Experimental Study of The Performance of The Dual Purpose Solar Collector

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ABSTRACT

In the present work, experimental study has been done to estimate the performance of solar heating system by air-water (Dual) solar collector. Flat plate dual solar collector with dimensions (120 cm length, 80 cm width and 15 cm thickness) has been used for heating the test space with dimensions (2×2×2.5) m. In this study, the system has been operated in Al-Najaf city with 45^o tilt angle to the south. The results obtained that the dual flat plate solar collector daily efficiency is 52.02 %.They also showed the ability to use dual solar collector absorber as heat exchanger in the night to maintain room temperature in the comfort condition for space heating in the winter season.

Keywords: Dual solar collector, Space heating, Solar radiation, Effectiveness

دراسة عملية لاداء المجمع الشمسي المزدوج الغرض

الخلاصة

في هذا البحث تم اجراء دراسة عملية لتخمين اداء منظومة تدفئة بالطاقة الشمسية باستخدام مجمع شمسي هوائي مائي (مزدوج) لهذا الغرض . تم استخدام مجمع شمسي مستوي بابعاد 120 سم طول، 80 سم عرض و 15 سم سمك لتدفئة حيز بأبعاد 2 م طول، 2 م عرض و 2.5 م ارتفاع . تم تشغيل هذه المنظومة في مدينة النجف (الكوفة) و بزاوية 45^o نحو الجنوب بالنسبة للمجمع الشمسي . لقد بينت النتائج العملية لهذه الدراسة ان الكفاءة اليومية للمجمع الشمسي المزدوج تساوي 52.02% . و كذلك اثبتت النتائج العملية انه من الممكن استخدام هذا النوع من المجمعات الشمسية كمبادل حراري في الليل للحفاظ على درجة حرارة فضاء معين ضمن درجات حرارة الراحة للأنسان كعملية تدفئة في فصل الشتاء.

INTRODUCTION

One of the easiest sources of renewable energy is solar energy. It is obtained from the sunlight and can be stored, used and converted into various forms. The sun provides us with heat and light that is essential to life all year round. Converting the sun's radiant energy into heat is the most common and well-developed solar conversion technology today [1]. A solar collector is a special kind of heat exchanger that transforms solar radiant energy into heat [2]. Among the solar thermal technology, the flat-plate solar collectors have been widely used as air heating collectors or water heating collectors. A design of solar collector that is able to provide both water and air has been proposed to increase annual thermal conversion ratio of solar energy. This type called air-water solar collector or dual-function solar collector [3]. Dual-function solar collector is able to provide space by hot air or hot water in winter season simultaneously [4].

Many researchers have studied these subjects in the past. Ma et. al. [3] studied the design of solar collector that is able to provide both hot water and hot air has been proposed to increase annual thermal conversion ratio of solar energy. By modifying the conventional flat-plate solar water heater, the collector with L-shape fins can also function as a double-flow solar air heater (upper and lower absorber plate air channel). Experiments have been conducted to investigate the dual functions of the collector. Assari et. al. [4] investigated experimentally and theoretically of dual purpose solar collector. Experimental data indicate that high temperature and high performance can be obtained using dual purpose solar collector (DPSC) compared to single water or air collector. A mathematical model based on effectiveness method has been developed for the investigation of thermal performance of DPSC. Ji et. al. [5] studied the thermal characteristics of a building wall integrated dual-function solar collector in water heating mode with natural circulation. As a modified building-integrated solar thermal system, building-integrated dual-function solar collector here proposed is able to provide passive space heating and water heating in cold winter. Ucar and Inalli [6] studied the thermal and exergy analysis of solar air collectors with passive augmentation techniques. In this experimental investigation, the shape and arrangement of absorber surfaces of the collectors were reorganized to provide better heat transfer surfaces suitable for the passive heat transfer augmentation techniques. Zhai et. al. [7] studied the comparison of heating and natural ventilation in a solar house induced by two roof solar collectors. In this research, two kinds of roof solar collectors (RSCs), namely, the single pass and the double pass are analyzed and compared.

Experimental Work

Experimental investigation was carried out on solar test rig consists of many main components to investigate experimentally utilize of air-water (Dual) solar collector for space heating, as shown in figures (1) and (2). Dual flat plate solar collector is the main component of the present system. It is consist of many parts: casing, absorber plate with its tubes, insulation and glass cover.

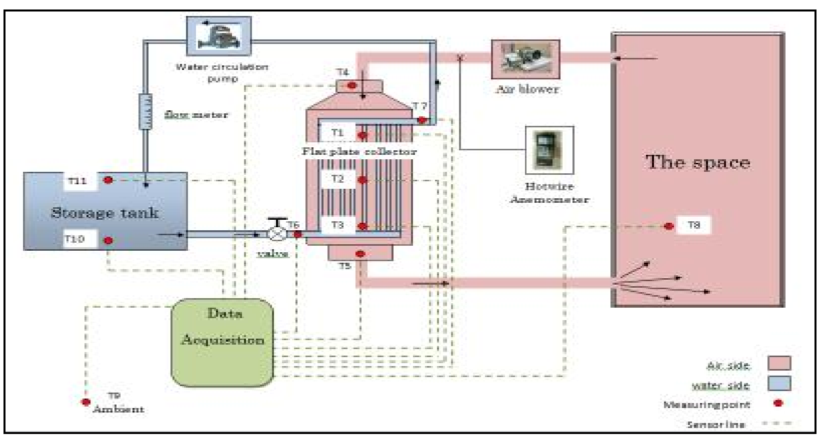

Figure (1) schematic diagram of test rig

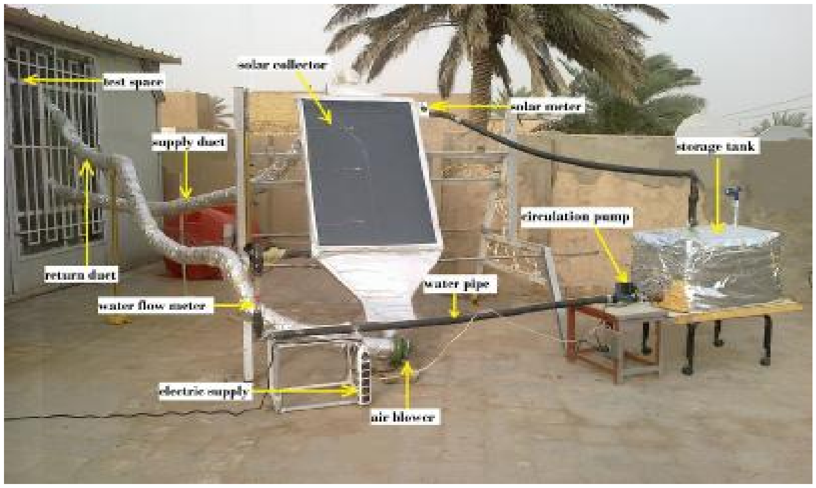

Figure (2) photography photo of test rig

The solar collector dimensions are (200×85×15) cm length, width and thickness respectively. The casing is made from Aluminum plates (0.5 mm) thickness with dimensions (136×85×15) cm length, width and depth respectively. Absorber is made from steel (k =73 W/m.K) with black coating (matt black paint). The riser tubes network is made from copper (k =385 W/m.K). It is consists from 8 riser tubes with 0.75 in diameter and 2 header tubes with 1.5 in diameter. In this collector, is used glass wool (k =0.038 W/m.K) as insulation. A (4mm) thickness glass cover used to decrease the heat energy losses between absorber plate and the ambient. Figure (3) is sectional view of dual flat plate solar collector and assembly of components. The remaining space between the absorber plate and glass cover represents the air flow channel with (50 mm) height. It is important in the solar collector components arrangements, tight any air leakage because the leakage of air will effect on the performance of the solar collector and decrease its efficiency.

The thermal energy that received from dual solar collector was stored in 100 litter water storage tank. The tank was made 3 cm thickness of polyurethane (k =0.045 W/m.K) and provide by 3 cm thickness of glass wool insulation. In order to circulate the water in the system, a circulation pump was used with 100 litter/hr water flow rate. Plastic pipes with 19.05 mm (0.75 in) diameter have been used to connect circulation pump, dual solar collector and storage tank. To know the utilize of dual flat plate solar collector for space heating, a test space with dimensions (2×2×2.5) m length, width and height respectively has been made. This room is made from 50mm thickness of polyurethane (k=0.045 W/m.K). The air through the system with velocity 2 m/s in 10 cm flexible ducts is circulating. A centrifugal blower type is chosen to circulate air through the system. These ducts were insulated by 3 cm thickness of glass wool insulation to decreases heat losses.

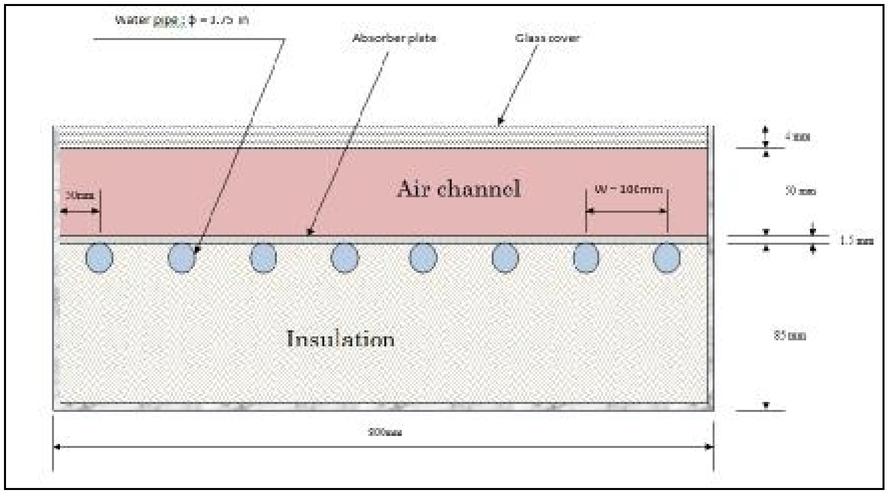

Figure (3) section of dual flat plate solar collector

Data acquisition device is used to record the temperature in many points of the test rig as shown in figure (1). Water flow rate, solar radiation and air flow rate were measured by flow meter, solar power meter and hot wire anemometer respectively. Test rig was instilled in Al-Kufa city with 45^o tilt angle to south for the solar collector. Experiment test was made on February 2013 (Sunny day). Table (1) show the parameters of experimental test was made in this study.

Table (1) experimental operation modes

Air velocity in duct (V_a)	2 m/s
Water volume flow rate ($\dot{V}_w$)	100 L/hr
Air density (ρ_a)	1.2 kg/m^3
Water density (ρ_w)	1000 kg/m^3
Specific heat of water (C_p)	4180 kJ/kg.K
Specific heat of air (C_p)	1000 kJ/kg.K
Storage tank volume	100 litter
Collector (length, width and thickness)	(120×80×15) cm
Air duct diameter (d_{duct})	10 cm

THEORETICAL PART

1- **Air and water mass flow** rate can be calculate from equation (1) and (2) as follow:

$$\dot{m}_a = \rho_a \cdot V_a \cdot A_{duct} \quad \dots (1)$$

$$\dot{m}_w = \rho_w \cdot \dot{V}_w \quad \dots (2)$$

Where:

A_{duct}: cross section duct area = $\frac{\pi}{4} \cdot d_{duct}^2$

2- **Useful energy for air and water** can be calculate from equation (3) for inlet and outlet air and water temperatures:

$$Q_{u_a} = \dot{m}_a \, . C_{p_a} \, . (T_{out_a} - T_{in_a}) \qquad \ldots (3)$$

$$Q_{u_w} = \dot{m}_w \, . C_{p_w} \, . (T_{out_w} - T_{in_w}) \qquad \ldots (4)$$

3- **Collector efficiency:** it is the ratio of the useful energy gain over some specified time period to the solar radiation energy over the same time period and can be calculate from below equation [8]

$$\eta = \frac{Q_u}{A_c \, . G_T} \qquad \ldots (5)$$

Where:
A_c : Collector absorber area (m^2).
G_T : Incident solar energy (W/m^2).

4- For fully mixed energy water storage tank, that heat capacity (Q_{st}) for the water storage can be calculate from equation (5) as follow: [9]

$$Q_{st} = M_w \, . (C_p)_{water} . (\Delta T_s) \qquad \ldots (6)$$

Where:
M_w : mass of water storage (kg)
ΔT_s : water temperature increasing (K)

5- **Effectiveness:** in the night, solar collector will operate as heat exchanger between air and water. The heat energy has been transferred from hot water in storage tank to the space cold air by absorber plate for heating. The effectiveness was used to represent the performance of heat exchanger. Effectiveness can be define as follow: [10]

$$\text{Effectiveness} = \varepsilon = \frac{\text{actual heat transfer}}{\text{maximum possible heat transfer}}$$

To determine the maximum possible heat transfer for the exchange:

$$Q_{max} = \left(\dot{m} \, . C_p\right)_{min} . (T_{inlet\,water} - T_{inlet\,air}) \qquad \ldots (7)$$

Where:

$$\left(\dot{m} \, . C_p\right)_{min} = \dot{m}_a \, . (C_p)_{air}$$

6- **Hourly solar radiation, useful energy and collector efficiency**

Trapezoidal rule has been used to calculate the amount of hourly solar radiation and hourly useful energy. Trapezoidal rule is a method of numerical integration and can be defined as follow: [11]

$$\int_{x_o}^{x_n} f(x)dx = \frac{h}{2}\left(y_o + 2y_1 + 2y_2 + \cdots\cdots\cdots\cdots\cdots + y_n\right) \quad .. (8)$$

Where:
h: time interval between any two readings

7- Average plate temperature
Average absorber plate temperature can be calculated from the below equation:

$$T_{plate} = \frac{T_1 + T_2 + T_3}{3} \quad .. (9)$$

Results and Discussion

This test consists of two parts. In the first part, two sides (air and water) of the system in the figure (1) will operate as solar collector from 8am to 6pm (air-water solar collector). The useful energy has been calculated for air and water through day time. In this time interval, air and water will gain the heat energy from solar radiation, water will store the heat in the water storage tank and the heated air pump by blower to the space for heating. The results showed the daily efficiency of air and water sides are 14.99 % and 34.22% respectively. In the second part, the system operates as air-water heat exchanger with zero solar radiation (night).

Figure (4) shows the relation between solar radiation and useful energy along the time in the collector. As was mentioned before, solar radiation increased with the time of day to reach maximum value between 1 pm – 2 pm. Total useful energy increase also with the same shape of solar energy. Total useful energy consists of air useful energy and water useful energy. The maximum water useful energy delayed about 2 hours from the maximum useful energy of air. Water useful energy is decrease faster than air useful energy in the last hours of day, because heat capacity (C_p) of water more than air.

Between 5pm and 6pm, solar radiation reduced gradually (not enough to heat the air). At the end of solar time, the storage of heat in the water work as heat source to maintain air temperature inside the space by transfer of heat across the absorber plate collector like a heat exchanger. Figure (4) shows the behavior of air and water in the night (zero solar radiation). In the night, Water storage heat energy rejected to absorber plate and air has been caught this heat. The amount of storage heat rejected from water is more than air heat gain from absorber, because the losses of heat from heat exchanger to the ambient.

Figure (5) shows the variation of space temperature, ambient temperature and average storage tank temperature within the time of one day. The temperature of the water inside storage tank continue to rise from the minimum value 20.6 ^oC in the starting of the test to the maximum value 36.8 ^oC at solar time. Then, the storage heat in water transfer to maintain air temperature in the night across heat exchanger (absorber plate), therefore the temperature of water inside tank decreased.

According to Khalid A. Joudi [12] for space heating, the minimum value of space comfort temperature in the winter varied from 19 ^oC to 22 ^oC. In this work, the heat of water transferred to the air by heat exchanger (collector) is enough to maintain the space temperature above the minimum value 19.8 ^oC. If the system is provides by a control devices, the water can store more heat. By controlling the air mass flow rate (variable speed fan) when the temperature inside the space during the day exceeds the comfortable level, then water accumulates more heat from the solar collector. That means; the heat energy in the water storage tank can be enough for longer time in the space heating. The variation of water storage heat energy with the time of day was shown in the figure (6). The useful energy of water from 8am to 5am, has been stored in the tank. At night the storage heat will decrease because it is used to heat space air temperature.

Figure (7) depicts the variation of average absorber plate temperature (T_1, T_2, T_3) and ambient temperature within the time. The high difference between plate and ambient temperature lead to increasing the energy losses from solar collector.

$$Q_{loss} = U_{loss} . A . \Delta T \rightarrow Q_{loss} \propto \Delta T$$

Because of low temperatures of ambient in the night (6pm to 8pm), the glass cover of collector has been covered by a layer of polyurethane to reduce energy losses.

Figure (8) and (9) show the variation of inlet and outlet temperature of water and air during the day respectively. At night, water temperatures reverse (cooling), because water rejects its heat to air for space heating. The variation of air and water heat exchanger effectiveness in the night is shown in the figure (10). This figure shows that the effectiveness of the two fluids do not behavior uniformly during the night, because the following:

1. Variation of temperature difference between inlet and outlet of water and air as shown in figures (8) and (9). The increasing in temperature difference between inlet and outlet of any fluid lead to increasing of effectiveness.
2. The energy losses from the system effect on heat exchanger performance.

This figure shows that water with effectiveness 0.4479 is more than air with average effectiveness 0.3767, because that isn't all heat rejected from water transfer to air because the losses.

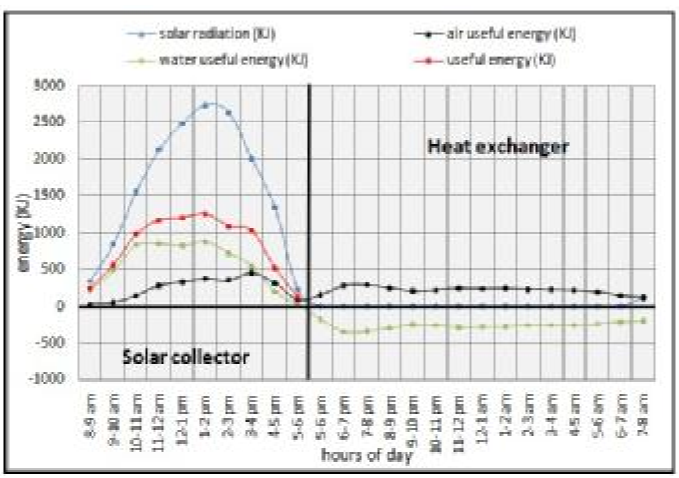

Figure (4) air-water solar collector and heat exchanger with solar radiation

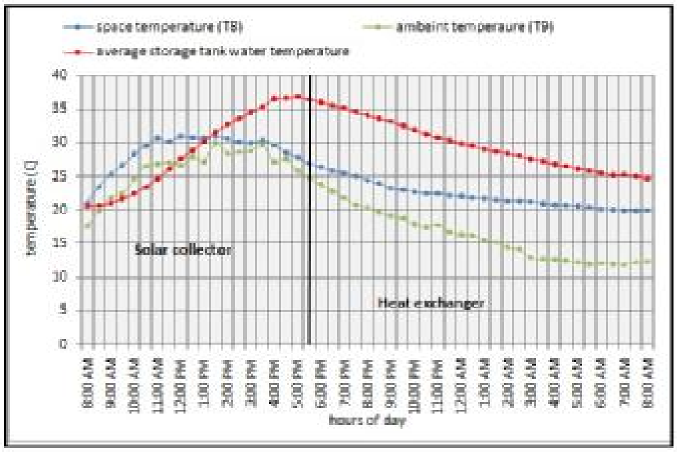

Figure (5) the variation of space, ambient, and storage tank water temperatures

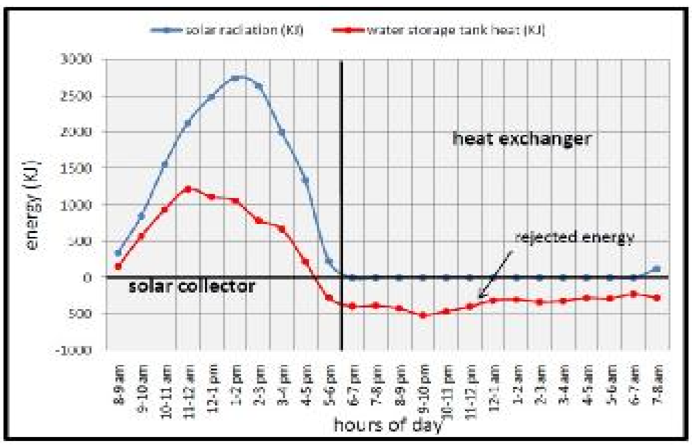

Figure (6) the variation of water storage tank heat with the time

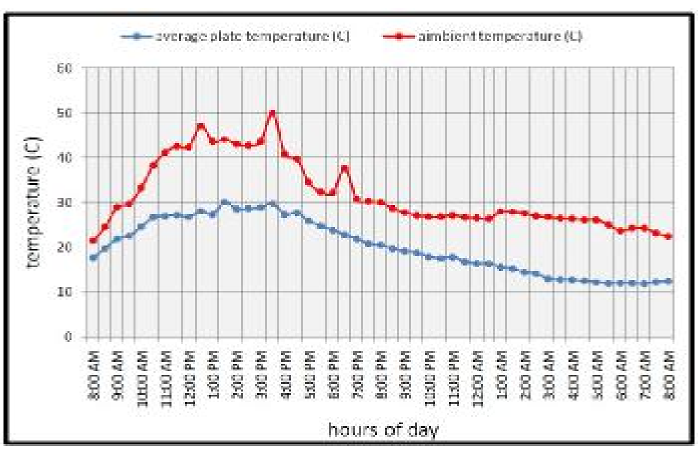

Figure (7) the variation of average absorber plate and ambient temperatures with time

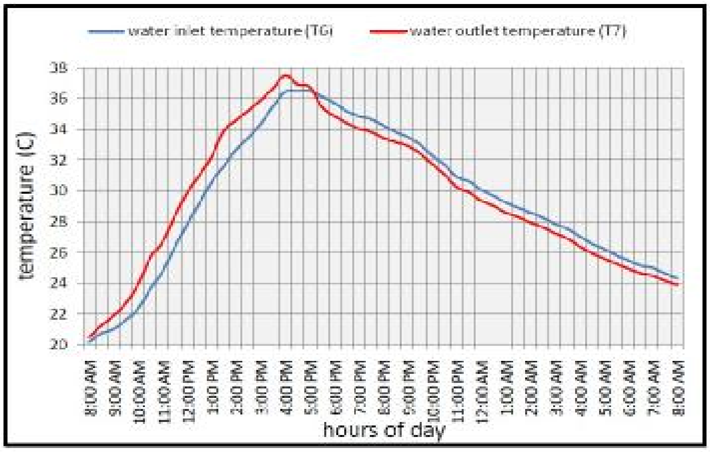

Figure (8) inlet and outlet water temperatures

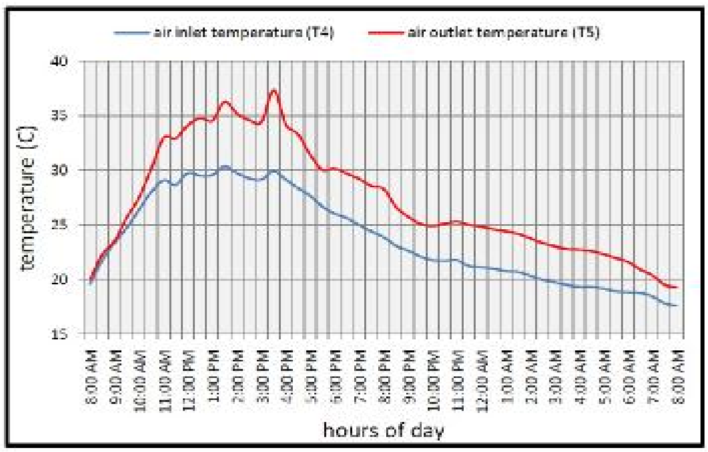

Figure (9) inlet and outlet air temperatures

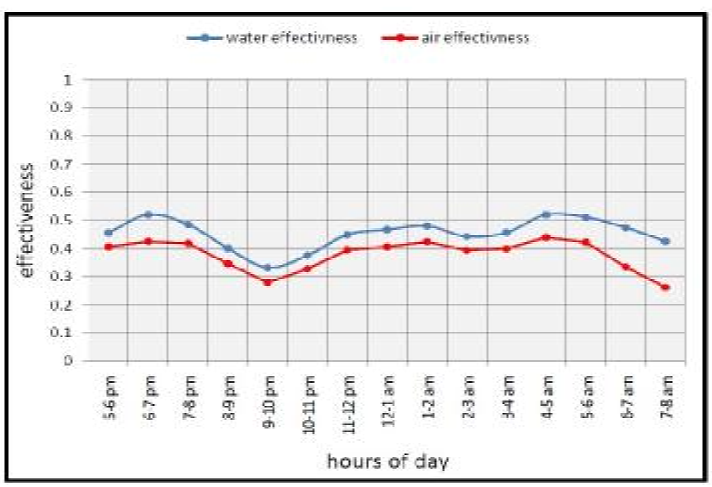

Figure (10) air and water heat exchanger effectiveness

CONCLUSIONS

From the results of the present work, the following conclusions are deduced:

1. The ability to use dual purpose solar collector as heat exchanger for space heating at night.
2. The solar collector energy losses increased when the temperature of absorber plate increased, i.e. effect on solar collector performance.
3. Air and water temperature difference of dual solar collector increased when solar radiation increased.
4. Water useful energy of water is greater than air useful energy in dual solar collector.
5. The effectiveness of water is greater than air effectiveness in air-water heat exchanger.
6. Using dual flat plate solar collector as heat exchanger will reduce cost and time.

NOMENCLATURE

A_c	Collector absorber plate area.	m^2
A_{duct}	Air duct cross section area.	m^2
C_p	Specific heat capacity.	J/kg. °C
d_{duct}	Air duct diameter.	m
G_T	Total incident solar radiation.	W/m^2
K	Conductivity	W/m. K
M	Mass	kg
$m^{\cdot}$	Mass flow rate	kg/s
Q_u	Useful energy	J
Q_{st}	Water storage energy	J
T	Temperature	K
V	Velocity	m/s
V^0	Volume flow rate	m^3/s
ε	Effectiveness	---
η	Collector efficiency	---
ρ	density	kg/m^3

SUBSCRIPTS

a	Air
in	inlet
max	Maximum
out	outlet
w	water

ABBREVIATIONS

DPSC	Dual purpose solar collector
RSC	Roof solar collector

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