EPJ Web of Conferences **180**, 02029 (2018) https://doi.org/10.1051/epjconf/201818002029
*EFM 2017*

# Flow Dynamics in the Vicinity of Tandem Buildings

*Renata* Gnatowska[1,*], *Radka* Kellnerová[2], and *Václav* Uruba[2,3]

[1]Czestochowa University of Technology, Faculty of Mechanical Engineering and Computer Science, 21 Armii Krajowej Av, 42-200 Czestochowa, Poland
[2]Institute of Thermomechanics, ASCR, v.v.i., Dolejškova 5, Praha 8, CR
[3]UWB, Faculty of Mechanical Engineering, Department of Power System Engineering, Universitní 8, Plzeň, CR

**Abstract.** The flow-field in the vicinity of tandem building model in a wind tunnel will be subjected to analysis of dynamics. The model is 3D consisting of the two blocks of different sizes arranged in a streamwise direction. Experiments were performed using time-resolved PIV technique in several measuring planes to capture both spatial and dynamical features.

## 1 Introduction

With increasing urbanization and density of population, the understanding of the problem of flow fields in urban environments and microclimate becomes more important. Increased interest in has been observed over the past few decades. It is governed by potential applications of the results in the design process of new buildings as well as optimization of the existing urban areas and city centres. Nowadays, this issue plays an important role in environmental protection, it concerns in particular the so called wind comfort around and between buildings, the life quality in urban areas as well as specific economic aspects of utilization of the defined zones. The studies of the wind environment around buildings are generally performed as wind tunnel experiments since it is the most well-established way to simulate a natural wind. Wind-tunnel measurements are performed with low-cost techniques such as hot-wire or hot-film anemometry (HWA or HFA) (e.g. Refs. [1-6]. Particle Image Velocimetry (PIV) is less often used because it is more elaborate and more expensive [7-8].

The objective of this paper is to provide a detailed experimental analysis of the flow interactions of buildings models situated one after another in a so-called tandem arrangement. The main aim is to clarify the flow field, found in the experiment performed using time-resolved PIV technique in several measuring planes to capture both spatial and dynamical features.

## 2 Experimental setup

The experiment with Particle Image Velocimetry (PIV) technics was carried out in the open-circuit wind tunnel at the Institute of Thermomechanics of the Academy of Sciences of the Czech Republic.

The analysed configuration of building models was located within ground boundary layer generated by the facility output from the contraction nozzle of a cross section of 250 x 250 mm. The test section of the wind tunnel is 3 m long, the measurements were performed in the central part of the tunnel. The SAFEX fog generator has been used to seed particles.

The laser beam from a dual-head Nd:YLF laser with a pulse energy of 10mJ at 1kHz illuminated the particles. Dantec CCD camera (SpeedSense 611) was used to capture pairs of particle images at a frame rate of 1 kHz, 4000 snapshots representing 4 s of real-time. The PIV measurements provided the velocity vector field with two velocity components (U and V) in the measuring plane of symmetry (XY) – see Fig. 1.

The research object represents the arrangement of two buildings modelled as rectangular of square base (0.025 m) and different heights settled in the flow domain. As depicted in Fig. 1, the height ratio of the buildings models is 0.6 and the distance between them is set to 1.5 of the length of the cuboid base side. The inflow boundary layer has been prescribed according to the equation (1).

$$U(y) = U(\delta)(y/\delta)^{\alpha} \qquad (1)$$

where:
$\alpha$ – terrain type factor,
$\delta$ – thickness of the ground layer.
The parameters chosen for the research were as follows: $\alpha = 0.15$ (suburban boundary layer), $\delta = 0.05$ m and $U(\delta) = 11$ m/s.

The same geometry has been studied in [8], however only the time-mean structure has been studied. In the presented study the space between the buildings has been subjected to analysis of the flow dynamics.

## 3 Results

The acquired vector fields were analysed using standard methods. First, classical statistical methods have been applied, then, to study dynamics of the flow-field, the POD method has been used as shown in [9].

---

[*] Corresponding author: gnatowska@imc.pcz.pl

## 3.1 Statistical analysis

The distributions of various statistical quantities will be represented in non-dimensional form, the reference velocity $U_{ref}$ was the velocity outside the boundary layer in the region just upstream the models at X = 0. The spatial coordinates X and Y were related to the buildings dimension D. In the measuring plane Z = 0.

In all figures to be presented in this chapter the vector-lines derived from the time-mean velocity field are added. Flow comes from left.

In Fig. 2 distribution of the streamwise mean velocity component $U_{mean}$, which is the component in X direction, is shown.

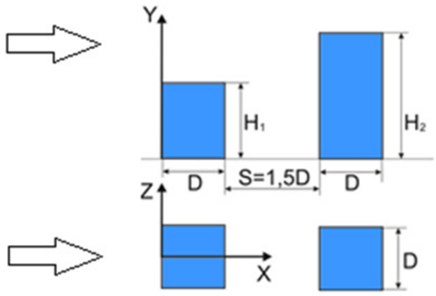

**Fig. 1.** The research object ($H_1$ = 0.03 m, $H_2$ = 0.05 m, D = 0.025 m).

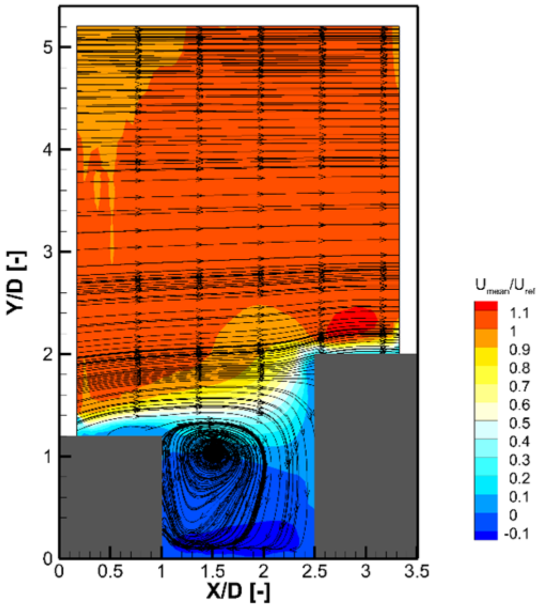

**Fig. 2.** Distribution of the streamwise velocity component $U_{mean}$.

The result shows not perturbed flow above the buildings, while in the space between the buildings a very strong vortex takes place, however the mean streamwise velocity component is quite small, positive or negative. The negative value means local backflow located close to the space between buildings bottom.

The vertical (direction of Y-axis) mean velocity component $W_{mean}$ distribution in Fig. 3 reveals strong downward flow region along the higher building windward wall, while the ascending leg behind the smaller building is considerably weaker. This fact indicates the strong 3D structure of the flow in this region with the important mean velocity component in the out-of-plane direction Z. However, of course not precisely in the plane of symmetry, but close to it. This result is supported by data presented in [8].

The dynamical activity could be quantified by means of the turbulent kinetic energy TKE, however in this case, only two velocity components are taken into account (X and Y directions). The distribution of the TKE is shown in Fig. 4.

Turbulence activity in the main flow above the buildings is relatively very low, as expected. Maximum of the TKE is located within the free shear layer above the smaller building roof and in the descending flow in front of the higher leeward building. However reaching the floor between the buildings calms the turbulence. Note also that very close to the windward wall of the higher building very week turbulent activity is detected, seems to be damped by interaction with the wall.

Evaluation of turbulence production is demonstrated using the velocity components covariance. In Fig. 5 distribution of the covariance of the in-plane X and Y velocity components is shown, normalized again using the $U_{ref}$.

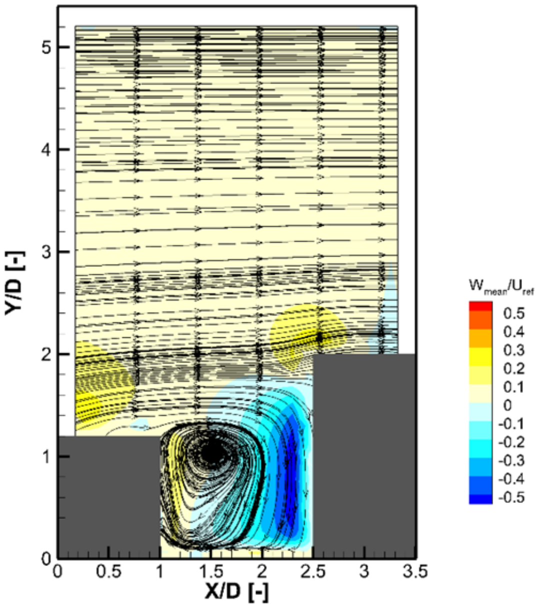

**Fig. 3.** Distribution of the vertical velocity component $W_{mean}$.

The physical interpretation of the velocity components covariance is the production of turbulence in regions of negative value, while positive value has no straightforward interpretation. The strong covariance negative region has been detected within the free shear layer above the smaller building roof, little upstream the location where the maximum of TKE is indicated (compare with Fig. 4).

## 3.2 Dynamical analysis

The spatial aspects of the flow dynamics have been studied using the Proper Orthogonal Decomposition (POD).

Multi-point velocity data from PIV allows us to use the POD for detection of large organised structures in the flow. The POD is actually interpreted as a re-expression of original data into new basis. The basis is chosen to emphasize turbulent kinetic energy (TKE). We applied a 'snapshot' modification, published by Sirovich (1987) [10], which is not so computationally demanding compared to the classic POD.

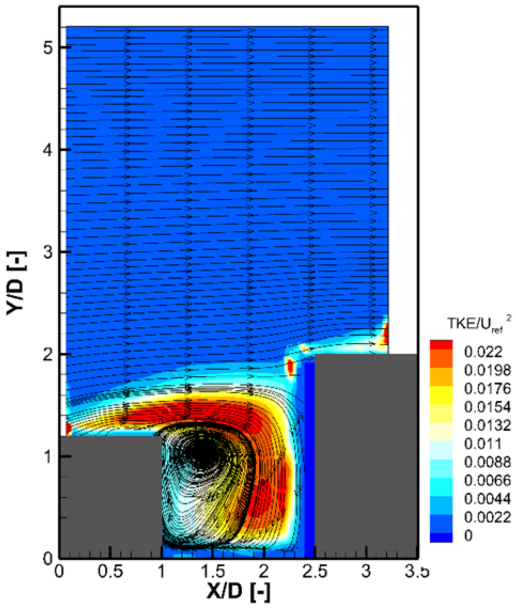

**Fig. 4.** Distribution of the turbulent kinetic energy.

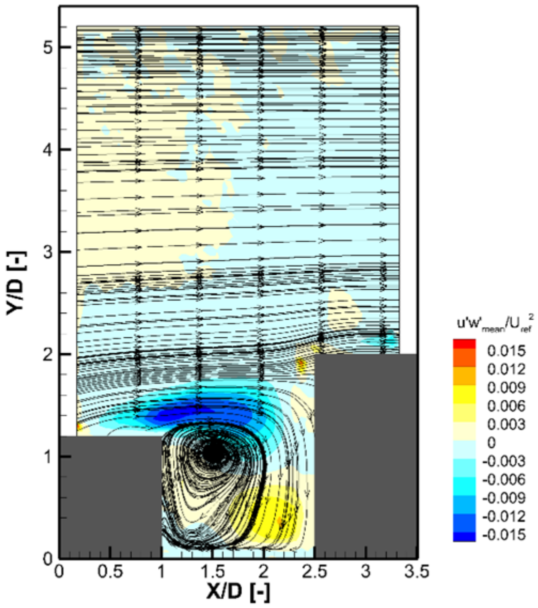

**Fig. 5.** Distribution of the covariance of in-plane velocity components.

Based on TKE, we are able to obtain spatial information about the most dominant TKE modes in the flow. Further, the speed of a convergence of the cumulative contribution from particular modes to the total TKE reveals how organised the flow is.

The calculation involves two velocity components, longitudinal U in the streamwise X direction and vertical W in wall-normal (Y) direction.

POD yields an eigenvalue for each mode. We can arrange numerically the eigenvalues from the largest one downwards. If we calculate contribution of particular eigenvalue to the total sum, we obtain its fractional the contribution to the entire TKE contained in the flow. The plot of relative and cumulative contributions from each mode can be seen in Fig. 6.

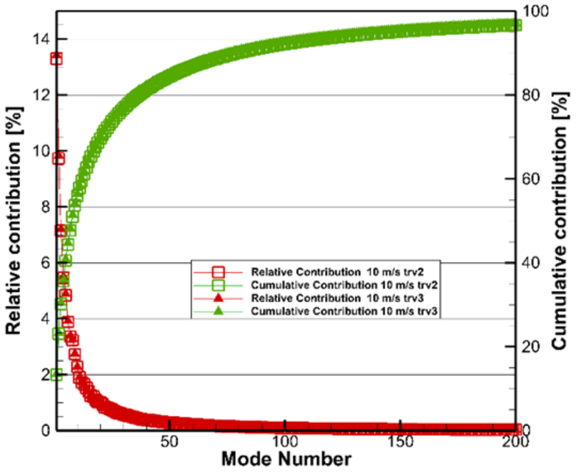

**Fig. 6.** Relative and cumulative contribution to the TKE from each mode.

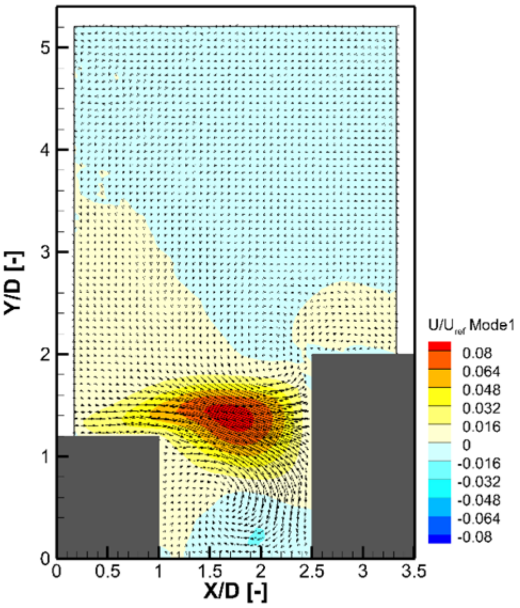

**Fig. 7.** The first POD mode topology, vector field with streamwise velocity component distribution.

The afore-mentioned first three modes contain 13%, 10% and 7% of TKE respectively.

To show the POD modes the vector fields could be used. As an example, the first POD mode is shown in Fig. 7, together with the distribution of the streamwise velocity component.

However in the vector field in Fig. 7 the vortical structures are not very clear. To represent the POD modes better the vector-lines were added. In Fig. 8 the first three modes most energetic for longitudinal velocity are depicted by contour-lines from left to right, respectively. The second row represents the three modes for wall-normal velocity.

Figure 8 reveals that the most dominant structure is the large vortex between the buildings and small vortex with opposite orientation upstream of the higher building present in the first POD mode. Below the large vortex, there is a jet-flow penetrating the space between the buildings. The second mode shows similar large vortex between buildings accompanied by weaker one below, within the gap between the buildings. In this mode, the other couple of small whirls was detected sitting below and above the leeward bigger building higher corner. The third mode has the similar structure as the first mode except for the structure of the orientation of the flow above the buildings.

The flow dynamics could be characterized by the system of vortices located between the buildings and close to the upper part of the downstream bigger building. This vortical unsteady behaviour will influence possible forced diffusion in the space between the building considerably.

## 4 Summaries

The flow structure between the tandem buildings has been studied using time-resolved PIV method in the plane of symmetry. Various vortical structures have been detected in the flow in the vicinity of the tandem buildings.

The time-mean flow-field is characterized by dominant clock-wise vortex filling the entire space between the buildings with the clock-wise orientation.

The flow dynamics in the region between the buildings is governed by smaller whirls appearing in particular close to upper part of the leeward bigger building.

This work was supported by the Grant Agency of the Czech Republic, projects No. 17-01088S and 15-18964S.

## References

1. Y. Uematsu, M. Yamada, H. Higashiyama, T. Orimo, *J. Wind Eng. Ind. Aerodyn.* **44** (1-3) 2289-2300 (1992)
2. N.J. Jamieson, P. Carpenter, P.D. Cenek, *J. Wind Eng. Ind. Aerodyn.* **44** (1-3) 2301-2312 (1992)
3. B. Blocken, T. Stathopoulos, J. Carmeliet, *J. Aerosp. Eng. - ASCE* **21** (4) 280-287 (2008)
4. A. Jarża, R. Gnatowska, *Chem Process Eng-Inz.* **27** (3/1), 721-735 (2006)
5. R. Gnatowska, *Int. J Turbo Jet. Eng.* **28** (1) 21-29 (2011)
6. R. Gnatowska, Pol J Environ Stud, 24(4), 1571-1577 (2015)
7. J.P.A.J. Van Beeck, G. Dezso, P. Planquart, *Microclimate Assessment by Sand € Erosion and Irwin Probes for Atmospheric Boundary Layer Wind Tunnels*, PHYSMOD 2009, Von Karman Institute (VKI), Sint-Genesius-Rode, Belgium, (2009)
8. R. Gnatowska, M. Sosnowski, V. Uruba, CFD modelling and PIV experimental validation of flow fields in urban environments, *E3S Web of Conferences*, **14**, 01034 (2017)
9. V. Uruba, Decomposition methods in turbulent research, EFM11, *EPJ Web of Conferences*, **25** 01095 (2012)
10. L. Sirovich, Turbulence and the dynamics of coherent structures. Part I: coherent structures. *Q. Appl. Math.* , **45** (3), 561-571 (1987)

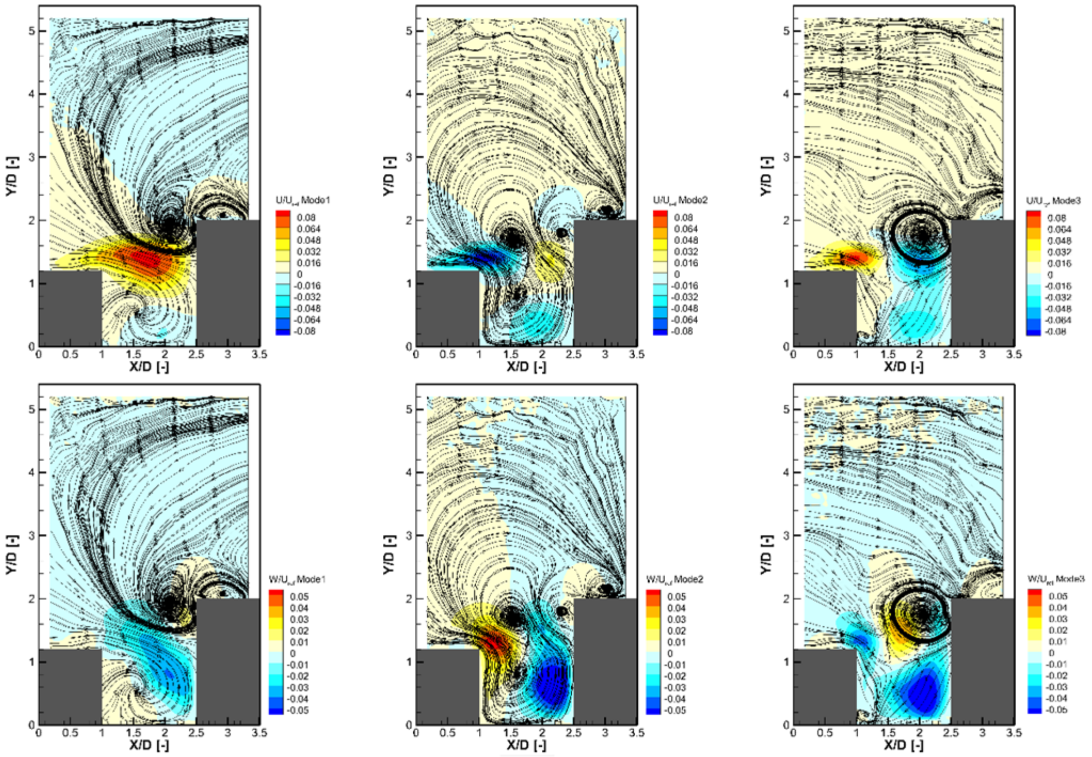

**Fig. 8.** Three POD modes between the buildings for longitudinal velocity (upper row) and wall-normal velocity (lower row).