Influence of the external dynamic wind pressure on the ventilation of double facades

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ABSTRACT: The ventilation rate in the cavity of a double facade is dependent on the characteristic of the wind directly in front of the facade. This effect was investigated by wind tunnel tests. The results show, that the turbulence and the integral length scale are not sufficient, to describe the amount of the air change. The frequency resp. the wavelength of the wind speed in the opening has a strong influence on the ventilation rate. Only a high quota in the wind spectrum that matches the dimensions of the openings leads to high ventilation rates.

1 INTRODUCTION

In northern Europe, specially in Germany, Austria, the Benelux and Switzerland the importance of double facades is still increasing significantly. In different estimations of several engineering offices, architects and facade specialists is predicated that a double facade area of 200.000 to 400.000 m² is erected yearly, that corresponds to a volume of 200 to 400 Million €.

Air conditioning systems which are not optimized can cause the so called “sick building syndrome” (Kröling, 1995) which means that the user of full air conditioned rooms feel uncomfortable which can increase the time where people call in sick. Twin facade systems are representing a possible solution to limit the period of time where mechanical ventilation of the buildings is necessary and in some cases it may even be possible to plan a building without an air conditioning system. To obtain comfortable low room temperatures in summer it is possible to combine a double facade with a ceiling with integrated cooling systems.

Twin facade systems are often used for buildings in exposed areas when window ventilation is not possible due to high wind velocities which causes uncomfortable draft in rooms and for buildings that are exposed to noise pollution when window ventilation is not possible due to for example traffic noise.

2 STATE OF THE ART

In the design of buildings using the twin facade system and the calculation of air change rates traditionally the thermal forces (temperature differences between the room temperature and the enviroment) and the different wind loads on the different sides (windward and lee side) of the building are investigated.

The influence of the air change rate in rooms and the temperature difference between the room and the environment is shown in (Ziller, 1999) and (Ziller 2000). Furthermore in this study the influence of the external wind loads, the buildings architecture (e.g. the door gap between the windward rooms and the rooms on the lee side) on the rooms ventilation is investigated.

Figure 1 and 2 are showing the ventilation coefficients of a room with a double facade. Figure 1 shows the results of a full scale measurement in comparison with the results of a model test where the ventilation coefficient is a function of the temperature difference $\Delta T_R = T_{Room}-T_{Enviroment}$, with 2 different window openings. Figure 2 shows the influence of the wind pressure on the room ventilation where the height of the door gap is varied.

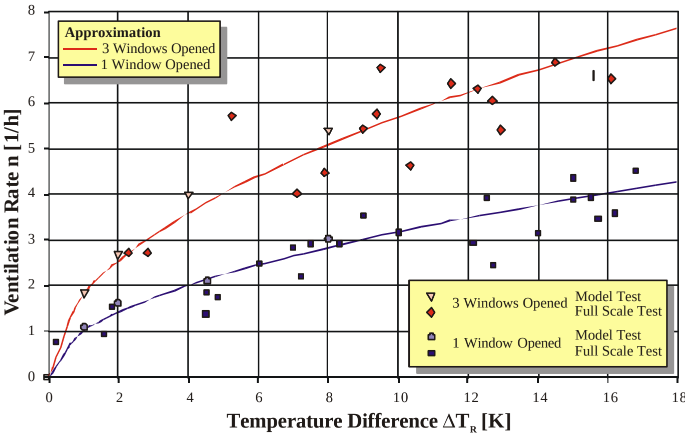


Figure 1: Ventilation coefficient in a room (full scale and model) with a double facade as a function of the temperature difference

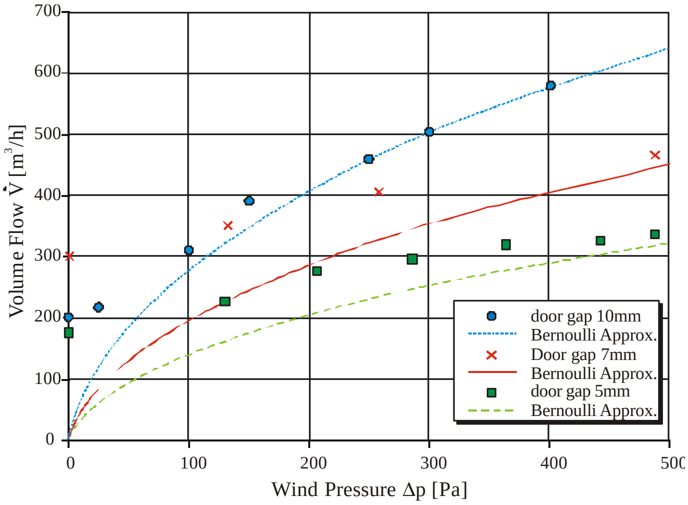


Figure 2: Model test results of the ventilation coefficient in a room as a function of the wind pressure and the hight of the door gap

3 BASIC APPROACH

Figure 2 shows the influence of the wind pressure differences on the room air change rate which are caused by the on-flow of the entire building (positive pressure at the windward side, negative pressure at the lee side). Pressure differences which are small-sized and occur on one side of the building are not considered yet.

Wind has in full size a turbulent character, which means that a permanent varying pressure distribution p(t,z) occurs on each side of the buildings surface due to the natural turbulence of the wind (Figure 3) which can be described as $p(t,z) = \overline{p} + \Delta p(t,z)$. This effect induces pressure differences $\Delta p_{ou}(t)$ between the inlet and the outlet of the secondary facade, which in turn results in a air flow in the gap between the inner and the outer glass front.

The aim of the investigations which are presented in this paper is to quantify the air flow in the gap between the two facades and to estimate this influence on the quality of the ventilation of the room.

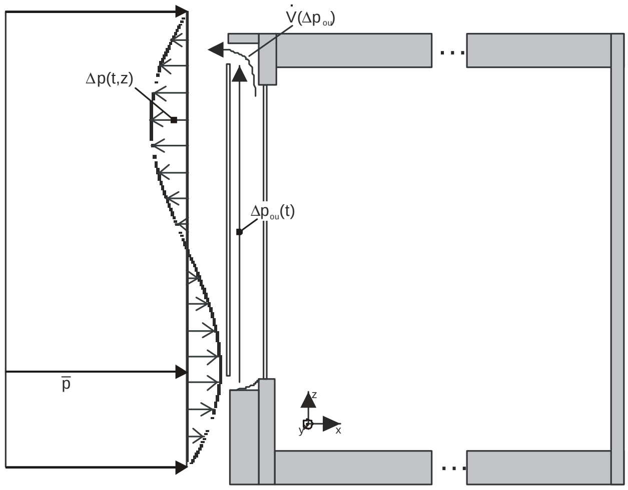


Figure 3: Influence of small-sized pressure differences on the flow characteristic of a double facade

4 THEORETICAL CONSIDERATIONS

One possibility to characterize wind gusts is to consider the integral lengthscale in vertical, transversal and longitudinal direction. For the investigation of the pressure differences between the openings in the 2ndary facade layer the vertical dimensions (L_{uz}) are of importance. Dependent on the height of the facade element and the surface roughness L_{uz} reaches values between L_{uz} = 15 and 100 m. It has to be noted that the integral lengthscale is a mean value, there are portions in the spectrum of a gust which correspond to the dimensions of the double facade as shown in the principal in Figure 3.

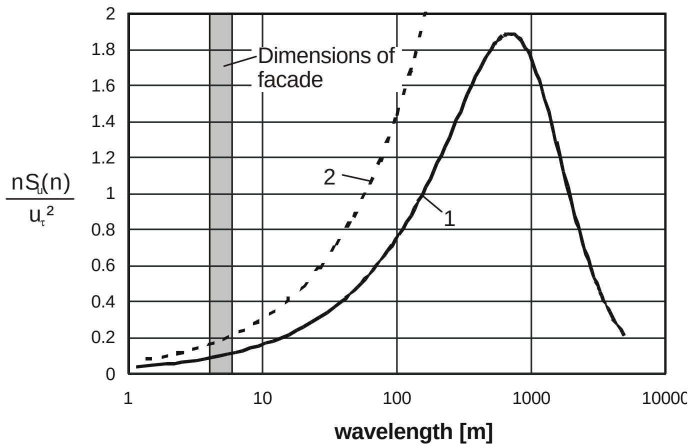


Figure 4: Spectral distribution of the wind velocity, Assumption of (Davenport, 1961 (1)) and (Cermak, 1976 (2))

The spectral distribution of the wind velocity (as a function of the wave length as shown in Figure 4) demonstrates that the maximum portion of the wave lengths are greater than 500m. The part which is important for the air flow in the gap of double facades (wave length of 4 to 6 m) is marked in the figure above (Figure 4). These are values where the distance between the inlet and the outlet corresponds to the half of the wave length.

5 MODEL TESTS

5.1 *Similarity Parameters*

To perform model tests it is necessary to derive so called similarity parameters which describe the physical process and allow the transformation of the model test results to the full scale. In the most model tests it is not possible to maintain all of the governing similarity parameters.

Without going into detail the here used similarity parameters are as follows:

Geometric model scale: 1:100
Velocity Scale: 1:1

5.2 *Wind Tunnel Model and Experimental Setup*

For the model tests the Wind Tunnel in the Institute of Steel Construction at the RWTH Aachen, Germany is used. This is an open-circuit type wind tunnel with dimensions of 2.50 m width and 1.70 m height. The maximum wind speed amounts ca. 30 m/s.

In order to meet the correct relation of the integral length scale of the wind-tunnel-wind and the full scale wind characteristic a model scale of M=1:100 is chosen. The depth of the gap between the two fa-

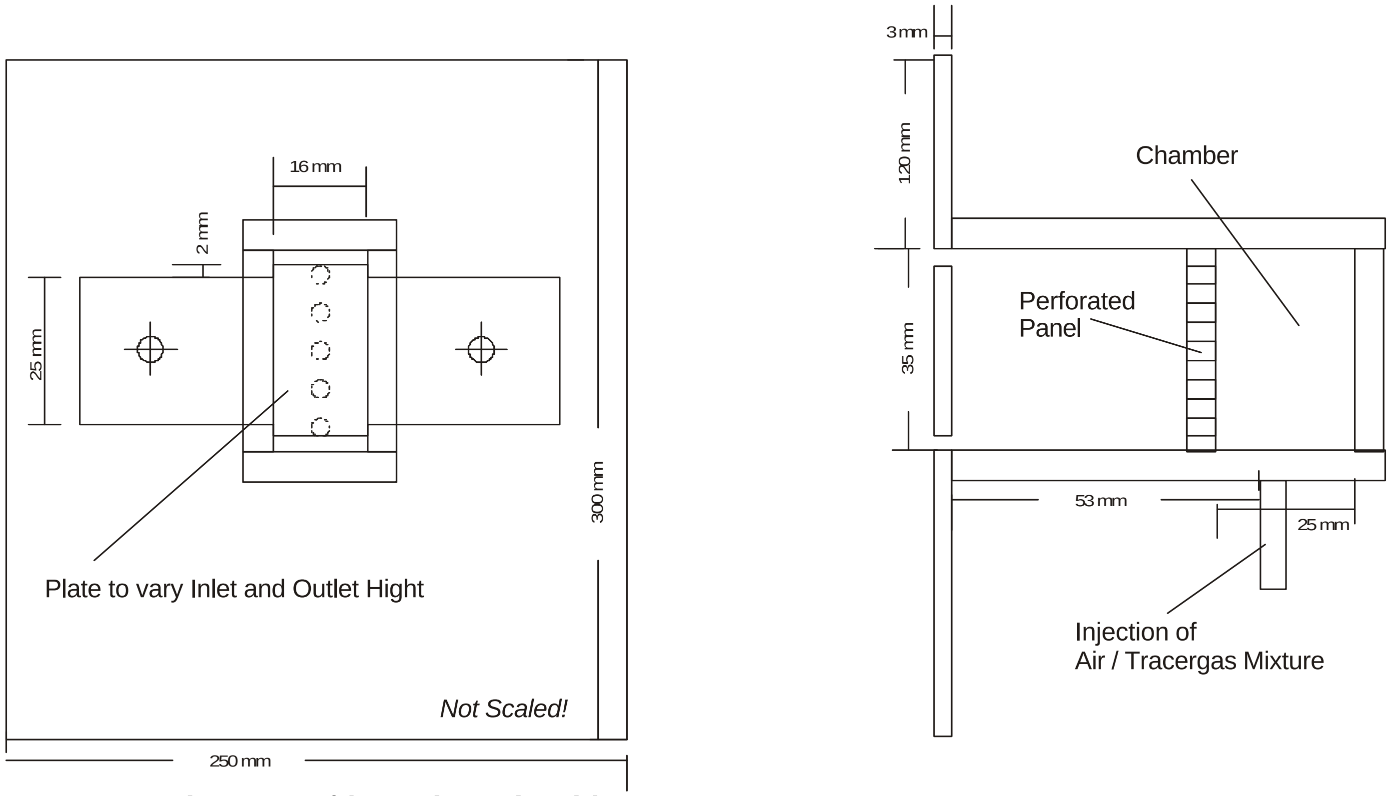


Figure 5: Principle Drawing of the Wind Tunnel Model

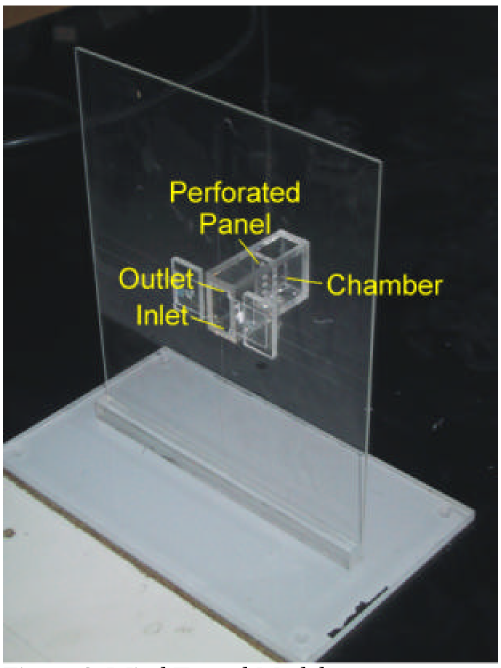
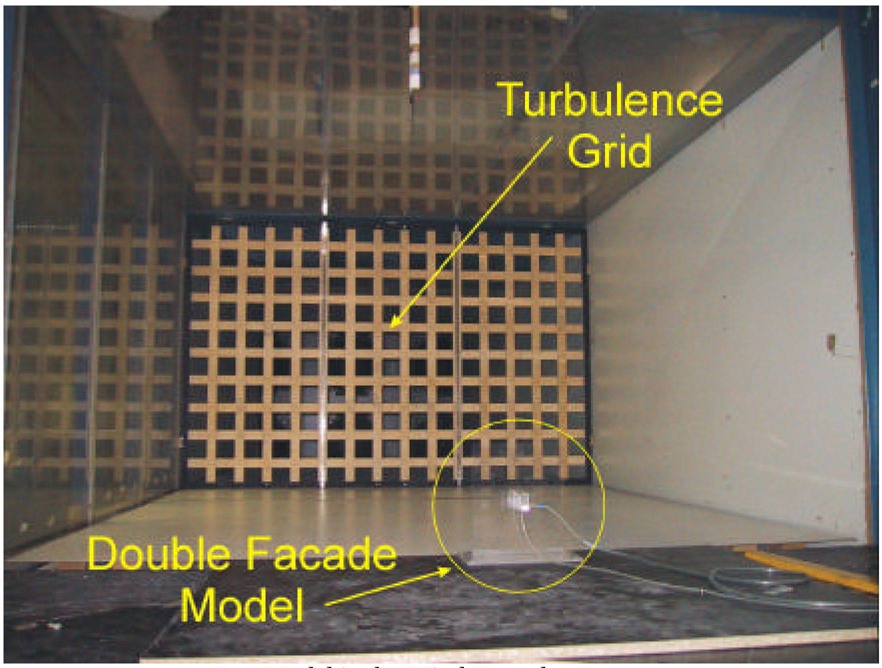


Figure 6: Wind Tunnel Model



Test Model in the Wind Tunnel

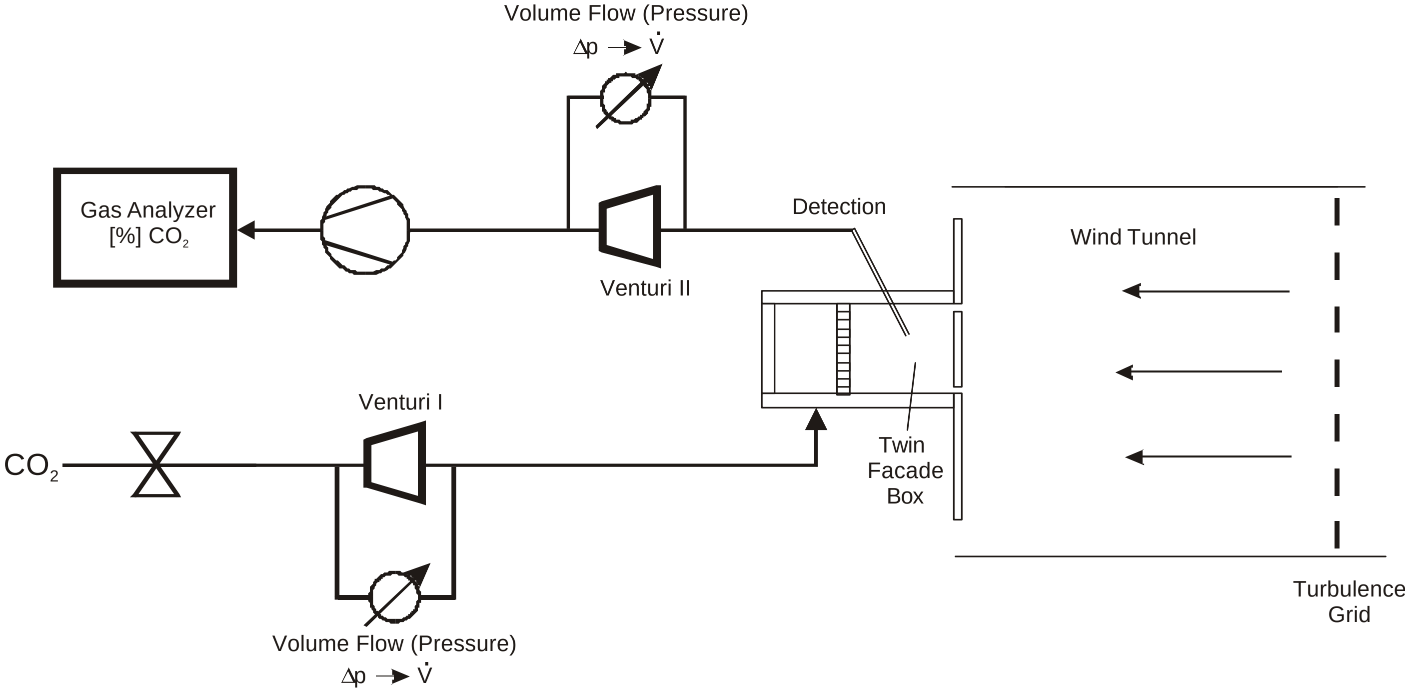


Figure 7: Principle Drawing of the Experimental Setup

cade layers is scaled up by a factor of 10 in order to reduce the influence of the surface roughness. A second reason to increase the depth of the gap is the experimental procedure, where tracer gas is used to measure the ventilation.

The measurement gas mixture gas is injected into a chamber which is connected by a perforated. panel to the space between the primary and secondary facade. The primary facade has inlet and outlet openings which are positioned at the bottom and at the top of the „twin facade box“.

To determine the influence of the size of the openings it is possible to vary the height of the model inlet and outlet in three steps.

Figure 5 shows a principle drawing of the wind tunnel model with its basic dimensions. Figure 6 shows pictures of the model itself (left side) and of the model in the wind tunnel (on the right side).

5.3 *Measurement Procedure*

The so called „Method of constant injection“ is used for the wind tunnel tests. Detailed information about this method are given in (Raatschen, 1995). That means that a gas mixture consisting of air and a tracer gas (CO_2) with a constant concentration and a constant volume flow is injected into the measurement volume, the twin facade box. The concentration and the volume flow of the tracer gas which can be varied by a throttle are recorded continuously during the tests. Probes of the gas mixture in the twin facade box are sampled where the concentration of the remained tracer gas is detected. The relation of the concentration of the injected tracer gas and the concentration of the tracer gas measured in the modelled twin facade box gives information about the wind induced volume flow in the facade box.

By taking a probe of the gas mixture in the facade box it is important to limit the probe volume flow to a certain level. Otherwise the flow characteristic inside of the box can be disturbed by the probe sampling and the measurement results are falsified. Compared to the volume flow of the injection and the volume flow of the air the volume flow of the probe has to be significantly smaller. Figure 6 shows the principle of the experimental setup.

The measurements in the wind tunnel were made without boundary layer, wind characteristic were changed by using a grid to induce a higher turbulence and a smaller integral length scale (table 1).

The turbulence was measured using a LDA (Laser-Doppler-Anemometer), the integral lengthscale was determined by the Taylor-hypothesis.

Table 1. Characteristics of the wind tunnel

	Turbulence I	integral lengthscale L_{uz}
no boundary layer	6 %	ca. 10 cm
no boundary layer, with grid	9 %	ca. 7 cm

6 MEASUREMENT RESULTS

The following diagrams are showing some of the results of the wind tunnel tests.

In Figure 8 the influence of the turbulence intensity and the mean wind velocity on the ventilation rate of the twin facade box is demonstrated.

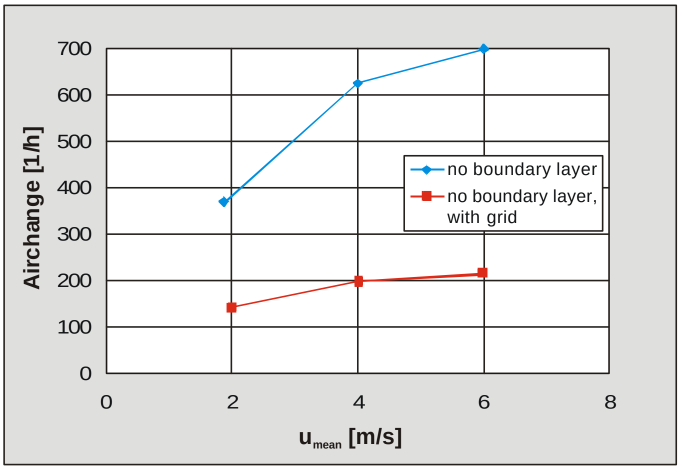


Figure 8: Ventilation rate dependent on the incoming wind

The ventilation rate of the cavity in "airchanges per hour" was ascertained for the real scale by using the scaling factors for geometry and time.

The height of the inlet and outlet in the primary facade is fixed during the measurements with approx. 180 mm. As expected the ventilation rate increases with an increasing mean wind velocity. Quite unexpected is that the ventilation rate for higher turbulence intensities (“no boundary layer with grid”) is reduced compared to the ventilation coefficient in the twin facade box with an on-flow characteristic with a low turbulence intensity. Due to this effect additional measurements to determine the effect of the turbulence intensity are necessary.

Hot wire probes are placed directly into the inlet and outlet openings (Figure 9) to detect the flow characteristic depending on the original turbulence intensity. In a second series of measurements the hot wire probes are placed in different distances to the model to get the mean velocity (scalar) and the turbulence.

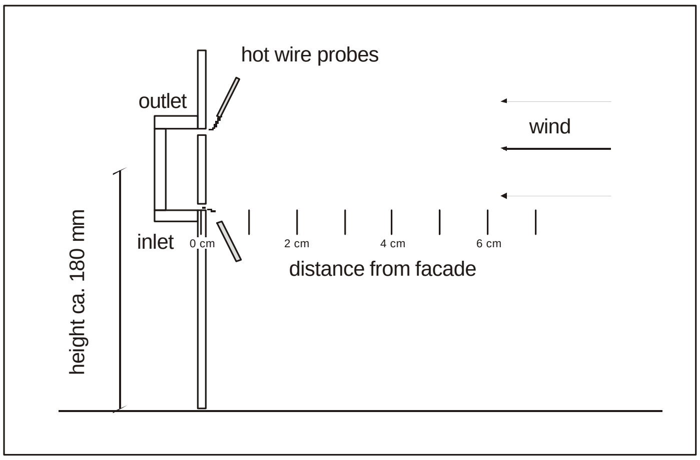


Figure 9: Positions of hot wire probes

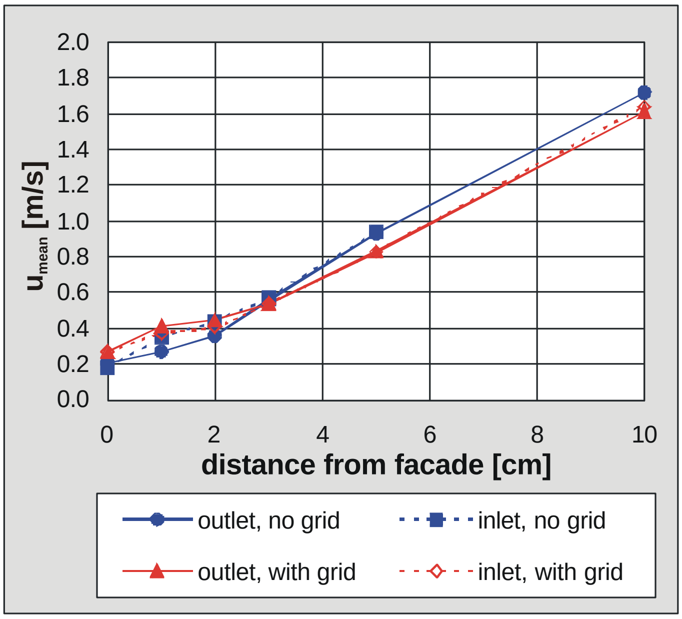


Figure 10: Mean wind speed in the facade openings (distance 0 cm) and in front of the facade

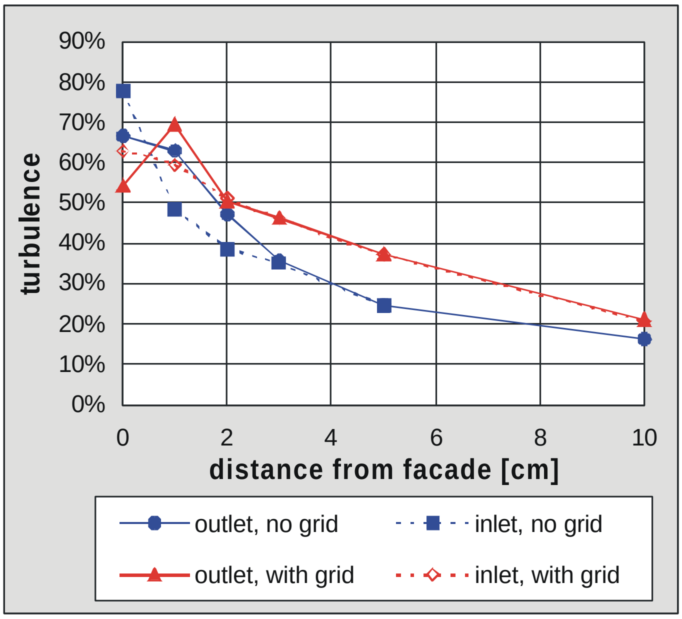


Figure 11: Turbulence in the facade openings (distance 0 cm) and in front of the facade

Regarding the high degrees of turbulence in the openings and close to the facade it has to be pointed out, that in this cases the direction of the wind speed changes, what can not be detected by the hot wire probes. This fact affects the results of a spectral analysis, nevertheless the normalised spectra of the wind speed in the ventilation openings give hints for an explanation of the unexpected ventilation rates (Figure 12). In the tests without grid, the frequencies in the range of 0 to ca. 4 Hz have a significant higher value as in the tests with the grid. Regarding the measured wind speeds and the dimensions of the modell, these frequencies are relevant for the air-change in the cavity. Higher frequencies cause mainly an oscillation of the enclosed air volume with only small effects concerning the air change.

For frequencies above 20 Hz, the spectral analysis gives higher values for the investigations with the turbulence grid in the wind tunnel.

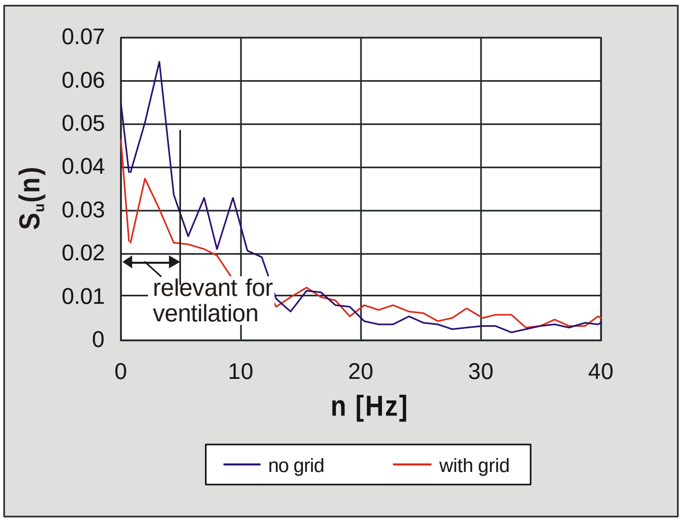


Figure 12: Spectrum of wind speed in the lower ventilation opening

7 NUMERICAL CALCULATIONS

Beneath the measurements of the ventilation rate by using the "method of constant injection" a second path to get information about the airchange was taken: A "semi-numerical" calculation, based on dynamic pressure measurements on a surface of a cube. For these calculations some assumptions concerning the characteristic of the air flow has to be done:

- the relevant flow resistance is given by the openings, the resistance of the cavity is neglected
- the air volume V in the cavity moves homogenous, internal eddies are neglected

With these assumptions the movement of the air, forced by the pressure differences between to points of the cube, that represent the openings, can be calculated. Small oscillations of the air volume in the cavity which are much smaller as the distance between the openings do not cause a significant air change. A complete air change is given, if the air volume V moves more then the distance between the openings. For this calculation only these large movements were considered.

Different geometric scales can be simulated by using the points with different distances on the cube. Differing from the air change measurements, the pressure was recorded with a boundary layer. This leads to different characteristics of the wind (table 2; Zillinger, 1995):

Table 2. Characteristics of the wind tunnel with boundary layer

	Turbulence I	integral lengthscale L_{uz}
with boundary layer	23 %	ca. 30 cm

The results are given in Figure 12, additionally the results of the measurements are marked. For this semi-numerical method, an increasing airchange rate for smaller integral lengthscales can be detected up to L_{uz} = 15 m. For the lowest integral lengthscale of 9 m, the ventilation rate is decreasing. The order of magnitude is suitable for the airchange measurements. A complete correlation could not be expected, as the characteristic of the incoming wind is different.

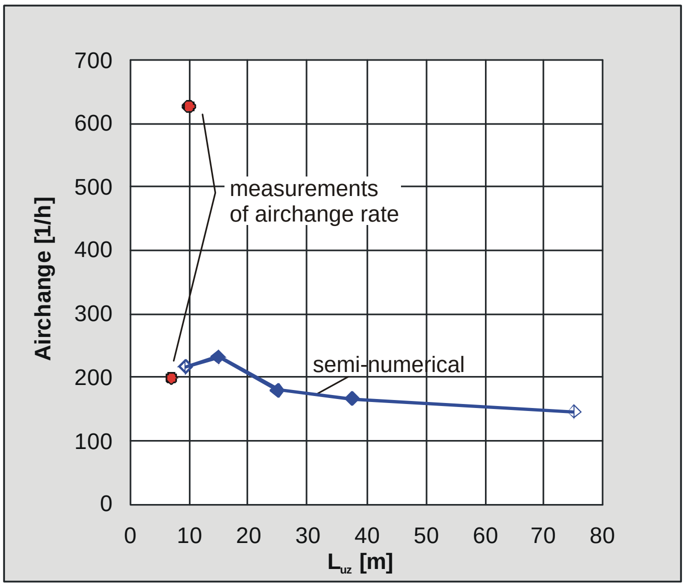


Figure 12: Results of numerical calculations based on pressure measurements (semi-numerical) for mean wind speed of 4 m/s

8 SUMMARY AND CONCLUSIONS

Model tests for the air change in the cavity of a double facade are performed to investigate the relation of the ventilation rate and the characteristics of wind. The wind tunnel was used without boundary layer, the wind characteristic was changed by using an additional grid.

The results of the air change measurements showed a significant reliance on the wind characteristic. The first assumption, that higher turbulence and lower integral lengthscale causes higher ventilation rate, could not be proved generally. The parameters "turbulence" and "integral lengthscale" are not sufficient for estimating the ventilation rate. Instead of this the frequencies of the wind speed directly in front of the facade an in the ventilation openings determine the ventilation rate.

The semi-numerical method of calculating the ventilation rate using measurements of dynamic pressure leads to results that correspond to the assumption for larger integral lengthscales, for very small integral lengthscale the trend of the measurements could be confirmed.

Going out from these results, further investigations have to be made: As the hot wire probes can not detect the direction of the wind speed, additionally the pressure has to measured parallel to the wind speed in the openings. The geometrical relation of the model and the wind and the characteristic of the wind has to be varied, to work out mathematical relations between the parameters. To verify the evidence of the model tests for real objects, the effects of Reynolds number have to be checked, measures in accomplished buildings are aspired.

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