

EXPERIMENTAL ANALYSIS OF THE THERMAL PERFORMANCE OF TWO SOLAR COLLECTORS MODELS UNDER EGYPTIAN CONDITION

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ABSTRACT

The thermal performance of two solar collectors (batch system) was experimentally tested. Experiments were carried out during seasons of 2015 and 2016 at Faculty of Agriculture, Zagazig University, Egypt. In January, inlet water temperatures for both models were around 17 °C , and outlet temperatures were 27 and 23°C for models A and B respectively, while in July, inlet water temperatures for both models were around 35 °C, and outlet temperatures were 55 and 49°C for model A and B respectively. Obtained results show that model (A) can rise water temperature higher than model (B) almost throughout the year. Energy collected varied between 655 and 335 W for models A and B respectively in January and 1955 and 975 W for models A and B respectively in July. However, The monthly average energy losses varied between 380 and 180 W for models A and B respectively in January and 1090 and 360 W for models A and B respectively in July. The average system efficiency varied from 43% to 50% in January for models A and B respectively while the system efficiency varied from 44% and 63% in July for models A and B respectively.

Keywords: *integrated collector, batch system , hot Water, renewable energy, solar radiation.*

INTRODUCTION

Solar collectors technology is used in many parts of the world including the U.S., China, India, and the Middle East. Systems have been adopted for a wide range of use patterns and climate conditions. However, most existing systems are geared toward wealthy clients. These systems often include sophisticated pumping systems and advanced materials. While these systems are profitable to their developers, they are often far beyond the financial constraints of households in poor communities of developing countries.

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Today, engineers and scientists can harness solar energy with common materials and basic technologies. The simplest version is the batch solar water heater, consisting of a water tank, a dark absorber to capture the sun's radiation effectively, and a sheet of glass to create a greenhouse effect. Water enters at the bottom and is 'baked' in the sun. As it warms, hot water travels to the top of the tank due to its lower density. When the water is ready for use, cool water is supplied to the inlet and hot water flows out the top. Batch heaters systems can also include insulation to help maintain the temperature of the heated water. Batch heaters (also known as "bread box" or integral collector storage systems) are simple passive systems consisting of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. Batch heaters are inexpensive and have few components in other words, less maintenance and fewer failures. A batch heater is mounted on the ground or on the roof. There are two main types of solar water heater systems: passive and active. Active systems integrate pumps and rotary elements and are therefore very expensive. Passive systems use natural water circulation, gravity, and/or pressurized water systems. Passive solar water heater systems are much less expensive than their active counterparts and are easier to maintain and repair. Consequently, passive systems are more suitable for low-income communities, (*Duffie and Beckman,2013*). (*Al-Madani,2006*) studied a batch solar water heater in Bahrain consisting of an evacuated, cylindrical glass tube. Water runs through copper coils, which act as collectors, located within the glass tube. Side-by-side testing of prototypes resulted in a maximum temperature difference between the inlet and outlet of the cylindrical batch system of 27.8°C with a maximum efficiency of 41.8%. he determined the cost of manufacturing the cylindrical batch system to be \$318, slightly less expensive than typical flat plate collectors of \$358. (*Akuffo and Jackson,1998*) investigated a simpler batch solar water heater in Ghana. The integrated storage-collector unit was a rectangular galvanized steel box with a total storage capacity of 90l. "Angle iron" was used to support the edges and prevent buckling and jute fiber was used for insulation. This design achieved a maximum temperature of 45°C by 4:30pm and provided 30°C water at 5:30am the next day. Daily ambient peak temperatures exceeded 37°C.

They recommend transferring the heated water to another, more insulated storage tank to lessen overnight heat loss. (*Mohamad,1997*) found that the thermal efficiency is comparable to conventional systems, estimated at 50%. Maximum average water temperature was 42°C at 5:00pm with an ambient temperature approximately 35°C; 5:00am water temperature was measured to be 34° with an ambient temperature approximately 18°C. he found that the thermal diode yielded a 10% improvement in maintaining the water temperature overnight when compared to a control prototype with no diode. The integrated collector water storage (ICWS) systems are simple type solar water heaters that can be used for the supply of hot water for domestic purposes, as alternative devices to the well known flat plate thermos phonic units (FPTU). Thermal protection of storage tanks is less effective in ICWS systems compared to FPTU systems and several methods are suggested to keep water temperature at a satisfactory level. Among them, the use of a selective absorber that reduces radiation thermal losses and double glazing, transparent insulation and inverted or evacuated absorber to suppress convection thermal losses, are suggested methods that preserve water storage heat. The use of compound parabolic collector (CPC) symmetric reflectors can result in ICS solar systems with effective water heating by using the non-uniform distribution of solar radiation on the cylindrical absorber surface (*Chouhan and Agarwal,2013*).(*Rahul et al.2011*), tested a natural circulation closed thermo-syphon flat plate solar water at the Faculty of Engineering of University of Mazan-daran located in Babol city (36N, 52E). Data were collected for several sunny and cloudy days. Experimental results show that a temperature rise of about 68 °C during the month of July at storage tank depth of 10 cm can be achieved by the heater. The 10 cm depth of the tank is optimum which can supply hot water for 24 hours, (*Gnanadason et al.2011*). The efficiency of solar thermal conversion is around 70% when compared to solar electrical direct conversion system which has an efficiency of only 17% ,(*Ahsan et al.2010*). the effects on collector efficiency of a double-pass sheet-and-tube solar water heater with fins attached under various arrayed density. In addition, the number of pair ducts and total mass flow rate are taken into account during the calculation procedure ,(*Kumar et al.2010*) . In the

afternoon, the cold water from the storage tank on the way to the sealed end was partially or fully mixed with the hot water returning to the storage tank without a clear water circulation loop; furthermore, such mixing became more intense with the increase in the inlet water temperature of solar tubes. This indicated that increasing the collector tilt-angle of SWHs had no positive effect on the thermosyphon circulation of the water inside tubes (*Narayan et al.2010*). When there is no solar radiation, the energy in the storage water flows to the absorber and service water. In both cases, the absorber loses some of the heat due to convection to the air in the gap spacing, radiation to the side walls and radiation to the top glass cover. The top glass cover loses heat due to convection. The objective of this work is to compare the thermal performance of two solar collectors (batch systems) obtained at different times of the year.

MATERIALS AND METHODS

Experiments were carried out during seasons of 2015 and 2016 at Faculty of Agriculture, Zagazig University, Egypt. (longitude = $35^{\circ} 30'$ and latitude = $31^{\circ} 31'$).

Materials

Batch systems

The simplest of all solar water heating systems is a batch system. It is simply one or several storage tanks coated with a black, solar-absorbing material in an enclosure with glazing across the top and insulation around the other sides. It is the simplest solar system to make and is quite popular with do-it-yourselfers. When exposed to direct sun during the day, the tank transfers the heat it absorbs to the water it holds. The heated water can be drawn for service directly from the tank or it can replace hot water that is drawn from an interior tank inside the residence.

Two systems were tested and compared (A and B).

System A : (Fig.1)consists of:

- 1- box (100 length×70 height× 50width cm),the base and one of the sides were made of wood (1.5 cm thickness) and the other sides and the top cover were made of single layered transparent glass. Four 40-cm-length legs were connected at the corners of the bottom of the box to raise the body of from the ground.

2- the cylinder tank (60 height×30 diameter cm) was made of metal painted with black paint to increase the efficiency of energy collection. There are 2 hose fittings, one of them to enter the cold water from pipe and the other to exit the hot water.

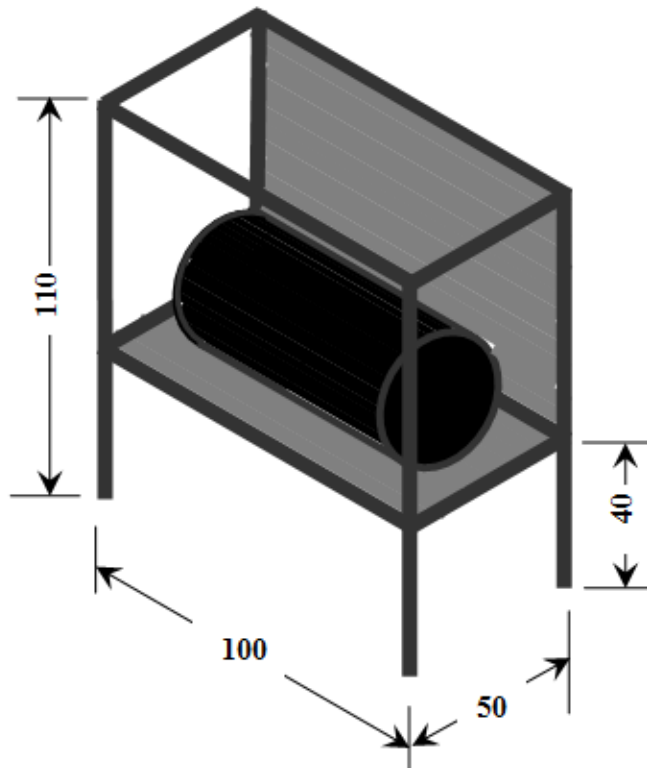
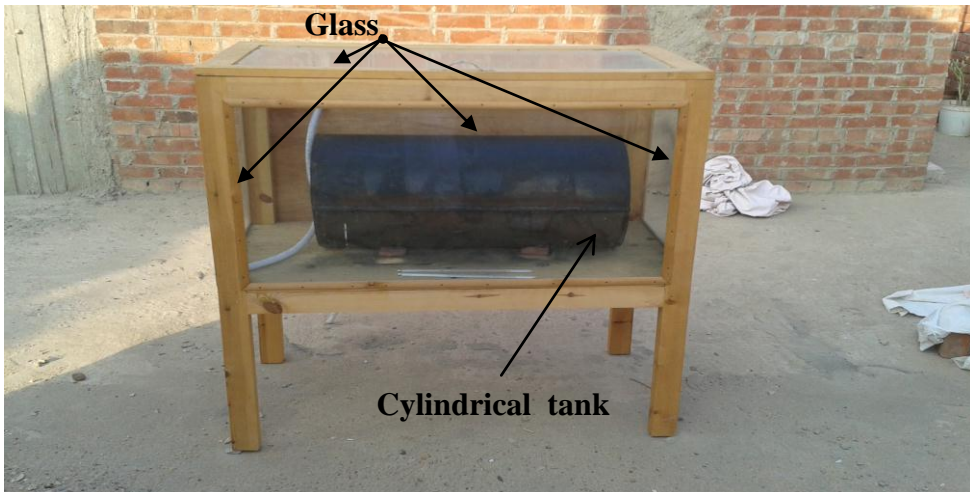


Figure (1): system A.

System B : (Fig. 2)consists of:

- 1- box (100 length× 50 width cm),the high of front side is (40cm) and the rare side is (70cm), the base and the all sides made of wood (1.5 cm thickness) and the top cover was made of single layered transparent glass. Four 40-cm-length legs were connected at the corners of the bottom of the box to raise the body of from the ground.
- 2- the cylinder tank (the same Specifications in system A).

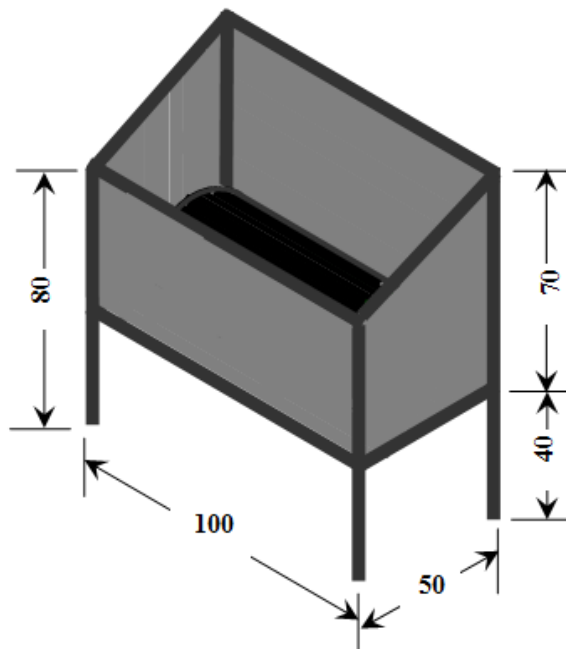
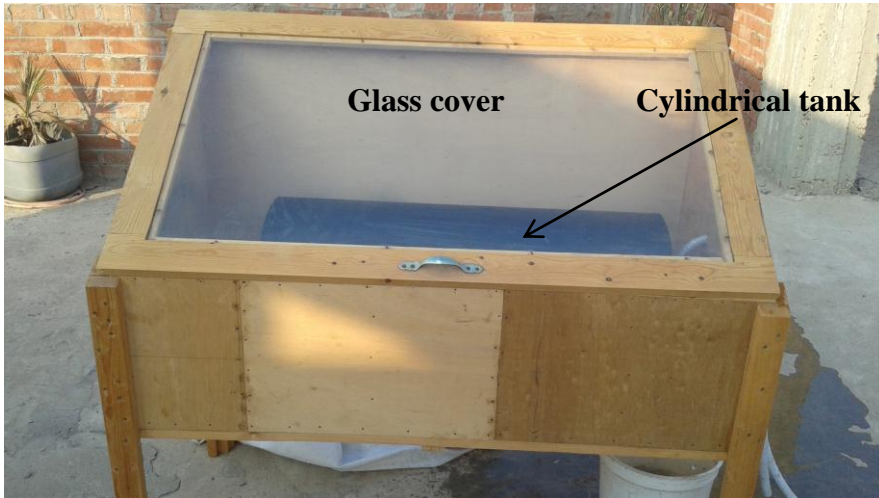


Figure (2): system B.

Methods

Experimental procedure

Sun strikes the water storage tank and heats the water. The hot water floats to the top and the coldest water remains at the bottom of the tank. A hose leading from the top of the tank carries the hottest water into the house. Temperature at the tanks outlet was measured from 10:00 am to 20:00 pm each hour for the all months of the year.

Measurements and Determinations

Solar radiation and temperature of ambient air were measured by "Watchdog" weather station model 900 ET. The Weather station measures wind speed (0-175 mph) \pm 5%, wind direction (2° increments) \pm 7°, temperature (-30° : 100° c), relative humidity (20 - 100%) \pm 3%, rainfall (0.01- 0.25 cm) \pm 2% and solar radiation (1 - 1250 W/m²). Air temperatures inside the collectors were recorded at different positions using thermometers with accuracy of 1 °c with maximum of 100°c and with calibrated thermocouples connected to a multi channel digital display with an accuracy of 0.05 °c.

Thermal performance of the solar collector:

The thermal performance of the solar collector can be described in terms of several parameters which are usually employed to assess that performance. These parameters and their effect on thermal performance can be calculated according to **Shewen *et al.* (1980)** as follows:

Absorbed solar energy (Q_{abs.}):

$$Q_{abs.} = \tau\alpha\beta IA_c, W$$

Where: τ : Effective transmittance of collector cover system, (0.8°),

α : Effective absorbance of collector cover system, (0.9°),

β : Effective shadow and dust of collector cover system, (0.95),

I: Solar energy flux incident on the surface of the collector, W/m² and

A_c: Surface area of the collector, m².

Useful heat gain (Q_{g.}): The useful energy collected by the solar energy collector is given as (**Kalogirou, 2009**):

$$Q_{g.} = mc_p (T_{ao} - T_{ai}), W$$

Where: m: Mass flow rate of water, kg/s, c_p: Specific heat of water, J/kg. °c,

T_{ao}: Outlet temperature of water, °c and T_{ai}: Inlet temperature of water, °c.

Heat transfer efficiency (η_n): The collector efficiency was calculated as (Sukhatme, 1998, Duffie and Beckman,2006):

$$\eta_n = (Q_g / Q_{abs.}) \times 100 \quad , \%$$

Solar collector heat losses (Q_L): $Q_L = Q_{abs.} - Q_g \quad , \quad W$

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following heads:

solar radiation and ambient temperature:

Fig. 3 shows average monthly solar insolation on the collector’s surface and average monthly air temperatures during 2015-2016. The monthly average solar insolation on the collector’s surface varied between 220 W/m².day in January and 460 W/m².day in July and average monthly air temperatures varied between 17 °c in January and 34 °c in July.

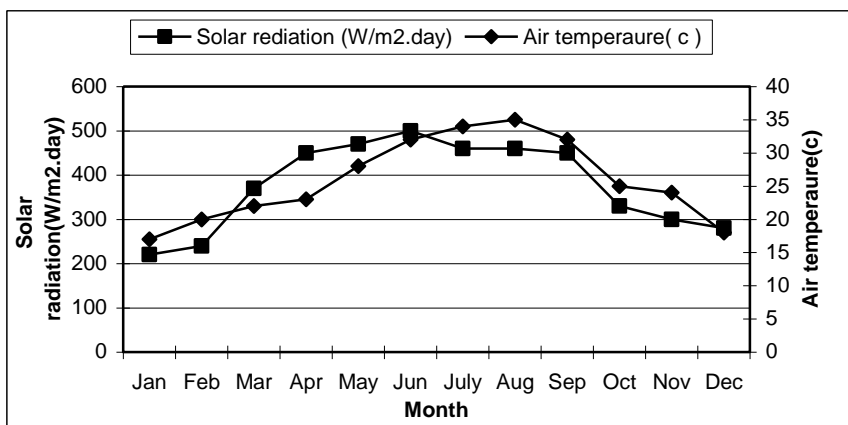


Fig. 3 Average monthly air temperatures and solar radiation.

Systems temperatures:

Fig. 4 shows average recorded monthly temperatures of inlet water $T_{(A,B)in}$ and outlet water $T_{(A)out}$ and $T_{(B)out}$ for the two models . The average monthly water temperatures were fairly throughout the year, for example in January, inlet water temperatures for both models were around 17 °C , and outlet temperatures were 27 and 23°C for models A and B respectively and in April, inlet water temperatures for both models were around 23 and outlet temperatures were 50 and 43°C, for models A and B respectively , while in July, inlet water temperatures for both models were around 34 and outlet temperatures were 55 and 49°C for models A and B

respectively and in October, inlet water temperatures for both models were around 25 and outlet temperatures were 39 and 35°C for models A and B respectively. From these observations, it is clear that model (A) can rise water temperature higher than model (B) almost throughout the year.

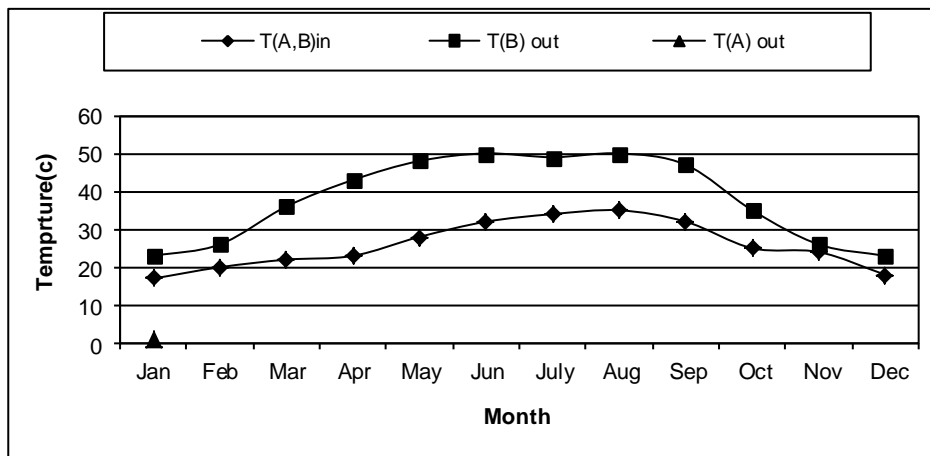


Fig. 4 Average monthly models temperatures .

Energy absorber, gain and losses:

Fig. 5 ,6 and 7 shows monthly average energy absorber to the water tank, energy gain and the solar collector heat losses. The monthly average energy collected varied between 860 and 430 W for models A and B respectively in December and 1955 and 975W for models A and B respectively in June. Average energy gain varied between 415 and 150 W for models A and B respectively in December and 895 and 655 W for models A and B respectively in June. However, The monthly average energy losses varied between 445 and 280 W for models A and B respectively in December and 1060 and 375 W for models A and B respectively in June.

From Fig. 5 models A absorbed the solar radiation more than model B because the absorber area for model A is bigger than B. This is due to the cover and the sides which were made of glass in model A. However these glass sides caused higher losses from energy collected compared with model B.

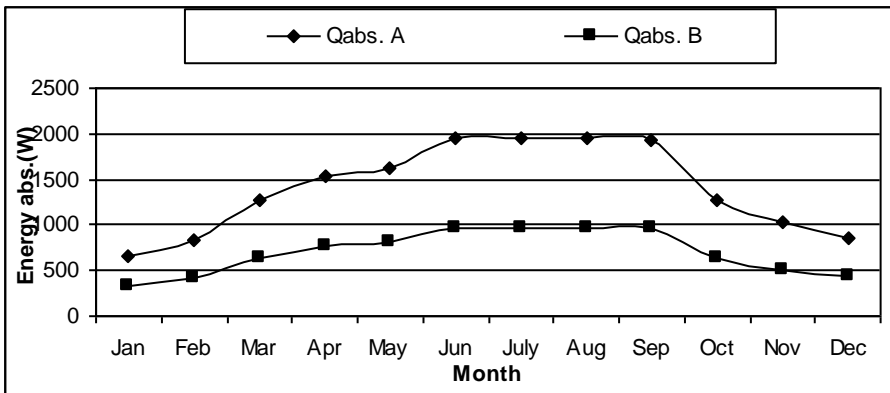


Fig. 5 Average monthly energy absorber for the two models .

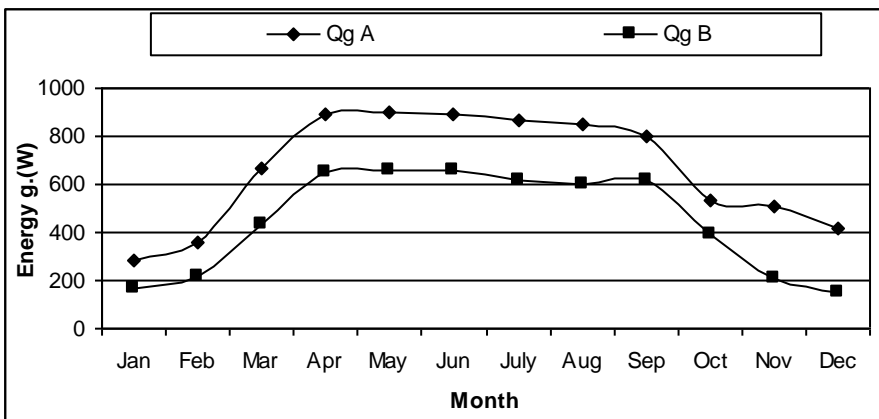


Fig. 6 Average monthly energy gain for the two models .

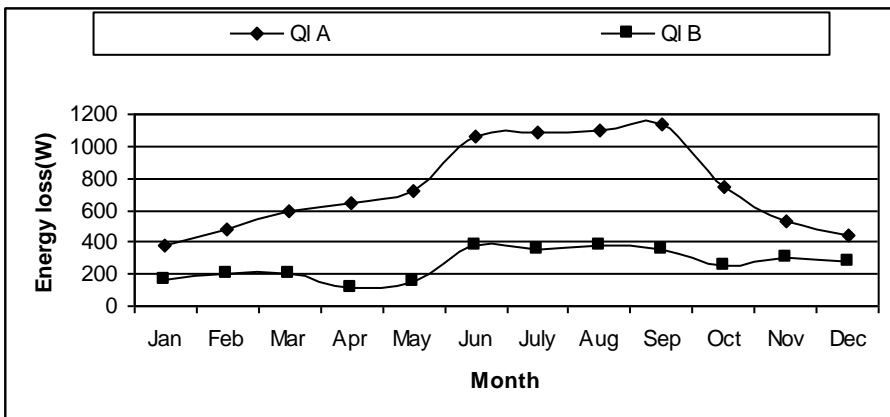


Fig. 7 Average monthly energy losses for the two models .

Systems efficiency:

Fig. 8 shows monthly average system efficiencies. The average system efficiency varied from 43% and 50% in January for models A and B respectively while the system efficiency varied from 44% and 63% in July for models A and B respectively. Model B is more efficient than model A in all months except November and December .

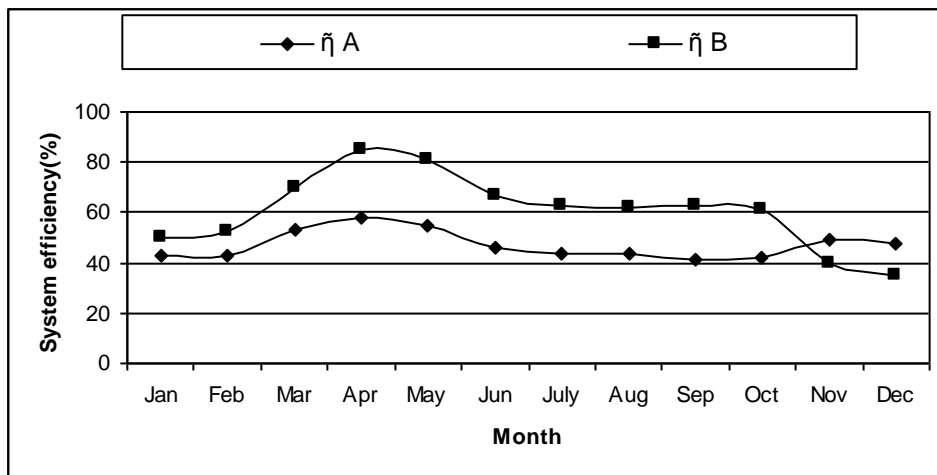


Fig. 8 Average monthly efficiency for the two models .

CONCLUSIONS

From the obtained results, it can be concluded that:

System (B) is capable of achieving significant energy savings in hot climate countries particularly in the present situation of acute energy short age and most suitable to supply the house needs.

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الملخص العربي التحليل التجريبي للأداء الحراري لنموذجين من المجمعات الشمسية تحت الظروف المصرية

د. منى محمود عبدالعزيز حسن

تم في هذا البحث دراسة الاداء الحراري لنموذجين مختلفين من المجمعات الشمسية التي تعمل بطريقة التدوير الطبيعي , تم اختبار المجمعات على مدار العام لموسمى ٢٠١٥ و ٢٠١٦ فى مدينة الزقازيق محافظة الشرقية بجمهورية مصر العربية. يتكون النموذج الاول من صندوق ذو اربعة اوجه زجاجية (الوجه العلوي والامامي والجانبين) اما الوجه الخلفي والقاعدة مصنوعة من الخشب والنموذج الثاني يتكون من صندوق ذي وجه واحد زجاجي فقط وهو الوجه العلوي وبقية الواجه كلها من الخشب و بداخل كلا منهما اسطوانة من المعدن مطلية باللون الاسود لامتناس اشعة الشمس النافذة عبر الزجاج و المحتوية على الماء كوعاء تخزينى للحرارة الممتصة لاستخدامها فى اغراض مختلفة مثل التدفئة للمنازل او مزارع الدواجن او الاستخدام المنزلى اليومي للمياه الساخنة.

أظهرت النتائج الاتى:

- متوسط الاشعاع الشمسى مختلف من شهر الى شهر اخر على مدار العام، حيث كان متوسط الاشعاع الشمسى ٢٢٠، ٤٦٠، وات /م^٢ خلال شهرى يناير و يوليو على التوالى فى حين كانت درجة حرارة الجو ١٧، ٣٤ درجة مئوية خلال شهرى ديسمبر و يونيو على التوالى.
- كانت درجات حرارة دخول الماء و خروجه من المجمع الشمسى مختلفة من وقت الى اخر، فمثلا كانت درجات الحرارة خلال شهر يناير ١٧، ٢٧، و ٢٣ درجة مئوية لدخول الماء للنظامين و خروجه من النظام A و النظام B على التوالى. فى حين كانت ٣٤، ٥٥ و ٤٩ خلال شهر يوليو لدخول الماء للنظامين و خروجه من النظام A و النظام B على التوالى.

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- بالنسبة لكمية الطاقة الممتصة على مدار اليوم كانت ٨٦٠ و ٤٣٠ وات/م^٢. اليوم للنظام A و النظام B على التوالي خلال شهر ديسمبر و ١٩٥٥ و ٩٧٥ على التوالي خلال شهر يونيه.
- اما كمية الطاقة المفقودة كانت ٤٤٥ و ٢٨٠ وات/م^٢. اليوم للنظام A و النظام B على التوالي خلال شهر ديسمبر و ١٠٦٠ و ٣٧٥ وات/م^٢. اليوم على التوالي خلال شهر يونيه.
- كانت كفاءة النظامين مختلفة ايضا على مدار العام فكانت ٤٣ و ٥٠ % للنظام A و النظام B على التوالي خلال شهر يناير و ٤٤ و ٦٣ % على التوالي خلال شهر يوليو.
- من خلال النتائج يتضح ان النظام B اكثر كفاءة من النظام A فيما عدا شهرى نوفمبر و ديسمبر.