Performance Comparison of Parabolic and Flat Plate Solar Collectors Utilizing in the Heating System of a Room-An Experimental Investigation

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Abstract- In the present study, two solar heating systems, including flat plate solar collector (FPC) and parabolic solar collector (PTC) for heating a room were experimentally studied and compared with each other. For doing this, an experiment was conducted in the winter and the performance of these two systems was first measured and then compared with each other. It should be mentioned that the PTC system was manufactured and tested in this study. The ambient temperature, solar radiation intensity, and working fluid temperature in different locations of the two heating systems were measured. The results showed that the PTC solar heating system has higher collector and total efficiencies compared to the FPC heating system. The total efficiencies of the FPC and PTC systems were 6% and 12%, respectively. It was also indicated that the PTC system with lower occupied space can produce higher thermal energy quality compared to the FPC heating system. It was also concluded that the PTC solar heating system is very suitable and efficient to utilize in the heating system of the building.

Keywords parabolic trough collector, flat plat collector, solar energy, solar heating system.

1. Introduction

Solar energy is a potential solution to the environmental problems being caused by fossil fuels. When fossil fuels are burned to generate electricity, they release harmful greenhouse gases into the atmosphere. Solar energy has many industrial and domestic applications. Uppal et al. used a solar heating system for automobile industries. They designed an economical solar heating system using parabolic dish collector. Their results showed that payback period of the solar system is 1.5 years [1].

Due to the high energy consumption of building sectors, the utilization of solar energy can employ a key role to optimize energy consumption [2]. Contrary to fossil fuel, solar energy source doesn't produce any environmental pollution. Moreover, solar energy is the most suitable renewable energy source that always is available and enough efficient for industrial and domestic applications. Iran has high potential of solar energy. Keshavarz et al. determined optimum slope of angles of solar collector for 30 Iranian cities using a mathematical model ad meteorological data of the cities. They obtained the yearly, seasonal and monthly slope angles for all the cities [3].

Solar water heating is a reliable and renewable energy technology used to water heater. Sunlight strikes and heats an absorbent surface within a solar collector or an actual storage tank. Either a heat transfer fluid or the actual potable water to be used flows through tubes attached to the absorber and picks up the heat from it (systems with a separate heat-transfer fluid loop include a heat exchanger that then heats the potable water.) The heated water is sorted in a separate preheat tank or conventional water heater tank until needed. If additional heat is needed, it is provided by electricity or fossil-fuel energy by the conventional water heating system. Generally, typically soar heating systems (SHS) are divided into active and passive systems. In the passive method, the building components like walls act as solar energy storage and delivered the absorbed energy to the building. In contrast, the active systems are often considered using different solar collectors. These systems absorb the solar energy and pass it to a fluid which warm water in a storage tank [4]. So far, many studies have been carried out on solar heating system using solar collector to heat a building. Hottel and Woertz, for the first time, have carried a detailed experimental study to assess the performance of flat-plate solar collectors for heating purposes in buildings [5]. Motte et al. 2013 have designed a new installation of solar collectors which were invisible from the ground. It could be set up on old and new houses. They calculated instantaneous efficiency of collector according to reduced temperature and showed that the performance of these types of collectors were similar to the old type [6]. Mirsha and Saikhedkar have done an investigation about a water heating system using evacuated tube collector in Raipur of India. They analysed thermal energy consumption that was produced by evacuated tube collectors. Comparisons between evacuated tube collectors in two cases: with and without water-in-glass showed that using water improves efficiency up to 66% [7]. Yaici and Entchev forecasted the performance parameters a solar energy system using ANFIS method. They concluded, the ANFIS method's results have a good agreement with the experiment data [8].

A detailed thermal performance analyse has been performed by Ayompe and Duffy in Berlin. After calculation of different energy parameters, they concluded that evacuated tube collectors were more suitable than flat plate collectors to use in heating system [9]. A seasonal energy storage investigation has been carried out by Raluy and his co-workers to heat 100m^2 spaces using flat plate solar collectors in Spain. They investigated environmental effects of utilizing solar heating plants. Their results showed that the auxiliary heating system produced the highest environmental pollution [10]. Patil et al. used a concrete absorber plate instead of metal absorber in the collector. They built a flat plate solar collector with concrete plate and tested with various mass flow rates in several months. They realized that the concrete collector produced sufficient heat for domestic applications [11]. Ciocan et al. studied for storing renewable energies in the form of compressed air. Their system efficiency was 37% up to 51%. The system produced needed heat and electricity in small scale [12]. Among different types of mentioned collectors, concentrator solar collectors have a more effective role to generate high temperatures in industrial processes. The PTCs can track sun in the sky using handy or automatic tracker system. PTCs have high efficiency in low incidence angles and this brings them an advantage over the FPCs in day-long performance [13]. PTCs produce high thermal energy, with a lower aperture area than the FPCs. These advantages make them suitable and reliable devices for solar building applications. Because of their special characteristics, PTCs are increasing worldwide rather than other types of solar collector [14]. They have extended applications: domestic hot water system, air conditioning, refrigeration, desalination, and etc. PTCs can produce various rang temperatures according to their concentrating ratio.

Some researchers have estimated the thermal efficiency of the SHS equipped with PTC. Togar et al. have done studies to decrease costs of concentrated solar plants. They employed the PTCs for producing heat and electricity and to decrease economical costs made computer program [15]. Li et al. have designed a new solar system that could supply the heating and lighting energies of a building, instantaneously. To achieve this goal, they used a novel parabolic trough collector, which had low price and high efficiency [16]. Qu and his co-workers have made a combined solar heating and cooling system using a 52m2 linear PTC. They improved the system performance by changing the area of the collectors and the storage tank's size. Their cooling system was the smallest high temperature system in the world [17]. Wang et al. investigated a novel hybrid solar system which can heat or cool building spaces. They used Genetic algorithm to optimize the energy consumption of the mentioned system [18]. Pandolfini and Krothapalli combined parabolic surface and flat plate collector. They placed receiver tubes inside a glass cover that covers the whole collector surface. It was able to reach the working fluid temperature up to 150°C and it had better performance compared to the other systems [19]. Martinopoulos and Tsalikis have assessed economic aspects of active and passive solar systems in building in Greece. They computed the necessary storage tank and needful area of collector to minimize energy costs for space heating. Their typical solar space and water heating system could provide 45% of the total heating loads [20]. Deng et al. presented a set-up of heating system that was combined with an air source heat pump and solar SHS with evacuated tube collector. They used this new layout for a rural house with an area of 81.4m2. According to their results the payback period of utilization of the SHS was 17.3 years that is lower than the air source heat pump period, i.e. 25 years [21]. Glembin et al. have simulated solar combination systems for space heating. They investigated various layouts of the SHS components for a house with a single family. They concluded that the direct radiator system that was connected to the collector had a lower performance in comparison of other layouts [22]. Verma and Murugesan applied solar and ground source heat pump to store thermal energy during the day. They used mentioned system to heat a space at night. The results of their experiments showed that using the ground heat pump causes heat leakage up to 23% at night [23].

Montes and Cortez designed and build a solar heating system in Peru. They presented a special configuration of the solar heating system to increase the system efficiency. They employed a linear regression for obtaining the model's equation coefficients. They concluded that to increase home temperature, volume of the chamber and the collector should have a small and large area respectively [24].

Some researchers used PV panels for solar systems. Yoshidau and Ueda investigated combination of a solar water heater with photovoltaic panels. They calculated the performance of combined solar system and showed that the performance of the system depends on climatic conditions [25].

Simms and Dorville designed and fabricated a solar water heater with PV cells that its absorber form was changed. In order to optimize the system, various parameters of the new solar water heater system were analyzed. The hybrid system could have increased temperatures of 7.5 Lit up to 20°C during 5.5 hours [26].

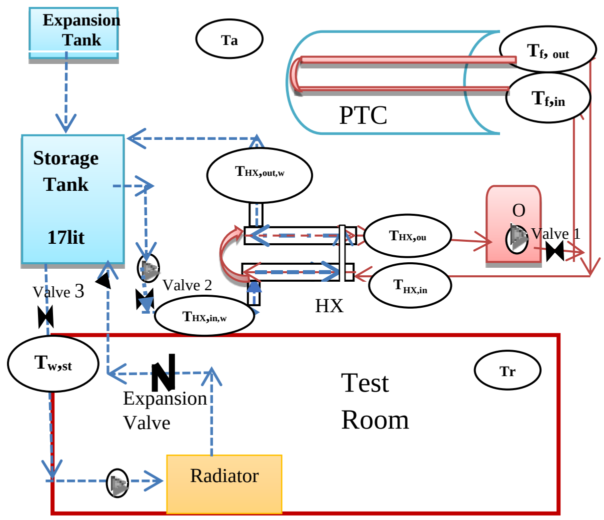
The literature review revealed that not much research has been focused on comparison of SHS and with the PTC and the FPC and there is a need to study these two systems further. This research conducted an experimental study and utilized two types of solar collectors, including an FPC and PTC to heat a building space. The PTC was first designed, manufactured, and then it was tested under different operating conditions. The PTC performance was assessed for space heating of a room. The performance of the SHS with the FPC and the PTC was also examined and compared with each other. These two systems were compared with similar environmental conditions to check out their performance.

2. Experimental Test Rig

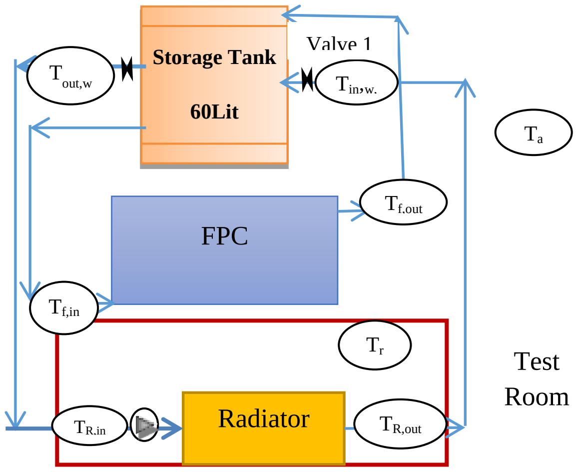
This section provides the detail information of the experimental test rig. The SHS equipped with FPC and PTC solar systems were installed and tested In Sirjan-Iran. ‘‘Figs. 1 and 2’’ show the schematics of these two systems. As shown in these Figs, the SHS with the PTC consists of collector, oil tank, heat exchanger, storage tank (17lit), expansion tank, radiator, valves, and pumps. The SHS with the FPC consists of collector, storage tank (60lit), radiator, and pumps. These two systems provide solar water heating for a room which was used as the test room (3×3.5m) in this study. The area and heat transfer coefficient of the room components are given in ‘‘Table 1’’. The both systems for comparison were separately connected to the room. Detail information of these two systems is given in the following sections.

Table1. Area and heat transfer coefficient of the room’s wall

Wall	N	S	E	W	Window	door	Ceiling
A(m^2)	8	6.8	9	9	1	2.2	9
h(W/m^2.K)	0.25	0.25	0.25	0.25	1.13	1.15	0.13



(a)



(b)

Fig. 1 Schematic of space heating system with (a) PTC and (b) FPC

2.1 Parabolic trough solar collector

As mentioned in the previous section, the manufactured PTC system consists of several components Details information of each component is given in ‘‘Table 2’’.

Table2. The geometric properties of the PTC

Components of collector	Value
Rim angle	99
Diameter of absorber tube	0.008m
The length of the collector (L)	1.32 m
Focal length (f)	0.25m
Reflectivity of reflector surface	0.9

Surface area of PTC	1.31 m^2
Surface area of receiver	0.033m^2
Aperture width	0.89 m
Concentrating ratio	39.5

‘‘Figs. 2 and 3’’ show the components of the PTC. The PTC has a width of 0.89m, 1.32m length, and 0.25m focal distance. The length of the PTC receiver was 1.32m. The outlet and inlet diameter of the absorber tube are 0.06m: 0.05m, receptively. In order to absorb more heat energy, the absorber tube was soldered to its below copper plate and it was colored with a black Polyurethane. The covers of absorber tubes should have small absorption coefficient and large reflection coefficient to reflect the maximum solar radiation. The reflector has the same shape with its frame. Pyrex glass was used around the absorber tube and this glass is a type of Borosilicate glass which is very resistible against thermal expansion. The absorber tube is located in the focal line of the reflector and is covered with a non-evacuated glass envelope. The absorber tube is a U-shaped copper tube that working fluid moves through it. The absorbed solar energy is converted into thermal energy and transferred to the working fluid. In order to reflect the maximum solar radiation to the absorber tube, an aluminum sheet was anodized. The anodized aluminum has more hardness, intensity and sustainability against corrosion and it also increases the reflective coefficient. In order to rotate the reflector surface of the PTC, handy steel levers were made and joined to the main structure. To absorb maximum solar energy, the PTC was south facing and rotated from East to West. Heat exchanger and pipes were insulated with 2cm

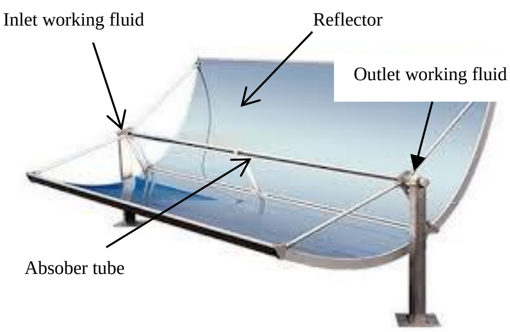


Fig. 2 Components of the PTC collector

Fig. 3 The Manufactured PTC collector (image by Mohammad Javad Arabpour)

wool glass to reduce heat losses. The tracing method of PTC was manual and the rotation of PTC has been done around one axis. As shown in Fig. 1, the PTC in the SHS has two heating thermal circuits: the heating loop with oil as the working fluid (1), and the heating loop with water as the working fluid (2). The heating loop (1) is between the collector and the thermal storage tank. The incident solar energy is absorbed by the oil fluid and delivered to the heat exchanger to heat the water in the thermal storage tank. The heating loop (2) is between the thermal storage tank and the room. The loop supplied the heating water to heat the room via the radiator. The selected oil is Behran oil and is produced in Iran. The characteristics of this oil are given in ‘‘Table 3’’.

Table3. Characteristics of Behran Oil

Viscosity at 100 °C (cSt)	Density (kg/m^3)	Fire point (°C)	Oil type
15.5	869	224	Behran10w-40

2.2 Flat plate collector

At the SHS with flat plate collector, absorption process of solar radiation and heat transfer to the working fluid is done by the collector which should have suitable heat transfer characteristics like high thermal conduction coefficient, high absorption coefficient, and low emittance coefficient. The used FPC is made by the Sangarcar Company in Iran. The absorber plate is a metal plate which on its back the working fluid tubes were soldered. The plate was made of anti-corrosion materials. The collector absorber is made of Titanium oxide that can absorb maximum radiation and have minimum reflection. The collector glass is a special glass with low amount of irons. The transmittance coefficient of the glass is 95% with high thermal resistance, up to 250°C. To decrease the collector heat loss further, the collector framework insulated with Rockwool that covers the back and edges of the absorber plate. The FPC framework is made of stainless steel and all the equipment insulted inside it. Characteristics of the used FPC are given in ‘‘Table 4’’. ‘‘Fig. 4’’ shows image of the FPC used in this study.

Table4. Characteristics of Flat plate collector

Component of collector	Value
Plate area	4m^2
Length	2m
Width	2m
Number of pipes	16
Pipe diameter	8mm
Tilt angle	30°

Fig. 4 Image of the FPC used in this study **(**image by Mohammad Javad Arabpour)

3. Measurement System and Data Collection

Experimental investigations of the two SHSs were conducted in a building in Sirjan-Iran (Latitude 29°28′ N, 55°34′E; altitude 1743m). The both SHS systems were installed on the roof of the building. To measure the systems' performance, the working fluid temperature, solar radiation and ambient temperature were measured. The selected places for measuring the temperature are shown in ‘‘Figs. 1 and 2’’. Two four-channel data loggers were used to measure the system temperatures Temperature of radiator in the room was recorded using a PT100 RTD class sensor. The solar radiation was measured using a pyranometer. The data collection was carried out every 15 mins. This should be mentioned that the time interval is needed to reach steady state conditions of the systems [18]. Characteristics of the measurement devices are given in ‘‘Table 5’’.

4. Equations to Assess the SHSs Performance

According to thermal analysis of the solar collector, the collector performance is dependent on solar radiation, ambient temperature, and heat losses. The absorbed useful energy per unit of PTC length is defined as ‘‘Eq. (1)’’:

$$Q_u = \acute{F}A_{ap}\big(I - (A_b/A_{ap})\, U_l(T_f - T_a)\big)/\acute{L} \tag{1}$$

Table5. Characteristics of the measurement devices

Instrument	Model	Measurement rang	Accuracy	Company
Pyranometer	TES-1333	Up 2000 Wm^{-2}	1Wm^{-2}	TES Taiwan
Digital temperature meter	TES-1317	-190+790 °C	±0.05%± 0.2°C	TES Taiwan
temperature meter	TES-1384	-148+1370°C	±0.05%± 1 °C	TES Taiwan

Where $\acute{F}$ is the PTC efficiency factor and it is given as ‘‘Eq. (2)’’ [3]:

$$\acute{F} = (1/U_l)/(1/U_l + D_{out,b}/hD_{in,b}$$
$$+D_{out,b}\ln(D_{out,b}/\,D_{in,b})\,/2k \tag{2}$$

The experimental power of the collector is defined as ‘‘Eq. (3)’’:

$$\dot{Q}_c = \dot{m}_f C_f\big(T_{f,out} - T_{f,in}\big) \tag{3}$$

Thermal efficiency of the PTC is calculated as ‘‘Eq. (4)’’:

$$\eta_c = \dot{Q}_c/IA_{ap} = \dot{m}_f C_f\big(T_{f,out} - T_{f,in}\big)/IA_{ap} \tag{4}$$

The PTC thermal efficiency is given as ‘‘Eq. (5)’’ [3]:

$$\eta_c = F\big[\eta_0 - A_{ap}U_l(T_{f,in} - T_a)/IA_b\big]$$
$$= a_1 + a_2\Delta T \tag{5}$$

Where η_0 is the optical efficiency and F is the thermal removal factor as ‘‘Eq. (6)’’:

$$F = \dot{m}_o\, C_o(1 - \exp\big[-(A_bU_l\acute{F}/\dot{m}_o\, C_o)\big])/A_bU_l \tag{6}$$

$$\Delta T = T_{f,in} - T_a \tag{7}$$

$$a_1 = F\eta_0 \tag{8}$$

$$a_2 = -(A_{ap}U_L/IA_b) \tag{9}$$

The efficiency of the FPC is calculated as ‘‘Eq. (10)’’ [3]:

$$\eta_c = F(\tau\alpha)_n - FU_l(T_{f,in} - T_a/I) \tag{10}$$

The heat loss of the room is calculated as ‘‘Eq. (11)’’:

$$\dot{L} = (AU)(T_r - T_a) \tag{11}$$

$$L = \int (AU)(T_r - T_a)^+\ dt \tag{12}$$

Symbol “+” indicates that just positive value of temperature difference should be considered [3]. The experimental useful energy of the collector is defined as ‘‘Eq. (13)’’:

$$Q_c = \int_{t_1}^{t_2} \dot{Q}_c\ dt \tag{13}$$

The heat gain of the water storage is calculated as ‘‘Eq. (14)’’:

$$Q_w = m_{w,st} C_w \Delta T_{w,st} \quad (14)$$

The thermal energy of radiator is calculated as ''Eq. (15)'':

$$Q_R = \int dt\, \dot{m}_{w,R} C_w (T_{R,out} - T_{R,in}) \quad (15)$$

Heat exchanger efficiency is calculated as ''Eq. (16)'':

$$\eta_{HX} = \dot{m}_o C_o \Delta T_{HX,o} / (\dot{m}C)_{min} (T_{HX,in,o} - T_{HX,in,w} \quad (16)$$

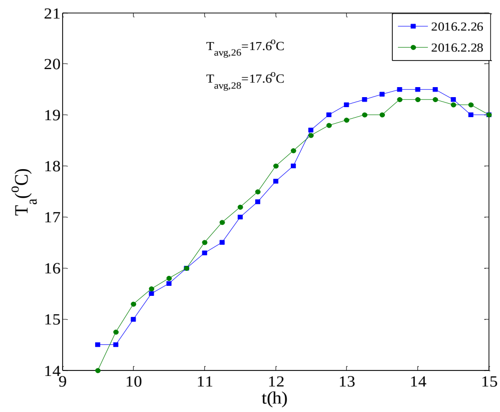
Finally, the total efficiency of the system is computed as ''Eq. (17)'':

$$\eta_t = \eta_c \eta_{HX} \quad (17)$$

5. Results and Discussion

5.1 The SHS with the PTC

To investigate the thermal performance of the PTC, the system was operated and tested on Feb 26 and 28 in winter 2016. The data collection was done every 15 mins. It should be noted that it is assumed that the system arrived at the steady state condition within the selected time interval. Figs. 5a and b show the ambient temperature and solar intensity variation during the test days. It should be pointed out the ambient temperature was measured in the shade and the solar radiation intensity was measured on the horizon.



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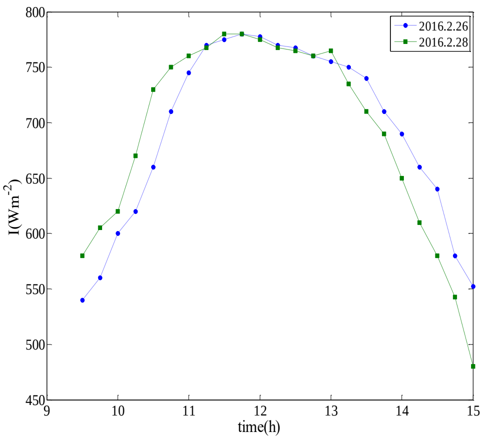
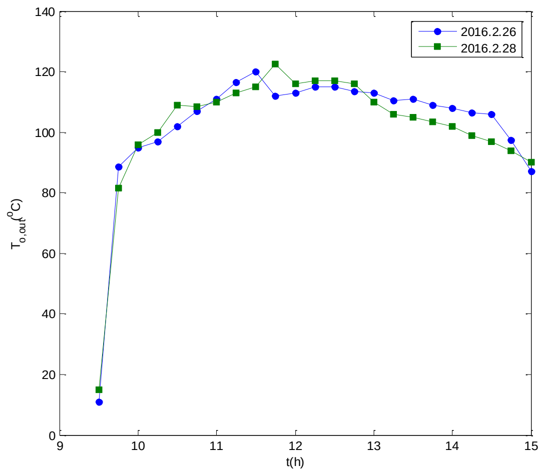


(b)

Fig. 5 Distributions of (a) ambient temperatures (b) solar radiations during the test day, Feb 26 and 28 2016.

The maximum temperature of the 26th and 28th of February were 19°C and 20.3°C and the minimum temperatures were 14.5°C and 14°C, respectively. The average ambient temperatures in these two days were the same, 17.6°C. The oil and the water flow rates were selected 0.0036 kg/s and 0.008kg/s, respectively and these two flow rates were constant during the test days [27]. To receive the maximum solar radiation by the PTC, the collector was directed toward the sun in order to normalize the beam solar radiation into the collector surface. The average wind velocity during the test day was 3m/s. ''Fig. 6 (a)'' shows the outlet oil temperature of the PTC.



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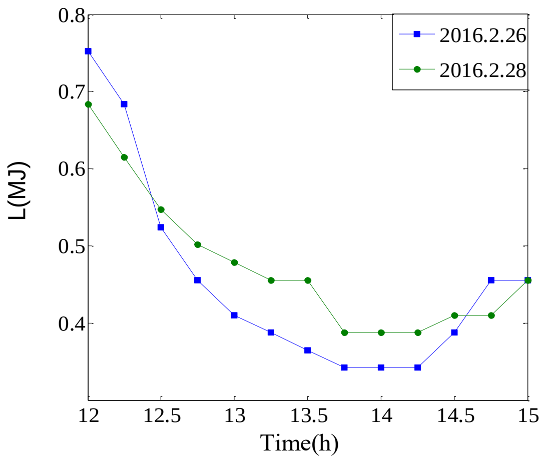

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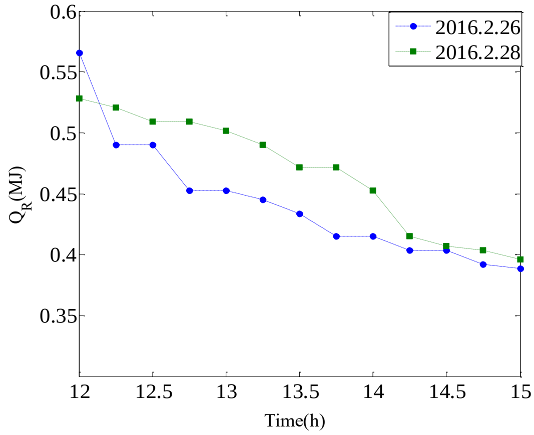


(c)

Fig. 6 (a): The outlet oil temperature of the PTC (b) The required heating load of the room (c) The delivered heating load to the room in Feb 26 and 28.

As shown in ‘‘Fig. 6,’’ the oil temperature reaches from 15°C to 90°C in a short time interval and keep going up to 122°C at 12pm. The maximum of the outlet oil temperature in Feb. 28 and Feb. 26 are 122.5°C and 120 °C, respectively, and the average values of oil temperatures during these days are 105.8°C and 103°C, respectively. ‘‘Fig. 6 (b)’’ shows the required heating load of the room and ‘‘Fig. 7 (c)’’ shows the delivered heating load to the room by the PTC system. It should be mentioned; the PTC system transferred the absorbed energy to the room after 12pm because until this time of the day the delivered heating load was not enough to supply the room heating load. As shown in ‘‘Fig. 6 (b);’’ the supplied heating load to the room is approximately constant after 12pm in the both test days. However, the supplied heating load is not still enough to compensate the escaped heating load from the room.

‘‘Fig. 7’’ shows the total efficiencies during the test days. As shown in ‘‘Fig. 7,’’ the maximum total efficiency is 15% during the test days.

‘‘Figs. 8 (a) and (b)’’ represent the PTC efficiencies and the total efficiencies versus temperature difference of ambient and inlet temperatures over the incident solar radiation. As shown in these figs., the PTC efficiencies versus ΔT/I on the both test days are approximately linear.

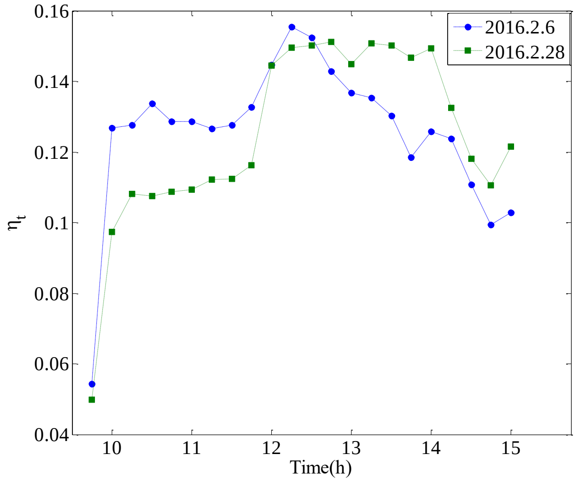
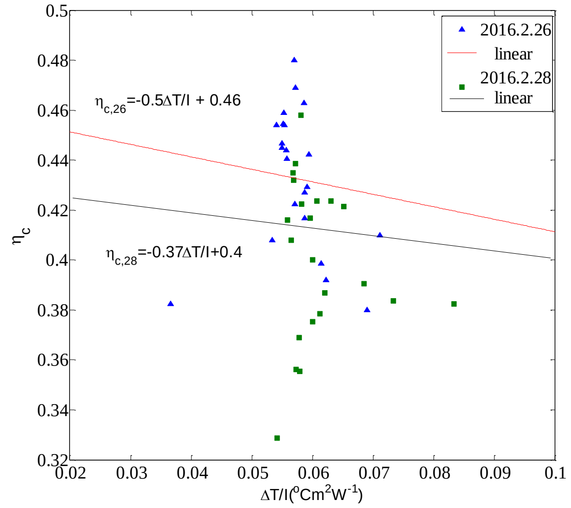


Fig. 7 The total efficiencies during the test days



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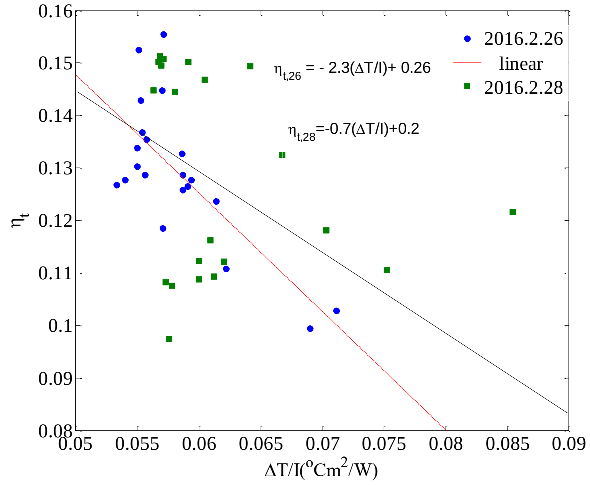
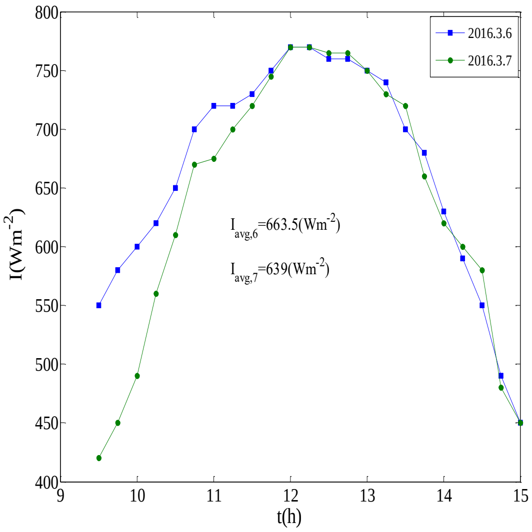


(b)

Fig. 8 The PTC thermal efficiency (a) and the total efficiencies (b) in the test days

5.2 The SHS with the FPC

This section provides the experimental assessment of flat plate solar collector on March 6 and 7 in 2016. ''Figs. 9 (a) and (b)'' show the incident solar radiation and the ambient temperature distributions, respectively, during the test days. The average of solar intensity on March 6 and 7 were 663.5Wm^{-2} and 639Wm^{-2}, respectively, and the average ambient temperatures in these days were 17.7 and 17.5 °C, respectively.



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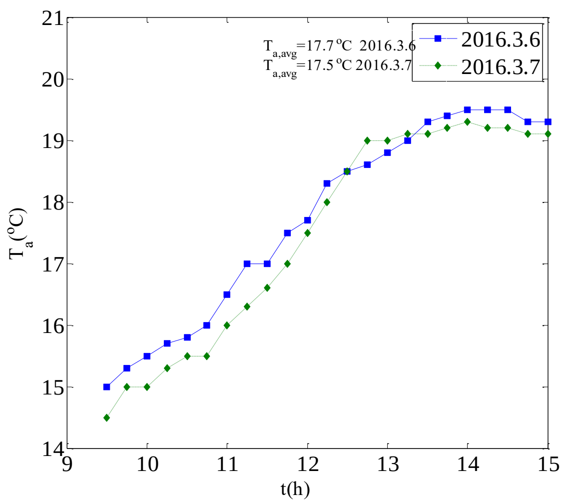


(b)

Fig. 9 Distributions of (a) ambient temperatures (b) solar radiations during the test days, March 6 and 7

''Fig. 10'' shows the thermal storage water temperature during the test days. As shown in this fig., the outlet water temperature of the FPC on March 6 begins from 55 °C and it reaches 73°C after 2.5 hours. The mean water temperature on this day is 67°C. The maximum and average of water temperature on March 7 are 73°C and 65°C, respectively. The water flow rate in this system was selected 0.008kg/s based on the ASHRAE 93-1986 [27].

The room required heating load lost to the ambient air and the room supplied heating load given by the radiator are shown in ''Figs. 11 (a) and (b)'', respectively.

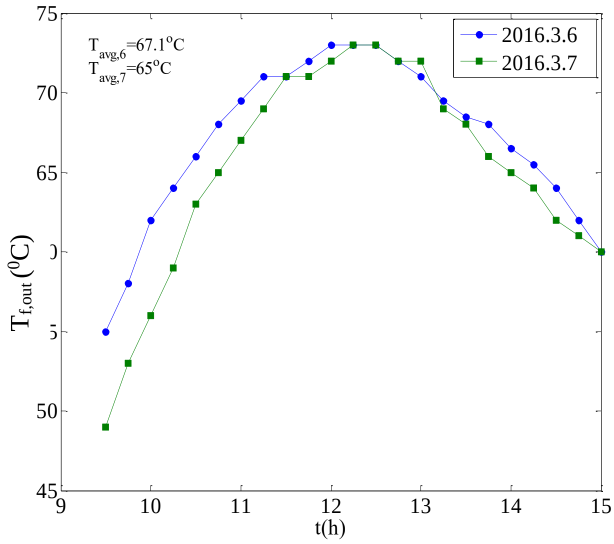
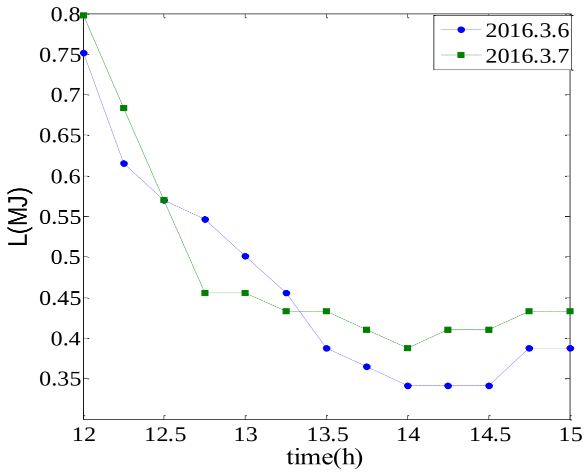


Fig. 10 The thermal storage water temperature during the test days



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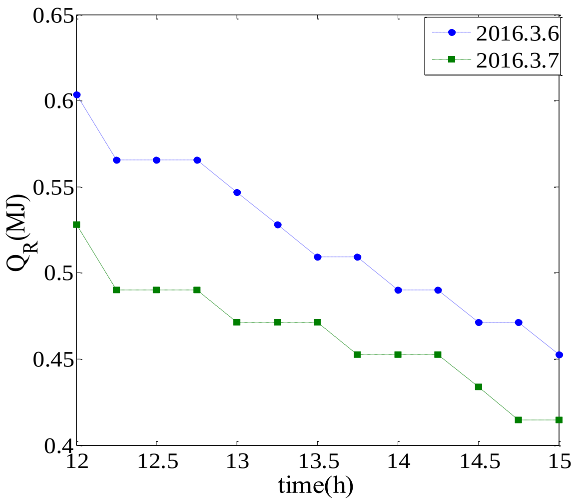


(b)

Fig. 11 The required heating load of the room (a) and the supplied heating to the room given by the radiator (b)

The total thermal efficiency of the SHS with the FPC is shown in ‘‘Fig. 12’’.

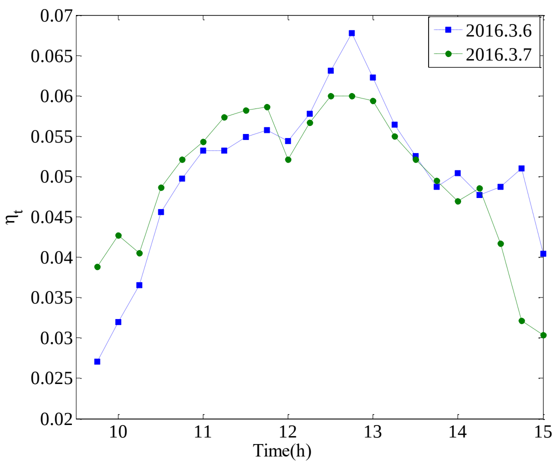
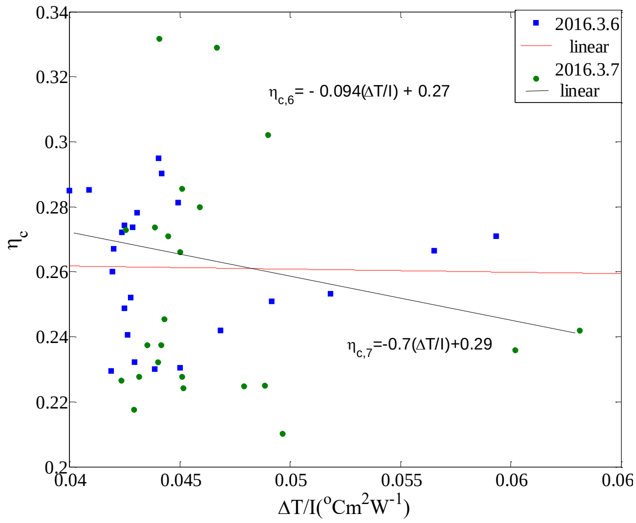


Fig. 12 The total thermal efficiency the SHS with the FPC versus time in March 6 and 7, 2016

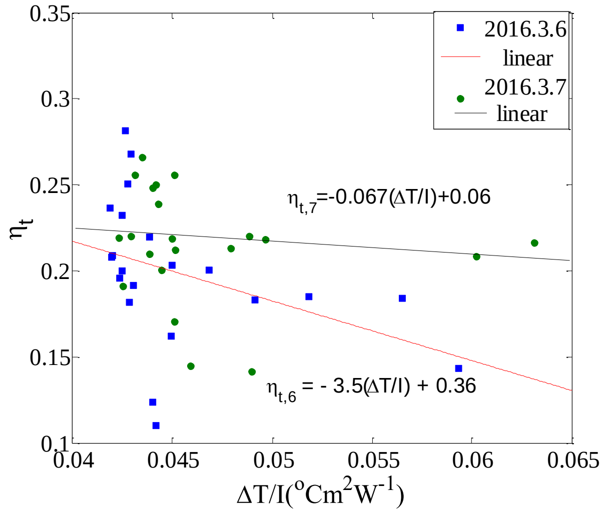
The collector and the total efficiencies versus $\frac{\Delta T}{I}$ in March 6 and 7 are shown in ‘‘Figs. 13 (a) and (b),’’ respectively.

6. Comparison of the Two Systems

In this section, the performance of the PTC and FPC heating systems are compared with each other. The days which have almost the same conditions (i.e. March 6 and Feb 26, 2016) have been selected for the comparison. The incident solar radiation and the ambient temperature for these two systems are shown in ‘‘Figs. 14 (a) and (b),’’ respectively. The averages of solar radiation in the selected days are 692 Wm^{-2} and 663.5 Wm^{-2}, respectively.

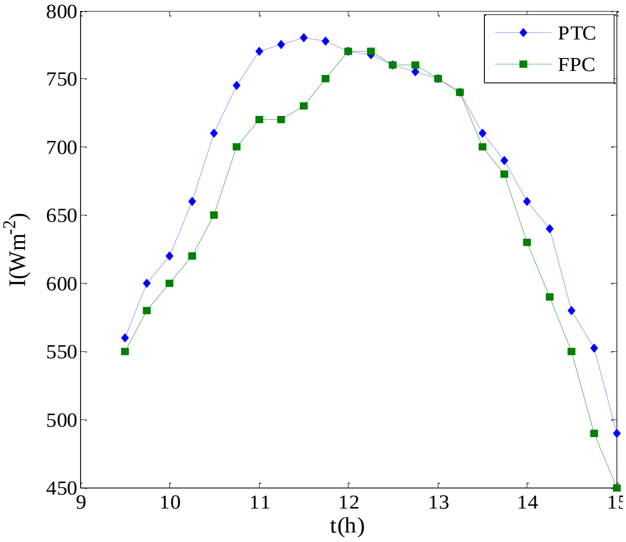


(a)

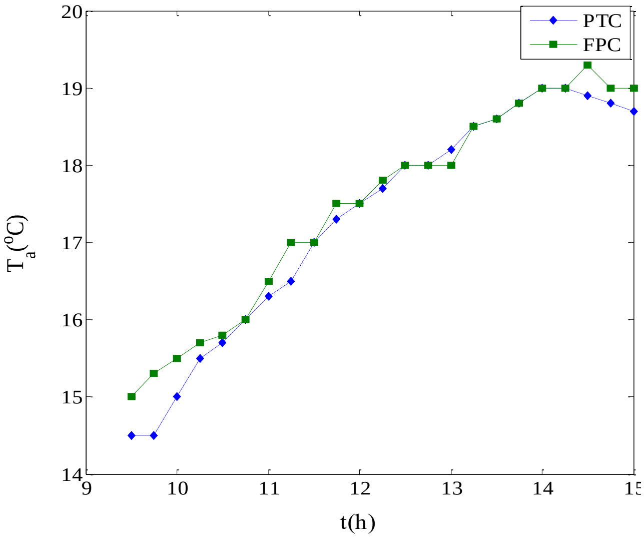


(b)

Fig. 13 The FPC (a) and total efficiencies (b) versus $\frac{\Delta T}{I}$. in March 6 and 7, 2016



(a)



(b)

Fig. 14: The PTC and FPC systems radiation (a) and the ambient temperature(b) distributions during the test days

‘‘Fig. 15’’ shows the output heating power of the collectors during the test days. As shown in this Fig. the average heating power of the FPC and PTC are 666.5 W and 398 W, respectively.

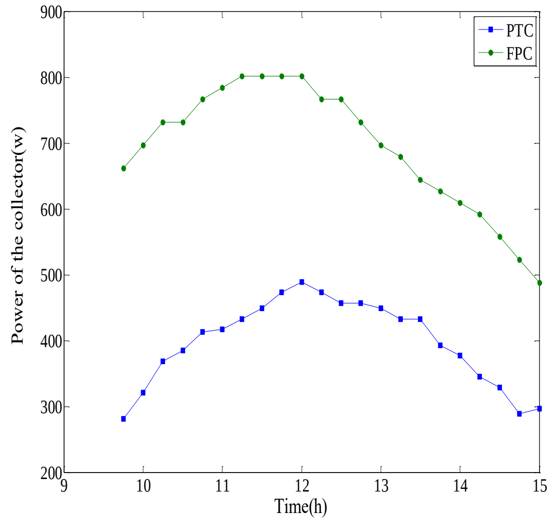
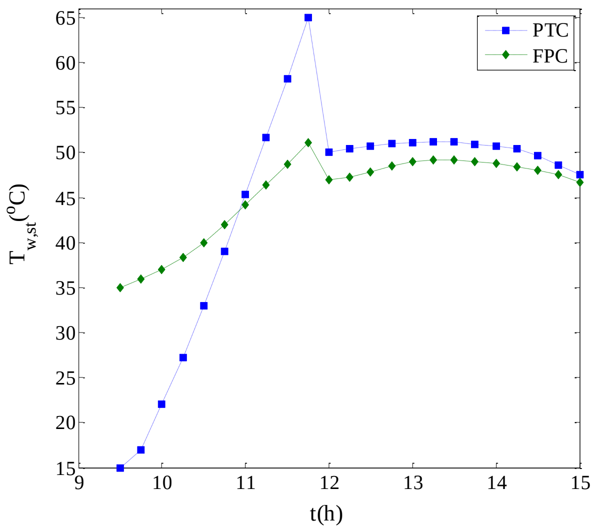
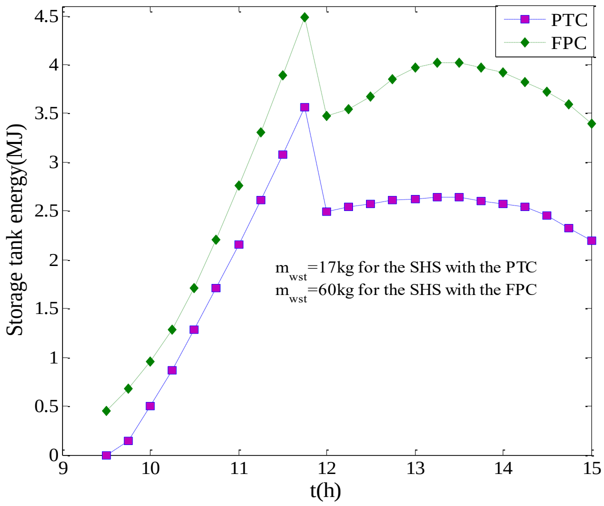


Fig. 15 Heating power of the FPC and the PTC during the test days

The water temperatures and the gained energy in the storage tank in the two systems are shown in Figs 16 (a) and (b), respectively. As shown in ‘‘Fig. 16,’’ the water temperature between 10:30 and 11:30 in the PTC system goes higher than the FPC system.



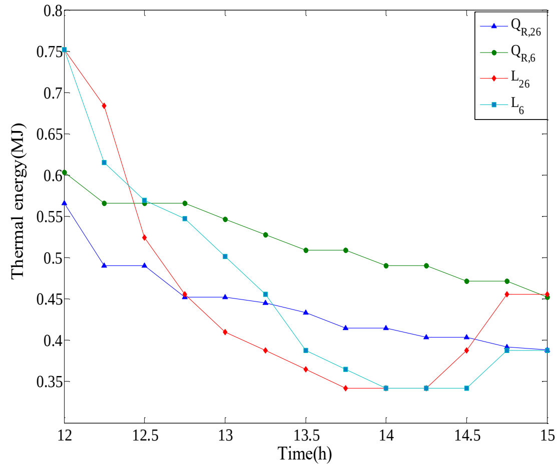
(a)



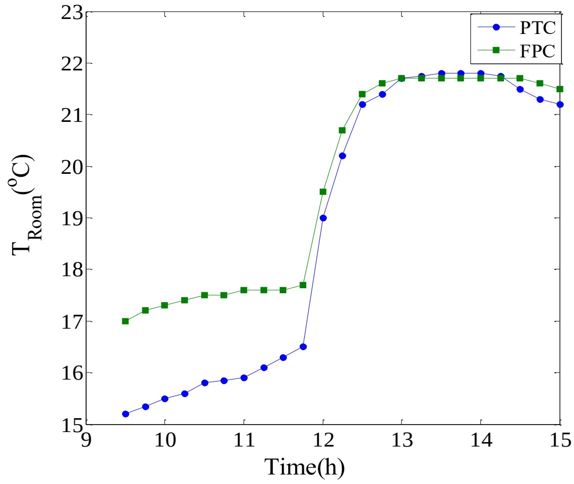
(b)

Fig. 16 (a): The thermal energy of the storage tank **(b)** water temperature of the storage tank versus time

The average gained energies by the storage tanks from 9:30 to 11:45 are 2.2MJ and 3.1MJ in the PTC and FPC heating systems, respectively. It should be mentioned that the heating system of the room is running from 11:45am and as it is shown in ‘‘Fig. 16,’’ the water temperature in the storage tank increases from initial time of experiment and goes up till 11:45. The solar system acted like a water heater system during this time. When the water temperature reaches 65°C at 11:45in the SHS with the PTC and 51.1°C in the SHS with the FPC, valve 3 located between the storage tank and the room radiator was opened and the hot water flows into the radiator. A sudden temperature decrease happens in the storage tank between 11:45 and 12:00 and the water temperature in the tank reaches 50 °C in the PTC system and 47°C in the FPC system. It should be pointed out that this sudden drop is because of preheating of cold water in the heating system which has a temperature close to the ambient temperature. It is also observed in ‘‘Fig. 16’’ that the temperature of the storage tank increases after 12:00 to 13:00 as the solar radiation in this interval is still increasing. The distributions of the room heat loss and the heat given to the room by the radiator are plotted in ‘‘Fig. 17’’.



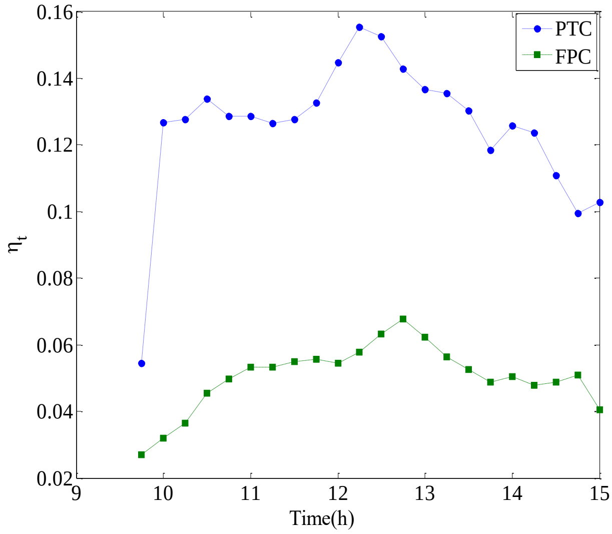
(a)



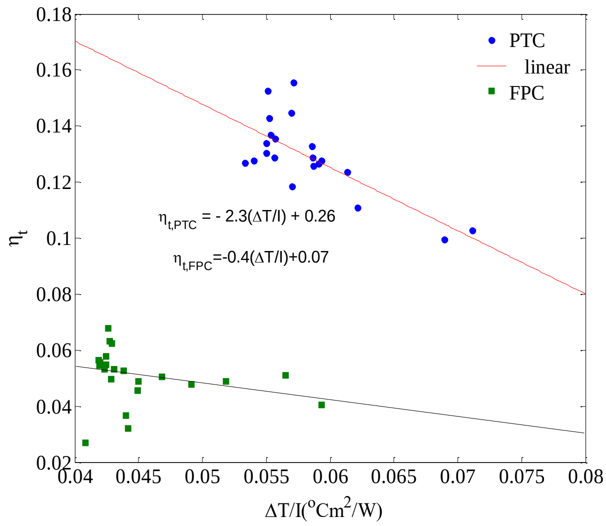
(b)

Fig. 17 (a) The heat load of the room and the radiator thermal energy **(b)** the room temperature in the test days

The average heat given to the room by the radiator in PTC and FPC systems are 0.44 MJ and 0.52 MJ, respectively. The room temperature distribution during the test days in the FPC and PTC systems are shown in ‘‘Fig. 17 (b)’’. As shown in this ‘‘Fig. 17,’’ the room temperature increases from 15 °C to 21.8 °C in the PTC system and 17 °C to 21.5°in the FPC system. The total efficiencies of the SHS with the PTC and the FPC are compared in ‘‘Fig. 18 (a), (b)’’. As stated earlier, the present solar system acted from 9.5 to 11:45 only heats the water inside the thermal storage tank and from 11:45 to 15:00 simultaneously receive the thermal energy in the storage tank and deliver the heat to the room. The mean total efficiency of the SHS with the PTC and FPC are 0.12 and 0.6, respectively. As shown in ‘‘Fig. 18 (a),’’ the total efficiency of the PTC solar heating system from the beginning of the day is higher than the FPC solar heating system. This is mainly due to the higher solar radiation intensity received by absorber placed at the center of the trough collector.



(a)



(b)

Fig. 18 The total efficiency of the SHS with PTC and FPC **(a)** versus time **(b)** versus ΔT/I

Conclusions

The aim of this study was to compare the performance of a solar heating system equipped with flat plate solar and parabolic solar collectors to heat a room. An experimental investigation was performed in winter 2016 and the system's performance was assessed and compared with each other in two days with similar environmental conditions. Comparison between temperatures and the thermal energies of the two solar heating system components were carried out. The results showed that the PTC system have a higher thermal energy quality and provide a higher water temperature in the storage tank. This fact made the PTC a reliable heating system to heat the room in spite of having a lower amount of water in the thermal storage tank compared to the FPC heating system. The results also showed that the total efficiency of the PTC heating system is higher than the FPC heating system and it states that the PTC system is more efficient in term of solar energy conversion.

Notation

The following symbols are used in this paper:

A_{ap}= Surface area of the collector aperture (m^2)

A_b= Surface area of the absorber tube (m^2)

C_f = fluid heat capacity (J/kg K)

C_o = oil heat capacity (J/kg K)

C_w = water heat capacity (J/kg K)

$D_{out,b}$= external diameter of the absorber tube (m)

$D_{in,b}$= internal diameter of the absorber tube (m)

F'= Efficiency factor

F= Heat removal factor

h= Convective heat transfer coefficient ($W/m^2.K$)

I=solar radiation (W/m^2)

k=Conductive coefficient (W/m.K)

L= Heat load (J)

$\dot{L}$= Heat load rate (W)

$\acute{L}$=Length of collector (m)

$m_{w,st}$= water mass of the storage tank (kg)

$\dot{m}_{w,R}$=mass flow rate of Raditor water (kg/s)

$\dot{m}_o$=Mass flow rate oil (kg/s)

Q_c=useful energy of the collector (J)

Q_u= useful energy of the collector per unit of PTC lengt (J)

Q_R=radiator energy (J)

Q_w=storage tank energy (J)

$\dot{Q}_c$= collector power (W)

T_a=ambient temperature (°C)

T_r=room temperature (°C)

$T_{f,in}$=inlet fluid temperature of the collector (°C)

$T_{f,out}$=outlet fluid temperature of the collector (°C)

$T_{R,in}$=inlet water temperature to radiator (°C)

$T_{R,out}$=outlet water temperature of raditor(°C)

$T_{HX,out,o}$=outlet oil temperature from heat exchanger (°C)

$T_{HX,in,o}$=inlet oil temperature to heat exchanger (°C)

$T_{HX,in,w}$=inlet water temperature to heat exchanger (°C)

$T_{w,st}$=water temperature of the storage tank (°C)

U_l= Loss coefficient (W/m^2. K)

ΔT_w= the water temperature difference in each interval (ºC)

α= absorption coefficient

τ= transmittance coefficient

η_0=optical efficiency

η_c= collector efficiency

η_{HX}= heat exchanger efficiency

η_t= total efficiency

References

[1] A. Uppal, J P Kesari, M. Zunaid, “Designing of Solar Process Heating System for Indian Automobile Industry Anubhav,” International journal of renewable energy research, Vol.6, No.4, pp.1627-1636, 2016.

[2] R. L. Romero, J. M. S. Lissen, J. S. Ramos, E. A. R. Jara and S. A. Domínguez, "Analysis of the economic feasibility and reduction of a building’s energy consumption and emissions when integrating hybrid solar thermal/PV/micro-CHP systems," Appl Energ, Vol. 165, pp. 828-838, 2016.

[3] S. A. Keshavarz, P. Talebizadeh, S. Adalatia, M. A. Mehrabian and M. Abdolzadeh, “Optimal Slope-Angles to Determine Maximum Solar Energy Gain for Solar Collectors Used in Iran”, International journal of renewable energy research, Vol.2, No.4, pp. 665-673, 2012.

[4] J. A. Duffi and W. A. Backman, *Solar Engineering of Thermal Processes*, 4rd ed., Wisconsin Madison, Wiley, 2006.

[5] H. Hottel and B. B. Woertz,‘‘Performance of Flat-Plate Solar Heat Collectors’’, Trans. ASME vol. 64, pp. 91-104, 1942.

[6] F. Motte, G. Notton, C. Cristofari and J. L. Canaletti, "A building integrated solar collector: Performances characterization and first stage of numerical calculation," Renew Energ, Vol. 49, pp. 1-5, 2013.

[7] D. Mishra and N. K. Saikhedkar, "A Study and Theoretical Analysis of Evacuated Tube Collectors as Solar Energy Conversion Device for Water Heating," Advance Physics Letter, vol. 1, Iss.3, pp. 26-35, 2014.

[8] W. Yaici and E. Entchev, Prediction of the performance of a solar thermal energy system using adaptive neuro-fuzzy inference system, 3rd International Conference on Renewable Energy Research and Applications Milwakuee, USA,pp. 601-604, Oct 2014.

[9] L. Ayompe and A. Duffy, "Thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial," Solr energ, vol. 90, pp. 17-28, 2013.

[10] R. G. Raluy, L. M. Serra, M. Guadalfajara and M. A. Lozanoa, "Life cycle assessment of central solar heating plants with seasonal storage," Energy Procedia,vol. 48, pp. 966-976, 2014.

[11] S. Patil, A. A. Keste and A. Sable, ‘‘Investigation and Development of Liquid Flat Plate Solar Collector using Concrete as Absorber Plate and its Performance Testing,’’ International journal of renewable energy research, Vol.6, No.4, pp.1212-1220, 2016.

[12] A. Ciocan, M. Tazerout, A. Ciocan, T.Pirosecaru, J. F. Durastanti, “Thermodynamic evaluation for a small scale compressed air energy storage system by integrating renewable energy sources,”, 4th International Conference on Renewable Energy Research and Applications, Palermo, Italy, pp.455-460, Nov 2015.

[13] S. A. Kalogirou, "Solar thermal collectors and applications Progress in Energy and Combustion," Science, vol. 30, pp. 231-295, 2004.

[14] M. Binotti, G. D. Zhu, A. Gray and P. G. Manzolini, "Geometric analysis of three-dimensional effects of parabolic trough collectors," Sol. Energ., vol. 88, pp. 88-96, 2013.

[15] E. M. Toygar, T. Bayram, O. Das, A. Yazar, M. Tastan, H. Calmaz and Ö. Faruk Kaya, “Design and Development of Solar Flat Mirror and Heat Storage System”, 3rd International Conference on Renewable Energy Research and Applications, Milwakuee, USA, pp. 821-827, Oct 2014.

[16] T. Li, F. Yang and C. Yuan, "A Novel olic Trough Solar Lighting and Thermal System for Building Energy Efficiency," IEEE International Conference on Automation Science and Engineering (CASE), Madison, pp. 17–20, August 2013.

[17] M. Qu, H. Yin and D. H. Archer, "A solar thermal cooling and heating system for a building: Experimental and model based performance analysis and design," Sol Energ, vol. 84, pp. 166–182, 2010.

[18] J. Wang, T. Mao and C. Duo, "Configuration optimization with operation strategy of solar assisted building cooling heating and power system to minimize energy consumption," Energy Procedia, vol. 88, pp. 742–747, 2016.

[19] J. Pandolfini and A. Krothapalli, "Thermodynamic Modeling of the Multiple Parabolic Reflector Flat Panel Collector," Energy Procedia, vol. 57, pp. 2762–2771, 2014.

[20] G. Martinopoulos and G. Tsalikis, "Active Solar Heating Systems for Energy 1 Efficient Buildings in Greece: A Technical Economic and Environmental Evaluation," part A Energ. Buildings, vol. 68, pp. 130-137, 2014.

[21] J. Deng, Z. Tian, J. Fan, M. Yang, S. Furbo and Z. Wang, "Simulation and optimization study on a solar space heating system combined with a low temperature ASHP for single family rural residential houses in Beijing,," Energ. Buildings, vol. 26, August, pp. 2–13, 2016.

[22] J. Glembin, T. Haselhorst, J. Steinweg and G. Rockendorf, "Simulation and evaluation of solar thermal combi systems with direct integration of solar heat into the space heating loop," Energy Procedia, vol. 91, pp. 450 – 459, 2016.

[23] V. Verma and K. Murugesan, "Experimental study of solar energy storage and space heating usingsolar assisted ground source heat pump system for Indian climaticconditions," Energ Buildings, vol. 139, pp. 569–577, 2017.

[24] C. E. Montes and S. Cortez, ‘‘Solar Heating System to Reduce Friaje in High Andean Homes’’, International journal of renewable energy research. Vol.6, No.4, pp. 1537-1544, 2016.

[25] Y. Yoshida, Y. Ueda, “Verification of Consumer's Benefits for Different Area Ratio of PV Array and Solar Thermal Water Heater Considering Regional Characteristics,” 4th International Conference on Renewable Energy Research and Applications, Palermo, Italy, pp. 472-477, Nov 2015.

[26] S. Simms and J. F. Dorville, “Thermal mance of a Hybrid PhotovoltaicThermal Collector with a Modified Absorber,” 4th International Conference on Renewable Energy Research and Applications, Palermo, Italy, pp. 600-605, Nov 2015.

[27] ASHRAE Standard 93, Method of Testing to Determine the Thermal Performance of Solar Collectors, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1986.