

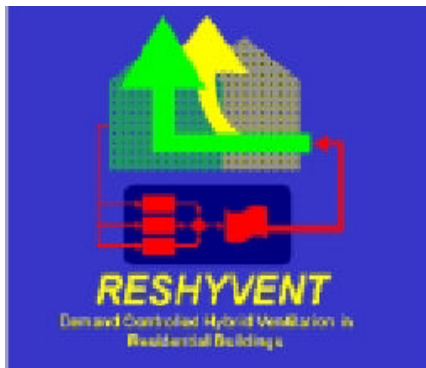


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## RESHYVENT

### Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables

Contract No: ENK6-CT2001-00533



**Report Title:**

### Solar chimneys

**RESHYVENT Report No:**

*RESHYVENT-WP3.4*

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## Introduction

The increasing impact of ventilation and air-conditioning to the total energy consumption of buildings has drawn attention to natural ventilation and passive cooling. Since the indoor air quality is a major concern in ventilation, and natural ventilation does not guarantee acceptable IAQ at any circumstances, an idea of hybrid ventilation has been introduced.

The basic idea of the hybrid ventilation is to employ natural forces as long as possible, and to use mechanical ventilation only when necessary. There are three basic concepts of hybrid ventilation:

- Alternating or combined natural and mechanical ventilation
- Fan assisted natural ventilation
- Stack and wind supported mechanical ventilation

Solar chimneys can generally be employed in all three concepts if the passive stack ventilation is involved. The passive stack ventilation relies on the stack effect created by the temperature difference between air temperature inside and outside a building. Unfortunately, sometimes there may be an insufficient air change in a building due to the small stack effect.

The performance of passive stack ventilation can be, in many cases, improved by means of devices utilizing renewable energies. The most often exploited renewable energy for this purpose is energy of wind. There are different kinds of wind cowls available on the market, which can significantly improve the performance of passive stack ventilation.

The attempts to employ solar energy with this objective (e.g. solar chimneys) have been quite rare so far. This report contains some outcomes of the investigations of a solar chimney performance, which were done at the Department of Thermodynamics and Environmental Engineering of the Brno University of Technology.

## 1. 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 of 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 absorbing solar radiation, 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. Such 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.

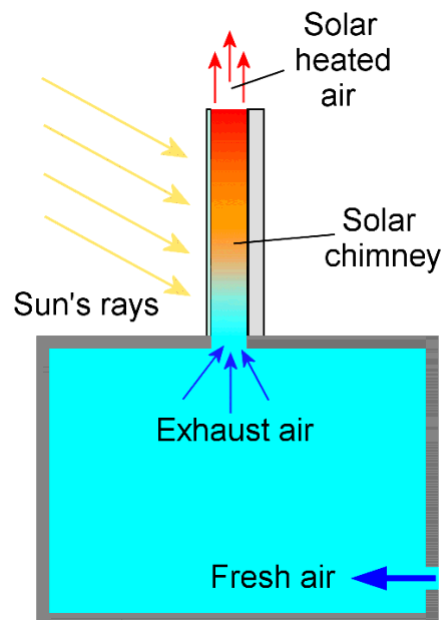


Fig. 1 The principle of solar chimney ventilation

The principle of the 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 (relying on the temperature difference between indoors and outdoors), 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 designed either as an integral part of a building or as a device used with a ventilation system. An example of the building integrated solar chimney is a double facade, which employs the

solar chimney principle in the facade cavity to decrease a heat gain to a building in summer. A solar chimney for ventilation purposes can be design in the same way. The problem of building integrated solar chimneys is that they have to be implemented in the design stage of the building construction. Another option is to design solar chimneys in such a way that they can be employed within existing ventilation systems.

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.

The lab-scale experiments provide useful information about the impact of chimney geometry to the chimney performance [3], [5].

By means of the full-scale experiments invaluable information about the real performance of solar chimneys under specific climatic conditions can be obtain [1].

Computer simulations are a powerful tool, which can be used not only in design, but also in optimization of the solar chimney operation [3]. Computer simulations also allow to model different scenarios of solar chimneys utilization like a combination of a solar chimney with an underground duct for pre-cooling of supply air, [4].

## **2. 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 was to investigate the performance of solar chimneys under the climatic conditions of the Czech Republic.

The experiences from the earlier mentioned studies were utilized in the design of these experimental chimneys. The experimental solar chimneys were 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.

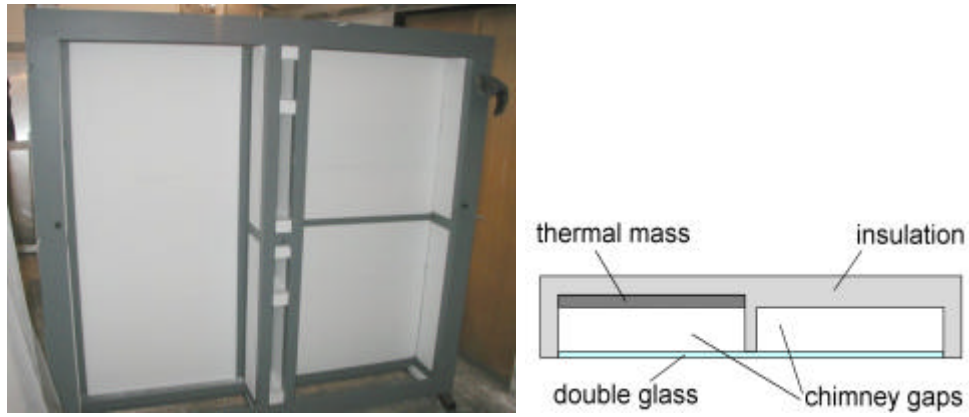


Fig. 2 Metal-frame construction of the chimneys.

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 is used 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 the 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.

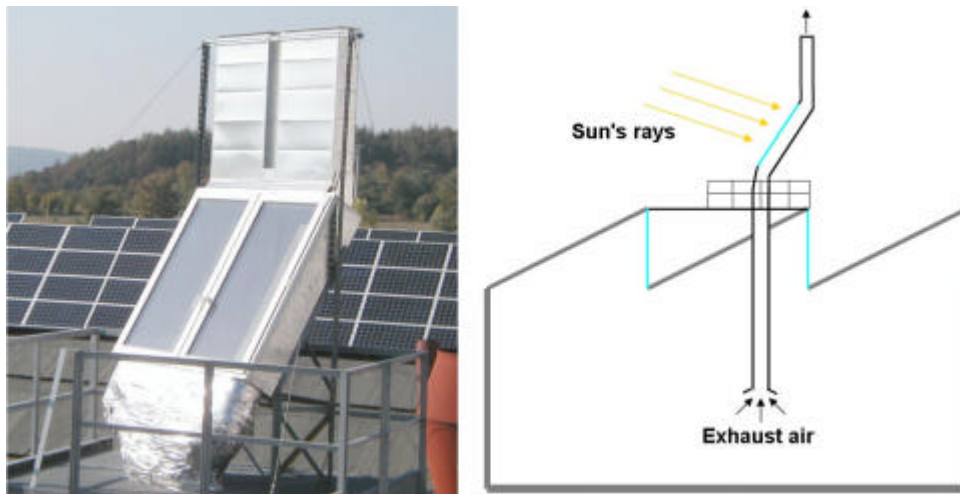


Fig. 3 Experimental solar chimneys

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.



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 in some of the studies into performance of solar chimney [1]. 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 little bit complicated for the measurements lasting several months, and so the air flow rates through the chimneys were measured by means of flow meters installed in the round ducts (Fig. 4).

Beside the air flow rates temperatures were measured at different locations of the chimneys. Thermocouples have been used in these measurements.

### **3. 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 indoors and 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 during these seasons. The main assets of solar chimney ventilation, in moderate climates, can be found during the warm season.

#### **3.1. Absorber temperature**

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 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. 5 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. The highest temperature during the day was lower than in case of the light-weight chimney, and just exceeded 60C.

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. It means that some air exchange between the chimney cavities and outdoor environment was possible. The absorber temperatures would probably be higher, if the chimneys were also closed at the top.

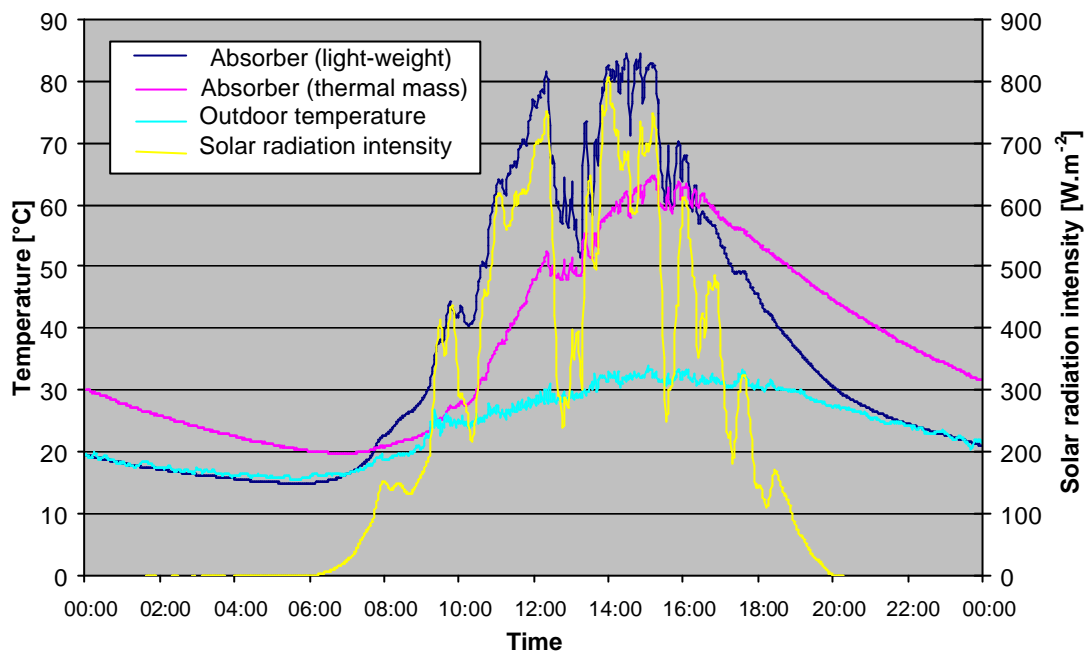


Fig. 5 Temperature of solar absorbers

If 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 and heat up exhaust 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 specific heat of concrete is quite similar to the specific heat of dry air).

### 3.2. Solar chimney vs. normal chimney

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.

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. 6 shows the air flow rates through the chimneys on a sunny summer day - July 20, 2003. It was a day with a very clear sky. The 5-minute moving average was applied to the data sets in order to make the chart better “readable”. As can be seen the curve of solar radiation intensity is very smooth. Such weather is really 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. 6 the air flow rate during the day was lower than air flow rate at night. It means that the impact of solar radiation to the performance of the solar chimney was, in current configuration, lower than the impact of the temperature difference between indoors and outdoors at night.

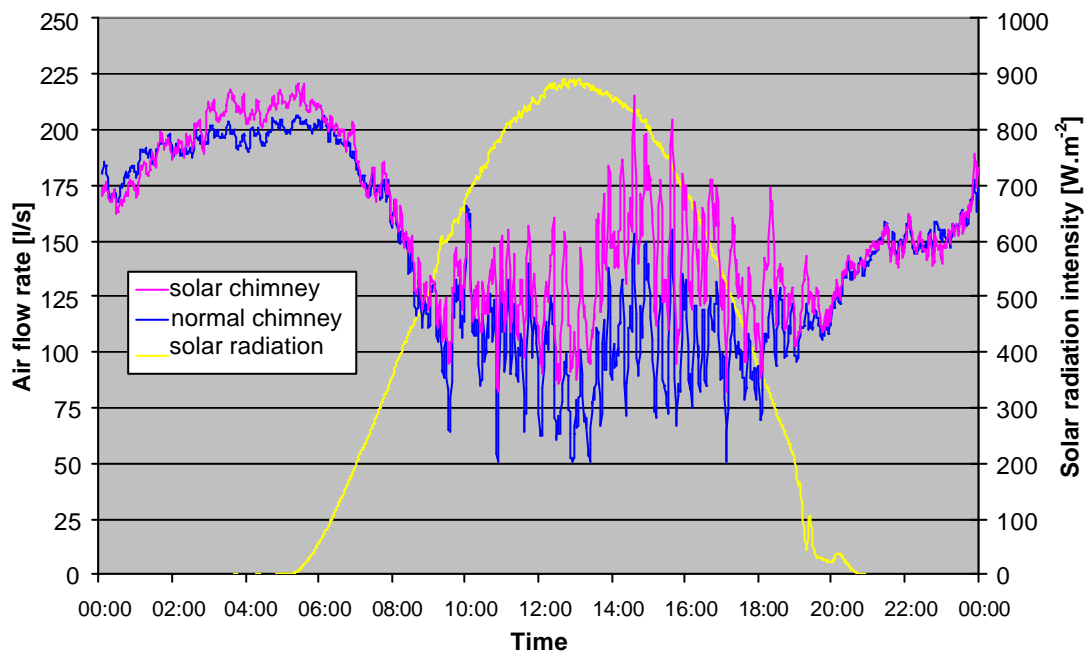


Fig. 6 Air flow rates through the chimneys (July 20, 2003)

The air flow rate through the solar chimney, between 8 A.M. and 6 P.M., was on average about 20% percent higher than air flow rate through the normal chimney.

The air flow rates plotted together with the temperature difference between the indoors and outdoors are shown in Fig. 7. As can be seen the air flow rate through the normal chimney did not drop to zero even when the outdoor air temperature was the same as the indoor air temperature.

This can only be explained by influence of wind, because the buoyancy force was negative in this situation and could not drive air from the lab through the chimney. Huge fluctuations of the air flow rate during the day would support this explanation.

The laboratory where the experimental solar chimneys are located is quite busy during the day. Opening and closing of doors (especially those to the outdoors) can influence the pressure difference between inside and outside of the lab induced by wind.

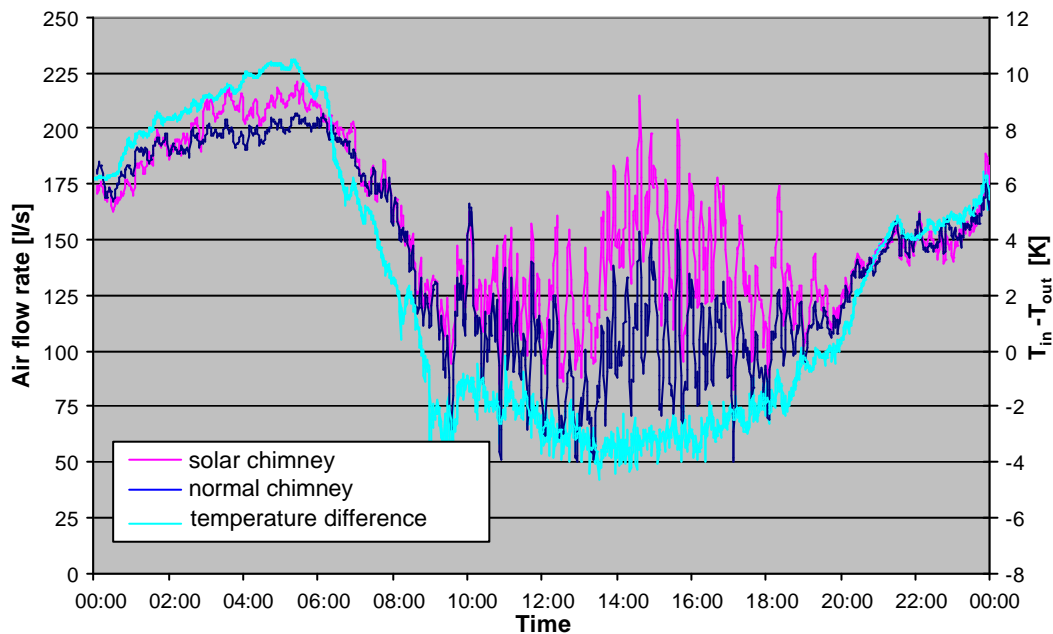


Fig. 7 Air flow rates and indoor-outdoor temperature difference

### 3.3. Influence of wind

As mentioned in the previous chapter influence of wind could be an important factor in the solar chimney performance. A wind gauge was installed above the solar chimneys in order to investigate the influence of wind on the chimney performance. The position of the wind gauge, which measured wind speed and direction, is in Fig. 8. The experimental solar chimneys are located in the area where wind speed and direction is significantly influenced by a nearby high-rise building. The wind gauge, therefore, was located close to the outlets of the chimneys.

The influence of wind was investigated when both chimneys worked as solar chimneys. It means that, unlike the previous situation, the chimney with thermal mass was not covered with insulation.



Fig. 8 The wind gauge

Fig. 9 shows air flow rates and solar radiation intensity on a sunny day in late summer (August 29, 2004). At night the air flow rate through the light-weight chimney was the same as the air flow rate through the chimneys with thermal mass. This corresponds with the situation when solar chimney was compared to the “normal” chimney in the pervious chapter. Wind velocity was quite small at night.

During the day the air flow rate in case of light-weight chimney was higher than in case of the chimney with thermal mass.

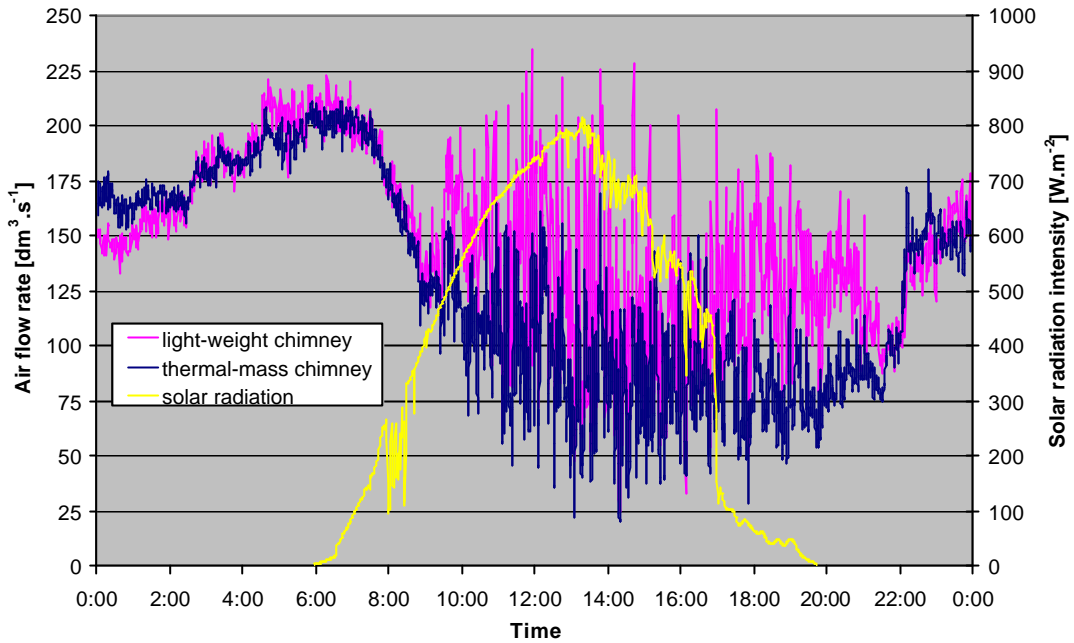


Fig. 9 Air flow rates through the chimneys (August 29, 2004)

The chart in Fig. 10 shows the air flow rates plotted together with the wind speed. The 15-minute moving average was applied to the data sets in order to make the chart better readable. As can be seen there is a correlation between gusts of wind and increase of the flow rate.

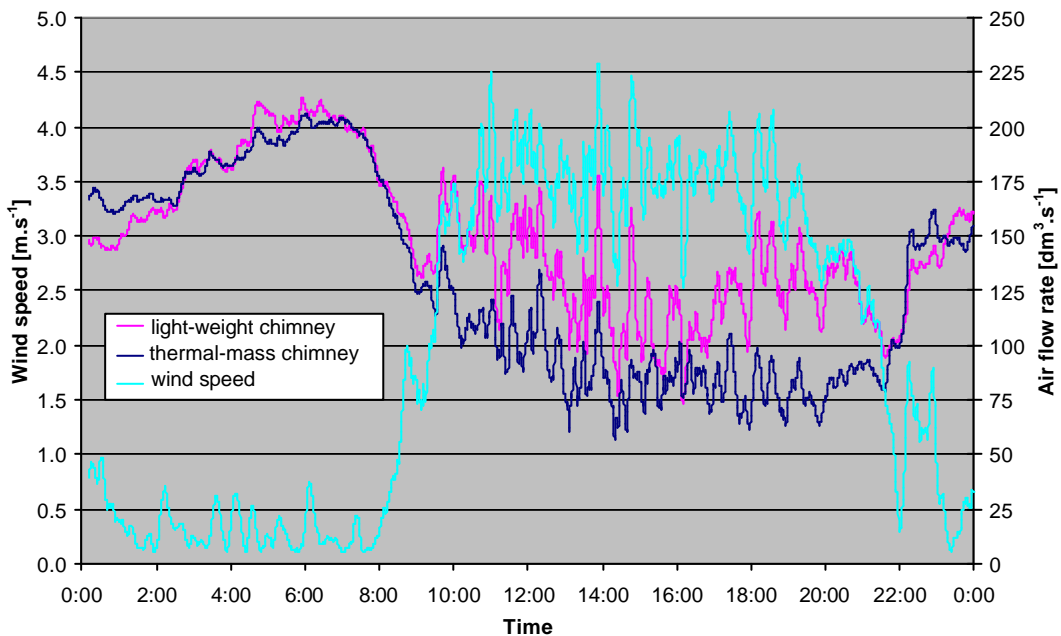


Fig. 10 Influence of wind (August 29, 2004)

Wind was blowing more or less from due south during the day, and so its influence on both chimneys should be the same. Wind speed and direction is plotted in Fig. 11.

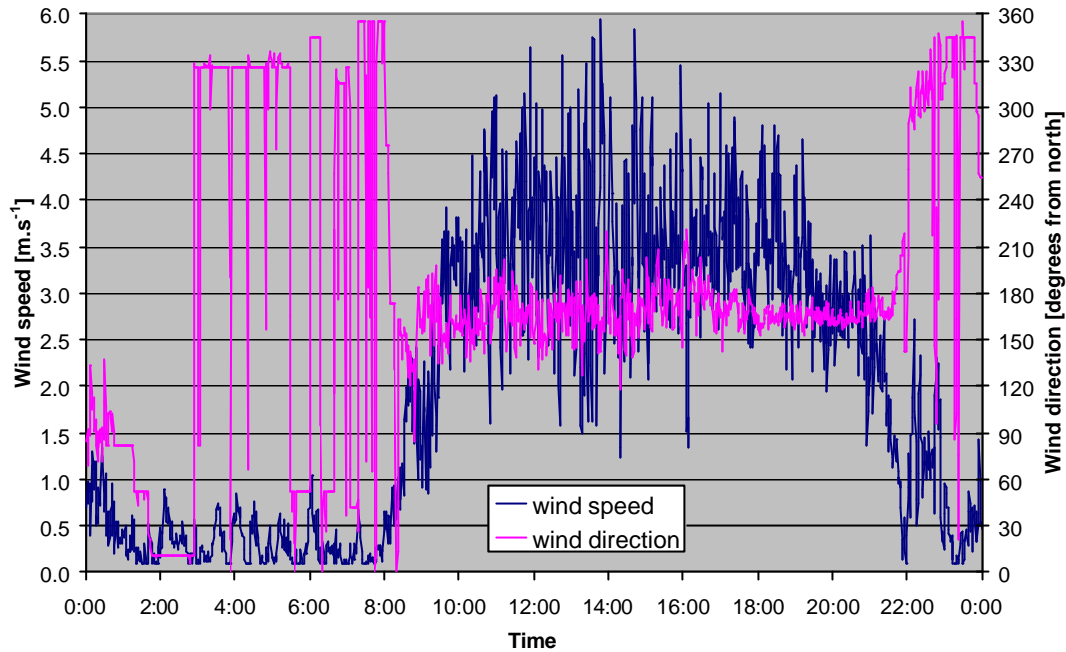


Fig. 11 Wind speed and direction (August 29, 2004)

The experimental solar chimneys had much higher cross section area than ducts used for passive stack ventilation in the building.

In the case of the solar chimneys for the demonstration house (chapter 4), the cross section area of solar chimneys is more than ten times bigger than the cross section area of the exhaust duct of the hybrid ventilation system. It means that the same pressure difference between the inside and outside of the house would cause much higher air flow rate through the solar chimneys than through the exhaust duct. This should provide a good potential for exploitation of solar chimneys for passive cooling.

#### 4. Demonstration house with hybrid ventilation

The experiences acquired with the experimental solar chimneys were utilized in design of solar chimneys for the demonstration house with hybrid ventilation, which was built in the Brno University campus (Fig. 12).

The experimental house is a double-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.



Fig. 12 Demonstration house with hybrid ventilation

The solar chimneys are positioned over the stairway in the house (Fig. 13). The stairway connects both floors, and so no ductwork is needed with such a position of the chimneys.

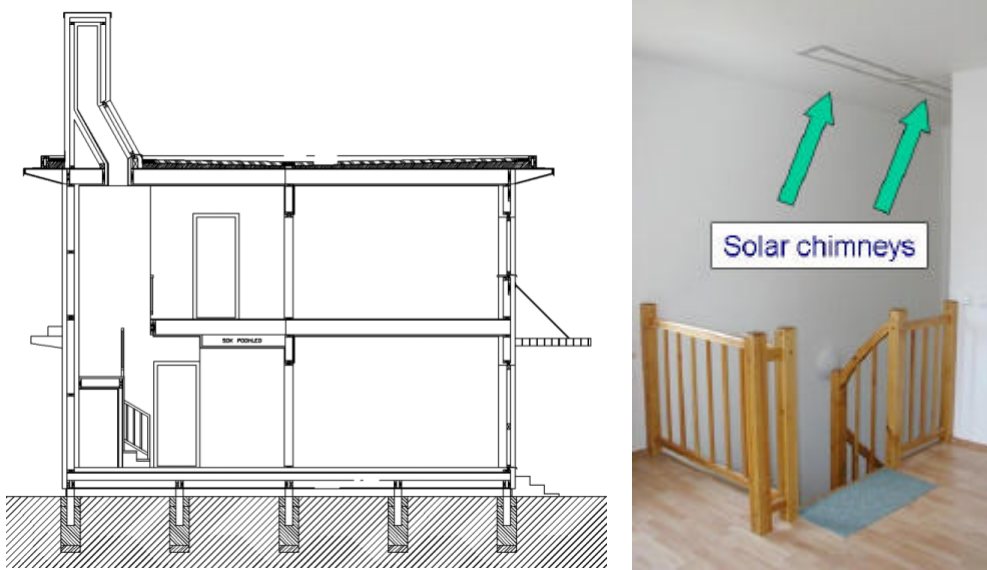


Fig. 13 Solar chimneys in the demo house

An option to use solar chimneys as skylights for the stairway was also considered, but it was abandoned for technical difficulties.

The experimental house will provide more realistic conditions for the investigation of the performance of solar chimney than the experimental facility on the roof of the lab.

Solar chimneys exploited for passive cooling could save significant amount of energy, if they are able to create similar level of thermal comfort as mechanical cooling (this goal seems to be achievable in certain types of buildings in moderate climates).

Even though the principle of solar chimney ventilation has been known for centuries, there are many possibilities to employ modern technologies in the solar chimney design. One option is to replace glazing with semi-transparent photovoltaic panels powering a DC fan. Such combination represents a fan assisted natural ventilation system, which could operate without an access to the power grid. The photovoltaic panels, in this case, could also provide power for a control system and actuators.

## 5. References

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