Exterior Climate and Building Ventilation

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SUMMARY

The article shows methods for wind influence on building ventilation systems analysis. Solution has been carried out through the experiment in wind tunnel as well as by CFD modelling. Mean pressures and pressure variations have been measured on the model surface with respect of the ventilation intake and exhaust usual situating, with height of the roof parapets modification. The experimental results was presented by pressure coefficients-output is possible convert to different boundary conditions. The wind effect was analysed in different wind direction. The measurement and simulation is focused to the top part of the building façade and to the roof.

INTRODUCTION

Natural ventilation is an air flow inward and outward interior and it is caused by a pressure difference between building interior and exterior. Natural ventilation can create the healthy indoor environment and can save energy but the prediction of ventilation can be difficult. The air is driven in and out due to pressure differences produced by wind or buoyancy forces. Intake air is not usually controlled.

Natural ventilation is typical permanent ventilation, with limited regulation. Energy efficiency depends on the local condition insight and outsight the building. It induces that the same system operates differently from the others in the same conditions. The main influence is caused by the wind.

METHODS

Wind influence on buildings

Wind influence on the building is investigated in the context with static load to the building bearing system. Air flows around the building and the influence on building systems was analysed in the last few years. Wind influence on pedestrians and ventilation systems is significant now.
Natural ventilation systems work with temperature differences or with the wind influence.
A typical system works with temperature difference and air intake is realised through the building envelope and air output is situated in the roof. Exterior conditions have influence on an air input (input items) and air flow on the building is fluctuating. There is an impact on the

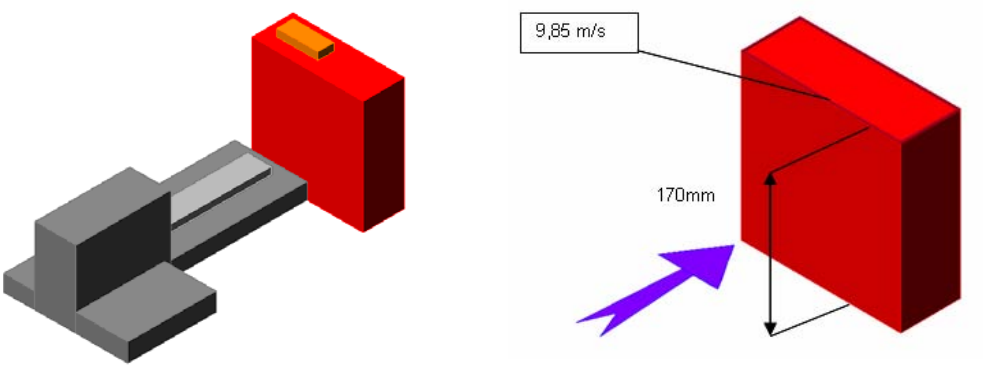
air output on the roof too. An air output is influenced by positive or negative pressure, which is induced by an aerodynamic effect (a building shape, ventilation systems, a parapet, etc.) Ventilation systems induced by the wind are systems where the wind influence is dominant and the density change by temperature difference is small. A typical system is a one side ventilation or a cross ventilation. But ventilation efficiency is fluctuating.

Exterior and building

There are many ways how to analyse the wind influence on the building. These methods were first of all evaluated for a bearing system design. Maximal pressure influence is needed for this purpose. Maximal wind velocity was statistically analysed in different directions. But ventilation systems work with real wind velocity and wind direction. We need typically average values and local extremes (low and high velocities and pressures). High wind pressure exceeds the ventilation function and regulation is needed, low wind pressure stops ventilation.

Measurement in a real building

Design conditions and the cause of systems failure were already measured in previous studies. Wind velocity measurement was realised in the area where the building was built. Data set was use for a local condition analysis. But data set analysis is really difficult and a correct interpretation is problematic [1].
Real measurement is typically realised with plate or membrane pressure indicators. Plate indicators are put to the building façade and wind pressure pressing the plate. Membrane bending is measured in membrane indicators. These indicators are convenient for extreme pressure measurement in particular.



a) b)

Figure 1. a) Model scheme of the Faculty and connected buildings, b) Faculty of Civil Engineering model with wind velocity in the roof layer (wind angle 0 - perpendicular to the wind direction)

Computer simulation

Computational fluid dynamics (CFD) provides an alternative approach to calculate ventilation and airflow distributions around buildings. Computer simulation substitute real measurement and save time in this field of study. The most problematic situations can be defined and modelled later in a wind tunnel with better accuracy. CFD models comparison with experimental measurement was compared in previous studies [2]. Experimental 2D model with one side ventilation was compared as the example.
The most common CFD method is Reynolds averaged Navier–Stokes (RANS) method. The method is relatively fast but there can be a problem with a turbulent region around the building especially around the roof. The better method is Large-eddy simulation (LES) which

separates flows into large eddies and small eddies and computes it separately with different methods.

Measurement on building model

Measurement on building model in the wind tunnel is more precise than real measurements. Air flow around the building, pressure on the building façade, flow trajectories can be measured with different wind velocities and azimuth.

The Aeronautical Research and Test Institute (VZLU) boundary layer wind tunnel was used for this measurement. Urban, suburban or plain terrain can be simulated and vertical wind profile can be modified.

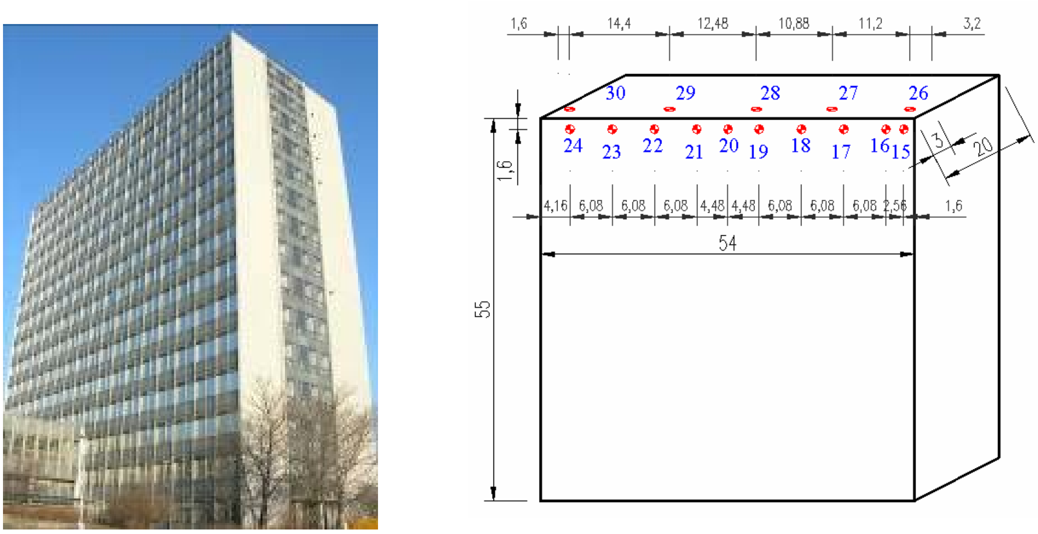


Figure 2. a) Faculty of Civil Engineering, b) The building model with measuring points (dimensions on real building)

A wind effect is determined by a wind velocity and wind direction, time dependence is according to a boundary layer scale. Meteorological effects in large scales are disturbing. That is reason why experimental measurement in the full scale is problematic (dates, intervals). Experimental measurement in the laboratory is time constant and repeatable. Models with complicated geometry and surrounding conditions can be measured too.

RESULTS

Study of the ventilation system performance needs detailed airflow information around and inside the building. The velocity and pressure distributions can be used to determine the ventilation rate.

The measurement was done in boundary layer wind tunnel in Prague. The model was in the scale 1:320 and in different configuration with changeable parapet high on the flat roof. This scale was convenient to model changes (surrounding building), the boundary layer wind tunnel dimension and profile. The real building is a rectangular 15-floor building. Building substructure is connected to surrounding buildings. The wind direction was changed with step 30°.

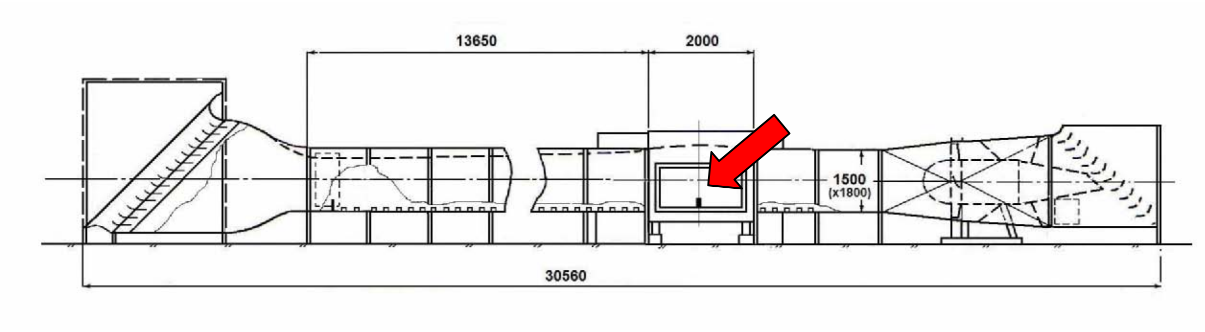


Figure 3. a) The Boundary layer wind tunnel (The Aeronautical Research and Test Institute in Prague) with marked model position

The principle of measurement uses an analogy between a model and a building with given boundary conditions.

Table 1. Measuring points and data set example (angle 0)

Measuring points	15	16	17	18	19	20
Average pressure [Pa]	30,9	42,9	43,4	41,78	41,68	42,27
Standard deviation [Pa]	23,5	22,5	22,3	21,72	19,74	21,75
Pressure coefficient c_{pi}	0,34	0,48	0,48	0,46	0,46	0,47

The measurement was done in the wind tunnel with three different wind velocities in 64 points on the model surface. Wind pressure in the building envelope was measured. The wind vertical profile corresponds to a sub-urban terrain (roughness length is 0,65mm, a suburban roughness). Dynamic pressure is 56,9 Pa in the model roof layer. The pressure was measured by Prandtl probe.
These pressure differences corresponds to the method of unit-less pressure coefficients c_{pi}.

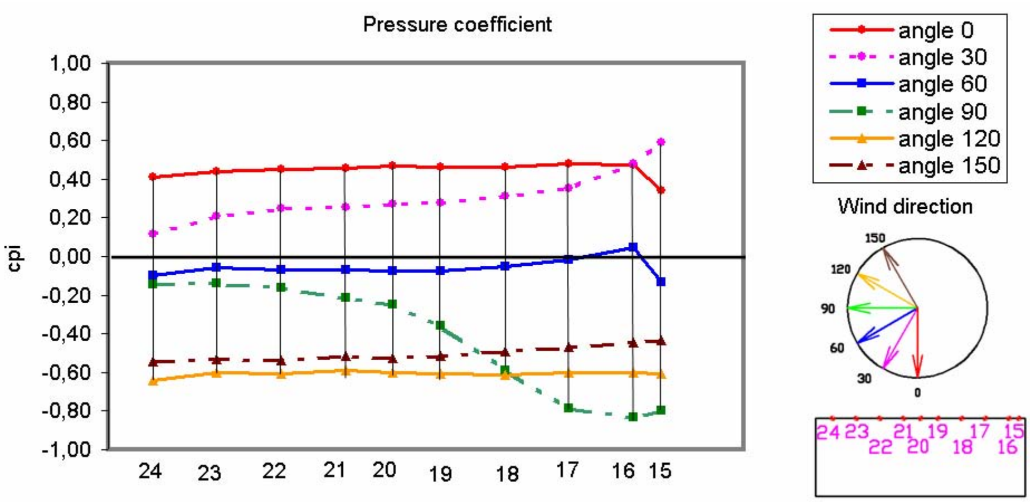


Figure 4. Pressure coefficients (without parapet) 1,6m below the roof layer

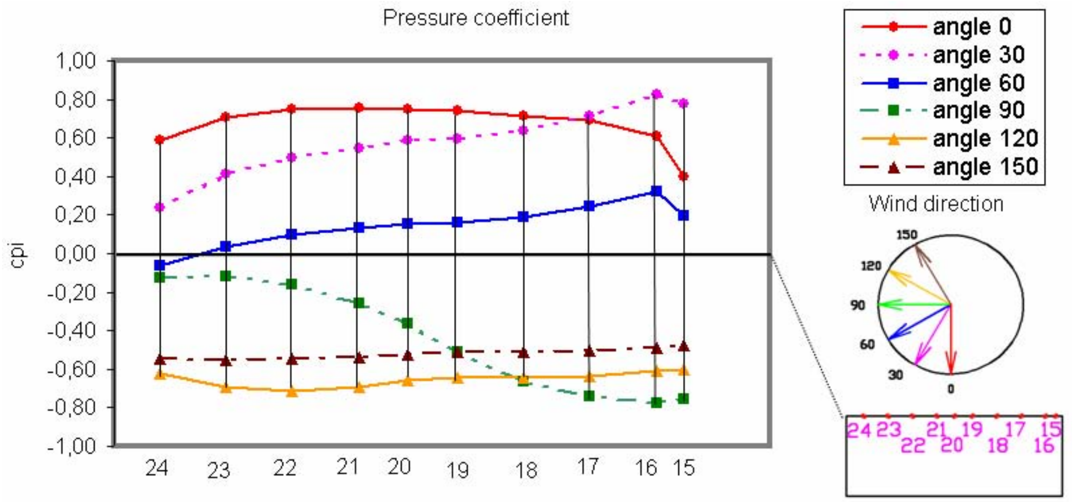


Figure 5. Pressure coefficients (parapet 3,5m) 1,6m below the roof layer

Results from the top part of windward façade (points 15-24) and the roof (points 26-30) are presented.

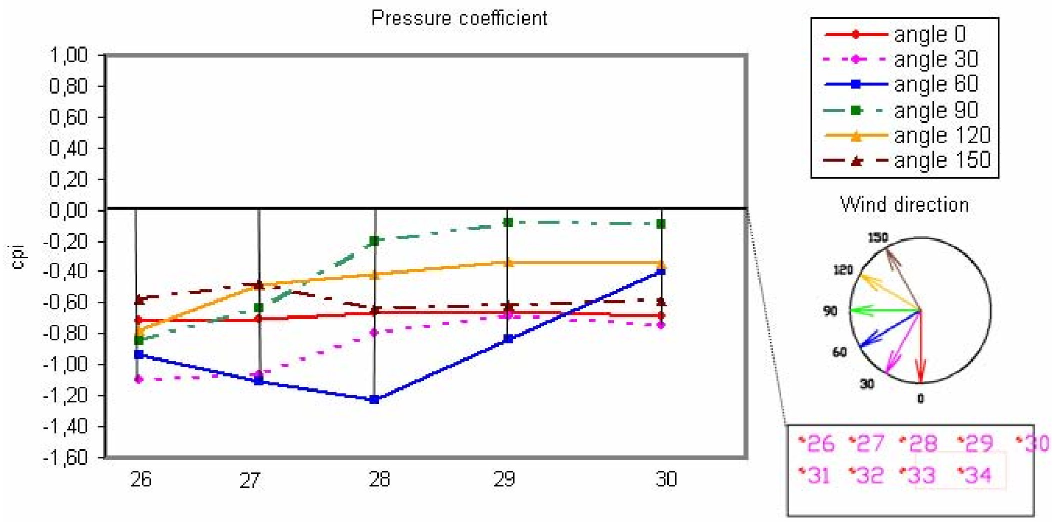


Figure 6. Pressure coefficients (without parapet) on the roof

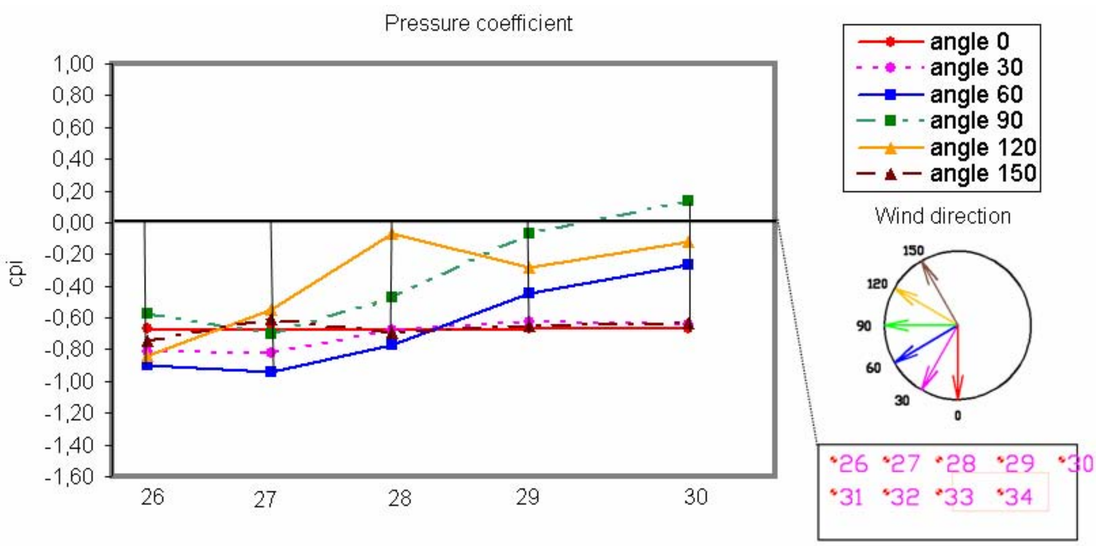


Figure 7. Pressure coefficients (parapet 3,5m) on the roof

The data set was recorded with frequency 10000 s^{-1} and was compared statistically. Average pressures, standard deviations and pressure coefficients cp were recalculated.
The coefficient c_{pi} may be recalculated to different conditions than those used during measurement.

$$c_{pi} = \frac{p_i - p_{ref}}{\frac{1}{2} \cdot r \cdot U_{ref}^2} \qquad (1)$$

Where p_i is pressure [Pa], p_{ref} is reference pressure [Pa] (roof layer), ρ is density [$kg \cdot m^{-3}$] and U_{ref} is reference velocity [$m.s^{-1}$]-air velocity in the roof layer.

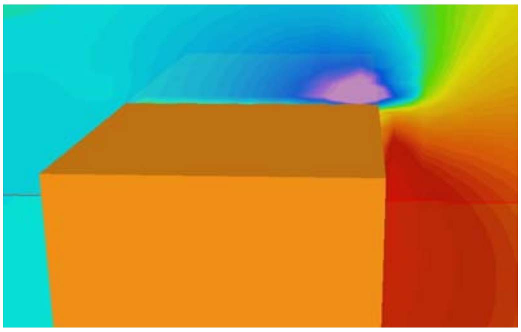
CFD simulation

ENVI-MET models

Software ENVI-MET is specialised software for external condition calculations. Surface parameters can be specified, different terrain properties may be applied. Building shapes are limited by rectangles. The exacting character of calculation demands time; the other disadvantage is interface. Boundary conditions are relatively simple.

FLOVENT models

Commercial CFD software is convenient for complicated situations. The wind profile can be specified (or set up) by vertical separation to layers with constant parameters. But the wind profile was not disturbed by a built up area.



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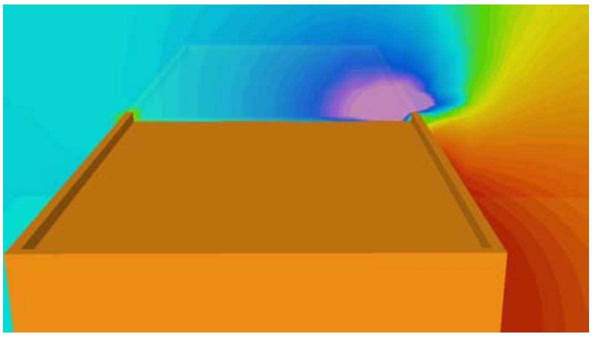

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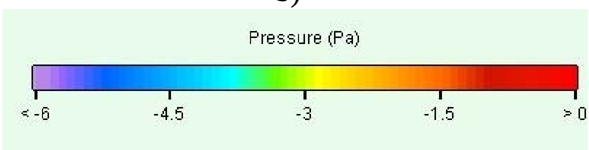

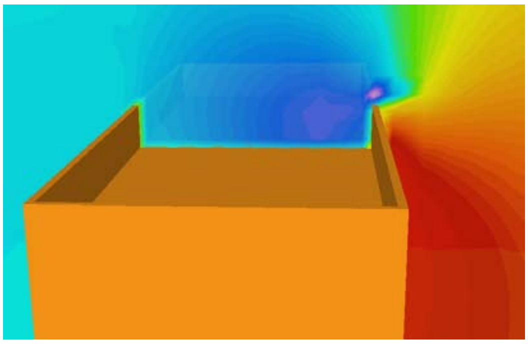

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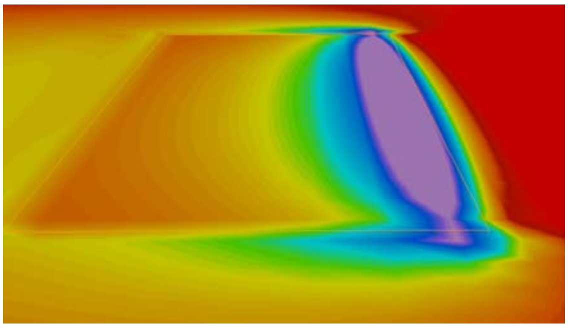
Figure 8. Pressure field in vertical section (wind angle 0) a) Building without parapet b) Building with parapet 0,6 m c) Building with parapet 3,5 m Flovent 6.1



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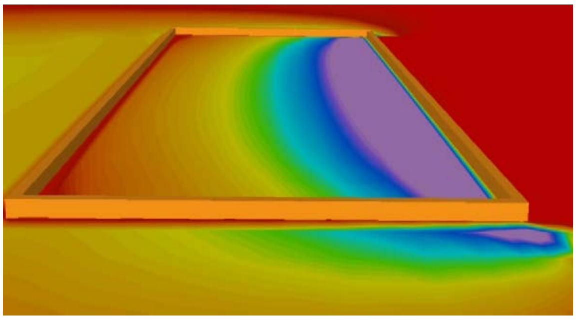

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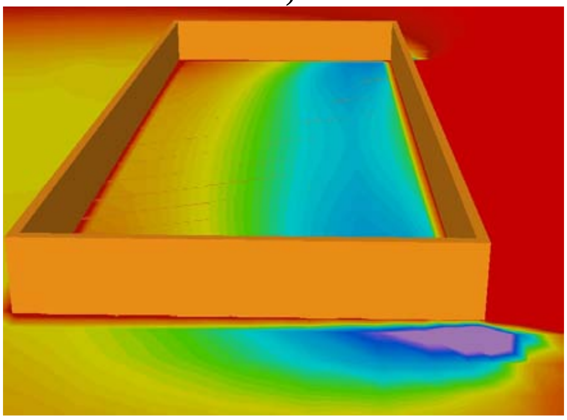

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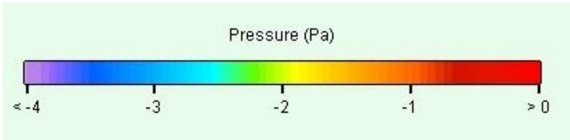

Figure 9. Pressure field in horizontal section – roof surface (wind angle 0) a) Building without parapet b) Building with parapet 0,6 m
c) Building with parapet 3,5 m
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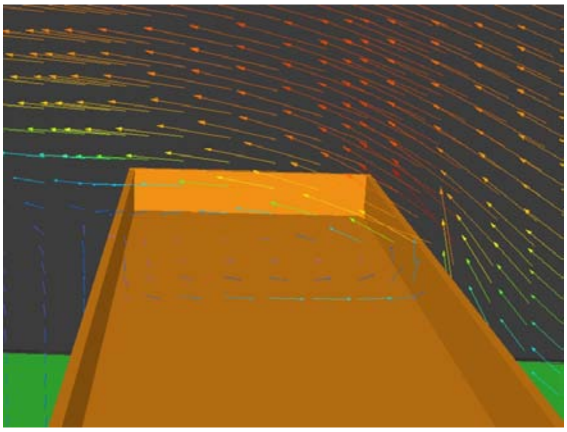
Characteristic airflow around the building roof was assessed (Fig. 9, 10). The reverse air flow arises in case of building with high parapet above the roof area (Fig.11).



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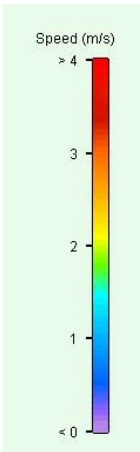

Figure 10. Velocity vectors around the building parapet (3,5m) (wind angle 0) a) Flovent 6.1

DISCUSSION

The air flow around a building surface and the influence on a ventilation system is relatively complicated. Even though simple flow can be determined by CFD simulation, the experimental measurement in the boundary layer wind tunnel must be done in case of detail investigation or complicated situation. The investigation results show that the higher parapet on the model induces higher pressure in the top part of building windward façade (the highest floor level).

The pressure influence on the roof surface with height of the roof parapets modification shows that smaller parapet increases negative pressure on the windward roof area. Higher parapet clams the reverse air flow close the roof surface. The reverse air flow can cause ventilation system failure especially if the input and exhaust is situated on the building roof. The air mixing risk is in this space. Building parapet with lower height (0,5-1,5m) is convenient for natural or hybrid ventilation exhausts – the wind support is the highest in windward part of the roof.

ACKNOWLEDGEMENT

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