, J. Assal, W. Ltaif, Experimental investigation of the performance of evacuated- tube solar collectors under eastern mediterranean climatic conditions, Energy Proc 6 (2011) 618−626, https://doi.org/10.1016/j.egypro.2011.05.071.
[12] H.H. Al-Kayiem, S.T. Mohammad, Potential of renewable energy resources with an emphasis on solar power in Iraq: an outlook, Resources 42 (2019) 1−20, https://doi.org/10.3390/resources8010042.
[13] A.I. Owaid, M. Tariq, S.S. Abd, R. Abbas, Design and performance evaluation of a solar space heating system using evacuated tubes solar collector in Baghdad, Iraq climate, Int J Adv Res Eng Technol 5 (2014) 115−129. https://www.academia.edu/6654010/.
[14] D.D. Deshpande, Computer modeling of a solar thermal system for space heating, Master's theses, Wright State University. https://corescholar.libraries.wright.edu/cgi/viewcontent.cgi?article=2824&context=etd_all, 2016.
[15] E. Kyrou, A feasibility study on Active solar space heating technology for office buildings in Greece, Master's theses, University of Strathclyde engineering. https://pdfs.semanticscholar.org/1774/1532eba6ce7d962dc7236dc151bf7f1c270c.pdf, 2016.
[16] V. Verma, K. Murugesan, Experimental study of solar energy storage and space heating using solar assisted ground source heat pump system for Indian climatic conditions, Elsevier, Energy and Buildings 139 (2017) 569−577, https://doi.org/10.1016/j.enbuild.2017.01.041.
[17] a S. Al Khalil, N. Abu Shaban, Design and evaluation of performance of solar air heater, Int J Mech Eng Technol 9 (2018) 328−334. https://www.researchgate.net/publication/324925019;
b E. Kyekyere, H. Nidiritu, M. Hawi, P. Mwumbe, Performance of water in glass evacuated tube solar water heater under Kenya climatic condition, Comput Water Energy Environ Eng 10 (2021) 37−48, https://doi.org/10.4236/cweee.2021.102003.
[18] O. Ayadi, S. Al-Dahidi, Comparison of solar thermal and solar electric space heating and cooling systems for buildings in different climatic regions, Elsevier, Sol Energy 188 (2019) 545−560, https://doi.org/10.1016/j.solener.2019.06.033.
[19] J. Zhao, L. Lyu, X. Li, Numerical analysis of the operation regulation in a solar heating system with seasonal water pool thermal storage, Elsevier, Renewable Energy 150 (2020) 1118−1126, https://doi.org/10.1016/j.renene.2019.10.077.
[20] M.D. Sarmouk, A. Smaili, H. Fellouah, A. Merabtine, Experimental and numerical investigations of a solar space heating system based on design of experiments method, Elsevier, Solar Energy 216 (2021) 396−410, https://doi.org/10.1016/j.solener.2021.01.039.
[21] Z.H. Abdul, S.F. Weimin, G.P. Zhang, Optimization of the solar space heating system with thermal energy storage using data-driven approach, Elsevier, Renewable Energy 190 (2022) 764−776, https://doi.org/10.1016/j.renene.2022.03.088.
[22] A.H. Shneishil, Design of hybrid solar-geothermal heat pump, Doctoral dissertation, Mustansiriyah University. 2014. https://www.researchgate.net/publication/332108605.
[23] M.A. Sabiha, R. Saidur, S. Mekhilef, O. Mahian, Solar thermal collectors and applications, Prog Energy Combust Sci 30 (2004) 231−295, https://doi.org/10.1016/j.pecs.2004.02.001.
[24] M.G. Budihardjo, I. Behnia, Water-in-glass evacuated tube solar water heaters, Sol Energy 76 (2004) 135−140, https://doi.org/10.1016/j.solener.2003.07.024.
[25] S.E. Zubriski, K.J. Dick, Measurement of the efficiency of evacuated tube solar collectors under various operating conditions, J Green Build 7 (2012) 114−130, https://doi.org/10.3992/jgb.7.3.114.
[26] M.M. Jamil, N.A. Che Sidik, M.N.A.W. Muhammed Yazid, Thermal performance of thermosyphon evacuated tube solar collector using TiO2/water nano fluid, J Adv Res Fluid Mech Therm Sci 20 (2016) 12−29. https://www.akademiabaru.com/doc/ARFMTSV20_N1_P12_29.pdf.
[27] M.I. Alhamid, N.N. Aisyah, Characteristics of evacuated tubular solar thermal collector as input energy for cooling system at Universities Indonesia, Renew Energy Techno Innovation Sustain Develop., AIP Conf Proc 1826 (2017) 1−8, https://doi.org/10.1063/1.4979232, 020016.
[28] H.J. Hammad, Thermal performance of evacuated tube solar heating system, MSc thesis, College of Engineering/University of Baghdad. 2009.
[29] L.M. Ayompe, A. Duffy, Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate, Appl Therm Eng 58 (2013) 447−454, https://doi.org/10.1016/j.applthermaleng.2013.04.062.
[30] B.J. Huang, W.Z. Ton, Ch Ch Wu, H.W. Ko, H. Sh Chang, R.H. Yen, J. Ch Wang, Maximum-power-point tracking control of solar heating system, Sol Energy 86 (2012) 3278−3287, https://doi.org/10.1016/j.solener.2012.08.019.
[31] D.P. Kothari, K.C. Singal, Rajesh Rangan, Renewable energy sources and emerging technologies, second edition ,Delhi, 2014.
[32] M. Zilli, A practical guide to the calculation of uncertainty of measurement, Open Toxicol J 6 (2013) 20−26. https://benthamopen.com/contents/pdf/TOTOXIJ/TOTOXIJ-6-20.pdf.