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EXPERIMENTAL INVESTIGATION OF ROOFTOP SOLAR CHIMNEY FOR NATURAL VENTILATION

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ABSTRACT

Rooftop solar chimney functions to create natural ventilation of buildings. It is a solar driven device which induces buoyancy force through the chimney channel to updraft the air out of the building. The design parameter of the rooftop solar chimney would affect the ventilation performance. This paper presents experimental results of measurements carried out on a modified rooftop solar chimney, with double absorber surfaces, horizontal and vertical. The system performance was evaluated at various design configurations and different operational condition. Three designs were tested and compared. The first design, model 1 was the basic rooftop solar chimney which contain vertical absorber plate, room's air inlet and total air outlet. The second design, model 2 was with two inlets, from the room and from the ambient through horizontal absorber, and total air outlet. The third design, model 3 was two inlets, but with extra vertical absorber plate installed in the middle of the vertical air outlet passage. The results demonstrated that operating the chimney with ambient air inlet show the lowest performance. Model 3 which is the rooftop solar chimney with additional vertical absorber in the air outlet passage showed performance enhancement with 1.2% and 7.6% compared to model 1 and model 2, respectively.

Keywords: rooftop solar chimney, ventilation, air outlet passage, vertical absorber.

INTRODUCTION

Solar Chimney is a thermal-solar device which utilizes the solar energy to create natural ventilation. Solar chimney contains absorber material which functions to absorb and convert the solar radiation to thermal energy which heats up the air particle along the chimney channel. The heated air particle creates a medium with lower density and produces buoyancy force. When the solar chimney installed on a roof of a building with air access between the space and the chimney, buoyancy force updrafts the air along the chimney channel and natural circulation of air is formed in the specified space. Solar chimneys technology can serve for many purposes, for example: natural space ventilation, drying of clothes and agriculture products, and even for electricity generation when they are implemented in large scales. Rooftop solar chimney (RTSC) operates based on the principle of natural heat transfer and stack effect in the buildings. The principle of the RTSC for space ventilation and air circulation is shown in Figure-1.

There are numerous of research have been carried to study the performance of solar chimney for ventilation application. [1], carried out an investigation on the performance of stack induced ventilation strategies on experimental room model in Malaysia's weather condition. The results show that the solar chimney can increase air flow in the room but also increase the heat gain. The use of solar wall increases air velocity.

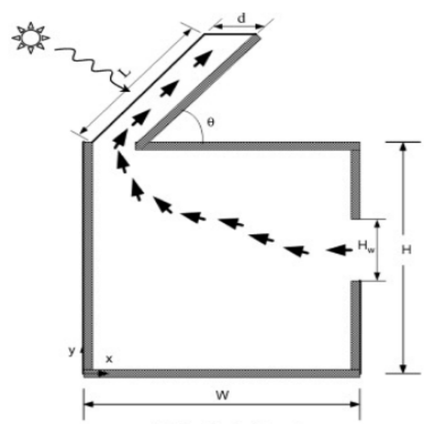

Figure-1. Schematic diagram of inclined draft by roof top solar chimney [2].

Degree of inclination of absorber in RTSC is affecting the performance, where the airflow rate varies with different inclination. Different inclined angle, θ has been applied to the solar chimney by [2] to study the effect on the flow pattern and ventilation rate. The analytical results showed that an optimum air flow rate value was achieved when the chimney inclination is between 45° and 70° for latitude of 28.4°N. The numerically predicted flow pattern inside the space supports this finding. A correlation was tested within a solar intensity greater than or equal to 500 W/m^2, and chimney width from 0.1 m to 0.35 m for different inclination angles. Acceptable results have been obtained from the correlation. Study by [3] showed that optimum inclination at any place varies from 40° to 60°

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depending upon latitude. The maximum mass flow rate through an inclined solar chimney at Jaipur (India, 27°N latitude) is achieved at 45°, which has 10% more than the flow rate at 30° and 60° inclinations. On the same context, [4] have conducted experimental investigation to explore the optimum inclination angle for natural solar air heating. They reported similar observations of [3], where the best performance of the solar air heater was obtained at 40° to 50° inclination.

The other design parameter affecting the performance of the RTSC is the ratio between height of absorber and gap between glass and absorber. Study by [5] showed that there is a potential of inducing ventilation corresponding to 55-150 m^3/h airflow rate for 300-700 W/m^2 solar radiation incident on the vertical surface. This rate is corresponding to 2-5.6 air changes per hour for a typical room of 27 m^3. Airflow increases linearly with increase in solar radiation or increase in gap between absorber and glass cover.

Other parameter, ratio between inlet and outlet area, would also affect the airflow. However, this ratio could not be obtained with the experiment carried out by [5]. Another study done by [6] shows that, the rate of ventilation increases with the increase of the ratio between height of absorber and gap between glass and absorber.

Solar intensity is one of the most influencing parameter on the roof top solar chimney performance. [7] Presented a mathematical model and analysis of an inclined type roof top solar chimney. The analysis was carried out with various collector areas which are 15 m^2, 150 m^2 and 600 m^2. The validated steady, one dimensional mathematical model successfully predicted the flow velocity and mass flow rate in the chimney passages. From their experiments, it is found that the solar intensity is the most influencing parameter. Even with a large collector area up to 600 m^2, the system is not able to feasibly perform when solar intensity is less than 400 W/m^2. The system performance also improves as the collector area and chimney height increases. The increase in wind speed reduces the system performance.

[8] have conducted a study on the combined wall-roof solar chimney. Wall-roof solar chimney is possible to create a maximum air flow of 2.3 m^3/s when the wall is extended to 3.45 m high with an inlet height of 0.15 m. The combined wall-roof solar chimney that has been tested in this experiment has induced an air change per hour up to 26. Wall-roof solar chimney is a highly efficient design where it could absorb more heat. However, wall chimney may affect the efficiency of ventilation because it depends on the orientation.

On the effect of chimney height on the performance of Rooftop Solar Chimney, [7] reported validated mathematical results with 2, 4 and 6 m chimney height. The results showed that the performance of the chimney is highly dependent on the height. At 6 m, a velocity of 1.8 m/s was achieved.

Performance of solar chimney could be affect by different parameter. Base on the current research and study, the parameter that could affect the performance of solar chimney is the inclination angle of absorber plate, ratio between height of absorber and gap between glass and absorber, area of absorber plate, height of the chimney and ambient air speed. It is realized that there is no research has been done on additional absorber plate in the application of the RTSC.

Therefore, the objective of the present research would be focusing on investigating the performance of modified solar chimney, with two inlets and two absorbers. Hence, three models have been tested embarking three different designs. These three designs are basic design of vertical chimney, modified design with additional ambient air inlet and horizontal absorber, and the third design with additional vertical absorber plate.

Experimental implementations

The experimental investigations were carried out using a prototype of RTSC installed on the top of an office construction in the Solar Research Site (SRS) in UTP. The period of measurements lasted for 4 months starting from August till end of November 2014. Set of measuring instruments were used with measuring program allow monitoring of the operational parameters over the day. The data acquisition was starting at 10.00am and continues till 4.00 pm.

Experiment setup

The fabricated prototype of the RTSC is installed on the roof of a construction used as office for the postgraduate students in the SRS, UTP, Perak, Malaysia, as shown schematically in Figure-2. The prototype was designed in a way that allows closing and opening of air inlets, and allow installation and removal of additional absorber plate in the middle of the vertical passage. By that means, the same prototype could provide three different designs, named as model 1, model 2, and model 3.

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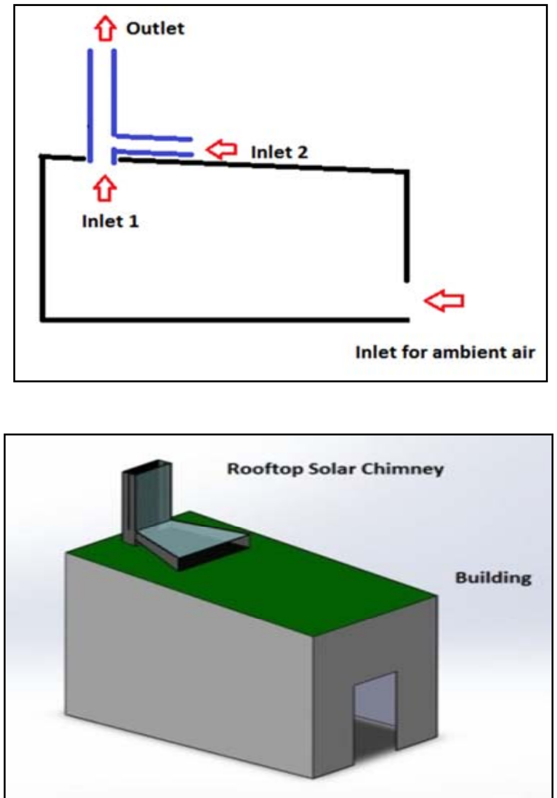

Figure-2. Outlines of the experimental setup.

The construction has 4.0 m and 3.5 heights at the back and front, respectively. The height and width of the vertical part of the chimney is 1.5 m and 1.0 m, respectively with gap of 0.14 m. The horizontal part is designed with convergence channel of 1.5 m width at the inlet reduced to 1.0 m at the connection with vertical part. The inlet of ambient air to the horizontal part is 1.5 mx 0.14 m. The covers of the vertical and horizontal collectors are made of Perspex.

The required data include the air velocity at different air aperture, surface temperature of the absorber plates, temperature of air at different air aperture and solar radiation during experimental period. The data is recorded manually every 2 hours from 10am to 4pm with the help of different instrument.

Measuring instrumentation

The measurements are carried out during the day time in 2 hours intervals from 10.00am to 4.00pm and the raw data are recorded manually. Thermometer type TK102, Figure-3(a), is used to capture the sensed temperature J type probes have measuring range from -100 to 750 ºC and ± 0.8 °C accuracy. The solar intensity is measured by solarimeter type KIMO Sl100 has a measuring range from 1 W/m^2 to 1300 W/m^2. The velocity and temperature of air are measured using portable hotwire probe with velocity measuring range from 0.15 m/s to 30 m/s and air temperature measuring range from -20 °C to 80 °C.

a. Temperature measuring tools KIMO TK102	b. Solar intensity measuring tool KIMO SL100

c. Air velocity and temperature measuring tool AMI 300

Figure-3. The measuring instrumentations.

The air velocity, and the flow rate, was measured at each cross section area of outlet and inlet. The measurement for one specified time was taken at eight locations in each cross section and the mean of them is considered as the mean velocity. The temperature was measured at the ambient, at inlet and outlet of the room, and at each inlet and outlet of the RTSC.

RESULTS AND DISCUSSION

The system is evaluated through experimental measurement under three different operational modes. The prototype is designed in such a way to allow manual modification by blocking some inlets. Three different operational modes have been investigated, as below:

- **Model 1:** Single vertical absorber plate, total air outlet and room's air outlet, as in Figure-4.

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- **Model 2:** Single vertical absorber plate, total air outlet, room's air outlet, ambient air inlet with horizontal absorber plate, as in Figure-5.
- **Model 3:** Two vertical absorber plate, total air outlet, room's air outlet. No ambient air inlet, as in Figure-6.

Figures 4, 5 and 6 show the design outlines of each model.

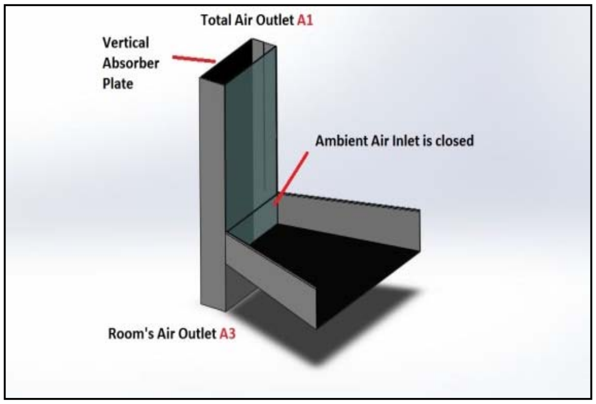

Figure-4. Model 1; Inlet from the room, exit from the top; one vertical absorber.

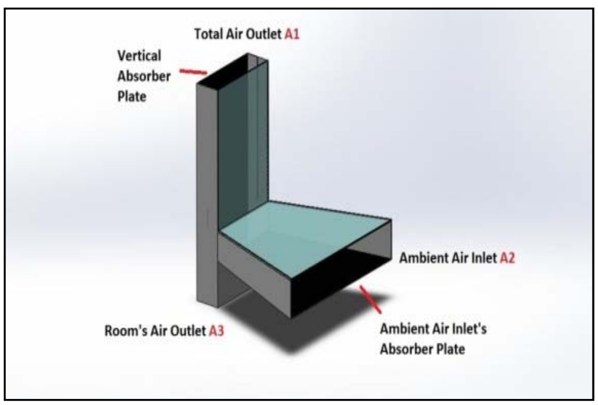

Figure-5. Model 2; Inlets from the room and the ambient, exit from the top; two absorbers, one vertical and horizontal.

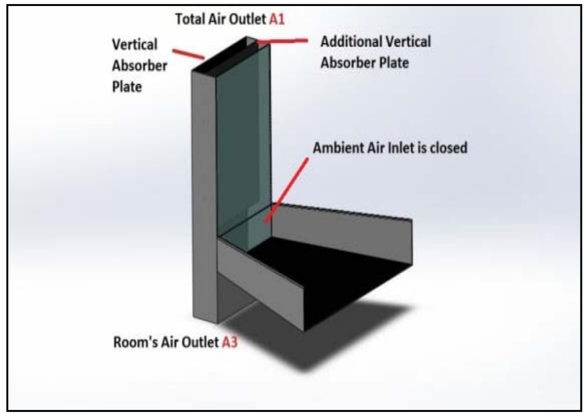

Figure-6. Model 3; inlet from the room, exit from the top; two vertical absorbers.

Air circulation in the room

Air circulation through the room is estimated by measuring the air flow rate at the exit from the room to the chimney, named inlet 1 in Figure-2. The average of five days average is shown in Table-1 for the tested modes. The enhancement is obtained by comparing with basic case, model 2. In the case of model 3 imposes higher air circulation by 7.6%. In case of model 2, the air circulation in the room is reduced by 7%, while the total air flow in the chimney is increased as shown in the next section.

Table-1. Comparison of average volume flow rate at room's air outlet for different model.

Operation mode	Average volume flow rate of the room's air outlet (m^3/s)	Percent of enhancement
Model 1	0.246	-
Model 2	0.230	-7%
Model 3	0.249	7.6%

Air flow in the chimney

The flow through the chimney is measured at the top outlet shown in Figure-2. The mean measurement values of five days are shown in Table-2. The results demonstrated that operational model 2 with horizontal and vertical absorbers enhanced the flow rate in the system. This is due to the extra air flow from the ambient through the horizontal passage. But the ambient air has low temperature compared to the air temperature in the room. Hence, this part of the flow rate extract considerable amount of thermal energy from the absorbers and causing reduction in the room air circulation.

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Table-2. Comparison of Average Volume Flow Rate at Total Air Outlet for different model.

Design model	Average volume flow rate of the total air outlet (m^3/s)	Percent of enhancement
Model 1	0.252	-
Model 2	0.278	9.3%
Model 3	0.253	0.4%

Heat gain

Figure-7 displays the rate of heat gained by the air flow through the chimney, for three tested models. The heat transfer rate is calculated using the mean values of the of five days repeatability, as:

$$Q = \dot{m} c_p \Delta T \quad (1)$$

Where:

Q Heat transfer rate from absorber (s) to air (W)

$\dot{m}$ Mass flow rate of air (kg/s)

c_p Specific heat capacity of air (kJ/kg·K)

ΔT Temperature difference between inlet and outlet of room air flow, only (K).

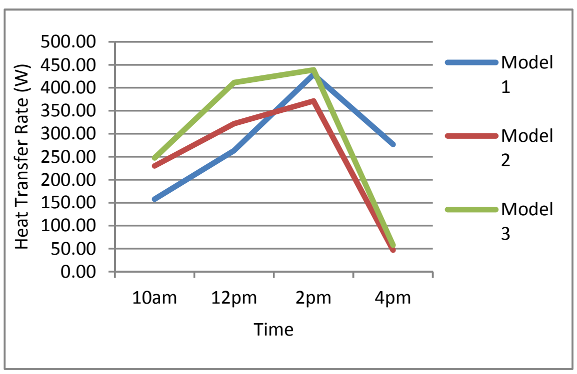

Figure-7. Average heat transfer rate from the absorber plate to the flowing air in the chimney.

Model 3, which equipped with and additional vertical absorber plate shows the highest heat transfer rate from 10 am to 2 pm. However, the heat transfer rate drop below 100W after 4pm which is lower compare to Model 1. The reason that temperature of air in the room becomes high due to the heat accumulation inside the building. However, during 2pm to 4pm, Model 1 has higher average heat transfer rate comparing to Model 2. The results show inconsistency due to the inconsistency of weather condition.

Model 2 has the lowest air flow rate at Room's Air Outlet among others. Model 2 equipped with additional ambient air inlet and additional absorber plate functions to preheat the ambient air before entering the chimney channel. The preheat air increase the temperature along the chimney channel and hence buoyancy force increase. However, the buoyancy force created is weakened by ambient air inlet itself. The buoyancy force created at Model 2 updraft the air through room's air outlet and ambient air inlet. For Model 1 and model 3, the buoyancy force updraft the air only though the room's air outlet. Therefore, Model 2 buoyancy force is weakened by up drafting air from two air aperture comparing to Model 1 and Model 3 which only up drafting air from one air aperture. Hence, the air flow rate at room's air outlet for Model 2 is lower compare to others.

CONCLUSIONS

Analysis of the experimental measurements on three different designs of roof top solar chimney demonstrate that the system designed with additional absorber plate in the vertical passage, model 3, has the best performance compared with another two designs without additional absorber plate. Model 3 provided the highest average air flow rate and highest heat transfer rate compared to the other investigated models. In terms of air flow rate, model 3 showed improvement of 1.2% and 7.6% compared to model 1and model 2, respectively. The additional of vertical absorber plate increases the heat transfer due to the increase in the contact area between the air particles and the hot absorber surfaces. High buoyancy force is produced and lead to high air flow rate.

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