International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 4 (2015) pp. 10453-10469

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# An Experimental Investigation and Performance Analysis of Evacuated Tube Assisted Solar Air Heater

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## Abstract

In the present study the thermal performance of an evacuated tube assisted solar air heater is experimentally investigated. Air is used as a working fluid in this experimental setup and tested in Chennai climatic conditions. The evacuated tube assisted solar air collector consists of thirty evacuated tubes and a header. The headertube consists of a pipe which is divided into two half in centre through which air flows. The exit temperature, temperature difference and efficiency are studied for the air flow rate of 170kg/hr, 190kg/hr and 205kg/hrat the velocities of 6.1 m/sec, 7 m/sec and 7.8 m/sec.The flat aluminium reflectors are used to enhance the performance of evacuated tube assisted solar air heater. It is observed that in case of flat aluminium sheet reflector assisted evacuated tube solar air heater outlet temperature is high and high temperature difference and has better thermal performance as compared to the without Flat Aluminium sheetreflector. The maximum outlet temperature and maximum temperature difference of air heater are found to be 90.5◦C and 57.5◦C at a flow rate of 205 kg/hr with Flat Aluminium sheet reflector.The maximum efficiency of the collector with flat aluminium sheet reflector is75.52% for the flow rate of205kg/hr. The maximum average solar air heater efficiency of 64.68% and 52.31% is observed forevacuated tube with flat aluminium reflector and without any reflector for the mass flow rate of 205 kg/hr.

**Keywords:** Thermal performance, Evacuated tube air heater, Flat aluminium reflector,air heaterefficiency, solar collector, Air heater.

## Introduction

Ever increasing demand for energy leads to depletion of scarce conventional sources of energy. Since the development of renewable energy technology wherever is feasible is important for the future to balance energy requirements. Solar energy is inexhaustible source of energy and it is an environmentally clean and free source of energy. Direct solar thermal applications have distinct advantage over other indirect applications. The direct solar thermal applications include solar air heating for space heating, and drying of agriculture and industrial products.The direct solar thermal applications include refrigeration and air conditioning also. Traditionally solar flat plate collector is used for this purpose. At present evacuated tube assisted collectors are tried for this purpose, which gives better performance and high temperature than flat plate collectors. Vishal Dabra *et al*., [1] studied the thermal performance of air heater as radiator arrangement of tubes using evacuated tube with the tilt angle of $30^o$ to $45^o$ and concluded that the thermal performance of the evacuated tube with or without reflector is better at the tilt angle of $30^o$ and proved that beyond $30^o$ inclination of evacuated tubes had no positive effect on thermosyphon phenomenon inside the evacuated tubes and hence the thermal performance. Liangdong Ma *et al*., [2] analysed the performance of evacuated tube with 'U' tube with and without copper ring fin between absorber tube and 'U' tube and concluded both experimentally and analytically that the copper ring fin increases the efficiency of the evacuated tube with 'U' tube collector.Siddharth Arora *et al*., [3]conducted an experiment on the performance of evacuated tube with heat pipe assisted collector to supply heat to refrigeration through water as working medium and concluded that the air gap between the heat pipe tube and collector tube plays important role in the performance. Ashish Kumaret al., [4] studied the performance of evacuated tube assisted solar air heater as direct heating of the air in the glass tubes with and without reflector at different mass flow rate and concluded that with reflector assisted arrangement the outlet temperature and efficiency is maximum.Selvakumar P et al., [5] conducted an experiment on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough for water heating purposes and concluded that the efficiency of therminol based evacuated tube collector coupled with parabolic trough is 40% more than that of water based evacuated tube collector coupled with parabolic trough. LamnatouChr*et al.,* [6] analysed the thermodynamic performance analysis of a solar tunnel dryer with an evacuated tube collector in which air heated directly in evacuated tubes. In this experimental study a novel solar air heater is designed and developed with different air flow configuration and header matrix for drying of agriculture products with an evacuated tube air collector with Aluminium reflector to enhance the performance, and air heater's collector performance is studied for with and without Aluminium sheet reflector at three different mass flow rates.

## Experimental Setup

The solar air heating system consists of a 125 mm diameter pipe header is concentrically placed in the 300 mm diameter pipe both of length 2250 mm with 30

number of 12.7 mm GI pipes connected to the 125 mm diameter pipe header and is inserted in Evacuated Tubes to a length of 1300 mm. The Evacuated tubes are connected to 300 mm diameter pipe. The collector header is divided into two parts, in the first fifteen numbers of tubes the air flows in downward direction in the GI pipes and upward direction in the remaining fifteen numbers of tubes. The 300 mm diameter tube is insulated with 50 mm fiberglass insulation. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness, and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three-layer magnetron sputter coating. Heat loss due to convection, conduction, and radiation is thus minimized, and it can withstand high temperature. The evacuated tube has inner and outer diameter of 38 mm and 48 mm respectively. The length of the evacuated tube is 1500 mm. The Collector has a dimension of 2250 mm X 1500 mm. The collector is placed at optimum tilt in accordance with the latitude and longitude of Chennai (13.084$^{o}$N, 80.27$^{o}$E) Tamilnadu, India along North-South direction, facing south to track maximum solar radiation throughout the day. This collector is used as a heat source for air heater. A blower motor of 0.375 KW,with three speedregulator to control the rate of flow of air is attached at the inlet of the solar collector to blow air into the collector. The arrangement of the experimental setup is as shown in the Figure-1. Temperature at inlet and outlet of the collector is measured with the help of k – type thermocouples connected to 12 point data logger and display unit, besides a hygrometer is attached to measure relative humidity. Solar insolation is measured using a solar power meter (TENMARS-TM207).The blower motor is then switched on. The air that is passed through the evacuated tube collector gets heated up.To enhance the performance of solar air heater flat aluminium sheets are placed below the evacuated tubes (Figure -2). The experiment is conducted for with flat Aluminium reflector and without Flat Aluminium reflector for the air flow rate of 170kg/hr, 190kg/hr and 205kg/hrat the velocities of 6.1 m/sec, 7 m/sec and 7.8 m/sec. During the experiment, ambient temperature, relative humidity and wind velocity, solar insolation, inlet and outlet temperatures of the collector are recorded on hourly basis from 08.30 am to 04.30 pm.

**Figure 1:** Experimental Setup

**Figure 2:** Experimental setup with Aluminium sheet Reflector

## Experimental Data Analysis

The inlet temperature ($T_{in}$) and outlet temperature ($T_{out}$) of the Evacuated tube collector are recorded at one hour time interval. The mass flow rate ($m_a$) of the air is recorded. The solar insolation (I) is recorded at one hour time interval. With aperture area ($A_p$), Specific heat of air ($C_{pa}$) and number of Evacuated Tubes (N) are known; the efficiency of the evacuated tube is given by

$$\text{Evacuated Tube Collector Efficiency} = \frac{m_a C_{pa} (T_{out} - T_{in})}{N A_p I}$$

The aperture area '$A_p$' of the evacuated tube collector be taken as π (L x R),Length of the evacuated tube 'L' and Radius of the evacuated tube 'R' is takenfor case of without flat aluminium reflector. The aperture area '$A_p$' of the evacuated tube collector be taken as 2(L x D), Length of the evacuated tube 'L' and Diameter of the evacuated tube 'D' is taken for case of Evacuated tube with flat aluminium reflector.

## Results and Discussion

In this experimental setup the air is the heated at three different air flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr. The experiment is performed for these three flow rates and the performance of solar air heater is evaluated, then the flat aluminium sheet reflector is placed below the evacuated tubes to enhance the performance and the solar air heater's performance is evaluated. The experiments were carried out during the month of December 2014 and February 2015, being wintermonths from 8.30 A.M. to 4.30 P.M on clear sky days.

**Evacuated Tube Collector at Flow Rate of 170kg/hr**

At the air flow rate of 170 kg/hr without reflector, it can be observed that the temperature of exit air from the evacuated tube solar collector steadily increases and it attains the maximum at 12.30 P.M. and decreases afterwards.The air velocity of 6.1 m/sec observed at the header pipe outlet. The other metrological parameters of relative humidity and air velocity at the experiment site is notedwhich is shown in the Table-1.

**Table 1:** Hourly Variation of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 0.5 | 1.1 | 1.8 | 0.7 | 2.6 | 0.6 | 0.9 | 3.3 | 1.6 |
| RH in % | 79.5 | 68.5 | 49 | 48.5 | 48 | 46 | 46 | 47.5 | 61.5 |
| $T_{in}$ $^oC$ | 30.2 | 30.4 | 33.5 | 34.3 | 35.7 | 36 | 35.6 | 33.6 | 33.4 |
| $T_{out}$ $^oC$ | 50.2 | 61.2 | 65.6 | 70.7 | 73.2 | 68.6 | 66 | 58.2 | 45.5 |

The relative humidity varies from 46% to 79.5% and wind velocity varies from 0.5 m/sec to 2.6 m/sec. Figure-3 shows the variation of inlet, exit, and temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 45.5$^o$C to 73.2$^o$C. The inlet temperature varies from 30.2$^o$C to 36$^o$C.The temperature difference varies from 12.1$^o$C to 37.5$^o$C.

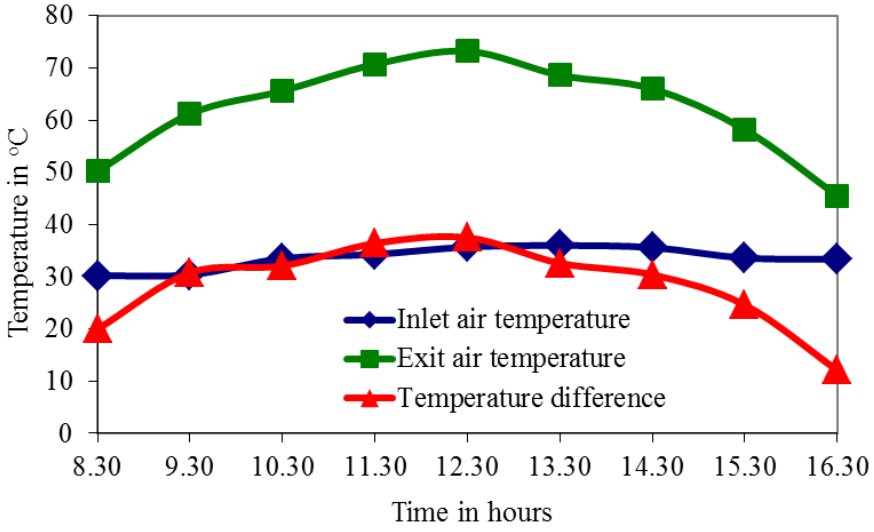


**Figure 3:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 457 W/m$^2$ to 1214 W/m$^2$. Figure-4 shows the variation of solar intensity and efficiency of the evacuated tube assisted solar air heater.The maximum solar intensity is 1214W/m$^2$ at 12:30 P.M. The maximum solar

intensity is achieved during the afternoon, after that it starts decreases with time. The exit temperature and temperature difference of air in evacuated tube collector depend upon solar intensity and air flow rate.

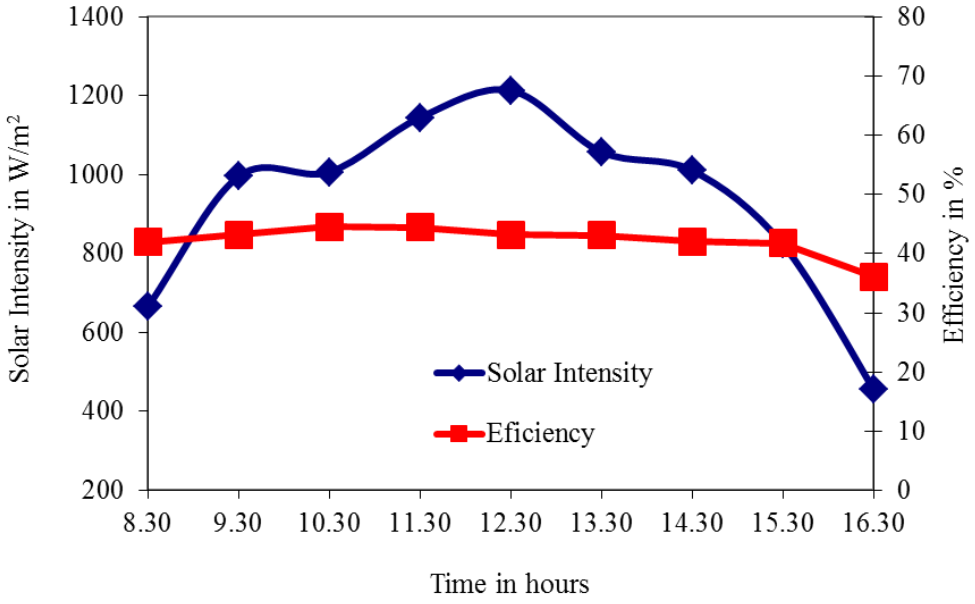


**Figure 4:** Variations of Solar intensity and Efficiency

The temperature of outlet air keeps on increasing at higher rate than the ambient temperature due to high absorption rate of solar radiation in evacuated tubes. The exit temperature and temperature difference is maximum at 12.30 P.M. during the day. When the solar intensity starts decreasing, the inlet, exit temperatures and temperature difference of air also decreases. The maximum exit temperature and temperature difference of air are 73.2$^{o}$C and 37.5$^{o}$C at 12:30 P.M.The efficiency of the evacuated tube assisted solar air heater varies from 36.09% to 44.57%. It is observed from the figure that form 11.30 A.M to 12.30 P.M the solar intensity increases from 1007 W/m$^2$ to 1145 W/m$^2$but the efficiencydecreasesfrom 44.57% to 44.44% may be due to heating of header matrix. But the heat carried by the air increases from 1522.69 J/sec to 1726.67 J/sec shows increased solar radiation absorption. As the solar intensity decreases the efficiency decreases in the afternoon.

**Evacuated Tube Collector at Flow Rate of 190kg/hr**

At the air flow rate of 190 kg/hr without reflector, it is noted that the temperature of exit air from the evacuated tube solar air heater steadily increases and it attains the maximum of 73.8$^{o}$C at 12.30 P.M. and decreases afterwards.The air velocity of 7 m/sec observed at the header pipe outlet. The other metrological parameters of relative humidity and air velocity at the experiment site is noted which is shown in the Table-2.

**Table 2:** Hourly Variations of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 0.6 | 0.9 | 1.5 | 0.6 | 1.3 | 4.0 | 2.4 | 1.7 | 2.9 |
| RH in % | 84.5 | 66 | 56 | 44.5 | 43.5 | 39.5 | 45.5 | 46 | 50.5 |
| $T_{in}$ °C | 30.1 | 30.3 | 33.2 | 34.5 | 34.4 | 35.1 | 35.9 | 35.2 | 33.8 |
| $T_{out}$ °C | 50.8 | 60.1 | 66.5 | 72.2 | 73.8 | 69.3 | 66.2 | 58.4 | 49.4 |

The relative humidity varies from 39.5% to 84.5% and wind velocity varies from 0.6m/se to 4.0 m/sec. Figure-5 shows the variation of inlet, exit, and temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 49.4°C to 73.8°C. The inlet temperature varies from 30.1°C to 35.9°C.The temperature difference raises from 15.6°C to 39.4°C.

The solar intensity varies from 480 W/m$^2$ to 1284 W/m$^2$. Figure-6 shows the solar intensity during experiment and efficiency of the evacuated tube assisted solar air heater. The maximum solar intensity is 1284W/m$^2$ at 12:30 P.M. The maximum solar intensity is achieved during the afternoon, after that it starts decreases with time.

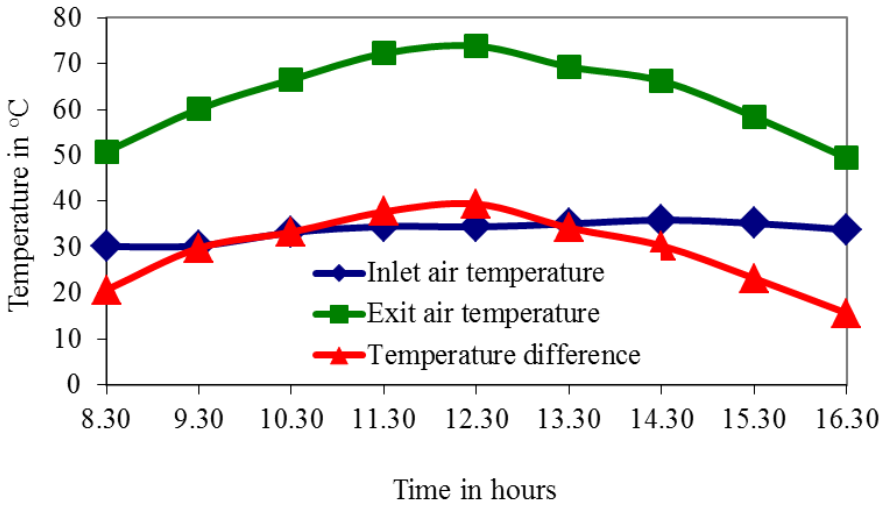


**Figure 5:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

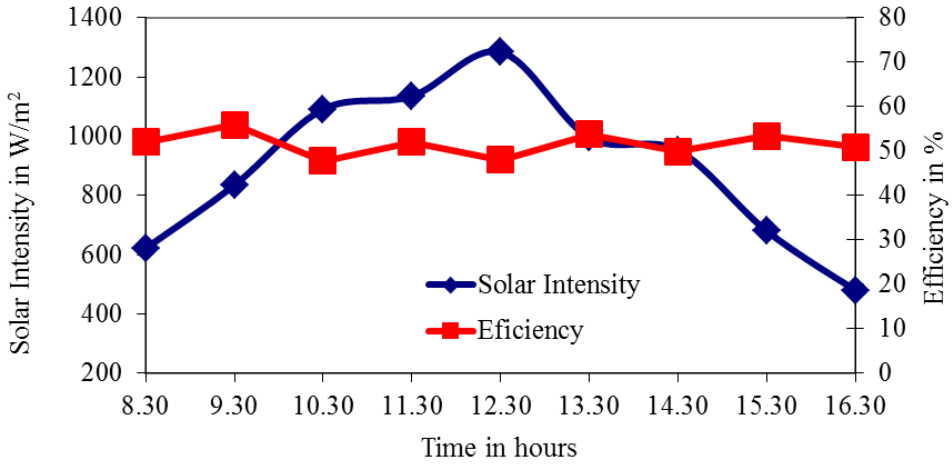


**Figure 6:** Variations of Solar intensity and Efficiency

The exit temperature increases with increase in solar intensity. The exit temperature and temperature difference is maximum at 12.30 P.M. during the day, then solar intensity starts decreases, then the inlet, exit temperatures and temperature difference of air also decreases. The maximum exit temperature and temperature difference of air are 73.8$^{o}$C and 39.4$^{o}$C at 12:30 P.M. The efficiency of the evacuated tube assisted solar air heater varies from 47.73% to 55.81%. It is observed that from 9.30 A.M. to 10.30 A.M. and 11.30 A.M. to 12.30 P.M when solar intensity increases the efficiency of the solar air heater decreases, this may be due to heating of header matrix but during this time the heat gained by the air increases in both the time periods. The reverse phenomenon is observed during 2.30 P.M to 3.30 P.M solar intensity decreases but the efficiency increases. This may due to heat release by the header matrix. The heat carried by the air in the air heater collector decreases from 1609.84 J/sec to 1231.08 J/sec during this period.

**Evacuated Tube Collector at Flow Rate of 205kg/hr**

At the air flow rate of 205 kg/hr without reflector, it is found that the temperature of exit air from the evacuated tube solar air heater steadily increases and it attains the maximum at 13.30 P.M. and decreases afterwards.The air velocity of 7.8 m/sec observed at the header pipe outlet. The other metrological parameters of relative humidity and air velocity at the experiment site is noted which is shown in the Table 3.

**Table 3:** Hourly Variations of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 1.1 | 1.7 | 1.3 | 1.2 | 2.7 | 1.3 | 1.3 | 0.8 | 2.7 |
| RH in % | 86 | 67.5 | 54 | 51 | 47 | 43.5 | 44.5 | 50 | 57 |
| $T_{in}$ $^{o}$C | 28.7 | 32.3 | 34 | 36 | 35 | 36.3 | 34.7 | 35.3 | 32.9 |
| $T_{out}$ $^{o}$C | 50.3 | 62.1 | 67.2 | 68.3 | 71.8 | 73.7 | 65.8 | 55.1 | 44.5 |

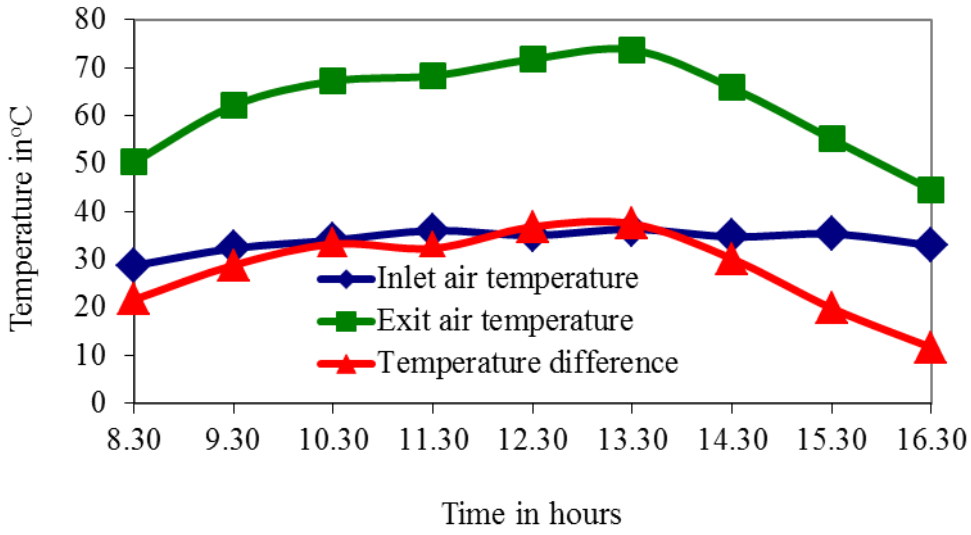


**Figure 7:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

The relative humidity varies from 43.5% to 86% and wind velocity varies from 0.8 m/sec to 2.7 m/sec. Figure-7 shows the variation of inlet, exit, and Temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 44.5°C to 73.7°C. The inlet temperature varies from 28.7°C to 36.3°C.The temperature difference varies from 11.6°C to 37.4°C.

The solar intensity varies from 437 W/m$^2$ to 1175 W/m$^2$. Figure-8 shows the variation of solar intensity and efficiency of the evacuated tube assisted solar air heater. The maximum solar intensity is 1175 W/m$^2$ at 12:30 P.M. The maximum solar intensity is achieved during the afternoon, after that it starts decreases with time.

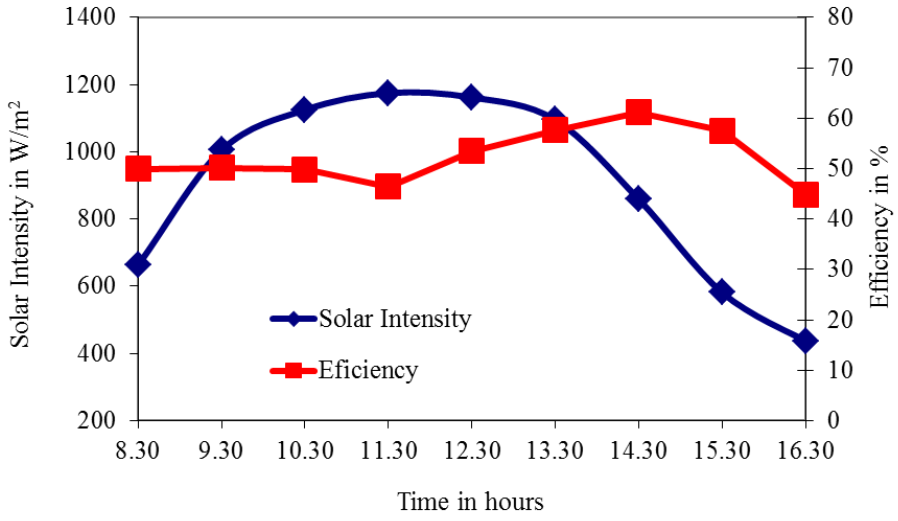


**Figure 8:** Variations of Solar intensity and Efficiency

The exit temperature and temperature difference is maximum at 13.30 P.M. during the day. When the solar intensity starts decreasing, the inlet, exit temperatures and temperature difference of air also decreases. The maximum exit temperature and temperature difference of air are 73.7$^{o}$C and 37.4$^{o}$C at 13:30 P.M. The efficiency of the evacuated tube assisted solar air heater varies from 44.81% to 61.11%. It is observed from the figure that from 9.30 A.M. to 11.30 A.M. when solar intensity increases the efficiency decreases, which may be due heating of header matrix. The reverse trend is observed during 12.30 P.M to 4.30 P.M. when solar intensity decreases the efficiency increases. It is noted that the heat gained by air in the solar air heater decreases continuously.

**Evacuated Tube Collector with Flat Aluminium Reflector at Flow Rate of 170 kg/hr**

At the air flow rate of 170 kg/hr withflat aluminium sheet reflector, it is noted that the temperature of exit air from the evacuated tube solar collector steadily increases and it attains the maximum at 10.30 A.M. and decreases afterwards.The air velocity of 6.1 m/sec observed at the header pipe outlet. The metrological parameter of relative humidity and air velocity at the experiment site are noted and is shown in the Table-4.

**Table 4:** Hourly Variations of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 1.4 | 2.6 | 2.4 | 1.2 | 2.7 | 3.0 | 1.5 | 2.3 | 0.9 |
| RH in % | 84.5 | 80 | 72.5 | 72 | 71 | 73.5 | 72.5 | 81 | 83 |
| $T_{in}$ $^{o}$C | 31.1 | 30 | 32.5 | 33.5 | 34 | 33 | 34 | 30 | 29 |
| $T_{out}$ $^{o}$C | 70.6 | 72.6 | 74.5 | 68.1 | 65.2 | 65.1 | 64.6 | 50.6 | 45.9 |

The relative humidity varies from 46% to 79.5% and wind velocity varies from 0.9 m/sec to 3.0 m/sec. Figure-9 shows the variation of inlet, Exit, and Temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 45.9$^{o}$C to 74.5$^{o}$C. The inlet temperature varies from 29$^{o}$C to 34$^{o}$C.The temperature difference increases from 16.5$^{o}$C to 42.6$^{o}$C.

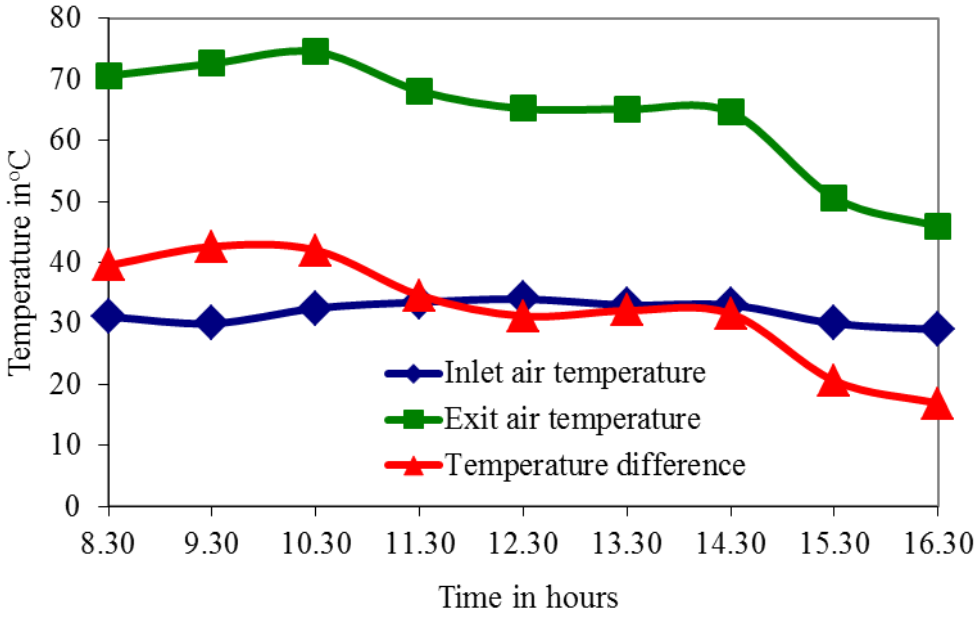


**Figure 9:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 454 W/m$^2$ to 1328 W/m$^2$. Figure-10 shows the variation of solar intensity and efficiency of the evacuated tube assisted solar air heater. The maximum solar intensity is 1328 W/m$^2$ at 10:30 A.M. The maximum solar intensity is achieved at 10.30 P.M. and decreases till 1.30 P.M and increases from 1.30 P.M. to 2.30 P.M. and decreases with time.

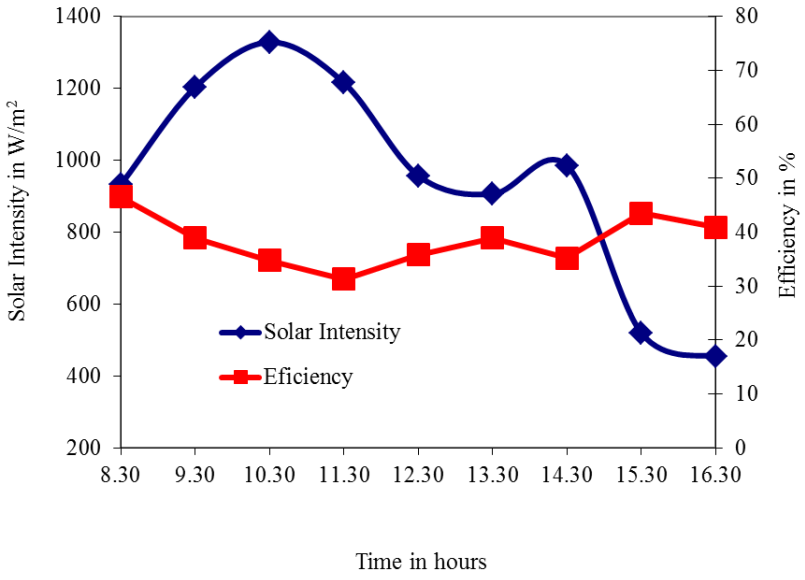


**Figure 10:** Variations of Solar intensity and Efficiency

The exit temperature and temperature difference is maximum at 9.30 A.M. during the day. When the solar intensity starts decreasing, the inlet, exit temperatures and temperature difference of air also decreases. The maximum exitair temperature of 74.5$^{o}$C at 10.30 A.M. and temperature difference of air is 42.6$^{o}$C at 9:30 A.M. The efficiency of the evacuated tube assisted solar air heater varies from 31.26% to 46.49%. It is observed that the efficiency decreases from 8.30 A.M to 11.30 A.M. whereas during this time the solar intensity increases, this may be due to heating of header matrix. It is also noted that the heat gained by the air increases during this time. From 2.30 P.M. onwards the solar intensity decreases whereas the efficiency increases. But it is observed that the heat gained by the air decreases continuously.

**Evacuated Tube Collector with Flat Aluminium Reflector at Flow Rate of 190 kg/hr**

At the air flow rate of 190 kg/hr withflat aluminium sheet reflector, it is found that the temperature of exit air from the evacuated tube solar collector steadily increases and it attains the maximum at 11.30 A.M. and decreases afterwards.The air velocity of 7 m/sec observed at the header pipe outlet. The metrological parameters of relative humidity and air velocity at the experiment site is noted which is shown in the Table-5.

**Table 5:** Hourly Variations of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 2.9 | 1.0 | 1.3 | 1.2 | 1.2 | 2.6 | 2.2 | 2.2 | 1.5 |
| RH in % | 85.5 | 80.5 | 70.5 | 57.5 | 50.5 | 53 | 51 | 54 | 65 |
| $T_{in}$ $^{o}$C | 28 | 30 | 32 | 33 | 34.5 | 33 | 32.5 | 32 | 30 |
| $T_{out}$ $^{o}$C | 57 | 60.1 | 66.7 | 74.8 | 69.6 | 65.2 | 62.4 | 56.9 | 38.3 |

The relative humidity varies from 50.5% to 85.5% and wind velocity varies from 1 m/sec to 2.9 m/sec. Figure-11 shows the variation of inlet, Exit, and Temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 38.3$^{o}$C to 74.8$^{o}$C. The inlet temperature varies from 28$^{o}$C to 34.5$^{o}$C.The temperature difference varies from 8.3$^{o}$C to 41.8$^{o}$C.

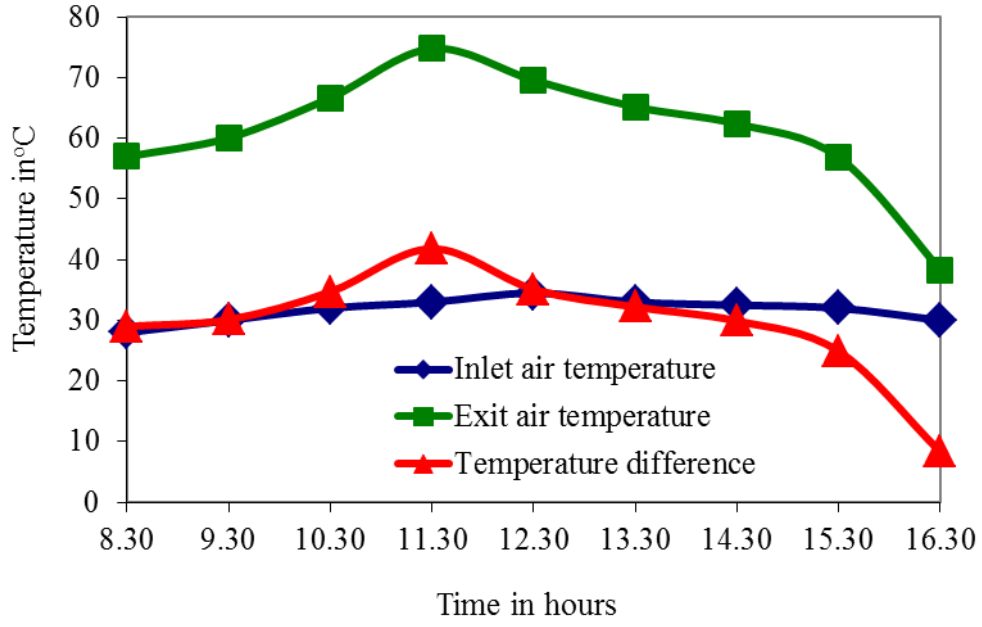


**Figure 11:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 266 W/m$^2$ to 1140 W/m$^2$. Figure-12 shows the variation of solar intensity and efficiency of the evacuated tube assisted solar air heater. The maximum solar intensity is 1140 W/m$^2$ at 11:30 A.M. The solar intensity increases continuously and after that decreases with time.

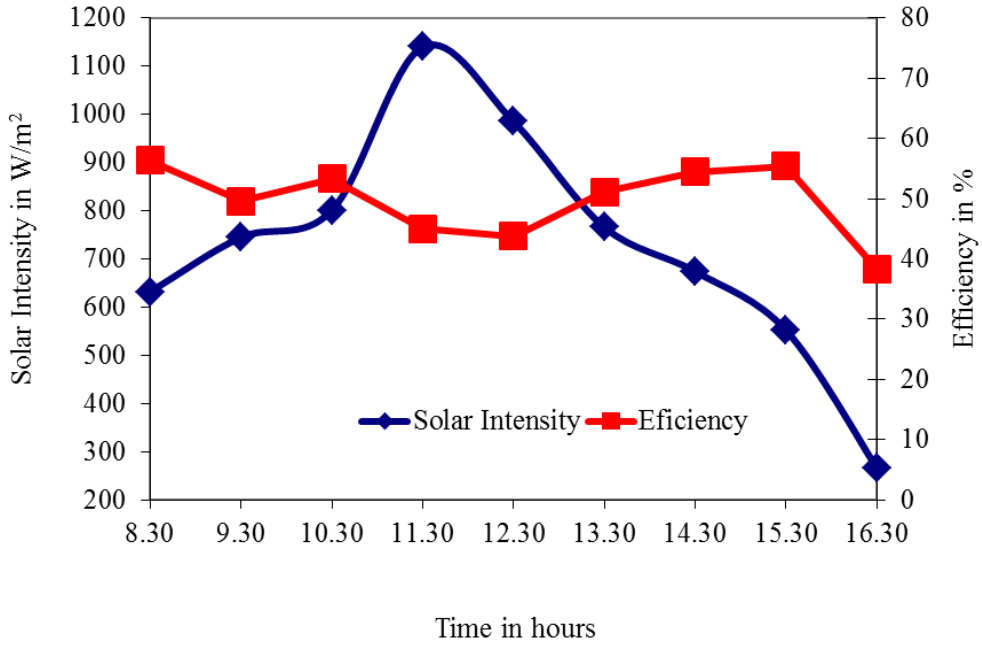


**Figure 12:** Variations of Solar intensity and Efficiency

The exit temperature and temperature difference is maximum at 11.30 A.M. during the day. When the solar intensity starts decreasing, the inlet, exit temperatures and temperature difference of air also decreases. The maximum exitair temperature and temperature difference of air are 74.8$^{o}$C and 41.8$^{o}$C at 11:30 A.M. The efficiency of the evacuated tube assisted solar air heater varies from 38.32% to 55.41%. As the solar intensity the efficiency increases in the beginning and from 10.30 A.M. to 11.30 A.M solar intensity increases from 801 W/m$^2$ to 1140 W/m$^2$, the efficiency decreases from 53.32% to 45.04%. This may be due to heating of header matrix.But it is observed that the heat gained by the air in the solar air heater increases from 1841.32 J/sec to 2218.08 J/sec. From 1.30 P.M. to 4.30 P.M the solar intensity decreases continuously with time but the efficiency increases from 1.30 P.M. to 3.30 P.M. and then decreases. But the heat gained by the air in the solar air heater decreases with time.

**Evacuated Tube Collector with Flat Aluminium Reflector at Flow Rate of 205 kg/hr**

At the air flow rate of 205 kg/hr with flat Aluminium sheet reflector, it can be observed that the temperature of exit air from the evacuated tube solar collector steadily increases and it attains the maximum at 12.30 P.M. and decreases afterwards.The air velocity of 7.8 m/sec observed at the header pipe outlet. The other metrological parameters of relative humidity and air velocity at the experiment site is noted which is shown in the Table-5.

The relative humidity varies from 50.5% to 79.5% and wind velocity varies from 0.5 m/sec to 2.9 m/sec. Figure-13 shows the variation of inlet, Exit, and Temperature difference of airwith time in evacuated tube collector assisted solar air heater. The exit temperature varies from 39.8$^{o}$C to 90.5$^{o}$C. The inlet temperature varies from 29.5$^{o}$C to 35.5$^{o}$C.The temperature difference varies from 7.8$^{o}$C to 57.5$^{o}$C.

**Table 6:** Hourly Variations of Relative Humidity, Wind Velocity, and Temperature

| Time | 8.30 A.M | 9.30 A.M | 10.30 A.M | 11.30 A.M | 12.30 P.M | 13.30 P.M | 14.30 P.M | 15.30 P.M | 16.30 P.M |
|---|---|---|---|---|---|---|---|---|---|
| Air Velocity m/sec | 0.5 | 2.6 | 4.5 | 2.8 | 5.1 | 1.5 | 2.8 | 3.1 | 2.5 |
| RH in % | 79.5 | 66 | 55 | 53.5 | 52.5 | 53 | 50.5 | 58 | 72 |
| $T_{in}$ $^{o}$C | 29.5 | 31.5 | 33.5 | 35.5 | 33 | 34.5 | 35 | 33 | 32 |
| $T_{out}$ $^{o}$C | 76.4 | 70.3 | 74 | 86 | 90.5 | 80.8 | 64.5 | 49.7 | 39.8 |

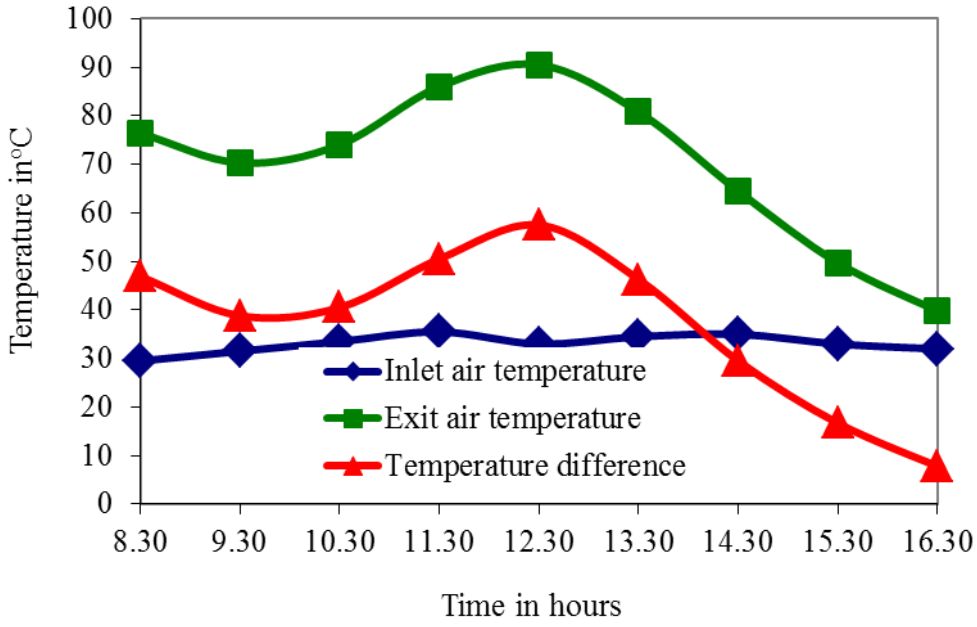


**Figure 13:** Variations of Air Inlet, Exit Temperatures and Temperature Difference

The solar intensity varies from 236 W/m$^2$ to 1188W/m$^2$. Figure-14 shows the variation of solar intensity and efficiency of the evacuated tube assisted solar air heater. The maximum solar intensity is 1188W/m$^2$ at 10:30 A.M. The exit temperature and temperature difference is maximum at 12.30 P.M. during the day. When the solar intensity starts decreasing, the inlet, exit temperatures and temperature difference of air also decreases. The maximum exitair temperature and temperature difference of air are 90.5$^o$C and 57.5$^o$C at 12:30P.M. The efficiency of the evacuated tube assisted solar air heater varies from 43.82% to 75.52%. The solar intensity increases from 756 W/m$^2$ to 1188 W/m$^2$ at 9.30 A.M. to10.30 A.M., butthe efficiency decreases from 60.06% to 54.16%. This shows the header matrix heated during this period. The heat gained by the air in the solar air heater increases from 2222.66 J/sec to 2778.32 J/sec. After 10.30 A.M the solar intensity decreases with time, whereas the collector efficiency of the solar air heater increases upto 1.30 P.M. to a maximum of 75.52% after that decreases with time. From 11.30 A.M to 12.30 P.M the solar intensity decreases from 1161 W/m$^2$ to 1010 W/m$^2$ the efficiency increases from 57.69% to 75.49%. This may be due to heat release by header matrix. The heat gained by the air in the solar air heater during this period increases from 2892.89 J/sec to 3293.89 J/sec.

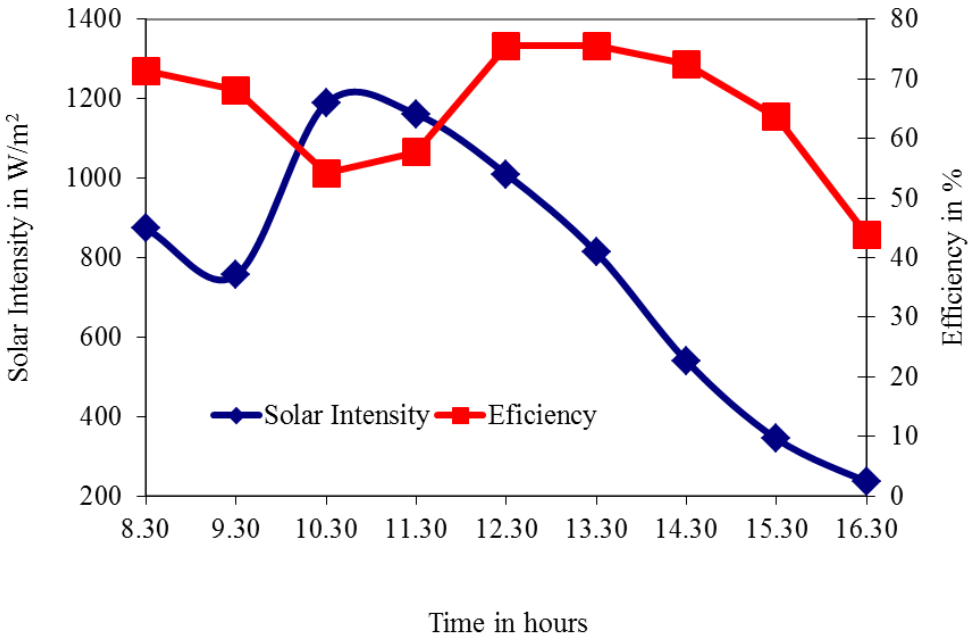


**Figure 14:** Variations of Solar intensity and Efficiency

## Conclusion

The maximum efficiency of 75.52% for the mass flow rate of 205 kg/hr is observed for evacuated tube with flat aluminium sheet assisted solar air heater collector. The aluminium sheet improves the collector performance for mass flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr considerably. It is observed from this experimental study that the increase in mass flow rate leads to increase in efficiency of the collector. The most important advantage of using evacuated tube solar heater is that it can be used even during winter season as this experimental work took place in the month of December 2014 and February 2015. In this solar air heater the wind velocity has no effect and relative humidity do not have considerable influence on evacuated tube collector performance for all modes of operation, since it makes use of evacuated tube collector. The temperature of outlet air steadily increases at higher rate than the ambient temperature due to high absorption rate of solar radiation in evacuated tubes.

The average solar intensity for evacuated tube without any reflector for mass flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr are 930.89 W/m$^2$, 897 W/m$^2$ and 900.22 W/m$^2$. The maximum average efficiency of 52.31% is observed for evacuated tube solar air heater without any reflector for the mass flow rate of 205 kg/hr. The average solar intensity for evacuated tube with flat aluminium reflector assisted solar air heater for the mass flow rates of 170 kg/hr, 190 kg/hr and 205 kg/hr are 944.56 W/m$^2$, 729 W/m$^2$ and 769 W/m$^2$. The maximum average efficiency of 64.68% is observed forevacuated tube with flat aluminium reflector assisted solar air heater for the mass

flow rate of 205 kg/hr. From this it is noted that the flat aluminium sheet reflector improves the efficiency of the evacuated tube assisted solar air heater considerably.

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