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de Paula, Reginaldo R.C.; Stocco, Jamily F.; Föeger, Lizandra B.; Cezana, Fernanda C.; Goulart, Elisa V.; Gomes, Marcos S.P.

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EXPERIMENTAL STUDIES OF THE FLOW PATTERNS IN URBAN STREET CANYONS – PART I: TALL BUILDINGS

Reginaldo R.C. de Paula[1], Jamily F. Stocco[2]; Lizandra B. Föeger[2], Fernanda C. Cezana[3], Elisa V. Goulart[3], Marcos S.P. Gomes[4]

[1]Mechanical Technical Department, Ifes, Vitoria, ES, Brazil
[2]Sanitary and Environmental Engineering Department, Ifes, Vitoria, ES, Brazil
[3] Environmental Engineering Department, Ufes, Vitoria, ES, Brazil
[4]Mechanical Engineering Department, PUC-Rio, Rio de Janeiro Brazil
e-mail: cottoreginaldo@gmail.com

ABSTRACT

The aim of this work was to understand the effect of tall buildings on vortices system in an urban region. Wind tunnel experiments with flow visualization and injection smoke techniques were carried out to analyze the flow pattern in an idealized urban region formed with six rectangular prismatic buildings. These scale model buildings (1/100) were arranged in a symmetric configuration with different aspect ratio *H*/*W*.

RESUMO

O objetivo principal deste trabalho foi analisar os efeitos que prédios altos podem causar no sistema de vórtices de uma área urbana. Foram realizados experimentos de túnel de vento com a técnica de injeção direta de fumaça para visualização do padrão do escoamento. Os modelos em escala reduzida (1/100) foram dispostos de forma simétrica em relação à rua e com diferentes espaçamentos entre eles.

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INTRODUCTION

Pollutants emitted from motor vehicles, gases from unexpected accidents and exhaust stacks, are sources of anthropogenic pollutants in urban areas. Due to their adverse effect in human health, various studies have been conducted to analyze the flow field patterns in urban areas, because ambient wind is responsible for the dispersion and transport of atmospheric pollutants. The building configurations such as street and building aspect ratios are important factors in this flow regime.

In recent years physical experiments and numerical simulation have been directed towards the study of the canyon flow regimes. Louka et al. (1998) performed field experiments to investigate the turbulent airflow in street canyons and its coupling to the turbulent airflow above roof. Yassin (2011) studied the impact of the roof profile and roof height on wind flow and vehicle exhaust within urban canyons by using the standard κ-ε turbulence model. In the present work wind tunnel experiments and flow visualization techniques were used to investigate the flow patterns in an idealized urban region.

MATERIAL AND METHODS

The flow considered in this work was investigated in an open return wind tunnel with test section (2.0 × 0.5 × 0.5) m located at Energy Laboratory of Ifes, Vitoria, Brazil. The direction of the wind was perpendicular to the surface of the obstacles. Six scale model prismatic rectangular buildings (1/100) were arranged in a symmetric configuration with three different distances between them. A smoke machine and injections methods were utilized for the flow visualization. Video recordings were made with digital camera with speed of 240 fps. A green laser (500 mW) passing through a semi-cylindrical lens was used to illuminate the vicinity of the buildings. Measurements of the velocity vertical profile of wind were obtained with a Pitot-static tube with probe of 3 mm diameter (TSI EBT720). Figure 1 shows the localization of measured wind velocities at the center line of the wind tunnel (y/H = 0.0) and on the top of buildings (y/H = 0.5). These points were represented by X_0, X_1, X_2, X_3, X_4, X_5 and X_6.

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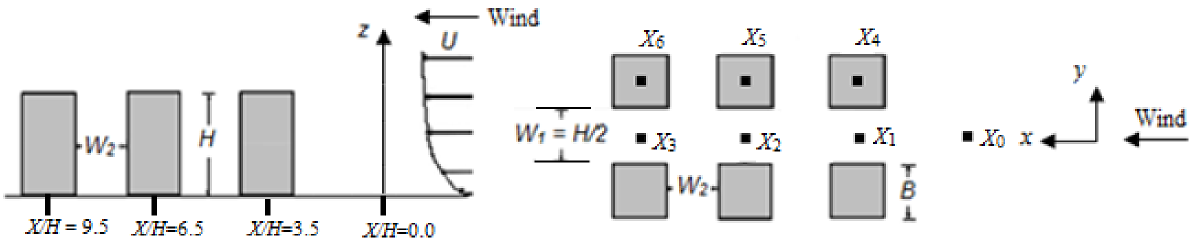
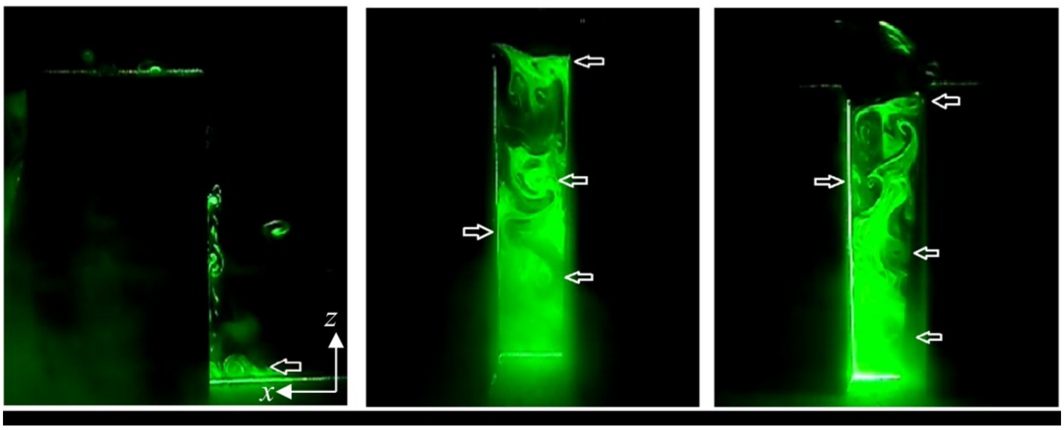


Figure 1. Schematic of urban street-canyon model arrangement with rectangular prismatic buildings and wind flow direction.

RESULTS

Figure 2 shows the flow patterns corresponding to H/W_2 = 4.0. Oncoming flow impinge on the frontal face of the first building, producing stagnation point and forming a standing vortex which was induced by flow separation, see Fig. 2(a). From the flow visualization was possible to capture the vortex-shedding phenomenon, near the top edge of the upwind building, see Fig. 2(a) and (b). Bellow the top of buildings there were generated a complex flow pattern with three dominant rotating vortex structures.



(a) (b) (c)

Figure 2. Side view $x - z$ plane at H/W_2 = 4.0: (a) flow in incident region; (b) flow between first and second buildings and (c) flow between second and third buildings.

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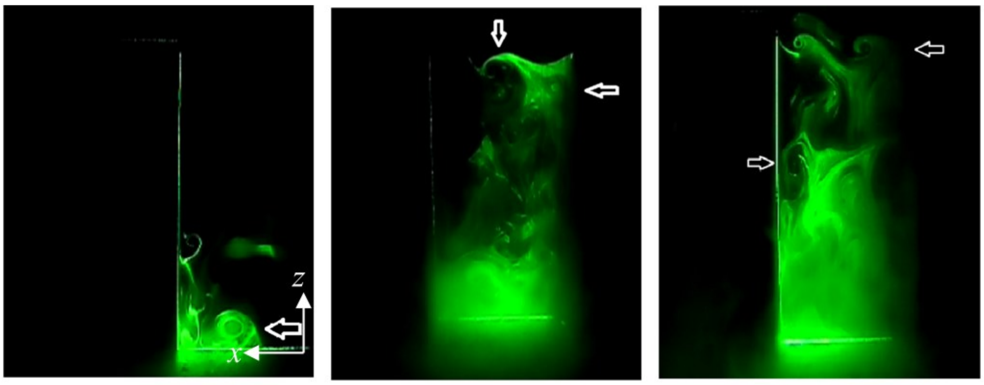
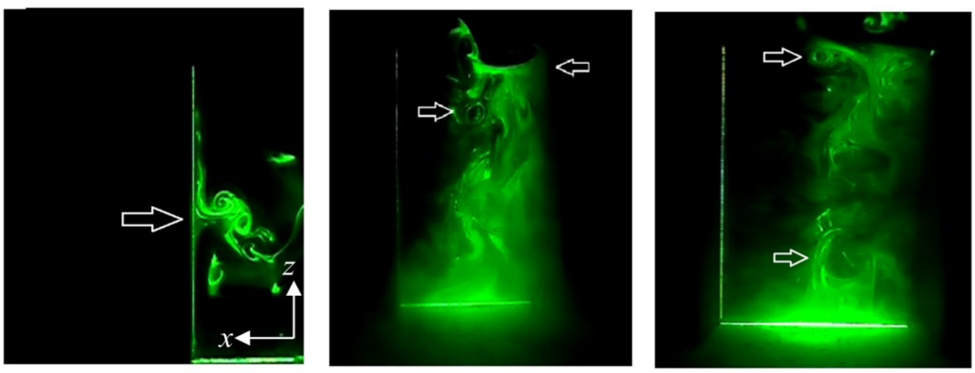
Figure 3 shows the flow patterns corresponding to H/W_2 = 2.0. Similar to flow pattern at H/W_2 = 1.0, a vertical roll vortex near ground on frontal face of the first building was also generated. The vortex shedding formation and various larger and small vortex structures within buildings spacing is clearly visible, see Figs. 3(a) and (b).

Figure 4 shows the flow patterns at H/W_2 = 1.33. On windward face of the first building was observed the formation of vortex near the stagnation point, see Fig. 4(a). This was clearly indication that on the upper one-half of the frontal face the flow was directed upward over the roof and on the lower surface the flow was driven toward the ground forming the vertical standing vortex. During flow experiments it was observed that vortex system behind upwind building had a weak interference on the downwind building flow.



(a) (b) (c)

Figure 3. Side view $x-z$ plane at H/W_2 = 2.0: (a) flow in incident region; (b) flow between first and second buildings and (c) flow between second and third buildings.



(a) (b) (c)

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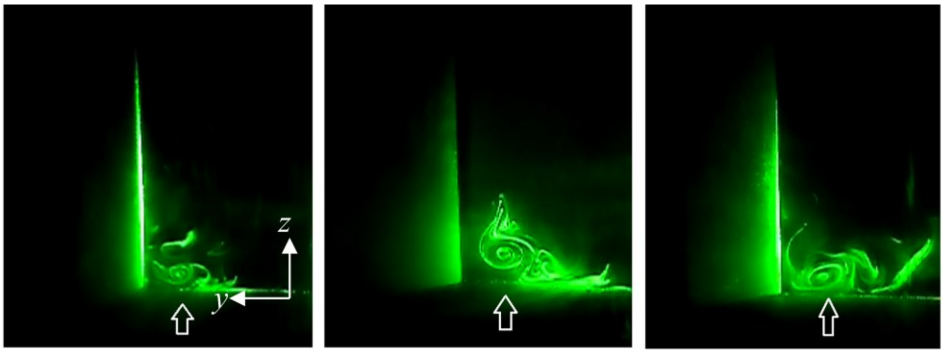
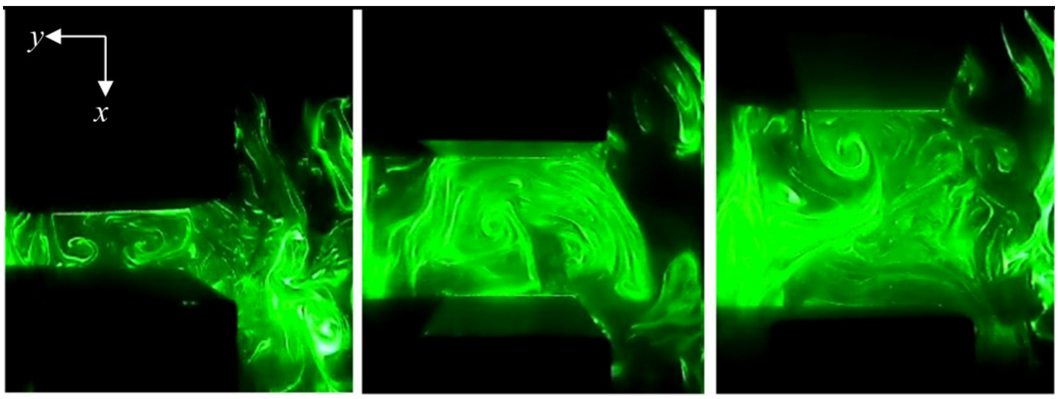
Figure 4. Side view $x - z$ plane at $H/W_2 = 1.33$: (a) flow in incident region; (b) flow between first and second buildings and (c) flow between second and third buildings.

Figure 5 shows the flow in the $y - z$ plane besides the first building at $H/W_2 = 4.0$; 2.0 and 0.633. Results showed the typical horseshoe vortex at the side wall of the obstacles caused by the adverse pressure gradient of the stagnation flow in the frontal face of the first building. Figure 6 shows the flow in the $x - y$ plane near the ground (z = 0.05 m) between first and second buildings at $H/W_2 = 4.0$; 2.0 and 1.33. The x-y plane at $H/W_2 = 4.0$ wind flow shows symmetric double vortex with circulations opposite to each other, as see Fig. 6(a). In Figure 6(c) is evidence that wind flow behind upwind building has a weak interference on the downwind building flow at $H/W_2 = 1.33$.



(a) (b) (c)

Figure 5. Side view $y - z$ plane of horseshoe vortex: (a) $H/W_2 = 4.0$; (b) $H/W_2 = 2.0$ and (c) $H/W_2 = 1.33$.



(a) (b) (c)

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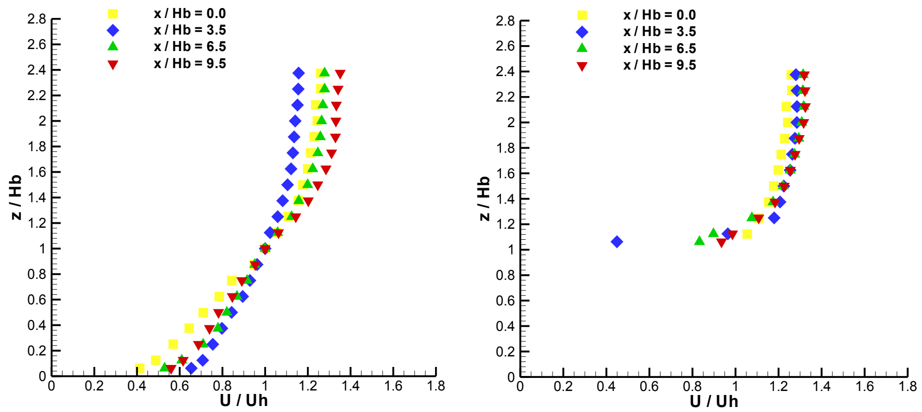
Figure 6. Top view $x - y$ plane of flow between first and second buildings: (a) $H/W_2 = 4.0$; (b) $H/W_2 = 2.0$ and (c) $H/W_2 = 1.33$.

Figure 7 shows the normalized mean vertical velocity profile, U/U_h, at center line of wind tunnel and on the roof of the buildings, respectively, points X_o, X_1, X_2, X_3, X_4, X_5 and X_6 corresponding to $H/W = 1.0$.



(a) (b)

Figure 8. Normalized mean vertical velocity profile at $H/W_2 = 1.0$: (a) center line of the street and (b) on the roof of the buildings.

CONCLUSIONS

Flow visualization for different aspect ratio, qualitatively showed that there was no fundamental change in the wind flow in frontal and side wall of the first building. All experiments exhibit the vertical standing and the horseshoe vortices systems. According to the aspect ratio, different vortex structures were identified within the canyon. At $H/W_2 = 2.0$, the flow field was defined by interaction between both buildings occurring great turbulence. With decrease H/W_2, was observed that wind flow behind upwind building has a weak interference on the downwind building flow at $H/W_2 = 1.33$.

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