ANALYSIS OF INDUCED AIRFLOW IN A SOLAR CHIMNEY

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Abstract. *Experiments were performed to analyze the induction of airflow in a solar chimney. It was used low cost materials and instrumentation common to the most of laboratories of Mechanical Engineering courses. Transparent plastic sheeting was used to cover the framework of the chimney, i.e., to the confinement of the air. The device was fixed over a black painted steel plate, used as a thermal energy collector surface. The plate was submitted to heating by an artificial radiation source (bank of lamps). The temperature of the plate was monitored by thermocouples, while the temperature and the flow rate of the air were determinate by a hot wire anemometer. It was observed that the prototype can provide airflows around 250 m^3/h. Thus, it is possible to extend the use of the device to the dispersion of fumes, gases, vapors and dust in industrial environments.*

Keywords: *Solar Chimney; Solar Radiation; Airflow.*

1. INTRODUCTION

The solar tower technique consists of the use of solar energy to induction of natural convective currents to promote an ascendant airflow in a duct. The solar radiation passes through a transparent roof, fixed at the base of the tower, and is absorbed by the soil, increasing the temperature of the air between the ground and the roof. When the buoyancy force is greater than the viscous force, the air starts to updraft. The induced airflow is directed to a vertical channel and used to move the blades of a turbine.

The efficiency of the buoyancy force that induces the airflow is directly dependent on the solar radiation intensity. The area of the solar collector, the height and the diameter of the tower are also variables that change the efficiency of the solar tower (Larbi et al., 2010).

According with Zhou et al. (2010), the roof material can be made with plastic or glass. The most common materials used to the absorption of the solar energy are soil and water; both can be used to heat storage, allowing the tower to work during the night.

The first mention of the solar tower was made by Isidoro Cabanyes, a spanish military that published his *Proyecto de motor solar*, in 1903 (Arce et al., 2009; Zhou et al., 2010). The solar tower mathematical concepts were first proposed by J. Schlaich and A. A. R. El Agib, in 1968 (Richards, 1982; Mullet, 1987).

Most of the research and application of the solar tower theory are directed to the production of energy. However, the concepts can also be used to the induction of airflow to promote dispersion of particulates in air, drying of materials and fruits and thermal conditioning of buildings.

1.1. Ventilation with solar tower

The ventilation is one of the most important factors to provide indoor air quality in buildings. There are lots of works that demonstrated the relation between the control of ventilation and the health of the occupants of the buildings (Seelig et al., 2004).

Basically, the ventilation devices to provide the renovation of the air in buildings can be divided in two categories: mechanical and passive. Among them, the most common passive device is the eolic exhauster, which aggregates the advantages of lightness, flexibility, easy maintenance, low cost and efficiency. Brasil (2004) studied the use of the eolic exhauster to the renovation of the air in buildings and found that it is possible to reach until 5 renovations / hour using the wind.

The solar tower can be used to promote air renovation in buildings. Bansal et al. (1993) mathematically analyzed the use of the solar tower to the induction of airflow in a ventilation system adapted to residences. Considering a solar collector area of 2.25 m^2, different values of air intake area and different discharge coefficients, they conclude that it is possible to induce airflows with rates between $14m^3/h$ and $330m^3/h$ when the tower is submitted to solar radiation intensity between 200 W/m^2 and 1000 W/m^2.

Ketlogetswe et al. (2008) studied the airflow inside a solar tower and identified that higher velocities were reached between 06h00 and 08h00, when the solar radiation increases from 100 W/m^2 to 500 W/m^2, remaining constant until 14h00, even when the solar radiation reaches 950 W/m^2 (at 12h00). They conclude that almost 47% of the solar energy was absorbed by the soil.

Maerefat and Haghighi (2010) investigated the solar tower coupling to an earth to air heat exchanger and concluded that the system can promote about 4 air renovations / hour in a room with dimensions of 4.0 m x 4.0 m x 4.0 m. In the present work, it was investigated the possibility of the use of the technique to promote ventilation to air renovation.

METODOLOGY

The framework of the chimney was built joining two rings of steel, with different diameters, by thin sticks of the same steel. The low ring had 1.0 m of diameter and the up ring had 5.0 cm of diameter. The sticks had 1.0 m of length and were welded to the rings at equally spaced distances. The framework was smoothly folded, so the chimney gets its final “J – shape”. The support of the chimney was made with five small sticks (5.0 cm of length) of steel, welded to the low ring.

A PVC tube (with 6.0 cm of diameter and 2.0 m of height) was fixed to the chimney, passing slightly over the up ring, until it be hardly trapped inside tube. The part of the frame that was not inside the tube was covered by a transparent plastic (see fig. 1).

As the experiments took place inside of a laboratory facility, a thermal radiation source (with incandescent lamps) was built to provide the heating of the chimney. Six lamps, each one of 200 W (totaling 1200 W) were fixed in a support frame, made with PVC tubes, and mounted at 1.0 m of floor (see fig. 2).

Figure 1. The chimney

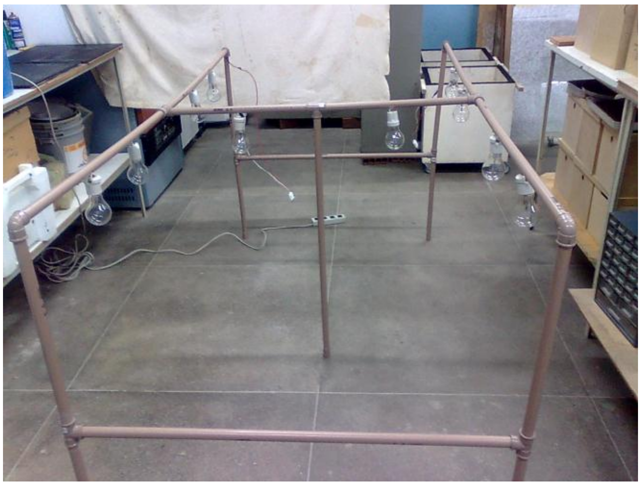

Figure 2. The thermal radiation source.

A black painted steel plate (dimensions: 0.50 m of length; 0.50 m of width and 5.0 mm of thickness), with 0.25 m^2 of area, was used as a thermal radiation absorption surface. It was mounted over an EPS leaf (dimensions: 0.50 m of length, 0.50 m of width and 10.0 mm of thickness), and fixed at the ground, beneath the chimney, according with fig. 3.

Figure 3. The thermal radiation absorption surface.

To monitoring of the temperatures during the experiments, two thermocouples (K – type, cromel-alumel, uncertainness of 0.7°C) were fixed on the surface of the plate (see fig. 4). The measurement equipment was programmed to register temperature data each 20 minutes.

Figure 4. Temperature's monitor.

The experiments were conducted in a laboratory (in-door conditions), where the chimney was heated by the thermal radiation source. Each experiment took 240 minutes. The measurements of air velocity, air flow and air temperature inside the tube were made at time intervals of 20 minutes, which consisted of five readings of each variable. The measurements were made with a hot wire anemometer (see fig. 5), manufactured by TSI Incorporated – VelociCalc model 8345 (uncertainness ± 3% of reading). The measurements were performed with the probe inserted in a hole (8.0 mm diameter) in the surface of the PVC tube.

Figure 5. Hot wire anemometer

RESULTS AND ANALYSES

The measurements obtained in the experiments were used to calculate the mean values of the temperatures, flow and velocity. In the figures 6 and 7 are presented the graphics for these variables.

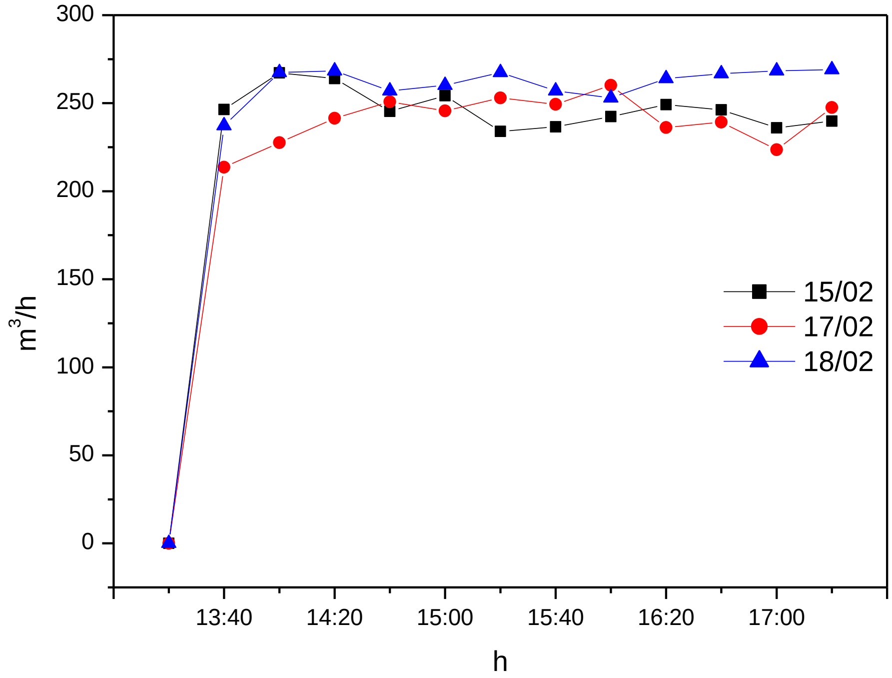

Figure 6. Air flow.

In the figure 6 are presented the mean values of the air flow inside the tube. It is observed that the curves present similar behaviors for the different days of the experiments. In the interval from 13h40 to 17h20, i.e., during steady state regime, the highest difference between the mean values of the flow was about 56m³/h – or 0,015 m^3/s. This effect can be attributed to the control of the ambient conditions where the experiment took place.

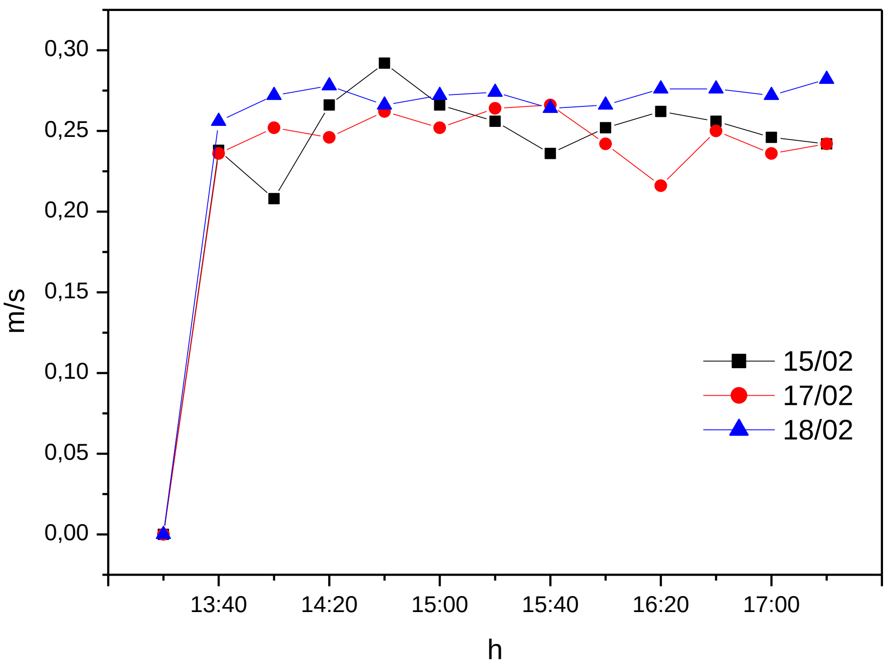

Figure 7. Curves for the velocity of air inside the tube.

In the figure 7 are presented the curves for the air velocity inside the tube. The tendency was the same observed in the case of the air flow (fig. 6). Between 13h40 and 17h20, the mean velocity variation was 0.84 m/s.

In table 1 are presented the mean values of the temperatures obtained after the experiments reached the steady state regime.

Table 1. Temperatures during the steady state regime.

	15/02	17/02	18/02
T plate (°C)	36.0	36.1	36.0
T flow (°C)	35.2	35.9	34.9
T ambient (°C)	31.5	32.0	31.0

The highest difference of temperature between the plate and the room was 5.0°C, observed during the experiment of the day 18/02. The highest temperature difference between the plate and the flow inside the tube was 1.1°C, in the day 18/02. The highest temperature difference between the air flow and the room was 3.9°C, in the days 17 and 18/02.

Using an experimental model (5.3 m of high, 1.0 m of width and 4.5 m² of area of solar radiation absorption surface), working in out-door conditions, obtained 7.0 ºC of difference between temperatures of the ambient (27°C) and the air flow (34°C). In table 1, despite of the small differences between the mean temperatures of the room and the plate surface, expressive values of air flow were obtained in the experiments, showing the potential of the use of the technique to provide air renovation in buildings.

In the table 2 are presented the means values of variables considering the mean values of the three experiments.

Table 2. Mean values.

Flow (m^3/h)	249.6
V (m/s)	0.26
T flow (°C)	34.6
T amb (°C)	30.9
T plate (°C)	34.4

Again, despite of the small temperatures differences, there were observed significant values (~ 250 m^3/h) for the air flow inside the tube, proving the feasibility of the technique to promote change of air inside buildings. Comparatively, Arce et al. (2009) obtained a mean air flow of magnitude 177.0 m³/h during a 24 hours out-door tests conditions.

The ANVISA (National Agency of Sanitary Vigilance), in the resolution RE n° 176, of 24 / October / 2000, recommends for acclimatized environments values of air velocity between 0.025 m/s and 0.25 m/s, measured at 1.5 m above the ground, and a minimum rate of 17 m³/hour/person for the air change. According to table 2, the values obtained for both variables were, respectively, 0.26 m/s and 249.6 m^3/h.

CONCLUSION

Despite of the small temperature differences between the room and the heat absorption plate, the values obtained for air flow and velocity were significant. It is believed that, if the intensity of solar radiation is considered, these values will be highest, enabling highest air's renovation rates inside buildings.

According to the resolution of the ANVISA (2000), and considering the results obtained in the literature, the technique may be use as a complement to conventional devices used to air renovation in buildings.

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