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STUDY OF DIFFERENT CONFIGURATIONS OF SOLAR CHIMNEY TO IMPROVE COMFORT INSIDE SHIPPING CONTAINERS

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Abstract. *Shipping containers become an easy way to build an internal environment. If occupied in warm climates, thermal discomfort usually occurs. The wall of a container is folded, and if a flat plane is placed against the inner side of it, cavities can be formed. These cavities can be used as solar chimneys if the bottom is opened to the inner side, and the top is opened to the outside. The aim of this work is to investigate some design parameters. One is the difference between using a metallic plate with an insulation to form the cavity or just an insulation in the air flow and heat transfer. Other is the influence of the air inlet and outlet dimensions in the air flow. To answer these questions, an experimental apparatus was built with one cavity. Electric heaters were used to warm the outside wall. Air velocity and temperature were measures at several heights. The results revealed that the use of a metallic plate while forming the cavity reduces the heat lost through the insulation in about 41%, and increases the air flow in about 15%. For the outlet, the results show that the height of the exit might be as small as 50 mm without affecting the air flow. For the inlet, no significant difference in the air flow was found even with the smaller tested height of 20 mm.*

Keywords: *solar chimney, shipping container, natural convection, solar energy, thermal comfort*

1. INTRODUCTION

The solar chimney is a technique that uses solar energy to warm the air inside a cavity, which promotes the suction of air from the internal environment. It might be used in the summer to ventilate the internal environment, positioning the outlet to the external environment. Or even be used in the winter, with the outlet to the interior, so the hot air returns to the room (Fig. 1).

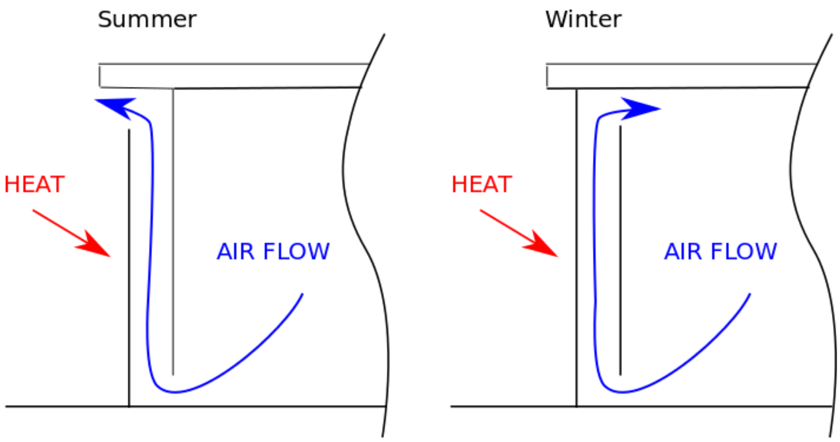


Figure 1. Behaviour of a solar chimney in the summer and in the winter

The cavities where the air flows are formed by placing an insulating material on the inner of the container's side wall. Their cross sections have a trapezoid shape, with the base formed by the insulation, and the other edges by the heated container wall (Fig. 2). This solar chimney was the purpose of previous experimental studies (Malta *et al.*, 2013, 2014), where the openings for the entrance and exit of air were 100 mm height. Smaller values for those openings might bring advantages to protect from rain, animals, or to leave the opening more discreet. The effect of varying their dimensions in the airflow was one of the goals of this work. Besides, in the previous work, it was found that a significant amount of heat passes through the insulation. In this work, the use of a reflective material between the insulation and the cavity to reduce the radiation received from the hot wall is also studied.

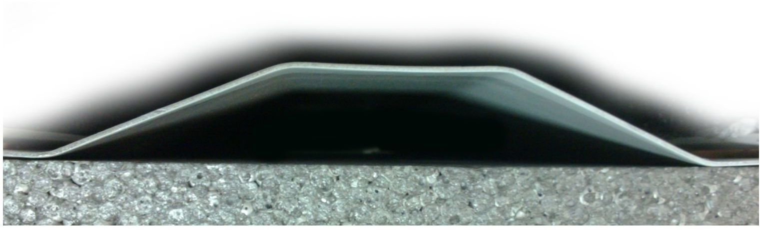


Figure 2. Cavity trapezoidal section

Several studies about solar chimney is found in literature. Some of them (Chen *et al.*, 2003; Arce *et al.*, 2009; Sandberg and Moshfegh, 1996; Ryan and Burek, 2010) are experimental studies, based on the contruction of an apparatus with apropriate instrumentation. Other works (Moshfegh and Sandberg, 1996; Gan, 1998; Bassiouny and Koura, 2008) are based on numerical simulation. To our knowledge, all the solar chimneys studied in the literature have retangular cross section, since they considered always the whole wall as a chimney. In the present work, however, the chimney is a cavity with trapezoidal cross section, and the wall would be made of several cavities of solar chimney.

2. EXPERIMENT

The experimental apparatus (Fig. 3) contains one cavity formed by the container folded wall and insulation (expandable polystyrene, Neopor®, BASF, 30 mm thick) closing the cavity. The cavity has 2.3 m height. Its cross section is trapezoidal, with the base equal to 208 mm, the top equal to 72 mm, and a height of 34.4 mm. The section area is equal to 4816 mm^2. In this series of experiments, a thick steel reflective plate was placed between the insulation and the cavity.

The wall was heated by four cylindrical electric heaters (2.2 m height). They were placed 20 cm from the metallic wall, with a reflective plate behind. Their total dissipated power set in the test was 500 W. Temperature and speed of air were measured in the center of the cavity, with a type K thermocouple (calibrated with a standard reference at 25, 37.5 and 50 °C, accuracy of $\pm$ 0.5 °C) and a hot-wire anemometer (Testo 405-V1, accuracy of 0.1 m/s + 5% of the measured value). Their profiles were obtained moving the sensors from the hot wall to the insulation. The temperature of the metallic wall was obtained with an infrared camera (FLIR T450sc, accuracy of $\pm$1 °C). To visualize the air behavior through the openings, smoke generated by a fog machine was mixed with the input air, and illuminated by a laser sheet created with a cylindrical lens.

It is usual for a solar chimney to have a protection from rain on the top. The container have beams above the walls that cannot be removed, and can be used for that protection. In this work, the distance between a fictitious beam created with the insulation material and the end of the cavity was varied to obtain the minimal opening that shall be used without significantly affecting the air flow. For the entrance, a similar study was developed.

3. RESULTS AND DISCUSSION

3.1 Cavity enclosure material

In a previously studied configuration of this solar chimney (Malta *et al.*, 2014), an insulation material was used to close the cavity, as the inside wall of the container. This was the solution first applied in adapted containers by ours partners of this project. An approximate energy balance was carried on those data from the velocity and temperature profiles. The metallic wall was heated with seven different powers, reaching average wall temperatures from 3.9 to 30.4 °C above the air inlet temperature. The heat across the metallic wall by conduction was estimated to vary from 25 to 279 W/m^2 from the lower to the higher wall temperature tested. After passing the wall, 73% of the heat was transferred to the air by convection, and 27% was transferred to the insulation by radiation between the surfaces. Most of the radiation received by the insulation surface was lost through the insulation (85%), and the rest was transferred to the air inside the cavity.

To reduce the heat lost through the insulation, it is proposed the use of a thin metallic plate as a reflective material closing the cavity, with the insulation placed just after. The use of this plate may also bring advantages because of its lower roughness, which might reduce the friction. In Fig. 4, the temperature and velocity profiles of both configurations are compared, with and without the metallic plate. The profiles were obtained in the center of the solar chimney, from the metallic wall to the insulation, in situations where the difference from the wall temperature and the inlet temperature were

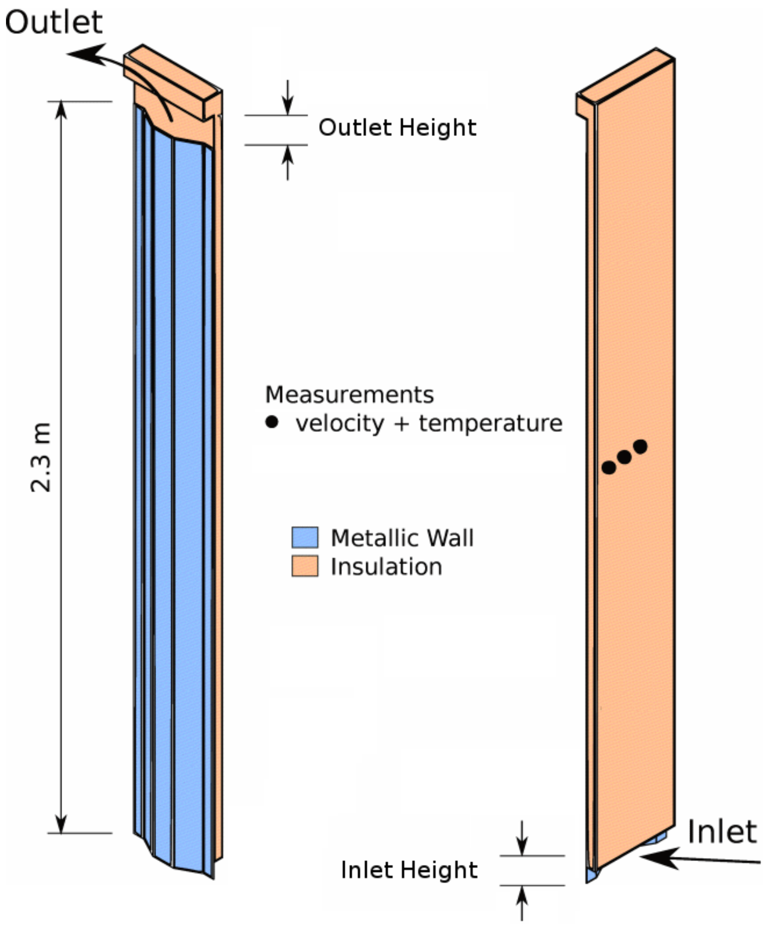


Figure 3. Experimental apparatus

the same. The use of the plate increased the average temperature in 14% and the average velocity in 15%. From Fig. 4a, it is observed that after 5 mm from the metallic wall the temperatures vary in an opposite way. Without the plate, it first decreases and then increases. The temperature in the insulation wall is higher than the center air temperature. In this case, the insulation receives heat from the metallic wall by radiation and, from the insulation wall, part is transferred to the cavity air by convection and part is lost through the insulation. On the other side, the use of the plate drastically reduces the radiation transferred between the walls. The temperature of the plate wall (T-Tinf) is 41% lower than the insulation without the plate. A similar reduction might be expected in the heat lost through the insulation. The air temperature is higher than the plate temperature. So, in this case, the plate receives heat by the air by convection, besides a small amount of radiation from the hot wall.

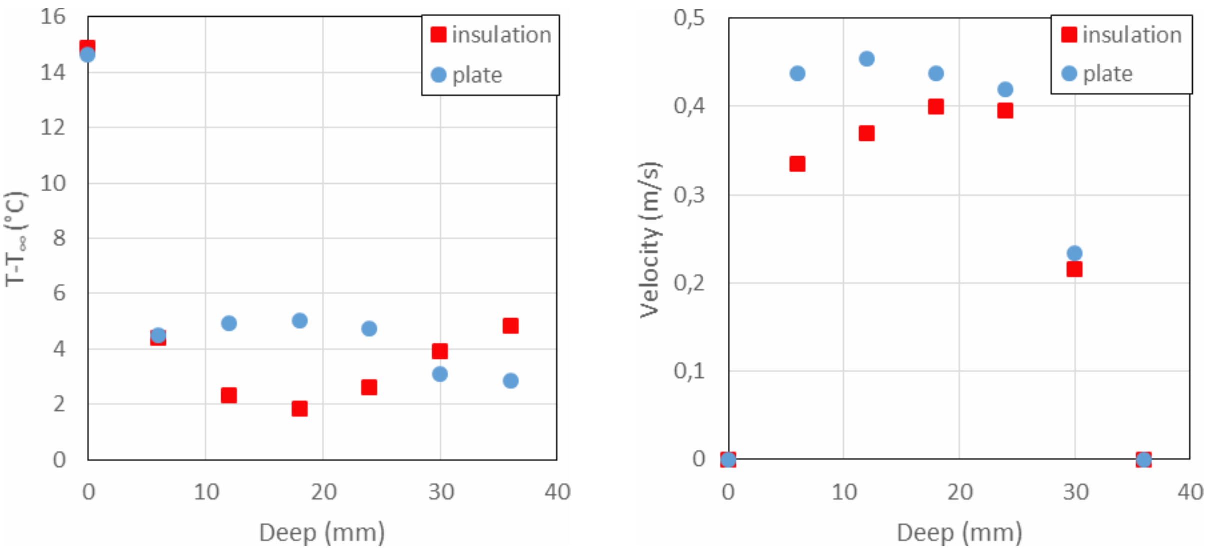
3.2 Air outlet and inlet

The outlet and the inlet height was changed to four different values (20, 35, 50 and 100 mm). Fig. 6 revealed the velocity in the center of the chimney in those configurations. Its variation might represents the variation of the air flow, considering that the form of the air velocity profile does not significantly change. The same configuration of the test with the metallic plate presented in the last section was used. For the outlet variation, the inlet height was kept in 100 mm. For the inlet variation, the outlet opening was kept in 50 mm.

For the outlet, the results show that the height of the exit might be as small as 50 mm without affecting the air flow (Fig. 6a). The use of an outlet height of 35 mm, which is the cavity deep, would reduce the air flow in about 9%. Moreover, the use of an outlet height of 20 mm would reduce the flow in about 19%. It is noteworthy that the variation is closed to the accuracy of the instrument, so we cannot ensure the precision of this value.

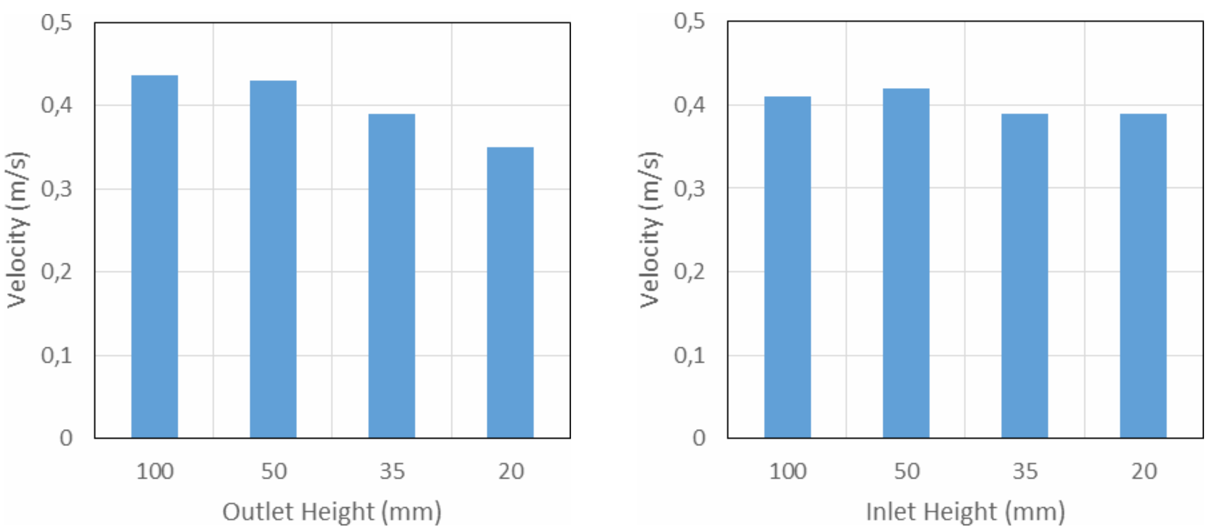
The behavior of the air after leaving the chimney outlet is showed in Fig. 6, using smoke mixed with the input air illuminated by a laser with planned beam for the outlet heights of 35 and 50 mm. It is observed the formation of a vortex under the top cover, and the change in direction more abrupt for the 35 mm height, which may result in the increase of the friction loss.

For the entrance, the difference found between the tested values are smaller (Fig. 6b). Only 5% of reduction in the air flow was found between the inlet heights of 100 and 20 mm. Furthermore, the variation is well below the accuracy of the



(a) (b)

Figure 4. Air temperature profile (a) and air velocity profile (b) with and without a reflective material over the insulation



(a) (b)

Figure 5. Air velocity in the centre for different outlet (a) and inlet (b) opening heights

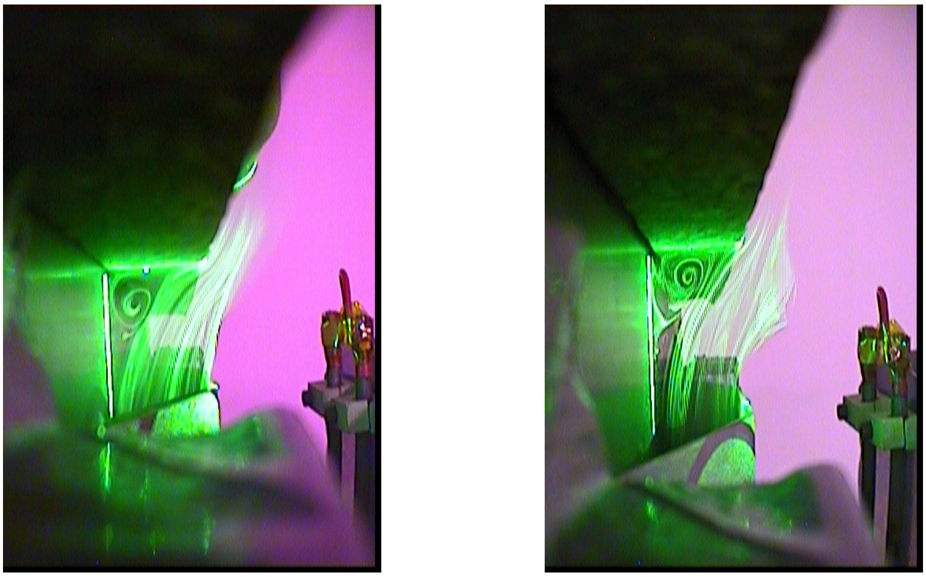
instrument, so we cannot conclude that there was really a significant difference.

4. CONCLUSION

In this work, the influence of some design parameters in the behavior of a solar chimney is studied. The main findings are:

- the use a reflective plate reduces by almost half the heat loss through the insulation and increases the air flow in about 15%;
- the outlet height might be as small as 50 mm without affecting the air flow;
- no significant difference in the air flow was found even with the smaller tested height of 20 mm.

The results of this work might be used when projecting a solar chimney, although further investigations are desirable to reach precise information about the energy exchanges, with the improvement of the measurements techniques, and also to study the behavior of a whole container with solar chimneys in real situation.



(a) (b)

Figure 6. Flow visualization for outlet opening height of 35 mm (a) and 50 mm (b)

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