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ANALYSIS OF A SOLAR CHIMNEY WITH DOUBLE INLET BY MEANS OF VENTURI EFFECT

Thales de Freitas Villas Bôas
Felipe Person Malta
Cyro Albuquerque Neto
Departamento de Engenharia Mecânica, Centro Universitário da FEI, São Bernardo do Campo, SP, Brasil 09850-901
thalesfvb@fei.edu.br, fperson.malta@gmail.com, cyroan@fei.edu.br

Abstract. *Solar chimneys can induce ventilation, and therefore, it can be implemented into the walls of a building in order to enhance thermal comfort. In a conventional solar chimney, only the bottom part of the room is ventilated while the top portion remains with a substantial thermal load. In this paper, the authors proceed with the analysis on how to remove air from both portions of the environment and still improving chimney's overall performance. This was achieved in a previous work by obstructing the chimney's cross section at a determined height, in which the top inlet is mounted, thus producing a similar effect of a venturi. The results indicated that the use of both inlets have other several benefits over the conventional layout, not only ventilating both portions of the room and improving overall performance, but it was also noticed that having an obstruction plate as venturi brought controllability to the flow. Through the new experiments it became clear that the chimney with a larger gap-to-height ratio induced a greater ventilation, mainly due to the increased area without a significant loss of average velocity. Finally, it was found that an obstructing gap between 1/5 and 3/5 of the full chimney's gap is optimal and preferable.*

Keywords: *Thermal Comfort, Solar Chimney, Solar Energy, Natural Convection*

1. INTRODUCTION

Power consumption is a worldwide issue nowadays since the existing and well-known sources of energy are running out. Alternative, renewable and sustainable sources must be developed and implemented with a reasonable cost and satisfactory efficiency in order to have an impact and create a society awareness.

Solar energy is the most abundant renewable source and despite of its non-constant incidence, it provides sufficient energy for mankind activities. In a solar chimney, air is heated and rises inside a cavity due to buoyancy forces, thus, creating an air flow. This flow can be used to generate electricity such as in solar updraft tower power plants, but among the applications available, the simpler one is ventilation. However, its optimization is strongly dependent from both design, materials and geometric characteristics, a fact that is well known by many researchers (Khanal and Lei, 2011).

Solar chimneys have a high sensitivity to its full gap, generally, the air flow rate increases with greater chimney gaps, however, Bouchair (1994) indicated that the gap dimension has a threshold value, in which above it, the flow starts to change its direction at the outlet, thus creating a backflow that can directly affect the air flow rate. This limitation led the authors to suggest an optimum gap-to-height ratio of 1/10. Recent studies (Imran et al., 2015) showed no evidence of backflow or reverse air flow circulation while experimenting a 1/13.3 gap-to-height ratio solar chimney.

Bassiouny and Koura (2008) demonstrated that inlet area has some improvement over the total air flow, but in their findings, the most sensible air flow variation was related to the chimney's gap.

Malta et al. (2013) studied the concept of the solar chimney while inserting it into a shipping container wall with the intention to improve thermal comfort while using it as an alternative to masonry. The results showed that the temperature increase was nearly linear proportional with height, moreover, they found that even a low heat flux can trigger the chimney. Their studies guided the present authors to think about the issues related to thermal comfort, leading to other studies upon the shipping container (Malta et al., 2014; Villas-Bôas et al., 2015). Villas-Bôas et al. (2016) introduces an effort of enhancing the ventilation using a metallic solar chimney with double inlet and a gap-to-height ratio of 1/100, demonstrating by means of flow visualization that the top inlet can easily ventilate the environment and even improve chimney's overall performance, removing thermal load from both top and bottom portions of an ambient.

The present analysis consists of an enhancement of this last work, where a larger gap-to-height ratio chimney was tested and a study of the influences and consistency of the obstruction gap dimension was made. This allowed the authors to analyze quantitively the mass flow being ventilated by each of the configurations of the venturi and compare to the previous work.

To the best of authors' knowledge, a multiple inlet solar chimney was firstly intended to be used with different environments such as on Asadi et al. (2016) work, therefore, the advances of ambient ventilation proposed with those studies may help engineers and architects to achieve thermal comfort on a single ambient.

2. EXPERIMENTAL PROCEDURE

A metallic solar chimney was carefully built for the experiments. Based on MDF, Aluminum, PMMA and Expandable polystyrene, the chimney has 2000 mm height and a gap-to-height of approximately 1/13.3. A top inlet of 10 mm x 370 mm was introduced at 1645 mm height, while both bottom inlet and outlet were set with an aperture of 50 mm x 370 mm.

A PMMA plate was placed at the top inlet, creating the venturi effect. This plate was varied during tests, causing an obstruction gap inside the chimney's cavity, the variations imposed were set from 0 mm of gap to 150 mm (full chimney gap) by increments of 30 mm as shown in Fig. 1.

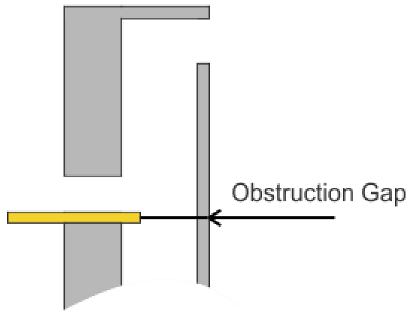

Figure 1. Obstruction gap dimension.

The conventional layout (insulator without the top inlet) was also tested, the intention was to compare the different configurations of venturi and check the air flow gain.

In order to eliminate heating fluctuations due to the nature of the sun, a heater was built to trigger the chimney. 4 ELBAC electrical resistances were attached to a flat, metallic plate with a semi-reflective surface, which was aimed to the solar chimney. Each electrical resistance has 2.2 m height, 9 mm of diameter and is capable of converting up to 2000 W into heat at 220 V. The final components layout is illustrated in Fig. 2.

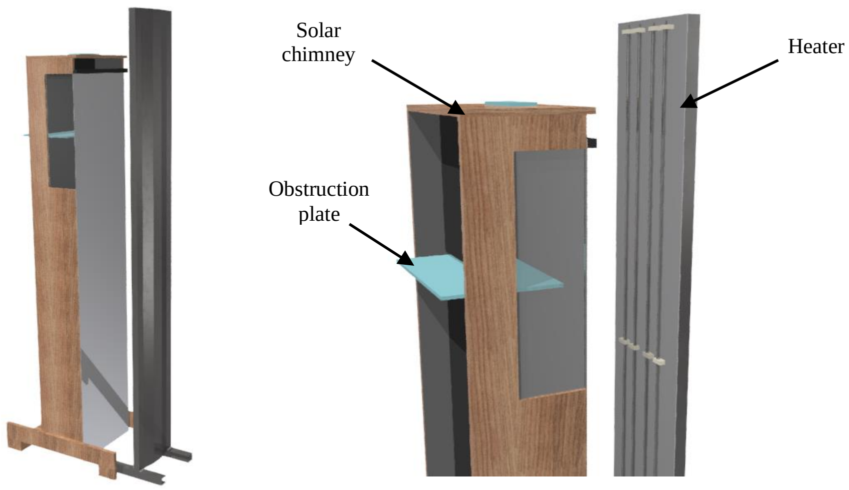

Figure 2. Components layout.

The apparatus received four K-type thermocouples (calibrated with standard references of 26.3 °C, 35.8 °C, 45.9 °C, 55.9 °C and 65.8 °C, accuracy of ± 0.8 °C) located at both inlets, outlet and at the cross section/half height of the chimney, an external thermocouple was used to acquire ambient temperature of the lab as well.

An FMA-900 Series air velocity transducer from OMEGA (calibrated from 0.20 m/s up to 1.20 m/s, accuracy equal to ± 0.06 m/s) was placed between the top inlet and outlet, being adjusted by a coordinated table attached to a step motor which was then controlled with assistance of an Arduino UNO board. This system allowed a cross section velocity scan, which was later related to the mass flow.

3. RESULTS AND DISCUSSION

The velocity profiles indicated a strong dependence by the venturi apparatus (Fig. 3), where narrower gaps induced an increase in total air flow being removed, proving what was observed by Villas-Bôas et al. (2016).

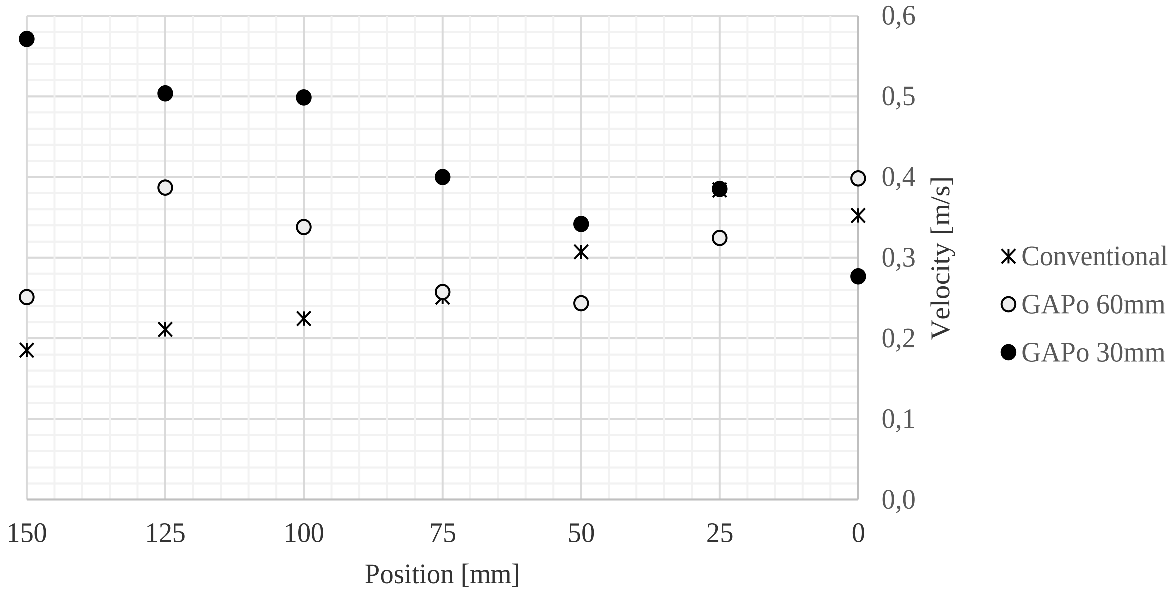

Figure 3. Velocity profiles acquired for some of venturi configurations tested (accuracy of ± 0.06 m/s).

This pattern may be formed because when the air flow is constricted, its velocity is increased, as well as its shear stress, which is then intended to drag air from the environment into the top inlet, thus creating an induced air flow. This velocity increase may also intensify the heat exchange by convection inside the chimney, hence, it may help the process of heating this induced air flow created, as well as homogenizing the velocities.

Through Fig. 3, one can see that both obstruction gaps of 30 mm and 60 mm had a significantly effect, increasing the cross section mean velocity as well as the mass flow as can be seen in Fig. 4.

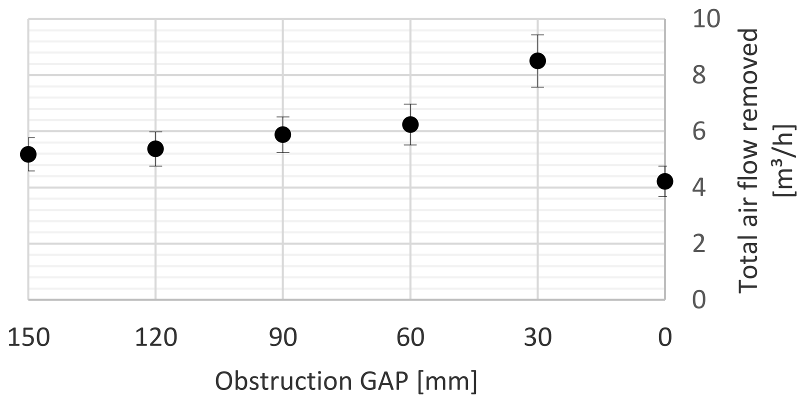

Figure 4. Total air flow removed by the constructed chimney.

The outlet air flow is based on the sum of the bottom air flow and the top air flow, with respect to their variations. Based on the experiments, it is clear through Fig. 4 that the optimal obstruction gap is situated between 1/5 and 3/5 of the chimney's full gap, increasing up to 55% of the total outlet air flow if compared to the conventional layout, while giving up to 8.50 m³/h of air removal, greater values if compared with the results from Villas-Bôas et al. (2016).

Moreover, while comparing the chimney tested by Villas-Bôas et al. (2016) and the presented version, it became clear that chimneys with larger gaps (full gap) not only gives a greater air flow in conventional arrangement, but also can reach a higher air flow gain with the obstruction plate.

4. CONCLUSIONS

The main aspects found were:

- The proposed chimney can ventilate both portions of the environment and even improve overall performance.
- The obstruction plate brought an intensification of the internal heat exchange while having velocity homogenizing characteristics.
- Comparisons with other studies indicated that chimneys with greater gap-to-height ratios perform better while using the venturi effect.
- An obstructing gap between 1/5 and 3/5 of the full chimney's gap can induce an air flow increase up to 55% if compared with the conventional chimney layout.

5. ACKNOWLEDGEMENTS

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