Heat and Mass Transfer Research Journal
Vol. 1, No. 1; 2017
Published by CanSRG
http://cansrg.com/journals/hmtrj/

On The Performance of Solar Air Heaters: Numerical Study

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Abstract

Solar air heaters are used in many applications such as space heating and crop drying. A major drawback of solar air heaters is their low thermal efficiency. An enhancement in the efficiencies of solar air heaters should be associated with an augmentation in heat gain by flowing air and a reduction in heat losses to the ambient environment. This paper drives insight into the influence of the solar air heaters configurations on heat gain and loss within solar air heaters. A comparison was held in this paper between three solar air heaters. Results showed that recovering heat losses from the glass cover of the heater by flowing air improves the efficiency of the heater more than does doubling the glass cover of the heater. However, for relatively high air flow rates, the efficiency of conventional solar air heaters is very close to that where heat losses form the glass cover is recovered by flowing air.

Keywords: *Solar Energy; Air Heaters; Heat Transfer; Performance.*

Nomenclature

A	area
c_P	specific heat at constant pressure
h	heat transfer coefficient
I	solar intensity
m	mass
M	air mass flow rate
T	temperature
U	overall heat transfer coefficient
Greek symbols	
α	absorptivity
η	efficiency
τ	transmissivity
Subscripts	
0	stagnant or preheat
a	air
ab	absorber
amb	ambient conditions
c	convection heat transfer
g	glass
prj	projection
r	radiation heat transfer
sky	sky

1. Introduction

In today's world, the industrial growth accompanied with the growth in the world's population created a continuously increasing need for energy. Renewable resources such as solar energy can be considered a promising solution for the world's energy crisis. Solar energy can be converted into thermal energy or electricity through solar collectors or photovoltaic panels, respectively. Solar air heaters are simple, compact and cheap solar collectors where incident solar irradiation is converted into thermal energy at the absorbing surface and then transferred to the flowing air by convection heat transfer.

Solar air heaters are used in many applications such as space heating, crop drying and paint spraying operations [1]. The major shortcoming of solar air heaters is their low thermal efficiency

Submitted: June 26, 2017 Revised: October 4, 2017 Accepted: December 27, 2017

due to poor convection heat transfer between flowing air and the absorbing plate. Many attempts have been reported in the literature to enhance the thermal efficiency of solar air heaters. Yeh and Ting [2] investigated the effect of free convection on the efficiency of solar air heaters. Yeh and Lin [3] studied the influence of the collector aspect ratio on the efficiency of solar air heaters. Forson et al. [4] compared between single and double pass solar air heaters both theoretically and experimentally. Naphon [5] studied the performance of double-pass solar air heater with longitudinal fins. Yeh et al. [6] explored the efficiency of upward type baffled solar air heaters. Gao et al. [7] studied natural convection inside cross corrugated solar air-heater with sine-wave absorber. Chaube et al. [8] enhanced heat transfer inside solar air heaters by using ribbed absorber. El-khawajah et al. [9] used wire mesh as an absorbing plate. Tian et al. [10] added porous material inside the collector.

Efficiencies of solar air heaters are evaluated based on the ratio of the portion of incident solar energy gained by flowing air to the portion of incident solar energy lost to the ambient environment. Nevertheless, most of the studies reported in the literature focused on augmenting the portion of incident solar energy gained by the air. However, reducing thermal losses to the ambient environment would guarantee improving the heater's efficiency. The paper drives insight into how solar heater configuration influences heat gain and heat loss within the heater. A comparison is held here between three solar air heaters named conventional solar air heater, double glass single pass solar air heater and double pass solar air heater.

2. Mathematical Analysis

Figure 1 shows schematic diagram for three configurations of solar air heaters. The three heaters are made of the same materials and have consistent dimensions. The energy balance for the three solar air heaters are expressed as follows.

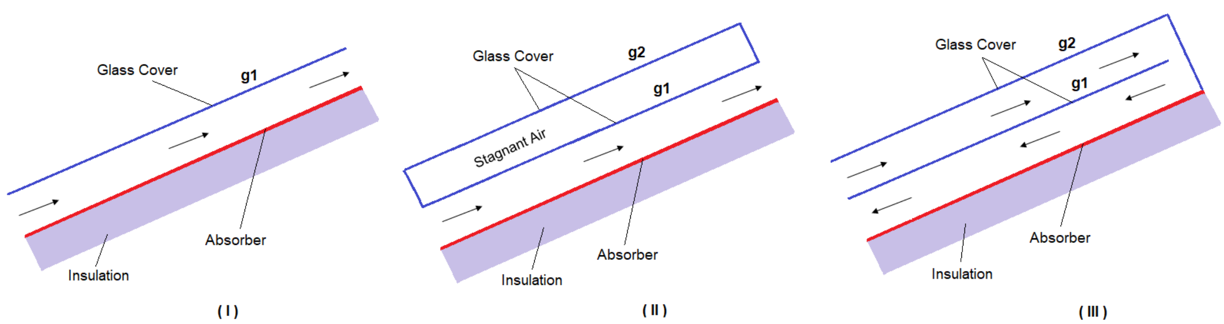


Figure 1. Solar air heaters configurations: (I) conventional solar air heater, (II) double glass single pass solar air heater, (III) double pass solar air heater.

I- Conventional solar air heater

The energy balance equation for the glass cover (g_1) is

$$mc_P \frac{dT}{dt} = I\, A_{prj}\, \alpha_g + A\, h_{(r)ab\text{-}g1}(T_{ab} - T_{g1}) - A\, h_{(c)g1\text{-}a}(T_{g1} - T_a) - A\, h_{(c)g1\text{-}amb}(T_{g1} - T_{amb}) - A\, h_{(r)g1\text{-}sky}(T_{g1} - T_{sky}) \quad (1)$$

The energy balance equation for the absorber is

$$mc_P \frac{dT}{dt} = I\, A_{prj}\, \tau_g\, \alpha_{ab} - A\, h_{(r)ab\text{-}g1}(T_{ab} - T_{g1}) - A\, h_{(c)ab\text{-}a}(T_{ab} - T_a) - A\, U_{ab\text{-}amb}(T_{ab} - T_{amb}) \quad (2)$$

The energy balance equation for circulating air is

$$M_a\, c_P\, \frac{dT}{dt} = A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a) + A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) \quad (3)$$

The overall efficiency of the conventional solar air heater is

$$\eta = \sum \frac{A\, h_{(c)ab-a}(T_{ab}-T_a) + A\, h_{(c)g1-a}(T_{g1}-T_a)}{I\, A_{prj}} \quad (4)$$

II- double glass single pass solar air heater

The energy balance equation for the glass cover (g_2) is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \alpha_g + A\, h_{(r)g1\text{-}g2}(T_{g1}\text{-}T_{g2}) - A\, h_{(c)g2\text{-}a0}(T_{g2}\text{-}T_{a0}) - A\, h_{(c)g2\text{-}amb}(T_{g2}\text{-}T_{amb}) - A\, h_{(r)g2\text{-}sky}(T_{g2}\text{-}T_{sky}) \quad (5)$$

The energy balance equation for the glass cover (g_1) is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \tau_g\, \alpha_g + A\, h_{(r)ab\text{-}g1}(T_{ab}\text{-}T_{g1}) - A\, h_{(r)g1\text{-}g2}(T_{g1}\text{-}T_{g2}) - A\, h_{(c)g1\text{-}a0}(T_{g1}\text{-}T_{a0}) - A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) \quad (6)$$

The energy balance equation for the absorber is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \tau_g\, \tau_g\, \alpha_{ab} - A\, h_{(r)ab\text{-}g1}(T_{ab}\text{-}T_{g1}) - A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a) - A\, U_{ab\text{-}amb}(T_{ab}\text{-}T_{amb}) \quad (7)$$

The energy balance equation for circulating air is

$$\dot{M}_a\, c_P\, \frac{dT}{dt} = A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a) + A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) \quad (8)$$

The overall efficiency of the conventional solar air heater is

$$\eta = \sum \frac{A\, h_{(c)ab-a}(T_{ab}-T_a) + A\, h_{(c)g1-a}(T_{g1}-T_a)}{I\, A_{prj}} \quad (9)$$

III- double pass solar air heater

The energy balance equation for the glass cover (g_2) is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \alpha_g + A\, h_{(r)g1\text{-}g2}(T_{g1}\text{-}T_{g2}) - A\, h_{(c)g2\text{-}a}(T_{g2}\text{-}T_{a0}) - A\, h_{(c)g2\text{-}amb}(T_{g2}\text{-}T_{amb}) - A\, h_{(r)g2\text{-}sky}(T_{g2}\text{-}T_{sky}) \quad (10)$$

The energy balance equation for the glass cover (g_1) is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \tau_g\, \alpha_g + A\, h_{(r)ab\text{-}g1}(T_{ab}\text{-}T_{g1}) - A\, h_{(r)g1\text{-}g2}(T_{g1}\text{-}T_{g2}) - A\, h_{(c)g1\text{-}a0}(T_{g1}\text{-}T_{a0}) - A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) \quad (11)$$

The energy balance equation for the absorber is

$$m c_P \frac{dT}{dt} = I\, A_{prj}\, \tau_g\, \tau_g\, \alpha_{ab} - A\, h_{(r)ab\text{-}g1}(T_{ab}\text{-}T_{g1}) - A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a) - A\, U_{ab\text{-}amb}(T_{ab}\text{-}T_{amb}) \quad (12)$$

The energy balance equation for circulating air is

$$\dot{M}_a\, c_P\, \frac{dT}{dt} = A\, h_{(c)g2\text{-}a}(T_{g2}\text{-}T_{a0}) + A\, h_{(c)g1\text{-}a0}(T_{g1}\text{-}T_{a0}) + A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) + A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a) \quad (13)$$

The overall efficiency of the conventional solar air heater is

$$\eta = \sum \frac{A\, h_{(c)g2\text{-}a}(T_{g2}\text{-}T_{a0}) + A\, h_{(c)g1\text{-}a0}(T_{g1}\text{-}T_{a0}) + A\, h_{(c)g1\text{-}a}(T_{g1}\text{-}T_a) + A\, h_{(c)ab\text{-}a}(T_{ab}\text{-}T_a)}{I\, A_{prj}} \quad (14)$$

3. Results and Discussion

Figures 2 shows a comparison between glass covers and absorbers temperatures for the three configurations of solar air heaters. The absorber temperature for the conventional solar air heater is the highest and the absorber temperature for the double pass solar air heater is the lowest among the three solar air heaters configurations. However, the temperature of the glass cover (g_1) is the highest for the double glass single pass solar air heater and the lowest for the conventional solar air heater. Moreover, the temperature of the glass cover (g_2) for the double glass single pass solar air heater is higher than that for the double pass solar air heater. Figure 2b illustrates that the energy is stored in the stagnant air between glass covers in the double glass single pass solar air heater, which is depicted by the remarkable increase in its temperature. In addition, air exit temperature from the double pass solar air heater is the highest while that from the conventional solar air heater is the lowest among the three solar air heaters configurations.

(a)

(b)

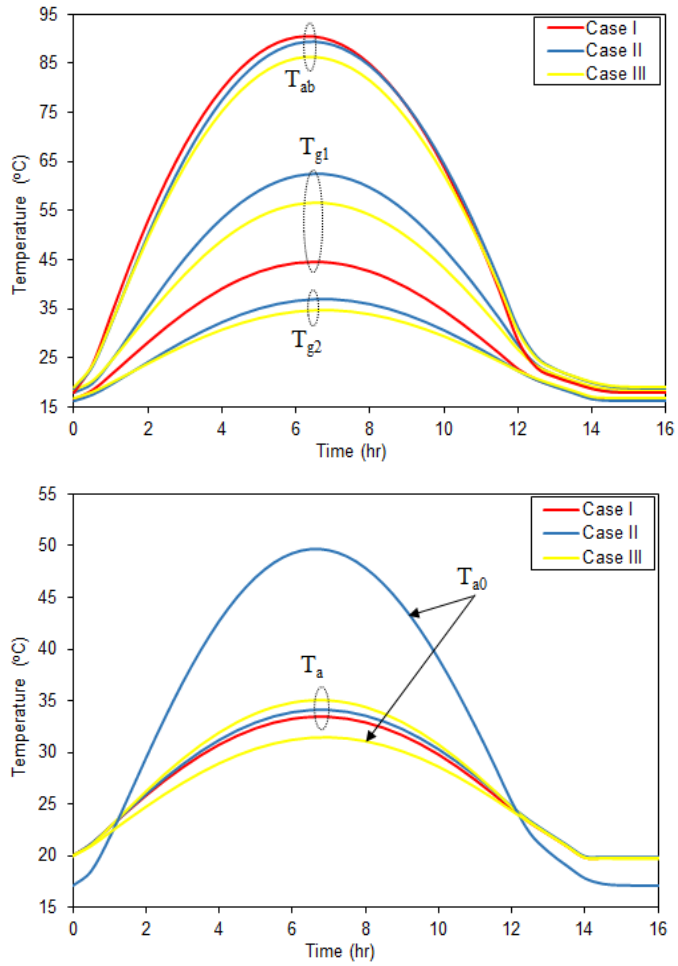


Figure 2. Temperature distribution comparison: (a) solar air heaters components, (b) circulating and stagnant air.

A comparison between the performance of the three configurations of solar air heaters is held in Figure 3. Among the three solar air heaters configurations, both air heat gain and overall solar air heater efficiency are the highest for the double pass solar air heater and the lowest for the conventional solar air heater.

Figure 4 shows a comparison between heat gains by the air in the three configurations of solar air heaters. The typical heat gain by the air from the absorbing plate is highest for the conventional solar air heater and the lowest for the double pass solar air heater. However, the total heat gain by the air from the two glass covers (g_1 and g_2) is the highest among the three air heaters configurations while the heat gain from the glass cover (g_1) is the lowest.

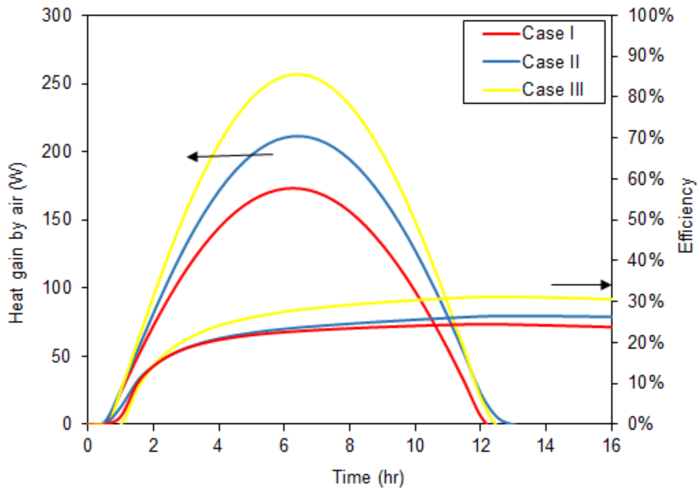


Figure 3. Performance comparison.

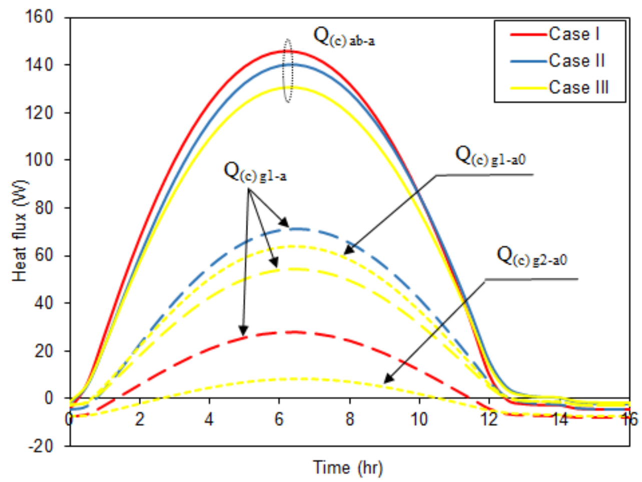


Figure 4. Heat gain comparison.

A comparison between heat losses from glass covers and bases of the heaters is illustrated in figure 5. As shown in figure 5a, both convection and radiation heat transfer from the glass cover are the highest for the conventional solar air heater and the lowest for the double pass solar air heater. Similarly, as shown in figure 5b, convection and radiation losses from the heater base are the highest for the conventional solar air heater and the lowest for the double pass solar air heater.

A parametric study was carried out for the influence of environmental and operational parameters on the performances of the three configurations of solar air heaters. The influence of the air mass flow rate on the performance and air exit temperature of each air heater is illustrated in figure 6. It is shown in figure 6a that the higher the air mass flow rate, the higher the efficiency of each solar air heater. However, for all flow rate ranges, the efficiency of the double pass solar air heater is the highest among all air heaters configurations. Nevertheless, the efficiency of the double glass single pass solar air heater is higher than that of the conventional solar air heater for low air mass flow rates while the efficiency of the conventional solar air heater is higher than that of the double glass single pass solar air heater for higher air mass flow rates. The difference between the air exit and inlet temperatures for the three solar air heaters configurations increases with the decrease in the air mass flow rate. Moreover, the air temperature difference for the double pass solar air heater is the highest and that for the conventional solar air heater is lowest among the three air heaters configurations. Furthermore, the deviation between the three configurations increases with the reduction in the air mass flow rate.

(a)

(b)

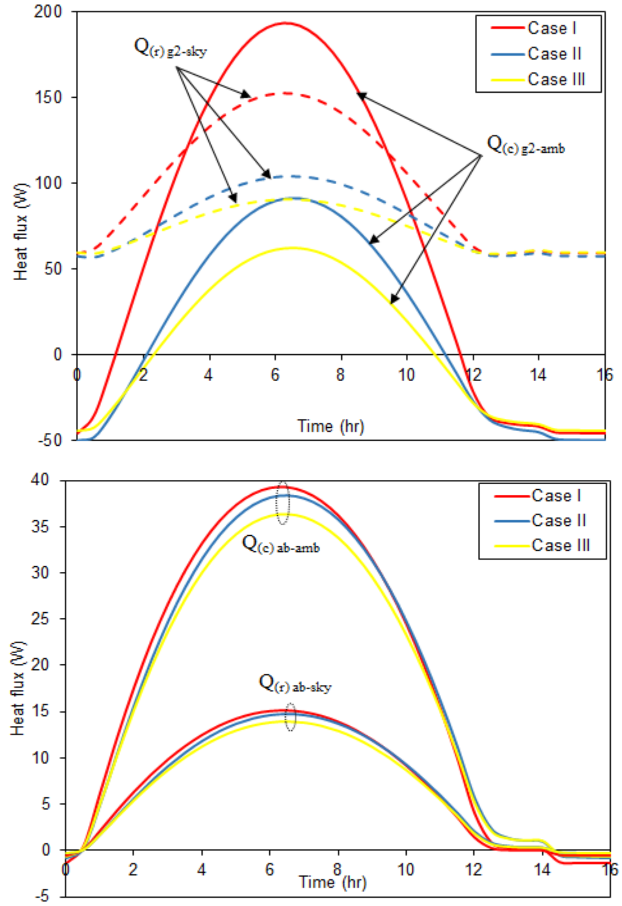
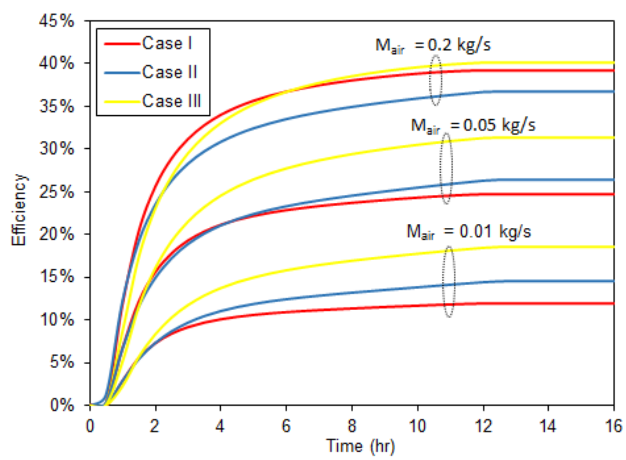


Figure 5. Heat loss comparison: (a) glass cover losses, (b) base losses.

(a)



(b)

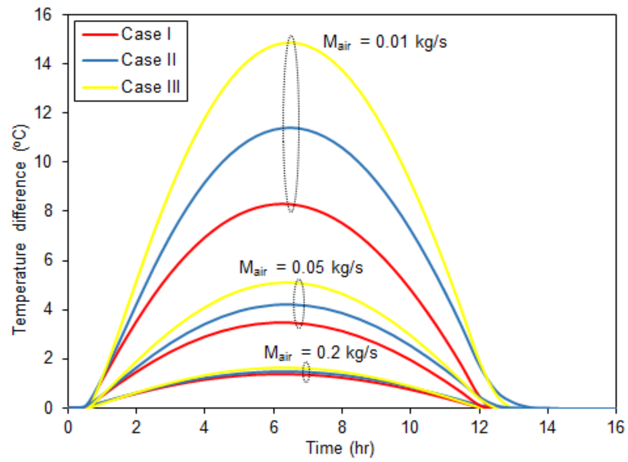


Figure 6. Influence of air flow rate: (a) heater efficiency, (b) exit-inlet temperature difference.

The influence of the solar intensity on the performance and air exit temperature of each air heater is shown in figure 7. Both the performance and the air temperature difference increase with increase in the incident solar intensity. Moreover, the efficiency and temperature difference for the double pass solar air heater are the highest while those for the conventional solar air heater are the lowest among all air heaters configurations.

(a)

(b)

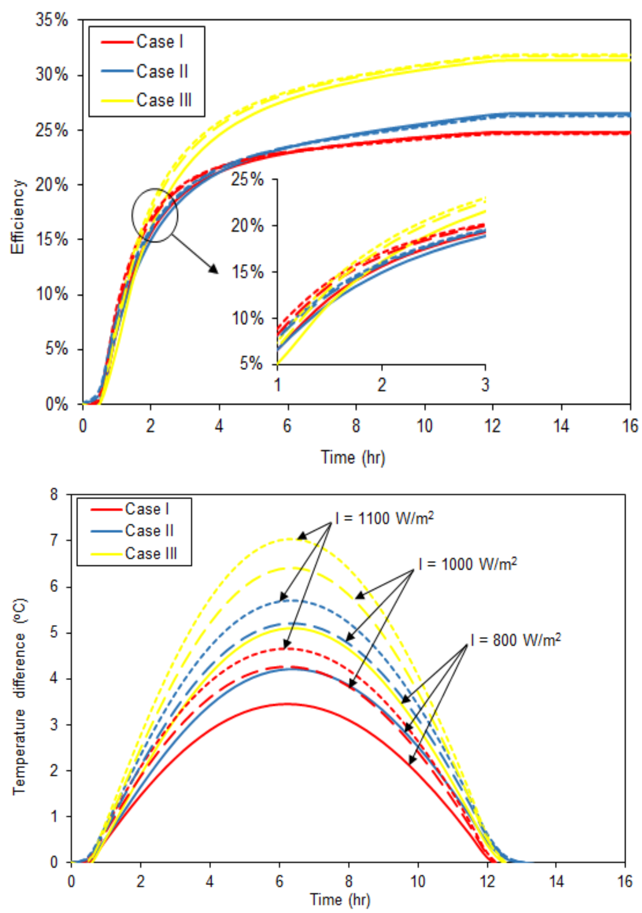
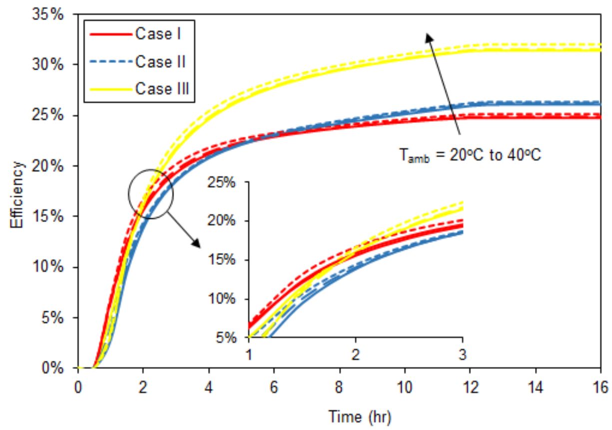


Figure 7. Influence of solar intensity: (a) heater efficiency, (b) exit-inlet temperature difference.

Figure 8 shows the influence of the ambient/inlet air temperature on the performance and air exit temperature of each solar air heater. Both the performance and the air temperature difference increase with the increase in the ambient/inlet temperature from 20ºC to 40ºC. Furthermore, the efficiency and temperature difference for the double pass solar air heater are the highest while those for the conventional solar air heater are the lowest among the three air heaters configurations.

(a)



(b)

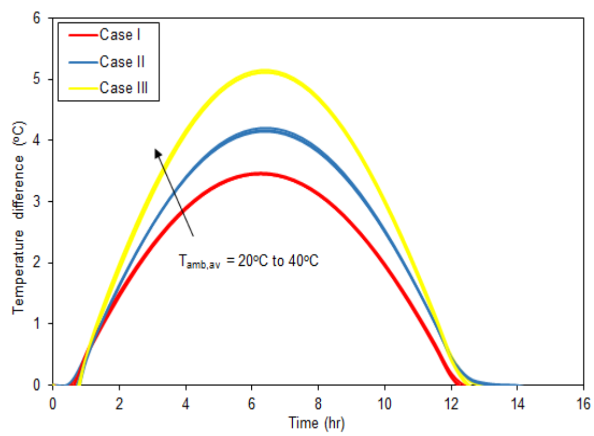


Figure 8. Influence of ambient temperature: (a) heater efficiency, (b) exit-inlet temperature difference

4. Conclusions

A numerical simulation for three configurations of solar air heaters named conventional solar air heater, double glass single pass solar air heater and double pass solar air heater are carried out. Heat gain by the air and heat losses from each solar air heater are compared. A comparison between the performances of the three configurations of solar air heaters showed that, for the same environmental and operational conditions, the performance of the double pass solar air heater is the highest and the performance of the conventional solar air heater is the lowest. The influence of various environmental and operational parameters on the performances of the three solar air heaters are studied and compared. Any increase in the incident solar intensity or the ambient/inlet air temperature or a reduction in the circulating air mass flow rate increases the performance and air exit temperature for each solar air heater. Moreover, for various environmental and operational conditions, the performance of the double pass solar air heater is the highest and the performance of the conventional solar air heater is the lowest among the three solar air heaters configurations. Nevertheless, for higher air mass flow rate, the performance of the conventional solar air heater overcomes that of the double glass single pass solar air heater.

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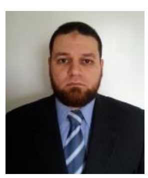
Biographical information



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