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Experimental investigation on solar air heater assisted natural ventilation in single-sided ventilated room

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Abstract

This paper presents an experimental study of solar air heater for natural ventilation in single-sided ventilated room (SSVR). This is a way to increment natural ventilation and as a consequence to improve indoor air quality. In the experiment, a flat plate collector with the length of 1.2 m, width 0.6 m and air gap 0.08 m is used. It is found that the temperature distribution of air and the induced natural air flow rate depend highly on heat input and the area of solar air heater. Experimental research indicates that the air change per hour (ACH) of room varies from 1 to 4 according to the solar incident radiation. The readings were compared with available published experimental and theoretical data. There was an acceptable trend match between experimental and published results. Instead of having a traditional solar chimney, the above approach of introducing a solar air heater method will give better solution for natural ventilation in multistory buildings.

Keywords: Solar air heater, natural ventilation, ACH, SSVR.

Nomenclature

t_{fi} - Air heater inlet temperature (°C); t_{fo} - Air heater outlet temperature (°C); t_a - Temperature of ambient air (°C); I_t - Total solar incident radiation (W/Sq. m); M_a – Mass flow rate of air in the air heater (kg/s); Q_u -Heat gain used for heating the air (kJ/s); C_p - Specific heat of air at constant pressure (kJ/kg K); ρ - Density of air (kg/m^3); $\forall$ – Volume flow rate of air (m^3/s); V – Volume of the test room (m^3); η - Efficiency of air heater; A_p – Area of absorber plate (m^2); v – velocity of air (m/sec); ACH- Air change per hour.

Introduction

Efficient air ventilation and thermal comfort are of great importance in urban and rural areas and in hot climate conditions. Ventilation is a primary factor in any type of building. It may be natural or mechanical ventilation. Natural ventilation may be preferred in most of the places due to more oxygen content, inexpensive, energy saving and being eco friendly. In the past decades building roof structures based on solar air collector utilization have attracted the attention of many investigators. Most of them were concerned with natural ventilation. Khedari *et al*. (1997) conducted an experimental study of a roof solar collection (RSC) made by using CPAC monier concrete tiles on the outside gypsum board on the inner side. Khedari *et al.* (1997) carried out another field measurement of the same kind RSC and the experimental results showed that large air gap and large and equal size of openings would induce the highest rate of air flow. Hirunlabh *et al*. (2001) proposed four different configurations of the RSC to maximize natural ventilation through numerical modeling.

Kishore (2001) developed a solar passive system which can provide thermal comfort throughout the year under different climate conditions. That system needs more modification in building roof to provide year round thermal comfort. Choudhury *et al.* (1988) proposed a detailed theoretical parametric analysis of a one-pass, corrugated, bare plate solar air heater. It can be easily and economically fabricated from existing corrugated aluminum sheet and it gives high air temperature and low air mass flow rate applicable to agricultural use. Many variations of solar chimney have been used widely in the past, and many are being developed again today (Sukhatme, 1996; Harris & Helwig, 2007; Marti-Merrero & Heras-Celemis, 2007). Visagavel and Srinivasan (2009) have done the numerical analysis on modification of window size and its effect on air flow. It concludes that modification of window does not increase ACH. So, further set up is needed to increase the ACH. Solar Chimney is existing set up. But, it needs more modification in existing building structure. But the Solar air heater set up can be retrofitted without much modification at low cost. Mathur *et al*. (2006) has developed small size chimney specially having absorber length less than 1 m. Most of the researchers have done the experiment for 2 m height chimney and above. But installation of that type of large chimney requires major modification in building. But in this paper, attempts have been made with a smaller size chimney which can be embedded in a regular window without major structural changes. This work only induces author to develop the model of solar air heater assisted ventilation in single side ventilated room.

Bassiouny and Nader SA Koura (2007) have made an analytical and numerical study of solar chimney using finite element model and concluded that the chimney width has a very significant effect of flow rate and ACH when compared to the inlet area size. The increase in the inlet size only improved the ACH by almost 11% of the existing Mathur *et al.* (2006) model. However, increasing the chimney width, the ACH is improved by almost 25% of the existing model. This work has motivated the author to use a 3 inch pipe (0.075 m) instead of one (or) 2 inch (0.005) duct pipe. If the increase in size of the duct pipe is

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made further, the ACH will definitely improve, but erecting the pipe to the height of 3 floors is practically difficult. So, the author restricted his experiment by using 3 inch pipe.

Table 1. Configurations of material used for experimental setup

Parts	Material	Dimension
Inlet/outlet pipe	Polyvinylchloride	7.5 cm (3 inch) dia.
Solar flat plate collector 2.1. box material	Galvanized iron sheet	1.2 m X 0.6 m X 0.14 m
2.2.Absorber plate	Galvanized iron sheet with black paint coated	1.2 X 0.6 m^2
2.3 Insulator	Thermocol (EPS) sheet	1 cm thick,1.2 X 0.6 m^2

In this paper, a new approach is carried out by introducing the solar air heater. The solar air heater inlet is connected with room outlet opening and the solar air heater outlet is connected with a natural draught with a height of 0.6 m (2 feet). The performance of the total experimental setup has been analyzed and compared with the previous published data. It gives good agreement on ACH.

Solar air heater setup with SSVR

The solar air heater setup comprises an inlet pipe, outlet pipe, solar flat plate collector as shown in Fig.1. These configurations were made by using local material indicated in Table 1. The experimental setup consists of 3 major parts. One is a cubical room, to which ventilation has to be provided. The structure is already exists as a part of the department block. The dimension of the room is 3 m X 1.8 m X 1.8 m. Total volume of the room is 9.72 m^3. It is single side ventilated with opening at one side. Door to the room is on one side. Opposite to the door, a 0.075 m circular opening is provided at the height of 2.4 m from the gourd level as shown in Fig.1.

The second part is the duct pipe. It is made up of polyvinyl chloride (PVC) material. It is not insulated. The diameter of the duct is 0.075 m (3 inch). The pipe is airproof and erected outside of the building. The length of the pipe which includes the four elbow bend pipes is 9 m length. The air heater is placed at the third floor terrace. The third part is solar flat plate collector which is actually solar air heater. Author introduces this concept as new one, since roof attached collector was tested only at various inclinations. But for the first time, a solar air heater is experimented for the ventilation purpose. It is a conventional solar air heater. It consists of an absorber plate, transparent cover and insulated container. The main advantage of a flat plate collector is that it utilizes both the beam and diffused components of the solar radiation.

The developed experimental solar air heater setup is shown in Fig.1. A rectangular chamber is made of galvanized sheet of size 1.2 m X 0.6 m X 0.14 m. The height of 0.14 m box is split into two chambers by an absorber plate at the height of 0.06 m from the transparent cover. The absorber plate is made up of galvanized sheet with a thickness of 0.001 m. The plain glass of 0.005 m thickness is the material used here for the transparent cover. The bottom and sides are insulated by thermocol (EPS) sheet and has a thickness of 0.025 m. The air flows between the absorber plate and bottom of the box. The gap between these two is 0.08 m.

Experimental methods

Fig.1 shows the block diagram of experimental set up. The solar air heater set up was supported by a bracket and could be tilted in different angles whereas here only 11° inclination was kept for experimental work. The solar air heater is an ordinary flat plate collector. The temperature at the inlet and outlet of solar air heater, room and atmosphere were measured by using T type thermocouples with the certainty of measurement of ±0.5°C. The velocity of air at near inlet and outlet of the room and inlet and outlet of solar air heater were measured by a hot bulb anemometer (Type ET3-2A) for which the certainty of measurement is ±0.02 ms^{-1}. Solar radiation was measured by using a pyranometer. The heater was placed north-south facing, so that no shadow shielded the surface area of the collector. Experiments were performed from 6 A.M to 6 P.M. Solar radiation, temperatures and velocities were measured for a day and were tabulated as shown in Table 2.

Table 2. Experimental readings of solar air heater based room ventilation system

Date	16-05-2007			Time period			6 A.M to 6 P.M	
Measured values								
Time of the day hr	t_a °C	t_{fi} °C	t_{fo} °C	I_t W/m²	v_1 m/sec	v_2 m/sec	v_3 m/sec	v_4 m/sec
6	25	25.98	29.93	100.02	0.9365	0.9365	0.9396	0.952
7	25.1	26.42	31.31	135.26	1.0593	1.0593	1.064	1.0814
8	26.7	29.89	39.48	338.50	1.5401	1.5401	1.5565	1.6058
9	28.5	32.95	45.64	487.06	1.7832	1.7832	1.8095	1.8846
10	30.2	36.07	52.33	666.63	2.0197	2.0197	2.0588	2.1671
11	31.7	38.70	57.84	816.10	2.1864	2.1864	2.2366	2.374
12	32.9	40.84	62.42	944.39	2.3129	2.3129	2.373	2.5361
13	33.8	41.14	61.12	856.43	2.2243	2.2243	2.2775	2.4224
14	34.3	40.43	57.26	688.80	2.0392	2.0392	2.0799	2.1915
15	34.3	39.26	53.17	539.37	1.8486	1.8486	1.8784	1.9621
16	33.6	36.03	43.74	246.72	1.3452	1.3452	1.3559	1.3897
17	32.1	32.93	36.44	82.27	0.8608	0.8608	0.8631	0.873
18	30.7	30.85	31.96	15.22	0.4423	0.4423	0.4425	0.4441

Mathematical modeling

A mathematical model of the experimental setup was developed for estimating the performance of the solar air heater under different ambient conditions. Heat losses and pressure drop were not accounted for calculation of ACH. The volume flow rate can be calculated as suggested by Sukathme *et al.* (1996) using the measured data, t_{fi}, t_{fo}, t_a, I_t. Efficiency (η) was also calculated from the following formula:

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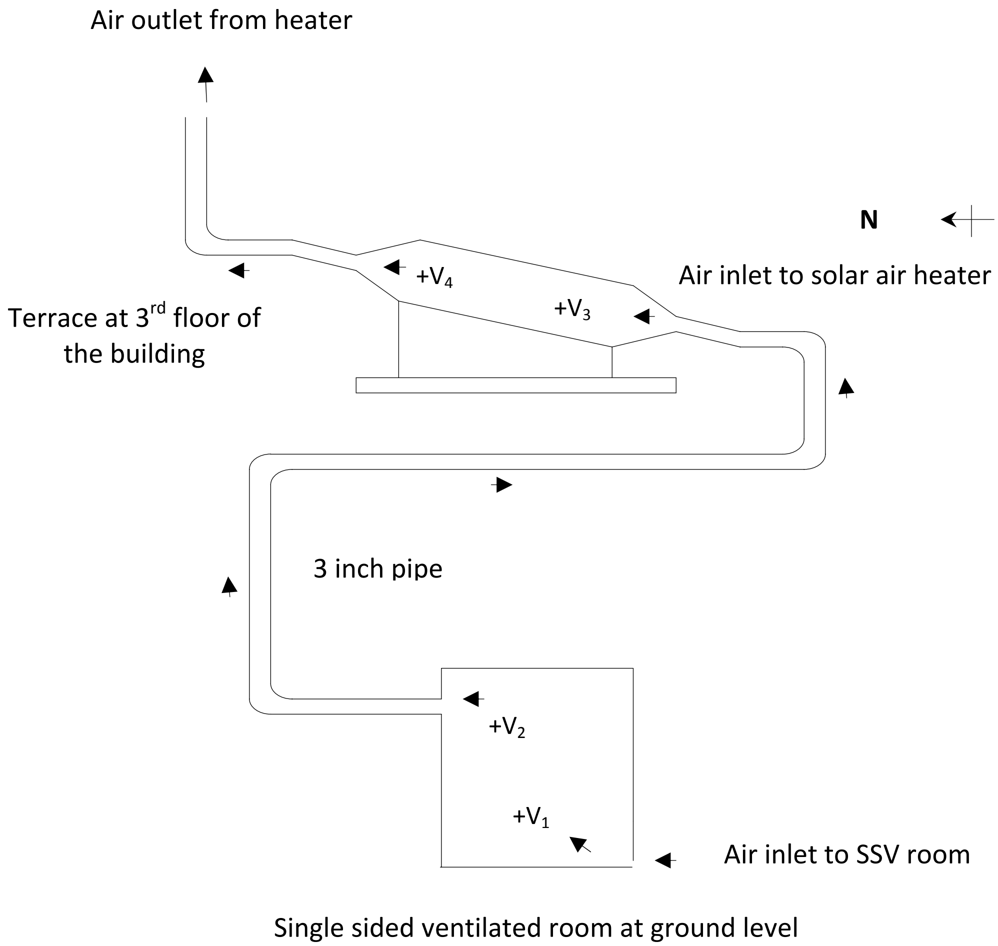
Fig.1 Block diagram of physical setup



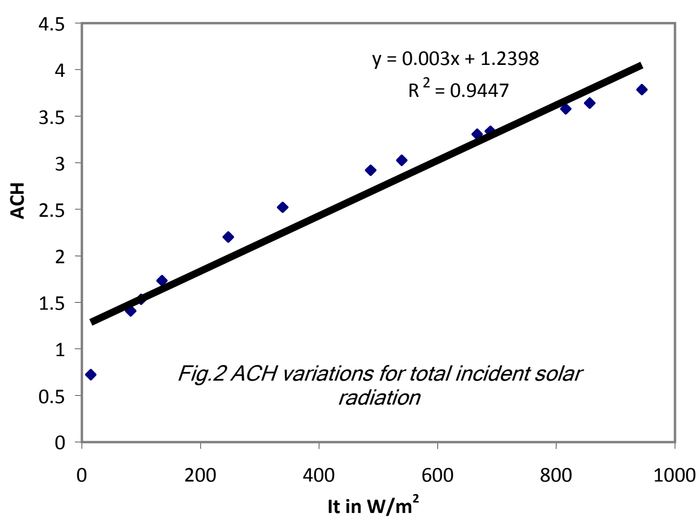


Fig.2 ACH variations for total incident solar radiation

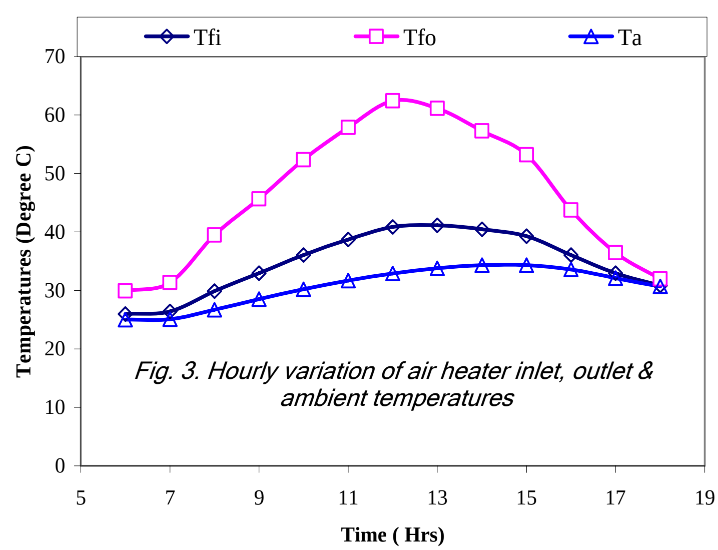


Fig. 3. Hourly variation of air heater inlet, outlet & ambient temperatures

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$$\eta = \frac{Q_u}{A_p \times I_t}$$

Then $Q_u = M_a \times C_p \times (t_{fo} - t_{fi})$

Where $M_a = \forall \times \rho$

$\forall$ = Area of pipe x Average velocity

Then $ACH = \dfrac{\forall \times 3600}{V}$

Experimental results and analysis

Testing the performance of the solar air heater was carried out on different days corresponding to different ambient conditions. It was not easy to make a comparison between the different results, because of the various climatic conditions. However, for a sample, calculations for a single day readings were shown in Table 3.

Fig. 2 indicates that ACH increases with the increase in solar radiation. Atmosphere temperature increases up to 3 pm and decreases further as shown in Fig. 3. Air heater inlet and outlet temperatures increase up to 12 noon and decrease afterwards. Efficiency and mass flow rate were following the same curve path. It clearly indicated that ACH depended on solar incident radiation. If the heat gain of the solar air heater is maximized, ACH will be improved further. Fig. 4 & 5 shows that efficiency also varies through out the day due to variation of total solar incident radiation. The mass flow rate per square meter of collector area also followed the same trend of the curve shown in Fig. 6.

Observations and results

Mathur *et al.* (2006) had done experiments on chamber of 27 m^3 volume, using an absorber plate of 1 m^2 area with a height of 0.9 m. The solar chimney was designed with an inlet height of 0.1 m, air gap of 0.1 m and chimney height of 0.95 m. Solar incident radiation was 300 w/m^2, 500 w/m^2 and 700 w/m^2. Bassiouny and Nader SA Koura (2007) had done numerical study for the same data and published optimized design data for maximum ACH. In this paper, the air gap is considered as the gap between absorber plate and bottom plate is of 0.08 m, the inlet height as inlet diameter of the heater 0.075 m, absorber height which is 1.2 m and the height of the chimney is taken from outlet of the room to outlet of the air heater which is a 6.6 m. Even though, the experimental setup appears to be similar, the inferences and the data are entirely different. Since no work has been attempted like this experimental setup. So, author has taken almost similar works of experimental set up and its outcome. Table 4 shows the summary of results for comparison. In this paper, the author has taken the solar incident radiation and ACH for comparison with the published data (Mathur *et al.,* 2006; Bassiouny& Nader SA Koura,2007) for traditional solar chimney.

The air change rate of traditional solar chimney for different solar radiation varies from 2 to 3.The solar air heater setup also gives ACH from 1 to 3. ACH fully depends upon the heat gain by the air. So it directly depends on the surface area of the absorber. If the surface area of the absorber increases, ACH also increases. The author has done the experiments with 0.72 m^2 area for 9.72 m^3. Fig.1 shows the plot of air change rate for 9.72 m^2 room at different radiation values

Fig. 4. Hourly variation of efficiency of solar air heater

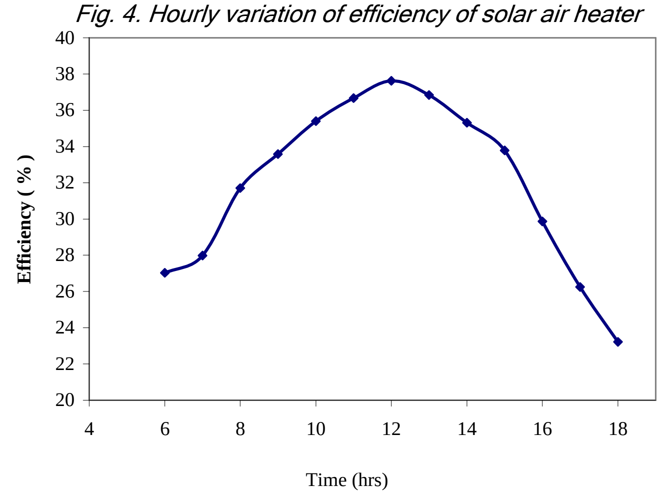


Fig. 5. Hourly variation of solar incident radiation

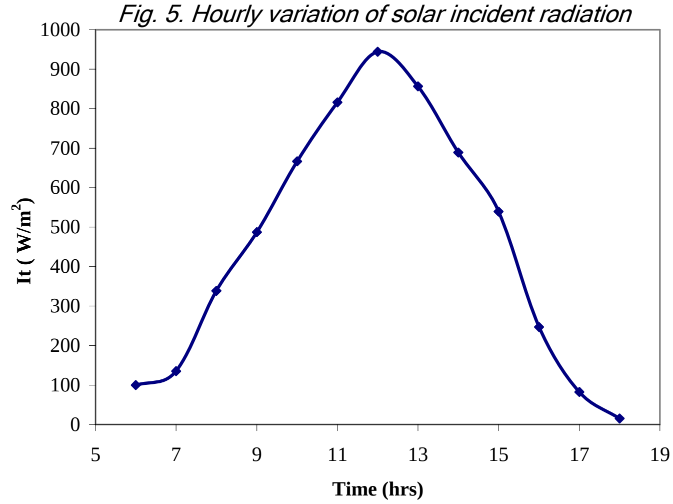
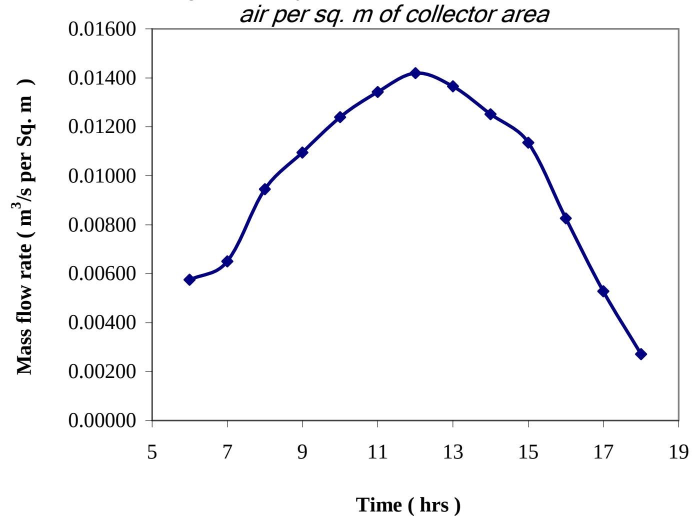


Fig. 6. Hourly variation of mass flow rate of air per sq. m of collector area



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for different ambient conditions. The air flow rate increases linearly with an increase in solar radiations. This work ensures that the natural ventilation can be provided to any type of residential and commercial building without major modification in the structure of the existing building.

Table 3. Experimental results of solar air heater based room ventilation system

Calculated values							
Avg. air velocity m/s	t_{fo}-t_{fi} °C	Density kg/m^3	Air flow rate m^3/s	ACH	Mass flow rate kg/s	Q_u kJ/s	Efficiency %
0.94	3.95	1.18	0.00416	1.54	0.00492	19.54	27.14
1.07	4.89	1.18	0.00471	1.74	0.00557	27.39	28.12
1.56	9.59	1.18	0.00689	2.55	0.00812	78.21	32.09
1.82	12.69	1.17	0.00801	2.97	0.00938	119.71	34.14
2.07	16.27	1.16	0.00912	3.38	0.01062	173.64	36.18
2.25	19.15	1.16	0.00992	3.67	0.01149	221.06	37.62
2.38	21.57	1.15	0.01053	3.90	0.01214	263.33	38.73
2.29	19.98	1.15	0.01010	3.74	0.01162	233.32	37.84
2.09	16.83	1.15	0.00922	3.41	0.01059	179.05	36.10
1.88	13.91	1.15	0.00832	3.08	0.00956	133.59	34.40
1.36	7.71	1.15	0.00600	2.22	0.00691	53.53	30.13
0.86	3.52	1.16	0.00382	1.41	0.00442	15.60	26.34
0.44	1.11	1.16	0.00196	0.72	0.00227	2.54	23.22

Mathur *et al.* (2006) have compared the experimental and theoretical results for different air gaps and stack heights. But, in the present experimental setup, there is no solar chimney. Instead, a 3 inch duct pipe has been introduced to displace the air from the room to the atmosphere, through a solar air heater. Normally, a solar chimney is made like a vertical solar air heater. But here, a solar air heater is positioned in 11° inclination from the ground level.

Conclusions

This investigation strongly suggests the solar air heater as an alternate idea for solar chimneys. In a regular solar chimney system, the air movement restriction is less, whereas in present set up, air heater has to be kept at the roof of the building, so a bend pipe has to be used. It gives a pressure drop and restrictions to the flow. Despite all the restrictions, the ACH is found to be coming up to 3. Normally ACH depends on temperature difference between inlet and outlet of heat generating medium. So, the heat gain of the heater depends on absorber plate area. If the area of absorber plate increases, the heat gain of the heater also increases. When compared with other published data, the absorber plate area to the room volume ratio in this setup produces very satisfactory results. Khedari *et al.* (1997) proved that solar chimney area to house volume with a rate of 0.24-0.36 m^2/m^3 (6 to 9 m^2/25 m^3 volume) induces the ACH between 12 A.M to 2 P.M was about 15 corresponding to 1.6 to 2.5 time/hr. per unit surface area of solar chimney. Similarly in this setup, the surface area of solar air heater to the room volume with a rate of 0.07 m^2/m^3 (0.72 m^2/9.72 m^3 volume) induces the ACH between 12 A.M to 2 P.M was about 3 corresponding to 4.1 time/hr. per unit surface area of solar air heater. It is better than the traditional solar chimney setup and may be viable for residential and commercial building ventilations.

Table 4. Summary of results for comparison with experimental & theoretical published data

Solar radiation W/m^2	ACH		
	Mathur *et al.* (2006)	Bassiouny & Nader SA Koura (2007)	Present study
300	2.0	2.5	2.4
500	2.2	3.2	2.6
700	3.0	3.5	2.9

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