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Measurement of air flow rate in a naturally ventilated double skin facade

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SUMMARY

Air flow rate in a naturally ventilated space is extremely difficult to measure due to the stochastic nature of wind, and as a consequence non-uniform and dynamic flow conditions.

This paper describes three different methods to measure the air flow in a full-scale outdoor test facility with a naturally ventilated double skin façade. In the first method, the air flow in the cavity is estimated on the basis of six measured velocity profiles. The second method is represented by constant injection of tracer gas and in the third method a measured relation in the laboratory is used to estimate the flow rate on the basis of continues measurement of the pressure difference between the surface pressure at the opening and inside pressure of the double skin façade.

Although all three measurement methods are difficult to use under such dynamic air flow conditions, two of them show reasonable agreement and can be used for experimental validation of numerical models of natural ventilation air flow.

INTRODUCTION

Assessment of the air change rate is crucial for the evaluation of indoor climate and the performance of a double skin façade. As a result, the air change rate repeatedly becomes a target for measurement, prediction and simulation. In the meantime, the air flow occurred in the naturally ventilated spaces is very intricate and extremely difficult to measure. The stochastic nature of wind and as a consequence non-uniform and dynamic flow conditions in combination with the assisting or opposing buoyancy force cause the main difficulties.

In the literature, there are three methods used for estimation of the air change rate in a naturally ventilated space. These are the tracer gas method, method of calculating the air flow from the measured velocity profiles in an opening or calculated from the expressions for the natural ventilation or scale modelling [1, 2], which involves measurements of air temperature, wind speed, wind direction, wind pressure coefficients on the surfaces and pressure drop across the opening.

Experimental investigation of the airflow rate requires measurement of many highly fluctuating parameters. The fluctuation frequency implies the high sampling frequency for the measurements. For example according to [1] the wind speed has to be measured at least at the frequency of 5 Hz, otherwise peaks in the wind velocity can be lost when averaged in time. As a consequence, measurements of the airflow rate are limited to time and costs. When measured with the tracer gas method the limitations are extended to the airflow rates, as with the high airflow rate the amount of injected tracer gas will be enormous. Because of these, the investigation of the natural air flow often is carried out in the controlled environment of the wind tunnel or scale models.

When assessing the airflow rate in a naturally ventilated double skin façade cavity the focus is still set on evaluation of the indoor air quality from the perspective of health and comfort.

Depending on external conditions and the double skin façade functioning mode the air flow rate in a ventilated cavity can have significant variation in order of magnitude and occurrence of a reverse flow (definition of DSF functioning modes is given in [3]). Contradictory, in a traditionally ventilated domain minimum air change rate is specified in requirements for the indoor air quality, while maximum is normally restricted by the energy savings considerations. In view of that, the great variations in the magnitude of airflow rate are identified as the distinctive element of the cavity flow.

The double skin façade physics can be characterized by three main topics: optics, heat transfer and air flow [4]. In the modern science, there is a strong background for calculation of optical and heat transfer processes, but prediction of the air flow in the double skin façade cavity is still behind. It is explained by the complexity of natural air flow phenomenon, by the limitations described above and by the lack of the experience in measurements of air flow in the full scale DSF cavity in external environment.

This paper describes three different methods used to measure the air flow in a full-scale outdoor test facility with a naturally ventilated double skin façade. These methods are the velocity profile method, the tracer gas method and the third one is the pressure difference method, which is based on the empirically obtained relations between pressure difference and flow rate through the opening.

METHODOLOGY

Velocity profile method

This method requires a set of anemometers to measure a velocity profile in the opening, and then the shape of the determined velocity profile depends on amount of anemometers installed. At the same time, the equipment located directly in the opening can become an obstruction for the flow appearance. Thus, the method becomes a trade off between the maximum desired amount of anemometers and the minimum desired flow obstruction. Instead of placing equipment directly in the opening in the case of the double skin façade, it can be placed in the DSF cavity, where the velocity profile can be measured in a few levels for better accuracy.

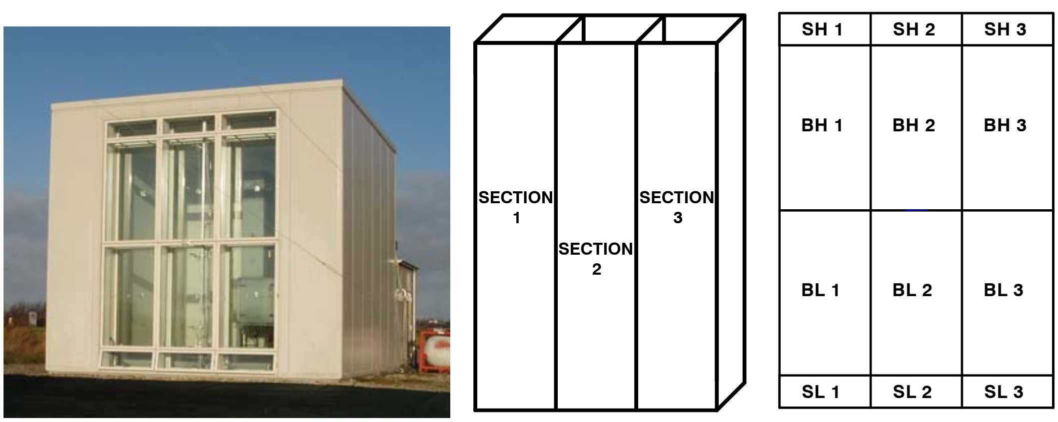
For the double skin façade, the negative aspect of this method is explained by airflow variation, as the air velocity in the cavity may vary from 0 to 5 m/s. This velocity range is challenging, as the equipment must be suitable for measurements of both low and higher velocities, moreover, it is necessary to be able to detect the reverse flow appearance.

Tracer gas method
This method requires the minimum amount of measurements and equipment, but it is characterized with frequent difficulties to obtain uniform concentration of the tracer gas, disturbances from the wind wash-out effects and finally with the time delay of signal caused by the time constant of gas analyzer. The constant injection method [5] is used in the experiments described further.

Pressure difference method
The pressure difference method is a technique, which is still in the testing and validation stage. It takes roots in preliminary testing of the openings, which calibrated to achieve a relation between the airflow rate and the pressure difference between the surface pressure at the opening and inside pressure of the double skin façade. As a result, when the pressure difference is measured during the experiments, the airflow can be calculated from the estimated relation.

EXPERIMENTAL SETUP

In this work, the full-scale experiments are conducted in period September-December, 2006 in the experimental test facility the 'Cube', which is described in detail in [6]. The 'Cube' is located in an open flat country with the DSF windows facing south. There are two experimental zones: the double skin façade cavity and the test room behind the DSF. The building has a shape of a cube with the dimensions 6x6x6 m. Window partitions of the façade visually subdivide the DSF into three sections. The definition of the sections is given in the Figure 1 and will be used in the further discussions. Internal dimensions of the double façade cavity are following, height – 5.5 m, width - 3.6 m, depth – 0.58 m. Operable windows at the top and bottom were open or close according to the ventilation mode of the DSF cavity.



a) b) c)

Transcription:

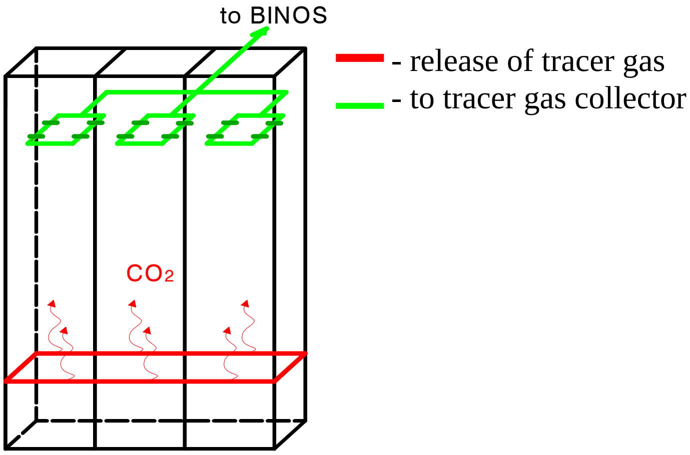
1st letter stands for	"**B**" – big	"**S**" – small
2nd letter stands for	"**H**" –high	"**L**" – low
Number stands for	"**1**" ,"**2**","**3**" – number of DSF section	

Figure 1. a) The 'Cube'. b) Section of the DSF cavity. c) DSF windows.

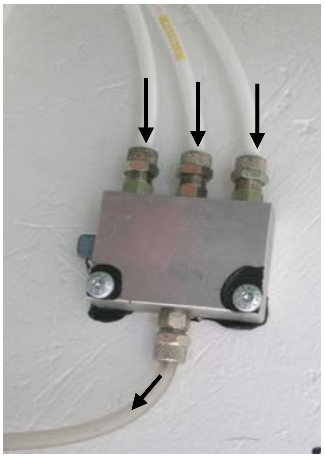
Certainly, further application of the experimental results set the main constrains in the design of the experimental setup. The measurements in the DSF, both the weather conditions and the conditions in the test room had to be registered as a reflection of the DSF performance. For rational comparison of the results all three methods are applied simultaneously, supported by measurements of wind velocity, wind direction, wind velocity profile, outside air temperature and vertical temperature gradient in the cavity. Next, the experimental setup is described separately for each method used.

The tracer gas method

Carbon dioxide (CO_2) is the tracer gas used during the whole period of experiments. Carbon dioxide was released in the lower part of the double skin façade cavity, but above the SL openings. Even distribution of the tracer gas along the DSF cavity was ensured by its delivery through a perforated tube of internal diameter 3.5 mm, perforation distance 4mm and 0.5mm diameter of perforations. Samples of the tracer gas dilution were taken in 12 points, Figure 2,a (4 samples per section) at the top of the DSF cavity, but below the SH- openings. All the samples were blended together in the collector, Figure 2,b, and then the concentration of the diluted tracer gas was measured by a gas analyzer BINOS. Concentration of carbon dioxide in the outdoor (incoming) air was measured continuously, by a gas analyzer URAS. Both of the devices were preliminary calibrated and had an accuracy of 10ppm. The Helios data logger collected the measurement data from the gas analyzers with the frequency 0.1 Hz. The constant injection method was used during the experiments and the quantity of the released tracer gas was kept constant.



a)



b)

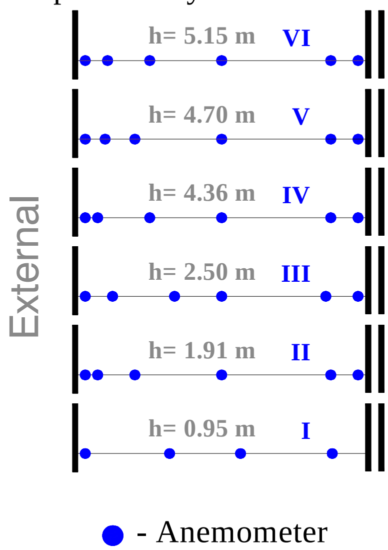
Figure 2. a) Experimental setup for the tracer gas method. b) Collector of the samples.

The velocity profile method

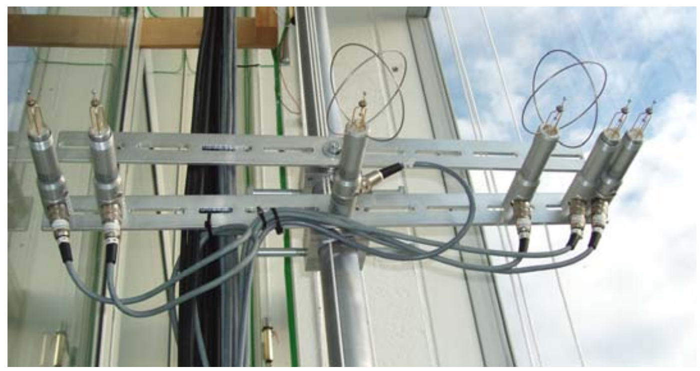
Measurements of the velocity profile in the double skin façade cavity has an advantage compared with the velocity profile measured directly in an opening, as in the cavity it is possible to measure velocity profiles in a few levels.

During the experiments in the 'Cube' all of the velocity measurements were conducted in the section 2 (Figure 1), the velocity profiles were measured in 6 levels, with the various number of anemometers in different levels. Levels are numbered with the Roman numbers in the Figure 3,a, with the frequency 10Hz. All in all 46 of hot-sphere anemometers were installed in the experimental setup, 34 of them were engaged in the measurements of the velocity profiles in different levels of the DSF cavity.

Temperature compensation is the main working principle of the hot sphere anemometers, therefore measurements of air velocity under the direct solar radiation access can be an issue for the accuracy of the experiments. In order to prevent this kind of error the hot sphere anemometers were preliminary tested and calibrated under the artificial sun conditions, in the wind tunnel.



a)



b)

Figure 3. a) and b) Positioning of anemometers in the DSF cavity.

Pressure difference method

This method gives an inspiration for finding a way to cope with the extremely high wind fluctuations. It includes two stages: a stage of calibration the opening and the stage of actual measurements, the latter one took part along with the other two techniques described above, while the former one was completed in the laboratory in advance.

The air flow through an opening is caused by the pressure differences in the separated environments. If the correlation between the pressure difference and air flow is known then the knowledge of one parameter indicates a possibility for calculation of another one.

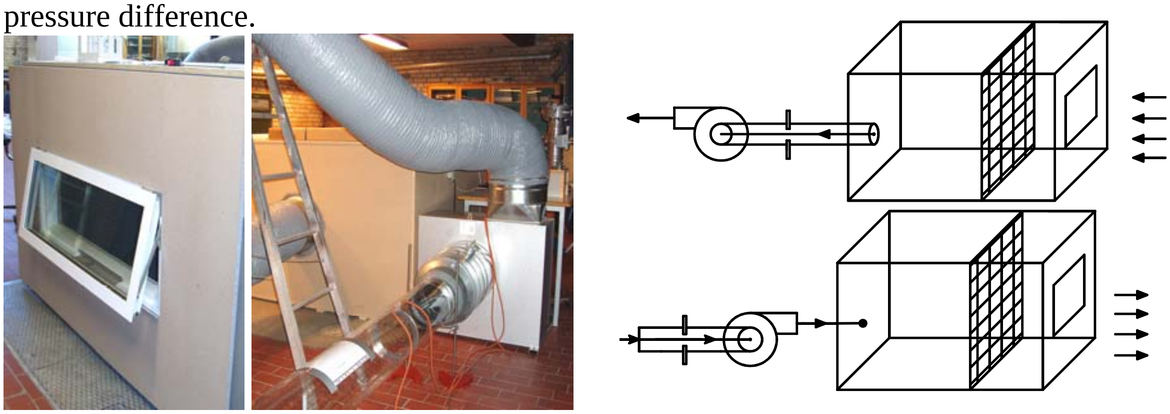
Since the variation of pressure at the window surface is the reflection of the pressure induced by wind, then the pressure difference had to be measured between pressure at the external window surface and the reference internal pressure.

A window of the same geometry as in the test facility ‘Cube’ was installed in a wooden well sealed box that was connected to a fan and an orifice where the airflow was measured. The window was tested for two cases with 15 different opening angles each. The first case tested is when the window works as an inlet opening and the other case is when it functions as an exhaust. With the purpose of finding the best location for the pressure difference measurements and at the same time to minimize disturbance from the flow turbulence a few points on the window surface and on the wall surface next to the window were tested. A relation between the pressure difference and the airflow passing through the opening can be expressed as in equation (1). Coefficients *a* and *b* depend on the opening degree of the window.

$$Q = a \cdot \Delta P^{b} \qquad (1)$$

Q - air flow, m^3/h
ΔP - pressure difference, [Pa]
a,b - empirically obtained coefficients

The isothermal conditions were kept during the tests. A micro manometer FCO510 measured the pressure difference.



a) b) c)

Figure 4. Experimental setup for preliminary opening calibration. a) Front side view. b) Back side view. c) Top- air supplied through the opening, bottom – air exhausted through the opening.

Next, the actual measurements of the air flow in the double skin façade cavity took place. This time the pressure difference was measured with six pressure transducers Furness Controls Ltd. FC044 (number of pressure transducers corresponds to the number of open windows in the ‘Cube’). The pressure difference was measured between the surface pressure at the opening and the reference pressure in the double façade cavity. The pressure on the external window surface was measured separately for each window while the reference pressure in the DSF cavity was only separated for the bottom openings SL and top openings SH and was measured at the corresponding height of the openings. Location of pressure measurements on the window external surface can be seen in the Figure 5 for the bottom openings SL, the same positions were used for top openings SH.

a) b) c)

Figure 5. a) Location of the pressure measurements at the window surfaces, SL-openings. b) Preheating mode. c) External air curtain mode.

Experimental conditions

Experiments in the naturally ventilated cavity were completed for the external air curtain mode (Figure 5), moreover the experiments in the mechanically driven flow in the cavity are available for DSF operation in the preheating mode (Figure 5).

The natural driving forces were responsible for the air flow in the cavity in the external air curtain mode, while in the preheating mode the double façade cavity is mechanically ventilated. In the former case, the air flow rate depends only on wind and buoyancy and limited by the opening size, while in the latter case the ventilation system keeps low and relatively constant air flow rate.

External air curtain mode is the frequently used solution in summer when it is necessary to prevent surplus solar gains into the room. In this mode, the air temperature in the cavity must not be very high in order to avoid heat transmission/radiation to the room. Thus the opening degree of the windows was adjusted to the mean air temperature in the double façade cavity was 5-10 degrees above the outdoor temperature, in order to avoid too high cavity temperatures in the external air curtain mode.

The preheating mode can be associated with the spring/autumn conditions when air preheated in a cavity supplied directly to the occupant. In this case higher air temperatures in the DSF cavity are desired, but the preheating ability of the DSF cavity is limited by the necessary air flow rate controlled by a ventilation system.

Air flow rate in the DSF cavity was measured both for the mechanically ventilated and naturally ventilated setup and the air temperature in the test room was kept constant to 22^{o}C.

RESULTS

Conducted experiments cover more than 2 weeks period in each ventilation mode. Air flow rate measured with the tracer gas technique contains periods with the great dilution of the tracer gas leading to serious uncertainties in the accuracy expressed by overestimation of the air flow rate. For example in the period October 6-9, measured air flow corresponds to 300-600 ACH in the DSF cavity. Because of the high wind speed (11 m /s) and wind direction directly into the DSF openings, occurred high air flow is likely as well as the occurrence of the wash-out effect.

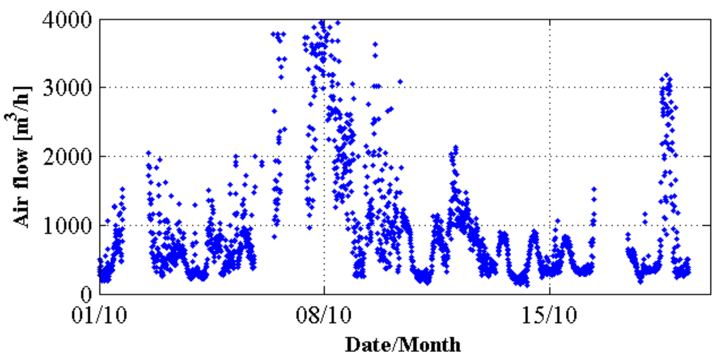


Figure 6. Air flow rate in the DSF cavity measured with the tracer gas technique in external air curtain mode.

Velocity profiles are measured in six levels in the double façade cavity, the mean air velocity within each profile is obtained by integration and finally 10 minutes mean air velocity in the cavity is calculated. Since the velocity profiles are measured only in the mid section of the cavity then there is an assumption of equal flow conditions in all three section of the DSF cavity needed for the air flow estimation.

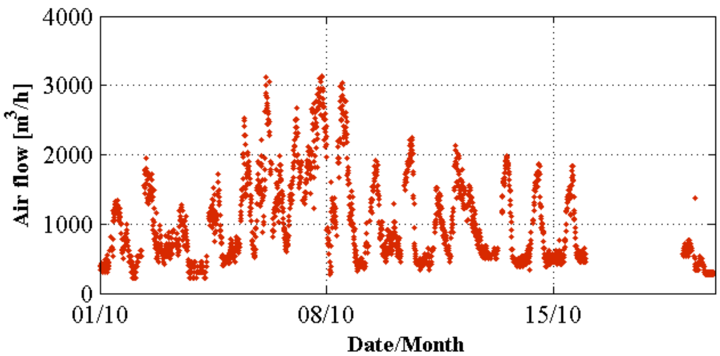


Figure 7. Air flow rate in the DSF cavity measured with the velocity profile technique in external air curtain mode.

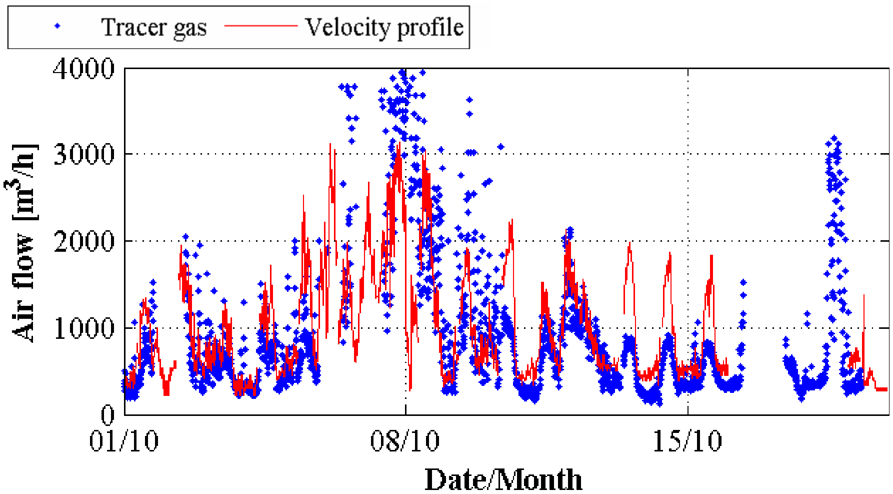
The hot-sphere anemometers do not determine the flow direction and the estimation of the air flow rate in the cavity is suitable only if there are no changes in flow direction within the profile, as appearance of the reverse flow, which is not possible to determine, is damaging for the accuracy of estimated airflow in the DSF cavity.

Air flow rates calculated for the SH and SL openings applying pressure difference method have serious disagreements and do not seem reasonable, Figure 8, b (mean measured flow 3812m^3/h or 3065m^3/h vs. 1007 m^3/h in the velocity profile method and 1011 m^3/h in the tracer gas method).

DISCUSSION

Although it is difficult to measure the air flow in a naturally ventilated double façade cavity, as there is no easy method either no accurate one exists, results obtained with the velocity profile and the tracer gas method show reasonable agreement (Figure 8) and can be used for experimental validation of numerical models of natural ventilation air flow.

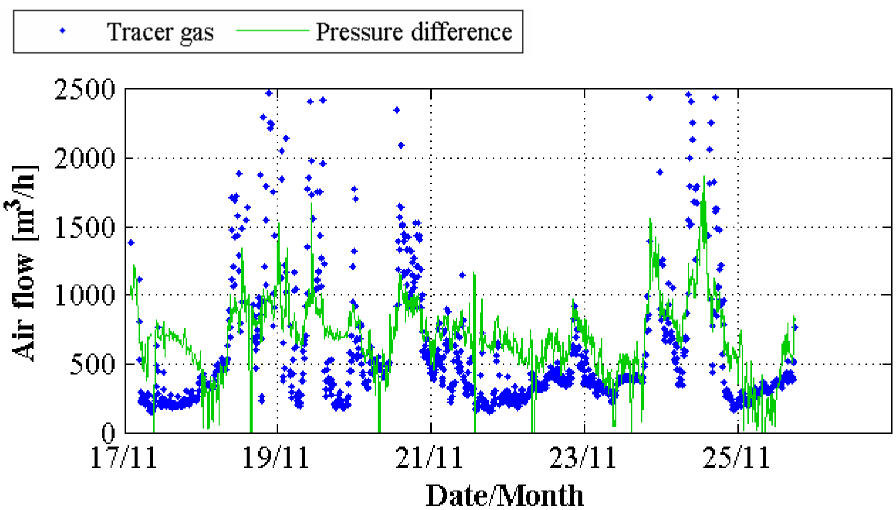
Despite the fact that the air flow rate estimated by the pressure difference method is disappointing, the encouraging is that this method has been relatively successful when cavity is mechanically ventilated (Figure 9). This method is very sensitive to the positioning of the surface pressure and reference measurement, to the fluctuations in wind direction and wind speed. The method failure with natural ventilation case and relative success with the mechanically driven flow argues for further investigation.



Method	Mean measured flow, m^3/h
Tracer gas	1011
Velocity profile	1007
Pressure difference, SH-openings	3812
Pressure difference, SL-openings	3065

a) b)

Figure 8. a) Air flow rate in the DSF cavity measured with the tracer gas and velocity profile technique in external air curtain mode. b) Mean measured air flow in external air curtain mode.



Method	Mean measured flow, m^3/h
Tracer gas	862
Velocity profile	562
Pressure difference, SH-openings	-
Pressure difference, SL-openings	709

a) b)

Figure 9. a) Air flow rate in the DSF cavity measured with the pressure difference method in preheating mode. b) Mean measured air flow in preheating mode.

When speaking about the air flow measurements in the double façade cavity with the velocity profile method it should be mentioned that due to repeatedly changing shape of the velocity profile (Figure 10), measurements of velocity only in the center line of the cavity is not acceptable simplification. Moreover, the number of measurement points within the velocity profile and measurement frequency are very essential for accuracy.

Another point to mention is the lack of method for visualization of the flow pattern in the DSF cavity. This is a serious draw back for the experiments, as the preliminary visualization tests would enhance positioning of velocity measuring equipment as well as they would help to determine better locations of the tracer gas injections and finally would serve for improvement of the measurements accuracy.

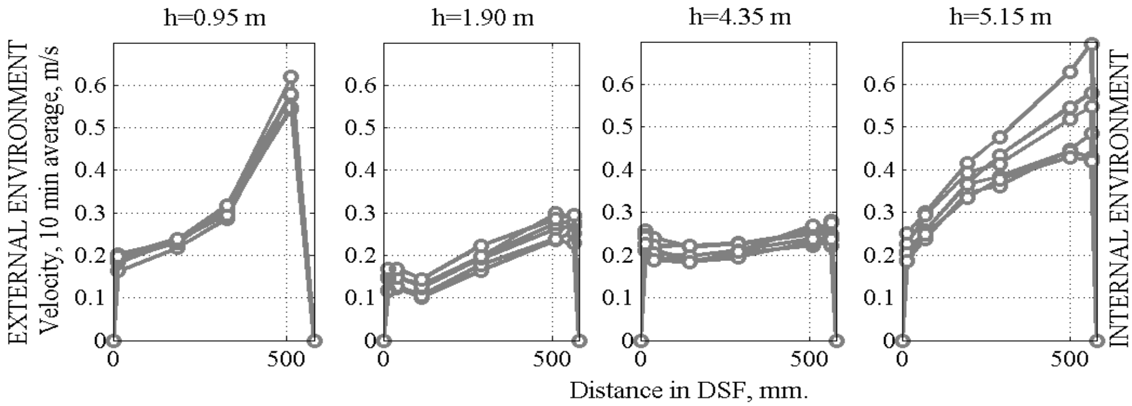


Figure 10. Example of the velocity profile deformation within the DSF cavity.

All three described measurement methods have sources of error and compared to laboratory conditions have relatively large uncertainties. Although two of the methods provide outcome with reasonable correspondence, there is a large potential for further research to improve accuracy when measuring air flow in naturally ventilated cavities.

ANKNOWLEDGEMENT

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