SOLAR CHIMNEYS FOR RESIDENTIAL VENTILATION

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ABSTRACT

An increasing impact of ventilation and air-conditioning to the total energy consumption of buildings has drawn attention to natural ventilation and passive cooling. The very common way of natural ventilation in residential buildings is passive stack ventilation. The passive stack ventilation relies on the stack effect created by the temperature difference between air temperature inside and outside a building. A solar chimney represents an option how to improve the performance of passive stack ventilation on hot sunny days, when there is a small difference between indoor and outdoor air temperature. The full-scale solar chimneys have been built and tested at the Department of Thermodynamics and Environmental Engineering at the Brno University of Technology. The main goal of the experiments is to investigate performance of solar chimneys under the climatic conditions of the Czech Republic. Two different constructions of a solar chimney have been tested; a light weight construction and the construction with thermal mass.

KEYWORDS

solar chimney, residential ventilation, passive cooling

PRINCIPLE OF SOLAR CHIMNEY VENTILATION

A solar chimney is a natural-draft device that uses solar radiation to move air upward, thus converting solar energy (heat) into kinetic energy (motion) of air. At constant pressure air density decreases with increasing temperature. It means that air with higher temperature than ambient air is driven upwards by the buoyancy force. A solar chimney exploits this physical phenomenon and uses solar energy to heat air up.

Since air is a transparent fluid (radiation-transmitting), it cannot be directly heated by solar radiation. Therefore, a solar chimney has to contain a solar absorber; a surface made of a material which absorbs solar radiation, and which allows solar heat to be transferred to the air by means of convection. The most common configurations of solar chimneys are those utilizing the "greenhouse" effect - air cavities with a transparent material (glass) on one side of the cavity and a solar absorber on the other side. These solar chimneys are very similar to solar air collectors.

Solar chimneys can be employed in many areas, e.g. ventilation, power generation or food drying. The principle of solar chimney ventilation is shown in Fig. 1. As can be seen in Fig. 1, solar chimney ventilation is a kind of stack ventilation. Exhaust air is heated up in a solar chimney by solar radiation, and buoyancy force, which is a driving force in this case, increases. Unlike passive stack ventilation (relaying on the indoor-outdoor temperature difference), the solar chimney ventilation works also when outdoor temperature is the same or higher than indoor air temperature. There are many possible configurations of a solar chimney. A solar chimney can be design either as an integral part of a building or as a device used with a ventilation system.

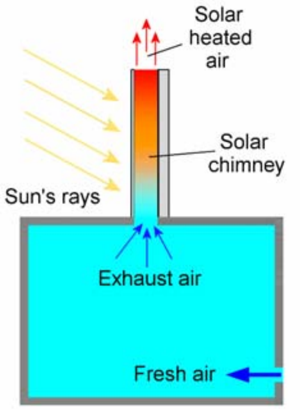

Fig. 1 The principle of solar chimney ventilation

Solar chimneys can also be used for night ventilation/cooling, but in this case they have to contain a heat storage mass. Several studies have been carried out with the aim to investigate the performance of solar chimneys in last several years. Some of these studies, however, were aimed at the utilization of solar chimneys for power generation.

EXPERIMENTAL SOLAR CHIMNEYS

The full-scale solar chimneys have been built and tested at the Department of Thermodynamics and Environmental Engineering at the Brno University of Technology. The main goal of the experiments is to investigate the performance of solar chimneys under the climatic conditions of the Czech Republic.

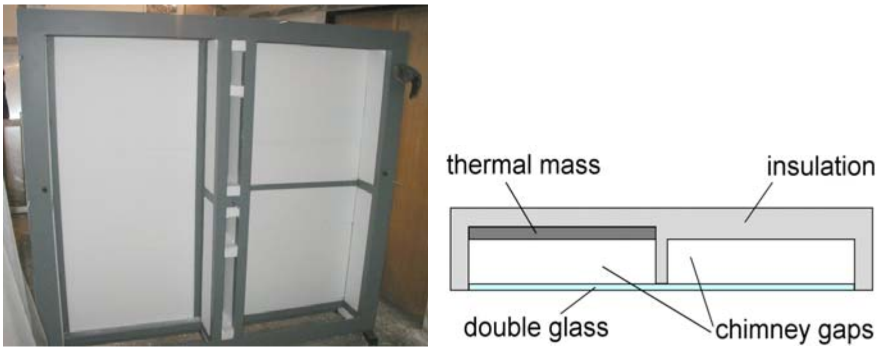

Fig. 2 Metal-frame construction of the chimneys.

The experimental solar chimneys are designed as an insulated metal frame construction. Two different versions of a solar chimney have been built; a light weight construction and a construction with thermal mass. Both chimneys are connected in parallel, as can be seen in Fig. 2. The thermal mass is made of 50 mm thick concrete layer.

The dimensions of the chimney gaps in the glazed part of the chimneys are: width 750 mm, height 1500 mm and depth 200 mm. A double pane glass was applied for the transparent parts of the chimneys. The glazed parts of the chimneys are inclined 30 degrees from the vertical to increase a heat gain in summer. The glazed parts are openable in order to allow cleaning and installation of measurements. The experimental solar chimneys have been located on the platform over the roof of the department's laboratory (Fig. 3). The chimneys are oriented to due south. The 5 m long vertical ducts are connected to the chimneys at the bottom, and the 1.5 m long rectangular ducts (of the same shape as chimney gaps) extend the chimneys at the top.

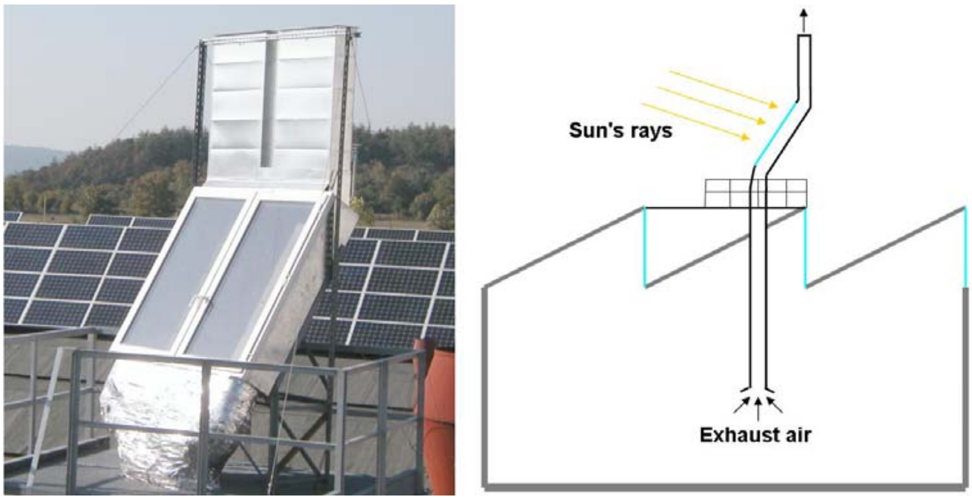

Fig. 3 Experimental solar chimneys

A PC based data acquisition system was used for monitoring of the performance of the solar chimneys. The main difficulty of the monitoring represented measurements of air flow rates through the chimneys. A tracer gas technique was employed for this purpose in the studies performed in Portugal, *Afonso at al (2000)*. A tracer gas was released at a constant rate in test chambers beneath the chimneys, and the air flow rate was obtained from the concentration of the tracer gas. This technique is a little bit complicated for the measurements lasting several months, and so the calorimetric principle flow meters have been installed in the ducts.

RESULTS OF EXPERIMENTS

The long-term monitoring of the performance of solar chimneys began in early March 2003. As expected the air flow through the chimneys in cold seasons is predominantly caused by the temperature difference between the indoors and the outdoors. The cold seasons (late fall, winter, and early spring) are not very interesting from the point of view of utilization of solar chimneys, because passive stack created by the indoor-outdoor temperature difference is usually sufficient for ventilation purposes. Moreover, passive cooling (or cooling in general) is not demanded in these seasons. The main assets of solar chimney ventilation, in moderate climates, can be found during the warm season.

The idea of having two geometrically identical chimneys allows comparative tests to be carried out. It means that the performance of one version of the solar chimney can be compared to the performance of the other version under the same weather conditions. In one of these tests the temperature of the chimney surface (solar absorber) was investigated. The solar absorber of the light-weight chimney is made of black-painted sheet metal; the absorber of the chimney with thermal mass is made of black-painted concrete. The experiments were performed at the zero air flow rate (the vertical ducts were closed at the bottom). The reason for closing the ducts was to achieve the same conditions in both chimneys.

Fig. 4 shows the absorber temperatures recorded on a summer day. As can be seen, the temperature of the metal sheet (light-weight chimney) follows very quickly changes in the solar radiation intensity. The highest temperature during the day exceeded 80 C. In case of the solar chimney with thermal mass fluctuations of the surface temperature are dampened by heat storage mass. The highest temperature during the day was lower than in case of the light way chimney (just over 60 C). The temperature of the absorber in case of light-weight chimney dropped to the outdoor air temperature immediately after sunset, while the temperature of the thermal mass remained higher than outdoor air temperature all night. The chimneys were not closed at the top during this experiment. Therefore, some air exchange between the chimney cavities and the outdoor environment was possible. The absorber temperatures would probably be higher, if the chimneys were also closed at the top.

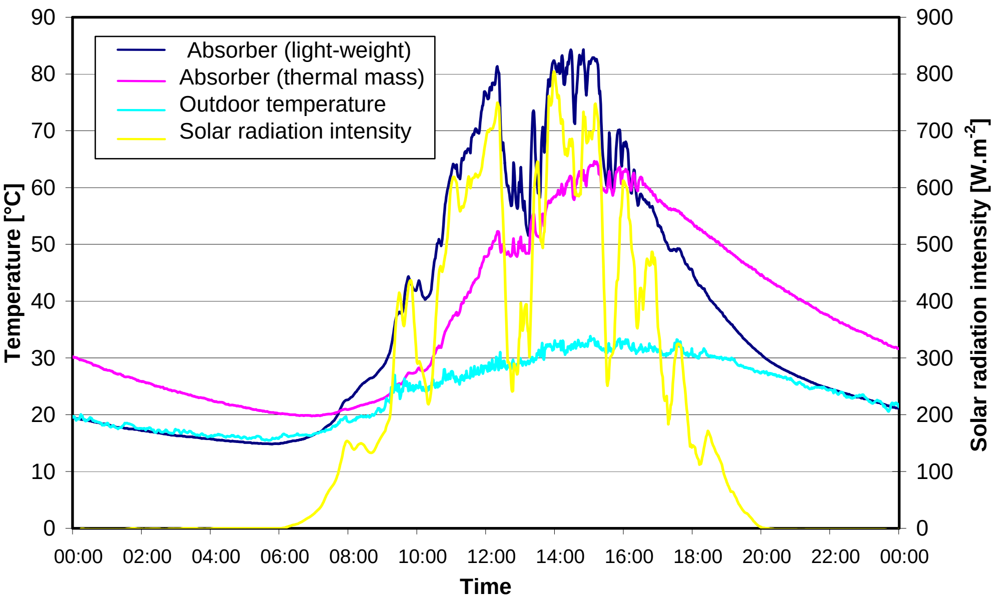

Fig. 4 Temperature of solar absorbers

If a solar chimney with thermal mass is to be used for night cooling, then it is beneficial to keep it closed during the day. In such situation solar heat is stored in the storage mass during day, and after sunset, when the chimney opens, the stored heat can be released to the passing air. The heat storage capacity of the experimental chimney is not very high. The thermal mass is around 120 kg of concrete, which gives the thermal capacity approximately 120 kJ/K .

The most interesting, from the point of view of utilization of solar chimneys, is a comparison of the solar chimney performance to the performance of a normal chimney. With two identical chimneys it is possible to investigate how the solar chimney stands in such comparison. For this purpose the glazed part of the chimney with thermal mass was covered with insulation, and so it worked as a normal chimney (stack). The thermal mass was not taken out of the chimney, but the influence of the thermal mass in such experiment was supposed to be small.

Fig. 5 shows the air flow rates through the chimneys on a sunny summer day - July 20, 2003. It was a day with very clear sky. As can be seen the curve of solar radiation intensity is very smooth. Such weather is ideal for the investigation of the solar chimney performance, because there are no fluctuations of the air flow rate caused by the sudden changes in solar radiation intensity (when a cloud passes over the sun). As can be seen in Fig. 5 the air flow rate during the day was lower than air flow rate at night. It means that the impact of the solar radiation to the performance of the solar chimney was, in current configuration, lower than the impact of the difference between indoor and outdoor temperature at night.

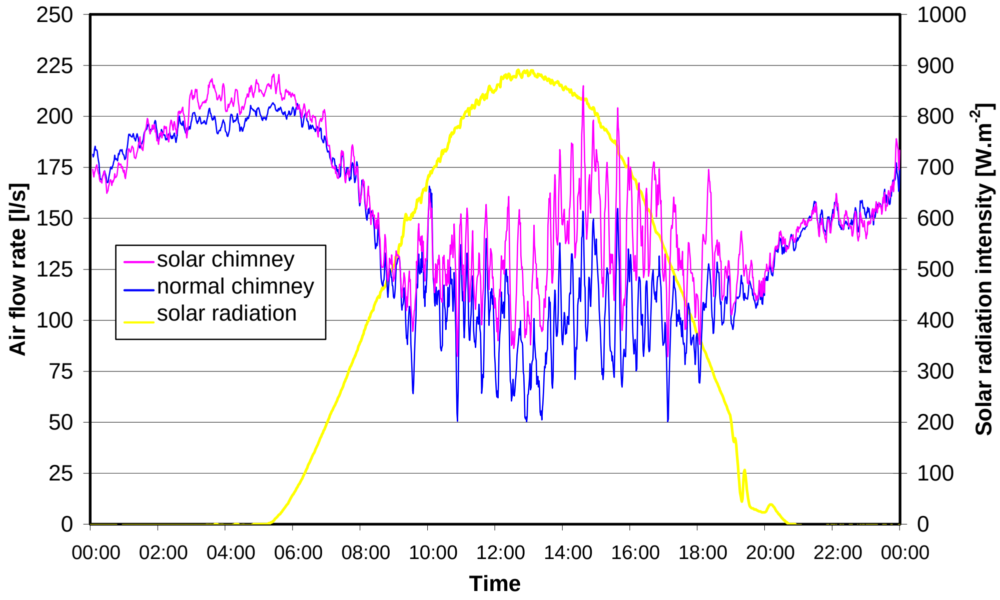

Fig. 5 Air flow rates through the chimneys

The air flow rate trough the solar chimney, between 8 A.M. and 6 P.M., was in average about 20% percent higher than air flow rate through the normal chimney. The air flow rates plotted together with the indoor-outdoor temperature difference (for July 20, 2003) are shown in Fig. 6. As can be seen the air flow rate through the normal chimney did not drop to zero even when the outdoor air temperature was lower than the indoor air temperature. This can only be explained by the influence of wind, because buoyancy force in this situation could not drive air from the lab trough the chimney. Huge fluctuations of the air flow rate during the day support the idea of significant impact of wind to the chimney performance.

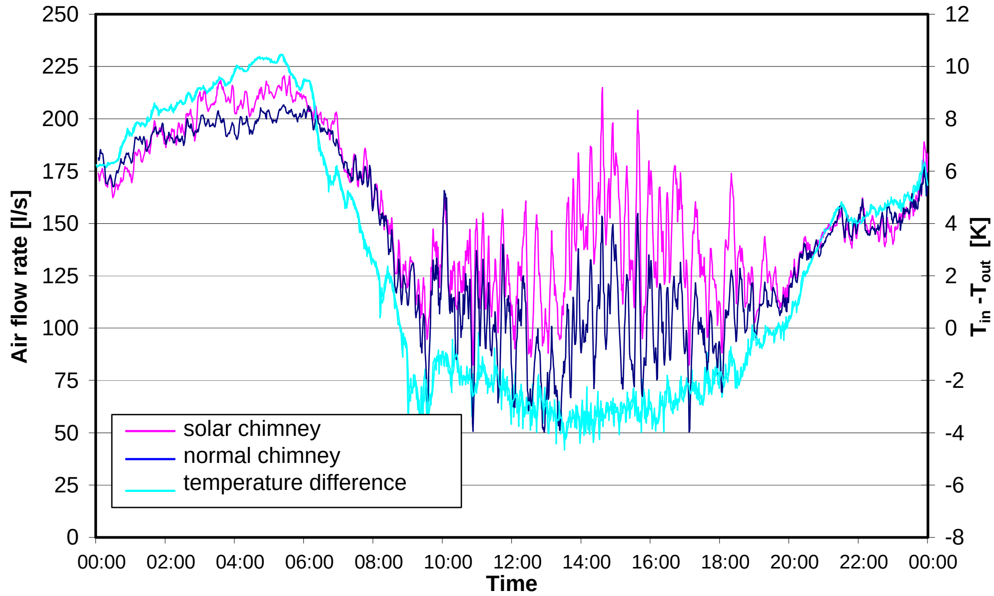

Fig. 6 Air flow rates and indoor-outdoor temperature difference

FUTURE PERSPECTIVE

The experiences acquired with the experimental solar chimneys were utilized in design of solar chimneys for an experimental house with hybrid ventilation, which was built in the university campus (Fig. 7). The experimental house is a two-storey building of the size of a single family house. The solar chimneys, which are a part of the hybrid ventilation system installed in the house, will be used for passive cooling. The solar chimneys are positioned over the stairway in the house. The stairway connects both floors, and so no ductwork is needed with such a position of the chimneys. The experimental house provides more realistic conditions for the investigation of the solar chimney performance than the experimental facility on the roof of the lab.

Fig. 7 Experimental house with hybrid ventilation

Even though the principle of solar chimney ventilation has been known for centuries, there is a possibility to employ modern technologies in the solar chimney design. One option is to replace glass with semi-transparent photovoltaic, which could power a DC fan. Such combination would represent a fan assisted natural ventilation system, which could operate without an access to the power grid. The photovoltaic panels, in this case, could also feed a control system, including motorized dampers.

Acknowledgements

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