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EXPERIMENTAL INVESTIGATION OF PEDESTRIAN LEVEL WINDS USING MULTIPLE MEASURING METHODS

D. Zacho*, P. Michálek*

Abstract: *In the project, methods for the pedestrian wind comfort determination were investigated. Few methods can be used for the qualitative and quantitative measurement of the wind condition at the pedestrian level. Pressure difference measurement by the omnidirectional Irwin probes, the Particle Image Velocimetry, the Hot wire anemometry, flow visualization by a little flags, sand spreading on surface around the building model, were used during solving this project. The Irwin probes are most frequently used for the pedestrian wind comfort measurement. The velocity calibration of the Irwin probe isn't trivial so other methods were used for its verification. In this contribution the comparison of all mentioned methods was described.*

Keywords: ***Pedestrian, pedestrian wind comfort, boundary layer wind tunnel, particle image velocimetry, environment, physical modeling.***

1 Introduction

The monitoring of the wind conditions at pedestrian level is very interesting topic for Central Europe. The criteria of the pedestrian wind comfort were set in countries with strong wind exposition (Nederland, Denmark, Great Britain, France, USA, Japan, …) first.

The expansion of the high-rise building development in Czech city centers needs the prediction of the pedestrian wind condition and it could be interesting for the Civil service of the Czech Republic. The High rise building can greatly affect the wind condition at the pedestrian level. Windy quiet rest area could be affected by the wind generated by new High-rise building. Such area would be good just for kiteflying.

The forecast of the wind condition at the pedestrian level can be done by the methods of physical or mathematical modeling of the atmospheric boundary layer. The physical modeling includes quantitative and qualitative methods. The qualitative method is for example visualization by the sand, small paper flags, cotton fibers, oil coating etc. The quantitative methods are the hot wire anemometry at the position, Particle image velocimetry (time resolved PIV), pressure measurement with the Irwin probes, measurement with the thermistors at the positions etc.

In case of the complicated topographic model, using few methods for the prediction of the pedestrian wind comfort is suitable. For example, visualization by sending or small paper flags, hot wire anemometry, and PIV in the area of interest.

The results of the pedestrian wind comfort prediction can use for the planning authority when they have to approve new project of high-rise building in the city centre for example.

2 Methods of the pedestrian wind conditions monitoring

The qualitative methods give information about the wind direction in the parter of the complex of building and the quantitative methods can give information about the wind speed and the wind speed fluctuation at the monitored positions. The pedestrian wind comfort is assessed in accordance with the criteria which were developed for the specific locality (Nederland, Denmark, USA, ...). The criteria

* Mgr. David Zacho: Výzkumný a zkušební letecký ústav, a.s., Beranových 130; 199 05, Prague; CZ, e-mail: zacho@vzlu.cz

* Ing. Petr Michálek, Ph.D.: Výzkumný a zkušební letecký ústav, a.s., Beranových 130; 199 05, Prague; CZ, e-mail: michalek@vzlu.cz

were made on base of subjective feelings of people which were surveyed by questionnaires. Unfortunately the criteria of the pedestrian wind comfort are absent for Central Europe.

2.1 Visualization by cotton fiber or small paper flags

This method is focused on the wind direction determination and depiction of the uniformity of the flow at the monitored positions. The cotton or the flags are put in surrounding of the high-rise building models. The cotton or the flags can rotate around its vertical axes. Into the model with cotton or flags the atmospheric boundary layer comes and the cotton or flags follow the wind with its gusts. The cotton or flags can be photographed with different shooter speed or with high speed camera. The resulting image of the flow field around the buildings model can be seen immediately after capturing of the photos or videos.

2.2 Visualization by sanding

The Vicinity of the building model or of the complex of buildings is filled with the sanding (pollen, small-grained sand ...) in uniform and thin layer. Then the modeled situation is exposed to the wind with the atmospheric boundary layer conditions with constant wind speed above the boundary layer. The building or complex of buildings forms the wind at the pedestrian level and the sending is swept from areas with the intensifying wind speed. If the wind speeds above the boundary layers increase the sanding will be swept over largest areas then before. If the photos will be taken there the maps of the sanding in different increasing wind speed there could make the sum of all pictures and there the map of the wind situation at pedestrian level in vicinity of the observe building or complex of building can be obtained.

2.3 The Hot Wire Anemometry

This method makes determining the field of the wind speed around the building model possible. It is standard method of anemometry which determining the mean velocity and the fluctuation part of the turbulent wind speed enables. The hot wire probes have high sensitivity to the wind direction. The building or complex of buildings is able to generate wind which direction can be each of 360 degrees with the same probability. There is need to determine the wind direction before the measurement with the hot wire. It could be disadvantage of using this method for the pedestrian level wind assessment.

2.4 Irwin probes

The Irwin probes (IP) and their physics are described in article H. P. A. H. Irwin, 1981. The IP is the omnidirectional pressure probe which consists from two small tubes with same longitudinal axis. The outer tube is mounted as at the same level as surrounding surface of the model and inner tube is placed at the pedestrian height (the body height or the centre of human body height). The pressure signal is connected with the wind speed by the hot wire anemometry. The mean value and the standard deviation of the wind speed signal as wrote Irwin can be reconstructed. This probe works good if the wind comes perpendicular with the axis of the IP tubes. General situation around building includes also vertical movement of the air mass. It could be the disadvantage of this method.

2.5 Particle Image Velocimetry measurement

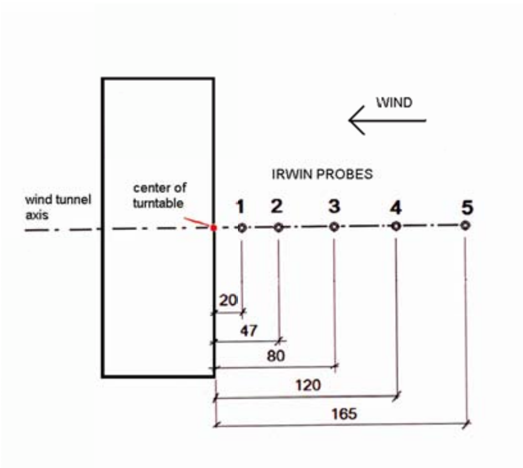
The PIV system makes possible showing the field of wind speed. If Time resolved PIV system is used, the mean value and standard deviation of the wind speed signal at all position in the shot can be determined. The clear and concise description of the PIV principle can be found at the Dantec dynamics web page for example. Extensive description of the PIV is in the Raffel, M. & Hansen, S. (2007). The wind flow is filled with particles with diameter about two micrometers and the light sheet is placed at the monitored area. The pictures of the particles in the light sheet in exactly time distance are taken. The correlation between two images gives information about shift of particles in subsection parts of full shot. The known time and the known shift of the particles between two pictures give information about size and direction of the wind velocity vector.

This method depends on quantity of particles in the monitored area and on the light sheet position. If there is complicated geometry of the building model or the complex of buildings model there could be problem with the light sheet setting. It could be disadvantage of the use of the PIV method for the pedestrian wind comfort assessment.

3 Results

This article describes the result of few experiments and measurement which were performed in Boundary Layer Wind Tunnel (BLWT) in Výzkumný a zkušební letecký ústav, s.s. (VZLU). Simulation of the atmospheric boundary layer in BLWT VZLU is correct and its similarity with real atmospheric boundary layer is in scale approximately 1:350. Simulation of the III. category of terrain as it is prescribed in codes (EUROCOD, Czech standard, ...) was used. The models of building were made in 1:350 scale and it guarantees the geometric similarity of this physical modeling.

The typical problem of the high rise building and its influence to the pedestrian wind comfort was chosen. It is the DownWash (DW) effect. It means that the high-rise building give a direction to the wind from higher part of the atmosphere and the wind blow down along the building envelope. The higher mean wind speed and strong wind gust is coming into the pedestrian level around the high-rise building. It is strongly unfavorable influence of the high-rise building on the pedestrian wind comfort.



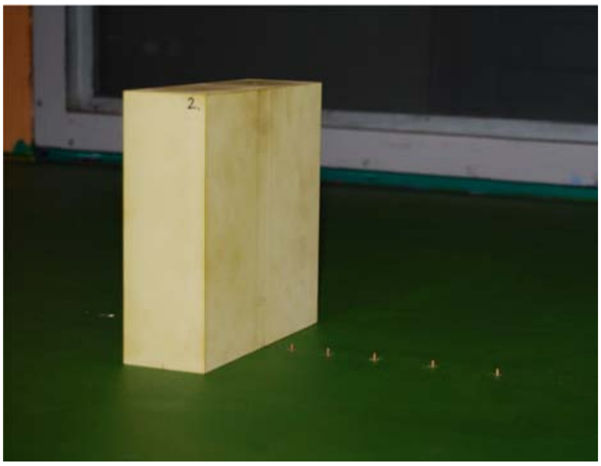


Fig. 1 & Fig 2: Experimental settings, downwash measurement.

The building of Faculty of civil engineering CVUT in Prague was chosen as the common building. Just high-rise part of the building was modeled. The model had dimensions 175 mm high, 175 wide and 55 mm depth. The position of the measurement point is labeled as ratio between distance of the point from the foot of the building and the height of the building (Fig. 1 & Fig. 2).

All tasks which were made during this work were focused on the comparison of various methods of the pedestrian wind condition determination. Specifying methodology for the pedestrian comfort assessment was the aim. It is very complex problem and using just one method isn't possible. It needs combination of visualization and measurement methods.

Literature shows the IP as good tool for this measurement so it was chosen as main probe for the pedestrian wind measurement. The calibration of the IP is realized on base of HWA. The Hot wire probe has strong sensitivity to the wind direction so the visualization with small paper flags at the IP positions was performed. Fig 3 shows position with clear wind direction and without it.

The calibration constants as it is required in the Irwin article were calculate from the pressure signal on IP 5 and the flow speed signal from HWA which was measured above the IP 5 position.

The wind speeds from IP measurement and from the HWA measurement at all points are compared in Fig. 7.

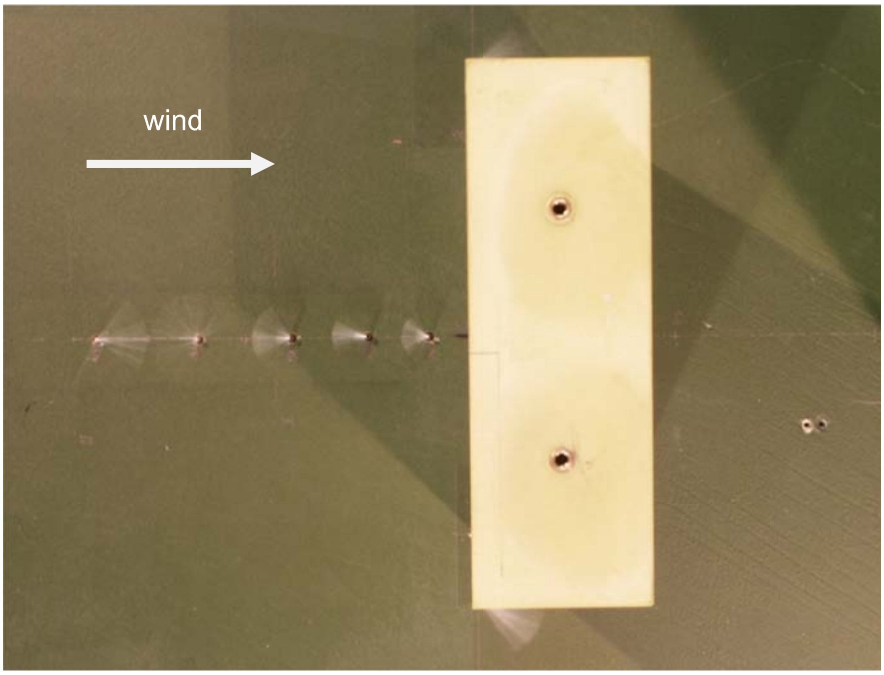


Fig. 3: Visualization of the wind flow by the paper flags.

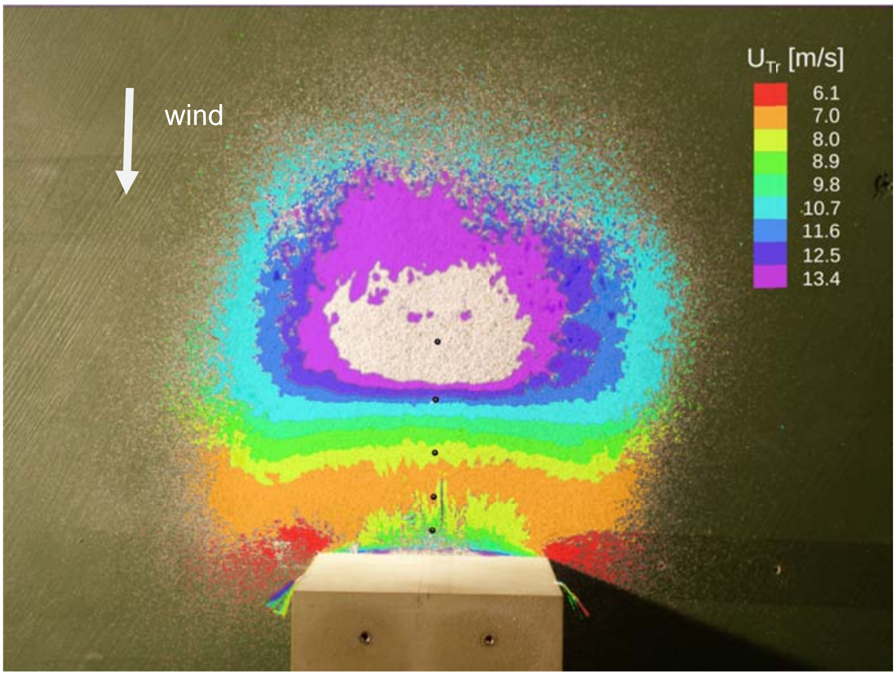


Fig. 4: Suma of nine digital pictures of the sending visualization method.

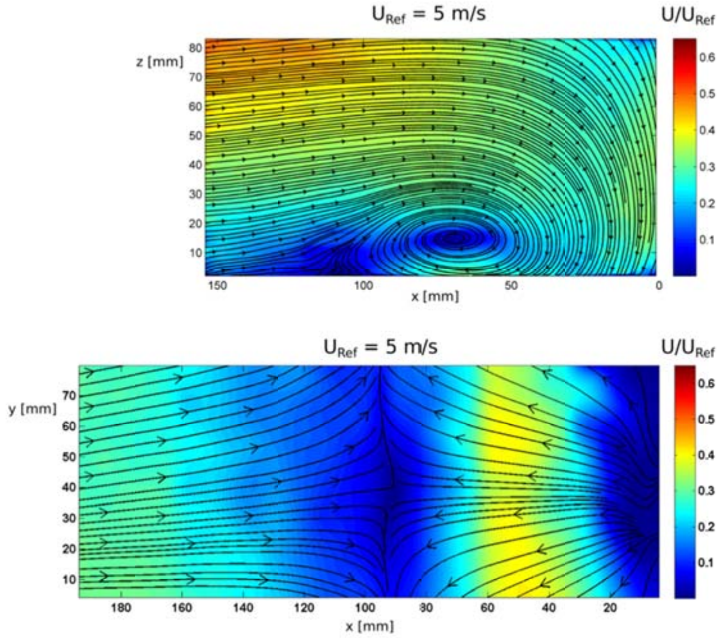


Fig. 5: Flow field in downwash effect in front of the building.

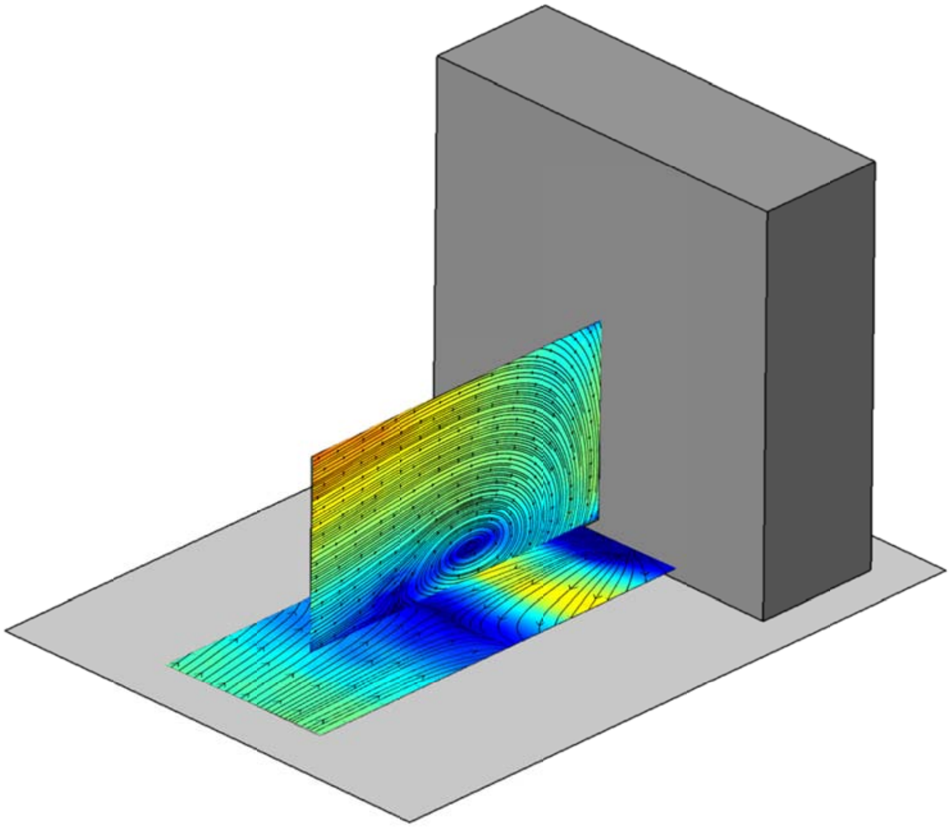


Fig. 6: The PIV results at the sagittal and the transversal plane.

The visualization by sanding method was used for the estimation of the flow field around the building. It is effective method, but the results depend on the weight of the sanding material and on the thickness of the sanding layer. The IP, HWA or PIV measurement are performed at the height of pedestrian but the sending is much smaller. But this method can show the areas around the building with strong wind exposure. The digital photography of the sequential swept of the sanding could be processed and the result of the digital image processing is on Fig. 4. The colors of the Fig. 4 represent bare areas which were bared at constant wind speed above the boundary layer. White color is the color of the sanding (the silica sand was used). The stagnation area is visible around the IP 5.

The PIV method is very effective visualization and measurement method for showing of the flow field in the monitored area. The Time Resolved PIV method was used with the 150 frames per second of the shooting frequency. Three thousand double frames were taken. It is enough long signal for the statistical analysis of the wind speed signal.

The comparison of the results from quantitative measurement methods is shown in Fig. 7. On horizontal axis is the ratio between the distance of the IP from foot of the building and the height of the modelled building. On vertical axis, there is the ratio between the wind speed which was measured at the monitored measurement point and the reference wind speed which was measured at the level which corresponds 10 m level in full scale. The relevant are: compressions of the IP and PIV measurement (methods which show the length of the velocity vector) and the HWA and PIV-U measurement (methods which show longitudinal part of the velocity vector).

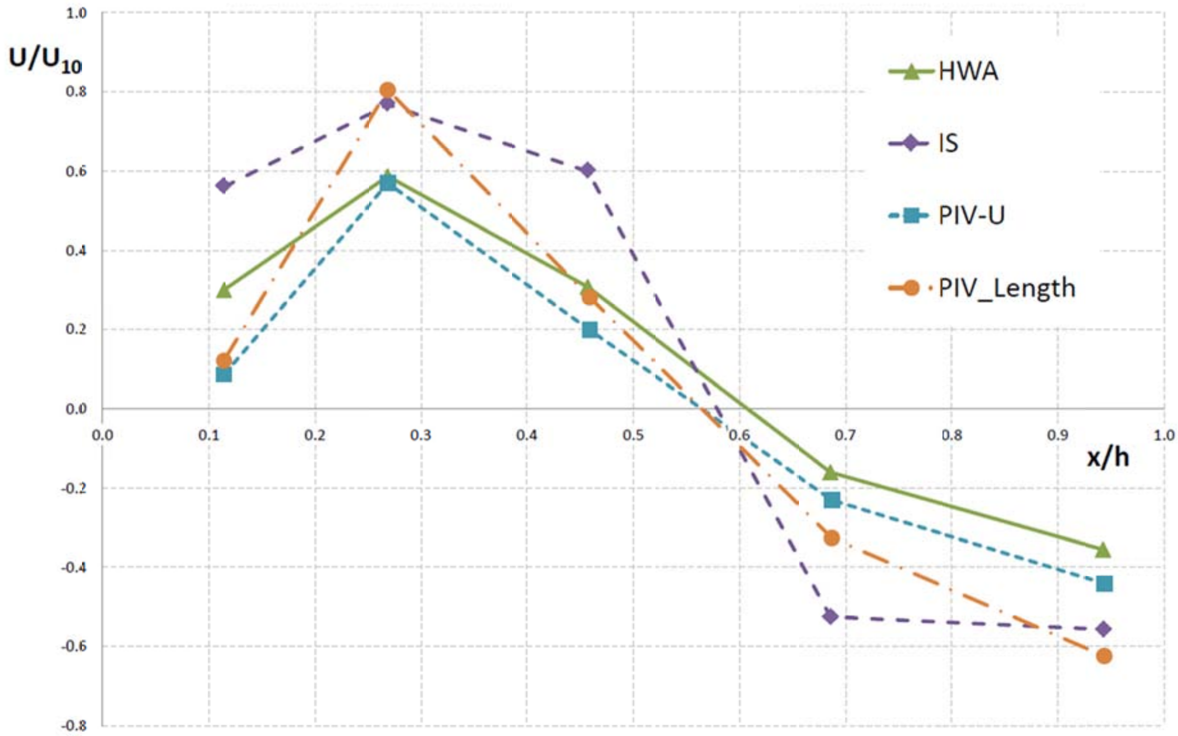


Fig. 7: Graph of the pedestrian wind measurement.

4 Conclusions

Correct prediction of the wind conditions at the pedestrian level around the new high-rise building can be created on base of combination of few methods of measurement and visualization.

Combination of the visualization with small paper flags and IP is the simplest one and this combination can be used in many positions in the model irrespective complexity of geometry modeled built-up area.

Time resolved PIV system could be very effective for the pedestrian wind comfort assessment. The setting of the PIV measurement (positioning of the light sheet) could be very expensive at the complicate geometry of the model.

The suitable solution of the pedestrian wind comfort assessment is the using of combination of methods mentioned above. The visualization can show areas with strong wind exposition and there measurements with the HWA or PIV can be performed. These case studies of the pedestrian wind comfort have to be carry out with consideration to effective employment of means.

Acknowledgement

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