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Effects of building configuration on ventilation performance of naturally-ventilated building

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Abstract

For wind-induced natural ventilation, a surrounding building and buildings' envelopes are two main factors to affect the indoor air flow characteristics. There are few research works studying the effect of surrounding buildings on indoor natural ventilation. In this work, Computational Fluid Dynamics (CFD) method was employed to model 18 different cases to investigate numerically the effect of an upstream building with two different heights to the target building with two different types of wing walls under two different wind directions (a wind incidence angle α=0° and α=45°). The results show the target building generally has a better natural ventilation performance when the wind obliquely incidents on the building. In addition, the effect on ventilation performance of wing walls is highly dependent on the environment including the approaching wind directions, the orientation of the target building and height of the upstream building.

Introduction

Over the last few decades, natural ventilation has come to be recognized as one way to achieve low-energy building design. In practice, single-sided ventilation is found to be common as it corresponds to the common space configuration of cellular rooms with closed doors. Previous studies (Allocca et al, 2002; Niu and Tung, 2008) indicated that when the wind speed was over 4m/s, wind effect was the main driving force for natural ventilation as opposed to buoyancy effect. There are numerous researches focused on the indoor air ventilation rate under wind-induced natural ventilation for an isolated building. In an urban environment, the effect of surrounding buildings and building envelopes are two main factors that affect the ventilation performance of buildings. However, there are few works studying the effect of surrounding buildings on indoor natural ventilation. In addition, wing wall is one type of green architectural features used in buildings and is believed to be able to improve natural ventilation in buildings. However, there are few studies focused on the natural ventilation performance of wing walls used in multi-story buildings. Combined with the effect of a surrounding building and wing walls under different wind direction, this study aims to investigate numerically the effect of an upstream building with two different heights to the target building with two different types of wing walls under two different wind directions (a wind incidence angle α=0° and α=45°).

Configuration description

The Computational Fluid Dynamics (CFD) method has been used to investigate numerically the effect of an upstream building with two different heights and two different types of wing walls on the indoor air flow characteristics and indoor air quality of a multi-story building. Table 1 shows that 18 different tests cases based on a 4-story building with and without vertical or horizontal wing walls and with and without an upstream building of two different heights under two different wind directions (a wind incidence angle of α = 0° and α = 45°) has been simulated. The computational domain and geometry of hypothetical target buildings are shown in Figure 1. The domain boundaries have sufficient distances to reduce the influence of the boundaries on air flow around the buildings as shown in Figure 1(a). It can be seen that the surrounding building of two different heights

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Building distribution	Isolated building	Isolated Building	Isolated building	Upstream building (height=Dz)	Upstream building (height=Dz)	Upstream building (height=Dz)	Upstream building (height=2Dz)	Upstream building (height=2Dz)	Upstream building (height=2Dz)
Green features	No wing walls	Vertical wing walls	Horizontal wing walls	No wing walls	Vertical wing walls	Horizontal wing walls	No wing walls	Vertical wing walls	Horizontal wing walls
Wind direction(α)	0°	0°	0°	0°	0°	0°	0°	0°	0°
	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16	Case 17	Case 18
Building distribution	Isolated building	Isolated building	Isolated building	Upstream building (height=Dz)	Upstream building (height=Dz)	Upstream building (height=Dz)	Upstream building (height=2Dz)	Upstream building (height=2Dz)	Upstream building (height=2Dz)
Green features	No wing walls	Vertical wing walls	Horizontal wing walls	No wing walls	Vertical wing walls	Horizontal wing walls	No wing walls	Vertical wing walls	Horizontal wing walls
Wind direction(α)	45°	45°	45°	45°	45°	45°	45°	45°	45°

Table 1: Cases configuration

(height = D_z /height = 2Dz) is located at the upstream in a distance of D_y from the target building. Figure 1(b) shows the two different wind incidence angles on the target building. In the figure, α is the angle between the wind direction and the normal to the building surface on windward side. The target building is a 1: 20 4-story building that has two independent rooms on each floor as shown in Figure 1(c). One room has an opening on the windward side while the other room has an opening on the leeward side. The dimension of all rooms in the target building is 6m×3m×3m in the prototype and the dimension of the opening is 1m×2m in the prototype. The window bottom is 1m above the floor in the prototype. There are 18 different cases as shown in Table 1. Each case was built independently in the computational domain.

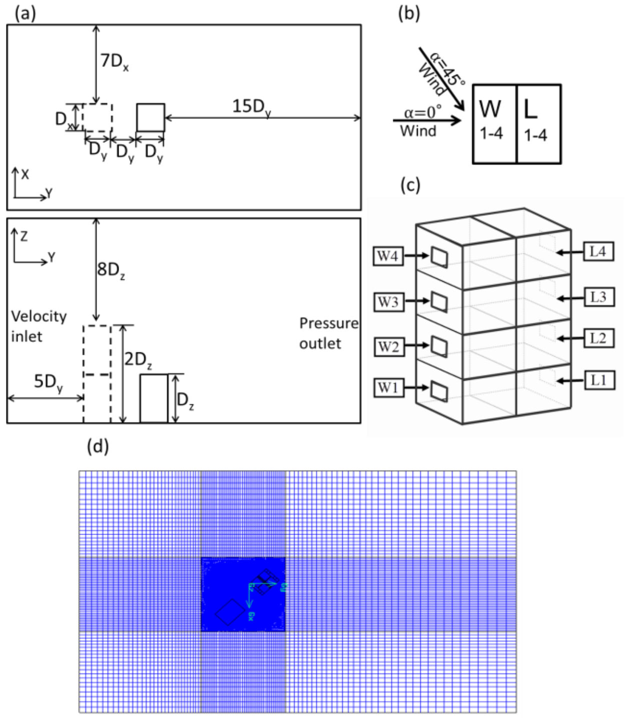


Figure 1. Computational domain, the geometry of hypothetical target building and mesh information of the domain

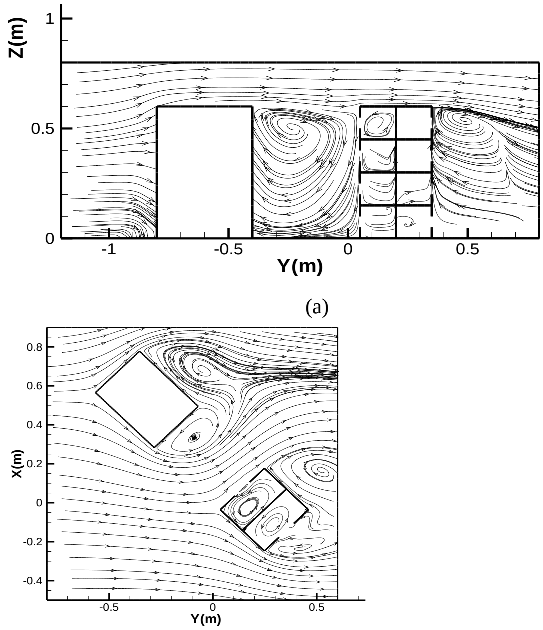
A series of similarity criteria should be satisfied in order to reproduce the original full-scale flow. The geometric similarity and boundary layer flow similarity are relativity easy to achieve with the model scaled. In a detailed review (Liu et al, 2010) about Reynolds number independence in different kinds of situations, for a flow system which ignored the thermal and Coriolis effects and similar boundary conditions achieved by the appropriate characteristic length L and reference velocity U_R, the turbulent flow would be similar at all high Reynolds numbers. In this work, the wind speed at the height of roof of the building is 4m/s, Reynolds number is about 4×10^4, which is much larger than the criteria. Thus the Reynolds independence can be satisfied. The wind profile in an urban environment is calculated by the following equation adopted by Etheridge et al., (1996):

$$V_z = V_{ref}V(H/D_z)^{\alpha} = 1.14V_{ref}Z^{0.25} \tag{1}$$

A mesh with 4.2million was adopted after mesh sensitivity tests. The turbulence at the inlet boundary was characterized by turbulence intensity and length scale, which are 8% and 1m, respectively.

Analysis of results

Figure 2 shows the effect of the upstream building on the flow fields around the target building.



(a)

(b)

Figure 2. Path line on the vertical centre plane and horizontal plane at the height of Z=0.37 m. (a) vertical centre plane of Case4. (b) Horizontal plane at the height of Z=0.37m in Case 14.

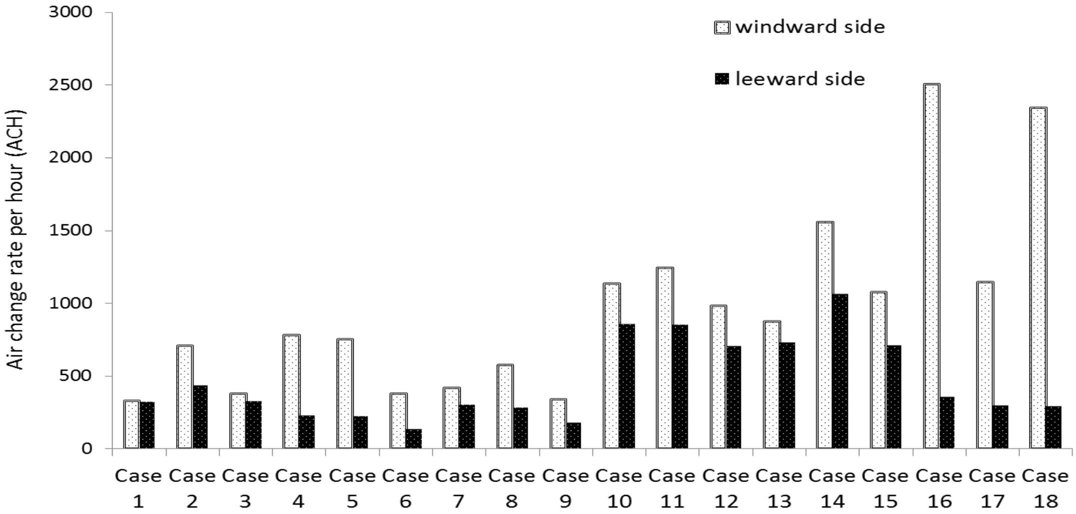


Figure 3. Average air change rate per hour (ACH) of 4 rooms in windward side and leeward side in each case

It can be seen from Figure 3 that the average Air Change Rate per Hour (ACH) for all cases at the wind angle of α=45 °(i.e. Case 10 – Case 18) has been increased by 2-5 times compared with those at the wind angel of α=0 ° (i.e. Case 1 – Case 9). The ACH is calculated using an integral method:

$$ACH = (0.5 \int_0^A |V_x|\, dA)/Vol_R \qquad (2)$$

It implies that the target building generally has a better natural ventilation when the wind obliquely incidents on the building. Regarding the performance of vertical wing walls, it can be seen that the average ACH for Case 2 and Case 14 is larger than that for Case 1 and Case 13 respectively on both the windward and leeward sides but the average ACH for Case 8 and Case 11 is larger than that for Case 7 and Case 10 respectively only on the windward side. The average ACH for Case 5 and Case 17 is even smaller than that for Case 4 and Case 16 respectively. It means that the ventilation performance of vertical wing walls is highly dependent on the environment including the approaching wind directions, the orientation of the target building and height of the upstream building. Regarding the performance of horizontal wing walls, there is no significant increase in the average ACH in all cases and there are even some adverse effects on the natural ventilation in several cases.

Conclusions

The result shows the effect on ventilation performance of wing walls, both vertical and horizontal is highly dependent on the environment including the approaching wind directions, the orientation of the target building and height of the upstream building. The ventilation performance generally is better when the wind incidence is at an oblique angle, such as the 45 ° case studied here, due to the intense turbulence generated by flow separation at the windward corners of the building and the associated flow entrainment across the window openings. Similarly an upstream building creates a complex flow regime within the space trapped between the upstream and the target buildings which enhances ventilation in some areas on the target building despite the wind shadow casted by the upstream building.

Acknowledgments

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