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VISUALIZATION STUDIES OF THE VORTEX SYSTEM AROUND 3-D RECTANGULAR BUILDINGS

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ABSTRACT

In this work, the vortex system around an isolated prismatic rectangular building was studied using smoke injection technique. This vortex system can be one of the causes of air quality problems, such as dangerous contaminants released in the near wake of the building in chemical-plants. Two models scale building with different aspect ratios were used in an atmospheric boundary wind tunnel. The qualitative analyses of video recorded images of smoke flow and laser light illumination provided a good view of the complex wind flow around an isolated building.

RESUMO

Neste trabalho, foi realizado um estudo do sistema de vórtices nas vizinhanças de um obstáculo retangular prismático utilizando a técnica de injeção direta de fumaça. Este sistema de vórtices pode causar sérios problemas de qualidade do ar, por exemplo, quando ocorre o lançamento de contaminantes perigosos na região de esteira próxima a edifícios situados em plantas químicas. Análises qualitativas dos registros das imagens forneceram uma boa visão do complexo campo de escoamento do vento nas vizinhanças do obstáculo.

INTRODUCTION

The presence of obstacle in the atmospheric boundary layer (ABL) can greatly perturb the wind field (SANTOS, 2000). The change in the flow field can affect the dispersion of pollutants released in their vicinity. The knowledge of the wind flow aerodynamics around building is important to good planning of indoor air pollution control strategies and to minimize the risk of outdoor pollution into a building (LIU et al., 2010).

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The flow pattern around a bluff body placed within the atmospheric boundary layer is very complex. The flow structure interaction is characterized by boundary layer separation, recirculation flow within a separation bubble on the roof and in the near wake, eventual reattachment of the flow, high turbulence levels, vortex horseshoe and vortex shedding (SANTOS, 2000). The wind flow around an isolated building has been studied through the use of wind tunnel experiments for many years (MARTINUZZI and TROPPEA, 1993). In this way, the application of smoke direct injection technique is useful for understanding flow structure interaction in many problems in wind engineering and environmental science. Becker et al. (2002) pointed out that flow visualization is not a technique that easily yields quantitative results, but it permits to obtain a clear perception of the flow pattern and helps to reduce the number of quantitative measurements on the flow regions with high gradients.

This work presents the results of a flow visualization experiment for studying the effect of isolated obstacle on the flow field in the atmospheric boundary layer using smoke direct injection technique. The aim of this work is to provide a qualitatively description of the effect of an isolated building on the flow structure and vortex system.

MATERIAL AND METHODS

Experiments were conducted in the atmospheric boundary layer wind tunnel located at Energy Laboratory of IFES, Vitoria, Espirito Santo. It is a low speed open-circuit tunnel with a section test of 2.0 m $\times$ 0.5 m $\times$ 1.5 m. Two scale model prismatic rectangular buildings (1/100) with different aspect ratios (L/H = 2.0 and L/H = 0.5) were used in wind tunnel experiments, where H = 0.10 m is the low building height and L is the length of side face of the obstacle. Figure 1 shows the sketch of the flow field analyzed in this study.

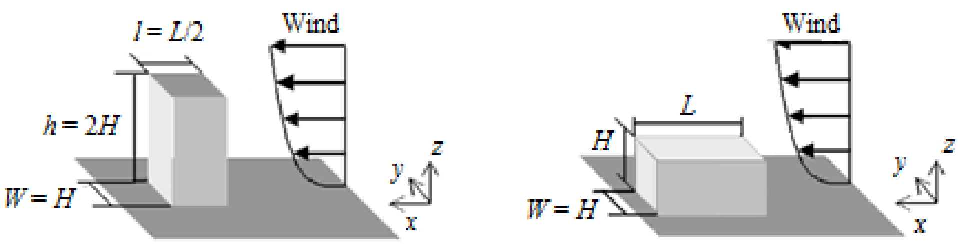

Figure 1. Sketches of the flow fields analyzed in this study.

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Smoke direct injection technique was used to visualize the wind flow around the obstacle immersed in an ABL. Fluid from a smoke machine was generated and emitted into the wind tunnel through a pipe (50 mm diameter), with the outflow downstream of the urban region. A green laser light (500mW) passing through a semi-cylindrical lens was used to illuminate the vicinity of the building to facilitate a clear visualization of the vortex system.

A digital camera (Fujifilm HS 10) operating at a speed of the 240 fps was used to record the smoke patterns. Selected sequences of video pictures were studied both digitally and visually. The Reynolds numbers (Re) were based on the building height, H, and wind velocity at the building height, U_h, with ρ_{air} = 1.185 kg/m^3 and μ_{air} = 1.82 $\times$ 10^{-5} kg / m^2.s. For L/H = 0.5 and U_h = 0.273 m/s, Re was 1.8 $\times$ 10^3 and for L/H = 0.5 and U_h = 0.325 m/s the Re was 4.2 $\times$ 10^3.

RESULTS

In the present study the effects of the aspect ratio (L/H) on the flow structure were investigated by use of visualization experiments. Figures 2 shows the flow pattern on the x – z plane in the incident region of the buildings with aspect ratios at L/H = 2.0 and L/H = 0.5, respectively. In the incident region it was observed the formation of vertical standing vortex. This vortex was generated by the downwards flow bellow of the stagnation point on the frontal face of the building and due to interaction of approaching flow and reverse flow.

Figure 3 presents the horseshoe vortex on the plane y – z on the side of building at L/H = 2.0 and L/H = 0.5. The horseshoe vortex stretches out sideways around the corners where flow separation occurs. Figure 4 shows the flow pattern on the x – y plane in the incident region of building with aspect ratio at L/H = 2.0. Horizontally is visible the well known horseshoe vortices systems near the ground level. These vortices extended over the entire width of the building and were deflected downstream. These structures were similar to that described by Becker et al. (2000).

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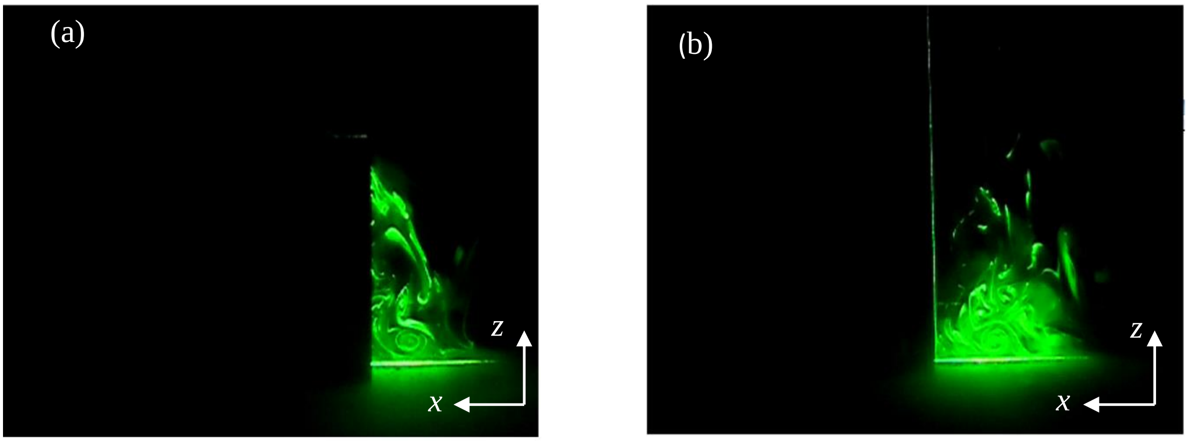

Figure 2 – Side view of flow in the incident region on the *x – z* plane: (a) *L*/*H* = 2.0 and (b) *L*/*H* = 0.5.

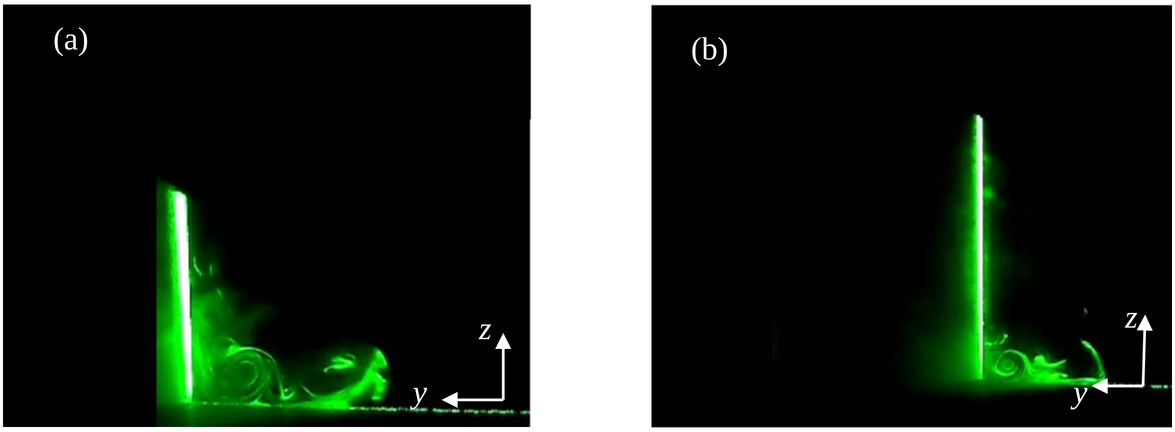

Figure 3 – Side view of flow in the incident region on the *y – z* plane: (a) *L*/*H* = 2.0 and (b) *L*/*H* = 0.5.

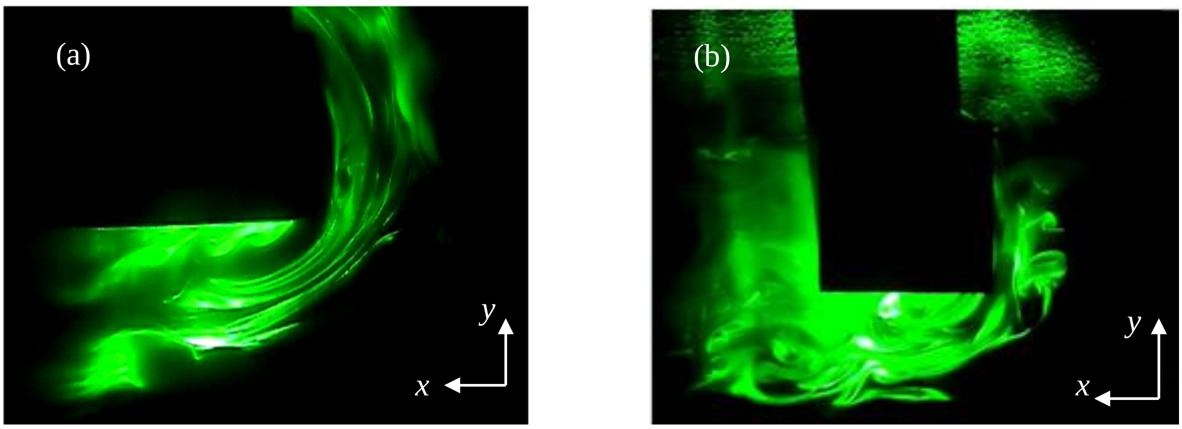

Figure 4 – Top view of flow in the incident region on the *x – y* plane: (a) *L*/*H* = 2.0 and (b) *L*/*H* = 0.5.

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Figure 5 shows the flow pattern on the x - z plane on the roof building. According to the flow visualization results, the flow pattern for L/H = 2.0 shows a large turbulent recirculation region of flow on the roof building, see Fig. 5(a). This can happens due to the separation of the boundary layer from the sharp edge of the building. The results of flow visualization also showed a reverse flow on the top of building with L/H = 0.5, see Fig. 5(b).

Figure 6 shows the flow pattern on the x – y plane in the near wake region of building with aspect ratios at L/H = 2.0 and L/H = 0.5. At the leeward side a separation bubble was generated, consequently a reverse flow was observed clearly. This reverse flow was responsible for the formation of slow eddies behind the building. Qualitatively the separation bubble was characterized by an increase of turbulence and a decrease of mean wind velocity.

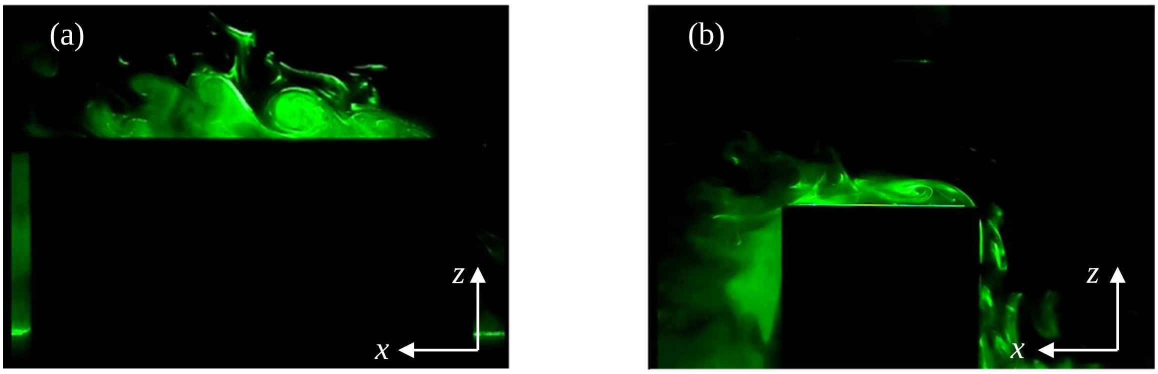

Figure 5 – Side view of flow in the near wake behind building on the y – z plane: (a) L/H = 2.0 and (b) L/H = 0.5.

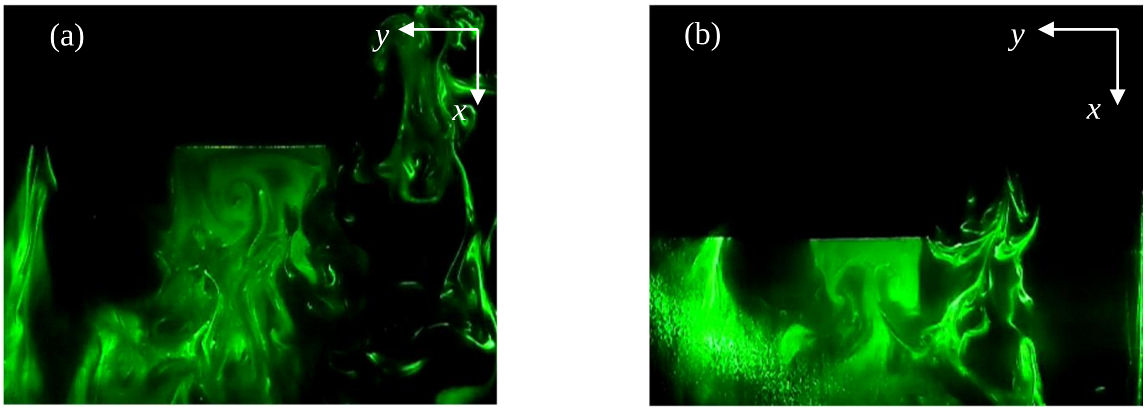

Figure 6 – Top view of flow in the near wake behind building on the x – y plane: (a) L/H = 2.0 and (b) L/H = 0.5.

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CONCLUSIONS

In this work the flow visualization using smoke injection and laser light illumination techniques show the existence of flow separation, recirculation region on roof top and behind building, standing and horseshoe vortices. Qualitatively the results suggested that flow around building with different aspect ratio presented a similar vortex structure, however with different length scale.

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REFERENCES

BECKER, S., LIENHART, H., DURST, F., **Flow around three-dimensional obstacles in boundary layers, Journal of Wind Engineering and Industrial Aerodynamics**. Vol. 90, pp. 265-279, 2002.

LIU, X.P., NIU, J.L., KWOK, K.C.S., WANG, J.H., LI, B.Z. **Investigation of indoor air pollutant dispersion and cross-contamination around a typical high-rise residential building: Wind tunnel tests.** Building and Environment, Vol. 45, pp. 1769-1778, 2010.

MARTINUZZI, R. and TROPEA, C. **The Flow Around Surface Mounted, Prismatic Obstacles Placed in a Fully Developed Channel Flow**. Journal of Fluids Engineering, Vol. 115, pp. 85-92.

SANTOS, J.M., **Flow and dispersion around isolated buildings.** PhD thesis. Department of Chemical Engineering, University of Manchester Institute of Science and Technology, Manchester, UK, 2000.