Interpretation on Result of Directions of Suction Opening on Solar Chimney Coherent with Building

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The performance of a solar chimney was investigated and integrated into a one-storey building. It was designed, manufactured and tested through the selection of different suction openings for the entry of air including right, left, front, back, both right & left and both front & back sides. A module was developed and implemented in CFD for identification of the energy effect on solar chimneys. Experimental results showed that in Tiruchirappalli (Longitude +78.69E, Latitude +10.81) the air changes per hour increased and decreased for various suction openings, indicating that there was a correct orientation of suction opening for a solar chimney for maximum ventilation. The results show that the solar chimney with 50° inclination angle at the left inlet suction opening was found to provide maximum ventilation. The findings between the CFD and experimental results show good agreement.

Keywords: Air flow rate, Air change per hour, CFD, Chimney orientation, Natural ventilation, solar chimney, Tiruchirappalli site.

Introduction
Natural ventilation systems using solar chimneys slowly began to be used in various places in Tamil Nadu like Tiruchirappalli. The main reason for this was that due to energy savings in building, induced ventilation reduced indoor air temperature, thereby reducing energy consumed by air conditioners. A model1 shows how to minimize flow rates between storeys and maximize the fresh air supply rates to all occupants. Particle image velocimetry2 (PIV) was developed to indentify the air velocity in a single-zone building with cross ventilation. A module3 was developed to determine of energy effect in a solar chimney at 45° integrated into a one storey building at Nanjing using the energy plus program. The result showed that maximizing the rate of ventilation with increased the height of the absorber and chimney gap ratio. A inclined solar chimney4 was investigated experimentally and numerically for an enhanced ventilation in Iraq, where the result showed that the inclined chimney performance was better that of a vertical chimney. An overview of solar chimney5 using CFD simulation by the effects of geometry and inclination angle was studied. A FORTRAN6 program was developed to investigate the effect of a solar chimney inclination angle on the air change per hour and the indoor flow pattern was numerically and analytically analyzed. When compared to the inlet area of the solar chimney7 the width had significant effect on the air flow rate and air change per hour. The performance of the solar chimney8 was integrated into a building. The results showed that mass flow rate first increased and then decreased with the width of the chimney and effects of the variation of inclination angle at different floors. The design of a solar chimney9 was integrated into a building using CFD modeling to identify the effects of inclination angle, double glazing, low emissivity and orientation of solar chimney finishes on the induced ventilation rate. A room10 (27 m³) was investigated experimentally at solar radiation 700 W/m² incident on a vertical surface with the height to air gap ratio of 2.83. It was found that the highest rate of ventilation induced with the help of solar energy was 5.6 air changes per hour. The main objective of this paper is to investigate the thermo fluid flow and energy performances of a solar chimney at 50° inclination angle5 integrated into a one storey building experimentally and CFD to find out the best orientation of suction openings that provide maximum

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air flow rate, air change per hour during summer in Tiruchirappalli located in the southern state of Tamil Nadu.

Mathematical model

For predicating the solar chimney performance, a mathematical model was developed as below.

- Laminar Flow under steady state conditions through a chimney was considered
- Between glass and absorber the air exchanges energy was treated as one-dimension.
- The temperature at the inlet of the chimney was treated as the same average room air temperature.
- Due to minimum air flow velocity, frictional losses were neglected.

The natural convection equations in the solar chimney may be written as:

Mathematical expression of the heat transferred to the moving air stream can be re-written as:

\[ h_g A_g T_g - [(h_g A_g + h_w A_w m C_f^1) T_T]/\gamma] + [h_w A_w T_w] = -[(m C_f^1) T_T]/\gamma \]  

\[ \text{(1)} \]

The air flow rate is given as

\[ m = c_d \rho_f \sqrt{(2g^*L_s^*\sin\theta^*(T_r - T_i))/((1 + A_r^2)T_r)} \]  

\[ \text{(2)} \]

The air change per hour is defined by

\[ \text{Air change per hour (ACH)} = m/\rho_f * 3600 / \text{Room total volume} \]  

\[ \text{(3)} \]

Experimental validation

Fig. 1.(a) shows the experimental module for exploring the performance of a solar chimney of a one storey building as a wooden cube chamber made of 1m³ volume. The side portion of this chamber was provided with openings having a dimension of 0.3x0.3m² for the suction of air at six different suction opening orientations like left, right, front, back, both left & right and both front & back of the south facing solar chimney. The highest portion of this chamber was fitted with the south facing solar chimney with dimensions of 1 x 0.4 x 0.15 m³ (length x width x air channel gap) inclined at angle (50°). The chimney consists of a 2 mm thick aluminum sheet colored with ordinary black paint to act as an absorber. The absorber sheet had a glass cover of 5 mm thickness. All the exposed sides of the base chamber were.
protected using 2.5 cm thick plywood sheets. Similarly 2.5 cm plywood was provided on the rear of the absorber to prevent heat losses. Temperatures at various points were measured by k-type thermocouples with temperature accuracy up to 0.1 °C. By using the absorber surface, the cubical wooden chamber inner surface of glazing, the outer surface of glazing, flow channel, room, and ambient temperatures were recorded at every 1min interval. Similarly, air velocity was measured with the help of a hot-wire anemometer having an accuracy of 0.1m/s placed 15 cm below the exit of the flow channel, at the center of the cross section. Mean stream velocity is greatest near the surface and the slowest along the stream line. The experimentation was undertaken over two months. During April & May 2014 solar radiation intensity was very high at Tiruchirappalli, compared to the remaining months. Every day, the data was recorded at one minute intervals between 9:00 a.m to 3:00 p.m for all suction opening orientations simultaneously as revealed in Fig. 1.(b). During this time solar radiation was varied continuously. Human comfort is required during this time. Here we indentified critical point of solar intensity between 11.00 a.m and 12.00 p.m for all different orientations. The average data was reported in this paper. Solar radiation was measured by a pyranometer having a least count of 15 W/m² and accuracy as ±1% of its reading. The pyranometer was oriented equidistance to the plane of absorber; hence the values of solar radiation mentioned in this paper indicate radiation on a south facing absorber at 50° inclination² for six different suction opening orientations. As the arrangement was placed on a roof, there was a possibility of error in the measurements due to natural wind effect. To reduce the effect of wind velocity, a wall having double height and triple width as compared to the model was placed on the suction sides. The experimental arrangement was capable of recording only the flow velocity in the flow channel.

Results and Discussion

CFD was used to identify the heat balance at the glazing, the absorber and along the flow channel provided by the equations (1) (2) and (3). Experiments were conducted on a solar chimney with right, left, front, back, both right & left, both front & back suction openings orientation in 2014. Fig. 2 shows the daily temperature evolution for fluid flow for left suction openings orientation for the south facing solar

![Fig. 2—Dynamic temperature contours for a one storey build-ing at left suction opening for [a – d] 9.00 a.m [a], 10.00 a.m [b], 11.00 a.m [c], 12.00 p.m [d]](image-url)
chimney. We must emphasize that approximately the mean indoor temperature on the left side suction opening was lower than that of the outdoor temperature of the chimney. As thermal radiation absorption induces an increase in the absorber wall temperature this affects the air-flow coming in contact with the walls and wind speeds effect in Tiruchirappalli’s latitude. I have to agree with the reviewer’s comments. Wind speed will not depend on latitude. Here we indentified that indoor air temperature is varied between 30°C to 32°C between 11.00 am and 12.00 pm for the left suction opening. Preferably human beings feel comfortable at these temperatures.

Solar intensity is the motive force and its natural variation in the universe is significant for the chimney’s performances. Fig. 3 and Fig. 4 show the effect of varying the suction entrances on mass flow rates and ACH at different solar radiations. This figure shows that an increase in the ACH and mass flow rate as solar radiation increases and approaches asymptotic trends. Maximum air change per hour obtained for the solar chimney at left is 157 at 12.30 p.m accompanied by 0.040 Kg/sec air flow rate, at the right it is 105 accompanied by 0.025 Kg/sec air flow rate, at the front side it is 115 accompanied by 0.031 Kg/sec air flow rate, at the back it is 90 accompanied by 0.023 Kg/sec air flow rate, at the left & right sides and the front & back sides was continuously reducing due to reverse flow taking place. The figures also show that there is a remarkable value when the ACH is 157 and mass flow rate 0.040 Kg/sec at a solar radiation of 820 W/m² on the left as compared to other suction openings. The above graphs suggests that with a constant gap between the absorber and the glazing and wind direction in Tiruchirappalli, the air flow as mean stream with a relatively smooth and good buoyancy causes better air flow rate and the ACH for left suction opening compared to the flow in other suction openings. The experimental climate conditions, solar chimney dimensions and material properties were used as input data for the CFD. The CFD and experimental results of the air change per hour (ACH) and mass flow rate for the vertical solar chimney with different suction openings at varying solar radiations obtained in this work were compared as shown in Table 1-Table 4. From the above table, the maximum and minimum deviation of ACH between the experimental and CFD results were calculated and were found at 10.4%, 0.7% respectively. It was similar for the air flow rate to be 10%, 0.5% respectively thereby indicating a fair agreement. This deviation is due to neglecting of heat losses from the solar chimney and the wind speed effect.

![Fig. 3—Air flow rate from solar chimney for different suction openings at solar radiation intensity](image)

![Fig. 4—ACH from solar chimney for different suction openings at solar radiation intensity](image)

<table>
<thead>
<tr>
<th>Suction opening</th>
<th>Solar radiation at 900 W/m²</th>
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<tbody>
<tr>
<td></td>
<td>Air flow rate(Kg/sec)</td>
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<tr>
<td></td>
<td>Experiment</td>
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<tr>
<td>Left</td>
<td>0.041</td>
</tr>
<tr>
<td>Right</td>
<td>0.030</td>
</tr>
<tr>
<td>Front</td>
<td>0.028</td>
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<tr>
<td>Back</td>
<td>0.029</td>
</tr>
<tr>
<td>Front &amp; Back</td>
<td>0.020</td>
</tr>
<tr>
<td>Left &amp; Right</td>
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Discharge coefficient determination

The discharge coefficient $C_d$ should be considered when the inlet velocities are non-uniform distribution, fluid streams contraction and roughness of the surface, etc. It is an important parameter used in theoretical models to determine the mass flow rate through a system. Here $C_d$ coefficient 0.55 was experimentally proved by using the equation derived by Bansal et al.\[10\] which is

$$\frac{m}{\rho f_1} = C_d A_2 [2(\Delta T/T_r)gL_d]^{1/2} [1+A_r^2]^{-1/2} \quad \cdots (4)$$

Conclusion

The use of the solar chimney to induce natural ventilation was studied experimentally and numerically. The following conclusions were extracted:

- The orientation of the suction opening entrances affects the performance of the chimney. Solar chimney at $50^\circ$ inclination angle on the left suction opening produces the best thermal performances in Tiruchirappalli’s latitude.
- There is remarkable value in the ACH which is 157 and mass flow rate of 0.040 Kg/sec at solar radiation 820 W/m\(^2\) at the left inlet.
- The maximum and minimum deviation of ACH between the experimental and CFD results were calculated and found to be 10.4%, 0.7% respectively.
- The maximum and minimum deviation of air flow rate between the experimental and CFD results were calculated and found to be 10%, 0.5% respectively.
- A discharge coefficient $C_d$ of 0.55 was experimentally obtained and it may be used to determine the mass flow rate on theoretical models of solar chimneys.

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